SWI-Prolog is a comprehensive and portable implementation of the Prolog programming language. SWI-Prolog aims to be a robust and scalable implementation supporting a wide range of applications. In particular, it ships with a wide range of interface libraries, providing interfaces to other languages, databases, graphics and networking. It provides extensive support for managing HTML/SGML/XML, JSON, YAML and RDF documents. The system is particularly suited for server applications due to robust support for multithreading and HTTP server libraries.

SWI-Prolog extends Prolog with tabling (SGL resolution). Tabling provides better termination properties and avoids repetitive recomputation. Following XSB, SWI-Prolog’s tabling supports sound negation using the Well Founded Semantics. Incremental tabling supports usage as a Deductive database.

SWI-Prolog is designed in the ‘Edinburgh tradition’. In addition to the ISO Prolog standard it is largely compatible to Quintus, SICStus and YAP Prolog. SWI-Prolog provides a compatibility framework developed in cooperation with YAP and instantiated for YAP, SICStus, IF/Prolog and XSB.

SWI-Prolog aims at providing a rich development environment, including extensive editor support, graphical source-level debugger, autoloading, a ‘make’ facility to reload edited files and much more. GNU-Emacs, SWI-Prolog editor for Windows, the PDT plugin for Eclipse or a Visual Studio Code plugin provide alternative environments. SWISH provides a web based environment.

This document gives an overview of the features, system limits and built-in predicates.
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Introduction

This document is a reference manual. That means that it documents the system, but it does not explain the basics of the Prolog language and it leaves many details of the syntax, semantics and built-in primitives undefined where SWI-Prolog follows the standards. This manual is intended for people that are familiar with Prolog. For those not familiar with Prolog, we recommend to start with a Prolog textbook such as [Bratko, 1986], [Sterling & Shapiro, 1986] or [Clocksin & Melish, 1987]. For more advanced Prolog usage we recommend [O’Keefe, 1990].

1.1 Positioning SWI-Prolog

Most implementations of the Prolog language are designed to serve a limited set of use cases. SWI-Prolog is no exception to this rule. SWI-Prolog positions itself primarily as a Prolog environment for ‘programming in the large’ and use cases where it plays a central role in an application, i.e., where it acts as ‘glue’ between components. At the same time, SWI-Prolog aims at providing a productive rapid prototyping environment. Its orientation towards programming in the large is backed up by scalability, compiler speed, program structuring (modules), support for multithreading to accommodate servers, Unicode and interfaces to a large number of document formats, protocols and programming languages. Prototyping is facilitated by good development tools, both for command line usage and for usage with graphical development tools. Demand loading of predicates from the library and a ‘make’ facility avoids the requirement for using declarations and reduces typing.

SWI-Prolog is traditionally strong in education because it is free and portable, but also because of its compatibility with textbooks and its easy-to-use environment.

Note that these positions do not imply that the system cannot be used with other scenarios. SWI-Prolog is used as an embedded language where it serves as a small rule subsystem in a large application. It is also used as a deductive database. In some cases, this is the right choice because SWI-Prolog has features that are required in the application, such as threading or Unicode support. In general though, for example: GNU-Prolog is more suited for embedding because it is small and can compile to native code; XSB is better for deductive databases because it provides a mature implementation of tabling including support for incremental updates and Well Founded Semantics\(^1\); and ECLiPSe is better at constraint handling.

The syntax and set of built-in predicates is based on the ISO standard [Hodgson, 1998]. Most extensions follow the ‘Edinburgh tradition’ (DEC10 Prolog and C-Prolog) and Quintus Prolog [Qui, 1997]. The infrastructure for constraint programming is based on hProlog [Demoen, 2002]. Some libraries are copied from the YAP\(^2\) system. Together with YAP, we developed a portability framework (see section C). This framework has been filled for SICStus Prolog, YAP, IF/Prolog and

\(^1\)Sponsored by Kyndi and with help from the XSB developers Theresa Swift and David S. Warren, SWI-Prolog now supports many of the XSB features.

\(^2\)http://www.dcc.fc.up.pt/~{}vsc/Yap/
Ciao. SWI-Prolog version 7 introduces various extensions to the Prolog language (see section 5). The string data type and its supporting set of built-in predicates is compatible with ECLiPSe.

1.2 Status and releases

This manual describes version 9.1 of SWI-Prolog. SWI-Prolog is widely considered to be a robust and scalable implementation of the Prolog language. It is widely used in education and research. In addition, it is in use for $24 \times 7$ mission critical commercial server processes. The site http://www.swi-prolog.org is hosted using the SWI-Prolog HTTP server infrastructure. It receives approximately 2.3 million hits and serves approximately 300 Gbytes on manual data and downloads each month. SWI-Prolog applications range from student assignments to commercial applications that count more than one million lines of Prolog code.

SWI-Prolog has two development tracks. Stable releases have an even minor version number (e.g., 6.2.1) and are released as a branch from the development version when the development version is considered stable and there is sufficient new functionality to justify a stable release. Stable releases often get a few patch updates to deal with installation issues or major flaws. A new Development version is typically released every couple of weeks as a snapshot of the public git repository. ‘Extra editions’ of the development version may be released after problems that severely hindered the user in their progress have been fixed.

Known bugs that are not likely to be fixed soon are described as footnotes in this manual.

1.3 Should I be using SWI-Prolog?

There are a number of reasons why it might be better to choose a commercial, or another free, Prolog system:

• **SWI-Prolog comes with no warranties**
  Although the developers or the community often provide a work-around or a fix for a bug, there is no place you can go to for guaranteed support. However, the full source archive is available and can be used to compile and debug SWI-Prolog using free tools on all major platforms. Users requiring more support should ensure access to knowledgeable developers.

• **Performance is your first concern**
  Various free and commercial systems have better performance. But, ‘standard’ Prolog benchmarks disregard many factors that are often critical to the performance of large applications. SWI-Prolog is not good at fast calling of simple predicates, but it is fast with dynamic code, meta-calling and predicates that contain large numbers of clauses or require more advanced clauses indexing. Many of SWI-Prolog’s built-in predicates are written in C and have excellent performance.

On the other hand, SWI-Prolog offers some facilities that are widely appreciated by users:

• **Comprehensive support of Prolog extensions**
  Many modern Prolog implementations extend the standard SLD resolution mechanism with which Prolog started and that is described in the ISO standard. SWI-Prolog offers most popular extensions.
Attributed variables provide Constraint Logic Programming and delayed execution based on instantiation (coroutining). Tabling or SGL resolution provides characteristics normally associated with bottom up evaluation: better termination, better predictable performance by avoiding recomputation and Well Founded Semantics for negation. Delimited continuations can be used to implement high level new control structures and Engines can be used to control multiple Prolog goals, achieving different control structures such as massive numbers of cooperating agents.

- **Nice environment**
  SWI-Prolog provides a good command line environment, including ‘Do What I Mean’, auto-completion, history and a tracer that operates on single key strokes. The system automatically recompiles modified parts of the source code using the `make/0` command. The system can be instructed to open an arbitrary editor on the right file and line based on its source database. It ships with various graphical tools and can be combined with the SWI-Prolog editor, PDT (Eclipse plugin for Prolog), VScode or GNU-Emacs.

- **Fast compiler**
  Even very large applications can be loaded in seconds on most machines. If this is not enough, there is the Quick Load Format. See `qcompile/1` and `qsave_program/2`.

- **Transparent compiled code**
  SWI-Prolog compiled code can be treated just as interpreted code: you can list it, trace it, etc. This implies you do not have to decide beforehand whether a module should be loaded for debugging or not, and the performance of debugged code is close to that of normal operation.

- **Source level debugger**
  The source level debugger provides a good overview of your current location in the search tree, variable bindings, your source code and open choice points. Choice point inspection provides meaningful insight to both novices and experienced users. Avoiding unintended choice points often provides a huge increase in performance and a huge saving in memory usage.

- **Profiling**
  SWI-Prolog offers an execution profiler with either textual output or graphical output. Finding and improving hotspots in a Prolog program may result in huge speedups.

- **Flexibility**
  SWI-Prolog can easily be integrated with C, supporting non-determinism in Prolog calling C as well as C calling Prolog (see section 12). It can also be *embedded* in external programs (see section 12.5). System predicates can be redefined locally to provide compatibility with other Prolog systems.

- **Threads**
  Robust support for multiple threads may improve performance and is a key enabling factor for deploying Prolog in server applications. Threads also facilitates debugging and maintenance of long running processes and embedded Prolog engines. The native IDE tools run in a separate thread. The `prolog_server` library provides telnet access and the pack `libssh` provides SSH login. With some restrictions regarding the compatibility of old and new code, code can be replaced while it is being executed in another thread. This allows for injecting `debug/3` statements as well as fixing bugs without downtime.
1.4. SUPPORT THE SWI-PROLOG PROJECT

- **Interfaces**
  SWI-Prolog ships with many extension packages that provide robust interfaces to processes, encryption, TCP/IP, TIPC, ODBC, SGML/XML/HTML, RDF, JSON, YAML, HTTP, graphics and much more.

1.4 Support the SWI-Prolog project

You can support the SWI-Prolog project in several ways. Academics are invited to cite one of the publications on SWI-Prolog. Users can help by identifying and/or fixing problems with the code or its documentation. Users can contribute new features or, more lightweight, contribute packs. Commercial users may consider contacting the developers to sponsor the development of new features or seek for opportunities to cooperate with the developers or other commercial users.

1.5 Implementation history

SWI-Prolog started back in 1986 with the requirement for a Prolog that could handle recursive interaction with the C-language: Prolog calling C and C calling Prolog recursively. In those days, Prolog systems were not very aware of their environment and we needed such a system to support interactive applications. Since then, SWI-Prolog’s development has been guided by requests from the user community, especially focusing on (in arbitrary order) interaction with the environment, scalability, (I/O) performance, standard compliance, teaching and the program development environment.

SWI-Prolog is based on a simple Prolog virtual machine called ZIP [Bowen et al., 1983, Neumerkel, 1993] which defines only 7 instructions. Prolog can easily be compiled into this language, and the abstract machine code is easily decompiled back into Prolog. As it is also possible to wire a standard 4-port debugger in the virtual machine, there is no need for a distinction between compiled and interpreted code. Besides simplifying the design of the Prolog system itself, this approach has advantages for program development: the compiler is simple and fast, the user does not have to decide in advance whether debugging is required, and the system only runs slightly slower in debug mode compared to normal execution. The price we have to pay is some performance degradation (taking out the debugger from the VM interpreter improves performance by about 20%) and somewhat additional memory usage to help the decompiler and debugger.

SWI-Prolog extends the minimal set of instructions described in [Bowen et al., 1983] to improve performance. While extending this set, care has been taken to maintain the advantages of decompilation and tracing of compiled code. The extensions include specialised instructions for unification, predicate invocation, some frequently used built-in predicates, arithmetic, and control (;/2, |/2), if-then (->/2) and negation-by-failure (\+/1).

SWI-Prolog implements *attributed variables* (constraints) and *delimited continuations* following the design in hProlog by Bart Demoen. The *engine* implementation follows the design proposed by Paul Tarau. Tabling was implemented by Benoit Desouter based on delimited continuations. Tabling has been extended with *answer subsumption* by Fabrizio Riguzzi. The implementation of *well founded semantics* and *incremental tabling* follows XSB and has been sponsored by Kyndi and mode possible by technical support from notably Theresa Swift and David S. Warren.

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3 [https://www.swi-prolog.org/Publications.html](https://www.swi-prolog.org/Publications.html)
4 [https://www.swi-prolog.org/howto/SubmitPatch.html](https://www.swi-prolog.org/howto/SubmitPatch.html)
5 [https://www.swi-prolog.org/pack/list](https://www.swi-prolog.org/pack/list)
6 [mailto:info@swi-prolog.org](mailto:info@swi-prolog.org)
1.6 Acknowledgements

Some small parts of the Prolog code of SWI-Prolog are modified versions of the corresponding Edinburgh C-Prolog code: grammar rule compilation and \texttt{writef/2}. Also some of the C-code originates from C-Prolog: finding the path of the currently running executable and some of the code underlying \texttt{absolute_file_name/2}. Ideas on programming style and techniques originate from C-Prolog and Richard O’Keefe’s \textit{thief} editor. An important source of inspiration are the programming techniques introduced by Anjo Anjewierden in PCE version 1 and 2.

Our special thanks go to those who had the fate of using the early versions of this system, suggested extensions or reported bugs. Among them are Anjo Anjewierden, Huub Knops, Bob Wielinga, Wouter Jansweijer, Luc Peerdeeman, Eric Nombden, Frank van Harmelen, Bert Rengel.

Martin Jansche (jansche@novell1.gs.uni-heidelberg.de) has been so kind to reorganise the sources for version 2.1.3 of this manual. Horst von Brand has been so kind to fix many typos in the 2.7.14 manual. Thanks! Randy Sharp fixed many issues in the 6.0.x version of the manual.

Bart Demoen and Tom Schrijvers have helped me adding coroutining, constraints, global variables and support for cyclic terms to the kernel. Tom Schrijvers has provided a first clp(fd) constraint solver, the CHR compiler and some of the coroutining predicates. Markus Triska contributed the current clp(fd) implementation as well as the clp(b) implementation.

Tom Schrijvers and Bart Demoen initiated the implementation of \textit{delimited continuations} (section 4.9), which was used by Benoit Desouter and Tom Schrijvers to implement \textit{tabling} (section 7) as a library. Fabrizio Riguzzi added a first implementation for \textit{mode directed tabling} (section 7.3).

The SWI-Prolog 7 extensions (section 5) are the result of a long heated discussion on the mailinglist. Nicos Angelopoulos’ wish for a smooth integration with the R language triggered the overall intend of these extensions to enable a smoother integration of Prolog with other languages. Michael Hendrix suggested and helped shaping SWI-Prolog \textit{quasi quotations}.

Paul Singleton has integrated Fred Dushin’s Java-calls-Prolog side with his Prolog-calls-Java side into the current bidirectional JPL interface package.

Richard O’Keefe is gratefully acknowledged for his efforts to educate beginners as well as valuable comments on proposed new developments.

Scientific Software and Systems Limited, \url{www.sss.co.nz} has sponsored the development of the SSL library, unbounded integer and rational number arithmetic and many enhancements to the memory management of the system.

Leslie de Koninck has made clp(QR) available to SWI-Prolog.

Jeff Rosenwald contributed the TIPC networking library and Google’s protocol buffer handling.

Paulo Moura’s great experience in maintaining Logtalk for many Prolog systems including SWI-Prolog has helped in many places fixing compatibility issues. He also worked on the MacOS port and fixed many typos in the 5.6.9 release of the documentation.

Kyndi (https://kyndi.com/) sponsored the development of the \textit{engines} interface (chapter 11). The final API was established after discussion with the founding father of engines, Paul Tarau and Paulo Moura. Kyndi also sponsored JIT indexing on multiple arguments as well as \textit{deep indexing}. Kyndi currently supports the implementation of XSB compatible tabling, including well founded semantics and incremental tabling. Theresa Swift, David S. Warren and Fabrizio Riguzzi provided input to realise advanced tabling.
Overview

2.1 Getting started quickly

2.1.1 Starting SWI-Prolog

Starting SWI-Prolog on Unix

By default, SWI-Prolog is installed as ‘swipl’. The command line arguments of SWI-Prolog itself and its utility programs are documented using standard Unix man pages. SWI-Prolog is normally operated as an interactive application simply by starting the program:

```
$ swipl
Welcome to SWI-Prolog ...
...
1 ?-
```

After starting Prolog, one normally loads a program into it using consult/1, which may be abbreviated by putting the name of the program file between square brackets. The following goal loads the file `likes.pl` containing clauses for the predicates `likes/2`:

```
?- [likes].
true.
?- 
```

Alternatively, the source file may be given as command line arguments:

```
$ swipl likes.pl
Welcome to SWI-Prolog ...
...
1 ?-
```

Both the above assume `likes.pl` is in your working directory. If you use the command line version `swipl` the working directory is the same as the shell from which you started SWI-Prolog. If you started the GUI version (`swipl-win`) this depends largely on the OS. You can use `pwd/0` and `cd/0` to find and change the working directory. The utility `ls/0` lists the contents of the working directory.
The file `likes.pl` is also installed in a subdirectory `demo` inside SWI-Prolog's installation directory and may be loaded regardless of the working directory using the command below. See `absolute_file_name/3` and `file_search_path/2` for details on how SWI-Prolog specifies file locations.

```prolog
?- [swi(demo/likes)].
true.
```

After this point, Unix and Windows users unite, so if you are using Unix please continue at section 2.1.2.

**Starting SWI-Prolog on Windows**

After SWI-Prolog has been installed on a Windows system, the following important new things are available to the user:

- A folder (called `directory` in the remainder of this document) called `swipl` containing the executables, libraries, etc., of the system. No files are installed outside this directory.

- A program `swipl-win.exe`, providing a window for interaction with Prolog. The program `swipl.exe` is a version of SWI-Prolog that runs in a console window.

- The file extension `.pl` is associated with the program `swipl-win.exe`. Opening a `.pl` file will cause `swipl-win.exe` to start, change directory to the directory in which the file to open resides, and load this file.

The normal way to start the `likes.pl` file mentioned in section 2.1.1 is by simply double-clicking this file in the Windows explorer.

### 2.1.2 Adding rules from the console

Although we strongly advice to put your program in a file, optionally edit it and use `make/0` to reload it (see section 2.1.4), it is possible to manage facts and rules from the terminal. The most convenient way to add a few clauses is by consulting the pseudo file `user`. The input is ended using the system end-of-file character.
2.1. GETTING STARTED QUICKLY

?- [user].
|: hello :- format('Hello world\n').
|: ^D
true.

?- hello.
Hello world
true.

The predicates assertz/1 and retract/1 are alternatives to add and remove rules and facts.

2.1.3 Executing a query

After loading a program, one can ask Prolog queries about the program. The query below asks Prolog what food ‘sam’ likes. The system responds with \(X = \langle value\rangle\) if it can prove the goal for a certain \(X\). The user can type the semi-colon (;) or spacebar\(^1\) if (s)he wants another solution. Use the RETURN key if you do not want to see more answers. Prolog completes the output with a full stop (.) if the user uses the RETURN key or Prolog knows there are no more answers. If Prolog cannot find (more) answers, it writes false. Finally, Prolog answers using an error message to indicate the query or program contains an error.

?- likes(sam, X).
X = dahl ;
X = tandoori ;
...
X = chips.
?- 

Note that the answer written by Prolog is a valid Prolog program that, when executed, produces the same set of answers as the original program.\(^2\)

2.1.4 Examining and modifying your program

If properly configured, the predicate edit/1 starts the built-in or user configured editor on the argument. The argument can be anything that can be linked to a location: a file name, predicate name, module name, etc. If the argument resolves to only one location the editor is started on this location, otherwise the user is presented a choice.

If a graphical user interface is available, the editor normally creates a new window and the system prompts for the next command. The user may edit the source file, save it and run make/0 to update any modified source file. If the editor cannot be opened in a window, it opens in the same console and leaving the editor runs make/0 to reload any source files that have been modified.

---

\(^1\)On most installations, single-character commands are executed without waiting for the RETURN key.

\(^2\)The SWI-Prolog top level differs in several ways from traditional Prolog top level. The current top level was designed in cooperation with Ulrich Neumerkel.
The program can also be decompiled using listing/1 as below. The argument of listing/1 is just a predicate name, a predicate indicator of the form Name/Arity, e.g., ?- listing(mild/1). or a head, e.g., ?- listing(likes(sam, _))., listing all matching clauses. The predicate listing/0, i.e., without arguments lists the entire program.\footnote{This lists several hook predicates that are defined by default and is typically not very informative.}

?- listing(mild).
mild(dahl).
mild(tandoori).
mild(kurma).
true.

2.1.5 Stopping Prolog

The interactive toplevel can be stopped in two ways: enter the system end-of-file character (typically Control-D) or by executing the halt/0 predicate:

?- halt.
$

2.2 The user’s initialisation file

After the system initialisation, the system consults (see consult/1) the user’s init file. This file is searched using absolute_file_name/3 using the path alias (see file_search_path/2) app_config. This is a directory named swi-prolog below the OS default name for placing application configuration data:

- On Windows, the CSIDL folder CSIDL_APPDATA, typically C:\Documents and Settings\username\Application Data.

- If the environment variable XDG_DATA_HOME is set, use this. This follows the free desktop standard.
2.3 Initialisation files and goals

Using command line arguments (see section 2.4), SWI-Prolog can be forced to load files and execute queries for initialisation purposes or non-interactive operation. The most commonly used options are `-f file` or `-s file` to make Prolog load a file, `-g goal` to define initialisation goals and `-t goal` to define the top-level goal. The following is a typical example for starting an application directly from the command line.

```
machine% swipl -s load.pl -g go -t halt
```

It tells SWI-Prolog to load `load.pl`, start the application using the entry point `go/0` and —instead of entering the interactive top level— exit after completing `go/0`.

The command line may have multiple `-g goal` occurrences. The goals are executed in order. Possible choice points of individual goals are pruned. If a `goal` fails execution stops with exit status 1. If a `goal` raises an exception, the exception is printed and the process stops with exit code 2.

The `-q` may be used to suppress all informational messages as well as the error message that is normally printed if an initialisation goal fails.

In MS-Windows, the same can be achieved using a short-cut with appropriately defined command line arguments. A typically seen alternative is to write a file `run.pl` with content as illustrated below. Double-clicking `run.pl` will start the application.

```
:- [load]. % load program
:- go. % run it
:- halt. % and exit
```

Section 2.11.2 discusses further scripting options, and chapter 14 discusses the generation of runtime executables. Runtime executables are a means to deliver executables that do not require the Prolog system.

The expansion of `~/.config`.

The directory can be found using this call:

```
?- absolute_file_name(app_config(.), Dir, [file_type(directory)]).
  Dir = '/home/jan/.config/swi-prolog'.
```

After the first startup file is found it is loaded and Prolog stops looking for further startup files. The name of the startup file can be changed with the `-f file` option. If `File` denotes an absolute path, this file is loaded, otherwise the file is searched for using the same conventions as for the default startup file. Finally, if `file` is `none`, no file is loaded.

The installation provides a file `customize/init.pl` with (commented) commands that are often used to customize the behaviour of Prolog, such as interfacing to the editor, color selection or history parameters. Many of the development tools provide menu entries for editing the startup file and starting a fresh startup file from the system skeleton.

See also the `-s` (script) and `-F` (system-wide initialisation) in section 2.4 and section 2.3.
2.4 Command line options

SWI-Prolog can be executed in one of the following modes:

```
swipl --help
swipl --version
swipl --arch
swipl --dump-runtime-variables
```

These options must appear as only option. They cause Prolog to print an informational message and exit. See section 2.4.1.

```
swipl [option ...] script-file [arg ...]
```

These arguments are passed on Unix systems if file that starts with `#!/path/to/executable [option ...]` is executed. Arguments after the script file are made available in the Prolog flag `argv`.

```
swipl [option ...] prolog-file ... [[--] arg ...]
```

This is the normal way to start Prolog. The options are described in section 2.4.2, section 2.4.3 and section 2.4.4. The Prolog flag `argv` provides access to `arg ...` If the `options` are followed by one or more Prolog file names (i.e., names with extension `.pl`, `.prolog` or (on Windows) the user preferred extension registered during installation), these files are loaded. The first file is registered in the Prolog flag `associated_file`. In addition, `pl-win[.exe]` switches to the directory in which this primary source file is located using `working_directory/2`.

```
swipl -o output -c prolog-file ...
```

The `-c` option is used to compile a set of Prolog files into an executable. See section 2.4.5.

```
swipl -o output -b bootfile prolog-file ...
```

Bootstrap compilation. See section 2.4.6.

### 2.4.1 Informational command line options

#### --arch

When given as the only option, it prints the architecture identifier (see Prolog flag `arch`) and exits. See also `--dump-runtime-variables`.

```
--dump-runtime-variables [=format]
```

When given as the only option, it prints a sequence of variable settings that can be used in shell scripts to deal with Prolog parameters. This feature is also used by `swipl-ld` (see section 12.5). Below is a typical example of using this feature.

```
eval 'swipl --dump-runtime-variables'
eval 'swipl --dump-runtime-variables'
ce -I$PLBASE/include -L$PLBASE/lib/$PLARCH ...
ce -I$PLBASE/include -L$PLBASE/lib/$PLARCH ...
```

The option can be followed by `=sh` to dump in POSIX shell format (default) or `=cmd` to dump in MS-Windows `cmd.exe` compatible format.

#### --help

When given as the only option, it summarises the most important options.
2.4. COMMAND LINE OPTIONS

--version
When given as the only option, it summarises the version and the architecture identifier.

--abi-version
Print a key (string) that represents the binary compatibility on a number of aspects. See section 2.22.

2.4.2 Command line options for running Prolog

Note that boolean options may be written as --name (true), --noname or --no-name (false). They are written as --no-name below as the default is ‘true’.

--debug-on-interrupt
Enable debugging on an interrupt signal (Control-C, SIGINT) immediately. Normally debugging on interrupt is enabled when entering the interactive toplevel. This flag can be used to start the debugger on an interrupt while executing goals from -g or initialization/[1,2]. See also the Prolog flag debug_on_interrupt.

--home[=DIR]
Use DIR as home directory. See section 12.6 for details. If DIR is omitted, the found location is printed and the process exits. If the location cannot be found an error is printed and the process exits with status 1.

--quiet
Set the Prolog flag verbose to silent, suppressing informational and banner messages. Also available as -q.

--no-debug
Disable debugging. See the current_prolog_flag/2 flag generate_debug_info for details.

--no-signals
Inhibit any signal handling by Prolog, a property that is sometimes desirable for embedded applications. This option sets the flag signals to false. See section 12.4.24 for details. Note that the handler to unblock system calls is still installed. This can be prevented using --sigalert=0 additionally. See --sigalert.

--no-threads
Disable threading for the multi-threaded version at runtime. See also the flags threads and gc_thread.

--no-packs
Do not attach extension packages (add-ons). See also attach_packs/0 and the Prolog flag packs.

--no-pce
Enable/disable the xpce GUI subsystem. The default is to make it available as autoload component if it is installed and the system can access the graphics. Using --pce load the xpce system in user space and --no-pce makes it unavailable in the session.
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--on-error =style
How to handle on errors. See the Prolog flag on error for details.
--on-warning =style
How to handle on warnings. See the Prolog flag on warning for details.
--pldoc [=port]
Start the PlDoc documentation system on a free network port and launch the user’s browser on
http://localhost:port. If port is specified, the server is started at the given port and the
browser is not launched.
--sigalert=NUM
Use signal NUM (1. . . 31) for alerting a thread. This is needed to make thread signal/2,
and derived Prolog signal handling act immediately when the target thread is blocked on an
interruptible system call (e.g., sleep/1, read/write to most devices). The default is to use
SIGUSR2. If NUM is 0 (zero), this handler is not installed. See prolog alert signal/2
to query or modify this value at runtime.
--no-tty
Unix only. Switches controlling the terminal for allowing single-character commands to the
tracer and get single char/1. By default, manipulating the terminal is enabled unless
the system detects it is not connected to a terminal or it is running as a GNU-Emacs inferior
process. See also tty control.
--win-app
This option is available only in swipl-win.exe and is used for the start-menu item. If
causes plwin to start in the folder ...\My Documents\Prolog or local equivalent
thereof (see win folder/2). The Prolog subdirectory is created if it does not exist.
-O
Optimised compilation. See current prolog flag/2 flag optimise for details.
-l file
Load file. This flag provides compatibility with some other Prolog systems.4 It is used in SWIProlog to skip the program initialization specified using initialization/2 directives.
See also section 2.11.2, and initialize/0.
-s file
Use file as a script file. The script file is loaded after the initialisation file specified with the
-f file option. Unlike -f file, using -s does not stop Prolog from loading the personal
initialisation file.
-f file
Use file as initialisation file instead of the default init.pl. ‘-f none’ stops SWI-Prolog
from searching for a startup file. This option can be used as an alternative to -s file that
stops Prolog from loading the personal initialisation file. See also section 2.2.
-F script
Select a startup script from the SWI-Prolog home directory.
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The script file is named


The default script name is deduced from the executable, taking the leading alphanumerical characters (letters, digits and underscore) from the program name. -F none stops looking for a script. Intended for simple management of slightly different versions. One could, for example, write a script iso.rc and then select ISO compatibility mode using pl -F iso or make a link from iso-pl to pl.

-x bootfile
Boot from bootfile instead of the system’s default boot file. A boot file is a file resulting from a Prolog compilation using the -b or -c option or a program saved using qsave_program/[1,2].

-p alias=path1[:path2 ... ]
Define a path alias for file_search_path. alias is the name of the alias, and argpath1 ... is a list of values for the alias. On Windows the list separator is ;. On other systems it is :. A value is either a term of the form alias(value) or pathname. The computed aliases are added to file_search_path/2 using asserta/1, so they precede predefined values for the alias. See file_search_path/2 for details on using this file location mechanism.

--traditional
This flag disables the most important extensions of SWI-Prolog version 7 (see section 5) that introduce incompatibilities with earlier versions. In particular, lists are represented in the traditional way, double quoted text is represented by a list of character codes and the functional notation on dicts is not supported. Dicts as a syntactic entity, and the predicates that act on them, are still supported if this flag is present.

--
Stops scanning for more arguments, so you can pass arguments for your application after this one. See current_prolog_flag/2 using the flag argv for obtaining the command line arguments.

2.4.3 Controlling the stack sizes

As of version 7.7.14 the stacks are no longer limited individually. Instead, only the combined size is limited. Note that 32 bit systems still pose a 128Mb limit. See section 2.20.1. The combined limit is by default 1Gb on 64 bit machines and 512Mb on 32 bit machines.

For example, to limit the stacks to 32Gb use the command below. Note that the stack limits apply per thread. Individual threads may be controlled using the stack_limit(+Bytes) option of thread_create. Any thread can call set_prolog_flag(stack_limit, Limit) (see stack_limit) to adjust the stack limit. This limit is inherited by threads created from this thread.

```
$ swipl --stack-limit=32g
```

--stack_limit=size[bkmg]
Limit the combined size of the Prolog stacks to the indicated size. The suffix specifies the value as bytes, Kbytes, Mbytes or Gbytes.
2.4.4 Running goals from the command line

\texttt{-g \textit{goal}}

\textit{Goal} is executed just before entering the top level. This option may appear multiple times. See section 2.3 for details. If no initialization goal is present the system calls \texttt{version/0} to print the welcome message. The welcome message can be suppressed with \texttt{-quiet}, but also with \texttt{-g \textit{true}}. \textit{Goal} can be a complex term. In this case quotes are normally needed to protect it from being expanded by the shell. A safe way to run a goal non-interactively is below. If go/0 succeeds \texttt{-g \textit{halt}} causes the process to stop with exit code 0. If it fails, the exit code is 1; and if it raises an exception, the exit code is 2.

\begin{verbatim}
% swipl <options> -g go -g halt
\end{verbatim}

\texttt{-t \textit{goal}}

Use \textit{goal} as interactive top level instead of the default goal \texttt{prolog/0}. The \textit{goal} can be a complex term. If the top-level goal succeeds SWI-Prolog exits with status 0. If it fails the exit status is 1. If the top level raises an exception, this is printed as an uncaught error and the top level is restarted. This flag also determines the goal started by \texttt{break/0} and \texttt{abort/0}. If you want to prevent the user from entering interactive mode, start the application with \texttt{-g \textit{goal} -t halt}.

2.4.5 Compilation options

\texttt{-c \textit{file} …}

Compile files into an ‘intermediate code file’. See section 2.11.

\texttt{-o \textit{output}}

Used in combination with \texttt{-c} or \texttt{-b} to determine output file for compilation.

2.4.6 Maintenance options

The following options are for system maintenance. They are given for reference only.

\texttt{-b \textit{initfile} …-c \textit{file} …}

Boot compilation. \textit{initfile} … are compiled by the C-written bootstrap compiler, \textit{file} … by the normal Prolog compiler. System maintenance only.

\texttt{-d \textit{token1},\textit{token2},…}

Print debug messages for DEBUG statements tagged with one of the indicated tokens. Only has effect if the system is compiled with the \texttt{-DO\_DEBUG} flag. System maintenance only.

\footnote{The letter M is used because the T was already in use. It is a mnemonic for Memoizing.}
2.5 UI Themes

UI (colour) themes play a role in two parts: when writing to the console and for the xpce-based development tools such as PceEmacs or the graphical debugger. Coloured console output is based on ansi_format/3. The central message infrastructure based on print_message/2 labels message (components) with a Prolog term that specifies the role. This is mapped to concrete colours by means of the hook prolog:console_color/2. Theming the IDE uses xpce class variables that are initialised from Prolog when xpce is loaded.

Themes are implemented as a Prolog file in the file search path library/theme. A theme can be loaded using (for example) the directive below in the user’s initialization file (see section 2.2).

```prolog
:- use_module(library(theme/dark)).
```

The theme file library(theme/auto) is provided to automatically choose a reasonable theme based on the environment. The current version detects the background color on xterm compatible terminal emulators (found on most Unix systems) and loads the dark theme if the background is ‘darkish’.

The following notes apply to the different platforms on which SWI-Prolog is supported:

**Unix/Linux** If an xterm compatible terminal emulator is used to run Prolog you may wish to load either an explicit theme or library(theme/auto).

**Windows** The swipl-win.exe graphical application can be themed by loading a theme file. The theme file also sets the foreground and background colours for the console.

2.5.1 Status of theme support

Theme support was added in SWI-Prolog 8.1.11. Only part of the IDE tools are covered and the only additional theme (dark) is not net well balanced. The interfaces between the theme file and notably the IDE components is not very well established. Please contribute by improving the dark theme. Once that is complete and properly functioning we can start adding new themes.

2.6 GNU Emacs Interface

SWI-Prolog provides tight integration with GNU Emacs through the sweep package. This package embeds SWI-Prolog as a dynamic Emacs module, allowing for Prolog queries to be executed directly from Emacs Lisp. The accompanying Emacs package sweepprolog.el, available for installation with the standard Emacs package manager package.el, builds on top of this embedding to provide a fully integrated development environment for SWI-Prolog in GNU Emacs.

GNU Emacs ships with by default with a Prolog mode called prolog.el. Compared to sweepprolog.el, this mode suffers from some problems that arise due to the lack of a proper Prolog parser. The original prolog.el by Masanobu Umeda has been included in GNU Emacs since 1989, in 2006 Stefan Monnier added explicit support for SWI-Prolog to prolog.el. In 2011, most of the original implementation has been replaced with a new Prolog mode written by initially for the XEmacs port by Stefan Bruda. Bruda’s mode was adapted to GNU Emacs by Stefan Monnier, who has been maintaining it along with other GNU Emacs contributor since. Users of this mode may find useful configuration suggestions at https://www.metalevel.at/pceprolog/.

Other Emacs package that can be useful for working with SWI-Prolog are:
• https://www.metalevel.at/ediprolog/
  Interact with SWI-Prolog directly in Emacs buffers.
• https://www.metalevel.at/etrace/
  Trace Prolog code with Emacs.
• https://emacs-lsp.github.io/dap-mode/page/configuration/
  #swi-prolog
  Debug Adapter Protocol (DAP) support for SWI-Prolog in Emacs via dap-mode and the debug_adapter pack from https://github.com/eshelyaron/debug_adapter
• https://emacs-lsp.github.io/lsp-mode/page/lsp-prolog/
  Language Server Protocol (LSP) support for SWI-Prolog in Emacs via lsp-mode and the lsp_server pack from https://github.com/jamesnvc/lsp_server

2.7 Online Help

2.7.1 library(help): Text based manual

This module provides help/1 and apropos/1 that give help on a topic or searches the manual for relevant topics.

By default the result of help/1 is sent through a pager such as less. This behaviour is controlled by the following:

• The Prolog flag help.pager, which can be set to one of the following values:

  false
  Never use a pager.

  default
  Use default behaviour. This tries to determine whether Prolog is running interactively in an environment that allows for a pager. If so it examines the environment variable PAGER or otherwise tries to find the less program.

  Callable
  A Callable term is interpreted as program_name(Arg, ...). For example, less(’-r’) would be the default. Note that the program name can be an absolute path if single quotes are used.

help(+What) [det]

Show help for What. What is a term that describes the topics(s) to give help for. Notations for What are:

Atom
  This ambiguous form is most commonly used and shows all matching documents. For example:

  ?- help(append).
Name / Arity
Give help on predicates with matching Name/Arity. Arity may be unbound.

Name // Arity
Give help on the matching DCG rule (non-terminal)

f(Name/Arity)
Give help on the matching Prolog arithmetic functions.

c(Name)
Give help on the matching C interface function

section(Label)
Show the section from the manual with matching Label.

If an exact match fails this predicates attempts fuzzy matching and, when successful, display the results headed by a warning that the matches are based on fuzzy matching.

If possible, the results are sent through a pager such as the less program. This behaviour is controlled by the Prolog flag help_pager. See section level documentation.

See also apropos/1 for searching the manual names and summaries.

show_html_hook(+HTML:string) [semidet,multifile]
Hook called to display the extracted HTML document. If this hook fails the HTML is rendered to the console as plain text using html_text/2.

apropos(+Query) [det]
Print objects from the manual whose name or summary match with Query. Query takes one of the following forms:

Type : Text
Find objects matching Text and filter the results by Type. Type matching is a case insensitive prefix match. Defined types are section, cfunction, function, iso_predicate, swi_builtin_predicate, library_predicate, dcg and aliases chapter, arithmetic, c_function, predicate, nonterminal and non_terminal. For example:

?- apropos(c:close).
?- apropos(f:min).

Text
Text is broken into tokens. A topic matches if all tokens appear in the name or summary of the topic. Matching is case insensitive. Results are ordered depending on the quality of the match.

2.7.2 library(explain): Describe Prolog Terms
The library(explain) describes prolog-terms. The most useful functionality is its cross-referencing function.
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<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>!.</td>
<td>Repeat last query</td>
</tr>
<tr>
<td>!nr.</td>
<td>Repeat query numbered (nr)</td>
</tr>
<tr>
<td>!str.</td>
<td>Repeat last query starting with (str)</td>
</tr>
<tr>
<td>h.</td>
<td>Show history of commands</td>
</tr>
<tr>
<td>!h.</td>
<td>Show this list</td>
</tr>
</tbody>
</table>

Table 2.1: History commands

?- explain(subset(_,_)).
"subset(_, _)" is a compound term
  from 2-th clause of lists:subset/2
  Referenced from 46-th clause of prolog_xref:imported/3
  Referenced from 68-th clause of prolog_xref:imported/3
lists:subset/2 is a predicate defined in
  /staff/jan/lib/pl-5.6.17/library/lists.pl:307
  Referenced from 2-th clause of lists:subset/2
  Possibly referenced from 2-th clause of lists:subset/2

Note that PceEmacs can jump to definitions and gxref/0 can be used for an overview of dependencies.

explain(@Term)  \[det\]
Give an explanation on Term. The argument may be any Prolog data object. If the argument is an atom, a term of the form Name/Arity or a term of the form Module:Name/Arity, explain/1 describes the predicate as well as possible references to it. See also gxref/0.

explain(@Term, -Explanation)  \[nondet\]
True when Explanation is an explanation of Term. The explaination is a list of elements that is printed using print_message(information, explain(Explanation)).

2.8 Command line history

SWI-Prolog offers a query substitution mechanism similar to what is seen in Unix shells. The availability of this feature is controlled by set_prolog_flag/2, using the history Prolog flag. By default, history is available if no interactive command line editor is available. To enable history, remembering the last 50 commands, put the following into your startup file (see section 2.2):

:- set_prolog_flag(history, 50).

The history system allows the user to compose new queries from those typed before and remembered by the system. The available history commands are shown in table 2.1. History expansion is not done if these sequences appear in quoted atoms or strings.
2.9. REUSE OF TOP-LEVEL BINDINGS

Figure 2.1: Reusing top-level bindings

```
1 ?- maplist(plus(1), 'hello', X).
X = [105,102,109,109,112].
2 ?- format('~s~n', [X]).
true.
3 ?-
```

2.9 Reuse of top-level bindings

Bindings resulting from the successful execution of a top-level goal are asserted in a database if they are not too large. These values may be reused in further top-level queries as $Var. If the same variable name is used in a subsequent query the system associates the variable with the latest binding.

Example:

Note that variables may be set by executing =/2:

```
6 ?- X = statistics.
X = statistics.
7 ?- $X.
true.
```

2.10 Overview of the Debugger

Imperative languages like C++, Python or JavaScript execute mostly linear code with some branching and subroutine calls. Their debuggers support stepping through the code and pausing on each line,
or running the program until it hits a breakpoint and pauses. When paused, the user can inspect the current program state or give the debugger commands.

Prolog has a logical execution model that involves attempting to prove logical predicates and needs a different debugging approach. SWI-Prolog uses the traditional Prolog "Byrd Box Model" or "4 Port Model" debugging approach described by [Byrd, 1980, Clocksin & Melish, 1987] with a couple of extensions to implement its command line debugger. There are two other debuggers available that build on this infrastructure: a graphical debugger and remote debugging in the web interface provided by SWISH.

Reference information to all predicates available for manipulating the debugger is in the debugger section (section 4.39).

### 2.10.1 The Byrd Box Model And Ports

Standard Prolog debugging tools are built around the so-called "Byrd Box Model" or "4 Port Model" which models each predicate in a Prolog program as a state machine ("box") that transitions through states ("ports") as a program is evaluated. The developer can ask the engine to pause for program inspection when it reaches specific ports or predicates.

As we go through this overview, remember that a "port" is just another word for a "state" in the state machine that each predicate transitions through during evaluation. The state machine is called a "box" because it is drawn like this:

```
*--------------------------------------*
Call | | Exit
---------> + descendant(X,Y) :- offspring(X,Y). + --------->
| |
| descendant(X,Z) :- |
<--------- + offspring(X,Y), descendant(Y,Z). + <---------
Fail | | Redo
*--------------------------------------*
```

The standard ports are: call, redo, exit and fail. SWI-Prolog extends this with two more: unify and exception. Each trace happens at a particular phase of predicate resolution. Recall that when resolving or "proving" a predicate, the Prolog engine:

1. Collects all rules that **might** match by having a head with the same name and number of arguments
   - call is traced, once, if any rules might match.
   - redo is also traced when the engine backtracks to find the next matching rule.

2. Finds the next matching rule whose head can be unified with the predicate
   - unify is traced with the results of unification if one is found.
   - fail is traced if no rule heads can be unified.

3. Applies variable assignments from unification to clauses in the rule body and continues at #1 with the updated clauses
4. After all of the body clauses of the matched rule have either succeeded, failed, or thrown an exception:

   - `exit` is traced if all of them succeeded (meaning this rule is true).
   - `fail` is traced if any of them failed (meaning this rule is false).
   - `exception` is traced if any of them threw an exception.

   This means there can be a lot of traces between the initial call and the end of tracing for a particular predicate.

2.10.2 Trace Mode Example

The `trace/0` predicate turns on "trace mode", which, by default, produces a trace and pauses at every port of every predicate to allow inspection of the state of the program. This is normally done from the Prolog console window, but for embedded Prolog systems or when Prolog runs as a daemon it can also be done by getting a prompt via the `libssh` package.

Note: If the native graphics plugin (XPCE) is available, the commands `gtrace/0` and `gspy/1` activate the graphical debugger while `tdebug/0` and `tspy/1` allow debugging of arbitrary threads.

Each goal is printed using the Prolog predicate `write_term/2`. The style is defined by the Prolog flag `debugger_write_options` and can be modified using this flag or using the `w`, `p` and `d` commands of the tracer (section 2.10.4).

Here’s an example debugging session that shows the basic flow. The `unify` port is off by default since it doesn’t add a lot of information in most cases for the command line debugger.

```prolog
is_a(rock1, rock).
is_a(rock2, rock).
color(rock1, red).
noun(X, Type) :- is_a(X, Type).
adjective(X, color, Value) :- color(X, Value).

?- trace.
true.

[trace] ?- noun(X, rock), adjective(X, color, red).
   Call: (11) noun(_9774, rock) ? creep
```

The `trace/0` predicate turned on trace mode, which is now indicated at every prompt by `[trace] ?-`. The initial query provided by the user was `noun(X, rock), adjective(X, color, red)` which is asking to find a “red rock”. Finally: the first port triggered was a `Call` to the first predicate in the initial query, indicating the engine is about to look for the first rule that matches `noun(_,9774, rock)`.

Pressing `spacebar`, `c`, or `enter` caused the tracer to print `creep` followed by the next trace. There are many additional commands available that are described later in the overview.
is_a(rock1, rock).
is_a(rock2, rock).
color(rock1, red).

noun(X, Type) :- is_a(X, Type).
adjective(X, color, Value) :- color(X, Value).

[trace]  ?- noun(X, rock), adjective(X, color, red).
...  
  Call: (12) is_a(_9774, rock) ? creep  
  Exit: (12) is_a(rock1, rock) ? creep  
  Exit: (11) noun(rock1, rock) ? creep  
...  

Next, the first clause of noun/2 gets a call trace since the engine is trying to find the next rule that matches is_a(_9774, rock). Since there is a fact that can unify: is_a(rock1, rock), the trace shows exit (i.e. succeeded) along with that value. Since that was the final predicate in the body of noun/2, noun/2 also gets an exit trace that shows the unified value of its head: noun(rock1, rock).

is_a(rock1, rock).
is_a(rock2, rock).
color(rock1, red).

noun(X, Type) :- is_a(X, Type).
adjective(X, color, Value) :- color(X, Value).

[trace]  ?- noun(X, rock), adjective(X, color, red).
...  
  Call: (11) adjective(rock1, color, red) ? creep  
  Call: (12) color(rock1, red) ? creep  
  Exit: (12) color(rock1, red) ? creep  
  Exit: (11) adjective(rock1, color, red) ? creep  
  X = rock1 ;  
...  

Prolog then moved to the next predicate in the initial query: adjective/3 and solved it in a similar way. Since that was the last predicate in the query, an answer was returned. Pressing ; requested the next answer and began Prolog backtracking.
2.10. OVERVIEW OF THE DEBUGGER

The only choice point to redo (i.e. backtrack over) was the is_a/2 clause of noun/2 since there was one potential match left to attempt to unify: is_a(rock2, rock). This succeeds with an exit trace since it does unify with the redo predicate and causes noun(rock2, rock) to also succeed with exit just as above.

As the traces continue, you can see the fail port get activated for color(rock2, red) since there is no way to prove that predicate and thus the whole query returns false.

Tracing will continue for every query you pose until you enter notrace. to turn off trace mode.

2.10.3 Trace Mode Options: leash/1 and visible/1

When you enable trace mode with trace/0, the tracer will, by default, pause and wait for a command at every port it hits on every predicate. The leash/1 predicate can be used to modify the ports to pause at. This is a global setting, so changes will remain until they are changed again or SWI-Prolog is restarted. Disabling the tracer via notrace/0 doesn’t affect which ports are leashed.

The leash/1 argument must start with + to add, or - to remove, followed by the name of a port such as call, exit, etc. There are special terms like all which can be used instead of manually adding or removing every port.

To stop only at the fail port, use leash/1 like this:

?- leash(-all).
true.

?- leash(+fail).
true.

?- trace.
true.

[trace] ?- noun(X, rock), adjective(X, color, red).
  Call: (11) noun(_3794, rock)
  Call: (12) is_a(_3794, rock)
  Exit: (12) is_a(rock1, rock)
  Exit: (11) noun(rock1, rock)
  Call: (11) adjective(rock1, color, red)
  Call: (12) color(rock1, red)
false.
Exit: (12) color(rock1, red)
Exit: (11) adjective(rock1, color, red)
X = rock1;
Redo: (12) is_a(_3794, rock)
Exit: (12) is_a(rock2, rock)
Exit: (11) noun(rock2, rock)
Call: (11) adjective(rock2, color, red)
Call: (12) color(rock2, red)
Fail: (12) color(rock2, red) ? creep
Fail: (11) adjective(rock2, color, red) ? creep false.

Now, only the lines that start with "Fail:" have "creep" after them because that was the only time
the tracer paused for a command. To never pause and just see all the traces, use leash(-all) and
don’t turn any ports back on.

The default ports are still printed out because a different setting, visible/1, controls which
ports are printed. visible/1 takes the same form of argument as leash/1. To only stop and
show the fail port, use leash/1 and visible/1 like this:

?- leash(-all).
ture.
?- leash(+fail).
ture.
?- visible(-all).
ture.
?- visible(+fail).
ture.
?- trace.
ture.

[trace] ?- noun(X, rock), adjective(X, color, red).
X = rock1;
   Fail: (12) color(rock2, red) ? creep
   Fail: (11) adjective(rock2, color, red) ? creep false.

2.10.4 Trace Mode Commands When Paused

You can do way more than just press spacebar when the tracer is paused at a port. All actions are
single-character commands which are executed without waiting for a return (unless the command line
option --no-tty is active). Pressing ? or h when paused will print out a list of these commands as well.
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Control Flow Commands

<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abort</td>
<td>Abort Prolog execution (see <code>abort/0</code>)</td>
</tr>
<tr>
<td>Break</td>
<td>Enter a Prolog break environment (see <code>break/0</code>)</td>
</tr>
<tr>
<td>Creep</td>
<td>Continue execution, stop at next port. (Also return, space)</td>
</tr>
<tr>
<td>Exit</td>
<td>Terminate Prolog (see <code>halt/0</code>)</td>
</tr>
<tr>
<td>Fail</td>
<td>Force failure of the current goal</td>
</tr>
<tr>
<td>Find</td>
<td>Search for a port (see below for the description of this command (section 2.10.4))</td>
</tr>
<tr>
<td>Ignore</td>
<td>Ignore the current goal, pretending it succeeded</td>
</tr>
<tr>
<td>Leap</td>
<td>Continue execution, stop at next spy point</td>
</tr>
<tr>
<td>No debug</td>
<td>Continue execution in 'no debug' mode</td>
</tr>
<tr>
<td>Repeat find</td>
<td>Repeat the last find command (see 'Find' (section 2.10.4))</td>
</tr>
<tr>
<td>Retry</td>
<td>Undo all actions (except for database and I/O actions) back to the call port of the current goal and resume execution at the call port</td>
</tr>
<tr>
<td>Spy</td>
<td>Set a spy point (see <code>spy/1</code>) on the current predicate. Spy points are described later in the overview (section 2.10.6).</td>
</tr>
<tr>
<td>No spy</td>
<td>Remove the spy point (see <code>nospy/1</code>) from the current predicate. Spy points are described later in the overview (section 2.10.6).</td>
</tr>
<tr>
<td>Up</td>
<td>Continue execution, stop at the next port of the parent goal (thus skipping this goal and all calls to children of this goal). This option is useful to stop tracing a failure driven loop.</td>
</tr>
</tbody>
</table>

Find (/) Description and Examples  The Find (/) command continues execution until a port matching a find pattern is found. After the /, the user can enter a line to specify the port to search for. This line consists of a set of letters indicating the port type, followed by an optional term, that should unify with the goal run by the port. If no term is specified it is taken as a variable, searching for any port of the specified type. If an atom is given, any goal whose functor has a name equal to that atom matches. Examples:

<table>
<thead>
<tr>
<th>Pattern</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>/f</td>
<td>Search for any fail port</td>
</tr>
<tr>
<td>/fe solve</td>
<td>Search for a fail or exit port of any goal with name solve</td>
</tr>
<tr>
<td>/c solve(a, _)</td>
<td>Search for a call to solve/2 whose first argument is a variable or the atom a</td>
</tr>
<tr>
<td>/a member(_, _)</td>
<td>Search for any port on member/2. This is equivalent to setting a spy point on member/2.</td>
</tr>
</tbody>
</table>

Informational Commands

<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alternatives</td>
<td>Show all goals that have alternatives</td>
</tr>
<tr>
<td>Goals</td>
<td>Show the list of parent goals (the execution stack). Note that due to tail recursion optimization a number of parent goals might not exist any more.</td>
</tr>
<tr>
<td>Help</td>
<td>Show available options (also ?)</td>
</tr>
<tr>
<td>Listing</td>
<td>List the current predicate with listing/1</td>
</tr>
</tbody>
</table>
Formatting Commands

<table>
<thead>
<tr>
<th>Command</th>
<th>Context</th>
<th>Display</th>
<th>Print</th>
<th>Write</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>Toggle 'Show Context'. If on, the context module of the goal is displayed between square brackets (see modules section (section 6)). Default is off.</td>
<td>Set the max_depth(Depth) option of debugger_write_options (section 2.12), limiting the depth to which terms are printed. See also the w and p options.</td>
<td>Set the Prolog flag debugger_write_options to [quoted(true), portray(true), max_depth(10), priority(699)]. This is the default.</td>
<td>Set the Prolog flag debugger_write_options to [quoted(true), attributes(write), priority(699)], bypassing portray/1, etc.</td>
</tr>
</tbody>
</table>

2.10.5 Trace Mode vs. Trace Point

A slight detour is useful to describe some related predicates that can be confusing: To only trace a single or select set of predicates, the trace/1 or trace/2 predicates can be used to set a trace point. Even though they use the same base predicate name trace, these predicates ignore the leash/1 and visible/1 global settings and don’t pause when they trace a port. They really are a different feature that also happens to do tracing.

A trace point is set on a particular predicate and traces the ports of that predicate whether or not you are in trace/0 trace mode. Each trace point can trace different ports if the trace/2 variant is used.

```
?- trace(is_a/2).
% is_a/2: [all]
true.

?- noun(X, rock), adjective(X, color, red).
T Call: is_a(_25702, rock)
T Exit: is_a(rock1, rock)
X = rock1 ;
T Redo: is_a(rock1, rock)
T Exit: is_a(rock2, rock)
false.
```

Notice that trace mode did not have to be turned on using trace/0 and that this only traced out the ports hit while executing is_a/2 and that the program was not ever paused.

In fact, if trace mode is turned on while using a trace point, things get very confusing because the trace point infrastructure itself will be traced!

```
?- trace(is_a/2).
% is_a/2: [all]
true.
```
2.10. OVERVIEW OF THE DEBUGGER

So, trace points are a confusingly named and separate feature from trace mode.

2.10.6 Spy Points and Debug Mode

Back to trace mode features: Because the tracing output of a Prolog program can often be quite large, sometimes it is useful to start trace mode at a particular point deep in the program. This is what a spy point is for. It specifies a predicate that should turn on trace mode.

A spy point is enabled like this: spy(mypredicate/2). After that command, the first time mypredicate/2 is encountered, trace mode will turn on and work just like it does normally. This includes paying attention to the global leash/1 and visible/1 settings. The spy point can be removed using nospy/1 or nospyall/0.
After the spy point is hit, the output above is identical to the traces generated by running trace/0 with the initial query, but is obviously missing all of the traces before the spy point.

Note that after \texttt{spy/1} is called, there is a new tag in front of \texttt{?-}, the \texttt{[debug]} tag:

\begin{verbatim}
?- spy(is_a/2).
% Spy point on is_a/2
true.
[debug] ?-
\end{verbatim}

This means the system is in "debug mode". Debug mode does two things: it tells the system to watch for spy points and it turns off some optimizations that would make the traces confusing. The ideal 4-port model ([Byrd, 1980]) as described in many Prolog books ([Clocksin & Melish, 1987]) is not visible in many Prolog implementations because code optimisation removes part of the choice and exit points. Backtrack points are not shown if either the goal succeeded deterministically or its alternatives were removed using the cut. When running in debug mode, choice points are only destroyed when removed by the cut and last call optimisation is switched off. [Note: This implies the system can run out of stack in debug mode, while no problems arise when running in non-debug mode.]

Debug mode can be turned off again using nodebug/0, but then the spy point will be ignored (but remembered). Turning debug mode back on via debug/0 will hit the spy point again.
So, debug mode allows Prolog to watch for spy points and enable trace mode when it hits one. The `tracing/0` and `debugging/0` predicates will report if the system is in either of those modes.

### 2.10.7 Breakpoints

Sometimes even spy points aren’t enough. There may be a predicate that is used in many different places and it would be helpful to turn on tracing mode only when one particular call to it is made. **Breakpoints** allow for turning on trace mode when a specific source file, line number, and character in that line are hit. The predicates used are `set_breakpoint/4` and `set_breakpoint/5`. Many breakpoints can be active at a time.

Note that the interface provided by these predicates is not intended for end-users. The built-in PceEmacs editor that is also embedded in the graphical debugger allow setting break points based on the cursor position.

*Example.pl* has now been modified to have multiple calls to `noun/2`:

```prolog
is_a(rock1, rock).
is_a(rock2, rock).
color(rock1, red).

noun(X, Type) :- is_a(X, Type).
adjective(X, color, Value) :- color(X, Value).
```
test_noun1(X, Type) :- noun(X, Type).

To enable tracing just when noun/2 is called from test_noun2/2, set_breakpoint/4 can be used like this:

?- set_breakpoint(’/...path.../Example.pl’, 8, 24, ID).
% Breakpoint 1 in 1-st clause of test_noun2/2 at Example.pl:8
ID = 1.

?- debug.
true.

[debug] ?- noun(X, rock).
X = rock1.

[debug] ?- test_noun1(X, rock).
X = rock1.

[debug] ?- test_noun2(X, rock).

Call: (11) noun(_49982, rock) ? creep
Call: (12) is_a(_49982, rock) ? creep
Exit: (12) is_a(rock1, rock) ? creep
Exit: (11) noun(rock1, rock) ? creep
Exit: (10) test_noun2(rock1, rock) ? creep
X = rock1.

[trace] ?- notrace.
true.

[debug] ?-

The call to set_breakpoint/4 had to specify the source file ("Example.pl"), the line number (8), and the character within that line (24) to precisely specify what clause should turn on trace mode (this is much easier using the graphical debugger because it shows source code).

The breakpoint won’t get triggered if the system isn’t in debug mode but, unlike setting a spy point, set_breakpoint/4 does not do this automatically. So, it was turned on manually using debug/0.

The output shows that only the call to test_noun2/2 (where the breakpoint was set) actually turned on trace mode. Note that the [Trace] ?- at the end shows that trace mode is left on after being triggered. It can be turned off again via notrace/0, which will leave the system in debug mode. All debugging modes can be shut off at once by calling nodebug/0 since shutting off debug mode automatically turns off trace mode.

In addition, SWI-Prolog supports attaching an arbitrary goal to each breakpoint via set_breakpoint_condition/2, which yields Conditional Breakpoints. A conditional breakpoint is the same as the regular breakpoints discussed thus far, except that whenever the breakpoint is triggered, the given goal is invoked and trace mode is only turned on in case it succeeds.
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To enable tracing just when noun/2 is called from test_noun2/2 with rock2 as the first argument, set_breakpoint.condition/2 can be used like below. Note that the condition is a Prolog string that is parsed to obtain the goal as well as the variable names. The resulting goal is called in the module in which the clause body is executed (see clause.property/2, property module).

?- set_breakpoint('.../Example.pl', 8, 24, ID).
ID = 1.

?- set_breakpoint_condition(1, "X == rock2").
true.

?- debug.
true.

[debug] ?- test_noun2(X, rock).
X = rock1 ;
X = rock2.

[debug] ?- test_noun2(rock2, rock).
Call: (11) noun(rock2, rock) ? creep
Call: (12) is_a(rock2, rock) ? creep
Exit: (12) is_a(rock2, rock) ? creep
Exit: (11) noun(rock2, rock) ? creep
Exit: (10) test_noun2(rock2, rock) ? creep
true.

[trace] ?-

2.10.8 Command Line Debugger Summary

In summary, there are really two distinct "tracing" features: trace mode and trace points. Both write traces to the console using the "Byrd Box Model" but that’s where similarity ends.

Trace Mode

Trace mode is the main Prolog command line debugger that allows for tracing the transitions through the resolution states of predicates represented by ports in the "Byrd Box Model” and optionally pausing for a command when certain ports are hit.

It can be turned on manually via trace/0, or (when put into debug mode using debug/0) when a specific predicate is encountered via spy/1, or when a specific call to a predicate is encountered via set_breakpoint/4 or set_breakpoint/5.

When in trace mode, visible/1 controls which ports are written to the console, and leash/1 controls which ports cause execution to pause to allow program inspection.

When execution is paused, there are many commands that can be used to inspect the state of the program, cause goals to fail or succeed, etc.

Trace mode is turned off via notrace/0 and debug mode is turned off via nodebug/0.
Trace Points

Trace points are a separate feature from trace mode that allow writing specified ports to the console when a predicate is being evaluated. It does not ever pause program execution and does not need to be in trace or debug mode to work.

They are turned on via trace/1 and trace/2.

They don’t pay attention to visible/1 (because the ports shown are set in trace/2) or leash/1 (because they don’t pause execution).

They can be turned off via trace/2.

2.11 Compilation

2.11.1 During program development

During program development, programs are normally loaded using the list abbreviation (?- [load].). It is common practice to organise a project as a collection of source files and a load file, a Prolog file containing only use_module/[1,2] or ensure_loaded/1 directives, possibly with a definition of the entry point of the program, the predicate that is normally used to start the program. This file is often called load.pl. If the entry point is called go, a typical session starts as:

```
% swipl
<banner>
1 ?- [load].
<compilation messages>
true.
2 ?- go.
<program interaction>
```

When using Windows, the user may open load.pl from the Windows explorer, which will cause swipl-win.exe to be started in the directory holding load.pl. Prolog loads load.pl before entering the top level. If Prolog is started from an interactive shell, one may choose the type swipl -s load.pl.

2.11.2 For running the result

There are various options if you want to make your program ready for real usage. The best choice depends on whether the program is to be used only on machines holding the SWI-Prolog development system, the size of the program, and the operating system (Unix vs. Windows).

Using PrologScript

A Prolog source file can be used directly as a Unix program using the Unix #! magic start. The Unix #! magic is allowed because if the first letter of a Prolog file is #, the first line is treated as a comment. To create a Prolog script, use one of the two alternatives below as first line. The first

---

6The #-sign can be the legal start of a normal Prolog clause. In the unlikely case this is required, leave the first line blank or add a header comment.
can be used to bind a script to a specific Prolog installation, while the latter uses the default prolog installed in $PATH.

```
#!/path/to/swipl
#!/usr/bin/env swipl
```

The interpretation of arguments to the executable in the *HashBang* line differs between Unix-derived systems. For portability, the `#!` must be followed immediately with an absolute path to the executable and should have none or one argument. Neither the executable path, nor the argument shall use quotes or spaces. When started this way, the Prolog flag `argv` contains the command line arguments that follow the script invocation.

Starting with version 7.5.8, `initialization/2` support the *When* options `program` and `main`, allowing for the following definition of a Prolog script that evaluates an arithmetic expression on the command line. Note that `main/0` is defined in the library `main`. It calls `main/1` with the command line arguments after disabling signal handling.

```
#!/usr/bin/env swipl
:- initialization(main, main).

main(Argv) :-
    concat_atom(Argv, ' ', SingleArg),
    term_to_atom(Term, SingleArg),
    Val is Term,
    format('\n', [Val]).
```

And here are two example runs:

```
% ./eval 1+2
3
% ./eval foo
ERROR: is/2: Arithmetic: ‘foo/0’ is not a function
```

Prolog script may be launched for debugging or inspection purposes using the `-l` or `-t`. For example, `-l` merely loads the script, ignoring `main` and `program` initialization.

```
swipl -l eval
<banner>
?- main.
2
true.
?- 
```

We can also force the program to enter the interactive toplevel after the application is completed using `-t prolog:`
Creating a shell script

With the introduction of PrologScript (see section 2.11.2), using shell scripts as explained in this section has become redundant for most applications.

Especially on Unix systems and not-too-large applications, writing a shell script that simply loads your application and calls the entry point is often a good choice. A skeleton for the script is given below, followed by the Prolog code to obtain the program arguments.

```bash
#!/bin/sh

base=<absolute-path-to-source>
PL=swipl
exec $PL -q -f "$base/load" --
```

```prolog
:- initialization go.

go :-
    current_prolog_flag(argv, Arguments),
    go(Arguments).

go(Args) :-
    ...
```

On Windows systems, similar behaviour can be achieved by creating a shortcut to Prolog, passing the proper options or writing a .bat file.

Creating a saved state

For larger programs, as well as for programs that are required to run on systems that do not have the SWI-Prolog development system installed, creating a saved state is the best solution. A saved state is created using qsave_program/[1,2] or the -c command line option. A saved state is a file containing machine-independent intermediate code in a format dedicated for fast loading. Optionally, the emulator may be integrated in the saved state, creating a single file, but machine-dependent, executable. This process is described in chapter 14.

---

7 Older versions extracted command line arguments from the HashBang line. As of version 5.9 all relevant setup can be achieved using directives. Due to the compatibility issues around HashBang line processing, we decided to remove it completely.

8 The saved state does not depend on the CPU instruction set or endianness. Saved states for 32- and 64-bits are not compatible. Typically, saved states only run on the same version of Prolog on which they have been created.
Compilation using the -c command line option

This mechanism loads a series of Prolog source files and then creates a saved state as qsave_program/2 does. The command syntax is:

```
% swipl [option ...] [-o output] -c file.pl ...
```

The `options` argument are options to qsave_program/2 written in the format below. The option names and their values are described with qsave_program/2.

```plaintext
--option-name=option-value
```

For example, to create a stand-alone executable that starts by executing main/0 and for which the source is loaded through load.pl, use the command

```
% swipl --goal=main --stand_alone=true -o myprog -c load.pl
```

This performs exactly the same as executing

```
% swipl <banner>
?- [load].
?- qsave_program(myprog, [goal(main), stand_alone(true)]).
?- halt.
```

2.12 Environment Control (Prolog flags)

The predicates current_prolog_flag/2 and set_prolog_flag/2 allow the user to examine and modify the execution environment. It provides access to whether optional features are available on this version, operating system, foreign code environment, command line arguments, version, as well as runtime flags to control the runtime behaviour of certain predicates to achieve compatibility with other Prolog environments.

**current_prolog_flag(Key, -Value)**  
ISO  
The predicate current_prolog_flag/2 defines an interface to installation features: options compiled in, version, home, etc. With both arguments unbound, it will generate all defined Prolog flags. With Key instantiated, it unifies Value with the value of the Prolog flag or fails if the Key is not a Prolog flag.

Flags marked changeable can be modified by the user using set_prolog_flag/2. Flag values are typed. Flags marked as bool can have the values true or false. The predicate
create_prolog_flag/3 may be used to create flags that describe or control behaviour of libraries and applications. The library settings provides an alternative interface for managing notably application parameters.

Some Prolog flags are not defined in all versions, which is normally indicated in the documentation below as "if present and true". A boolean Prolog flag is true iff the Prolog flag is present and the Value is the atom true. Tests for such flags should be written as below:

```
( current_prolog_flag(windows, true)
  -> <Do MS-Windows things>
  ; <Do normal things>
)
```

Some Prolog flags are scoped to a source file. This implies that if they are set using a directive inside a file, the flag value encountered when loading of the file started is restored when loading of the file is completed. Currently, the following flags are scoped to the source file: generate_debug_info and optimise.

A new thread (see section 10) copies all flags from the thread that created the new thread (its parent). As a consequence, modifying a flag inside a thread does not affect other threads.

**abi_version (dict)**

The flag value is a dict with keys that describe the version of the various Application Binary Interface (ABI) components. See section 2.22 for details.

**access_level (atom, changeable)**

This flag defines a normal 'user' view (user, default) or a 'system' view. In system view all system code is fully accessible as if it was normal user code. In user view, certain operations are not permitted and some details are kept invisible. We leave the exact consequences undefined, but, for example, system code can be traced using system access and system predicates can be redefined.

**address_bits (integer)**

Address size of the hosting machine. Typically 32 or 64. Except for the maximum stack limit, this has few implications to the user. See also the Prolog flag arch.

**age_close_streams (boolean, changeable)**

When true (default false), that atom garbage collector streams that are garbage collected while being open. In addition, a warning is printed. Below is an example of such a warning.

```
WARNING: AGC: closed <stream>(0x560e29014400)
```

Note that closing I/O streams should not be left to the (atom) garbage collector because it may take long before the atom garbage collector runs and because that atom garbage collector is conservative, which implies that it is not guaranteed that all garbage atoms are reclaimed. Code that uses I/O streams should use setup_call_cleanup/3 using the skeleton below, where process/1 is a predicate that reads from or writes to Stream.

---

9. This is implemented using the copy-on-write technique.
10. Future versions are likely to change the default to true.
Note that the setting for this flag in the main thread applies.

**age_margin** (*integer, changeable*)

If this amount of atoms possible garbage atoms exist perform atom garbage collection at the first opportunity. Initial value is 10,000. May be changed. A value of 0 (zero) disables atom garbage collection. See also `PL_register_atom()`.

**allow_dot_in_atom** (*bool, changeable*)

If true (default false), dots may be embedded into atoms that are not quoted and start with a letter. The embedded dot must be followed by an identifier continuation character (i.e., letter, digit or underscore). The dot is allowed in identifiers in many languages, which can make this a useful flag for defining DSLs. Note that this conflicts with cascading functional notation. For example, `Post.meta.author` is read as `.Post, 'meta.author'` if this flag is set to true.

**allow_variable_name_as_functor** (*bool, changeable*)

If true (default is false), `Functor(arg)` is read as if it were written `'Functor'(arg)`. Some applications use the Prolog `read/1` predicate for reading an application-defined script language. In these cases, it is often difficult to explain to non-Prolog users of the application that constants and functions can only start with a lowercase letter. Variables can be turned into atoms starting with an uppercase atom by calling `read_term/2` using the option `variable_names` and binding the variables to their name. Using this feature, `F(x)` can be turned into valid syntax for such script languages. Suggested by Robert van Engelen. SWI-Prolog specific.

**android** (*bool*)

If present and true, it indicates we are running on the Android OS. The flag is not present in other operating systems.

**android_api** (*integer*)

If running on Android, it indicates the compile-time API Level defined by the C macro `__ANDROID_API__`. It is not defined if running on other operating systems. The API level may or may not match the API level of the running device, since it is the API level at compile time.

**answer_write_options** (*term, changeable*)

This argument is given as option-list to `write_term/2` for printing results of queries. Default is `[quoted(true), portray(true), max_depth(10), attributes(portray)]`.

**apple** (*bool*)

If present and true, the operating system is MacOSX. Defined if the C compiler used

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11 Given that SWI-Prolog has no limit on the length of atoms, 10,000 atoms may still occupy a lot of memory. Applications using extremely large atoms may wish to call `garbage.collect.atoms/0` explicitly or lower the margin.
to compile this version of SWI-Prolog defines __APPLE__. Note that the unix is also defined for MacOSX.

apple_universal_binary bool If present and true, SWI-Prolog has been build as a universal binary. Universal binaries contain native executable code for multiple architectures. Currently the supported architectures are x86_64 and arm64. The architecture prefix for components is fat-darwin while the arch depends on the actual CPU type.

arch (atom)
Identifier for the hardware and operating system SWI-Prolog is running on. Used to select foreign files for the right architecture. See also section 12.2.3 and file_search_path/2. For Apple, see also apple_universal_binary.

argv (list, changeable)
List is a list of atoms representing the application command line arguments. Application command line arguments are those that have not been processed by Prolog during its initialization. Note that Prolog’s argument processing stops at -- or the first non-option argument. See also os_argv.¹²

associated_file (atom)
Set if Prolog was started with a prolog file as argument. Used by e.g., edit/0 to edit the initial file.

autoload (atom, changeable)
This flag controls autoloading predicates based on autoload/1 and autoload/2 as well as predicates from autoload libraries. It has the following values:

false
Predicates are never auto-loaded. If predicates have been imported before using autoload/[1,2], load the referenced files immediately using use_module/[1,2]. Note that most of the development utilities such as listing/1 have to be explicitly imported before they can be used at the toplevel.

explicit
Do not autoload from autoload libraries, but do use lazy loading for predicates imported using autoload/[1,2].

user
As false, but to autoload library predicates into the global user module. This makes the development tools and library implicitly available to the toplevel, but not to modules.

user_or_explicit
Combines explicit with user, providing lazy loading of predicates imported using autoload/[1,2] and implicit access to the whole library for the toplevel.

true
Provide full autoloading everywhere. This is the default.

back_quotes (codes, chars, string, symbol_char, changeable)
Defines the term-representation for back-quoted material. The default is codes. If --traditional is given, the default is symbol_char, which allows using ’ in operators composed of symbols.¹³ See also section 5.2.

¹²Prior to version 6.5.2, argv was defined as os_argv is now. The change was made for compatibility reasons and because the current definition is more practical.

¹³Older versions had a boolean flag backquoted_strings, which toggled between string and symbol_char.
backtrace (bool, changeable)
If true (default), print a backtrace on an uncaught exception.

backtrace_depth (integer, changeable)
If backtraces on errors are enabled, this flag defines the maximum number of frames that
is printed (default 20).

backtrace_goal_depth (integer, changeable)
The frame of a backtrace is printed after making a shallow copy of the goal. This flag
determines the depth to which the goal term is copied. Default is ‘3’.

backtrace_show_lines (bool, changeable)
If true (default), try to reconstruct the line number at which the exception happened.

bounded (bool)
ISO Prolog flag. If true, integer representation is bound by min_integer and
max_integer. If false integers can be arbitrarily large and the min_integer and
max_integer are not present. See section 4.27.2.

break_level (integer)
Current break-level. The initial top level (started with -t) has value 0. See break/0.
This flag is absent from threads that are not running a top-level loop.

c_cc (atom, changeable)
Name of the C compiler used to compile SWI-Prolog. Normally either gcc or cc. See
section 12.5.

c_cflags (atom, changeable)
CFLAGS used to compile SWI-Prolog. See section 12.5.

c_ldflags (atom, changeable)
LDFLAGS used to link SWI-Prolog. See section 12.5.

c_libplso (atom, changeable)
Libraries needed to link extensions (shared object, DLL) to SWI-Prolog. Typically empty
on ELF systems and -lswipl on COFF-based systems. See section 12.5.

c_libs (atom, changeable)
Libraries needed to link executables that embed SWI-Prolog. Typically -lswipl if the
SWI-Prolog kernel is a shared (DLL). If the SWI-Prolog kernel is in a static library, this
flag also contains the dependencies.

char_conversion (bool, changeable)
Determines whether character conversion takes place while reading terms. See also
char_conversion/2.

character_escapes (bool, changeable)
If true (default), read/1 interprets \ escape sequences in quoted atoms and strings.
May be changed. This flag is local to the module in which it is changed. See
section 2.16.1.

character_escapes_unicode (bool, changeable)
If true (default), write/1 and friends write escaped characters using the \uXXXX or
\uxxxxxxxxx syntax rather than the ISO Prolog \x<hex>\ syntax. SWI-Prolog reads
both.

cmake_build_type (atom)
Provides the cmake build type used to build this version of SWI-Prolog.
colon_sets_calling_context (bool)
Using the construct ⟨module⟩:⟨goal⟩ sets the calling context for executing ⟨goal⟩. This flag is defined by ISO/IEC 13211-2 (Prolog modules standard). See section 6.

color_term (bool, changeable)
This flag is managed by library ansi_term, which is loaded at startup if the two conditions below are both true. Note that this implies that setting this flag to false from the system or personal initialization file (see section 2.2) disables colored output. The predicate message_property/2 can be used to control the actual color scheme depending in the message type passed to print_message/2.

- stream_property(current_output, tty(true))
- \( + \) current_prolog_flag(color_term, false)

compile_meta_arguments (atom, changeable)
This flag controls compilation of arguments passed to meta-calls marked ‘0’ or ‘^’ (see meta_predicate/1). Supported values are:

false (default). Meta-arguments are passed verbatim. If the argument is a control structure ((A,B), (A:B), (A\_¿B:C), etc.) it is compile to an temporary clause allocated on the environment stack when the meta-predicate is called.

control
Compile meta-arguments that contain control structures to an auxiliary predicate. This generally improves performance as well as the debugging experience.

always
Always create an intermediate clause, even for system predicates.\(^{14}\)

compiled_at (atom)
Describes when the system has been compiled. Only available if the C compiler used to compile SWI-Prolog provides the \_DATE\_ and \_TIME\_ macros.

console_menu (bool)
Set to true in swipl-win.exe to indicate that the console supports menus. See also section 4.35.4.

cpu_count (integer, changeable)
Number of physical CPUs or cores in the system. The flag is marked read-write both to allow pretending the system has more or less processors. See also thread_setconcurrency/2 and the library thread. This flag is not available on systems where we do not know how to get the number of CPUs. This flag is not included in a saved state (see qsave_program/1).

dde (bool)
Set to true if this instance of Prolog supports DDE as described in section 4.44.

debug (bool, changeable)
Switch debugging mode on/off. If debug mode is activated the system traps encountered spy points (see spy/1) and break points. In addition, last-call optimisation is disabled and the system is more conservative in destroying choice points to simplify debugging.

\(^{14}\)This may be used in the future for replacing the normal head of the generated predicate with a special reference (similar to database references as used by, e.g., assert/2) that provides direct access to the executable code, thus avoiding runtime lookup of predicates for meta-calling.
Disabling these optimisations can cause the system to run out of memory on programs that behave correctly if debug mode is off.

**debug_on_error (bool, changeable)**
If true, start the tracer after an error is detected. Otherwise just continue execution. The goal that raised the error will normally fail. See also the Prolog flag report_error. Default is true.

**debug_on_interrupt (bool, changeable)**
If true, start the debugger on Control-C.\(^{15}\). The initial value is false and the value is set to true when entering the interactive top level. See --debug-on-interrupt to start handling interrupts immediately.

**debugger_show_context (bool, changeable)**
If true, show the context module while printing a stack-frame in the tracer. Normally controlled using the ‘C’ option of the tracer.

**debugger_write_options (term, changeable)**
This argument is given as option-list to write_term/2 for printing goals by the debugger. Modified by the ‘w’, ‘p’ and ‘(N) d’ commands of the debugger. Default is [quoted(true), portray(true), max_depth(10), attributes(portray)].

**determinism_error (atom, changeable)**
This flag defines the behaviour when the predicate determinism is not according to its declaration. See det/1. Possible values are error (default), warning and silent.

**dialect (atom)**
Fixed to swi. The code below is a reliable and portable way to detect SWI-Prolog.

```
is_dialect(swi) :-
    catch(current_prolog_flag(dialect, swi), _, fail).
```

**double_quotes (codes,chars,atom,string, changeable)**
This flag determines how double quoted strings are read by Prolog and is —like character_escapes and back_quotes— maintained for each module. The default is string, which produces a string as described in section 5.2. If --traditional is given, the default is codes, which produces a list of character codes, integers that represent a Unicode code-point. The value chars produces a list of one-character atoms and the value atom makes double quotes the same as single quotes, creating a atom. See also section 5.

**editor (atom, changeable)**
Determines the editor used by edit/1. See section 4.4.1 for details on selecting the editor used.

**emacs_inferior_process (bool)**
If true, SWI-Prolog is running as an inferior process of (GNU/X-)Emacs. SWI-Prolog assumes this is the case if the environment variable EMACS is t and INFERIOR is yes.

**encoding (atom, changeable)**
Default encoding used for opening files in text mode. The initial value is deduced from the environment. See section 2.19.1 for details.

\(^{15}\)More precisely when receiving SIGINT
executable (atom)
Pathname of the running executable. Used by qsave_program/2 as default emulator.

executable_format (atom)
Format of the SWI-Prolog executable, e.g. elf for when swipl is an ELF binary file.

exit_status (integer)
Set by halt/1 to its argument, making the exit status available to hooks registered with at_halt/1.

file_name_case_handling (atom, changeable)
This flag defines how Prolog handles the case of file names. The flag is used for case normalization and to determine whether two names refer to the same file.\(^{16}\) It has one of the following values:

- **case_sensitive**
The filesystem is fully case sensitive. Prolog does not perform any case modification or case insensitive matching. This is the default on Unix systems.

- **case_preserving**
The filesystem is case insensitive, but it preserves the case with which the user has created a file. This is the default on Windows systems.

- **case_insensitive**
The filesystem doesn’t store or match case. In this scenario Prolog maps all file names to lower case.

file_name_variables (bool, changeable)
If true (default false), expand \$\arg\{varname\} and ~ in arguments of built-in predicates that accept a file name (open/3, exists_file/1, access_file/2, etc.). The predicate expand_file_name/2 can be used to expand environment variables and wildcard patterns. This Prolog flag is intended for backward compatibility with older versions of SWI-Prolog.

file_search_cache_time (number, changeable)
Time in seconds for which search results from absolute_file_name/3 are cached. Within this time limit, the system will first check that the old search result satisfies the conditions. Default is 10 seconds, which typically avoids most repetitive searches for (library) files during compilation. Setting this value to 0 (zero) disables the cache.

float_max (float)
The biggest representable floating point number.

float_max_integer (float)
The highest integer that can be represented precisely as a floating point number.

float_min (float)
The smallest representable floating point number above 0.0. See also nexttoward/2.

float_overflow (atom, changeable)
One of error (default) or infinity. The first is ISO compliant. Using infinity, floating point overflow is mapped to positive or negative Inf. See section 4.27.2.

\(^{16}\)BUG: Note that file name case handling is typically a property of the filesystem, while Prolog only has a global flag to determine its file handling.
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**float_rounding** (*atom, changeable*)
Defines how arithmetic rounds to a float. Defined values are `to_nearest` (default), `to_positive`, `to_negative` or `to_zero`. For most scenarios the function `roundtoward/2` provides a safer and faster alternative.

**float_undefined** (*atom, changeable*)
One of `error` (default) or `nan`. The first is ISO compliant. Using `nan`, undefined operations such as `sqrt(-2.0)` is mapped to NaN. See section 4.27.2.

**float_underflow** (*atom, changeable*)
One of `error` or `ignore` (default). The second is ISO compliant, binding the result to 0.0.

**float_zero_div** (*atom, changeable*)
One of `error` (default) or `infinity`. The first is ISO compliant. Using `infinity`, division by 0.0 is mapped to positive or negative `Inf`. See section 4.27.2.

**gc** (*bool, changeable*)
If true (default), the garbage collector is active. If false, neither garbage collection, nor stack shifts will take place, even not on explicit request. May be changed.

**gc_thread** (*bool*)
If true (default if threading is enabled), atom and clause garbage collection are executed in a separate thread with the alias `gc`. Otherwise the thread that detected sufficient garbage executes the garbage collector. As running these global collectors may take relatively long, using a separate thread improves real time behaviour. The `gc` thread can be controlled using `set_prolog.gc_thread/1`.

**generate_debug_info** (*bool, changeable*)
If true (default) generate code that can be debugged using `trace/0`, `spy/1`, etc. Can be set to `false` using the `--no-debug`. This flag is scoped within a source file. Many of the libraries have `:- set_prolog_flag(generate_debug_info, false)` to hide their details from a normal trace.\(^{17}\)

**gmp_version** (*integer*)
If Prolog is linked with GMP, this flag gives the major version of the GMP library used. See also section 12.4.10. This flag is not present when linked to LibBF. Use non-existence of the Prolog flag `bounded` to test for big integer and rational number support.

**gui** (*bool*)
Set to `true` if XPCE is around and can be used for graphics.

**heartbeat** (*integer, changeable*)
If not zero, call `prolog:heartbeat/0` every \(N\) inferences. \(N\) is rounded to a multiple of 16.

**history** (*integer, changeable*)
If \(integer > 0\), support Unix `csh(1)`-like history as described in section 2.8. Otherwise, only support reusing commands through the command line editor. The default is to set this Prolog flag to 0 if a command line editor is provided (see Prolog flag `readline`) and 15 otherwise.

---

\(^{17}\)In the current implementation this only causes a flag to be set on the predicate that causes children to be hidden from the debugger. The name anticipates further changes to the compiler.
home (atom)
SWI-Prolog’s notion of the home directory. SWI-Prolog uses its home directory to find its startup file as ⟨home⟩/boot.prc and to find its library as ⟨home⟩/library. Some installations may put architecture independent files in a shared home and also define shared_home. System files can be found using absolute_file_name/3 as swi(file). See file_search_path/2.

hwnd (integer)
In swipl-win.exe, this refers to the MS-Windows window handle of the console window.

integer_rounding_function (down,toward_zero)
ISO Prolog flag describing rounding by // and rem arithmetic functions. Value depends on the C compiler used.

iso (bool, changeable)
Include some weird ISO compatibility that is incompatible with normal SWI-Prolog behaviour. Currently it has the following effect:

- The //2 (float division) always returns a float, even if applied to integers that can be divided.
- In the standard order of terms (see section 4.6.1), all floats are before all integers.
- atom_length/2 yields a type error if the first argument is a number.
- clause/[2,3] raises a permission error when accessing static predicates.
- abolish/[1,2] raises a permission error when accessing static predicates.
- Syntax is closer to the ISO standard:
  - Within functional notation and list notation terms must have priority below 1000. That means that rules and control constructs appearing as arguments need bracketing. A term like [a :- b, c]. must now be disambiguated to mean [(a :- b), c] or [(a :- b, c)].
  - Operators appearing as operands must be bracketed. Instead of X == -, true. write X == (-), true. Currently, this is not entirely enforced.
  - Backslash-escaped newlines are interpreted according to the ISO standard. See section 2.16.1.

large_files (bool)
If present and true, SWI-Prolog has been compiled with large file support (LFS) and is capable of accessing files larger than 2GB. This flag is always true on 64-bit hardware and true on 32-bit hardware if the configuration detected support for LFS. Note that it may still be the case that the file system on which a particular file resides puts limits on the file size.

last_call_optimisation (bool, changeable)
Determines whether or not last-call optimisation is enabled. Normally the value of this flag is the negation of the debug flag. As programs may run out of stack if last-call optimisation is omitted, it is sometimes necessary to enable it during debugging.

libswipl (atom, changeable)
Path where the SWI-Prolog shared library libswipl, the SWI-Prolog shared object that provides Prolog, resides. On some systems this can be determined reliably from...
2.12. ENVIRONMENT CONTROL (PROLOG FLAGS)

the running system. On these systems the flag is read-only. On other systems it is the
configured target installation location and thus this value can be wrong if the installation
has been relocated. As we do not have a cross-platform reliable way to compute this path
the flag is read-write on such platforms.\footnote{When running from the build environment,
this flag is adjusted to reflect the location in the build tree.}

Currently, this flag is reliable on Windows and POSIX systems providing the dladdr() function. This function is provided on Linux and MacOS.

**malloc (atom)**
Set after a successful identification of the used malloc() implementation. Currently possibly values are tcmalloc and ptmalloc. See section 4.43.2 for details.

**max_answers_for_subgoal (integer, changeable)**
Limit the number of answers in a table. The atom infinite clears the flag. By default this flag is not defined. See section 7.10 for details.

**max_answers_for_subgoal_action (atom, changeable)**
The action taken when a table reaches the number of answers specified in max_answers_for_subgoal. Supported values are bounded_rationality, error (default) or suspend.

**max arity (unbounded)**
ISO Prolog flag describing there is no maximum arity to compound terms.

**max char code (integer)**
Highest (Unicode) code point that is supported. SWI-Prolog supports all Unicode code points from 0 (zero) upto and including the value of this flag. Currently 0xFFFF on Windows (UCS-2) and 0x10FFFF on most other platforms.

**max integer (integer)**
Maximum integer value if integers are bounded. See also the flag bounded and section 4.27.2.

**max procedure arity (integer)**
Maximum arity for a predicate. An attempt to define or call such a predicate results in a representation_error(max_procedure arity) exception. Currently set to 1024.

**max rational size (integer, changeable)**
Limit the size in bytes for rational numbers. This tripwire can be used to identify cases where setting the Prolog flag prefer_rationals to true creates excessively big rational numbers and, if precision is not required, one should use floating point arithmetic.

**max rational size action (atom, changeable)**
Action when the max_rational_size tripwire is exceeded. Possible values are error (default), which throws a tripwire resource error and float, which converts the rational number into a floating point number. Note that rational numbers may exceed the range for floating point numbers.

**max table answer size (integer, changeable)**
Limit the size of an answer substitution for tabling. The atom infinite clears the flag. By default this flag is not defined. See section 7.10 for details.
max_table_answer_size_action (atom, changeable)
The action taken if an answer substitution larger than max_table_answer_size is added to a table. Supported values are error (default), bounded_rationality, suspend and fail.

max_table_subgoal_size (integer, changeable)
Limit the size of a goal term accessing a table. The atom infinite clears the flag. By default this flag is not defined. See section 7.10 for details.

max_table_subgoal_size_action (atom, changeable)
The action taken if a tabled goal exceeds max_table_subgoal_size. Supported values are error (default), abstract and suspend.

max_tagged_integer (integer)
Maximum integer value represented as a ‘tagged’ value. Tagged integers require one word storage. Larger integers are represented as ‘indirect data’ and require significantly more space.

message_context (list(atom), changeable)
Context information to add to messages of the levels error and warning. The list may contain the elements thread to add the thread that generates the message to the message, time or time(Format) to add a time stamp. The default time format is %T.%3f. The default is [thread]. See also format_time/3 and print_message/2.

min_integer (integer)
Minimum integer value if integers are bounded. See also the flag bounded and section 4.27.2.

min_tagged_integer (integer)
Start of the tagged-integer value range.

mitigate_spectre (bool, changeable)
When true (default false), enforce mitigation against the Spectre timing-based security vulnerability. Spectre based attacks can extract information from memory owned by the process that should remain invisible, such as passwords or the private key of a web server. The attacks work by causing speculative access to sensitive data, and leaking the data via side-channels such as differences in the duration of successive instructions. An example of a potentially vulnerable application is SWISH. SWISH allows users to run Prolog code while the swish server must protect the privacy of other users as well as its HTTPS private keys, cookies and passwords.

Currently, enabling this flag reduces the resolution of get_time/1 and statistics/2 CPU time to 20µs.

WARNING: Although a coarser timer makes a successful attack of this type harder, it does not reliably prevent such attacks in general. Full mitigation may require compiler support to disable speculative access to sensitive data.

occurs_check (atom, changeable)
This flag controls unification that creates an infinite tree (also called cyclic term) and can have three values. Using false (default), unification succeeds, creating an infinite tree. Using true, unification behaves as unify_with_occurs_check/2, failing silently. Using error, an attempt to create a cyclic term results in an occurs_check exception. The latter is intended for debugging unintentional creations of cyclic terms. Note that this
flag is a global flag modifying fundamental behaviour of Prolog. Changing the flag from its default may cause libraries to stop functioning properly.

**on_error** *(atom, changeable)*

Determines how to act on an error printed using `print_message/2`, i.e., an error that is reported to the user. The possible values are `print` (default), `status` and `halt`. Using `halt` the process halts immediately with status 1. Otherwise execution continues. Using `status halt/0` exits with status 1 if one or more errors were printed by the process. In `compile` mode (see `-c`) the default is `status`. This flag can be set from the commandline using `--on-error`. See also section 4.3.2.

**on_warning** *(atom, changeable)*

As `on_error`, but for warnings. The default is always `print`. The commandline option is `--on-warning`.

**open_shared_object** *(bool)*

If true, `open_shared_object/2` and friends are implemented, providing access to shared libraries (.so files) or dynamic link libraries (.DLL files).

**optimise** *(bool, changeable)*

If true, compile in optimised mode. The initial value is true if Prolog was started with the `-O` command line option. The `optimise` flag is scoped to a source file. Currently optimised compilation implies compilation of arithmetic, and deletion of redundant `true/0` that may result from `expand_goal/2`.

Later versions might imply various other optimisations such as integrating small predicates into their callers, eliminating constant expressions and other predictable constructs. Source code optimisation is never applied to predicates that are declared dynamic (see `dynamic/1`).

**optimise_unify** *(bool, changeable)*

If true (default), allow the compiler to (re)move explicit unification calls (=/2). While this behaviour can significantly improve performance, it is not yet handled properly by the source-level debugger. See section 2.18.3.

**os_argv** *(list, changeable)*

List is a list of atoms representing the command line arguments used to invoke SWI-Prolog. Please note that all arguments are included in the list returned. See `argv` to get the application options.

**packs** *(bool)*

If true, extension packs (add-ons) are attached. Can be set to false using the `--no-packs`.

**path_max** *(integer)*

Maximum length of a file pathname as reported by the OS. This length does typically not directly define the number of characters in the file name. The actual limit may be shorter due to jargonencoding (e.g., on POSIX systems it typically defines the length limit of the (often) UTF-8 encoded name). The underlying file system may impose additional limits.

**pid** *(int)*

Process identifier of the running Prolog process. Existence of this flag is implementation-defined.
**pipe** *(bool, changeable)*  
If true, `open(pipe(command), mode, Stream)`, etc. are supported. Can be changed to disable the use of pipes in applications testing this feature. Not recommended.

**portable_vmi** *(bool, changeable)*  
If true (default), generate `.qlf` files and saved states that run both on 32 bit and 64-bit hardware. If false, some optimized virtual machine instructions are only used if the integer argument is within the range of a tagged integer for 32-bit machines.

**posix_shell** *(atom, changeable)*  
Path to a POSIX compatible shell. This default is typically `/bin/sh`. This flag is used by `shell/1` and `qsave_program/2`.

**prefer_rationals** *(bool, changeable)*  
Only provided if the system is compiled with unbounded and rational arithmetic support (see `bounded`). If true, prefer arithmetic to produce rational numbers over floats. This implies:

- Division (`/2`) of two integers produces a rational number.
- Power (`^/2`) of two integers produces a rational number, also if the second operant is a negative number. For example, `2^(-2)` evaluates to `1/4`.

Using true can create excessively large rational numbers. The Prolog flag `max_rational_size` can be used to detect and act on this tripwire.

If false, rational numbers can only be created using the functions `rational/1`, `rationalize/1` and `rdiv/2` or by reading them. See also `rational_syntax`, section 2.16.1 and section 4.27.2.

The current default is false. We consider changing this to true in the future. Users are strongly encouraged to set this flag to true and report issues this may cause.

**print_write_options** *(term, changeable)*  
Specifies the options for `write_term/2` used by `print/1` and `print/2`.

**prompt_alternatives_on** *(atom, changeable)*  
Determines prompting for alternatives in the Prolog top level. Default is determinism, which implies the system prompts for alternatives if the goal succeeded while leaving choice points. Many classical Prolog systems behave as groundness: they prompt for alternatives if and only if the query contains variables.

**protect_static_code** *(bool, changeable)*  
If true (default false), `clause/2` does not operate on static code, providing some basic protection from hackers that wish to list the static code of your Prolog program. Once the flag is true, it cannot be changed back to false. Protection is default in ISO mode (see Prolog flag `iso`). Note that many parts of the development environment require `clause/2` to work on static code, and enabling this flag should thus only be used for production code.

**qcompile** *(atom, changeable)*  
This option provides the default for the `qcompile(+Atom)` option of `load_files/2`.

**rational_syntax** *(atom, changeable)*  
Determines the read and write syntax for rational numbers. Possible values are natural (e.g., `1/3`) or compatibility (e.g., `lr3`). The compatibility syntax is always accepted. This flag is module sensitive.
The default for this flag is currently compatibility, which reads and writes rational numbers as e.g., 1r3.\(^\text{19}\) We will consider natural as a default in the future. Users are strongly encouraged to set this flag to natural and report issues this may cause.

**readline (atom, changeable)**

Specifies which form of command line editing is provided. Possible values are below. The flag may be set from the user’s init file (see section 2.3) to one of false, readline or editline. This causes the toplevel not to load a command line editor (false) or load the specified one. If loading fails the flag is set to false.

- **false**
  - No command line editing is available.
- **readline**
  - The library readline is loaded, providing line editing based on the GNU readline library.
- **editline**
  - The library editline is loaded, providing line editing based on the BSD libedit. This is the default if editline is available and can be loaded.
- **swipl_win**
  - SWI-Prolog uses its own console (swipl-win.exe on Windows, the Qt based swipl-win on MacOS) which provides line editing.

**report_error (bool, changeable)**

If true, print error messages; otherwise suppress them. May be changed. See also the debug_on_error Prolog flag. Default is true, except for the runtime version.

**resource_database (atom)**

Set to the absolute filename of the attached state. Typically this is the file boot32.prc, the file specified with -x or the running executable. See also resource/3.

**runtime (bool)**

If present and true, SWI-Prolog is compiled with -DO_RUNTIME, disabling various useful development features (currently the tracer and profiler).

**sandboxed_load (bool, changeable)**

If true (default false), load_files/2 calls hooks to allow library(sandbox) to verify the safety of directives.

**saved_program (bool)**

If present and true, Prolog has been started from a state saved with qsave_program/[1,2].

**shared_home (atom)**

Indicates that part of the SWI-Prolog system files are installed in (prefix)/share/swipl instead of in the home at the (prefix)/lib/swipl. This flag indicates the location of this shared home and the directory is added to the file search path swi. See file_search_path/2 and the flag home.

**shared_object_extension (atom)**

Extension used by the operating system for shared objects. .so for most Unix systems and .dll for Windows. Used for locating files using the file_type executable. See also absolute_file_name/3.

\(^{19}\)There is still some discussion on the separating character. See section 2.16.1.
shared_object_search_path (atom)
Name of the environment variable used by the system to search for shared objects.

shared_table_space (integer, changeable)
Space reserved for storing shared answer tables. See section 7.9 and the Prolog flag table_space.

shift_check (bool, changeable)
When true (default false), check for suspicious delimited continuations captured by shift_for_copy/1.

signals (bool)
Determine whether Prolog is handling signals (software interrupts). This flag is false if the hosting OS does not support signal handling or the command line option --no-signals is active. See section 12.4.24 for details.

stack_limit (int, changeable)
Limits the combined sizes of the Prolog stacks for the current thread. See also --stack-limit and section 2.20.1.

stream_type_check (atom, changeable)
Defines whether and how strictly the system validates that byte I/O should not be applied to text streams and text I/O should not be applied to binary streams. Values are false (no checking), true (full checking) and loose. Using checking mode loose (default), the system accepts byte I/O from text stream that use ISO Latin-1 encoding and accepts writing text to binary streams.

string_stack_tripwire (int, changeable)
Maintenance for foreign language string management. Prints a warning if the string stack depth hits the tripwire value. See section 12.4.13 for details.

system_thread_id (int)
Available in multithreaded version (see section 10) where the operating system provides system-wide integer thread identifiers. The integer is the thread identifier used by the operating system for the calling thread. On Linux systems this is the PID of the thread.

table_incremental (bool, changeable)
Set the default for whether to use incremental tabling or not. Initially set to false. See table/1.

table_shared (bool, changeable)
Set the default for whether to use shared tabling or not. Initially set to false. See table/1.

table_space (integer, changeable)
Space reserved for storing answer tables for tabled predicates (see table/1). When exceeded a resource_error(table_space) exception is raised.

table_subsumptive (bool, changeable)
Set the default choice between variant tabling and subsumptive tabling. Initially set to false. See table/1.

threads (bool, changeable)
True when threads are supported. If the system is compiled without thread support the

---

20BUG: Currently only counts the space occupied by the nodes in the answer tries.
value is \texttt{false} and read-only. Otherwise the value is \texttt{true} unless the system was started with the \texttt{--no-threads}. Threading may be disabled only if no threads are running. See also the \texttt{gc_thread} flag.

**timezone** (integer)
Offset in seconds west of GMT of the current time zone. Set at initialization time from the \texttt{timezone} variable associated with the POSIX \texttt{tzset()} function. See also \texttt{format_time/3}.

**tmp_dir** (atom, changeable)
Path to the temporary directory. initialised from the environment variable \texttt{TMP} or \texttt{TEMP} in windows. If this variable is not defined a default is used. This default is typically \texttt{/tmp} or \texttt{c:/temp} in windows.

**toplevel_goal** (term, changeable)
Defines the goal that is executed after running the initialization goals and entry point (see \texttt{-g, initialization/2} and section 2.11.2. The initial value is \texttt{default}, starting a normal interactive session. This value may be changed using the command line option \texttt{-t}. The explicit value \texttt{prolog} is equivalent to \texttt{default}. If \texttt{initialization(Goal,main)} is used and the toplevel is \texttt{default}, the toplevel is set to \texttt{halt} (see \texttt{halt/0}).

**toplevel_list_wfs_residual_program** (bool, changeable)
If \texttt{true} (default) and the answer is \texttt{undefined} according to the Well Founded Semantics (see section 7.6), list the \texttt{residual program} before the answer. Otherwise the answer terminated with \texttt{undefined}. See also \texttt{undefined/0}.

**toplevel_mode** (atom, changeable)
If \texttt{backtracking} (default), the toplevel backtracks after completing a query. If \texttt{recursive}, the toplevel is implemented as a recursive loop. This implies that global variables set using \texttt{b_setval/2} are maintained between queries. In \texttt{recursive} mode, answers to toplevel variables (see section 2.9) are kept in backtrackable global variables and thus \texttt{not copied}. In \texttt{backtracking} mode answers to toplevel variables are kept in the recorded database (see section 4.14.2).

The recursive mode has been added for interactive usage of CHR (see section 9),\textsuperscript{21} which maintains the global constraint store in backtrackable global variables.

**toplevel_name_variables** (bool, changeable)
If \texttt{true} (default), give names to variables at the toplevel instead of printing them as \_NNN. The variables are named \_A, \_B, ... Variables that appear only once (singletons) are printed as \_.

**toplevel_print_anon** (bool, changeable)
If \texttt{true}, top-level variables starting with an underscore (_) are printed normally. If \texttt{false} they are hidden. This may be used to hide bindings in complex queries from the top level.

**toplevel_print_factorized** (bool, changeable)
If \texttt{true} (default \texttt{false}) show the internal sharing of subterms in the answer substitution. The example below reveals internal sharing of leaf nodes in red-black trees as implemented by the \texttt{rb_trees} predicate \texttt{rb_new/1}:

\textsuperscript{21}Suggested by Falco Nogatz
?- set_prolog_flag(toplevel_print_factorized, true).
?- rb_new(X).
X = t(_, _), % where
  _ = black(' ', _, ' ')

If this flag is false, the % where notation is still used to indicate cycles as illustrated below. This example also shows that the implementation reveals the internal cycle length, and not the minimal cycle length. Cycles of different length are indistinguishable in Prolog (as illustrated by S == R).

?- S = s(S), R = s(s(R)), S == R.
S = s(S),
R = s(s(R)).

toplevel_prompt (atom, changeable)
Define the prompt that is used by the interactive top level. The following ~ (tilde) sequences are replaced:

```
~m Type in module if not user (see module/1)
~l Break level if not 0 (see break/0)
~d Debugging state if not normal execution (see debug/0, trace/0)
~! History event if history is enabled (see flag history)
```

toplevel_var_size (int, changeable)
Maximum size counted in literals of a term returned as a binding for a variable in a top-level query that is saved for re-use using the $ variable reference. See section 2.9.

trace_gc (bool, changeable)
If true (default false), garbage collections and stack-shifts will be reported on the terminal. May be changed. Values are reported in bytes as $G+T$, where $G$ is the global stack value and $T$ the trail stack value. ‘Gained’ describes the number of bytes reclaimed. ‘used’ the number of bytes on the stack after GC and ‘free’ the number of bytes allocated, but not in use. Below is an example output.

```
% GC: gained 236,416+163,424 in 0.00 sec;
  used 13,448+5,808; free 72,568+47,440
```

traditional (bool)
Available in SWI-Prolog version 7. If true, ‘traditional’ mode has been selected using --traditional. Notice that some SWI7 features, like the functional notation on dicts, do not work in this mode. See also section 5.

tty_control (bool, changeable)
Determines whether the terminal is switched to raw mode for get_single_char/1, which also reads the user actions for the trace. May be set. If this flag is false at startup, command line editing is disabled. See also the --no-tty command line option.

unix (bool)
If present and true, the operating system is some version of Unix. Defined if the C compiler used to compile this version of SWI-Prolog either defines __unix__ or unix. On other systems this flag is not available. See also apple and windows.
unknown (fail,warning,error, changeable)
Determines the behaviour if an undefined procedure is encountered. If fail, the predicate fails silently. If warn, a warning is printed, and execution continues as if the predicate was not defined, and if error (default), an existence_error exception is raised. This flag is local to each module and inherited from the module’s import-module. Using default setup, this implies that normal modules inherit the flag from user, which in turn inherit the value error from system. The user may change the flag for module user to change the default for all application modules or for a specific module. It is strongly advised to keep the error default and use dynamic/1 and/or multifile/1 to specify possible non-existence of a predicate.

unload_foreign_libraries (bool, changeable)
If true (default false), unload all loaded foreign libraries. Default is false because modern OSes reclaim the resources anyway and unloading the foreign code may cause registered hooks to point to no longer existing data or code.

user_flags (Atom, changeable)
Define the behaviour of set_prolog_flag/2 if the flag is not known. Values are silent, warning and error. The first two create the flag on-the-fly, where warning prints a message. The value error is consistent with ISO: it raises an existence error and does not create the flag. See also create_prolog_flag/3. The default is silent, but future versions may change that. Developers are encouraged to use another value and ensure proper use of create_prolog_flag/3 to create flags for their library.

var_prefix (bool, changeable)
If true (default false), variables must start with an underscore (\_). May be changed. This flag is local to the module in which it is changed. See section 2.16.1.

verbose (atom, changeable)
This flag is used by print_message/2. If its value is silent, messages of type informational and banner are suppressed. The -q switches the value from the initial normal to silent.

verboseautoload (bool, changeable)
If true the normal consult message will be printed if a library is autoloaded. By default this message is suppressed. Intended to be used for debugging purposes.

verbose_search (bool, changeable)
If true (default false), print messages indicating the progress of absolute_file_name/[2,3] in locating files. Intended for debugging complicated file-search paths. See also file_search_path/2.

verbose_load (atom, changeable)
Determines messages printed for loading (compiling) Prolog files. Current values are full (print a message at the start and end of each file loaded), normal (print a message at the end of each file loaded), brief (print a message at end of loading the toplevel file), and silent (no messages are printed, default). The value of this flag is normally controlled by the option silent(Boolean) provided by load_files/2.

version (integer)
The version identifier is an integer with value:

\[10000 \times \text{Major} + 100 \times \text{Minor} + \text{Patch}\]
version_data (swi(Major, Minor, Patch, Extra))
Part of the dialect compatibility layer; see also the Prolog flag dialect and section C. Extra provides platform-specific version information as a list. Extra is used for tagged versions such as “7.4.0-rc1”, in which case Extra contains a term tag(rc1).

version_git (atom)
Available if created from a git repository. See git-describe for details.

vmi_builtin (bool, changeable)
Determines whether well known built-ins such as true/0 or atom/1 are handled by their translation into virtual machine code. The default for this flag is true, unless debug mode is enabled. Setting this flag to false may improve other runtime instrumentation results. Note that optimized arithmetic (−O, see Prolog flag optimise) is currently not translated into a normal predicate call.

warn_override_implicit_import (bool, changeable)
If true (default), a warning is printed if an implicitly imported predicate is clobbered by a local definition. See use_module/1 for details.

win_file_access_check (atom, changeable)
Controls the behaviour or access_file/2 under Windows. There is no reliable way to check access to files and directories on Windows. This flag allows for switching between three alternative approximations.

access
Use Windows _waccess() function. This ignores ACLs (Access Control List) and thus may indicate that access is allowed while it is not.

getfilesecurity
Use the Windows GetFileSecurity() function. This does not work on all file systems, but is probably the best choice on file systems that do support it, notably local NTFS volumes.

openclose
Try to open the file and close it. This works reliable for files, but not for directories. Currently directories are checked using _waccess(). This is the default.

windows (bool)
If present and true, the operating system is an implementation of Microsoft Windows. This flag is only available on MS-Windows based versions. See also unix.

wine_version (atom)
If present, SWI-Prolog is the MS-Windows version running under the Wine emulator.

write_attributes (atom, changeable)
Defines how write/1 and friends write attributed variables. The option values are described with the attributes option of write_term/2. Default is ignore.

write_help_with_overstrike (bool)
Internal flag used by help/1 when writing to a terminal. If present and true it prints bold and underlined text using overstrike.

xpce (bool)
Available and set to true if the XPCE graphics system is loaded.

xpce_version (atom)
Available and set to the version of the loaded XPCE system.
xref (bool, changeable)
If true, source code is being read for analysis purposes such as cross-referencing. Otherwise (default) it is being read to be compiled. This flag is used at several places by term_expansion/2 and goal_expansion/2 hooks, notably if these hooks use side effects. See also the libraries prolog_source and prolog_xref.

set_prolog_flag(:Key, +Value) [ISO]
Define a new Prolog flag or change its value. Key is an atom. If the flag is a system-defined flag that is not marked changeable above, an attempt to modify the flag yields a permission_error. If the provided Value does not match the type of the flag, a type_error is raised.

Some flags (e.g., unknown) are maintained on a per-module basis. The addressed module is determined by the Key argument.

In addition to ISO, SWI-Prolog allows for user-defined Prolog flags. The type of the flag is determined from the initial value and cannot be changed afterwards. Defined types are boolean (if the initial value is one of false, true, on or off), atom if the initial value is any other atom, integer if the value is an integer that can be expressed as a 64-bit signed value. Any other initial value results in an untyped flag that can represent any valid Prolog term.

The behaviour when Key denotes a non-existent key depends on the Prolog flag user_flags. The default is to define them silently. New code is encouraged to use create_prolog_flag/3 for portability.

create_prolog_flag(+Key, +Value, +Options) [YAP]
Create a new Prolog flag. The ISO standard does not foresee creation of new flags, but many libraries introduce new flags. Options is a list of the options below. See also user_flags.

access(+Access)
Define access rights for the flag. Values are read_write and read_only. The default is read_write.

type(+Atom)
Define a type restriction. Possible values are boolean, atom, integer, float and term. The default is determined from the initial value. Note that term restricts the term to be ground.

keep(+Boolean)
If true, do not modify the flag if it already exists. Otherwise (default), this predicate behaves as set_prolog_flag/2 if the flag already exists.

2.13 An overview of hook predicates

SWI-Prolog provides a large number of hooks, mainly to control handling messages, debugging, startup, shut-down, macro-expansion, etc. Below is a summary of all defined hooks with an indication of their portability.

• portray/1
  Hook into write_term/3 to alter the way terms are printed (ISO).
• message_hook/3
  Hook into print_message/2 to alter the way system messages are printed (Quintus/SICStus).

• message_property/2
  Hook into print_message/2 that defines prefix, output stream, color, etc.

• message_prefix_hook/2
  Hook into print_message/2 to add additional prefixes to the message such as the time and thread.

• library_directory/1
  Hook into absolute_file_name/3 to define new library directories (most Prolog systems).

• file_search_path/2
  Hook into absolute_file_name/3 to define new search paths (Quintus/SICStus).

• term_expansion/2
  Hook into load_files/2 to modify read terms before they are compiled (macro-processing) (most Prolog systems).

• goal_expansion/2
  Same as term_expansion/2 for individual goals (SICStus).

• prolog_load_file/2
  Hook into load_files/2 to load other data formats for Prolog sources from ‘non-file’ resources. The load_files/2 predicate is the ancestor of consult/1, use_module/1, etc.

• prolog_edit:locate/3
  Hook into edit/1 to locate objects (SWI).

• prolog_edit:edit_source/1
  Hook into edit/1 to call an internal editor (SWI).

• prolog_edit:edit_command/2
  Hook into edit/1 to define the external editor to use (SWI).

• prolog_list_goal/1
  Hook into the tracer to list the code associated to a particular goal (SWI).

• prolog_trace_interception/4
  Hook into the tracer to handle trace events (SWI).

• prolog:debug_control_hook/1
  Hook in spy/1, nospy/1, nospyall/0 and debugging/0 to extend these control predicates to higher-level libraries.

• prolog:help_hook/1
  Hook in help/0, help/1 and apropos/1 to extend the help system.

• resource/3
  Define a new resource (not really a hook, but similar) (SWI).
2.14. AUTOMATIC LOADING OF LIBRARIES

- exception/3
  Old attempt to a generic hook mechanism. Handles undefined predicates (SWI).

- attr.unify_hook/2
  Unification hook for attributed variables. Can be defined in any module. See section 8.1 for details.

2.14 Automatic loading of libraries

If —at runtime— an undefined predicate is trapped, the system will first try to import the predicate from the module's default module (see section 6.10. If this fails the auto loader is activated.\(^ {22} \) On first activation an index to all library files in all library directories is loaded in core (see library_directory/1, file_search_path/2 and reload_library_index/0). If the undefined predicate can be located in one of the libraries, that library file is automatically loaded and the call to the (previously undefined) predicate is restarted. By default this mechanism loads the file silently. The current_prolog_flag/2 key verbose_autoload is provided to get verbose loading. The Prolog flag autoload can be used to enable/disable the autoload system. A more controlled form of autoloading as well as lazy loading application modules is provided by autoload/[1,2].

Autoloading only handles (library) source files that use the module mechanism described in chapter 6. The files are loaded with use_module/2 and only the trapped undefined predicate is imported into the module where the undefined predicate was called. Each library directory must hold a file INDEX.pl that contains an index to all library files in the directory. This file consists of lines of the following format:

\[
\text{index(Name, Arity, Module, File).}
\]

The predicate make/0 updates the autoload index. It searches for all library directories (see library_directory/1 and file_search_path/2) holding the file MKINDEX.pl or INDEX.pl. If the current user can write or create the file INDEX.pl and it does not exist or is older than the directory or one of its files, the index for this directory is updated. If the file MKINDEX.pl exists, updating is achieved by loading this file, normally containing a directive calling make_library_index/2. Otherwise make_library_index/1 is called, creating an index for all *.pl files containing a module.

Below is an example creating an indexed library directory.

\[
\%
\text{% mkdir $XDG_DATA_HOME-.config}/swi-prolog/lib}
\%
\text{% cd $XDG_DATA_HOME-.config}/swi-prolog/lib}
\%
\text{% swipl -g 'make_library_index(.)' -t halt}
\]

If there is more than one library file containing the desired predicate, the following search schema is followed:

1. If there is a library file that defines the module in which the undefined predicate is trapped, this file is used.

\(^ {22} \) Actually, the hook user:exception/3 is called; only if this hook fails it calls the autoloader.
2. Otherwise library files are considered in the order they appear in the `library_directory/1` predicate and within the directory alphabetically.

**autoload_path(+DirAlias)**

Add `DirAlias` to the libraries that are used by the autoloader. This extends the search path autoload and reloads the library index. For example:

```prolog
:- autoload_path(library(http)).
```

If this call appears as a directive, it is term-expanded into a clause for `user:file_search_path/2` and a directive calling `reload_library_index/0`. This keeps source information and allows for removing this directive.

**make_library_index(+Directory)**

Create an index for this directory. The index is written to the file 'INDEX.pl' in the specified directory. Fails with a warning if the directory does not exist or is write protected.

**make_library_index(+Directory, +ListOfPatterns)**

Normally used in `MKINDEX.pl`, this predicate creates `INDEX.pl` for `Directory`, indexing all files that match one of the file patterns in `ListOfPatterns`.

Sometimes library packages consist of one public load file and a number of files used by this load file, exporting predicates that should not be used directly by the end user. Such a library can be placed in a sub-directory of the library and the files containing public functionality can be added to the index of the library. As an example we give the XPCE library's `MKINDEX.pl`, including the public functionality of `trace/browse.pl` to the autoloadable predicates for the XPCE package.

```prolog
:- prolog_load_context(directory, Dir),
   make_library_index(Dir,
   [ '*.pl',
     'trace/browse.pl',
     'swi/*.pl'
   ]).
```

**reload_library_index**

Force reloading the index after modifying the set of library directories by changing the rules for `library_directory/1, file_search_path/2`, adding or deleting `INDEX.pl` files. This predicate does not update the `INDEX.pl` files. Check `make_library_index/[1,2]` and `make/0` for updating the index files.

Normally, the index is reloaded automatically if a predicate cannot be found in the index and the set of library directories has changed. Using `reload_library_index/0` is necessary if directories are removed or the order of the library directories is changed.

When creating an executable using either `qsave_program/2` or the `-c` command line options, it is necessary to load all predicates that would normally be autoloaded explicitly. This is discussed in section 14. See `autoload_all/0`. 
2.15 Packs: community add-ons

SWI-Prolog has a mechanism for easy incorporation of community extensions. See the pack landing page for details and available packs. This section documents the built-in predicates to attach packs. Predicates for creating, registering and installing packs are provided by the library prolog_pack.

Attach packs

Attaches all packs in subdirectories of directories that are accessible through the file search path (see absolute_file_name/3) pack. The default for this search path is given below. See file_search_path/2 for the app_data search path.

user:file_search_path(pack, app_data(pack)).

The predicate attach_packs/0 is called on startup of SWI-Prolog.

attach_packs(+Directory)
Attach all packs in subdirectories of Directory. Same as attach_packs(Directory, []).

attach_packs(+Directory, +Options)
Attach all packs in subdirectories of Directory. Options is one of:

search(+Where)
Determines the order in which pack library directories are searched. Default is to add new packages at the end (last). Using first, new packages are added at the start.

duplicate(+Action)
Determines what happens if a pack with the same name is already attached. Default is warning, which prints a warning and ignores the new pack. Other options are keep, which is like warning but operates silently and replace, which detaches the old pack and attaches the new.

The predicate attach_packs/2 can be used to attach packages that are bundled with an application.

2.16 The SWI-Prolog syntax

SWI-Prolog syntax is close to ISO-Prolog standard syntax, which is based on the Edinburgh Prolog syntax. A formal description can be found in the ISO standard document. For an informal introduction we refer to Prolog text books (see section 1) and online tutorials. In addition to the differences from the ISO standard documented here, SWI-Prolog offers several extensions, some of which also extend the syntax. See section 5 for more information.

2.16.1 ISO Syntax Support

This section lists various extensions w.r.t. the ISO Prolog syntax.

Processor Character Set

The processor character set specifies the class of each character used for parsing Prolog source text. Character classification is fixed to Unicode. See also section 2.19.
Nested comments

SWI-Prolog allows for nesting /* ...*/ comments. Where the ISO standard accepts /* ...*/ as a comment, SWI-Prolog will search for a terminating */. This is useful if some code with /* ...*/ comment statements in it should be commented out. This modification also avoids unintended commenting in the example below, where the closing */ of the first comment has been forgotten.23

```prolog
/* comment
code
/* second comment */
code
```

Character Escape Syntax

Within quoted atoms (using single quotes: ’⟨atom⟩’) special characters are represented using escape sequences. An escape sequence is led in by the backslash (\) character. The list of escape sequences is compatible with the ISO standard but contains some extensions, and the interpretation of numerically specified characters is slightly more flexible to improve compatibility. Undefined escape characters raise a syntax_error exception.24

```
\a
Alert character. Normally the ASCII character 7 (beep).
\b
Backspace character.
\c
No output. All input characters up to but not including the first non-layout character are skipped. This allows for the specification of pretty-looking long lines. Not supported by ISO. Example:

```prolog
format(’This is a long line that looks better if it was \c split across multiple physical lines in the input’)```

\(NEWLINE\)

When in ISO mode (see the Prolog flag iso), only skip this sequence. In native mode, white space that follows the newline is skipped as well and a warning is printed, indicating that this construct is deprecated and advising to use \c. We advise using \c or putting the layout before the \, as shown below. Using \c is supported by various other Prolog implementations.

---

23Recent copies of GCC give a style warning if /* is encountered in a comment, which suggests that this problem has been recognised more widely.
24Up to SWI-Prolog 6.1.9, undefined escape characters were copied verbatim, i.e., removing the backslash.
and will remain supported by SWI-Prolog. The style shown below is the most compatible solution.\(^25\)

```prolog
format('This is a long line that looks better if it was \ 
split across multiple physical lines in the input')
```

instead of

```prolog
format('This is a long line that looks better if it was\ 
split across multiple physical lines in the input')
```

Note that SWI-Prolog also allows unescaped newlines to appear in quoted material. This is not allowed by the ISO standard, but used to be common practice before.

\e

Escape character (ASCII 27). Not ISO, but widely supported.

\f

Form-feed character.

\n
Next-line character.

\r

Carriage-return only (i.e., go back to the start of the line).

\s

Space character. Intended to allow writing 0’ \s to get the character code of the space character. Not ISO.

\t

Horizontal tab character.

\v

Vertical tab character (ASCII 11).

\xx...\x

Hexadecimal specification of a character. The closing \ is obligatory according to the ISO standard, but optional in SWI-Prolog to enhance compatibility with the older Edinburgh standard. The code \xa\3 emits the character 10 (hexadecimal ‘a’) followed by ‘3’. Characters specified this way are interpreted as Unicode characters. See also \u.

\uxxxxx

Unicode character specification where the character is specified using exactly 4 hexadecimal digits. This is an extension to the ISO standard, fixing two problems. First, where \x defines a numeric character code, it doesn’t specify the character set in which the character should be interpreted. Second, it is not needed to use the idiosyncratic closing \ ISO Prolog syntax.

\(^{25}\)Future versions will interpret \(\langle return\) according to ISO.
Same as \uXXXX, but using 8 digits to cover the whole Unicode set.

\40
Octal character specification. The rules and remarks for hexadecimal specifications apply to octal specifications as well.

\\
Escapes the backslash itself. Thus, ‘\\’ is an atom consisting of a single \.

‘
Single quote. Note that ‘‘’ and ’’’ both describe the atom with a single ’, i.e., ‘’’ == ’’’ is true.

" Double quote.

\ Back quote.

Character escaping is only available if current_prolog_flag(character_escapes, true) is active (default). See current_prolog_flag/2. Character escapes conflict with writef/2 in two ways: \40 is interpreted as decimal 40 by writef/2, but as octal 40 (decimal 32) by read. Also, the writef/2 sequence \l is illegal. It is advised to use the more widely supported format/[2,3] predicate instead. If you insist upon using writef/2, either switch character_escapes to false, or use double \\, as in writef('\\l').

Syntax for non-decimal numbers

SWI-Prolog implements both Edinburgh and ISO representations for non-decimal numbers. According to Edinburgh syntax, such numbers are written as ⟨radix⟩’⟨number⟩, where ⟨radix⟩ is a number between 2 and 36. ISO defines binary, octal and hexadecimal numbers using 0⟨bxo⟩⟨number⟩. For example: A is 0b100 \ 0xf00 is a valid expression. Such numbers are always unsigned.

Using digit groups in large integers

SWI-Prolog supports splitting long integers into digit groups. Digit groups can be separated with the sequence ⟨underscore⟩, ⟨optional white space⟩. If the ⟨radix⟩ is 10 or lower, they may also be separated with exactly one space. The following all express the integer 1 million:

| 1_000_000  |
| 1 000 000  |
| 1_000__/*more*/000 |

Integers can be printed using this notation with format/2, using the ˜I format specifier. For example:

?- format(’˜I’, [1000000]).
1_000_000

The current syntax has been proposed by Ulrich Neumerkel on the SWI-Prolog mailinglist.
Rational number syntax

As of version 8.1.22, SWI-Prolog supports rational numbers as a primary citizen atomic data type if SWI-Prolog is compiled with the GMP library. This can be tested using the bounded Prolog flag. An atomic type also requires a syntax. Unfortunately there are few options for adding rational numbers without breaking the ISO standard.26

ECLiPSe and SWI-Prolog have agreed to define the canonical syntax for rational numbers to be e.g., 1r3. In addition, ECLiPSe accepts 1_3 and SWI-Prolog can be asked to accept 1/3 using the module sensitive Prolog flag rational_syntax, which has the values below. Note that write_canonical/1 always uses the compatible 1r3 syntax.

natural

This is the default mode where we ignore the ambiguity issue and follow the most natural ⟨integer⟩/⟨nonneg⟩ alternative. Here, ⟨integer⟩ follows the normal rules for Prolog decimal integers and ⟨nonneg⟩ does the same, but does not allows for a sign. Note that the parser translates a rational number to its canonical form which implies there are no common divisors in the resulting numerator and denominator. Examples of ration numbers are:

- 1/2
- 2/4
- 1 000 000/33 000
- -3/5

We expect very few programs to have text parsed into a rational number while a term was expected. Note that for rationals appearing in an arithmetic expression the only difference is that evaluation moves from runtime to compiletime. The utility list_rationals/0 may be used on a loaded program to check whether the program contains rational numbers inside clauses and thus may be subject to compatibility issues. If a term is intended this can be written as 1/(1,2), (1)/2, 1 / 2 or some variation thereof.

compatibility

Read and write rational numbers as e.g., 1r3. In other words, this adheres to the same rules as natural above, but using the ‘r’ instead of ‘/’. Note that this may conflict with traditional Prolog as ‘r’ can be defined as an infix operator. The same argument holds for 0x23 and similar syntax for numbers that are part of the ISO standard.

While the syntax is controlled by the flag rational_syntax, behavior on integer division and exponentiation is controlled by the flag prefer_rationals. See section section 4.27.2 for arithmetic on rational numbers.

NaN and Infinity floats and their syntax

SWI-Prolog supports reading and printing ‘special’ floating point values according to Proposal for Prolog Standard core update wrt floating point arithmetic by Joachim Schimpf and available in ECLiPSe Prolog. In particular,

26ECLiPSe uses numerator_denominator. This syntax conflicts with SWI-Prolog digit groups (see section 2.16.1) and does not have a recognised link to rational numbers. The notation 1/3r and 1/3R have also been proposed. The 1/3r is compatible to Ruby, but is hard to parse due to the required look-ahead and not very natural. See also https://en.wikipedia.org/wiki/Rational_data_type.
• Infinity is printed as \(+1.0\text{Inf}\) or \(-1.0\text{Inf}\). Any sequence matching the regular expression \([+-]?\sd+[,]\sd+\text{Inf}\) is mapped to plus or minus infinity.

• NaN (Not a Number) is printed as \(1.xxx\text{NaN}\), where \(1.xxx\) is the float after replacing the exponent by ‘1’. Such numbers are read, resulting in the same NaN. The NaN constant can also be produced using the function \(\text{nan/0}\), e.g.,

```
?- A is nan.
A = 1.5\text{NaN}.
```

By default SWI-Prolog arithmetic (see section 4.27) follows the ISO standard with describes that floating point operations either produce a normal floating point number or raise an exception. section 4.27.2 describes the Prolog flags that can be used to support the IEEE special float values. The ability to create, read and write such values facilitates the exchange of data with languages that can represent the full range of IEEE doubles.

**Force only underscore to introduce a variable**

According to the ISO standard and most Prolog systems, identifiers that start with an uppercase letter or an underscore are variables. In the past, Prolog by BIM provided an alternative syntax, where only the underscore (_) introduces a variable. As of SWI-Prolog 7.3.27 SWI-Prolog supports this alternative syntax, controlled by the Prolog flag \(\text{var_prefix}\). As the character escapes flag, this flag is maintained per module, where the default is \(\text{false}\), supporting standard syntax.

Having only the underscore introduce a variable is particularly useful if code contains identifiers for case sensitive external languages. Examples are the RDF library where code frequently specifies property and class names and the R interface for specifying functions or variables that start with an uppercase character. Lexical databases where part of the terms start with an uppercase letter is another category were the readability of the code improves using this option.

**Unicode Prolog source**

The ISO standard specifies the Prolog syntax in ASCII characters. As SWI-Prolog supports Unicode in source files we must extend the syntax. This section describes the implication for the source files, while writing international source files is described in section 3.1.3.

The SWI-Prolog Unicode character classification is currently based on version 14.0.0 of the Unicode standard. Please note that \(\text{char_type/2}\) and friends, intended to be used with all text except Prolog source code, is based on the C library locale-based classification routines.

• *Quoted atoms and strings*
  Any character of any script can be used in quoted atoms and strings. The escape sequences \(\backslash\text{uxxxxx}\) and \(\backslash\text{uxxxxxxxxx}\) (see section 2.16.1) were introduced to specify Unicode code points in ASCII files.

• *Atoms and Variables*
  We handle them in one item as they are closely related. The Unicode standard defines a syntax

\(^{27}\)Samer Abdallah suggested this feature based on experience with non-Prolog users using the RDF library.
for identifiers in computer languages. In this syntax identifiers start with `ID_Start` followed by a sequence of `ID_Continue` codes. Such sequences are handled as a single token in SWI-Prolog. The token is a `variable` iff it starts with an uppercase character or an underscore (_). Otherwise it is an atom. Note that many languages do not have the notion of character case. In such languages variables `must` be written as `_name`.

- **Numbers**
  Decimal number characters (Nd) are accepted to form numbers, regardless of the Unicode block in which they appear. Currently this is supported for integers, rational numbers (see section 2.16.1) and floating point numbers. In any number, all digits must come from the same block, i.e., if the nominator of a rational is uses Indian script, so must the denominator. All special characters such as the sign, rational separator, floating point `.`, and floating point exponent must use their usual ASCII character.

- **White space**
  All characters marked as separators (Z*) in the Unicode tables are handled as layout characters.

- **Control and unassigned characters**
  Control and unassigned (C*) characters produce a syntax error if encountered outside quoted atoms/strings and outside comments. Quoted writing (e.g., `writeq/1`) of an atom or string that contains one of these characters causes the atom or string to be quoted and the control or unassigned characters to be written using an escape sequence. See section 2.16.1.

- **Other characters**
  The first 128 characters follow the ISO Prolog standard. Unicode symbol and punctuation characters (general category S* and P*) act as gluing symbol characters (i.e., just like ==: an unquoted sequence of symbol characters are combined into an atom).

  Other characters (this is mainly No: a numeric character of other type) are currently handled as ‘solo’.

**Singleton variable checking**

A singleton variable is a variable that appears only one time in a clause. It can always be replaced by _, the anonymous variable. In some cases, however, people prefer to give the variable a name. As mistyping a variable is a common mistake, Prolog systems generally give a warning (controlled by the `style_check/1`) if a variable is used only once. The system can be informed that a variable is meant to appear once by starting it with an underscore, e.g., `_Name`. Please note that any variable, except plain _, shares with variables of the same name. The term `t(_X, _X)` is equivalent to `t(X, X)`, which is different from `t(_, _)`.

As Unicode requires variables to start with an underscore in many languages, this schema needs to be extended. After a proposal by Richard O’Keefe.

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28 [http://www.unicode.org/reports/tr31/](http://www.unicode.org/reports/tr31/)
29 After a proposal by Richard O’Keefe.
• Normal variables

All other variables are ‘normal’ variables. Note this makes \texttt{\textunderscore var} a normal variable.\footnote{Some Prolog dialects write variables this way.}

Any normal variable appearing exactly once in the clause \textit{and} any named singleton variables appearing more than once are reported. Below are some examples with warnings in the right column. Singleton messages can be suppressed using the style\texttt{check/1} directive.

\begin{verbatim}
Singleton variables: [\textunderscore a]
Singleton variables: [\textunderscore 12]
Singleton variables: [A]
Singleton-marked variables appearing more than once: [\textunderscore a]
Singleton-marked variables appearing more than once: [\textunderscore A]
\end{verbatim}

\begin{verbatim}
test(_).
test(a).
test(_12).
test(A).
test(_A).
test(_a).
test(_).
test(_a, _a).
test(_a, _a).
test(A, _A).
test(A, A).
test_1(X)
test_2(X)
\end{verbatim}

\textbf{Semantic singletons} Starting with version 6.5.1, SWI-Prolog has \textit{syntactic singletons} and \textit{semantic singletons}. The first are checked by \texttt{read\_clause/3} (and \texttt{read\_term/3} using the option \texttt{singletons\(\texttt{(warning)}\)}). The latter are generated by the compiler for variables that appear alone in a \textit{branch}. For example, in the code below the variable \texttt{X} is not a \textit{syntactic} singleton, but the variable \texttt{X} does not communicate any bindings and replacing \texttt{X} with \texttt{_} does not change the semantics.

\begin{verbatim}
test :-
   ( test_1(X)
    ; test_2(X)
   ).
\end{verbatim}

\section{2.17 Rational trees (cyclic terms)}

SWI-Prolog supports rational trees, also known as cyclic terms. ‘Supports’ is so defined that most relevant built-in predicates terminate when faced with rational trees. Almost all SWI-Prolog’s built-in term manipulation predicates process terms in a time that is linear to the amount of memory used to represent the term on the stack. The following set of predicates safely handles rational trees: 
\begin{verbatim}
\texttt{=\slash/2, \textbar=\slash/2, \textbar=\slash/2, \textbar<\slash/2,
\textbar=\<\slash/2, \textbar=\:\textbar=\slash/2, \textbar=\:\textbar=\slash/2,\textbar=\textbar=\slash/2,\textbar=\textbar=\slash/2,\textbar=\textbar=\slash/2,}
\texttt{acyclic\_term/1, bagof/3, compare/3, copy\_term/2, cyclic\_term/1, dif/2, duplicate\_term/2, findall/3, ground/1,}
\texttt{term\_hash/2, numbervars/3, numbervars/4, recorda/3, recordz/3, setof/3,}
\texttt{subsumes\_term/2, term\_variables/2, throw/1, unify\_with\_occurs\_check/2,}
\texttt{unifiable/3, when/2, write/1 (and related predicates)}
\end{verbatim}

In addition, some built-ins recognise rational trees and raise an appropriate exception. Arithmetic evaluation belongs to this group. The compiler (\texttt{asserta/1, etc.}) also raises an exception. Future
versions may support rational trees. Predicates that could provide meaningful processing of rational trees raise a representation error. Predicates for which rational trees have no meaningful interpretation raise a type error. For example:

1 ?- A = f(A), asserta(a(A)).
ERROR: asserta/1: Cannot represent due to 'cyclic_term'
2 ?- A = 1+A, B is A.
ERROR: is/2: Type error: 'expression' expected, found '@(S_1,[S_1=1+S_1])' (cyclic term)

2.18 Just-in-time clause indexing

SWI-Prolog provides ‘just-in-time’ indexing over multiple arguments. ‘Just-in-time’ means that clause indexes are not built by the compiler (or asserta/1 for dynamic predicates), but on the first call to such a predicate where an index might help (i.e., a call where at least one argument is instantiated). This section describes the rules used by the indexing logic. Note that this logic is not ‘set in stone’. The indexing capabilities of the system will change. Although this inevitably leads to some regressing on some particular use cases, we strive to avoid significant slowdowns.

The list below describes the clause selection process for various predicates and calls. The alternatives are considered in the order they are presented.

- **Special purpose code**
  Currently two special cases are recognised by the compiler: static code with exactly one clause and static code with two clauses, one where the first argument is the empty list ([ ]) and one where the first argument is a non-empty list ([ _ | _ ]).

- **Linear scan on first argument**
  The principal clause list maintains a key for the first argument. An indexing key is either a constant or a functor (name/arity reference). Calls with an instantiated first argument and less than 10 clauses perform a linear scan for a possible matching clause using this index key. If the result is deterministic it is used. Otherwise the system looks for better indexes.

- **Hash lookup**
  If none of the above applies, the system considers the available hash tables for which the corresponding argument is instantiated. If a table is found with acceptable characteristics, it is used. Otherwise it assesses the clauses for all instantiated arguments and selects the best candidate for creating a new hash table. If there is no single argument that provides an acceptable hash quality it will search for a combination of arguments. Searching for index candidates is only performed on the first 254 arguments.

If a single-argument index contains multiple compound terms with the same name and arity and at least one non-variable argument, a list index is created. A subsequent query where this

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31 JIT indexing was added in version 5.11.29 (Oct. 2011).
32 Up to 7.7.2 this result was used also when non-deterministic.
33 The last step was added in SWI-Prolog 7.5.8.
argument is bound to a compound causes jiti indexing to be applied recursively on the arguments of the term. This is called deep indexing. See also section 2.18.1

Clauses that have a variable at an otherwise indexable argument must be linked into all hash buckets. Currently, predicates that have more than 10% such clauses for a specific argument are not considered for indexing on that argument.

Disregarding variables, the suitability of an argument for hashing is expressed as the number of unique indexable values divided by the standard deviation of the number of duplicate values for each value plus one.

The indexes of dynamic predicates are deleted if the number of clauses is doubled since its creation or reduced below 1/4th. The JIT approach will recreate a suitable index on the next call. Indexes of running predicates cannot be deleted. They are added to a ‘removed index list’ associated to the predicate. Outdated indexes of predicates are reclaimed by garbage_collect_clauses/0. The clause garbage collector is scheduled automatically, based on time and space based heuristics. See garbage_collect_clauses/0 for details.

The library prolog-jiti provides jiti.list/0,1 to list the characteristics of all or some of the created hash tables.

Dynamic predicates are indexed using the same rules as static predicates, except that the special purpose schemes are never applied. In addition, the JTI index is discarded if the number of clauses has doubled since the predicate was last assessed or shrinks below one fourth. A subsequent call reassesses the statistics of the dynamic predicate and, when applicable, creates a new index.

2.18.1 Deep indexing

As introduced in section 2.18, deep indexing creates hash tables distinguish clauses that share a compound with the same name and arity. Deep indexes allow for efficient lookup of arbitrary terms. Without it is advised to flatten the term, i.e., turn \( F(X) \) into two arguments for the fact, one argument denoting the functor \( F \) and the second the argument \( X \). This works fine as long as the arity of the each of the terms is the same. Alternatively we can use term_hash/2 or term_hash/4 to add a column holding the hash of the term. That approach can deal with arbitrary arities, but requires us to know that the term is ground (term_hash/2) or up to which depth we get sufficient selectivity (term_hash/4).

Deep indexing does not require this knowledge and leads to efficient lookup regardless of the instantiation of the query and term. The current version does come with some limitations:

- The decision which index to use is taken independently at each level. Future versions may be smarter on this.
- Deep indexing only applies to a single argument indexes (on any argument).
- Currently, the depth of indexing is limited to 7 levels.

---

34 Deep indexing was added in version 7.7.4.
35 Earlier versions simply used the number of unique values, but poor distribution of values makes a table less suitable. This was analysed by Fabien Noth and Günter Kniesel.
2.18. JUST-IN-TIME CLAUSE INDEXING

Note that, when compiling DCGs (see section 4.13) and the first body term is a literal, it is included into the clause head. See for example the grammar and its plain Prolog representation below.

\[
\begin{align*}
\text{det(det(a), sg)} & \rightarrow "a". \\
\text{det(det(an), pl)} & \rightarrow "an". \\
\text{det(det(the), _)} & \rightarrow "the". \\
\end{align*}
\]

Deep argument indexing will create indexes for the 3rd list argument, providing speedup and making clause selection deterministic if all rules start with a literal and all literals are unique in the first 6 elements. Note that deep index creation stops as soon as a deterministic choice can be made or there are no two clauses that have the same name/arity combination.

### 2.18.2 Future directions

- The ‘special cases’ can be extended. This is notably attractive for static predicates with a relatively small number of clauses where a hash lookup is too costly.
- Create an efficient decision diagram for selecting between low numbers of static clauses.
- Implement a better judgements for selecting between deep and plain indexes.

### 2.18.3 Indexing for body code

The current SWI-Prolog versions only consider the head for generating clause indexing. This would make it impossible to examine a head argument and pass the argument in the body without copying the argument. Consider the two clauses below. Both have equal semantics under Prolog. The first version would loose clause indexing while the second creates a copy of the \( f/1 \) argument. Neither is desirable.

\[
\begin{align*}
p(X) & \leftarrow X = f(I), \text{integer}(I), q(X). \\
p(f(I)) & \leftarrow \text{integer}(I), q(f(X)).
\end{align*}
\]

As of SWI-Prolog 8.3.21, unifications against head arguments that happen before anything else in the body are compiled special. Effectively, the term unified too is moved into the head (providing indexing) and places where this term is used simply use the corresponding argument. The explicit unification is removed. Decompilation (\texttt{clause/2}) reverses this process, but may not produce exactly the same term. The re-inserted unifications are ordered according to the argument position and the variable is always on the left hand of the \( =/2 \). Thus,

\[
p(X, Y) \leftarrow f(_) = Y, X = g(_), q(X, Y).
\]

Is decompiled into the following equivalent clause.
\[ p(X, Y) :- X = g(_), Y = f(_), q(X, Y). \]

Additional notes:

- This transformation is only performed on static code.

- The unifications must immediately follow the head in a conjunction.

- As sole exception, calls to `true/0` are skipped. This allows `goal_expansion/2` to convert goals to `true` while preserving this optimization.

- If the head argument is not used the body unification is still moved into the head. The decompiler does not inverse the process in that case. Thus, \[ p(X) :- X = a. \]
  is fully equivalent to \[ p(a). \]

- Currently this optimization is enabled regardless of the Prolog flag `optimise`. As this optimization harms source-level debugging, this may not be desirable. On the other hand we do not want determinism to depend on optimization while this optimization affects determinism.

### 2.18.4 Indexing and portability

The base-line functionality of Prolog implementations provides indexing on constants and functor (name/arity) on the first argument. This must be your assumption if wide portability of your program is important. This can typically be achieved by exploiting `term_hash/2` or `term_hash/4` and/or maintaining multiple copies of a predicate with reordered arguments and wrappers that update all implementations (assert/retract) and selects the appropriate implementation (query).

YAP provides full JIT indexing, including indexing arguments of compound terms. YAP’s indexing has been the inspiration for enhancing SWI-Prolog’s indexing capabilities.

### 2.19 Wide character support

SWI-Prolog represents characters using Unicode. Unicode defines code points in the range \(0 \ldots 0x10FFFF\). These code points represent virtually any character in any language. In addition, the Unicode standard defines character classes (letter, digit, punctuation, etc.), case conversion and much more. Unicode is a super set of ISO 8859-1 (ISO Latin-1), which is a superset of US-ASCII.

SWI-Prolog has two representations for atoms and string objects (see section 5.2). If the text fits in ISO Latin-1, it is represented as an array of 8-bit characters. Otherwise the text is represented as an array of `wchar_t` characters. On virtually all systems except for MS-Windows, `wchar_t` is a 32-bit unsigned integer and thus capable of representing all Unicode code points. On MS-Windows `wchar_t` is a 16-bit unsigned integer and thus only capable of representing the code points \(0 \ldots 0xFFFF\). As of SWI-Prolog version 8.5.14, the `wchar_t` is (on Windows) interpreted as a UTF-16 string. The UTF-16 encoding uses surrogate pairs to represent the code points \(0x10000 \ldots 0x10FFFF\) as two code units in the \(0xD800 \ldots 0xDFFF\). As Unicode code points, this range is unassigned. For consistency, SWI-Prolog does not accept integers in the surrogate pair range as valid code points, e.g.
The internal character representation is completely transparent to the Prolog user. Users of the foreign language interface as described in chapter 12 sometimes need to be aware of these issues though.

Character coding comes into view when characters of strings need to be read from or written to file or when they have to be communicated to other software components using the foreign language interface. In this section we only deal with I/O through streams, which includes file I/O as well as I/O through network sockets.

### 2.19.1 Wide character encodings on streams

Although characters are uniquely coded using the Unicode standard internally, streams and files are byte (8-bit) oriented and there are a variety of ways to represent the larger Unicode codes in an 8-bit octet stream. The most popular one, especially in the context of the web, is UTF-8. Bytes 0 ... 127 represent simply the corresponding US-ASCII character, while bytes 128 ... 255 are used for multi-byte encoding of characters placed higher in the Unicode space. Especially on MS-Windows the 16-bit UTF-16 standard, represented by pairs of bytes, is also popular.

Prolog I/O streams have a property called encoding which specifies the used encoding that influences get_code/2 and put_code/2 as well as all the other text I/O predicates.

The default encoding for files is derived from the Prolog flag encoding, which is initialised from `setlocale(LC_CTYPE, NULL)` to one of `text`, `utf8` or `iso_latin_1`. One of the latter two is used if the encoding name is recognized, while `text` is used as default. Using `text`, the translation is left to the wide-character functions of the C library.\(^3\) The encoding can be specified explicitly in `load_files/2` for loading Prolog source with an alternative encoding, open/4 when opening files or using `set_stream/2` on any open stream. For Prolog source files we also provide the encoding/1 directive that can be used to switch between encodings that are compatible with US-ASCII (`ascii`, `iso_latin_1`, `utf8` and many locales). See also section 3.1.3 for writing Prolog files with non-US-ASCII characters and section 2.16.1 for syntax issues. For additional information and Unicode resources, please visit [http://www.unicode.org/](http://www.unicode.org/).

SWI-Prolog currently defines and supports the following encodings:

- **octet**
  - Default encoding for binary streams. This causes the stream to be read and written fully untranslated.

- **ascii**
  - 7-bit encoding in 8-bit bytes. Equivalent to `iso_latin_1`, but generates errors and warnings on encountering values above 127.

- **iso_latin_1**
  - 8-bit encoding supporting many Western languages. This causes the stream to be read and written fully untranslated. The above is the SWI-Prolog native name. This encoding may be specified using the official IANA name `ISO-8859-1`.

---

\(^3\) The Prolog native UTF-8 mode is considerably faster than the generic mbrtowc() one.
text

C library default locale encoding for text files. Files are read and written using the C library functions mbtowc() and wcrtomb(). This may be the same as one of the other encodings, notably it may be the same as iso_latin_1 for Western languages and utf8 in a UTF-8 context.

utf8

Multi-byte encoding of full Unicode, compatible with ascii. See above. The above is the SWI-Prolog native name. This encoding may be specified using the official IANA name UTF-8.

utf16be

UTF-16 encoding. Reads input in pairs of bytes. utf16be is Big Endian, putting the most significant byte first and utf16le is Little Endian, putting the most significant byte second. UTF-16 can represent full Unicode using surrogate pairs. The above are the SWI-Prolog native names. These encodings may be specified using the official IANA names UTF-16BE and UTF-16LE. For backward compatibility we also support unicode_be and unicode_le.

Note that not all encodings can represent all characters. This implies that writing text to a stream may cause errors because the stream cannot represent these characters. The behaviour of a stream on these errors can be controlled using set_stream/2. Initially the terminal stream writes the characters using Prolog escape sequences while other streams generate an I/O exception.

BOM: Byte Order Mark

From section 2.19.1, you may have got the impression that text files are complicated. This section deals with a related topic, making life often easier for the user, but providing another worry to the programmer. BOM or Byte Order Marker is a technique for identifying Unicode text files as well as the encoding they use. Such files start with the Unicode character 0xFEFF, a non-breaking, zero-width space character. This is a pretty unique sequence that is not likely to be the start of a non-Unicode file and uniquely distinguishes the various Unicode file formats. As it is a zero-width blank, it even doesn’t produce any output. This solves all problems, or . . .

Some formats start off as US-ASCII and may contain some encoding mark to switch to UTF-8, such as the encoding="UTF-8" in an XML header. Such formats often explicitly forbid the use of a UTF-8 BOM. In other cases there is additional information revealing the encoding, making the use of a BOM redundant or even illegal.

The BOM is handled by SWI-Prolog open/4 predicate. By default, text files are probed for the BOM when opened for reading. If a BOM is found, the encoding is set accordingly and the property bom(true) is available through stream_property/2. When opening a file for writing, writing a BOM can be requested using the option bom(true) with open/4.

2.20 System limits

2.20.1 Limits on memory areas

The SWI-Prolog engine uses three stacks the local stack (also called environment stack) stores the environment frames used to call predicates as well as choice points. The global stack (also called
2.20. SYSTEM LIMITS

The heap

With the heap, we refer to the memory area used by malloc() and friends. SWI-Prolog uses the area to store atoms, functors, predicates and their clauses, records and other dynamic data. No limits are imposed on the addresses returned by malloc() and friends.

2.20.2 Other Limits

Clauses The only limit on clauses is their arity (the number of arguments to the head), which is limited to 1024. Raising this limit is easy and relatively cheap; removing it is harder.

Atoms and Strings SWI-Prolog has no limits on the length of atoms and strings. The number of atoms is limited to 16777216 (16M) on 32-bit machines. On 64-bit machines this is virtually unlimited. See also section 12.4.2.

Memory areas On 32-bit hardware, SWI-Prolog data is packed in a 32-bit word, which contains both type and value information. The size of the various memory areas is limited to 128 MB for each of the areas, except for the program heap, which is not limited. On 64-bit hardware there are no meaningful limits.

Nesting of terms Most built-in predicates that process Prolog terms create an explicitly managed stack and perform optimization for processing the last argument of a term. This implies they can process deeply nested terms at constant and low usage of the C stack, and the system raises a resource error if no more stack can be allocated. Currently only read/1 and write/1 (and all variations thereof) still use the C stack and may cause the system to crash in an uncontrolled way (i.e., not mapped to a Prolog exception that can be caught).

Integers On most systems SWI-Prolog is compiled with support for unbounded integers by means of the GNU GMP library. In practice this means that integers are bound by the global stack size. Too large integers cause a resource_error. On systems that lack GMP, integers are 64-bit on 32- as well as 64-bit machines.

Integers up to the value of the max_tagged_integer Prolog flag are represented more efficiently on the stack. For integers that appear in clauses, the value (below max_tagged_integer or not) has little impact on the size of the clause.

Floating point numbers Floating point numbers are represented as C-native double precision floats, 64-bit IEEE on most machines.
<table>
<thead>
<tr>
<th>Area name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>local stack</strong></td>
<td>The local stack is used to store the execution environments of procedure invocations. The space for an environment is reclaimed when it fails, exits without leaving choice points, the alternatives are cut off with the !/0 predicate or no choice points have been created since the invocation and the last subclause is started (last call optimisation).</td>
</tr>
<tr>
<td><strong>global stack</strong></td>
<td>The global stack is used to store terms created during Prolog’s execution. Terms on this stack will be reclaimed by backtracking to a point before the term was created or by garbage collection (provided the term is no longer referenced).</td>
</tr>
<tr>
<td><strong>trail stack</strong></td>
<td>The trail stack is used to store assignments during execution. Entries on this stack remain alive until backtracking before the point of creation or the garbage collector determines they are no longer needed. As the trail and global stacks are garbage collected together, a small trail can cause an excessive amount of garbage collections. To avoid this, the trail is automatically resized to be at least 1/6th of the size of the global stack.</td>
</tr>
</tbody>
</table>

Table 2.2: Memory areas
2.20.3 Reserved Names

The boot compiler (see -b option) does not support the module system. As large parts of the system are written in Prolog itself we need some way to avoid name clashes with the user’s predicates, database keys, etc. Like Edinburgh C-Prolog [Pereira, 1986] all predicates, database keys, etc., that should be hidden from the user start with a dollar (\$) sign.

2.21 SWI-Prolog and 64-bit machines

Most of today’s 64-bit platforms are capable of running both 32-bit and 64-bit applications. This asks for some clarifications on the advantages and drawbacks of 64-bit addressing for (SWI-)Prolog.

2.21.1 Supported platforms

SWI-Prolog can be compiled for a 32- or 64-bit address space on any system with a suitable C compiler. Pointer arithmetic is based on the type (u)intptr_t from stdint.h, with suitable emulation on MS-Windows.

2.21.2 Comparing 32- and 64-bits Prolog

Most of Prolog’s memory usage consists of pointers. This indicates the primary drawback: Prolog memory usage almost doubles when using the 64-bit addressing model. Using more memory means copying more data between CPU and main memory, slowing down the system.

What then are the advantages? First of all, SWI-Prolog’s addressing of the Prolog stacks does not cover the whole address space due to the use of type tag bits and garbage collection flags. On 32-bit hardware the stacks are limited to 128 MB each. This tends to be too low for demanding applications on modern hardware. On 64-bit hardware the limit is \(2^{32}\) times higher, exceeding the addressing capabilities of today’s CPUs and operating systems. This implies Prolog can be started with stack sizes that use the full capabilities of your hardware.

Multi-threaded applications profit much more because every thread has its own set of stacks. The Prolog stacks start small and are dynamically expanded (see section 2.20.1). The C stack is also dynamically expanded, but the maximum size is reserved when a thread is started. Using 100 threads at the maximum default C stack of 8Mb (Linux) costs 800Mb virtual memory!\(^{37}\)

The implications of theoretical performance loss due to increased memory bandwidth implied by exchanging wider pointers depend on the design of the hardware. We only have data for the popular IA32 vs. AMD64 architectures. Here, it appears that the loss is compensated for by an instruction set that has been optimized for modern programming. In particular, the AMD64 has more registers and the relative addressing capabilities have been improved. Where we see a 10% performance degradation when placing the SWI-Prolog kernel in a Unix shared object, we cannot find a measurable difference on AMD64.

2.21.3 Choosing between 32- and 64-bit Prolog

For those cases where we can choose between 32 and 64 bits, either because the hardware and OS support both or because we can still choose the hardware and OS, we give guidelines for this decision.

---

\(^{37}\)C-recursion over Prolog data structures is removed from most of SWI-Prolog. When removed from all predicates it will often be possible to use lower limits in threads. See [http://www.swi-prolog.org/Devel/CStack.html](http://www.swi-prolog.org/Devel/CStack.html)
First of all, if SWI-Prolog needs to be linked against 32- or 64-bit native libraries, there is no choice as it is not possible to link 32- and 64-bit code into a single executable. Only if all required libraries are available in both sizes and there is no clear reason to use either do the different characteristics of Prolog become important.

Prolog applications that require more than the 128 MB stack limit provided in 32-bit addressing mode must use the 64-bit edition. Note however that the limits must be doubled to accommodate the same Prolog application.

If the system is tight on physical memory, 32-bit Prolog has the clear advantage of using only slightly more than half of the memory of 64-bit Prolog. This argument applies as long as the application fits in the virtual address space of the machine. The virtual address space of 32-bit hardware is 4GB, but in many cases the operating system provides less to user applications.

The only standard SWI-Prolog library adding significantly to this calculation is the RDF database provided by the semweb package. It uses approximately 80 bytes per triple on 32-bit hardware and 150 bytes on 64-bit hardware. Details depend on how many different resources and literals appear in the dataset as well as desired additional literal indexes.

Summarizing, if applications are small enough to fit comfortably in virtual and physical memory, simply take the model used by most of the applications on the OS. If applications require more than 128 MB per stack, use the 64-bit edition. If applications approach the size of physical memory, fit in the 128 MB stack limit and fit in virtual memory, the 32-bit version has clear advantages. For demanding applications on 64-bit hardware with more than about 6GB physical memory the 64-bit model is the model of choice.

2.22 Binary compatibility

SWI-Prolog first of all attempts to maintain source code compatibility between versions. Data and programs can often be represented in binary form. This touches a number of interfaces with varying degrees of compatibility. The relevant version numbers and signatures are made available by PL_version_info(), the --abi-version and the Prolog flag abi_version.

Foreign extensions

Dynamically loadable foreign extensions have the usual dependencies on the architecture, ABI model of the (C) compiler, dynamic link library format, etc. They also depend on the backward compatibility of the PL_* API functions provided lib libswipl.

A compatible API allows distribution of foreign extensions in binary form, notably for platforms on which compilation is complicated (e.g., Windows). This compatibility is therefore high on the priority list, but must infrequently be compromised.

PL_version_info(): PL_VERSION_FLI, abi_version key: foreign_interface

Binary terms

Terms may be represented in binary format using PL_record_external() and fast_write/2. As these formats are used for storing binary terms in databases or communicate terms between Prolog processes in binary form, great care is taken to maintain compatibility.

PL_version_info(): PL_VERSION_REC, abi_version key: record
QLF files

QLF files (see `qcompile/1`) are binary representation of Prolog file or module. They represent clauses as sequences of *virtual machine* (VM) instructions. Their compatibility relies on the QLF file format and the ABI of the VM. Some care is taken to maintain compatibility.

```erlang
PL_version_info(): PL_VERSION_QLF, PL_VERSION_QLF_LOAD and PL_VERSION_VM, abi_version key: qlf, qlf_min_load, vmi
```

Saved states

Saved states (see `-c` and `qsave_program/2`) is a zip file that contains the entire Prolog database using the same representation as QLF files. A saved state may contain additional resources, such as foreign extensions, data files, etc. In addition to the dependency concerns of QLF files, built-in and core library predicates may call *internal* foreign predicates. The interface between the public built-ins and internal foreign predicates changes frequently. Patch level releases in the *stable branch* will as much as possible maintain compatibility.

The relevant ABI version keys are the same as for QLF files with one addition:

```erlang
PL_version_info(): PL_VERSION_BUILT_IN, abi_version key: built_in
```
Initialising and Managing a Prolog Project

Prolog text-books give you an overview of the Prolog language. The manual tells you what predicates are provided in the system and what they do. This chapter explains how to run a project. There is no ultimate ‘right’ way to do this. Over the years we developed some practice in this area and SWI-Prolog’s commands are there to support this practice. This chapter describes the conventions and supporting commands.

The first two sections (section 3.1 and section 3.2) only require plain Prolog. The remainder discusses the use of the built-in graphical tools that require the XPCE graphical library installed on your system.

3.1 The project source files

Organisation of source files depends largely on the size of your project. If you are doing exercises for a Prolog course you’ll normally use one file for each exercise. If you have a small project you’ll work with one directory holding a couple of files and some files to link it all together. Even bigger projects will be organised in sub-projects, each using its own directory.

3.1.1 File Names and Locations

File Name Extensions

The first consideration is what extension to use for the source files. Tradition calls for .pl, but conflicts with Perl force the use of another extension on systems where extensions have global meaning, such as MS-Windows. On such systems .pro is the common alternative. On MS-Windows, the alternative extension is stored in the registry key HKEY_CURRENT_USER/Software/SWI/Prolog/fileExtension or HKEY_LOCAL_MACHINE/Software/SWI/Prolog/fileExtension. All versions of SWI-Prolog load files with the extension .pl as well as with the registered alternative extension without explicitly specifying the extension. For portability reasons we propose the following convention:

If there is no conflict because you do not use a conflicting application or the system does not force a unique relation between extension and application, use .pl.

With a conflict choose .pro and use this extension for the files you want to load through your file manager. Use .pl for all other files for maximal portability.

Project Directories

Large projects are generally composed of sub-projects, each using its own directory or directory structure. If nobody else will ever touch your files and you use only one computer, there is little to worry
about, but this is rarely the case with a large project.

To improve portability, SWI-Prolog uses the POSIX notation for filenames, which uses the forward slash (/) to separate directories. Just before reaching the file system, SWI-Prolog uses `prolog_to_os_filename/2` to convert the filename to the conventions used by the hosting operating system. It is strongly advised to write paths using the /, especially on systems using the \ for this purpose (MS-Windows). Using \ violates the portability rules and requires you to double the \ due to the Prolog quoted-atom escape rules.

Portable code should use `prolog_to_os_filename/2` to convert computed paths into system paths when constructing commands for `shell/1` and friends.

**Sub-projects using search paths**

Thanks to Quintus, Prolog adapted an extensible mechanism for searching files using `file_search_path/2`. This mechanism allows for comfortable and readable specifications.

Suppose you have extensive library packages on graph algorithms, set operations and GUI primitives. These sub-projects are likely candidates for re-use in future projects. A good choice is to create a directory with sub-directories for each of these sub-projects.

Next, there are three options. One is to add the sub-projects to the directory hierarchy of the current project. Another is to use a completely dislocated directory. Third, the sub-project can be added to the SWI-Prolog hierarchy. Using local installation, a typical `file_search_path/2` is:

```prolog
:- prolog_load_context(directory, Dir),
    asserta(user:file_search_path(myapp, Dir)).
user:file_search_path(graph, myapp(graph)).
user:file_search_path(ui, myapp(ui)).
```

When using sub-projects in the SWI-Prolog hierarchy, one should use the path alias `swi` as basis. For a system-wide installation, use an absolute path.

Extensive sub-projects with a small well-defined API should define a load file with calls to `use_module/1` to import the various library components and export the API.

**3.1.2 Project Special Files**

There are a number of tasks you typically carry out on your project, such as loading it, creating a saved state, debugging it, etc. Good practice on large projects is to define small files that hold the commands to execute such a task, name this file after the task and give it a file extension that makes starting easy (see section 3.1.1). The task `load` is generally central to these tasks. Here is a tentative list:

- **load.pl**
  Use this file to set up the environment (Prolog flags and file search paths) and load the sources. Quite commonly this file also provides convenient predicates to parse command line options and start the application.

- **run.pl**
  Use this file to start the application. Normally it loads `load.pl` in silent-mode, and calls one of the starting predicates from `load.pl`. 
• **save.pl**
  Use this file to create a saved state of the application by loading `load.pl` and calling `qsave_program/2` to generate a saved state with the proper options.

• **debug.pl**
  Loads the program for debugging. In addition to loading `load.pl` this file defines rules for `portray/1` to modify printing rules for complex terms and customisation rules for the debugger and editing environment. It may start some of these tools.

### 3.1.3 International source files

As discussed in section 2.19, SWI-Prolog supports international character handling. Its internal encoding is UNICODE. I/O streams convert to/from this internal format. This section discusses the options for source files not in US-ASCII.

SWI-Prolog can read files in any of the encodings described in section 2.19. Two encodings are of particular interest. The text encoding deals with the current locale, the default used by this computer for representing text files. The encodings `utf8`, `unicode_le` and `unicode_be` are UNICODE encodings: they can represent—in the same file—characters of virtually any known language. In addition, they do so unambiguously.

If one wants to represent non US-ASCII text as Prolog terms in a source file, there are several options:

• **Use escape sequences**
  This approach describes NON-ASCII as sequences of the form `\octal\`. The numerical argument is interpreted as a UNICODE character.\(^1\) The resulting Prolog file is strict 7-bit US-ASCII, but if there are many NON-ASCII characters it becomes very unreadable.

• **Use local conventions**
  Alternatively the file may be specified using local conventions, such as the EUC encoding for Japanese text. The disadvantage is portability. If the file is moved to another machine, this machine must use the same locale or the file is unreadable. There is no elegant way if files from multiple locales must be united in one application using this technique. In other words, it is fine for local projects in countries with uniform locale conventions.

• **Using UTF-8 files**
  The best way to specify source files with many NON-ASCII characters is definitely the use of UTF-8 encoding. Prolog can be notified of this encoding in two ways, using a UTF-8 BOM (see section 2.19.1) or using the directive `:- encoding(utf8)`. Many of today’s text editors, including PceEmacs, are capable of editing UTF-8 files. Projects that were started using local conventions can be re-coded using the Unix `iconv` tool or often using commands offered by the editor.

### 3.2 Using modules

Modules have been debated fiercely in the Prolog world. Despite all counter-arguments we feel they are extremely useful because:

\(^1\)To my knowledge, the ISO escape sequence is limited to 3 octal digits, which means most characters cannot be represented.
3.3. THE TEST-EDIT-RELOAD CYCLE

- **They hide local predicates**
  This is the reason they were invented in the first place. Hiding provides two features. They allow for short predicate names without worrying about conflicts. Given the flat name-space introduced by modules, they still require meaningful module names as well as meaningful names for exported predicates.

- **They document the interface**
  Possibly more important than avoiding name conflicts is their role in documenting which part of the file is for public usage and which is private. When editing a module you may assume you can reorganise anything except the name and the semantics of the exported predicates without worrying.

- **They help the editor**
  The PceEmacs built-in editor does on-the-fly cross-referencing of the current module, colouring predicates based on their origin and usage. Using modules, the editor can quickly find out what is provided by the imported modules by reading just the first term. This allows it to indicate in real-time which predicates are not used or not defined.

Using modules is generally easy. Only if you write meta-predicates (predicates reasoning about other predicates) that are exported from a module is a good understanding required of the resolution of terms to predicates inside a module. Here is a typical example from readutil.

```prolog
:- module(read_util,
    [ read_line_to_codes/2, % +Fd, -Codes
      read_line_to_codes/3, % +Fd, -Codes, ?Tail
      read_stream_to_codes/2, % +Fd, -Codes
      read_stream_to_codes/3, % +Fd, -Codes, ?Tail
      read_file_to_codes/3, % +File, -Codes, +Options
      read_file_to_terms/3 % +File, -Terms, +Options
    ]).
```

3.3 The test-edit-reload cycle

SWI-Prolog does not enforce the use of a particular editor for writing Prolog source code. Editors are complicated programs that must be mastered in detail for real productive programming. If you are familiar with a specific editor you should not be forced to change. You may specify your favourite editor using the Prolog flag `editor`, the environment variable `EDITOR` or by defining rules for `prolog-edit:edit_source/1`.

The use of a built-in editor, which is selected by setting the Prolog flag `editor` to `pce_emacs`, has advantages. The XPCE `editor` object, around which the built-in PceEmacs is built, can be opened as a Prolog stream allowing analysis of your source by the real Prolog system.

3.3.1 Locating things to edit

The central predicate for editing something is `edit/1`, an extensible front-end that searches for objects (files, predicates, modules, as well as XPCE classes and methods) in the Prolog database.
If multiple matches are found it provides a choice. Together with the built-in completion on atoms bound to the TAB key this provides a quick way to edit objects:

?- edit(country).
Please select item to edit:

1 chat:country/10  '/home/jan/.config/swi-prolog/lib/chat/countr.pl':16
2 chat:country/1   '/home/jan/.config/swi-prolog/lib/chat/world0.pl':72

Your choice?

3.3.2 Editing and incremental compilation

One of the nice features of Prolog is that the code can be modified while the program is running. Using pure Prolog you can trace a program, find it is misbehaving, enter a break environment, modify the source code, reload it and finally do retry on the misbehaving predicate and try again. This sequence is not uncommon for long-running programs. For faster programs one will normally abort after understanding the misbehaviour, edit the source, reload it and try again.

One of the nice features of SWI-Prolog is the availability of make/0, a simple predicate that checks all loaded source files to see which ones you have modified. It then reloads these files, considering the module from which the file was loaded originally. This greatly simplifies the trace-edit-verify development cycle. For example, after the tracer reveals there is something wrong with prove/3, you do:

?- edit(prove).

Now edit the source, possibly switching to other files and making multiple changes. After finishing, invoke make/0, either through the editor UI (Compile/Make (Control-C Control-M)) or on the top level, and watch the files being reloaded.²

?- make.
% show compiled into photo_gallery 0.03 sec, 3,360 bytes

3.4 Using the PceEmacs built-in editor

3.4.1 Activating PceEmacs

Initially edit/1 uses the editor specified in the EDITOR environment variable. There are two ways to force it to use the built-in editor. One is to set the Prolog flag editor to pce_emacs and the other is by starting the editor explicitly using the emacs/[0,1] predicates.

²Watching these files is a good habit. If expected files are not reloaded you may have forgotten to save them from the editor or you may have been editing the wrong file (wrong directory).
3.4. USING THE PCEEMACS BUILT-IN EDITOR

3.4.2 Bluffing through PceEmacs

PceEmacs closely mimics Richard Stallman’s GNU-Emacs commands, adding features from modern window-based editors to make it more acceptable for beginners.3

At the basis, PceEmacs maps keyboard sequences to methods defined on the extended editor object. Some frequently used commands are, with their key-binding, presented in the menu bar above each editor window. A complete overview of the bindings for the current mode is provided through Help/Show key bindings (Control-h Control-b).

Edit modes

Modes are the heart of (Pce)Emacs. Modes define dedicated editing support for a particular kind of (source) text. For our purpose we want Prolog mode. There are various ways to make PceEmacs use Prolog mode for a file.

• Using the proper extension
   If the file ends in .pl or the selected alternative (e.g. .pro) extension, Prolog mode is selected.

• Using #!/path/to/.../swipl
   If the file is a Prolog Script file, starting with the line #!/path/to/swipl options, Prolog mode is selected regardless of the extension.

• Using -*- Prolog -*-
   If the above sequence appears in the first line of the file (inside a Prolog comment) Prolog mode is selected.

• Explicit selection
   Finally, using File/Mode/Prolog you can switch to Prolog mode explicitly.

Frequently used editor commands

Below we list a few important commands and how to activate them.

• Cut/Copy/Paste
   These commands follow Unix/X11 traditions. You’re best suited with a three-button mouse. After selecting using the left-mouse (double-click uses word-mode and triple line-mode), the selected text is automatically copied to the clipboard (X11 primary selection on Unix). Cut is achieved using the DEL key or by typing something else at the location. Paste is achieved using the middle-mouse (or wheel) button. If you don’t have a middle-mouse button, pressing the left- and right-button at the same time is interpreted as a middle-button click. If nothing helps, there is the Edit/Paste menu entry. Text is pasted at the caret location.

• Undo
   Undo is bound to the GNU-Emacs Control-_ as well as the MS-Windows Control-Z sequence.

• Abort
   Multi-key sequences can be aborted at any stage using Control-G.

---

3 Decent merging with MS-Windows control-key conventions is difficult as many conflict with GNU-Emacs. Especially the cut/copy/paste commands conflict with important GNU-Emacs commands.
• **Find**

Find (Search) is started using Control-S (forward) or Control-R (backward). PceEmacs implements *incremental search*. This is difficult to use for novices, but very powerful once you get the clue. After one of the above start keys, the system indicates search mode in the status line. As you are typing the search string, the system searches for it, extending the search with every character you type. It illustrates the current match using a green background.

If the target cannot be found, PceEmacs warns you and no longer extends the search string. During search, some characters have special meaning. Typing anything but these characters commits the search, re-starting normal edit mode. Special commands are:

- **Control-S**
  Search forwards for next.
- **Control-R**
  Search backwards for next.
- **Control-W**
  Extend search to next word boundary.
- **Control-G**
  Cancel search, go back to where it started.
- **ESC**
  Commit search, leaving caret at found location.
- **Backspace**
  Remove a character from the search string.

• **Dynamic Abbreviation**

Also called *dabbrev*, dynamic abbreviation is an important feature of Emacs clones to support programming. After typing the first few letters of an identifier, you may press Alt-/ causing PceEmacs to search backwards for identifiers that start the same and use it to complete the text you typed. A second Alt-/ searches further backwards. If there are no hits before the caret, it starts searching forwards. With some practice, this system allows for entering code very fast with nice and readable identifiers (or other difficult long words).

• **Open (a file)**

Is called File/Find file (Control-x Control-f). By default the file is loaded into the current window. If you want to keep this window, press Alt-s or click the little icon at the bottom left to make the window sticky.

• **Split view**

Sometimes you want to look at two places in the same file. To do this, use Control-x 2 to create a new window pointing to the same file. Do not worry, you can edit as well as move around in both. Control-x 1 kills all other windows running on the same file.

These are the most commonly used commands. In section 3.4.3 we discuss specific support for dealing with Prolog source code.

---

4 GNU-Emacs keeps extending the string, but why? Adding more text will not make it match.
3.4. USING THE PCEEMACS BUILT-IN EDITOR

3.4.3 Prolog Mode

In the previous section (section 3.4.2) we explained the basics of PceEmacs. Here we continue with Prolog-specific functionality. Possibly the most interesting is Syntax highlighting. Unlike most editors where this is based on simple patterns, PceEmacs syntax highlighting is achieved by Prolog itself actually reading and interpreting the source as you type it. There are three moments at which PceEmacs checks (part of) the syntax.

- **After typing a clause.**
  After typing a clause that is not preceded by a symbol character, the system assumes you completed a clause, tries to find the start of this clause and verifies the syntax. If this process succeeds it colours the elements of the clause according to the rules given below. Colouring is done using information from the last full check on this file. If it fails, the syntax error is displayed in the status line and the clause is not coloured.

- **After the command Control-c Control-s.**
  Acronym for Check Syntax, it performs the same checks as above for the clause surrounding the caret. On a syntax error, however, the caret is moved to the expected location of the error.\(^5\)

- **After pausing for two seconds.**
  After a short pause (2 seconds), PceEmacs opens the edit buffer and reads it as a whole, creating an index of defined, called, dynamic, imported and exported predicates. After completing this, it re-reads the file and colours all clauses and calls with valid syntax.

- **After typing Control-l Control-l.**
  The Control-l command re-centers the window (scrolls the window to make the caret the center of the window). Typing this command twice starts the same process as above.

The colour schema itself is defined in emacs/prolog_colour. The colouring can be extended and modified using multifile predicates. Please check this source file for details. In general, underlined objects have a popup (right-mouse button) associated with common commands such as viewing the documentation or source. **Bold** text is used to indicate the definition of objects (typically predicates when using plain Prolog). Other colours follow intuitive conventions. See table 3.4.3.

Layout support Layout is not ‘just nice’, it is essential for writing readable code. There is much debate on the proper layout of Prolog. PceEmacs, being a rather small project, supports only one particular style for layout.\(^6\)

Below are examples of typical constructs.

```prolog
head(arg1, arg2).

head(arg1, arg2) :- !.

head(Arg1, arg2) :- !,
    call1(Arg1).

head(Arg1, arg2) :
```

\(^5\)In most cases the location where the parser cannot proceed is further down the file than the actual error location.

\(^6\)Defined in Prolog in the file emacs/prolog_mode, you may wish to extend this. Please contribute your extensions!
Table 3.1: Colour conventions

<table>
<thead>
<tr>
<th>Colour</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue bold</td>
<td>Head of an exported predicate</td>
</tr>
<tr>
<td>Red bold</td>
<td>Head of a predicate that is not called</td>
</tr>
<tr>
<td>Black bold</td>
<td>Head of remaining predicates</td>
</tr>
<tr>
<td>Blue</td>
<td>Call to built-in or imported predicate</td>
</tr>
<tr>
<td>Red</td>
<td>Call to undefined predicate</td>
</tr>
<tr>
<td>Purple</td>
<td>Call to dynamic predicate</td>
</tr>
<tr>
<td>Dark green</td>
<td>Comment</td>
</tr>
<tr>
<td>Dark blue</td>
<td>Quoted atom or string</td>
</tr>
<tr>
<td>Brown</td>
<td>Variable</td>
</tr>
</tbody>
</table>

PceEmacs uses the same conventions as GNU-Emacs. The TAB key indents the current line according to the syntax rules. Alt-q indents all lines of the current clause. It provides support for head, calls (indented 1 tab), if-then-else, disjunction and argument lists broken across multiple lines as illustrated above.
3.5. THE GRAPHICAL DEBUGGER

Finding your way around

The command Alt-. extracts name and arity from the caret location and jumps (after conformation or edit) to the definition of the predicate. It does so based on the source-location database of loaded predicates also used by edit/1. This makes locating predicates reliable if all sources are loaded and up-to-date (see make/0).

In addition, references to files in use_module/[1,2], consult/1, etc. are red if the file cannot be found and underlined blue if the file can be loaded. A popup allows for opening the referenced file.

3.5 The Graphical Debugger

SWI-Prolog offers two debuggers. One is the traditional text console-based 4-port Prolog tracer and the other is a window-based source level debugger. The window-based debugger requires XPCE installed. It operates based on the prolog_trace_interception/4 hook and other low-level functionality described in chapter B.

Window-based tracing provides a much better overview due to the eminent relation to your source code, a clear list of named variables and their bindings as well as a graphical overview of the call and choice point stack. There are some drawbacks though. Using a textual trace on the console, one can scroll back and examine the past, while the graphical debugger just presents a (much better) overview of the current state.

3.5.1 Invoking the window-based debugger

Whether the text-based or window-based debugger is used is controlled using the predicates guitracer/0 and noguitracer/0. Entering debug mode is controlled using the normal predicates for this: trace/0 and spy/1. In addition, PceEmacs prolog mode provides the command Prolog/Break at (Control-c b) to insert a break-point at a specific location in the source code.

The graphical tracer is particularly useful for debugging threads. The tracer must be loaded from the main thread before it can be used from a background thread.

guitracer
This predicate installs the above-mentioned hooks that redirect tracing to the window-based environment. No window appears. The debugger window appears as actual tracing is started through trace/0, by hitting a spy point defined by spy/1 or a break point defined using the PceEmacs command Prolog/Break at (Control-c b).

noguitracer
Disable the hooks installed by guitracer/0, reverting to normal text console-based tracing.

gtrace
Utility defined as guitracer,trace.

gdebug
Utility defined as guitracer,debug.

gspy(+Predicate)
Utility defined as guitracer,spy(Predicate).
3.6 The Prolog Navigator

Another tool is the Prolog Navigator. This tool can be started from PceEmacs using the command Browse/Prolog navigator, from the GUI debugger or using the programmatic IDE interface described in section 3.8.

3.7 Cross-referencer

A cross-referencer is a tool that examines the caller-callee relation between predicates, and, using this information to explicate dependency relations between source files, finds calls to non-existing predicates and predicates for which no callers can be found. Cross-referencing is useful during program development, reorganisation, clean-up, porting and other program maintenance tasks. The dynamic nature of Prolog makes the task non-trivial. Goals can be created dynamically using call/1 after construction of a goal term. Abstract interpretation can find some of these calls, but they can also come from external communication, making it impossible to predict the callee. In other words, the cross-referencer has only partial understanding of the program, and its results are necessarily incomplete. Still, it provides valuable information to the developer.

SWI-Prolog’s cross-referencer is split into two parts. The standard Prolog library prolog_xref is an extensible library for information gathering described in section A.40, and the XPCE library pce_xref provides a graphical front-end for the cross-referencer described here. We demonstrate the tool on CHAT80, a natural language question and answer system by Fernando C.N. Pereira and David H.D. Warren.

gxref

Run cross-referencer on all currently loaded files and present a graphical overview of the result.

As the predicate operates on the currently loaded application it must be run after loading the application.

The left window (see figure 3.1) provides browsers for loaded files and predicates. To avoid long file paths, the file hierarchy has three main branches. The first is the current directory holding the sources. The second is marked alias, and below it are the file-search-path aliases (see file_search_path/2 and absolute_file_name/3). Here you find files loaded from the system as well as modules of the program loaded from other locations using the file search path. All loaded files that fall outside these categories are below the last branch called /). Files where the system found suspicious dependencies are marked with an exclamation mark. This also holds for directories holding such files. Clicking on a file opens a File info window in the right pane.

The File info window shows a file, its main properties, its undefined and not-called predicates and its import and export relations to other files in the project. Both predicates and files can be opened by clicking on them. The number of callers in a file for a certain predicate is indicated with a blue underlined number. A left-click will open a list and allow editing the calling predicate.

The Dependencies (see figure 3.2) window displays a graphical overview of dependencies between files. Using the background menu a complete graph of the project can be created. It is also possible to drag files onto the graph window and use the menu on the nodes to incrementally expand the graph. The underlined blue text indicates the number of predicates used in the destination file. Left-clicking opens a menu to open the definition or select one of the callers.
3.7. CROSS-REFERENCER

Figure 3.1: File info for chatop.pl, part of CHAT80

Figure 3.2: Dependencies between source files of CHAT80
Module and non-module files The cross-referencer threads module and non-module project files differently. Module files have explicit import and export relations and the tool shows the usage and consistency of the relations. Using the Header menu command, the tool creates a consistent import list for the module that can be included in the file. The tool computes the dependency relations between the non-module files. If the user wishes to convert the project into a module-based one, the Header command generates an appropriate module header and import list. Note that the cross-referencer may have missed dependencies and does not deal with meta-predicates defined in one module and called in another. Such problems must be resolved manually.

Settings The following settings can be controlled from the settings menu:

Warn autoload By default disabled. If enabled, modules that require predicates to be autoloaded are flagged with a warning and the file info window of a module shows the required autoload predicates.

Warn not called If enabled (default), the file overview shows an alert icon for files that have predicates that are not called.

3.8 Accessing the IDE from your program

Over the years a collection of IDE components have been developed, each with its own interface. In addition, some of these components require each other, and loading IDE components must be on demand to avoid the IDE being part of a saved state (see qsave_program/2). For this reason, access to the IDE is concentrated on a single interface called prolog_ide/1:

prolog_ide(+Action)
This predicate ensures the IDE-enabling XPCE component is loaded, creates the XPCE class prolog_ide and sends Action to its one and only instance @prolog_ide. Action is one of the following:

open_navigator(+Directory)
Open the Prolog Navigator (see section 3.6) in the given Directory.

open_debug_status
Open a window to edit spy and trace points.

open_query_window
Open a little window to run Prolog queries from a GUI component.

thread_monitor
Open a graphical window indicating existing threads and their status.

ddebug_monitor
Open a graphical front-end for the debug library that provides an overview of the topics and catches messages.

xref
Open a graphical front-end for the cross-referencer that provides an overview of predicates and their callers.
3.9 Summary of the IDE

The SWI-Prolog development environment consists of a number of interrelated but not (yet) integrated tools. Here is a list of the most important features and tips.

- **Atom completion**
  The console\(^7\) completes a partial atom on the TAB key and shows alternatives on the command Alt-?.

- **Use edit/1 for finding locations**
  The command edit/1 takes the name of a file, module, predicate or other entity registered through extensions and starts the user’s preferred editor at the right location.

- **Select editor**
  External editors are selected using the EDITOR environment variable, by setting the Prolog flag editor, or by defining the hook prolog.edit:edit_source/1.

- **Update Prolog after editing**
  Using make/0, all files you have edited are re-loaded.

- **PceEmacs**
  Offers syntax highlighting and checking based on real-time parsing of the editor’s buffer, layout support and navigation support.

- **Using the graphical debugger**
  The predicates guitracer/0 and noguitracer/0 switch between traditional text-based and window-based debugging. The tracer is activated using the trace/0, spy/1 or menu items from PceEmacs or the Prolog Navigator.

- **The Prolog Navigator**
  Shows the file structure and structure inside the file. It allows for loading files, editing, setting spy points, etc.

\(^7\)On Windows this is realised by swipl-win.exe, on Unix through the GNU readline library, which is included automatically when found by configure.
4.1 Notation of Predicate Descriptions

We have tried to keep the predicate descriptions clear and concise. First, the predicate name is printed in **bold face**, followed by the arguments in *italics*. Arguments are preceded by a *mode indicator*.

4.1.1 The argument mode indicator

An *argument mode indicator* gives information about the intended direction in which information carried by a predicate argument is supposed to flow. Mode indicators (and types) are not a formal part of the Prolog language but help in explaining intended semantics to the programmer. There is no complete agreement on argument mode indicators in the Prolog community. We use the following definitions:¹

¹These definitions are taken from the *PlDoc* markup language description. *PlDoc* markup is used for source code markup (as well as for the commenting tool). The current manual has only one mode declaration per predicate and therefore predicates with mode (++,--) and (--,+) are described as (?,?). The @-mode is often replaced by chr+. 
++ At call time, the argument must be \textit{ground}, i.e., the argument may not contain any variables that are still unbound.

+ At call time, the argument must be instantiated to a term satisfying some (informal) type specification. The argument need not necessarily be ground. For example, the term \([\_]\) is a list, although its only member is the anonymous variable, which is always unbound (and thus nonground).

- Argument is an \textit{output} argument. It may or may not be bound at call-time. If the argument is bound at call time, the goal behaves as if the argument were unbound, and then unified with that term after the goal succeeds. This is what is called being \textit{steadfast}: instantiation of output arguments at call-time does not change the semantics of the predicate, although optimizations may be performed. For example, the goal \texttt{findall(X, Goal, [T])} is good style and equivalent to \texttt{findall(X, Goal, Xs), Xs = [T]}\textsuperscript{2} Note that any \textit{determinism} specification, e.g., \texttt{det}, only applies if the argument is unbound. For the case where the argument is bound or involved in constraints, \texttt{det} effectively becomes \textit{semidet}, and \texttt{multi} effectively becomes \textit{nondet}.

– At call time, the argument must be unbound. This is typically used by predicates that create ‘something’ and return a handle to the created object, such as \texttt{open/3}, which creates a \texttt{stream}.

? At call time, the argument must be bound to a \textit{partial term} (a term which may or may not be ground) satisfying some (informal) type specification. Note that an unbound variable is a partial term. Think of the argument as either providing input or accepting output or being used for both input and output. For example, in \texttt{stream.property(S, reposition(Bool))}, the \texttt{reposition} part of the term provides input and the unbound-at-call-time \texttt{Bool} variable accepts output.

: Argument is a \textit{meta-argument}, for example a term that can be called as goal. The predicate is thus a \textit{meta-predicate}. This flag implies +.

@ Argument will not be further instantiated than it is at call-time. Typically used for type tests.

! Argument contains a mutable structure that may be modified using \texttt{setarg/3} or \texttt{nb_setarg/3}.

See also section 4.8 for examples of meta-predicates, and section 6.5 for mode flags to label meta-predicate arguments in module export declarations.

### 4.1.2 Predicate indicators

Referring to a predicate in running text is done using a \textit{predicate indicator}. The canonical and most generic form of a predicate indicator is a term \([\langle\text{module}\rangle::\langle\text{name}\rangle/\langle\text{arity}\rangle]\). The module is generally omitted if it is irrelevant (case of a built-in predicate) or if it can be inferred from context.
Non-terminal indicators

Compliant to the ISO standard draft on Definite Clause Grammars (see section 4.13), SWI-Prolog also allows for the non-terminal indicator to refer to a DCG grammar rule. The non-terminal indicator is written as [⟨module⟩] : ⟨name⟩ // ⟨arity⟩.

A non-terminal indicator ⟨name⟩ // ⟨arity⟩ is understood to be equivalent to ⟨name⟩ / ⟨arity⟩+2, regardless of whether or not the referenced predicate is defined or can be used as a grammar rule. The //-notation can be used in all places that traditionally allow for a predicate indicator, e.g., the module declaration, spy/1, and dynamic/1.

4.1.3 Predicate behaviour and determinism

To describe the general behaviour of a predicate, the following vocabulary is employed. In source code, structured comments contain the corresponding keywords:

| det     | A deterministic predicate always succeeds exactly once and does not leave a choicepoint. |
| semidet | A semi-deterministic predicate succeeds at most once. If it succeeds it does not leave a choicepoint. |
| nondet  | A non-deterministic predicate is the most general case and no claims are made on the number of solutions (which may be zero, i.e., the predicate may fail) and whether or not the predicate leaves a choicepoint on the last solution. |
| multi   | As nondet, but succeeds at least once. |
| undefined | Well founded semantics third value. See undefined/0. |

4.2 Character representation

In traditional (Edinburgh) Prolog, characters are represented using character codes. Character codes are integer indices into a specific character set. Traditionally the character set was 7-bit US-ASCII. 8-bit character sets have been allowed for a long time, providing support for national character sets, of which iso-latin-1 (ISO 8859-1) is applicable to many Western languages.

ISO Prolog introduces three types, two of which are used for characters and one for accessing binary streams (see open/4). These types are:

- **code**
  A character code is an integer representing a single character. As files may use multi-byte encoding for supporting different character sets (utf-8 encoding for example), reading a code from a text file is in general not the same as reading a byte.

- **char**
  Alternatively, characters may be represented as one-character atoms. This is a natural representation, hiding encoding problems from the programmer as well as providing much easier debugging.

---

3This, however, makes a specific assumption about the implementation of DCG rules, namely that DCG rules are pre-processed into standard Prolog rules taking two additional arguments, the input list and the output list, in accumulator style. This need not be true in all implementations.
• **byte**
  
  Bytes are used for accessing binary streams.

In SWI-Prolog, character codes are *always* the Unicode equivalent of the encoding. That is, if `get_code/1` reads from a stream encoded as KOI8-R (used for the Cyrillic alphabet), it returns the corresponding Unicode code points. Similarly, assembling or disassembling atoms using `atom_codes/2` interprets the codes as Unicode points. See section 2.19.1 for details.

To ease the pain of the two character representations (code and char), SWI-Prolog’s built-in predicates dealing with character data work as flexible as possible: they accept data in any of these formats as long as the interpretation is unambiguous. In addition, for output arguments that are instantiated, the character is extracted before unification. This implies that the following two calls are identical, both testing whether the next input character is an `a`.

```prolog
peek_code(Stream, a).
peek_code(Stream, 97).
```

The two character representations are handled by a large number of built-in predicates, all of which are ISO-compatible. For converting between code and character there is `char_code/2`. For breaking atoms and numbers into characters there are `atom_chars/2`, `atom_codes/2`, `number_chars/2` and `number_codes/2`. For character I/O on streams there are `get_char/[1,2]`, `get_code/[1,2]`, `get_byte/[1,2]`, `peek_char/[1,2]`, `peek_code/[1,2]`, `peek_byte/[1,2]`, `put_code/[1,2]`, `put_char/[1,2]` and `put_byte/[1,2]`. The Prolog flag `double_quotes` controls how text between double quotes is interpreted.

## 4.3 Loading Prolog source files

This section deals with loading Prolog source files. A Prolog source file is a plain text file containing a Prolog program or part thereof. Prolog source files come in three flavours:

A **traditional** Prolog source file contains Prolog clauses and directives, but no *module declaration* (see `module/1`). They are normally loaded using `consult/1` or `ensure_loaded/1`. Currently, a non-module file can only be loaded into a single module.\(^4\)

A **module** Prolog source file starts with a module declaration. The subsequent Prolog code is loaded into the specified module, and only the *exported* predicates are made available to the context loading the module. Module files are normally loaded with `use_module/[1,2]`. See chapter 6 for details.

A **include** Prolog source file is loaded using the `include/1` directive, textually including Prolog text into another Prolog source. A file may be included into multiple source files and is typically used to share *declarations* such as multifile or dynamic between source files.

Prolog source files are located using `absolute_file_name/3` with the following options:

---

\(^4\)This limitation may be lifted in the future. Existing limitations in SWI-Prolog’s source code administration make this non-trivial.
locate_prolog_file(Spec, Path) :-
    absolute_file_name(Spec,
        [ file_type(prolog),
            access(read)
        ],
        Path).

The file_type(prolog) option is used to determine the extension of the file using prolog_file_type/2. The default extension is .pl. Spec allows for the path alias construct defined by absolute_file_name/3. The most commonly used path alias is library(LibraryFile). The example below loads the library file ordsets.pl (containing predicates for manipulating ordered sets).

    :- use_module(library(ordsets)).

SWI-Prolog recognises grammar rules (DCG) as defined in [Clocksin & Melish, 1987]. The user may define additional compilation of the source file by defining the dynamic multifile predicates term_expansion/2, term_expansion/4, goal_expansion/2 and goal_expansion/4. It is not allowed to use assert/1, retract/1 or any other database predicate in term_expansion/2 other than for local computational purposes. Code that needs to create additional clauses must use compile_aux_clauses/1. See library(apply_macros) for an example.

A directive is an instruction to the compiler. Directives are used to set (predicate) properties (see section 4.15), set flags (see set_prolog_flag/2) and load files (this section). Directives are terms of the form :- ⟨term⟩. Here are some examples:

    :- use_module(library(lists)).
    :- dynamic
        store/2. % Name, Value

The directive initialization/1 can be used to run arbitrary Prolog goals. The specified goal is started after loading the file in which it appears has completed.

SWI-Prolog compiles code as it is read from the file, and directives are executed as goals. This implies that directives may call any predicate that has been defined before the point where the directive appears. It also accepts ?- ⟨term⟩. as a synonym.

SWI-Prolog does not have a separate reconsult/1 predicate. Reconsulting is implied automatically by the fact that a file is consulted which is already loaded.

Advanced topics are handled in subsequent sections: mutually dependent files (section 4.3.2), multithreaded loading (section 4.3.2) and reloading running code (section 4.3.2).

The core of the family of loading predicates is load_files/2. The predicates consult/1, ensure_loaded/1, use_module/1, use_module/2 and reexport/1 pass the file argument directly to load_files/2 and pass additional options as expressed in the table 4.1:

5It does work for normal loading, but not for qcompile/1.
4.3. LOADING PROLOG SOURCE FILES

<table>
<thead>
<tr>
<th>Predicate</th>
<th>if</th>
<th>must_be_module</th>
<th>import</th>
</tr>
</thead>
<tbody>
<tr>
<td>consult/1</td>
<td>true</td>
<td>false</td>
<td>all</td>
</tr>
<tr>
<td>ensure_loaded/1</td>
<td>not_loaded</td>
<td>false</td>
<td>all</td>
</tr>
<tr>
<td>use_module/1</td>
<td>not_loaded</td>
<td>true</td>
<td>all</td>
</tr>
<tr>
<td>use_module/2</td>
<td>not_loaded</td>
<td>true</td>
<td>specified</td>
</tr>
<tr>
<td>reexport/1</td>
<td>not_loaded</td>
<td>true</td>
<td>all</td>
</tr>
<tr>
<td>reexport/2</td>
<td>not_loaded</td>
<td>true</td>
<td>specified</td>
</tr>
</tbody>
</table>

Table 4.1: Properties of the file-reading predicates. The import column specifies what is imported if the loaded file is a module file.

**load_files(:Files)**

Equivalent to load_files([Files, []]). Same as consult/1, See load_files/2 for supported options.

**load_files(:Files, +Options)**

The predicate load_files/2 is the parent of all the other loading predicates except for include/1. It currently supports a subset of the options of Quintus load_files/2. Files is either a single source file or a list of source files. The specification for a source file is handed to absolute_file_name/2. See this predicate for the supported expansions. Options is a list of options using the format OptionName(OptionValue).

The following options are currently supported:

**autoload(Bool)**

If true (default false), indicate that this load is a demand load. This implies that, depending on the setting of the Prolog flag verbose_autoload, the load action is printed at level informational or silent. See also print_message/2 and current_prolog_flag/2.

**check_script(Bool)**

If false (default true), do not check the first character to be # and skip the first line when found.

**derived_from(File)**

Indicate that the loaded file is derived from File. Used by make/0 to time-check and load the original file rather than the derived file.

**dialect(+Dialect)**

Load Files with enhanced compatibility with the target Prolog system identified by Dialect. See expects_dialect/1 and section C for details.

**encoding(Encoding)**

Specify the way characters are encoded in the file. Default is taken from the Prolog flag encoding. See section 2.19.1 for details.

**expand(Bool)**

If true, run the filenames through expand_file_name/2 and load the returned files. Default is false, except for consult/1 which is intended for interactive use. Flexible location of files is defined by file_search_path/2.
CHAPTER 4. BUILT-IN PREDICATES

format(+Format)
Used to specify the file format if data is loaded from a stream using the stream(Stream) option. Default is source, loading Prolog source text. If qlf, load QLF data (see qcompile/1).

if(Condition)
Load the file only if the specified condition is satisfied. The value true loads the file unconditionally, changed loads the file if it was not loaded before or has been modified since it was loaded the last time, not_loaded loads the file if it was not loaded before, and exists is as changed, but the call load_files/2 silently if the file does not exist.

imports(Import)
Specify what to import from the loaded module. The default for use_module/1 is all. Import is passed from the second argument of use_module/2. Traditionally it is a list of predicate indicators to import. As part of the SWI-Prolog/YAP integration, we also support Pred as Name to import a predicate under another name. Finally, Import can be the term except(Exceptions), where Exceptions is a list of predicate indicators that specify predicates that are not imported or Pred as Name terms to denote renamed predicates. See also reexport/2 and use_module/2. If Import equals all, all operators are imported as well. Otherwise, operators are not imported. Operators can be imported selectively by adding terms op(Pri,Assoc,Name) to the Import list. If such a term is encountered, all exported operators that unify with this term are imported. Typically, this construct will be used with all arguments unbound to import all operators or with only Name bound to import a particular operator.

modified(TimeStamp)
Claim that the source was loaded at TimeStamp without checking the source. This option is intended to be used together with the stream(Input) option, for example after extracting the time from an HTTP server or database.

module(+Module)
Load the indicated file into the given module, overruling the module name specified in the :- module(Name, ...) directive. This currently serves two purposes: (1) allow loading two module files that specify the same module into the same process and force and (2): force loading source code in a specific module, even if the code provides its own module name. Experimental.

must_be_module(Bool)
If true, raise an error if the file is not a module file. Used by use_module/[1,2].

qcompile(Atom)
How to deal with quick-load-file compilation by qcompile/1. Values are:

never
Default. Do not use qcompile unless called explicitly.

auto
Use qcompile for all writeable files. See comment below.

6BUG: Name/Arity as NewName is currently implemented using a link clause. This harms efficiency and does not allow for querying the relation through predicate_property/2.
large
  Use qcompile if the file is ‘large’. Currently, files larger than 100 Kbytes are considered large.

part
  If load_files/2 appears in a directive of a file that is compiled into Quick Load Format using qcompile/1, the contents of the argument files are included in the .qlf file instead of the loading directive.

If this option is not present, it uses the value of the Prolog flag qcompile as default.

optimise(+Boolean)
  Explicitly set the optimization for compiling this module. See optimise.

redefine_module(+Action)
  Defines what to do if a file is loaded that provides a module that is already loaded from another file. Action is one of false (default), which prints an error and refuses to load the file, or true, which uses unload_file/1 on the old file and then proceeds loading the new file. Finally, there is ask, which starts interaction with the user. ask is only provided if the stream user_input is associated with a terminal.

reexport(Bool)
  If true re-export the imported predicate. Used by reexport/1 and reexport/2.

register(Bool)
  If false, do not register the load location and options. This option is used by make/0 and load_hotfixes/1 to avoid polluting the load-context database. See source_file_property/2.

sandboxed(Bool)
  Load the file in sandboxed mode. This option controls the flag sandboxed_load. The only meaningful value for Bool is true. Using false while the Prolog flag is set to true raises a permission error.

scope_settings(Bool)
  Scope style_check/1 and expects_dialect/1 to the file and files loaded from the file after the directive. Default is true. The system and user initialization files (see -f and -F) are loading with scope_settings(false).

silent(Bool)
  If true, load the file without printing a message. The specified value is the default for all files loaded as a result of loading the specified files. This option writes the Prolog flag verbose_load with the negation of Bool.

stream(Input)
  This SWI-Prolog extension compiles the data from the stream Input. If this option is used, Files must be a single atom which is used to identify the source location of the loaded clauses as well as to remove all clauses if the data is reconsulted.
  This option is added to allow compiling from non-file locations such as databases, the web, the user (see consult/1) or other servers. It can be combined with format(qlf) to load QLF data from a stream.

The load_files/2 predicate can be hooked to load other data or data from objects other than files. See prolog_load_file/2 for a description and http/http_load for an example. All hooks for load_files/2 are documented in section B.10.
consult(:File)

Read File as a Prolog source file. Calls to consult/1 may be abbreviated by just typing a number of filenames in a list. Examples:

?- consult(load).
% consult load or load.pl
?- [library(lists)].
% load library lists
?- [user].
% Type program on the terminal

The predicate consult/1 is equivalent to load_files(File, []), except for handling the special file user, which reads clauses from the terminal. See also the stream(Input) option of load_files/2. Abbreviation using ?- [file1, file2]. does not work for the empty list([]). This facility is implemented by defining the list as a predicate. Applications may only rely on using the list abbreviation at the Prolog toplevel and in directives.

ensure_loaded(:File)

If the file is not already loaded, this is equivalent to consult/1. Otherwise, if the file defines a module, import all public predicates. Finally, if the file is already loaded, is not a module file, and the context module is not the global user module, ensure_loaded/1 will call consult/1.

With this semantics, we hope to get as close as possible to the clear semantics without the presence of a module system. Applications using modules should consider using use_module/1,2.

Equivalent to load_files(Files, [if(not_loaded)]). 7

include(+File)   [ISO]

Textually include the content of File at the position where the directive :- include(File). appears. The include construct is only honoured if it appears as a directive in a source file. Textual include (similar to C/C++ #include) is obviously useful for sharing declarations such as dynamic/1 or multifile/1 by including a file with directives from multiple files that use these predicates.

Textually including files that contain clauses is less obvious. Normally, in SWI-Prolog, clauses are owned by the file in which they are defined. This information is used to replace the old definition after the file has been modified and is reloaded by, e.g., make/0. As we understand it, include/1 is intended to include the same file multiple times. Including a file holding clauses multiple times into the same module is rather meaningless as it just duplicates the same clauses. Including a file holding clauses in multiple modules does not suffer from this problem, but leads to multiple equivalent copies of predicates. Using use_module/1 can achieve the same result while sharing the predicates.

If include/1 is used to load files holding clauses, and if these files are loaded only once, then these include/1 directives can be replaced by other predicates (such as consult/1). However, there are several cases where either include/1 has no alternative, or using any alternative also requires other changes. An example of the former is using include/1 to share directives. An example of the latter are cases where clauses of different predicates are distributed over multiple files: If these files are loaded with include/1, the directive

---

7On older versions the condition used to be if(changed). Poor time management on some machines or copying often caused problems. The make/0 predicate deals with updating the running system after changing the source code.
discontiguous/1 is appropriate, whereas if they are consulted, one must use the directive multifile/1.

To accommodate included files holding clauses, SWI-Prolog distinguishes between the source location of a clause (in this case the included file) and the owner of a clause (the file that includes the file holding the clause). The source location is used by, e.g., edit/1, the graphical tracer, etc., while the owner is used to determine which clauses are removed if the file is modified. Relevant information is found with the following predicates:

- **source_file/2** describes the owner relation.
- **predicate_property/2** describes the source location (of the first clause).
- **clause_property/2** provides access to both source and ownership.
- **source_file_property/2** can be used to query include relationships between files.

**require(+Predicates)**

Declare that this file/module requires the specified predicates to be defined “with their commonly accepted definition”. *Predicates* is either a list of predicate indicators or a comma-list of predicate indicators. First, all built-in predicates are removed from the set. The remaining predicates are searched using the library index used for autoloading and mapped to a set of autoload/2 directives. This implies that the targets will be loaded lazily if autoloading is not completely disabled and loaded using use_module/2 otherwise. See autoload.

The require/1 directive provides less control over the exact nature and location of the predicate. As autoload/2, it prevents a local definition of this predicate. As SWI-Prolog guarantees that the set of built-in predicates and predicates available for autoloading is unambiguous (i.e., has no duplicates) the specification is unambiguous. It provides four advantages over autoload/2: (1) the user does not have to remember the exact library, (2) the directive can be supported in other Prolog systems\(^8\), providing compatibility despite differences in library and built-in predicate organization, (3) it is robust against changes to the SWI-Prolog libraries and (4) it is less typing.

**encoding(+Encoding)**

This directive can appear anywhere in a source file to define how characters are encoded in the remainder of the file. It can be used in files that are encoded with a superset of US-ASCII, currently UTF-8 and ISO Latin-1. See also section 2.19.1.

**make**

Consult all source files that have been changed since they were consulted. It checks all loaded source files: files loaded into a compiled state using pl -c ... and files loaded using consult/1 or one of its derivatives. The predicate make/0 is called after edit/1, automatically reloading all modified files. If the user uses an external editor (in a separate window), make/0 is normally used to update the program after editing. In addition, make/0 updates the autoload indices (see section 2.14) and runs list_undefined/0 from the check library to report on undefined predicates.

**library_directory(?Atom)**

Dynamic predicate used to specify library directories. Defaults to app_config(lib) (see

\(^8\)SICStus provides it
file_search_path/2) and the system’s library (in this order) are defined. The user may add library directories using assertz/1, asserta/1 or remove system defaults using retract/1. Deprecated. New code should use file_search_path/2.

file_search_path(+Alias, -Path)
Dynamic multifile hook predicate used to specify ‘path aliases’. This hook is called by absolute_file_name/3 to search files specified as Alias(Name), e.g., library(lists). This feature is best described using an example. Given the definition:

```plaintext
file_search_path(demo, '/usr/lib/prolog/demo').
```

the file specification demo(myfile) will be expanded to /usr/lib/prolog/demo/myfile. The second argument of file_search_path/2 may be another alias.

Below is the initial definition of the file search path. This path implies swi(⟨Path⟩) and refers to a file in the SWI-Prolog home directory. The alias foreign(⟨Path⟩) is intended for storing shared libraries (.so or .DLL files). See also use_foreign_library/1.

```plaintext
user:file_search_path(library, X) :-
    library_directory(X).
user:file_search_path(swi, Home) :-
    current_prolog_flag(home, Home).
user:file_search_path(foreign, swi(ArchLib)) :-
    current_prolog_flag(arch, Arch),
    atom_concat('lib/', Arch, ArchLib).
user:file_search_path(path, Dir) :-
    getenv('PATH', Path),
    (   current_prolog_flag(windows, true)
    ->  atomic_list_concat(Dirs, ';', Path)
    ;   atomic_list_concat(Dirs, ':', Path)
    ),
    member(Dir, Dirs).
user:file_search_path(user_app_data, Dir) :-
    '$xdg_prolog_directory'(data, Dir).
user:file_search_path(common_app_data, Dir) :-
    '$xdg_prolog_directory'(common_data, Dir).
user:file_search_path(user_app_config, Dir) :-
    '$xdg_prolog_directory'(config, Dir).
user:file_search_path(common_app_config, Dir) :-
    '$xdg_prolog_directory'(common_config, Dir).
user:file_search_path(app_data, user_app_data('.'))
user:file_search_path(app_data, common_app_data('.'))
user:file_search_path(app_config, user_app_config('.'))
user:file_search_path(app_config, common_app_config('.')).
```

The '$xdg_prolog_directory'/2 uses either the XDG Base Directory or win_folder/2 on Windows. On Windows, user config is mapped to roaming appdata
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(CSIDL_APPDATA), user data to the non-roaming (CSIDL_LOCAL_APPDATA) and common
data to (CSIDL_COMMON_APPDATA).

The file_search_path/2 expansion is used by all loading predicates as well as by
absolute_file_name/[2,3].

The Prolog flag verbose_file_search can be set to true to help debugging Prolog’s
search for files.

expand_file_search_path(+Spec, -Path) [nondet]
Unifies Path with all possible expansions of the filename specification Spec. See also
absolute_file_name/3.

prolog_file_type(?Extension, ?Type)
This dynamic multifile predicate defined in module user determines the extensions considered
by file_search_path/2. Extension is the filename extension without the leading dot, and
Type denotes the type as used by the file_type(Type) option of file_search_path/2.
Here is the initial definition of prolog_file_type/2:

```
user:prolog_file_type(pl, prolog).
user:prolog_file_type(Ext, prolog) :-
    current_prolog_flag(associate, Ext),
    Ext \== pl.
user:prolog_file_type(qlf, qlf).
user:prolog_file_type(Ext, executable) :-
    current_prolog_flag(shared_object_extension, Ext).
```

Users can add extensions for Prolog source files to avoid conflicts (for example with perl) as well as to be compatible with another Prolog implementation. We suggest using .pro for avoiding conflicts with perl. Overriding the system definitions can stop the system from finding libraries.

source_file(?File)
True if File is a loaded Prolog source file. File is the absolute and canonical path to the source
file.

source_file(:Pred, ?File)
True if the predicate specified by Pred is owned by file File, where File is an absolute path name
(see absolute_file_name/2). Can be used with any instantiation pattern, but the database
only maintains the source file for each predicate. If Pred is a multifile predicate this predicate
succeeds for all files that contribute clauses to Pred. See also clause_property/2. Note
that the relation between files and predicates is more complicated if include/1 is used. The
predicate describes the owner of the predicate. See include/1 for details.

source_file_property(?File, ?Property)
True when Property is a property of the loaded file File. If File is non-var, it can be a file
specification that is valid for load_files/2. Defined properties are:

9The current implementation performs a linear scan through all clauses to establish this set of files.
derived_from(Original, OriginalModified)

File was generated from the file Original, which was last modified at time OriginalModified at the time it was loaded. This property is available if File was loaded using the derived_from(Original) option to load_files/2.

includes(IncludedFile, IncludedFileModified)

File used include/1 to include IncludedFile. The last modified time of IncludedFile was IncludedFileModified at the time it was included.

included_in(MasterFile, Line)

File was included into MasterFile from line Line. This is the inverse of the includes property.

load_context(Module, Location, Options)

Module is the module into which the file was loaded. If File is a module, this is the module into which the exports are imported. Otherwise it is the module into which the clauses of the non-module file are loaded. Location describes the file location from which the file was loaded. It is either a term ⟨file⟩:⟨line⟩ or the atom user if the file was loaded from the terminal or another unknown source. Options are the options passed to load_files/2. Note that all predicates to load files are mapped to load_files/2, using the option argument to specify the exact behaviour.

load_count(-Count)

Count is the number of times the file have been loaded, i.e., 1 (one) if the file has been loaded once.

modified(Stamp)

File modification time when File was loaded. This is used by make/0 to find files whose modification time is different from when it was loaded.

source(Source)

One of file if the source was loaded from a file, resource if the source was loaded from a resource or state if the file was included in the saved state.

module(Module)

File is a module file that declares the module Module.

number_of_clauses(Count)

Count is the number of clauses associated with File. Note that clauses loaded from included files are counted as part of the main file.

reloading

Present if the file is currently being reloaded.

exists_source(+Source)

[semidet]

True if Source (a term valid for load_files/2) exists. Fails without error if this is not the case. The predicate is intended to be used with conditional compilation (see section 4.3.1 For example:

```
:- if(exists_source(library(error))).
:- use_module_library(error).
:- endif.
```

The implementation uses absolute_file_name/3 using file_type(prolog).
exists_source(+Source, -File) [semidet]
   As exists_source/1, binding File to an atom describing the full absolute path to the source file.

unload_file(+File)
   Remove all clauses loaded from File. If File loaded a module, clear the module’s export list and disassociate it from the file. File is a canonical filename or a file indicator that is valid for load_files/2.

   This predicate should be used with care. The multithreaded nature of SWI-Prolog makes removing static code unsafe. Attempts to do this should be reserved for development or situations where the application can guarantee that none of the clauses associated to File are active.

prolog_load_context(?Key, ?Value)
   Obtain context information during compilation. This predicate can be used from directives appearing in a source file to get information about the file being loaded as well as by the term_expansion/2 and goal_expansion/2 hooks. See also source_location/2 and if/1. The following keys are defined:

<table>
<thead>
<tr>
<th>Key</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>directory</td>
<td>Directory in which source lives</td>
</tr>
<tr>
<td>dialect</td>
<td>Compatibility mode. See expects_dialect/1.</td>
</tr>
<tr>
<td>file</td>
<td>Similar to source, but returns the file being included when called while an include file is being processed</td>
</tr>
<tr>
<td>module</td>
<td>Module into which file is loaded</td>
</tr>
<tr>
<td>reload</td>
<td>true if the file is being reloaded. Not present on first load</td>
</tr>
<tr>
<td>script</td>
<td>Boolean that indicates whether the file is loaded as a script file (see -s)</td>
</tr>
<tr>
<td>source</td>
<td>File being loaded. If the system is processing an included file, the value is the main file. Returns the original Prolog file when loading a .qlf file.</td>
</tr>
<tr>
<td>stream</td>
<td>Stream identifier (see current_input/1)</td>
</tr>
<tr>
<td>term.position</td>
<td>Start position of last term read. See also stream_property/2 (position property and stream_position_data/3).</td>
</tr>
<tr>
<td>term</td>
<td>Term being expanded by expand_term/2.</td>
</tr>
<tr>
<td>variable_names</td>
<td>A list of ‘Name = Var’ of the last term read. See read_term/2 for details.</td>
</tr>
</tbody>
</table>

   The directory is commonly used to add rules to file_search_path/2, setting up a search path for finding files with absolute_file_name/3. For example:

```prolog
:- dynamic user:file_search_path/2.
:- multifile user:file_search_path/2.

:- prolog_load_context(directory, Dir),
   asserta(user:file_search_path(my_program_home, Dir)).
   ...
```
source_location(-File, -Line)
If the last term has been read from a physical file (i.e., not from the file user or a string), unify File with an absolute path to the file and Line with the line number in the file. New code should use prolog:load_context/2.

at_halt(:Goal)
Register Goal to be run from PL_cleanup(), which is called when the system halts. The hooks are run in the reverse order they were registered (FIFO). Success or failure executing a hook is ignored. If the hook raises an exception this is printed using print_message/2. An attempt to call halt/[0,1] from a hook is ignored. Hooks may call cancel_halt/1, causing halt/0 and PL_halt(0) to print a message indicating that halting the system has been cancelled.

cancel_halt(+Reason)
If this predicate is called from a hook registered with at_halt/1, halting Prolog is cancelled and an informational message is printed that includes Reason. This is used by the development tools to cancel halting the system if the editor has unsaved data and the user decides to cancel.

:- initialization(:Goal)
[ISO]
Call Goal after loading the source file in which this directive appears has been completed. In addition, Goal is executed if a saved state created using qsave_program/1 is restored.

The ISO standard only allows for using :- Term if Term is a directive. This means that arbitrary goals can only be called from a directive by means of the initialization/1 directive. SWI-Prolog does not enforce this rule.

The initialization/1 directive must be used to do program initialization in saved states (see qsave_program/1). A saved state contains the predicates, Prolog flags and operators present at the moment the state was created. Other resources (records, foreign resources, etc.) must be recreated using initialization/1 directives or from the entry goal of the saved state.

Up to SWI-Prolog 5.7.11, Goal was executed immediately rather than after loading the program text in which the directive appears as dictated by the ISO standard. In many cases the exact moment of execution is irrelevant, but there are exceptions. For example, load_foreign_library/1 must be executed immediately to make the loaded foreign predicates available for exporting. SWI-Prolog now provides the directive use_foreign_library/1 to ensure immediate loading as well as loading after restoring a saved state. If the system encounters a directive :- initialization(load_foreign_library(...)), it will load the foreign library immediately and issue a warning to update your code. This behaviour can be extended by providing clauses for the multifile hook predicate prolog:initialize_now(Term, Advice), where Advice is an atom that gives advice on how to resolve the compatibility issue.
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`initialization(:Goal, +When)`
Similar to `initialization/1`, but allows for specifying when `Goal` is executed while loading the program text:

- **now**
  Execute `Goal` immediately.
- **after_load**
  Execute `Goal` after loading the program text in which the directive appears. This is the same as `initialization/1`.
- **prepare_state**
  Execute `Goal` as part of `qsave_program/2`. This hook can be used for example to eagerly execute initialization that is normally done lazily on first usage.
- **restore_state**
  Do not execute `Goal` while loading the program, but only when restoring a saved state.\(^{11}\)

- **program**
  Execute `Goal` once after executing the `-g` goals at program startup. Registered goals are executed in the order encountered and a failure or exception causes the Prolog to exit with non-zero exit status. These goals are not executed if the `-l` is given to merely load files. In that case they may be executed explicitly using `initialize/0`. See also section 2.11.2.

- **main**
  When Prolog starts, the last goal registered using `initialization(Goal, main)` is executed as main goal. If `Goal` fails or raises an exception, the process terminates with non-zero exit code. If not explicitly specified using the `-t` the toplevel goal is set to `halt/0`, causing the process to exit with status 0. An explicitly specified toplevel is executed normally. This implies that `-t prolog` causes the application to start the normal interactive toplevel after completing `Goal`. See also the Prolog flag `toplevel_goal` and section 2.11.2.

`initialize`\(^{[det]}\)
Run all initialization goals registered using `initialization(Goal, program)`. Raises an error `initialization_error(Reason, Goal, File:Line)` if `Goal` fails or raises an exception. `Reason` is `failed` or the exception raised.

- **compiling**
  True if the system is compiling source files with the `-c` option or `qcompile/1` into an intermediate code file. Can be used to perform conditional code optimisations in `term_expansion/2` (see also the `-O` option) or to omit execution of directives during compilation.

4.3.1 Conditional compilation and program transformation

ISO Prolog defines no way for program transformations such as macro expansion or conditional compilation. Expansion through `term_expansion/2` and `expand_term/2` can be seen as part of the de-facto standard. This mechanism can do arbitrary translation between valid Prolog terms read from files.

\(^{11}\text{Used to be called restore. restore is still accepted for backward compatibility.}\)
the source file to Prolog terms handed to the compiler. As term_expansion/2 can return a list, the transformation does not need to be term-to-term.

Various Prolog dialects provide the analogous goal_expansion/2 and expand_goal/2 that allow for translation of individual body terms, freeing the user of the task to disassemble each clause.

term_expansion(+Term1, -Term2)
Dynamic and multifile predicate, normally not defined. When defined by the user all terms read during consulting are given to this predicate. If the predicate succeeds Prolog will assert Term2 in the database rather than the read term (Term1). Term2 may be a term of the form ?- Goal. or :- Goal. Goal is then treated as a directive. If Term2 is a list, all terms of the list are stored in the database or called (for directives). If Term2 is of the form below, the system will assert Clause and record the indicated source location with it:

'$$source\_location'(⟨File⟩, ⟨Line⟩):⟨Clause⟩

When compiling a module (see chapter 6 and the directive module/2), expand_term/2 will first try term_expansion/2 in the module being compiled to allow for term expansion rules that are local to a module. If there is no local definition, or the local definition fails to translate the term, expand_term/2 will try term_expansion/2 in module user. For compatibility with SICStus and Quintus Prolog, this feature should not be used. See also expand_term/2, goal_expansion/2 and expand_goal/2.

It is possible to act on the beginning and end of a file by expanding the terms begin_of_file and end_of_file. The latter is supported by most Prolog systems that support term expansion as read_term/3 returns end_of_file on reaching the end of the input. Expanding begin_of_file may be used to initialise the compilation, for example base on the file name extension. It was added in SWI-Prolog 8.1.1.

The current macro-expansion mechanism originates from Prolog systems in the 1980s and 1990s. It has several flaws, (1) the hooks act globally (except for definitions in a module), (2) it is hard to deal with interactions between transformations, (3) macros can not be reused between modules using the normal module export/import protocol and (4) it is hard to make source code aware tools such as the graphical debugger act properly in the context of macro expansion. Several Prolog implementations have tried to implement better expansion mechanisms. None of these solve all problems and all are largely incompatible with our current macro expansion. Future versions may provide a new mechanism to solve these issues.

Controlled interaction is provided between macro expansion defined in a module and the user and system modules. Here, SWI-Prolog uses a pipeline where the result of local module expansion is the input for the expansion in user, which is the input for the expansion in system. See also section 6.10.

Scoping, i.e., make a rule defined in a module only active if this module is imported into the module being compiled, can be emulated by defining the macro globally in the user module and using prolog_load_context/2 and some logic to verify the macro expansion should apply. If (goal) expansion effectively defined inlining it is good practice to also define the predicate and have the macro expansion check that the predicate is in scope. Here is an example.

```prolog
:- module(ml, [double/2]).
```
4.3. LOADING PROLOG SOURCE FILES

\[
\text{double}(X, D) :- D \text{ is } X \times 2.
\]

\[
\text{user:goal_expansion(double}(X,D), D \text{ is } X \times 2) :-
\]
\[
\text{prolog_load_context}(\text{module}, M),
\]
\[
\text{predicate_property}(M: \text{double}(_, _), \text{imported_from}(m1)).
\]

For term expansion that is not related to a specific predicate we can define a sentinel predicate rather than using the goal predicate and check it is imported into the current module to verify that the module that defines the expansion is imported into the current compilation context.

**expand_term(+Term1, -Term2)**

This predicate is normally called by the compiler on terms read from the input to perform preprocessing. It consists of four steps, where each step processes the output of the previous step.

1. Test conditional compilation directives and translate all input to \([\text{false}]\) if we are in a ‘false branch’ of the conditional compilation. See section 4.3.1.
2. Call **term_expansion/2**. This predicate is first tried in the module that is being compiled and then in modules from which this module inherits according to **default_module/2**. The output of the expansion in a module is used as input for the next module. Using the default setup and when compiling a normal application module \(M\), this implies expansion is executed in \(M\), **user** and finally in **system**. Library modules inherit directly from **system** and can thus not be re-interpreted by term expansion rules in **user**.
3. Call DCG expansion (**dcg_translate_rule/2**).
4. Call **expand_goal/2** on each body term that appears in the output of the previous steps.

**goal_expansion(+Goal1, -Goal2)**

Like **term_expansion/2**, **goal_expansion/2** provides for macro expansion of Prolog source code. Between **expand_term/2** and the actual compilation, the body of clauses analysed and the goals are handed to **expand_goal/2**, which uses the **goal_expansion/2** hook to do user-defined expansion.

The predicate **goal_expansion/2** is first called in the module that is being compiled, and then follows the module inheritance path as defined by **default_module/2**, i.e., by default **user** and **system**. If **Goal** is of the form \(\text{Module:Goal}\) where \(\text{Module}\) is instantiated, **goal_expansion/2** is called on **Goal** using rules from module **Module** followed by default modules for **Module**.

Only goals appearing in the body of clauses when reading a source file are expanded using this mechanism, and only if they appear literally in the clause, or as an argument to a defined meta-predicate that is annotated using ‘0’ (see **meta_predicate/1**). Other cases need a real predicate definition.

The expansion hook can use **prolog_load_context/2** to obtain information about the context in which the goal is expanded such as the module, variable names or the encapsulating term.

**expand_goal(+Goal1, -Goal2)**

This predicate is normally called by the compiler to perform preprocessing using
\texttt{goal\_expansion/2}. The predicate computes a fixed-point by applying transformations until there are no more changes. If optimisation is enabled (see \texttt{-O} and \texttt{optimise}), \texttt{expand\_goal/2} simplifies the result by removing unneeded calls to \texttt{true/0} and \texttt{fail/0} as well as trivially unreachable branches.

If \texttt{goal\_expansion/2} \textit{wraps} a goal as in the example below the system still reaches fixed-point as it prevents re-expanding the expanded term while recursing. It does re-enable expansion on the \textit{arguments} of the expanded goal as illustrated in \texttt{t2/1} in the example.\footnote{After discussion with Peter Ludemann and Paulo Moura on the forum.}

\begin{verbatim}
:- meta_predicate run(0).
may_not_fail(test(_)).
may_not_fail(run(_)).
goal_expansion(G, (G *-> true ; error(goal_failed(G),_))) :-
    may_not_fail(G).
t1(X) :- test(X).
t2(X) :- run(run(X)).

Is expanded into

t1(X) :-
    (    test(X)
        *-> true
        ;    error(goal_failed(test(X)), _)
    ).

t2(X) :-
    (    run((run(X)*->true;error(goal_failed(run(X)),_)))
        *-> true
        ;    error(goal_failed(run(run(X))), _)
    ).
\end{verbatim}

Note that goal expansion should not bind any variables in the clause. Doing so may impact the semantics of the clause if the variable is also used elsewhere. In the general case this is not verified. It is verified for \texttt{\+/1} and \texttt{;/2}, resulting in an exception.

\textbf{compile\_aux\_clauses(+\textit{Clauses})}
Compile clauses on behalf of \texttt{goal\_expansion/2}. This predicate compiles the argument clauses into static predicates, associating the predicates with the current file but avoids changing the notion of current predicate and therefore discontiguous warnings.

Note that in some cases multiple expansions of similar goals can share the same compiled auxiliary predicate. In such cases, the implementation of \texttt{goal\_expansion/2} can use \texttt{predicate\_property/2} using the property defined to test whether the predicate is already defined in the current context.
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**dcg_translate_rule(+In, -Out)**

This predicate performs the translation of a term Head→Body into a normal Prolog clause. Normally this functionality should be accessed using expand_term/2.

**var_property(+Var, ?Property)**

True when Property is a property of Var. These properties are available during goal- and term-expansion. Defined properties are below. Future versions are likely to provide more properties, such as whether the variable is referenced in the remainder of the term. See also goal_expansion/2.

**fresh(Bool)**

*Bool* has the value true if the variable is guaranteed to be unbound at entry of the goal, otherwise its value is false. This implies that the variable first appears in this goal or a previous appearance was in a negation (\(+/1\)) or a different branch of a disjunction.

**singleton(Bool)**

*Bool* has the value true if the variable is a syntactic singleton in the term it appears in. Note that this tests that the variable appears exactly once in the term being expanded without making any claim on the syntax of the variable. Variables that appear only once in multiple branches are not singletons according to this property. Future implementations may improve on that.

**name(Name)**

True when variable appears with the given name in the source.

**Program transformation with source layout info**

This sections documents extended versions of the program transformation predicates that also transform the source layout information. Extended layout information is currently processed, but unused. Future versions will use for the following enhancements:

- More precise locations of warnings and errors
- More reliable setting of breakpoints
- More reliable source layout information in the graphical debugger.

**expand_goal(+Goal1, ?Layout1, -Goal2, -Layout2)**

**goal_expansion(+Goal1, ?Layout1, -Goal2, -Layout2)**

**expand_term(+Term1, ?Layout1, -Term2, -Layout2)**

**term_expansion(+Term1, ?Layout1, -Term2, -Layout2)**

**dcg_translate_rule(+In, -Out, -LayoutOut)**

These versions are called before their 2-argument counterparts. The input layout term is either a variable (if no layout information is available) or a term carrying detailed layout information as returned by the subterm_positions of read_term/2. The output layout should be a variable if no layout information can be computed for the expansion; a sub-term can also be a variable to indicate “don’t know”.
Conditional compilation

Conditional compilation builds on the same principle as term_expansion/2, goal_expansion/2 and the expansion of grammar rules to compile sections of the source code conditionally. One of the reasons for introducing conditional compilation is to simplify writing portable code. See section C for more information. Here is a simple example:

```prolog
:- if(+sourceExports(library(lists), suffix/2)).

suffix(Suffix, List) :-
    append(_, Suffix, List).
:- endif.
```

Note that these directives can only appear as separate terms in the input. SWI-Prolog accommodates syntax extensions under conditional compilation by silently ignoring syntax errors when in the false branch. This allow, for example, for the code below. With rational number support 1r3 denotes the rational number 1/3 while without it is a syntax error. Note that this only works properly if (1) the syntax error still allows to re-synchronize on the full stop of the invalid clause and (2) the subsequent conditional compilation directive is valid.

```prolog
:- if(current_prolog_flag(bounded, false)).

one_third(1r3).
:- endif.
```

Typical usage scenarios include:

- Load different libraries on different dialects.
- Define a predicate if it is missing as a system predicate.
- Realise totally different implementations for a particular part of the code due to different capabilities.
- Realise different configuration options for your software.

```prolog
:- if(:Goal)

Compile subsequent code only if Goal succeeds. For enhanced portability, Goal is processed by expand_goal/2 before execution. If an error occurs, the error is printed and processing proceeds as if Goal has failed.

:- elif(:Goal)

Equivalent to :- else. :- if(Goal). ... :- endif. In a sequence as below, the section below the first matching elif is processed. If no test succeeds, the else branch is processed.

```prolog
:- if(test1).
    section_1.
:- endif.
```
section_2.
    :- elif(test3).
section_3.
    :- else.
section_else.
    :- endif.

:- else
    Start ‘else’ branch.

:- endif
    End of conditional compilation.

### 4.3.2 Reloading files, active code and threads

Traditionally, Prolog environments allow for reloading files holding currently active code. In particular, the following sequence is a valid use of the development environment:

- Trace a goal
- Find unexpected behaviour of a predicate
- Enter a `break` using the `b` command
- Fix the sources and reload them using `make/0`
- Exit the break, `retry` executing the now fixed predicate using the `r` command

Reloading a previously loaded file is safe, both in the debug scenario above and when the code is being executed by another `thread`. Executing threads switch atomically to the new definition of modified predicates, while clauses that belong to the old definition are (eventually) reclaimed by `garbage_collect_clauses/0`.\(^{13}\) Below we describe the steps taken for reloading a file to help understanding the limitations of the process.

1. If a file is being reloaded, a `reload context` is associated to the file administration. This context includes a table keeping track of predicates and a table keeping track of the module(s) associated with this source.

2. If a new predicate is found, an entry is added to the context predicate table. Three options are considered:
   (a) The predicate is new. It is handled the same as if the file was loaded for the first time.
   (b) The predicate is foreign or thread local. These too are treated as if the file was loaded for the first time.
   (c) Normal predicates. Here we initialise a pointer to the `current clause`.

3. New clauses for ‘normal predicates’ are considered as follows:

---

\(^{13}\)As of version 7.3.12. Older versions wipe all clauses originating from the file before loading the new clauses. This causes threads that executes the code to (typically) die with an `undefined predicate` exception.
(a) If the clause’s byte-code is the same as the predicates current clause, discard the clause and advance the current clause pointer.
(b) If the clause’s byte-code is the same as some clause further into the clause list of the predicate, discard the new clause, mark all intermediate clauses for future deletion, and advance the current clause pointer to the first clause after the matched one.
(c) If the clause’s byte-code matches no clause, insert it for future activation before the current clause and keep the current clause.

4. Properties such as dynamic or meta_predicate are in part applied immediately and in part during the fixup process after the file completes loading. Currently, dynamic and thread_local are applied immediately.

5. New modules are recorded in the reload context. Export declarations (the module’s public list and export/1 calls) are both applied and recorded.

6. When the end-of-file is reached, the following fixup steps are taken
   (a) For each predicate
      i. The current clause and subsequent clauses are marked for future deletion.
      ii. All clauses marked for future deletion or creation are (in)activated by changing their ‘erased’ or ‘created’ generation. Erased clauses are (eventually) reclaimed by the clause garbage collector, see garbage_collect_clauses/0.
      iii. Pending predicate property changes are applied.
   (b) For each module
      i. Exported predicates that are not encountered in the reload context are removed from the export list.

The above generally ensures that changes to the content of source files can typically be activated safely using make/0. Global changes such as operator changes, changes of module names, changes to multi-file predicates, etc. sometimes require a restart. In almost all cases, the need for restart is indicated by permission or syntax errors during the reload or existence errors while running the program.

In some cases the content of a source file refers ‘to itself’. This is notably the case if local rules for goal_expansion/2 or term_expansion/2 are defined or goals are executed using directives.\textsuperscript{14} Up to version 7.5.12 it was typically needed to reload the file twice, once for updating the code that was used for compiling the remainder of the file and once to effectuate this. As of version 7.5.13, conventional transaction semantics apply. This implies that for the thread performing the reload the file’s content is first wiped and gradually rebuilt, while other threads see an atomic update from the old file content to the new.\textsuperscript{15}

Errors and warnings during compilation

Errors and warnings reported while compiling a file are reported using print_message/2. Typical errors are syntax errors, errors during macro expansion by term_expansion/2 and

\textsuperscript{14}Note that initialization/1 directives are executed after loading the file. SWI-Prolog allows for directives that are executed while loading the file using :- Goal or initialization/2

\textsuperscript{15}This feature was implemented by Keri Harris.
4.3. LOADING PROLOG SOURCE FILES

goal_expansion/2, compiler errors such as illegal clauses or an attempt to redefine a system predicate and errors caused by executing directives, notably using initialization/1 and initialization/2.

Merely reporting error messages and warnings is typically desirable for interactive usage. Non-interactive applications often require to be notified of such issues, typically using the exit code of the process. We can distinguish two types of errors and warnings: (1) those resulting from loading an invalid program and (2) messages that result from running the program. A typical example is user code that wishes to try something and in case of an error report this and continue.

```prolog
...,
  E = error(_,_),
catch(do_something, E,
    print_message(error, E)),
...
```

User code may be (and often is) started from directives, while running user code may involve compilation due to autoloading, loading of data files, etc. As a result, it is unclear whether an error message should merely be printed, should result in a non-zero exit status at the end or should immediately terminate the process.

The default behaviour is defined by the Prolog flags on_error and on_warning. It can be fine tuned by defining the hook predicate message_hook/3. The compiler calls print_message/2 using the level silent and the message below if errors or warnings where printed during the execution of load_files/2.

**load_file_errors(File, Errors, Warnings)**

Here, File is the raw file specification handed to load_files/2, i.e., ‘myfile.pl’ or library(lists), Errors is the number of errors printed while loading and Warnings is the number of warnings printed while loading. Note that these counts include messages from (initialization) directives.

This allows the user to fine tune the behaviour on errors and, for example, halt the process on a non-zero error count right after loading the file with errors using the code below.

```prolog
:- multifile user:message_hook/3.

user:message_hook(load_file_errors(_File, Errors, _Warnings),
    _Level, _Lines) :-
  Errors > 0,
  halt(1).
```

**Compilation of mutually dependent code**

Large programs are generally split into multiple files. If file A accesses predicates from file B which accesses predicates from file A, we consider this a mutual or circular dependency. If traditional load predicates (e.g., consult/1) are used to include file B from A and A from B, loading either file results in a loop. This is because consult/1 is mapped to load_files/2 using the
option if(true)(.) Such programs are typically loaded using a load file that consults all required (non-module) files. If modules are used, the dependencies are made explicit using use_module/1 statements. The use_module/1 predicate, however, maps to load_files/2 with the option if(not_loaded)(.) A use_module/1 on an already loaded file merely makes the public predicates of the used module available.

Summarizing, mutual dependency of source files is fully supported with no precautions when using modules. Modules can use each other in an arbitrary dependency graph. When using consult/1, predicate dependencies between loaded files can still be arbitrary, but the consult relations between files must be a proper tree.

Compilation with multiple threads

This section discusses compiling files for the first time. For reloading, see section 4.3.2.

Multiple threads can compile files concurrently. This requires special precautions only if multiple threads wish to load the same file at the same time. Therefore, load_files/2 checks whether some other thread is already loading the file. If not, it starts loading the file. If a thread detects that another thread is already loading the file the thread blocks until the other thread finishes loading the file. After waiting, and if the file is a module file, it imports the exported predicates and operators from the module.

Note that this schema does not prevent deadlocks under all situations. Consider two mutually dependent (see section 4.3.2) module files A and B, where thread 1 starts loading A and thread 2 starts loading B at the same time. Both threads will deadlock when trying to load the used module.

The current implementation does not detect such cases and the involved threads will freeze. This problem can be avoided if a mutually dependent collection of files is always loaded from the same start file.

4.3.3 Quick load files

SWI-Prolog supports compilation of individual or multiple Prolog source files into ‘Quick Load Files’. A ‘Quick Load File’ (.qlf file) stores the contents of the file in a precompiled format.

These files load considerably faster than source files and are normally more compact. They are machine-independent and may thus be loaded on any implementation of SWI-Prolog. Note, however, that clauses are stored as virtual machine instructions. Changes to the compiler will generally make old compiled files unusable.

Quick Load Files are created using qcompile/1. They are loaded using consult/1 or one of the other file-loading predicates described in section 4.3. If consult/1 is given an explicit .pl file, it will load the Prolog source. When given a .qlf file, it will load the file. When no extension is specified, it will load the .qlf file when present and the .pl file otherwise.

qcompile(:File)

Takes a file specification as consult/1, etc., and, in addition to the normal compilation, creates a Quick Load File from File. The file extension of this file is .qlf. The basename of the Quick Load File is the same as the input file.

If the file contains ‘:- consult(+File)’, ‘:- [+File]’ or ‘:- load_files(+File, [qcompile(part), ...])’ statements, the referred files are compiled into the same .qlf file. Other directives will be stored in the .qlf file and executed in the same fashion as when loading the .pl file.
For `term_expansion/2`, the same rules as described in section 2.11 apply.

Conditional execution or optimisation may test the predicate `compiling/0`.

Source references (`source_file/2`) in the Quick Load File refer to the Prolog source file from which the compiled code originates.

```prolog
qcompile(:File, +Options)
```

As `qcompile/1`, but processes additional options as defined by `load_files/2`. `Options` are passed to `load_files/2`. In addition the following options are processed:

```prolog
include(+Include)
```

What to include into the QLF file. Currently accepts only a single value: the atom `user`. When specified, files loaded indirectly from `File` that do not come from the Prolog library are included into the `.qlf` file. This may be used to generate a single file from an application. The result is comparable to a `save state` (see `qsave_program/2`) with the following differences:

- Only your application code is included. The Prolog libraries and boot files are not.
- Only Prolog code is included. `.qlf` files cannot include arbitrary `resources`.
- The file can be loaded into a running Prolog process, while a saved state can only be loaded into a virgin Prolog virtual machine.

### 4.4 Editor Interface

SWI-Prolog offers an extensible interface which allows the user to edit objects of the program: predicates, modules, files, etc. The editor interface is implemented by `edit/1` and consists of three parts: locating, selecting and starting the editor. Any of these parts may be customized. See section 4.4.1.

The built-in edit specifications for `edit/1` (see `prolog_edit:locate/3`) are described in the table below:

<table>
<thead>
<tr>
<th>Fully specified objects</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>⟨Module⟩⟨Name⟩⟨Arity⟩</td>
<td>Refers to a predicate</td>
</tr>
<tr>
<td>module(⟨Module⟩)</td>
<td>Refers to a module</td>
</tr>
<tr>
<td>file(⟨Path⟩)</td>
<td>Refers to a file</td>
</tr>
<tr>
<td>source_file(⟨Path⟩)</td>
<td>Refers to a loaded source file</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ambiguous specifications</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>⟨Name⟩⟨Arity⟩</td>
<td>Refers to this predicate in any module</td>
</tr>
<tr>
<td>⟨Name⟩</td>
<td>Refers to (1) the named predicate in any module with any arity, (2) a (source) file, or (3) a module.</td>
</tr>
</tbody>
</table>

```prolog
edit(+Specification)
```

First, exploit `prolog_edit:locate/3` to translate `Specification` into a list of `Locations`. If there is more than one ‘hit’, the user is asked to select from the locations found. Finally, `prolog_edit:edit_source/1` is used to invoke the user’s preferred editor. Typically, `edit/1` can be handed the name of a predicate, module, basename of a file, XPCE class, XPCE method, etc.
edit
Edit the ‘default’ file using edit/1. The default file is either the first .pl file from the
commandline (the associated file, see the Prolog flag associated_file or the first script
file specified using the -s or -l command line option. When using the Windows shell while
SWI-Prolog is associated with the .pl extension this is the file loaded by double-clicking a
.pl file. See also section 2.11.2.

4.4.1 Customizing the editor interface

The predicates described in this section are hooks that can be defined to disambiguate specifications
given to edit/1, find the related source, and open an editor at the given source location.

prolog_edit:locate(+Spec, -FullSpec, -Location)
Where Spec is the specification provided through edit/1. This multifile predicate is used to
enumerate locations where an object satisfying the given Spec can be found. FullSpec is unified
with the complete specification for the object. This distinction is used to allow for ambiguous
specifications. For example, if Spec is an atom, which appears as the basename of a loaded file
and as the name of a predicate, FullSpec will be bound to file(Path) or Name/Arity.

Location is a list of attributes of the location. Normally, this list will contain the term
file(File) and, if available, the term line(Line).

prolog_edit:locate(+Spec, -Location)
Same as prolog_edit:locate/3, but only deals with fully specified objects.

prolog_edit:edit_source(+Location)
Start editor on Location. See prolog_edit:locate/3 for the format of a location term.
This multifile predicate is normally not defined. If it succeeds, edit/1 assumes the editor is
started.

If it fails, edit/1 uses its internal defaults, which are defined by the Prolog flag editor
and/or the environment variable EDITOR. The following rules apply. If the Prolog flag
editor is of the format $<name>, the editor is determined by the environment variable <name>. Else, if this flag is pce_emacs or built_in and XPCE is loaded or can be loaded, the built-in
Emacs clone is used. Else, if the environment EDITOR is set, this editor is used. Finally, vi is
used as default on Unix systems and notepad on Windows.

See the default user preferences file customize/init.pl for examples.

prolog_edit:edit_command(+Editor, -Command)
Determines how Editor is to be invoked using shell/1. Editor is the determined editor
(see prolog_edit:edit_source/1), without the full path specification, and without a
possible (.exe) extension. Command is an atom describing the command. The following
%-sequences are replaced in Command before the result is handed to shell/1:

| %e | Replaced by the (OS) command name of the editor |
| %f | Replaced by the (OS) full path name of the file   |
| %d | Replaced by the line number                      |
If the editor can deal with starting at a specified line, two clauses should be provided. The first
pattern invokes the editor with a line number, while the second is used if the line number is
unknown.

The default contains definitions for vi, emacs, emacsclient, vim, notepad* and
wordpad*. Starred editors do not provide starting at a given line number.

Please contribute your specifications to bugs@swi-prolog.org.

\texttt{prolog\_edit:load}

Normally an undefined multifile predicate. This predicate may be defined to provide loading
hooks for user extensions to the edit module. For example, XPCE provides the code below to
load \texttt{swi\_edit}, containing definitions to locate classes and methods as well as to bind this
package to the PceEmacs built-in editor.

\begin{verbatim}
:- multifile prolog_edit:load/0.
prolog_edit:load :-
    ensure_loaded(library(swi_edit)).
\end{verbatim}

4.5 Verify Type of a Term

Type tests are semi-deterministic predicates that succeed if the argument satisfies the requested type.
Type-test predicates have no error condition and do not instantiate their argument. See also library
error.

\texttt{var(@Term)} \hspace{1cm} [ISO]

True if \texttt{Term} currently is a free variable.

\texttt{nonvar(@Term)} \hspace{1cm} [ISO]

True if \texttt{Term} currently is not a free variable.

\texttt{integer(@Term)} \hspace{1cm} [ISO]

True if \texttt{Term} is bound to an integer.

\texttt{float(@Term)} \hspace{1cm} [ISO]

True if \texttt{Term} is bound to a floating point number.

\texttt{rational(@Term)}

True if \texttt{Term} is bound to a rational number. Rational numbers include integers.

\texttt{rational(@Term, -Numerator, -Denominator)}

True if \texttt{Term} is a rational number with given \texttt{Numerator} and \texttt{Denominator}. The \texttt{Numerator} and
\texttt{Denominator} are in canonical form, which means \texttt{Denominator} is a positive integer and there
are no common divisors between \texttt{Numerator} and \texttt{Denominator}.

\texttt{number(@Term)} \hspace{1cm} [ISO]

True if \texttt{Term} is bound to a rational number (including integers) or a floating point number.
atom(@Term)  \[ISO\]
True if Term is bound to an atom.

blob(@Term, ?Type)
True if Term is a blob of type Type. See section 12.4.9.

string(@Term)
True if Term is bound to a string. Note that string here refers to the built-in atomic type string as described in section 5.2. Starting with version 7, the syntax for a string object is text between double quotes, such as "hello". See also the Prolog flag double_quotes.

atomic(@Term)  \[ISO\]
True if Term is bound (i.e., not a variable) and is not compound. Thus, atomic acts as if defined by:

\[
\text{atomic}(\text{Term}) :-
\quad \text{nonvar}(\text{Term}),
\quad \text{\}+ compound(\text{Term}).
\]

SWI-Prolog defines the following atomic datatypes: atom (atom/1), string (string/1), integer (integer/1), floating point number (float/1) and blob (blob/2). In addition, the symbol [] (empty list) is atomic, but not an atom. See section 5.1.

compound(@Term)  \[ISO\]
True if Term is bound to a compound term. See also functor/3 =../2, compound_name arity/3 and compound_name arguments/3.

callable(@Term)  \[ISO\]
True if Term is bound to an atom or a compound term. This was intended as a type-test for arguments to call/1, call/2 etc. Note that callable only tests the surface term. Terms such as (22,true) are considered callable, but cause call/1 to raise a type error. Module-qualification of meta-argument (see meta_predicate/1) using :/2 causes callable to succeed on any meta-argument.  

Consider the program and query below:

```prolog
:- meta_predicate p(0).

p(G) :- callable(G), call(G).

?- p(22).
ERROR: Type error: ‘callable’ expected, found ‘22’
ERROR: In:
ERROR: [6] p(user:22)
```

---

16 In traditional Prolog systems, double quoted text is often mapped to a list of character codes.

17 We think that callable/1 should be deprecated and there should be two new predicates, one performing a test for callable that is minimally module aware and possibly consistent with type-checking in call/1 and a second predicate that tests for atom or compound.
4.6. COMPARISON AND UNIFICATION OF TERMS

ground(\(@\)Term) \[ISO\]
True if Term holds no free variables. See also nonground/2 and term.variables/2.

cyclic_term(\(@\)Term)
True if Term contains cycles, i.e. is an infinite term. See also acyclic_term/1 and section 2.17.18

acyclic_term(\(@\)Term) \[ISO\]
True if Term does not contain cycles, i.e. can be processed recursively in finite time. See also cyclic_term/1 and section 2.17.

4.6 Comparison and Unification of Terms

Although unification is mostly done implicitly while matching the head of a predicate, it is also pro-
vided by the predicate =/2.

?Term1 = ?Term2 \[ISO\]
Unify Term1 with Term2. True if the unification succeeds. It acts as if defined by the following
fact:

\( (\text{Term}, \text{Term}) \).

For behaviour on cyclic terms see the Prolog flag occurs_check. Calls to =/2 in a clause
body are compiled and may be (re)moved depending on the Prolog flag optimise_unify. See also section 2.18.3.

\(@\)Term1 \(\neq\) \(@\)Term2 \[ISO\]
Equivalent to \(+\)Term1 = Term2.

This predicate is logically sound if its arguments are sufficiently instantiated. In other cases,
such as ?- X \(\neq\) Y., the predicate fails although there are solutions. This is due to the
incomplete nature of \(+/1.

To make your programs work correctly also in situations where the arguments are not yet suffi-
ciently instantiated, use dif/2 instead.

4.6.1 Standard Order of Terms

Comparison and unification of arbitrary terms. Terms are ordered in the so-called “standard order”. This
order is defined as follows:

1. Variables \(<\) Numbers \(<\) Strings \(<\) Atoms \(<\) Compound Terms
2. Variables are sorted by address.
3. Numbers are compared by value. Mixed integer/float are compared as floats. If the comparison
is equal, the float is considered the smaller value. If the Prolog flag iso is defined, all floating
point numbers precede all integers.

18The predicates cyclic_term/1 and acyclic_term/1 are compatible with SICStus Prolog. Some Prolog systems
supporting cyclic terms use is_cyclic/1.
4. *Strings* are compared alphabetically.

5. *Atoms* are compared alphabetically.

6. *Compound* terms are first checked on their arity, then on their functor name (alphabetically) and finally recursively on their arguments, leftmost argument first.

Although variables are ordered, there are some unexpected properties one should keep in mind when relying on variable ordering. This applies to the predicates below as to predicate such as `sort/2` as well as libraries that reply on ordering such as library `assoc` and library `ordsets`. Obviously, an established relation `A @< B` no longer holds if `A` is unified with e.g., a number. Also unifying `A` with `B` invalidates the relation because they become equivalent (`==/2`) after unification.

As stated above, variables are sorted by address, which implies that they are sorted by ‘age’, where ‘older’ variables are ordered before ‘newer’ variables. If two variables are unified their ‘shared’ age is the age of oldest variable. This implies we can examine a list of sorted variables with ‘newer’ (fresh) variables without invalidating the order. Attaching an attribute, see section 8.1, turns an ‘old’ variable into a ‘new’ one as illustrated below. Note that the first always succeeds as the first argument of a term is always the oldest. This only applies for the first attribute, i.e., further manipulation of the attribute list does not change the ‘age’.

```prolog
?- T = f(A,B), A @< B.
T = f(A, B).

?- T = f(A,B), put_attr(A, name, value), A @< B.
false.
```

The above implies you can use e.g., an assoc (from library `assoc`, implemented as an AVL tree) to maintain information about a set of variables. You must be careful about what you do with the attributes though. In many cases it is more robust to use attributes to register information about variables.

\[\text{@Term1} \equiv \text{@Term2} \quad \text{[ISO]}\]

True if `Term1` is equivalent to `Term2`. A variable is only identical to a sharing variable.

\[\text{@Term1} \lessdot \equiv \text{@Term2} \quad \text{[ISO]}\]

Equivalent to \(+\text{Term1} \equiv \text{Term2}.\)

\[\text{@Term1} \prec \text{@Term2} \quad \text{[ISO]}\]

True if `Term1` is before `Term2` in the standard order of terms.

\[\text{@Term1} \preceq \text{@Term2} \quad \text{[ISO]}\]

True if both terms are equal (`==/2`) or `Term1` is before `Term2` in the standard order of terms.

\[\text{@Term1} \succ \text{@Term2} \quad \text{[ISO]}\]

True if `Term1` is after `Term2` in the standard order of terms.

\[\text{@Term1} \succeq \text{@Term2} \quad \text{[ISO]}\]

True if both terms are equal (`==/2`) or `Term1` is after `Term2` in the standard order of terms.

\text{\texttt{compare}(?Order, \text{@Term1}, \text{@Term2})}

Determine or test the `Order` between two terms in the standard order of terms. `Order` is one of `<`, `>` or `=` with the obvious meaning.
4.6.2 Special unification and comparison predicates

This section describes special purpose variations on Prolog unification. The predicate `unify_with_occurs_check/2` provides sound unification and is part of the ISO standard. The predicate `subsumes_term/2` defines ‘one-sided unification’ and is part of the ISO proposal established in Edinburgh (2010). Finally, `unifiable/3` is a ‘what-if’ version of unification that is often used as a building block in constraint reasoners.

\[
\text{unify}(\text{Term1}, \text{Term2}) \quad \text{[ISO]}
\]

As =/2, but using sound unification. That is, a variable only unifies to a term if this term does not contain the variable itself. To illustrate this, consider the two queries below.

1 ?- A = f(A).
   A = f(A).
2 ?- unify_with_occurs_check(A, f(A)).
   false.

The first statement creates a cyclic term, also called a rational tree. The second executes logically sound unification and thus fails. Note that the behaviour of unification through =/2 as well as implicit unification in the head can be changed using the Prolog flag `occurs_check`.

The SWI-Prolog implementation of `unify_with_occurs_check/2` is cycle-safe and only guards against creating cycles, not against cycles that may already be present in one of the arguments. This is illustrated in the following two queries:

?- X = f(X), Y = X, unify_with_occurs_check(X, Y).
   X = Y, Y = f(Y).
?- X = f(X), Y = f(Y), unify_with_occurs_check(X, Y).
   X = Y, Y = f(Y).

Some other Prolog systems interpret `unify_with_occurs_check/2` as if defined by the clause below, causing failure on the above two queries. Direct use of `acyclic_term/1` is portable and more appropriate for such applications.

\[
\text{unify_with_occurs_check}(X, X) :\text{ acyclic_term}(X).
\]

\(+Term1 \equiv +Term2\)

True if `Term1` is a variant of (or structurally equivalent to) `Term2`. Testing for a variant is weaker than equivalence (\(==/2\)), but stronger than unification (=/2). Two terms \(A\) and \(B\) are variants iff there exists a renaming of the variables in \(A\) that makes \(A\) equivalent (==) to \(B\) and vice versa.\(^{19}\) Examples:

\(^{19}\)Row 7 and 8 of this table may come as a surprise, but row 8 is satisfied by (left-to-right) \(A \rightarrow C, B \rightarrow A\) and (right-to-left) \(C \rightarrow A, A \rightarrow B\). If the same variable appears in different locations in the left and right term, the variant relation can be broken by consistent binding of both terms. E.g., after binding the first argument in row 8 to a value, both terms are no longer variant.
A term is always a variant of a copy of itself. Term copying takes place in, e.g., `copy_term/2`, `findall/3` or proving a clause added with `asserta/1`. In the pure Prolog world (i.e., without attributed variables), `=@=/2` behaves as if defined below. With attributed variables, variant of the attributes is tested rather than trying to satisfy the constraints.

```prolog
a =@= A :: false
A =@= B :: true
x(A, A) =@= x(B, C) :: false
x(A, A) =@= x(B, B) :: true
x(A, A) =@= x(A, B) :: false
x(A, B) =@= x(C, D) :: true
x(A, B) =@= x(B, A) :: true
x(A, B) =@= x(C, A) :: true
```

The SWI-Prolog implementation is cycle-safe and can deal with variables that are shared between the left and right argument. Its performance is comparable to `=/2`, both on success and (early) failure. 20

This predicate is known by the name `variant/2` in some other Prolog systems. Be aware of possible differences in semantics if the arguments contain attributed variables or share variables. 21

```prolog
A =@= B :-
  copy_term(A, Ac),
  copy_term(B, Bc),
  numbervars(Ac, 0, N),
  numbervars(Bc, 0, N),
  Ac == Bc.
```

The current implementation is contributed by Kuniaki Mukai.

21 In many systems `variant` is implemented using two calls to `subsumes_term/2`.

22 This predicate is often named `subsumes_chk/2` in older Prolog dialects. The current name was established in the ISO WG17 meeting in Edinburgh (2010). The `chk` postfix was considered to refer to determinism as in e.g., `memberchk/2`.
to make $X$ and $Y$ equivalent. This predicate can handle cyclic terms. Attributed variables are handled as normal variables. Associated hooks are not executed.

$?=(@\text{Term}1, @\text{Term}2)$
Succeeds if the syntactic equality of $\text{Term}1$ and $\text{Term}2$ can be decided safely, i.e. if the result of $\text{Term}1 == \text{Term}2$ will not change due to further instantiation of either term. It behaves as if defined by $?=\text{(X,Y)} :- \neg \text{unifiable}(X,Y,[|])$.

### 4.7 Control Predicates

The predicates of this section implement control structures. Normally the constructs in this section, except for $\text{repeat/0}$, are translated by the compiler. Please note that complex goals passed as arguments to meta-predicates such as $\text{findall/3}$ below cause the goal to be compiled to a temporary location before execution. It is faster to define a sub-predicate (i.e., $\text{one_character_atoms/1}$ in the example below) and make a call to this simple predicate. See also the Prolog flag compile_meta_arguments.

```prolog
one_character_atoms(As) :-
    findall(A, (current_atom(A), atom_length(A, 1)), As).
```

$\text{fail}$
Always fail. The predicate $\text{fail/0}$ is translated into a single virtual machine instruction.

$\text{false}$
Same as fail, but the name has a more declarative connotation.

$\text{true}$
Always succeed. The predicate $\text{true/0}$ is translated into a single virtual machine instruction.

$\text{repeat}$
Always succeed, provide an infinite number of choice points.

$!$
Cut. Discard all choice points created since entering the predicate in which the cut appears. In other words, commit to the clause in which the cut appears and discard choice points that have been created by goals to the left of the cut in the current clause. Meta calling is opaque to the cut. This implies that cuts that appear in a term that is subject to meta-calling ($\text{call/1}$) only affect choice points created by the meta-called term. The following control structures are transparent to the cut: $;/2$, $->/2$ and $*->/2$. Cuts appearing in the condition part of $->/2$ and $*->/2$ are opaque to the cut. The table below explains the scope of the cut with examples. Prunes here means “prunes $X$ choice point created by $X$”.

---

23This predicate was introduced for the implementation of $\text{dif/2}$ and $\text{when/2}$ after discussion with Tom Schrijvers and Bart Demoen. None of us is really happy with the name and therefore suggestions for a new name are welcome.
:Goal1, :Goal2
Conjunction (and). True if both Goal1 and Goal2 are true.

:Goal1 ; :Goal2
Disjunction (or). True if either Goal1 or Goal2 succeeds. Note that the semantics change if Goal1 contains ->/2 or *->/2. ;/2 is transparent to cuts. See !/0 for details. For example:

?- (between(1,2,X) ; X = a).
   X = 1 ;
   X = 2 ;
   X = a.

It is strongly advised to always use parenthesis around disjunctions. Conjunctions inside a disjunction should not use parenthesis. Traditionally the ; is placed at the start of the line rather than at the end because a ; at the end of a line is easily overlooked. Below is an example of the preferred style used in SWI-Prolog.

p :-
   a,
   ( b,
       c
   ; d
   ).

Although ;/2 is a control structure that is normally handled by the compiler, SWI-Prolog implements ;/2 as a true predicate to support call/2 and friends as well as to allow for querying predicate properties, for example to support code analysis.

:Goal1 | :Goal2
Equivalent to ;/2. Retained for compatibility only. New code should use ;/2.

:Condition -> :Action
If-then and If-Then-Else. The ->/2 construct commits to the choices made at its left-hand side, destroying choice points created inside the clause (by ;/2), or by goals called by this clause. Unlike !/0, the choice point of the predicate as a whole (due to multiple clauses) is not destroyed. Disregarding the interaction with !/0, the combination ;/2 and ->/2 acts as if defined as:

24Some users prefer a newline after the ;.
Please note that \((\text{If} \rightarrow \text{Then})\) acts as \((\text{If} \rightarrow \text{Then} ; \text{fail})\), making the construct \text{fail} if the condition fails. This unusual semantics is part of the ISO and all de-facto Prolog standards.

Please note that \((\text{if} \rightarrow \text{then};\text{else})\) is read as \((((\text{if} \rightarrow \text{then});\text{else})\) and that the combined semantics of this syntactic construct as defined above is different from the simple nesting of the two individual constructs, i.e., the semantics of \(-/>/2\) changes when embedded in \(;/2\). See also \text{once/1}.

As with \(;/2\), this construct is always nested in parenthesis. Here is an example of the preferred layout for SWI-Prolog.

```prolog
p :-
  a,
  (  b,
      c
  ->  d,
      e
  ;  f
  ->  g
  ;  h
 ).
```

\textbf{Condition *---> :Action ; :Else}

This construct implements the so-called ‘soft-cut’. The control is defined as follows: If \text{Condition} succeeds at least once, the semantics is the same as \((\text{call(Condition)}, \text{Action})\).\(^{25}\) If \text{Condition} does not succeed, the semantics is that of \((\!+ \text{Condition}, \text{Else})\). In other words, if \text{Condition} succeeds at least once, simply behave as the conjunction of \text{call(Condition)} and \text{Action}, otherwise execute \text{Else}. The construct is known under the name \text{if/3} in some other Prolog implementations.

The construct \(A *---> B\), i.e., without an \text{Else} branch, the semantics is the same as \((\text{call(A)}, B)\).

This construct is rarely used. An example use case is the implementation of \text{OPTIONAL} in \text{SPARQL}. The optional construct should preserve all solutions if the argument succeeds as least once but still succeed otherwise. This is implemented as below.

```prolog
optional(Goal) :-
  (  Goal
      *--->  true
    ;  true
  ).
```

\(^{25}\)Note that the \text{Condition} is wrapped in \text{call/1}, limiting the scope of the cut \(!/0\)
Now calling e.g., `optional(member(X, [a,b]))` has the solutions \( X = a \) and \( X = b \), while `optional(member(X, []))` succeeds without binding \( X \).

\[ \text{\texttt{\textbackslash+ :Goal \[ISO\]}} \]
True if ‘Goal’ cannot be proven (mnemonic: + refers to \textit{provable} and the backslash (\) is normally used to indicate negation in Prolog).

Many Prolog implementations (including SWI-Prolog) provide \texttt{not/1}. The \texttt{not/1} alternative is deprecated due to its strong link to logical negation.

### 4.8 Meta-Call Predicates

Meta-call predicates are used to call terms constructed at run time. The basic meta-call mechanism offered by SWI-Prolog is to use variables as a subclause (which should of course be bound to a valid goal at runtime). A meta-call is slower than a normal call as it involves actually searching the database at runtime for the predicate, while for normal calls this search is done at compile time.

\texttt{call(Goal)} \[ISO\]

Call \textit{Goal}. This predicate is normally used for goals that are not known at compile time. For example, the Prolog toplevel essentially performs \texttt{read(Goal), call(Goal)}. Also a \textit{meta} predicates such as \texttt{ignore/1} are defined using call:

```prolog
ignore(Goal) :- call(Goal), !.
ignore(_).
```

Note that a plain variable as a body term acts as \texttt{call/1} and the above is equivalent to the code below. SWI-Prolog produces the same code for these two programs and \texttt{listing/1} prints the program above.

```prolog
ignore(Goal) :- Goal, !.
ignore(_).
```

Note that \texttt{call/1} restricts the scope of the cut \(! / 0\). A cut inside \textit{Goal} only affects choice points created by \textit{Goal}.

\texttt{call(Goal, +ExtraArg1, \ldots)} \[ISO\]

Append \textit{ExtraArg1, ExtraArg2, \ldots} to the argument list of \textit{Goal} and call the result. For example, \texttt{call(plus(1), 2, X)} will call \texttt{plus(1, 2, X)}, binding \( X \) to 3.

The \texttt{call/[2..]} construct is handled by the compiler. The predicates \texttt{call/[2-8]} are defined as real (meta)-predicates and are available to inspection through \texttt{current_predicate/1, predicate_property/2, etc.}\textsuperscript{26} Higher arities are handled by the compiler and runtime system, but the predicates are not accessible for inspection.\textsuperscript{27}

\textsuperscript{26}Arities 2..8 are demanded by ISO/IEC 13211-1:1995/Cor.2:2012.

\textsuperscript{27}Future versions of the reflective predicate may fake the presence of \texttt{call/9...} Full logical behaviour, generating all these pseudo predicates, is probably undesirable and will become impossible if \texttt{max_arity} is removed.
4.8. META-CALL PREDICATES

apply(:Goal, +List)  
Append the members of List to the arguments of Goal and call the resulting term. For example:
apply(plus(1), [2, X]) calls plus(1, 2, X). New code should use call/[2..] if the length of List is fixed.

not(:Goal)  
True if Goal cannot be proven. Retained for compatibility only. New code should use \+/1.

once(:Goal)  
Make a possibly nondet goal semidet, i.e., succeed at most once. Defined as:

\[
\begin{align*}
\text{once}(\text{Goal}) & : - \\
& \quad \text{call}(\text{Goal}), !.
\end{align*}
\]

once/1 can in many cases be replaced with ->/2. The only difference is how the cut behaves (see !/0). The following two clauses below are identical. Be careful about the interaction with ;/2. The apply_macros library defines an inline expansion of once/1, mapping it to (Goal->true;fail). Using the full if-then-else constructs prevents its semantics from being changed when embedded in a ;/2 disjunction.

1) a :- once((b, c)), d.
2) a :- b, c -> d.

ignore(:Goal)  
Calls Goal as once/1, but succeeds, regardless of whether Goal succeeded or not. Defined as:

\[
\begin{align*}
\text{ignore}(\text{Goal}) & : - \\
& \quad \text{Goal}, !.
\end{align*}
\]

call_with_depth_limit(:Goal, +Limit, -Result)  
If Goal can be proven without recursion deeper than Limit levels, call_with_depth_limit/3 succeeds, binding Result to the deepest recursion level used during the proof. Otherwise, Result is unified with depth_limit_exceeded if the limit was exceeded during the proof, or the entire predicate fails if Goal fails without exceeding Limit.

The depth limit is guarded by the internal machinery. This may differ from the depth computed based on a theoretical model. For example, true/0 is translated into an inline virtual machine instruction. Also, repeat/0 is not implemented as below, but as a non-deterministic foreign predicate.

\[
\begin{align*}
\text{repeat}. \\
\text{repeat} & : - \\
& \quad \text{repeat}.
\end{align*}
\]
As a result, call_with_depth_limit/3 may still loop infinitely on programs that should theoretically finish in finite time. This problem can be cured by using Prolog equivalents to such built-in predicates.

This predicate may be used for theorem provers to realise techniques like iterative deepening. See also call_with_inference_limit/3. It was implemented after discussion with Steve Moyle smoyle@ermine.ox.ac.uk.

**call_with_inference_limit**(Goal, +Limit, -Result)

Equivalent to call(Goal), but limits the number of inferences for each solution of Goal.\(^{28}\)

Execution may terminate as follows:

- If Goal does not terminate before the inference limit is exceeded, Goal is aborted by injecting the exception inference_limit_exceeded into its execution. After termination of Goal, Result is unified with the atom inference_limit_exceeded. Otherwise,
- If Goal fails, call_with_inference_limit/3 fails.
- If Goal succeeds without a choice point, Result is unified with !.
- If Goal succeeds with a choice point, Result is unified with true.
- If Goal throws an exception, call_with_inference_limit/3 re-throws the exception.

An inference is defined as a call or redo on a predicate. Please note that some primitive built-in predicates are compiled to virtual machine instructions for which inferences are not counted. The execution of predicates defined in other languages (e.g., C, C++) count as a single inference. This includes potentially expensive built-in predicates such as sort/2.

Calls to this predicate may be nested. An inner call that sets the limit below the current is honoured. An inner call that would terminate after the current limit does not change the effective limit. See also call_with_depth_limit/3 and call_with_time_limit/2.

**setup_call_cleanup**(Setup, :Goal, :Cleanup)

Calls (once(Setup), Goal). If Setup succeeds, Cleanup will be called exactly once after Goal is finished: either on failure, deterministic success, commit, or an exception. The execution of Setup is protected from asynchronous interrupts like call_with_time_limit/2 (package clib) or thread_signal/2. In most uses, Setup will perform temporary side-effects required by Goal that are finally undone by Cleanup.

Success or failure of Cleanup is ignored, and choice points it created are destroyed (as once/1). If Cleanup throws an exception, this is executed as normal while it was not triggered as the result of an exception the exception is propagated as normal. If Cleanup was triggered by an exception the rules are described in section 4.10.1

Typically, this predicate is used to cleanup permanent data storage required to execute Goal, close file descriptors, etc. The example below provides a non-deterministic search for a term in a file, closing the stream as needed.

```prolog
term_in_file(Term, File) :-
    setup_call_cleanup(open(File, read, In),
```

\(^{28}\)This predicate was realised after discussion with Ulrich Neumerkel and Markus Triska.
Note that it is impossible to implement this predicate in Prolog. The closest approximation would be to read all terms into a list, close the file and call \texttt{member/2}. Without \texttt{setup_call_cleanup/3} there is no way to gain control if the choice point left by \texttt{repeat/0} is removed by a cut or an exception.

\texttt{setup_call_cleanup/3} can also be used to test determinism of a goal, providing a portable alternative to \texttt{deterministic/1}:

\begin{verbatim}
?- setup_call_cleanup(true,(X=1;X=2), Det=yes).
X = 1 ;
X = 2,
Det = yes ;
\end{verbatim}

This predicate is under consideration for inclusion into the ISO standard. For compatibility with other Prolog implementations see \texttt{call_cleanup/2}.

\textbf{setup_call_catcher_cleanup(:Setup, :Goal, +Catcher, :Cleanup)}

Similar to \texttt{setup_call_cleanup} with additional information on the reason for calling \texttt{Cleanup}. Prior to calling \texttt{Cleanup}, \texttt{Catcher} unifies with the termination code (see below). If this unification fails, \texttt{Cleanup} is not called.

\begin{verbatim}
exit
Goal succeeded without leaving any choice points.

fail
Goal failed.

!
Goal succeeded with choice points and these are now discarded by the execution of a cut (or other pruning of the search tree such as if-then-else).

exception(Exception)
Goal raised the given Exception.

external_exception(Exception)
Goal succeeded with choice points and these are now discarded due to an exception. For example:
\end{verbatim}
?- setup_call_catcher_cleanup(true, (X=1;X=2),
                      Catcher, writeln(Catcher)),
     throw(ball).
external_exception(ball)
ERROR: Unhandled exception: Unknown message: ball

\textbf{call\_cleanup}(:Goal, :Cleanup)

Same as \texttt{setup\_call\_cleanup(true, Goal, Cleanup)}. This is provided for compatibility with a number of other Prolog implementations only. Do not use \texttt{call\_cleanup/2} if you perform side-effects prior to calling that will be undone by \texttt{Cleanup}. Instead, use \texttt{setup\_call\_cleanup/3} with an appropriate first argument to perform those side-effects.

\textbf{call\_cleanup}(:Goal, +Catcher, :Cleanup) \hspace{1cm} \textit{[deprecated]}

Same as \texttt{setup\_call\_catcher\_cleanup(true, Goal, Catcher, Cleanup)}. The same warning as for \texttt{call\_cleanup/2} applies.

\textbf{undo}(:Goal)

Add \texttt{Goal} to the trail. \texttt{Goal} is executed as \texttt{ignore/1} on the first opportunity after backtracking to a point before the call to \texttt{Goal}. This predicate is intended to make otherwise persistent changes to the database or created by foreign procedures backtrackable if it is possible to define a goal that reverts the effect of the initial call. A typical use case is to define a \textit{backtrackable assert}.

\begin{verbatim}
\texttt{b\_assertz(Term) :-}
  \texttt{assertz(Term, Ref),}
  \texttt{undo(erase(Ref)).}
\end{verbatim}

Without \texttt{undo/1} we can achieve something similar by leaving a choicepoint using the almost portable\footnote{\texttt{assertz/2} is not part of the ISO standard but supported by multiple systems.} alternative below.

\begin{verbatim}
\texttt{b\_assertz(Term) :-}
  \texttt{assertz(Term, Ref),}
  \texttt{(  true}
    \texttt{;  erase(Ref),}
    \texttt{fail}
  \texttt{).}
\end{verbatim}

The \texttt{undo/1} based solution avoids leaving a choice point open and, more importantly, keeps undoing the assert also if the choice point from the second alternative is pruned.

Currently the following remarks apply

\begin{itemize}
  \item \texttt{Goal} is \textit{copied} when it is registered.
  \item “First opportunity” means after backtracking or at the first call port reached.
\end{itemize}
• Multiple undo goals may be scheduled that are executed as a batch. If multiple goals raise an exception, the most urgent is preserved after all goals have been executed.
• It is not allowed for Goal to call undo/1. An attempt to do so results in a permission_error exception.
• Note that an exception that is caught higher in the call stack backtracks and therefore ensures Goal is called.

See also snapshot/1 and transaction/1.

4.9 Delimited continuations

The predicates reset/3 and shift/1 implement delimited continuations for Prolog. Delimited continuations for Prolog are described in [Schrijvers et al., 2013] (preprint PDF). The mechanism allows for proper coroutines, two or more routines whose execution is interleaved, while they exchange data. Note that coroutines in this sense differ from coroutines realised using attributed variables as described in chapter 8.

Note that shift/1 captures the forward continuation. It notably does not capture choicepoints. Choicepoints created before the continuation is captured remain open, while choicepoints created when the continuation is executed live their normal life. Unfortunately the consequences for committing a choicepoint is complicated. In general a cut (!/0) in the continuation does not have the expected result. Negation (!+/1) and if-then(-else) (->/2) behave as expected, provided the continuation is called immediately. This works because for !+/1 and ->/2 the continuation contains a reference to the choicepoint that must be cancelled and this reference is restored when possible. If, as with tabling, the continuation is saved and called later, the commit has no effect. We illustrate the three scenarios using with the programs below.

```
t1 :-
    reset(gbad, ball, Cont),
    (        Cont == 0
    ->  true
    ;  writeln(resuming),
    call(Cont)
    ).

gbad :-
    n, !, fail.
gbad.

n :-
    shift(ball),
    writeln(n).
```

Here, the !/0 has no effect:

?- t1.
resuming

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The second example uses `\+/1`, which is essentially `(G->fail;true)`.

```
reset(gok, ball, Cont),
( Cont == 0 -> true
 ; writeln(resuming),
   call(Cont)
 ).
gok :- \+ n.
```

In this scenario the normal semantics of `\+/1` is preserved:

```
?- t1.
resuming
n
false.
```

In the last example we illustrate what happens if we assert the continuation to be executed later. We write the negation using if-then-else to make it easier to explain the behaviour.

```
:- dynamic cont/1.
t3 :-
   retractall(cont(_)),
   reset(gassert, ball, Cont),
   ( Cont == 0 -> true
   ; asserta(cont(Cont))
   ).
c3 :-
   cont(Cont),
   writeln(resuming),
   call(Cont).
gassert :-
   ( n -> fail
   ; true
   ).
```
4.10 Exception handling

The predicates catch/3 and throw/1 provide ISO compliant raising and catching of exceptions.

catch(:Goal, +Catcher, :Recover) [ISO]
Behaves as call/1 if no exception is raised when executing Goal. If an exception is raised using throw/1 while Goal executes, and the Goal is the innermost goal for which Catcher unifies with the argument of throw/1, all choice points generated by Goal are cut, the system

Now, t3/0 succeeds twice. This is because n/0 shifts, so the commit to the fail/0 branch is not executed and the true/0 branch is evaluated normally. Calling the continuation later using c3/0 fails because the choicepoint that realised the if-then-else does not exist in the continuation and thus the effective continuation is the remainder of n/0 and fail/0 in gassert/0.

?- t3.
true ;
true.
?- c3.
resuming
n
false.

The suspension mechanism provided by delimited continuations is used to implement tabling [Desouter et al., 2015], (available here). See section 7.

reset(:Goal, ?Ball, -Continuation)
Call Goal. If Goal calls shift/1 and the argument of shift/1 can be unified with Ball,30 shift/1 causes reset/3 to return, unifying Continuation with a goal that represents the continuation after shift/1. In other words, meta-calling Continuation completes the execution where shift left it. If Goal does not call shift/1, Continuation are unified with the integer 0 (zero).31

shift(+Ball)
Abandon the execution of the current goal, returning control to just after the matching reset/3 call. This is similar to throw/1 except that (1) nothing is ‘undone’ and (2) the 3th argument of reset/3 is unified with the continuation, which allows the code calling reset/3 to resume the current goal.

shift_for_copy(+Ball) [experimental]
Similar to shift/1. This version is intended for situations where it is assumed the continuation is copied and saved to be executed one or multiple times in a different context. This notably prevents restoring choice points saved for \+/1, If~>Then; Else, etc.

4.10 Exception handling

The predicates catch/3 and throw/1 provide ISO compliant raising and catching of exceptions.
backtracks to the start of `catch/3` while preserving the thrown exception term, and `Recover` is called as in `call/1`.

The overhead of calling a goal through `catch/3` is comparable to `call/1`. Recovery from an exception is much slower, especially if the exception term is large due to the copying thereof or is decorated with a stack trace using, e.g., the library `prolog_stack` based on the `prolog_exception_hook/4` hook predicate to rewrite exceptions.

**throw(+Exception)**

Raise an exception. The system looks for the innermost `catch/3` ancestor for which `Exception` unifies with the `Catcher` argument of the `catch/3` call. See `catch/3` for details.

ISO demands that `throw/1` make a copy of `Exception`, walk up the stack to a `catch/3` call, backtrack and try to unify the copy of `Exception` with `Catcher`. SWI-Prolog delays backtracking until it actually finds a matching `catch/3` goal. The advantage is that we can start the debugger at the first possible location while preserving the entire exception context if there is no matching `catch/3` goal. This approach can lead to different behaviour if `Goal` and `Catcher` of `catch/3` call shared variables. We assume this to be highly unlikely and could not think of a scenario where this is useful.\(^{32}\)

In addition to explicit calls to `throw/1`, many built-in predicates throw exceptions directly from C. If the `Exception` term cannot be copied due to lack of stack space, the following actions are tried in order:

1. If the exception is of the form `error(Formal, ImplementationDefined)`, try to raise the exception without the `ImplementationDefined` part.
2. Try to raise `error(resource_error(stack), global)`.
3. Abort (see `abort/0`).

If an exception is raised in a call-back from C (see chapter 12) and not caught in the same call-back, `PL_next_solution()` fails and the exception context can be retrieved using `PL_exception()`.

**catch_with_backtrace(:Goal, +Catcher, :Recover)**

As `catch/3`, but if library `prolog_stack` is loaded and an exception of the shape `error(Format, Context)` is raised `Context` is extended with a backtrace. To catch an error and print its message including a backtrace, use the following template:

```prolog
:- use_module(library(prolog_stack)).

...,  
catch_with_backtrace(Goal, Error, 
    print_message(error, Error)),
...,  
```

This is good practice for a catch-all wrapper around an application. See also `main/0` from library `main`.

\(^{32}\)I’d like to acknowledge Bart Demoen for his clarifications on these matters.
4.10. Exception Handling

4.10.1 Urgency of exceptions

Under some conditions an exception may be raised as a result of handling another exception. Below are some of the scenarios:

- The predicate `setup_call_cleanup/3` calls the cleanup handler as a result of an exception and the cleanup handler raises an exception itself. In this case the most urgent exception is propagated into the environment.

- Raising an exception fails due to lack of resources, e.g., lack of stack space to store the exception. In this case a resource exception is raised. If that too fails the system tries to raise a resource exception without (stack) context. If that fails it will raise the exception `$aborted`, also raised by `abort/0`. As no stack space is required for processing this atomic exception, this should always succeed.

- Certain callback operations raise an exception while processing another exception or a previous callback already raised an exception before there was an opportunity to process the exception. The most notable callback subject to this issue are `prolog_event_hook/1` (supporting e.g., the graphical debugger), `prolog_exception_hook/4` (rewriting exceptions, e.g., by adding context) and `print_message/2` when called from the core facilities such as the internal debugger. As with `setup_call_cleanup/3`, the most urgent exception is preserved.

If the most urgent exceptions needs to be preserved, the following exception ordering is respected, preserving the topmost matching error.

1. `$aborted` (abort/0)
2. `time_limit_exceeded(call_with_time_limit/2)`
3. `error(resource_error( Resource ), Context)`
4. `error(Formal, Context)`
5. All other exceptions

Note The above resolution is not described in the ISO standard. This is not needed either because ISO does not specify `setup_call_cleanup/3` and does not deal with environment management issues such as (debugger) callbacks. Neither does it define `abort/0` or timeout handling. Notably `abort/0` and timeout are non-logical control structures. They are implemented on top of exceptions as they need to unwind the stack, destroy choice points and call cleanup handlers in the same way. However, the pending exception should not be replaced by another one before the intended handler is reached. The abort exception cannot be caught, something which is achieved by wrapping the `cleanup handler` of `catch/3` into `call_cleanup( Handler, abort )`.

4.10.2 Debugging and exceptions

Before the introduction of exceptions in SWI-Prolog a runtime error was handled by printing an error message, after which the predicate failed. If the Prolog flag `debug_on_error` was in effect (default), the tracer was switched on. The combination of the error message and trace information is generally sufficient to locate the error.
With exception handling, things are different. A programmer may wish to trap an exception using catch/3 to avoid it reaching the user. If the exception is not handled by user code, the interactive top level will trap it to prevent termination.

If we do not take special precautions, the context information associated with an unexpected exception (i.e., a programming error) is lost. Therefore, if an exception is raised which is not caught using catch/3 and the top level is running, the error will be printed, and the system will enter trace mode.

If the system is in a non-interactive call-back from foreign code and there is no catch/3 active in the current context, it cannot determine whether or not the exception will be caught by the external routine calling Prolog. It will then base its behaviour on the Prolog flag `debug_on_error`:

- `current_prolog_flag(debug_on_error, false)`
  The exception does not trap the debugger and is returned to the foreign routine calling Prolog, where it can be accessed using `PL_exception()`. This is the default.

- `current_prolog_flag(debug_on_error, true)`
  If the exception is not caught by Prolog in the current context, it will trap the tracer to help analyse the context of the error.

While looking for the context in which an exception takes place, it is advised to switch on debug mode using the predicate `debug/0`. The hook `prolog_exception_hook/4` can be used to add more debugging facilities to exceptions. An example is the library `http/http_error`, generating a full stack trace on errors in the HTTP server library.

### 4.10.3 The exception term

#### General form of the ISO standard exception term

The predicate `throw/1` takes a single argument, the `exception term`, and the ISO standard stipulates that the exception term be of the form `error(Formal, Context)` with:

- **Formal**
  the ‘formal’ description of the error, as listed in chapter 7.12.2 pp. 62-63 (“Error classification”) of the ISO standard. It indicates the `error class` and possibly relevant `error context` information. It may be a compound term of arity 1,2 or 3 - or simply an atom if there is no relevant error context information.

- **Context**
  additional context information beyond the one in Formal. If may be unset, i.e. a fresh variable, or set to something that hopefully will help the programmer in debugging. The structure of Context is left unspecified by the ISO Standard, so SWI-Prolog creates its own convention (see below).

Thus, constructing an error term and throwing it might take this form (although you would not use the illustrative explicit naming given here; instead composing the exception term directly in a one-liner):

```
Exception = error(Formal, Context),
Context   = ... some local convention ...,
```
4.10. EXCEPTION HANDLING

Formal = type_error(ValidType, Culprit), % for "type error" for example
ValidType = integer, % valid atoms are listed in the ISO standard
Culprit = ... some value ..., throw(Exception)

Note that the ISO standard formal term expresses what should be the case or what is the expected correct state, and not what is the problem. For example:

• •
  If a variable is found to be uninstantiated but should be instantiated, the error term is instantiation_error: The problem is not that there is an unwanted instantiation, but that the correct state is the one with an instantiated variable.

• •
  In case a variable is found to be instantiated but should be uninstantiated (because it will be used for output), the error term is uninstantiation_error(Culprit): The problem is not that there is lack of instantiation, but that the correct state is the one which Culprit (or one of its subterms) is more uninstantiated than is the case.

• •
  If you try to disassemble an empty list with compound_name_arguments/3, the error term is type_error(compound,[]). The problem is not that [] is (erroneously) a compound term, but that a compound term is expected and [] does not belong to that class.

Throwing exceptions from applications and libraries

User predicates are free to choose the structure of their exception terms (i.e., they can define their own conventions) but should adhere to the ISO standard if possible, in particular for libraries.

Notably, exceptions of the shape error(Formal,Context) are recognised by the development tools and therefore expressing unexpected situations using these exceptions improves the debugging experience.

In SWI-Prolog, the second argument of the exception term, i.e., the Context argument, is generally of the form context(Location, Message), where:

• Location
describes the execution context in which the exception occurred. While the Location argument may be specified as a predicate indicator (Name/Arity), it is typically filled by the prolog.stack library. This library recognises uncaught errors or errors caught by catch_with_backtrace/3 and fills the Location argument with a backtrace.

• Message
provides an additional description of the error or can be left as a fresh variable if there is nothing appropriate to fill in.

ISO standard exceptions can be thrown via the predicates exported from error. Termwise, these predicates look exactly like the Formal of the ISO standard error term they throw:

• •
  instantiation_error/1 (the argument is not used: ISO specifies no argument)
4.11 Printing messages

The predicate `print_message/2` is used to print a message term in a human-readable format. The other predicates from this section allow the user to refine and extend the message system. A common usage of `print_message/2` is to print error messages from exceptions. The code below prints errors encountered during the execution of `Goal`, without further propagating the exception and without starting the debugger.

```prolog
...,
catch(Goal, E,
    ( print_message(error, E),
      fail
    ),
...)
```

Another common use is to define `message_hook/3` for printing messages that are normally silent, suppressing messages, redirecting messages or make something happen in addition to printing the message.

`print_message(+Kind, +Term)`

The predicate `print_message/2` is used by the system and libraries to print messages. `Kind` describes the nature of the message, while `Term` is a Prolog term that describes the
content. Printing messages through this indirection instead of using \texttt{format/3} to the stream \texttt{user.error} allows displaying the message appropriate to the application (terminal, logfile, graphics), acting on messages based on their content instead of a string (see \texttt{message.hook/3}) and creating language specific versions of the messages. See also section 4.11.1. The following message kinds are known:

\textbf{banner}

The system banner message. Banner messages can be suppressed by setting the Prolog flag \texttt{verbose} to \texttt{silent}.

\textbf{debug(Topic)}

Message from library(debug). See \texttt{debug/3}.

\textbf{error}

The message indicates an erroneous situation. This kind is used to print uncaught exceptions of type \texttt{error(Formal, Context)}. See section introduction (section 4.11). An error message causes the process to halt with status 1 if the Prolog flag \texttt{on.error} is set to \texttt{halt} and the message is not intercepted by \texttt{message.hook/3}. Not intercepted error messages increment the \texttt{errors} key for \texttt{statistics/2}.

\textbf{help}

User requested help message, for example after entering ‘h’ or ‘?’ to a prompt.

\textbf{information}

Information that is requested by the user. An example is \texttt{statistics/0}.

\textbf{informational}

Typically messages of events and progress that are considered useful to a developer. Such messages can be suppressed by setting the Prolog flag \texttt{verbose} to \texttt{silent}.

\textbf{silent}

Message that is normally not printed. Applications may define \texttt{message.hook/3} to act upon such messages.

\textbf{trace}

Messages from the (command line) tracer.

\textbf{warning}

The message indicates something dubious that is not considered fatal. For example, discontiguous predicates (see \texttt{discontiguous/1}). A warning message causes the process to halt with status 1 if the Prolog flag \texttt{on.warning} is set to \texttt{halt} and the message is not intercepted by \texttt{message.hook/3}. Not intercepted warning messages increment the \texttt{warnings} key for \texttt{statistics/2}.

The predicate \texttt{print.message/2} first translates the \texttt{Term} into a list of ‘message lines’ (see \texttt{print.message.lines/3} for details). Next, it calls the hook \texttt{message.hook/3} to allow the user to intercept the message. If \texttt{message.hook/3} fails it prints the message unless \texttt{Kind} is \texttt{silent}.

The \texttt{print.message/2} predicate and its rules are in the file \texttt{/plhome}/boot/messages.pl, which may be inspected for more information on the error messages and related error terms. If you need to write messages from your own predicates, it is recommended to reuse the existing message terms if applicable. If no existing message term is applicable, invent a fairly unique term that represents the event and define a
rule for the multifile predicate prolog:message//1. See section 4.11.1 for a deeper discussion and examples.

See also message_to_string/2.

**print_message_lines(+Stream, +Prefix, +Lines)**

Print a message (see print_message/2) that has been translated to a list of message elements. The elements of this list are:

\[(\text{Format})-(\text{Args})\]

Where \text{Format} is an atom and \text{Args} is a list of format arguments. Handed to \text{format/3}.

**flush**

If this appears as the last element, \text{Stream} is flushed (see flush_output/1) and no final newline is generated. This is combined with a subsequent message that starts with \text{at_same_line} to complete the line.

**at_same_line**

If this appears as first element, no prefix is printed for the first line and the line position is not forced to 0 (see format/1,^N).

**ansi(+Attributes, +Format, +Args)**

This message may be intercepted by means of the hook prolog:message_line_element/2. The library ansi_term implements this hook to achieve coloured output. If it is not intercepted it invokes format(Stream, Format, Args).

**url(Location)**

Print a source location. \text{Location} is one of the terms File:Line:Column, File:Line or File. When using library ansi_term, this is translated into a hyperlink for modern terminals.

**url(URL, Label)**

Print \text{Label}. When using library ansi_term, this is translated into a hyperlink for modern terminals.

**nl**

A new line is started. If the message is not complete, \text{Prefix} is printed before the remainder of the message.

**begin(Kind, Var)**

**end(Var)**

The entire message is headed by begin(Kind, Var) and ended by end(Var). This feature is used by, e.g., library ansi_term to colour entire messages.

\[(\text{Format})\]

Handed to \text{format/3} as format(Stream, Format, []). Deprecated because it is ambiguous if Format collides with one of the atomic commands.

See also print_message/2 and message_hook/3.

**message_hook(+Term, +Kind, +Lines)**

Hook predicate that may be defined in the module user to intercept messages from print_message/2. \text{Term} and \text{Kind} are the same as passed to print_message/2. \text{Lines}
is a list of format statements as described with \texttt{print_message_lines/3}. See also \texttt{message\_to\_string/2}.

This predicate must be defined dynamic and multifile to allow other modules defining clauses for it too.

\textbf{thread\_message\_hook}(\texttt{+Term, +Kind, +Lines})

As \texttt{message\_hook/3}, but this predicate is local to the calling thread (see \texttt{thread\_local/1}). This hook is called \textit{before} \texttt{message\_hook/3}. The ‘pre-hook’ is indented to catch messages they may be produced by calling some goal without affecting other threads.

\textbf{message\_property}(\texttt{+Kind, ?Property})

This hook can be used to define additional message kinds and the way they are displayed. The following properties are defined:

\textbf{color}(-\texttt{Attributes})

Print message using ANSI terminal attributes. See \texttt{ansi\_format/3} for details. Here is an example, printing help messages in blue:

\begin{verbatim}
:- multifile user:message\_property/2.
user:message\_property(help, color([fg(blue)])).
\end{verbatim}

\textbf{prefix}(-\texttt{Prefix})

Prefix printed before each line. This argument is handed to \texttt{format/3}. The default is \texttt{’\~{}N’}. For example, messages of kind \texttt{warning} use \texttt{’\~{}NWarning: ’}.

\textbf{tag}(-\texttt{Tag})

Defines the text part for the \texttt{prefix} property for error and warning messages.

\textbf{location\_prefix}(\texttt{+Location, -FirstPrefix, -ContinuePrefix})

Used for printing messages that are related to a source location. Currently, \texttt{Location} is a term \texttt{File:Line}. \texttt{FirstPrefix} is the prefix for the first line and \texttt{-ContinuePrefix} is the prefix for continuation lines. For example, the default for errors is

\begin{verbatim}
location\_prefix(File:Line, 
    ’\~{}NERRO\_ERROR: ‘\w:\’d:-\{File,Line\}, ‘\~{}N\t\’)).
\end{verbatim}

\textbf{stream}(-\texttt{Stream})

Stream to which to print the message. Default is \texttt{user\_error}.

\textbf{wait}(-\texttt{Seconds})

Amount of time to wait after printing the message. Default is not to wait.

\textbf{prolog\_message\_line\_element}(\texttt{+Stream, +Term})

This hook is called to print the individual elements of a message from \texttt{print\_message\_lines/3}. This hook is used by e.g., library \texttt{ansi\_term} to colour messages on ANSI-capable terminals.

\textbf{prolog\_message\_prefix\_hook}(\texttt{+ContextTerm, -Prefix})

This hook is called to add context to the message prefix. \texttt{ContextTerm} is a member of the list
provided by the `message_context`. `Prefix` must be unified with an atomic value that is added to the message prefix.

**message_to_string(+Term, -String)**
Translates a message term into a string object (see section 5.2).

**version**
Write the SWI-Prolog banner message as well as additional messages registered using `version/1`. This is the default *initialization goal* which can be modified using `-g`.

**version(+Message)**
Register additional messages to be printed by `version/0`. Each registered message is handed to the message translation DCG and can thus be defined using the hook `prolog:message//1`. If not defined, it is simply printed.

### 4.11.1 Printing from libraries

Libraries should *not* use `format/3` or other output predicates directly. Libraries that print informational output directly to the console are hard to use from code that depend on your textual output, such as a CGI script. The predicates in section 4.11 define the API for dealing with messages. The idea behind this is that a library that wants to provide information about its status, progress, events or problems calls `print_message/2`. The first argument is the `level`. The supported levels are described with `print_message/2`. Libraries typically use informational and warning, while libraries should use exceptions for errors (see `throw/1`, `type_error/2`, etc.).

The second argument is an arbitrary Prolog term that carries the information of the message, but *not* the precise text. The text is defined by the grammar rule `prolog:message//1`. This distinction is made to allow for translations and to allow hooks processing the information in a different way (e.g., to translate progress messages into a progress bar).

For example, suppose we have a library that must download data from the Internet (e.g., based on `http_open/3`). The library wants to print the progress after each downloaded file. The code below is a good skeleton:

```prolog
download_urls(List) :-
    length(List, Total),
    forall(nth1(I, List, URL),
        (download_url(URL),
         print_message(informational,
                        download_url(URL, I, Total))))).
```

The programmer can now specify the default textual output using the rule below. Note that this rule may be in the same file or anywhere else. Notably, the application may come with several rule sets for different languages. This, and the user-hook example below are the reason to represent the message as a compound term rather than a string. This is similar to using message numbers in non-symbolic languages. The documentation of `print_message_lines/3` describes the elements that may appear in the output list.

```prolog
:- multifile
    prolog:message//1.
```
4.12 Handling signals

As of version 3.1.0, SWI-Prolog is able to handle software interrupts (signals) in Prolog as well as in foreign (C) code (see section 12.4.16).

Signals are used to handle internal errors (execution of a non-existing CPU instruction, arithmetic domain errors, illegal memory access, resource overflow, etc.), as well as for dealing with asynchronous interprocess communication.

Signals are defined by the POSIX standard and part of all Unix machines. The MS-Windows Win32 provides a subset of the signal handling routines, lacking the vital functionality to raise a signal in another thread for achieving asynchronous interprocess (or interthread) communication (Unix kill() function).

\[ \text{on} \text{signal}(\text{+Signal}, \text{-Old}, \text{:New}) \]

Determines how Signal is processed. Old is unified with the old behaviour, while the behaviour is switched to New. As with similar environment control predicates, the current value is retrieved using on_signal(Signal, Current, Current).

The action description is an atom denoting the name of the predicate that will be called if Signal arrives. on_signal/3 is a meta-predicate, which implies that \langle Module\rangle:\langle Name\rangle refers to \langle Name\rangle/1 in module \langle Module\rangle. The handler is called with a single argument: the name of the signal as an atom. The Prolog names for signals are explained below.

Four names have special meaning. throw implies Prolog will map the signal onto a Prolog exception as described in section 4.10, ignore causes Prolog to ignore the signal entirely, debug specifies the debug interrupt prompt that is initially bound to SIGINT (Control-C) and default resets the handler to the settings active before SWI-Prolog manipulated the handler.

Signals bound to a foreign function through PL_signal() are reported using the term '\$foreign_function'(Address).

After receiving a signal mapped to throw, the exception raised has the following structure:

\[ \text{error(signal(\langle SigName\rangle, \langle SigNum\rangle), \langle Context\rangle)} \]
The signal names are defined by the POSIX standard as symbols of the form $\text{SIG}(\text{SIGNAME})$. The Prolog name for a signal is the lowercase version of $\langle\text{SIGNAME}\rangle$. The predicate `current_signal/3` may be used to map between names and signals.

Initially, the following signals are handled unless the command line option `--no-signals` is specified:

- `int` Prompts the user, allowing to inspect the current state of the process and start the tracer.
- `usr2` Bound to an empty signal handler used to make blocking system calls return. This allows `thread_signal/2` to interrupt threads blocked in a system call. See also `prolog_alert_signal/2`.
- `pipe` Ignored.
- `hup, term, abrt, quit` Causes normal Prolog cleanup (e.g., `at_halt/1`) before terminating the process with the same signal.
- `segv, ill, bus, sys` Dumps the C and Prolog stacks and runs cleanup before terminating the process with the same signal.
- `fpe, alrm, xcpu, xfsz, vtalrm` Throw a Prolog exception (see above).

`current_signal(?Name, ?Id, ?Handler)`
Enumerate the currently defined signal handling. `Name` is the signal name, `Id` is the numerical identifier and `Handler` is the currently defined handler (see `on_signal/3`).

`prolog_alert_signal(?Old, +New)`
Query or set the signal used to unblock blocking system calls on Unix systems and process pending Prolog signals. The default is `SIGUSR2`. See also `--sigalert`.

### 4.12.1 Notes on signal handling

Before deciding to deal with signals in your application, please consider the following:

- **Portability**
  On MS-Windows, the signal interface is severely limited. Different Unix brands support different sets of signals, and the relation between signal name and number may vary. Currently, the system only supports signals numbered 1 to 32. Installing a signal outside the limited set of supported signals in MS-Windows crashes the application.

- **Safety**
  Immediately delivered signals (see below) are unsafe. This implies that foreign functions called from a handler cannot safely use the SWI-Prolog API and cannot use C `longjmp()`. Handlers

---

33: TBD: the system should support the Unix realtime signals
defined as throw are unsafe. Handlers defined to call a predicate are safe. Note that the predicate can call throw/1, but the delivery is delayed until Prolog is in a safe state.

The C-interface described in section 12.4.16 provides the option PL_SIGSYNC to select either safe synchronous or unsafe asynchronous delivery.

• Time of delivery

Using throw or a foreign handler, signals are delivered immediately (as defined by the OS). When using a Prolog predicate, delivery is delayed to a safe moment. Blocking system calls or foreign loops may cause long delays. Foreign code can improve on that by calling PL_handle_signals().

Signals are blocked when the garbage collector is active.

4.13 DCG Grammar rules

Grammar rules form a comfortable interface to difference lists. They are designed both to support writing parsers that build a parse tree from a list of characters or tokens and for generating a flat list from a term.

Grammar rules look like ordinary clauses using -->/2 for separating the head and body rather than :-/2. Expanding grammar rules is done by expand_term/2, which adds two additional arguments to each term for representing the difference list.

The body of a grammar rule can contain three types of terms. A callable term is interpreted as a reference to a grammar rule. Code between {...} is interpreted as plain Prolog code, and finally, a list is interpreted as a sequence of literals. The Prolog control-constructs (+/1, ->/2, ;//2, ,/2 and !/0) can be used in grammar rules.

We illustrate the behaviour by defining a rule set for parsing an integer.

integer(I) -->
    digit(D0),
    digits(D),
    { number_codes(I, [D0|D]) }
).

digits([D|T]) -->
    digit(D), !,
    digits(T).

digits([]) -->
    [].

digit(D) -->
    [D],
    { code_type(D, digit) }
).

Grammar rule sets are called using the built-in predicates phrase/2 and phrase/3:

phrase(?DCGBody, ?List)
    Equivalent to phrase(DCGBody, InputList, []).
phrase(:DCGBody, ?List, ?Rest)

True when DCGBody applies to the difference List/Rest. Although DCGBody is typically a callable term that denotes a grammar rule, it can be any term that is valid as the body of a DCG rule.

The example below calls the rule set integer//1 defined in section 4.13 and available from library(dcg/basics), binding Rest to the remainder of the input after matching the integer.

?- [library(dcg/basics)].
?- atom_codes('42 times', Codes),
   phrase(integer(X), Codes, Rest).
X = 42
Rest = [32, 116, 105, 109, 101, 115]

The next example exploits a complete body. Given the following definition of digit_weight//1, we can pose the query below.

digit_weight(W) -->
   [D],
   { code_type(D, digit(W)) }.

?- atom_codes('Version 3.4', Codes),
   phrase("Version ",
         digit_weight(Major), ".", digit_weight(Minor)),
   Codes).
Major = 3,
Minor = 4.

The SWI-Prolog implementation of phrase/3 verifies that the List and Rest arguments are unbound, bound to the empty list or a list cons cell. Other values raise a type error. The predicate call_dcg/3 is provided to use grammar rules with terms that are not lists.

Note that the syntax for lists of codes changed in SWI-Prolog version 7 (see section 5.2). If a DCG body is translated, both "text" and 'text' is a valid code-list literal in version 7. A version 7 string ("text") is not acceptable for the second and third arguments of phrase/3. This is typically not a problem for applications as the input of a DCG rarely appears in the source code. For testing in the toplevel, one must use double quoted text in versions prior to 7 and back quoted text in version 7 or later.

See also portray_text/1, which can be used to print lists of character codes as a string to the top level and debugger to facilitate debugging DCGs that process character codes. The library apply_macros compiles phrase/3 if the argument is sufficiently instantiated, eliminating the runtime overhead of translating DCGBody and meta-calling.

34The ISO standard allows for both raising a type error and accepting any term as input and output. Note the tail of the list is not checked for performance reasons.
call_dcg(:DCGBody, ?State0, ?State)

As phrase/3, but without type checking State0 and State. This allows for using DCG rules for threading an arbitrary state variable. This predicate was introduced after type checking was added to phrase/3.\(^{35}\)

A portable solution for threading state through a DCG can be implemented by wrapping the state in a list and use the DCG semicontext facility. Subsequently, the following predicates may be used to access and modify the state:\(^{36}\)

\[
\begin{align*}
\text{state}(S), \ [S] & \rightarrow [S]. \\
\text{state}(S0, S), \ [S] & \rightarrow [S0].
\end{align*}
\]

As stated above, grammar rules are a general interface to difference lists. To illustrate, we show a DCG-based implementation of reverse/2:

\[
\begin{align*}
\text{reverse}(&\text{List}, \text{Reversed}) : - \\
&\text{phrase}(	ext{reverse}(	ext{List}), \text{Reversed}).
\end{align*}
\]

\[
\begin{align*}
\text{reverse}([{}]) & \rightarrow [{}]. \\
\text{reverse}([H|T]) & \rightarrow \text{reverse}(T), [H].
\end{align*}
\]

### 4.14 Database

SWI-Prolog offers several ways to store data in globally accessible memory, i.e., outside the Prolog stacks. Data stored this way notably does not change on backtracking. Typically it is a bad idea to use any of the predicates in this section for realising global variables that can be assigned to. Typically, first consider representing data processed by your program as terms passed around as predicate arguments. If you need to reason over multiple solutions to a goal, consider findall/3, aggregate/3 and related predicates.

Nevertheless, there are scenarios where storing data outside the Prolog stacks is a good option. Below are the main options for storing data:

**Using dynamic predicates** Dynamic predicates are predicates for which the list of clauses is modified at runtime using asserta/1, assertz/1, retract/1 or retractall/1. Following the ISO standard, predicates that are modified this way need to be declared using the dynamic/1 directive. These facilities are defined by the ISO standard and widely supported. The mechanism is often considered slow in the literature. Performance depends on the Prolog implementation. In SWI-Prolog, querying dynamic predicates has the same performance as static ones. The manipulation predicates are fast. Using retract/1 or retractall/1 on a predicate registers the predicate as ‘dirty’. Dirty predicates are cleaned by garbage_collect_clauses/0, which is normally automatically invoked. Some workloads may result in significant performance reduction due to skipping retracted clauses and/or clause garbage collection.

---

\(^{35}\) After discussion with Samer Abdallah.

\(^{36}\) This solution was proposed by Markus Triska.
Dynamic predicates can be wrapped using library `persistency` to maintain a backup of the data on disk. Dynamic predicates come in two flavours, `shared` between threads and `local` to each thread. The latter version is created using the directive `thread_local/1`.

The recorded database The ‘recorded database’ registers a list of terms with a `key`, an atom or compound term. The list is managed using `recorda/3, recordz/3` and `erase/1`. It is queried using `recorded/3`. The recorded database is not part of the ISO standard but fairly widely supported, notably in implementations building on the ‘Edinburgh tradition’. There are few reasons to use this database in SWI-Prolog due to the good performance of dynamic predicates. Advantages are (1) the handle provides a direct reference to a term, (2) cyclic terms can be stored and (3) attributes (section 8.1) are preserved. Disadvantages are (1) the terms in a list associated with a key are not indexed, (2) the poorly specified `immediate update semantics` (see section 4.14.5 applies to the recorded database and (3) reduced portability.

The `flag/3` predicate The predicate `flag/3` associates one simple value (number or atom) with a key (atom, integer or compound). It is an old SWI-Prolog specific predicate that should be considered deprecated, although there is no plan to remove it.

Using global variables The predicates `b_setval/2` and `nb_setval/2` associate a term living on the Prolog stack with a name, either backtrackable or non-backtrackable. Backtrackable and non-backtrackable assignment without using a global name can be realised with `setarg/3` and `nb_setarg/3`. Notably the latter are used to realise aggregation as e.g., `aggregate_all/3` performs.

Tries As of version 7.3.21, SWI-Prolog provides `tries` (prefix trees) to associate a term `variant` with a value. Tries have been introduced to support `tabling` and are described in section 4.14.4.

### 4.14.1 Managing (dynamic) predicates

**abolish(:PredicateIndicator)**  
ISO
Removes all clauses of a predicate with functor `Functor` and arity `Arity` from the database. All predicate attributes (dynamic, multifile, index, etc.) are reset to their defaults. Abolishing an imported predicate only removes the import link; the predicate will keep its old definition in its definition module.

According to the ISO standard, `abolish/1` can only be applied to dynamic procedures. This is odd, as for dealing with dynamic procedures there is already `retract/1` and `retractall/1`. The `abolish/1` predicate was introduced in DEC-10 Prolog precisely for dealing with static procedures. In SWI-Prolog, `abolish/1` works on static procedures, unless the Prolog flag `iso` is set to `true`.

It is advised to use `retractall/1` for erasing all clauses of a dynamic predicate.

**abolish(+Name, +Arity)**

Same as `abolish(Name/Arity)`. The predicate `abolish/2` conforms to the Edinburgh standard, while `abolish/1` is ISO compliant.

**copy_predicate_clauses(:From, :To)**

Copy all clauses of predicate `From` to `To`. The predicate `To` must be dynamic or undefined. If `To` is undefined, it is created as a dynamic predicate holding a copy of the clauses of `From`. If
To is a dynamic predicate, the clauses of From are added (as in \texttt{assertz/1}) to the clauses of To. To and From must have the same arity. Acts as if defined by the program below, but at a much better performance by avoiding decompilation and compilation.

\begin{verbatim}
copy_predicate_clauses(From, To) :-
  head(From, MF:FromHead),
  head(To, MT:ToHead),
  FromHead =.. [\_\_|Args],
  ToHead =.. [\_\_|Args],
  forall(clause(MF:FromHead, Body),
    assertz(MT:ToHead, Body)).

define_predicate(Clause)
end
\end{verbatim}

\texttt{head(From, M:Head)} :-
  strip_module(From, M, Name/Arity),
  functor(Head, Name, Arity).

\textbf{redefine_system_predicate(+Head)}

This directive may be used both in module user and in normal modules to redefine any system predicate. If the system definition is redefined in module user, the new definition is the default definition for all sub-modules. Otherwise the redefinition is local to the module. The system definition remains in the module system.

Redefining system predicate facilitates the definition of compatibility packages. Use in other contexts is discouraged.

\textbf{retract(+Term)} \[\text{ISO,nondet}\]

When Term is an atom or a term it is unified with the first unifying fact or clause in the database. The fact or clause is removed from the database. The \texttt{retract/1} predicate respects the logical update view. This implies that \texttt{retract/1} succeeds for all clauses that match Term when the predicate was called. The example below illustrates that the first call to \texttt{retract/1} succeeds on bee on backtracking despite the fact that bee is already retracted.\footnote{Example by Jan Burse}

\begin{verbatim}
:- dynamic insect/1.
insect(ant).
insect(bee).
?- (    retract(insect(I)),
    writeln(I),
    retract(insect(bee)),
    fail
;    true
). ant ;
bee.
\end{verbatim}
If multiple threads start a retract on the same predicate at the same time their notion of the *entry generation* is adjusted such that they do not retract the same first clause. This implies that, if multiple threads use `once(retract(Term))`, no two threads will retract the same clause. Note that on backtracking over `retract/1`, multiple threads may retract the same clause as both threads respect the logical update view.

```
retractall(+Head) [ISO, det]
```

All facts or clauses in the database for which the *head* unifies with *Head* are removed. If *Head* refers to a predicate that is not defined, it is implicitly created as a dynamic predicate. See also `dynamic/1`.

```
asserta(+Term) [ISO]
assertz(+Term) [ISO]
assert(+Term) [deprecated]
```

Assert a clause (fact or rule) into the database. The predicate `asserta/1` asserts the clause as first clause of the predicate while `assertz/1` assert the clause as last clause. The deprecated `assert/1` is equivalent to `assertz/1`. If the program space for the target module is limited (see `set_module/1`), `asserta/1` can raise a `resource_error(program_space)` exception. The example below adds two facts and a rule. Note the double parentheses around the rule.

```
?- assertz(parent('Bob', 'Jane')).
?- assertz(female('Jane')).
?- assertz((mother(Child, Mother) :-
     parent(Child, Mother),
     female(Mother))).
```

```
asserta(+Term, -Reference)
assertz(+Term, -Reference)
assert(+Term, -Reference) [deprecated]
```

Equivalent to `asserta/1, assertz/1, assert/1`, but in addition unifies `Reference` with a handle to the asserted clauses. The handle can be used to access this clause with `clause/3` and `erase/1`.

**Transactions**

Traditionally, Prolog database updates add or remove individual clauses. The *Logical Update View* ensures that a goal that is started on a dynamic predicate does not see modifications due to `assert/1` or `retract/1` during its life time. See section 4.14.5. In a multi-threaded context this assumption still holds for individual predicates: concurrent modifications to a dynamic predicate are invisible.

*Transactions* allow running a goal in *isolation*. The goals running inside the transaction ‘see’ the database as it was when the transaction was started together with database changes done by the transaction goal. Other threads see no changes until the transaction is *committed*. The commit, also if it involved multiple clauses spread over multiple predicates, becomes *atomically* visible to other threads. Transactions have several benefits [Wielemaker, 2013]

---

38The ISO standard only allows using `dynamic/1` as a directive.
• If a database update requires multiple `assert/1` and/or `retract/1` operations, a transaction ensure either all are executed or the database remains unchanged. Notably unexpected exceptions or failures cannot leave the database in an inconsistent state.

• Other threads do not see the intermediate inconsistent states when a database update that consists of multiple assert and/or retract is performed in a transaction. This notably avoids the need to use locks (see `with_mutex/2`) in threads that read the data. A reading thread may still need to use `snapshot/1` if a goal depends on multiple calls to dynamic predicates. Unlike locks, transaction and snapshot based synchronization allows both readers and writers to make progress simultaneously.\(^{39}\)

Transactions on their own do not guarantee consistency. For example, when running the code below to update the temperature concurrently from multiple threads it is possible for the global state to have multiple `temperature/1` clauses.

```
update_temperature(Temp) :-
    transaction(( retractall(temperature(_)),
                 asserta(temperature(Temp)))).
```

Global consistency can be achieved by wrapping the above transaction using `with_mutex/2` or by using `transaction/3` with a constraint that demands a single clause for `temperature/1`

• Transactions allow for “what if” reasoning over the dynamic database. This is particularly useful when combined with the deductive database facilities provided by tabling (see section 7).

SWI-Prolog transactions only affect the dynamic database. Static predicates are globally visible and shared at all times. In particular, transactions do not affect loading source files and thus, source files loaded inside a transaction (e.g., due to autoloading) are immediately globally visible. This may pose problems if loading source files provide clauses for dynamic predicates.

```
transaction(:Goal)
transaction(:Goal, +Options)
```

Run `Goal` as once/1 in a transaction. This implies that access to dynamic predicates ‘sees’ the dynamic predicates at the moment the transaction is started, together with the modifications issued by `Goal`. Thus, `Goal` does not see changes to dynamic predicates from other threads and other threads do not see modifications by `Goal (isolation)`. If `Goal` succeeds, all modifications become atomically visible to the other threads. If `Goal` fails or raises an exception all local modifications are discarded and `transaction/1` fails or passes the exception.

Currently the number of database changes inside a transaction (or snapshot, see `snapshot/1`) is limited to \(2^{32} - 1\). If this limit is exceeded a `representation_error(transaction_generations)` exception is raised.

Transactions may be nested. The above mentioned limitation for the number of database changes applies to the combined number in nested transactions.

\(^{39}\)Read-write locks also provide readers and writers to make progress simultaneously, but readers see all intermediate states rather than a consistent state.
If _Goal_ succeeds, the transaction is **committed**. This implies that (1) any clause that is asserted in the transaction and not retracted in the same transaction is made **globally visible** and (2) and clause the existed before the transaction and is retracted in the transaction becomes **globally invisible**. Multiple transactions may retract the same clause and be committed, i.e., committing a retract that was already performed is a no-op. All modifications become **atomically visible** to other threads. The `transaction/3` variation allows for verifying **constraints** just before the commit takes place.

**Clause ordering** Inside a transaction clauses can be added using `asserta/1` and `assertz/1`. If only a single transaction is active at any point in time transactions preserve the usual ordering of clauses. However, if multiple transactions manipulate the same predicate(s) concurrently (typically using `transaction/3`), the final order of the clauses is the order in which the transactions asserted the clauses and **not** the order in which the transactions are committed.

The `transaction/1` variant is equivalent to `transaction(Goal,[]).` The `transaction/2` variant processed the following options:

- **bulk(+Boolean)**
  When true, accumulate events from changes to dynamic predicates (see `prolog_listen/2`) and trigger these events as part of the commit phase. This implies that if the transaction is not committed the events are never triggered. Failure to trigger the events causes the transaction to be discarded. Experimental.

- **transaction(:Goal, :Constraint, +Mutex)**
  Similar to `transaction/1`, but allows verifying `Constraint` during the commit phase. This predicate follows the steps below. Any failure or exception during this process discards the transaction and releases `Mutex` when applicable. `Constraint` may modify the database. Such modifications follow the semantics that apply for `Goal`.
  - Call `once(Goal)`
  - Lock `Mutex`
  - Change the visibility to the **current** global state combined with the changes made by `Goal`
  - Call `once(Constraint)`
  - Commit the changes
  - Unlock `Mutex`.

This predicate is intended to execute multiple transactions with a time consuming `Goal` in part concurrently. For example, it can be used for a **Compare And Swap** (CAS) like design. We illustrate this using a simple counter in the code below. Note that the transaction fails if some other thread concurrently updated the counter. This is why we need the `repeat/0` and a final `!/0`. The CAS-style update is in general useful if `Goal` is expensive and conflicts are rare.

```prolog
:- dynamic counter/1.
increment_counter(Delta) :-
```

---

**SWI-Prolog 9.1 Reference Manual**
repeat,
    transaction(( counter(Value),
      Value2 is Value+Delta,
    ),
    ( retract(counter(Value)),
      asserta(counter(Value2))
  ),
  counter_lock),
!.

snapshot(:Goal)
Similar to transaction/1, but always discards the local modifications. In other words, snapshot/1 allows a thread to examine a frozen state of the dynamic predicates and/or make isolated modifications without affecting other threads and without making permanent changes to the database. Where transactions allow the global state to be updated atomically from one consistent state to the next, a snapshot allows reasoning about a consistent state.

current_transaction(-Goal) [nondet]
True when called inside a transaction running Goal. This predicate generates candidates from the current (nested) transaction outward. Goal is a plain goal if the calling context module is the same as matching transaction/1 or snapshot/1 and a qualified callable term otherwise. Note that this only enumerates transactions in the current thread.

transaction_updates(-Updates)
Unify Updates with a list of database updates that would be effectuated if the transaction is going to be committed at this stage. Updates is a list of terms defined below. The elements are sorted on the change generation, i.e., the order in which the operations were performed.

asserta(+ClauseRef)
assertz(+ClauseRef)
The given clause will be asserted at the start or end. Note that due to competing transactions the clause may no longer be the first/last clause of the predicate.

erased(+ClauseRef)
The given clause will be removed. This may be due to erase/1, retract/1 or retractall/1.

Impact of transactions
Transactions interact with other facilities that depend on changing dynamic predicates. This section discusses these interactions.

Last modified generation Using the predicate_property/2 property last_modified_generation(Generation) we can determine whether a predicate was modified. When a predicate is changed inside a transaction this generation is not updated. The generation for dynamic predicates that are modified in the transaction is updated to the commit generation when the transaction is committed. Asking for the last modified generation inside the transaction examines the log of modified clauses and reports the generation as one of
• The global modified generation if the predicate was not modified in the transaction and
not modified outside the transaction to beyond the start generation of the transaction. If
the modified generation is higher than the transaction start generation, this generation is
reported. 40

• The transaction start generation plus the local generation of the last change if the predicate
is modified inside the transaction.

Wait for database changes The predicate thread_wait/2 does not wakeup threads for changes
inside a transaction. The wakeup is delayed until the transaction is committed. Note that
thread_wait/2 cannot be meaningfully called from inside a transaction because no external
entities can cause changes to the dynamic database inside the transaction.

Incremental tabling Consistency of tables must be restored if the transaction is rolled back. For
local tables this is realised as follows:

• Tables are either marked to be invalidated on rollback or, for monotonic tabling individual
answers are marked to be removed on rollback.

• A table is marked to be invalidated if, while it is created or reevaluated, at least one
dependent dynamic predicate has been modified inside the transaction.

• Answers are marked to be retracted when they result from monotonic reevaluation based
on changes inside the transaction.

In other words: tables being reevaluated inside a transaction that do not depend on predicates
modified inside the transaction remain valid. Monotonic tables that get new answers due to
asserts inside the transaction have these answers removed during the rollback while the table
remains valid. Monotonic tables that are for some reason invalidated inside the transaction are
invalidated during the rollback.

Correct interaction between tabling and transaction currently only deals with local tables. Shared
tables should not be combined with transactions. Future versions may improve on that.
A possible route is to make a local copy from a shared table when (re)evaluation is performed
inside a transaction.

Status SWI-Prolog transaction basics and API are stable. Interaction with other parts of the system
that depend on dynamic predicates is still unsettled. Future versions may support non-determinism
through transactions and snapshots.

4.14.2 The recorded database

recorda(+Key, +Term, -Reference)
Assert Term in the recorded database under key Key. Key is a small integer (range
min_tagged_integer ... max_tagged_integer, atom or compound term. If the key is
a compound term, only the name and arity define the key. Reference is unified with an opaque
handle to the record (see erase/1).

40BUG: Note that the above implies that inside a transaction we observe a changing last modified generation for predicates
that have only been modified outside the transaction while these changes are not visible.
4.14. DATABASE

recorda(+Key, +Term)
   Equivalent to recorda(Key, Term, _).

recordz(+Key, +Term, -Reference)
   Equivalent to recorda/3, but puts the Term at the tail of the terms recorded under Key.

recordz(+Key, +Term)
   Equivalent to recordz(Key, Term, _).

recorded(?Key, ?Value, ?Reference)
   True if Value is recorded under Key and has the given database Reference. If Reference is given, this predicate is semi-deterministic. Otherwise, it must be considered non-deterministic. If neither Reference nor Key is given, the triples are generated as in the code snippet below. See also current_key/1.

   current_key(Key),
   recorded(Key, Value, Reference)

recorded(+Key, -Value)
   Equivalent to recorded(Key, Value, _).

erase(+Reference)
   Erase a record or clause from the database. Reference is a db-reference returned by recorda/3, recordz/3 or recorded/3, clause/3, assert/2, asserta/2 or assertz/2. Fail silently if the referenced object no longer exists. Notably, if multiple threads attempt to erase the same clause one will succeed and the others will fail.

instance(+Reference, -Term)
   Unify Term with the referenced clause or database record. Unit clauses are represented as Head :- true.

4.14.3 Flags

The predicate flag/3 is the oldest way to store global non-backtrackable data in SWI-Prolog. Flags are global and shared by all threads. Their value is limited to atoms, small (64-bit) integers and floating point numbers. Flags are thread-safe. The flags described in this section must not be confused with Prolog flags described in section 2.12.

get_flag(+Key, -Value)
   True when Value is the value currently associated with Key. If Key does not exist, a new flag with value ‘0’ (zero) is created.

set_flag(+Key, Value)
   Set flag Key to Value. Value must be an atom, small (64-bit) integer or float.

41Note that, without a given Key, some implementations return triples in the order defined by recorda/2 and recordz/2.
flag(+Key, -Old, +New)

True when Old is the current value of the flag Key and the flag has been set to New. New can be an arithmetic expression. The update is atomic. This predicate can be used to create a shared global counter as illustrated in the example below.

```
next_id(Id) :-
    flag(my_id, Id, Id+1).
```

4.14.4 Tries

Tries (also called digital tree, radix tree or prefix tree) maintain a mapping between a variant of a term (see =@=@=/2) and a value. They have been introduced in SWI-Prolog 7.3.21 as part of the implementation of tabling. The current implementation is rather immature. In particular, the following limitations currently apply:

- Tries are not thread-safe.
- Tries should not be modified while non-deterministic predicates such as trie_gen/3 are running on the trie.
- Terms cannot have attributed variables.
- Terms cannot be cyclic. Possibly this will not change because cyclic terms can only be supported after creating a canonical form of the term.

We give the definition of these predicates for reference and debugging tabled predicates. Future versions are likely to get a more stable and safer implementation. The API to tries should not be considered stable.

trie_new(-Trie)

Create a new trie and unify Trie with a handle to the trie. The trie handle is a blob. Tries are subject to atom garbage collection.

trie_destroy(+Trie)

Destroy Trie. This removes all nodes from the trie and causes further access to Trie to raise an existence_error exception. The handle itself is reclaimed by atom garbage collection.

is_trie(@Trie) [semidet]

True when Trie is a trie object. See also current_trie/1.

current_trie(-Trie) [nondet]

True if Trie is a currently existing trie. As this enumerates and then filters all known atoms this predicate is slow and should only be used for debugging purposes. See also is_trie/1.

trie_insert(+Trie, +Key)

Insert the term Key into Trie. If Key is already part of Trie the predicates fails silently. This is the same as trie_insert/2, but using a fixed reserved Value.
trie_insert(+Trie, +Key, +Value)
   Insert the term Key into Trie and associate it with Value. Value can be any term. If Key-Value
   is already part of Trie, the predicates fails silently. If Key is in Trie associated with a different
   value, a permission_error is raised.

trie_update(+Trie, +Key, +Value)
   As trie_insert/3, but if Key is in Trie, its associated value is updated.

trie_insert(+Trie, +Term, +Value, -Handle)
   As trie_insert/3, returning a handle to the trie node. This predicate is currently unsafe as
   Handle is an integer used to encode a pointer. It was used to implement a pure Prolog version
   of the tabling library.

trie_delete(+Trie, +Key, ?Value)
   Delete Key from Trie if the value associated with Key unifies with Value.

trie_lookup(+Trie, +Key, -Value)
   True if the term Key is in Trie and associated with Value.

trie_term(+Handle, -Term)
   True when Term is a copy of the term associated with Handle. The result is undefined (including
   crashes) if Handle is not a handle returned by trie_insert.new/3 or the node has been
   removed afterwards.

trie_gen(+Trie, ?Key)
   True when Key is a member of Trie. See also trie_gen_compiled/2.

trie_gen(+Trie, ?Key, -Value)
   True when Key is associated with Value in Trie. Backtracking retrieves all pairs. Currently
   scans the entire trie, even if Key is partly known. Currently unsafe if Trie is modified while the
   values are being enumerated. See also trie_gen_compiled/3.

trie_gen_compiled(+Trie, ?Key)
   Similar to trie_gen/3, but uses a compiled representation of Trie. The compiled represen-
   tation is created lazily and manipulations of the trie (insert, delete) invalidate the current
   compiled representation. The compiled representation generates answers faster and, as it runs
   on a snapshot of the trie, is immune to concurrent modifications of the trie. This predicate is
   used to generate answers from answer tries as used for tabled execution. See section 7.

trie_property(?Trie, ?Property)
   True if Trie exists with Property. Intended for debugging and statistical purposes. Retrieving
   some of these properties visit all nodes of the trie. Defined properties are

value_count(-Count)
   Number of key-value pairs in the trie.

node_count(-Count)
   Number of nodes in the trie.

size(-Bytes)
   Required storage space of the trie.
compiled_size(-Bytes)
    Required storage space for the compiled representation as used by trie_gen_compiled/2,3.
hashed(-Count)
    Number of nodes that use a hashed index to its children.
lookup_count(-Count)
    Number of trie_lookup/3 calls (only when compiled with O_TRIE_STATS).
gen_call_count(-Count)
    Number of trie_gen/3 calls (only when compiled with O_TRIE_STATS).
wait(-Count)
    Number of times a thread waited on this trie for another thread to complete it (shared tabling, only when compiled with O_TRIE_STATS).
deadlock(-Count)
    Number of times this trie was part of a deadlock and its completion was abandoned (shared tabling, only when compiled with O_TRIE_STATS).

In addition, a number of additional properties are defined on answer tries.

invalidated(-Count)
    Number of times the trie was invalidated (incremental tabling).
reevaluated(-Count)
    Number of times the trie was re-evaluated (incremental tabling).
idg_affected_count(-Count)
    Number of answer tries affected by this one (incremental tabling).
idg_dependent_count(-Count)
    Number of answer tries this one depends on (incremental tabling).
idg_size(-Bytes)
    Number of bytes in the IDG node representation.

4.14.5 Update view

Traditionally, Prolog systems used the immediate update view: new clauses became visible to predicates backtracking over dynamic predicates immediately, and retracted clauses became invisible immediately.

Starting with SWI-Prolog 3.3.0 we adhere to the logical update view, where backtrackable predicates that enter the definition of a predicate will not see any changes (either caused by assert/1 or retract/1) to the predicate. This view is the ISO standard, the most commonly used and the most ‘safe’. Logical updates are realised by keeping reference counts on predicates and generation information on clauses. Each change to the database causes an increment of the generation of the database. Each goal is tagged with the generation in which it was started. Each clause is flagged with the generation it was created in as well as the generation it was erased from. Only clauses with a ‘created’ ... ‘erased’ interval that encloses the generation of the current goal are considered visible.

42For example, using the immediate update view, no call to a dynamic predicate is deterministic.
4.14. DATABASE

4.14.6 Indexing databases

The indexing capabilities of SWI-Prolog are described in section 2.18. Summarizing, SWI-Prolog creates indexes for any applicable argument, pairs of arguments and indexes on the arguments of compound terms when applicable. Extended JIT indexing is not widely supported among Prolog implementations. Programs that aim at portability should consider using `term_hash/2` and `term_hash/4` to design their database such that indexing on constant or functor (name/arity reference) on the first argument is sufficient. In some cases, using the predicates below to add one or more additional columns (arguments) to a database predicate may improve performance. The overall design of code using these predicates is given below. Note that as `term_hash/2` leaves the hash unbound if `Term` is not ground. This causes the lookup to be fast if `Term` is ground and correct (but slow) otherwise.

```prolog
:- dynamic
   x/2.

assert_x(Term) :-
   term_hash(Term, Hash),
   assertz(x(Hash, Term)).

x(Term) :-
   term_hash(Term, Hash),
   x(Hash, Term).
```

`term_hash(+Term, -HashKey)`

If `Term` is a ground term (see `ground/1`), `HashKey` is unified with a positive integer value that may be used as a hash key to the value. If `Term` is not ground, the predicate leaves `HashKey` an unbound variable. Hash keys are in the range 0...16,777,215, the maximal integer that can be stored efficiently on both 32 and 64 bit platforms.

This predicate may be used to build hash tables as well as to exploit argument indexing to find complex terms more quickly.

The hash key does not rely on temporary information like addresses of atoms and may be assumed constant over different invocations and versions of SWI-Prolog.\(^\text{43}\) Hashes differ between big and little endian machines. The `term_hash/2` predicate is cycle-safe.\(^\text{44}\)

`term_hash(+Term, +Depth, +Range, -HashKey)`

As `term_hash/2`, but only considers `Term` to the specified `Depth`. The top-level term has depth 1, its arguments have depth 2, etc. That is, `Depth = 0` hashes nothing; `Depth = 1` hashes atomic values or the functor and arity of a compound term, not its arguments; `Depth = 2` also indexes the immediate arguments, etc.

`HashKey` is in the range \([0...\text{Range} - 1]\). `Range` must be in the range \([1...2147483647]\).

`variant_sha1(+Term, -SHA1)`

Compute a SHA1-hash from `Term`. The hash is represented as a 40-byte hexadecimal atom.

\(^{43}\)Last change: version 5.10.4

\(^{44}\)BUG: All arguments that (indirectly) lead to a cycle have the same hash key.
Unlike `term_hash/2` and friends, this predicate produces a hash key for non-ground terms. The hash is invariant over variable-renaming (see `=?=/2`) and constants over different invocations of Prolog.\footnote{BUG: The hash depends on word order (big/little-endian) and the wordsize (32/64 bits).}

This predicate raises an exception when trying to compute the hash on a cyclic term or attributed term. Attributed terms are not handled because `subsumes_chk/2` is not considered well defined for attributed terms. Cyclic terms are not supported because this would require establishing a canonical cycle. That is, given A=[a—a] and B=[a,a—B], A and B should produce the same hash. This is not (yet) implemented.

This hash was developed for lookup of solutions to a goal stored in a table. By using a cryptographic hash, heuristic algorithms can often ignore the possibility of hash collisions and thus avoid storing the goal term itself as well as testing using `=?=/2`.

\begin{verbatim}
variant_hash(+Term, -HashKey) [det]
Software Copyright (c) 1995-2009, Ernesto Borello, University of Pisa
This variant hash was developed for lookup of solutions to a goal stored in a table.
It is slower than the cryptographic hash but faster than the term_hash.
\end{verbatim}

\section{Declaring predicate properties}

This section describes directives which manipulate attributes of predicate definitions. The functors `dynamic/1`, `multifile/1`, `discontiguous/1`, and `public/1` are operators of priority 1150 (see `op/3`), which implies that the list of predicates they involve can just be a comma-separated list:

\begin{verbatim}
:- dynamic
    foo/0,
    baz/2.
\end{verbatim}

In SWI-Prolog all these directives are just predicates. This implies they can also be called by a program. Do not rely on this feature if you want to maintain portability to other Prolog implementations.

Notably with the introduction of tabling (see section \ref{tabling}) it is common that a set of predicates require multiple options to be set. SWI-Prolog offers two mechanisms to cope with this. The predicate `dynamic/2` can be used to make a list of predicates dynamic and set additional options. In addition and for compatibility with XSB,\footnote{Note that `as` is in XSB a high-priority operator and in SWI a low-priority and therefore both the sets of predicate indicators as multiple options require parenthesis.} all the predicates below accept a term `as((:\text{PredicateIndicator}, \ldots), (+\text{Options}))`, where `Options` is a \textit{comma-list} of one of more of the following options:

\begin{verbatim}
incremental
\end{verbatim}

\begin{verbatim}
opaque
\end{verbatim}

\begin{verbatim}
\end{verbatim}

\footnote{In XSB, `opaque` is distinct from the default in the sense that dynamic switching between `opaque` and `incremental` is allowed.}
4.15. DECLARING PREDICATE PROPERTIES

abstract(\textit{Level})

Used together with \texttt{incremental} to reduce the dependency graph. See section 7.7.

\texttt{volatile}

Do not save this predicate. See \texttt{volatile/1}.

\texttt{multifile}

Predicate may have clauses in multiple clauses. See \texttt{multifile/1}.

\texttt{discontiguous}

Predicate clauses may not be contiguous in the file. See \texttt{discontiguous/1}.

\texttt{shared}

Dynamic predicate is shared between all threads. This is currently the default.

\texttt{local}

\texttt{private}

Dynamic predicate has distinct set of clauses in each thread. See \texttt{thread\_local/1}.

Below are some examples, where the last two are semantically identical.

\begin{verbatim}
:- dynamic person/2 as incremental.
:- dynamic (person/2,organization/2) as (incremental, abstract(0)).
:- dynamic([ person/2, organization/2 ],
           [ incremental(true),
             abstract(0) ]).
\end{verbatim}

\texttt{dynamic(\textit{:PredicateIndicator}, \ldots \ [ISO])}

As \texttt{dynamic/1}, but allows for setting additional properties. This predicate allows for setting multiple properties on multiple predicates in a single call. SWI-Prolog also offers the XSB compatible :- \texttt{dynamic (p/1) as (incremental,abstract(0))} syntax. See the introduction of section 4.15. Defined \texttt{Options} are:

\texttt{incremental(+Boolean)}

Make the dynamic predicate signal depending \texttt{tables}. See section 7.7.

\texttt{abstract(0)}

This option must be used together with \texttt{incremental}. The only supported value is 0. With this option a call to the incremental dynamic predicate is recorded as the most generic term for the predicate rather than the specific variant.
thread(+Local)
    Local is one of shared (default) or local. See also thread_local/1.

multifile(+Boolean)
discontiguous(+Boolean)
volatile(+Boolean)
    Set the corresponding property. See multifile/1, discontiguous/1 and volatile/1.

compile_predicates(:ListOfPredicateIndicators)
    Compile a list of specified dynamic predicates (see dynamic/1 and assert/1) into normal static predicates. This call tells the Prolog environment the definition will not change anymore and further calls to assert/1 or retract/1 on the named predicates raise a permission error. This predicate is designed to deal with parts of the program that are generated at runtime but do not change during the remainder of the program execution.\(^\text{49}\)

multifile :PredicateIndicator, . . . \[ISO\]
    Informs the system that the specified predicate(s) may be defined over more than one file. This stops consult/1 from redefining a predicate when a new definition is found.

discontiguous :PredicateIndicator, . . . \[ISO\]
    Informs the system that the clauses of the specified predicate(s) might not be together in the source file. See also style_check/1.

public :PredicateIndicator, . . .
    Instructs the cross-referencer that the predicate can be called. It has no semantics.\(^\text{50}\) The public declaration can be queried using predicate_property/2. The public/1 directive does not export the predicate (see module/1 and export/1). The public directive is used for (1) direct calls into the module from, e.g., foreign code, (2) direct calls into the module from other modules, or (3) flag a predicate as being called if the call is generated by meta-calling constructs that are not analysed by the cross-referencer.

non_terminal :PredicateIndicator, . . .
    Sets the non_terminal property on the predicate. This indicates that the predicate implements a grammar rule. See predicate_property/2. The non_terminal property is set for predicates exported as Name\(\llcorner\)Arity as well as predicates that have at least one clause written using the \(\rightarrow\)/2 notation.

4.16 Examining the program

current_atom(-Atom)
    Successively unifies Atom with all atoms known to the system. Note that current_atom/1 always succeeds if Atom is instantiated to an atom.

\(^{49}\)The specification of this predicate is from Richard O’Keefe. The implementation is allowed to optimise the predicate. This is not yet implemented. In multithreaded Prolog, however, static code runs faster as it does not require synchronisation. This is particularly true on SMP hardware.

\(^{50}\)This declaration is compatible with SICStus. In YAP, public/1 instructs the compiler to keep the source. As the source is always available in SWI-Prolog, our current interpretation also enhances the compatibility with YAP.
4.16. EXAMINING THE PROGRAM

**current_blob(?Blob, ?Type)**
Examine the type or enumerate blobs of the given Type. Typed blobs are supported through the foreign language interface for storing arbitrary BLOBs (Binary Large Object) or handles to external entities. See section 12.4.9 for details.

**current_functor(?Name, ?Arity)**
True when Name/Arity is a known functor. This means that at some point in time a term with name Name and Arity arguments was created. Functor objects are currently not subject to garbage collection. Due to timing, t/2 below with instantiated Name and Arity can theoretically fail, i.e., a functor may be visible in instantiated mode while it is not yet visible in unbound mode. Considering that the only practical value of current_functor/2 we are aware of is to analyse resource usage we accept this impure behaviour.

```prolog
t(Name, Arity) :-
    ( current_functor(Name, Arity)
    -> current_functor(N, A), N == Name, A == Arity
    ; true
    ).
```

**current_flag(-FlagKey)**
Successively unifies FlagKey with all keys used for flags (see flag/3).

**current_key(-Key)**
Successively unifies Key with all keys used for records (see recorda/3, etc.).

**current_predicate(:PredicateIndicator)** [ISO]
True if PredicateIndicator is a currently defined predicate. A predicate is considered defined if it exists in the specified module, is imported into the module or is defined in one of the modules from which the predicate will be imported if it is called (see section 6.10). Note that current_predicate/1 does not succeed for predicates that can be autoloaded unless they are imported using autoload/2. See also current_predicate/2 and predicate_property/2.

If PredicateIndicator is not fully specified, the predicate only generates values that are defined in or already imported into the target module. Generating all callable predicates therefore requires enumerating modules using current_module/1. Generating predicates callable in a given module requires enumerating the import modules using import_module/2 and the autoloadable predicates using the predicate_property/2 autoload.

**current_predicate(?Name, :Head)**
Classical pre-ISO implementation of current_predicate/1, where the predicate is represented by the head term. The advantage is that this can be used for checking the existence of a predicate before calling it without the need for functor/3:

```prolog
call_if_exists(G) :-
    current_predicate(_, G),
    call(G).
```
Because of this intended usage, current_predicate/2 also succeeds if the predicate can be autoloaded. Unfortunately, checking the autoloader makes this predicate relatively slow, in particular because a failed lookup of the autoloader will cause the autoloader to verify that its index is up-to-date.

**predicate_property(:Head, ?Property)**

True when *Head* refers to a predicate that has property *Property*. With sufficiently instantiated *Head*, predicate_property/2 tries to resolve the predicate the same way as calling it would do: if the predicate is not defined it scans the default modules (see default_module/2) and finally tries the autoloader. Unlike calling, failure to find the target predicate causes predicate_property/2 to fail silently. If *Head* is not sufficiently bound, only currently locally defined and already imported predicates are enumerated. See current_predicate/1 for enumerating all predicates. A common issue concerns generating all built-in predicates. This can be achieved using the code below:

```prolog
generate_built_in(Name/Arity) :-
   predicate_property(system:Head, built_in),
   functor(Head, Name, Arity),
   \+ sub_atom(Name, 0, _, _, $). % discard reserved names
```

The predicate predicate_property/2 is covered by part-II of the ISO standard (modules). Although we are not aware of any Prolog system that implements part-II of the ISO standard, predicate_property/2 is available in most systems. There is little consensus on the implemented properties though. SWI-Prolog’s auto loading feature further complicate this predicate.

*Property* is one of:

**autoload(File)**

True if the predicate can be autoloaded from the file *File*. Like undefined, this property is not generated.

**built_in**

True if the predicate is locked as a built-in predicate. This implies it cannot be redefined in its definition module and it can normally not be seen in the tracer.

**defined**

True if the predicate is defined. This property is aware of sources being reloaded, in which case it claims the predicate defined only if it is defined in another source or it has seen a definition in the current source. See compile_aux_clauses/1.

**det**

The predicate is defined to be deterministic using det/1.

**discontiguous**

True after discontiguous/1 was used to flag that the clauses of the predicates may not be contiguous.

**dynamic**

True if assert/1 and retract/1 may be used to modify the predicate. This property is set using dynamic/1.
exported
True if the predicate is in the public list of the context module.

imported_from(Module)
Is true if the predicate is imported into the context module from module Module.

file(FileName)
Unify FileName with the name of the source file in which the predicate is defined. See also source_file/2 and the property line_count. Note that this reports the file of the first clause of a predicate. A more robust interface can be achieved using nth_clause/3 and clause_property/2.

foreign
True if the predicate is defined in the C language.

implementation_module(-Module)
True when Module is the module in which Head is or will be defined. Resolving this property goes through the same search mechanism as when an undefined predicate is encountered, but does not perform any loading. It searches (1) the module inheritance hierarchy (see default_module/2) and (2) the autoload index if the unknown flag is not set to fail in the target module.

indexed(Indexes)
Indexes is a list of additional (hash) indexes on the predicate. Each element of the list is a term ArgSpec-Index. ArgSpec denotes the indexed argument(s) and is one of

single(Argument)
Hash on a single argument. Argument is the 1-based argument number.

multi(ArgumentList)
Hash on a combination of arguments.

deep(Position)
Index on a sub-argument. Position is a list holding first the argument of the predicate then the argument into the compound and recursively into deeper compound terms.

interpreted
True if the predicate is defined in Prolog. We return true on this because, although the code is actually compiled, it is completely transparent, just like interpreted code.

iso
True if the predicate is covered by the ISO standard (ISO/IEC 13211-1).

line_count(LineNumber)
Unify LineNumber with the line number of the first clause of the predicate. Fails if the predicate is not associated with a file. See also source_file/2. See also the file property above, notably the reference to clause_property/2.
multifile
True if there may be multiple (or no) files providing clauses for the predicate. This property is set using multifile/1.

meta_predicate(Head)
If the predicate is declared as a meta-predicate using meta_predicate/1, unify Head with the head-pattern. The head-pattern is a compound term with the same name and arity as the predicate where each argument of the term is a meta-predicate specifier. See meta_predicate/1 for details.

monotonic
True if the predicate is tabled or dynamic using monotonic propagation. See section 7.8.

nodebug
Details of the predicate are not shown by the debugger. This is the default for built-in predicates. User predicates can be compiled this way using the Prolog flag generate_debug_info.

non_terminal
True if the predicate implements a grammar rule. See non_terminal/1.

notrace
Do not show ports of this predicate in the debugger.

number_of_clauses(ClauseCount)
Unify ClauseCount to the number of clauses associated with the predicate. Fails for foreign predicates. This property respects the logical update view and counts visible clauses at the moment the predicate was started.

number_of_rules(RuleCount)
Similar to number_of_clauses(ClauseCount), but only counts rules. A rule is defined as a clauses that has a body that is not just true (i.e., a fact).

last_modified_generation(Generation)
Database generation at which the predicate was modified for the last time. Intended to quickly assesses the validity of caches.

opaque
This property applies to dynamic and tabled predicates. For dynamic predicates it (temporary) stops propagating updates to dependent incrementally or monotonic tabled predicates. For tabled predicates it is not an error for an opaque predicate to depend on incremental or monotonic dynamic or tabled predicates.

public
Predicate is declared public using public/1. Note that without further definition, public predicates are considered undefined and this property is not reported.

quasi_quotation_syntax
The predicate (with arity 4) is declared to provide quasi quotation syntax with quasi_quotation_syntax/1.

size(Bytes)
Memory used for this predicate. This includes the memory of the predicate header, the combined memory of all clauses including erased but not yet garbage collected clauses (see garbage_collect_clauses/0 and clause_property/2) and the memory
used by clause indexes (see the indexed(Indexes) property. Excluded are lingering data structures. These are garbage data structures that have been detached from the predicate but cannot yet be reclaimed because they may be in use by some thread.

ssu
The predicate has been defined using single sided unification rules. See section 5.6.

static
The definition can not be modified using assertz/1 and friends. This property is the opposite from dynamic, i.e., for each defined predicate, either static or dynamic is true but never both.

tabled
True of the predicate is tabled. The tabled(?Flag) property can be used to obtain details about how the predicate is tabled.

tabled(?Flag)
True of the predicate is tabled and Flag applies. Any tabled predicate has one of the mutually exclusive flags variant or subsumptive. In addition, tabled predicates may have one or more of the following flags

shared
The table is shared between threads. See section 7.9.

incremental
The table is subject to incremental tabling. See section 7.7

Use the tabled property to enumerate all tabled predicates. See table/1 for details.

thread local
If true (only possible on the multithreaded version) each thread has its own clauses for the predicate. This property is set using thread local/1.

transparent
True if the predicate is declared transparent using the module_transparent/1 or meta_predicate/1 declaration. In the latter case the property meta_predicate(Head) is also provided. See chapter 6 for details.

undefined
True if a procedure definition block for the predicate exists, but there are no clauses for it and it is not declared dynamic or multfile. This is true if the predicate occurs in the body of a loaded predicate, an attempt to call it has been made via one of the meta-call predicates, the predicate has been declared as e.g., a meta-predicate or the predicate had a definition in the past. Originally used to find missing predicate definitions. The current implementation of list undefined/0 used cross-referencing. Deprecated.

visible
True when predicate can be called without raising a predicate existence error. This means that the predicate is (1) defined, (2) can be inherited from one of the default modules (see default_module/2) or (3) can be autoloaded. The behaviour is logically consistent iff the property visible is provided explicitly. If the property is left unbound, only defined predicates are enumerated.

volatile
If true, the clauses are not saved into a saved state by qsave_program/[1,2]. This property is set using volatile/1.
**dwim Predicate**

`dwim Predicate(+Term, -Dwim)`

'Do What I Mean' ('dwim') support predicate. *Term* is a term, whose name and arity are used as a predicate specification. *Dwim* is instantiated with the most general term built from *Name* and the arity of a defined predicate that matches the predicate specified by *Term* in the 'Do What I Mean' sense. See `dwim_match/2` for 'Do What I Mean' string matching. Internal system predicates are not generated, unless the access level is `system` (see `access_level`). Backtracking provides all alternative matches.

**clause**

`clause(:Head, ?Body)`  
True if *Head* can be unified with a clause head and *Body* with the corresponding clause body. Gives alternative clauses on backtracking. For facts, *Body* is unified with the atom `true`. Note that SWI-Prolog allows `clause/2` to work on both dynamic and static code. Note that `clause/2` decompiles the actual clause and may return a clause that is different from the source or asserted clause, i.e., `clause/2` only promises semantic equivalence.

`clause(:Head, ?Body, ?Reference)`  
Equivalent to `clause/2`, but unifies *Reference* with a unique reference to the clause (see also `assert/2`, `erase/1`). If *Reference* is instantiated to a reference the clause’s head and body will be unified with *Head* and *Body*.

**nthClause**

`nth_clause(?, Pred, ?Index, ?Reference)`  
Provides access to the clauses of a predicate using their index number. Counting starts at 1. If *Reference* is specified it unifies *Pred* with the most general term with the same name/arity as the predicate and *Index* with the index number of the clause. Otherwise the name and arity of *Pred* are used to determine the predicate. If *Index* is provided, *Reference* will be unified with the clause reference. If *Index* is unbound, backtracking will yield both the indexes and the references of all clauses of the predicate. The following example finds the 2nd clause of `append/3`:

```
?- use_module(library(lists)).
...
?- nth_clause(append(_,_,_), 2, Ref), clause(Head, Body, Ref).
Ref = <clause>(0x994290),
Head = lists:append([_G23|_G24], _G21, [_G23|_G27]),
```

**clause Property**

`clause property(+ClauseRef, -Property)`  
Queries properties of a clause. *ClauseRef* is a reference to a clause as produced by `clause/3`, `nth_clause/3` or `prolog_frame_attribute/3`. Unlike most other predicates that access clause references, `clause_property/2` may be used to get information about erased clauses that have not yet been reclaimed. *Property* is one of the following:

**file**

`file(FileName)`  
Unify *FileName* with the name of the file from which the clause is loaded. Fails if the clause was not created by loading a file (e.g., clauses added using `assertz/1`). See also `source`.

---

51 Using `clause/2` is disallowed if either the flag `iso` or `protect_static_code` is true.
### 4.17 Input and output

SWI-Prolog provides two different packages for input and output. The native I/O system is based on the ISO standard predicates `open/3`, `close/1` and friends. Being more widely portable and equipped with a clearer and more robust specification, new code is encouraged to use these predicates for manipulation of I/O streams.

Section 4.17.3 describes `tell/1`, `see/1` and friends, providing I/O in the spirit of the traditional Edinburgh standard. These predicates are layered on top of the ISO predicates. Both packages are fully integrated; the user may switch freely between them.

#### 4.17.1 Predefined stream aliases

Each thread has five stream aliases: `user_input`, `user_output`, `user_error`, `current_input`, and `current_output`. Newly created threads inherit these stream aliases from their parent. The `user_input`, `user_output` and `user_error` aliases of the main thread are initially bound to the standard operating system I/O streams (`stdin`, `stdout` and `stderr`.

---

52 Actually based on Quintus Prolog, providing this interface before the ISO standard existed.
normally bound to the POSIX file handles 0, 1 and 2). These aliases may be re-bound, for example if standard I/O refers to a window such as in the swipl-win.exe GUI executable for Windows. They can be re-bound by the user using set_prolog_IO/3 and set_stream/2 by setting the alias of a stream (e.g., set_stream(S, alias(user_output))). An example of rebinding can be found in library prolog_server, providing a telnet service. The aliases current_input and current_output define the source and destination for predicates that do not take a stream argument (e.g., read/1, write/1, get_code/1, ...). Initially, these are bound to the same stream as user_input and user_error. They are re-bound by see/1, tell/1, set_input/1 and set_output/1. The current_output stream is also temporary re-bound by with_output_to/2 or format/3 using e.g., format(atom(A), ...). Note that code which explicitly writes to the streams user_output and user_error will not be redirected by with_output_to/2.

Compatibility Note that the ISO standard only defines the user_* streams. The ‘current’ streams can be accessed using current_input/1 and current_output/1. For example, an ISO compatible implementation of write/1 is

\[
\text{write(Term)} :\text{-} \text{current_output(Out)}, \text{write_term(Out, Term)}.
\]

while SWI-Prolog additionally allows for

\[
\text{write(Term)} :\text{-} \text{write(current_output, Term)}.
\]

### 4.17.2 ISO Input and Output Streams

The predicates described in this section provide ISO compliant I/O, where streams are explicitly created using the predicate open/3. The resulting stream identifier is then passed as a parameter to the reading and writing predicates to specify the source or destination of the data.

This schema is not vulnerable to filename and stream ambiguities as well as changes to the working directory. On the other hand, using the notion of current-I/O simplifies reusability of code without the need to pass arguments around. E.g., see with_output_to/2.

SWI-Prolog streams are, compatible with the ISO standard, either input or output streams. To accommodate portability to other systems, a pair of streams can be packed into a stream-pair. See stream_pair/3 for details.

SWI-Prolog stream handles are unique symbols that have no syntactical representation. They are written as <stream>(hex-number), which is not valid input for read/1. They are realised using a blob of type stream (see blob/2 and section 12.4.9).

**open**(+SrcDest, +Mode, −Stream, +Options)  
True when SrcDest can be opened in Mode and Stream is an I/O stream to/from the object. SrcDest is normally the name of a file, represented as an atom or string. Mode is one of read, write, append or update. Mode append opens the file for writing, positioning the file pointer at the end. Mode update opens the file for writing, positioning the file pointer at the beginning of the file without truncating the file. Stream is either a variable, in which case it
is bound to an integer identifying the stream, or an atom, in which case this atom will be the stream identifier.\footnote{New code should use the \texttt{alias(Alias)} option for compatibility with the ISO standard.}

SWI-Prolog also allows \texttt{SrcDest} to be a term \texttt{pipe(Command)}. In this form, \texttt{Command} is started as a child process and if \texttt{Mode} is \texttt{write}, output written to \texttt{Stream} is sent to the standard input of \texttt{Command}. Vice versa, if \texttt{Mode} is \texttt{read}, data written by \texttt{Command} to the standard output can be read from \texttt{Stream}. On Unix systems, \texttt{Command} is handed to popen() which hands it to the Unix shell. On Windows, \texttt{Command} is executed directly and therefore shell syntax such as redirecting (using e.g., \texttt{> file}) does not work. Use of the \texttt{pipe(Command)} feature is deprecated. The predicate \texttt{process_create/3} from \texttt{process} provides a richer and more portable alternative for interacting with processes including handling all three standard streams.

If \texttt{SrcDest} is an IRI, i.e., starts with \texttt{⟨scheme⟩://}, where \texttt{⟨scheme⟩} is a non-empty sequence of lowercase ASCII letters \texttt{open/3,4} calls hooks registered by \texttt{register_iri_scheme/3}. Currently the only predefined IRI scheme is \texttt{res}, providing access to the \texttt{resource database}. See section 14.4.

The following \texttt{Options} are recognised by \texttt{open/4}:

\begin{itemize}
  \item \texttt{alias(Atom)}
    \begin{description}
    \item \texttt{Gives the stream a name. Below is an example. Be careful with this option as stream names are global. See also \texttt{set_stream/2}.}
    \end{description}
    \begin{footnotesize}
    \begin{verbatim}
?− open(data, read, Fd, [alias(input)]).
    ..., read(input, Term), ...
    \end{verbatim}
    \end{footnotesize}
  \item \texttt{bom(Bool)}
    \begin{description}
    \item \texttt{Check for a BOM (Byte Order Marker) or write one. If omitted, the default is \texttt{true} for mode \texttt{read} and \texttt{false} for mode \texttt{write}. See also \texttt{stream_property/2} and especially section 2.19.1 for a discussion of this feature.}
    \end{description}
  \item \texttt{buffer(Buffering)}
    \begin{description}
    \item \texttt{Defines output buffering. The atom \texttt{full} (default) defines full buffering, \texttt{line buffering} by line, and \texttt{false} implies the stream is fully unbuffered. Smaller buffering is useful if another process or the user is waiting for the output as it is being produced. See also \texttt{flush_output/[0,1]}. This option is not an ISO option.}
    \end{description}
  \item \texttt{close_on_abort(Bool)}
    \begin{description}
    \item \texttt{If \texttt{true} (default), the stream is closed on an abort (see \texttt{abort/0}). If \texttt{false}, the stream is not closed. If it is an output stream, however, it will be flushed. Useful for logfiles and if the stream is associated to a process (using the \texttt{pipe/1} construct).}
    \end{description}
  \item \texttt{create(+List)}
    \begin{description}
    \item \texttt{Specifies how a new file is created when opening in \texttt{write}, \texttt{append} or \texttt{update} mode. Currently, \texttt{List} is a list of atoms that describe the permissions of the created file.\footnote{Added after feedback from Joachim Shimpf and Per Mildner.} Defined values are below. Not recognised values are silently ignored, allowing for adding platform specific extensions to this set.}
    \end{description}
\end{itemize}
read
  Allow read access to the file.

write
  Allow write access to the file.

execute
  Allow execution access to the file.

default
  Allow read and write access to the file.

all
  Allow any access provided by the OS.

Note that if List is empty, the created file has no associated access permissions. The create options map to the POSIX mode option of open(), where read map to 0444, write to 0222 and execute to 0111. On POSIX systems, the final permission is defined as (mode & ~umask).

encoding(Enc)
  Define the encoding used for reading and writing text to this stream. The default encoding for type text is derived from the Prolog flag encoding. For binary streams the default encoding is octet. For details on encoding issues, see section 2.19.1.

eof_action(Action)
  Defines what happens if the end of the input stream is reached. The default value for Action is eof_code, which makes get0/1 and friends return -1, and read/1 and friends return the atom end_of_file. Repetitive reading keeps yielding the same result. Action error is like eof_code, but repetitive reading will raise an error. With action reset, Prolog will examine the file again and return more data if the file has grown.

locale(+Loc)
  Set the locale that is used by notably format/2 for output on this stream. See section 4.23.

lock(LockingMode)
  Try to obtain a lock on the open file. Default is none, which does not lock the file. The value read or shared means other processes may read the file, but not write it. The value write or exclusive means no other process may read or write the file. Locks are acquired through the POSIX function fcntl() using the command F_SETLKW, which makes a blocked call wait for the lock to be released. Please note that fcntl() locks are advisory and therefore only other applications using the same advisory locks honour your lock. As there are many issues around locking in Unix, especially related to NFS (network file system), please study the fcntl() manual page before trusting your locks!
  The lock option is a SWI-Prolog extension.

newline(Mode)
  Set end-of-line processing for the stream. Mode is one of posix, dos or detect. This option is ignored for binary streams. Using detect on an output stream raises an exception. See also set_stream/2.

type(Type)
  Using type text (default), Prolog will write a text file in an operating system compatible way. Using type binary the bytes will be read or written without any translation. See also the option encoding.
wait(Bool)

This option can be combined with the lock option. If false (default true), the open call returns immediately with an exception if the file is locked. The exception has the format permission_error(lock, source_sink, SrcDest).

The option reposition is not supported in SWI-Prolog. All streams connected to a file may be repositioned.

open(+SrcDest, +Mode, –Stream)  
[ISO]
Equivalent to open/4 with an empty option list.

open_null_stream(–Stream)
Open an output stream that produces no output. All counting functions are enabled on such a stream. It can be used to discard output (like Unix /dev/null) or exploit the counting properties. The initial encoding of Stream is utf8, enabling arbitrary Unicode output. The encoding can be changed to determine byte counts of the output in a particular encoding or validate if output is possible in a particular encoding. For example, the code below determines the number of characters emitted when writing Term.

```
write_length(Term, Len) :-
    open_null_stream(Out),
    write(Out, Term),
    character_count(Out, Len0),
    close(Out),
    Len = Len0.
```

close(+Stream)  
[ISO]
Close the specified stream. If Stream is not open, an existence error is raised. See stream_pair/3 for the implications of closing a stream pair.

If the closed stream is the current input, output or error stream, the stream alias is bound to the initial standard I/O streams of the process. Calling close/1 on the initial standard I/O streams of the process is a no-op for an input stream and flushes an output stream without closing it.\(^{55}\)

close(+Stream, +Options)  
[ISO]
Provides close(Stream, [force(true)]) as the only option. Called this way, any resource errors (such as write errors while flushing the output buffer) are ignored.

stream_property(?Stream, ?StreamProperty)  
[ISO]
True when StreamProperty is a property of Stream. If enumeration of streams or properties is demanded because either Stream or StreamProperty are unbound, the implementation enumerates all candidate streams and properties while locking the stream database. Properties are fetched without locking the stream and may be outdated before this predicate returns due to asynchronous activity.

\(^{55}\)This behaviour was defined with purely interactive usage of Prolog in mind. Applications should not count on this behaviour. Future versions may allow for closing the initial standard I/O streams.
alias(Atom)
   If Atom is bound, test if the stream has the specified alias. Otherwise unify Atom with the first alias of the stream.\(^{56}\)

buffer(Buffering)
   SWI-Prolog extension to query the buffering mode of this stream. Buffering is one of full, line or false. See also open/4.

buffer_size(Integer)
   SWI-Prolog extension to query the size of the I/O buffer associated to a stream in bytes. Fails if the stream is not buffered.

bom(Bool)
   If present and true, a BOM (Byte Order Mark) was detected while opening the file for reading, or a BOM was written while opening the stream. See section 2.19.1 for details.

close_on_abort(Bool)
   Determine whether or not abort/0 closes the stream. By default streams are closed.

close_on_exec(Bool)
   Determine whether or not the stream is closed when executing a new process (exec() in Unix, CreateProcess() in Windows). Default is to close streams. This maps to fcntl() F_SETFD using the flag FD_CLOEXEC on Unix and (negated) HANDLE_FLAG_INHERIT on Windows.

encoding(Encoding)
   Query the encoding used for text. See section 2.19.1 for an overview of wide character and encoding issues in SWI-Prolog.

end_of_stream(E)
   If Stream is an input stream, unify E with one of the atoms not, at or past. See also at_end_of_stream/[0,1].

eof_action(A)
   Unify A with one of eof_code, reset or error. See open/4 for details.

error(Bool)
   When true, the stream is in an error state. Applies to both input and output streams.

file_name(Atom)
   If Stream is associated to a file, unify Atom to the name of this file.

file_no(Integer)
   If the stream is associated with a POSIX file descriptor, unify Integer with the descriptor number. SWI-Prolog extension used primarily for integration with foreign code. See also Sfileno() from SWI-Stream.h.

input
   True if Stream has mode read.

locale(Locale)
   True when Locale is the current locale associated with the stream. See section 4.23.

mode(IOMode)
   Unify IOMode to the mode given to open/4 for opening the stream. Values are: read, write, append and the SWI-Prolog extension update.

\(^{56}\)BUG: Backtracking does not give other aliases.
newline(NewlineMode)
  One of posix or dos. If dos, text streams will emit \r\n for \n and discard \r from
input streams. Default depends on the operating system.

nlink(-Count)
  Number of hard links to the file. This expresses the number of ‘names’ the file has. Not
supported on all operating systems and the value might be bogus. See the documentation
of fstat() for your OS and the value st_nlink.

output
  True if Stream has mode write, append or update.

position(Pos)
  Unify Pos with the current stream position. A stream position is an opaque
term whose fields can be extracted using stream_position_data/3. See also
set_stream_position/2.

reposition(Bool)
  Unify Bool with true if the position of the stream can be set (see seek/4). It is assumed
the position can be set if the stream has a seek-function and is not based on a POSIX file
descriptor that is not associated to a regular file.

representation_errors(Mode)
  Determines behaviour of character output if the stream cannot represent a character. For
example, an ISO Latin-1 stream cannot represent Cyrillic characters. The behaviour is
one of error (throw an I/O error exception), prolog (write \x<hex>\), unicode
(write \uXXXX or \UXXXXXXXX escape sequences) or xml (write &\#...; XML
character entity). The initial mode is unicode for the user streams and error for all
other streams. See also section 2.19.1 and set_stream/2.

timeout(-Time)
  Time is the timeout currently associated with the stream. See set_stream/2 with the
same option. If no timeout is specified, Time is unified to the atom infinite.

type(Type)
  Unify Type with text or binary.

tty(Bool)
  This property is reported with Bool equal to true if the stream is associated with a
terminal. See also set_stream/2.

write_errors(Atom)
  Atom is one of error (default) or ignore. The latter is intended to deal with service
processes for which the standard output handles are not connected to valid streams. In
these cases write errors may be ignored on user_error.

current_stream(?Object, ?Mode, ?Stream)
  The predicate current_stream/3 is used to access the status of a stream as well as to
generate all open streams. Object is the name of the file opened if the stream refers to an open
file, an integer file descriptor if the stream encapsulates an operating system stream, or the
atom [] if the stream refers to some other object. Mode is one of read or write.

  This predicate is deprecated. New code should use the ISO predicate stream_property/2.
is_stream(+Term)

True if Term is a stream name or valid stream handle. This predicate realises a safe test for the existence of a stream alias or handle.

stream_pair(?StreamPair, ?Read, ?Write)

This predicate can be used in mode (-,+,-) to create a stream-pair from an input stream and an output stream. Mode (+,-,-) can be used to get access to the underlying streams. If a stream has already been closed, the corresponding argument is left unbound. If mode (+,-,-) is used on a single stream, either Read or Write is unified with the stream while the other argument is left unbound. This behaviour simplifies writing code that must operate both on streams and stream pairs.

Stream-pairs can be used by all I/O operations on streams, where the operation selects the appropriate member of the pair. The predicate close/1 closes the still open streams of the pair. The output stream is closed before the input stream. If closing the output stream results in an error, the input stream is still closed. Success is only returned if both streams were closed successfully.

set_stream_position(+Stream, +Pos)

Set the current position of Stream to Pos. Pos is a term as returned by stream_property/2 using the position(Pos) property. See also seek/4.

stream_position_data(?Field, +Pos, -Data)

Extracts information from the opaque stream position term as returned by stream_property/2 requesting the position(Pos) property. Field is one of line_count, line_position, char_count or byte_count. See also line_count/2, line_position/2, character_count/2 and byte_count/2.

seek(+Stream, +Offset, +Method, -NewLocation)

Reposition the current point of the given Stream. Method is one of bof, current or eof, indicating positioning relative to the start, current point or end of the underlying object. NewLocation is unified with the new offset, relative to the start of the stream.

Positions are counted in ‘units’. A unit is 1 byte, except for text files using 2-byte Unicode encoding (2 bytes) or wchar encoding (sizeof(wchar_t)). The latter guarantees comfortable interaction with wide-character text objects. Otherwise, the use of seek/4 on non-binary files (see open/4) is of limited use, especially when using multi-byte text encodings (e.g. UTF-8) or multi-byte newline files (e.g. DOS/Windows). On text files, SWI-Prolog offers reliable backup to an old position using stream_property/2 and set_stream_position/2. Skipping N character codes is achieved calling get_code/2 N times or using copy_stream_data/3, directing the output to a null stream (see open_null_stream/1). If the seek modifies the current location, the line number and character position in the line are set to 0.

If the stream cannot be repositioned, a permission_error is raised. If applying the offset would result in a file position less than zero, a domain_error is raised. Behaviour when seeking to positions beyond the size of the underlying object depend on the object and possibly the operating system. The predicate seek/4 is compatible with Quintus Prolog, though

---

57 As of version 7.1.19, it is allowed to close one of the members of the stream directly and close the pair later.
58 Introduced in version 5.6.4 after extending the position term with a byte count. Compatible with SICStus Prolog.
the error conditions and signalling is ISO compliant. See also stream_property/2 and set_stream_position/2.

**set_stream(+Stream, +Attribute)**
Modify an attribute of an existing stream. *Attribute* specifies the stream property to set. If *stream* is a *pair* (see stream_pair/3) both streams are modified, unless the property is only meaningful on one of the streams or setting both is not meaningful. In particular, eof_action only applies to the *read* stream, representation_errors only applies to the *write* stream and trying to set alias or line_position on a pair results in a permission_error exception. See also stream_property/2 and open/4.

**alias(AliasName)**
Set the alias of an already created stream. If *AliasName* is the name of one of the standard streams, this stream is rebound. Thus, set_stream(S, current_input) is the same as set_input/1, and by setting the alias of a stream to user_input, etc., all user terminal input is read from this stream. See also interactor/0.

**buffer(Buffering)**
Set the buffering mode of an already created stream. Buffering is one of full, line or false.

**buffer_size(+Size)**
Set the size of the I/O buffer of the underlying stream to *Size* bytes.

**close_on_abort(Bool)**
Determine whether or not the stream is closed by abort/0. By default, streams are closed.

**close_on_exec(Bool)**
Set the close_on_exec property. See stream_property/2.

**encoding(Atom)**
Defines the mapping between bytes and character codes used for the stream. See section 2.19.1 for supported encodings. The value bom causes the stream to check whether the current character is a Unicode BOM marker. If a BOM marker is found, the encoding is set accordingly and the call succeeds. Otherwise the call fails.

**eof_action(Action)**
Set end-of-file handling to one of eof_code, reset or error.

**file_name(FileName)**
Set the filename associated to this stream. This call can be used to set the file for error locations if *Stream* corresponds to *FileName* and is not obtained by opening the file directly but, for example, through a network service.

**line_position(LinePos)**
Set the line position attribute of the stream. This feature is intended to correct position management of the stream after sending a terminal escape sequence (e.g., setting ANSI character attributes). Setting this attribute raises a permission error if the stream does not record positions. See line_position/2 and stream_property/2 (property position).

**locale(+Locale)**
Change the locale of the stream. See section 4.23.
newline(NewlineMode)
Set input or output translation for newlines. See corresponding stream_property/2 for details. In addition to the detected modes, an input stream can be set in mode detect. It will be set to dos if a \r character was removed.

timeout(Seconds)
This option can be used to make streams generate an exception if it takes longer than Seconds before any new data arrives at the stream. The value infinite (default) makes the stream block indefinitely. Like wait_for_input/3, this call only applies to streams that support the select() system call. For further information about timeout handling, see wait_for_input/3. The exception is of the form

    error(timeout_error(read, Stream), _)

type(Type)
Set the type of the stream to one of text or binary. See also open/4 and the encoding property of streams. Switching to binary sets the encoding to octet. Switching to text sets the encoding to the default text encoding.

record_position(Bool)
Do/do not record the line count and line position (see line_count/2 and line_position/2). Calling set_stream(S, record_position(true)) resets the position the start of line 1.

representation_errors(Mode)
Change the behaviour when writing characters to the stream that cannot be represented by the encoding. See also stream_property/2 and section 2.19.1.

tty(Bool)
Modify whether Prolog thinks there is a terminal (i.e. human interaction) connected to this stream. On Unix systems the initial value comes from isatty(). On Windows, the initial user streams are supposed to be associated to a terminal. See also stream_property/2.

set_prolog_IO(+In, +Out, +Error)
Prepare the given streams for interactive behaviour normally associated to the terminal. In becomes the user_input and current_input of the calling thread. Out becomes user_output and current_output. If Error equals Out an unbuffered stream is associated to the same destination and linked to user_error. Otherwise Error is used for user_error. Output buffering for Out is set to line and buffering on Error is disabled. See also prolog/0 and set_stream/2. The clib package provides the library prolog_server, creating a TCP/IP server for creating an interactive session to Prolog.

set_system_IO(+In, +Out, +Error)
Bind the given streams to the operating system I/O streams 0-2 using POSIX dup2() API. In becomes stdin. Out becomes stdout. If Error equals Out an unbuffered stream is associated to the same destination and linked to stderr. Otherwise Error is used for stderr. Output buffering for Out is set to line and buffering on Error is disabled. The operating system I/O streams are shared across all threads. The three streams must be related to a file descriptor or a domain_error file_stream is raised. See also stream_property/2, property file_no(Fd).
4.17. INPUT AND OUTPUT

Where `set_prolog_IO/3` rebinds the Prolog streams `user_input`, `user_output` and `user_error` for a specific thread providing a private interactive session, `set_system_IO/3` rebinds the shared console I/O and also captures Prolog kernel events (e.g., low-level debug messages, unexpected events) as well as messages from foreign libraries that are directly written to `stdout` or `stderr`.

This predicate is intended to capture all output in situations where standard I/O is normally lost, such as when Prolog is running as a service on Windows.

### 4.17.3 Edinburgh-style I/O

The package for implicit input and output destinations is (almost) compatible with Edinburgh DEC-10 and C-Prolog. The reading and writing predicates refer to, resp., the current input and output streams. Initially these streams are connected to the terminal. The current output stream is changed using `tell/1` or `append/1`. The current input stream is changed using `see/1`. The stream’s current value can be obtained using `telling/1` for output and `seeing/1` for input.

Source and destination are either a file, `user`, or a term `pipe(Command)`. The reserved stream name `user` refers to the terminal. The ISO I/O layer uses `user_input`, `user_output` and `user_error`. In the predicate descriptions below we will call the source/destination argument `SrcDest`. Below are some examples of source/destination specifications.

```prolog
?- see(data).  % Start reading from file `data'.
?- tell(user).  % Start writing to the terminal.
?- tell(pipe(lpr)). % Start writing to the printer.
```

Another example of using the `pipe/1` construct is shown below. Note that the `pipe/1` construct is not part of Prolog’s standard I/O repertoire.

```prolog
getwd(Wd) :-
    seeing(Old), see(pipe(pwd)),
    collect_wd(String),
    seen, see(Old),
    atom_codes(Wd, String).

collect_wd([C|R]) :-
    get0(C), C \== -1, !,
    collect_wd(R).
collect_wd([]).
```

The effect of `tell/1` is not undone on backtracking, and since the stream handle is not specified explicitly in further I/O operations when using Edinburgh-style I/O, you may write to unintended streams more easily than when using ISO compliant I/O. For example, the following query writes both "a" and "b" into the file ‘out’:

```prolog
?- (tell(out), write(a), false ; write(b)), told.
```

59 The ISO I/O layer uses `user_input`, `user_output` and `user_error`.

60 As of version 5.3.15, the pipe construct is supported in the MS-Windows version, both for `swipl.exe` and `swipl-win.exe`. The implementation uses code from the LUA programming language (http://www.lua.org).
Compatibility notes

Unlike Edinburgh Prolog systems, telling/1 and seeing/1 do not return the filename of the current input/output but rather the stream identifier, to ensure the design pattern below works under all circumstances.\footnote{Filenames can be ambiguous and SWI-Prolog streams can refer to much more than just files.}

\begin{verbatim}
...,
telling(Old), tell(x),
...,
told, tell(Old),
...,
\end{verbatim}

The predicates telling/1 and seeing/1 first check for user, the pipe(command) and a stream handle. Otherwise, if the argument is an atom it is first compared to open streams associated to a file with exactly the same name. If such a stream exists, created using tell/1 or see/1, output (input) is switched to the open stream. Otherwise a file with the specified name is opened.

The behaviour is compatible with Edinburgh Prolog. This is not without problems. Changing directory, non-file streams, and multiple names referring to the same file easily lead to unexpected behaviour. New code, especially when managing multiple I/O channels, should consider using the ISO I/O predicates defined in section 4.17.2.

\begin{verbatim}
see(+SrcDest)
Open SrcDest for reading and make it the current input (see set_input/1). If SrcDest is a stream handle, just make this stream the current input. See the introduction of section 4.17.3 for details.
tell(+SrcDest)
Open SrcDest for writing and make it the current output (see set_output/1). If SrcDest is a stream handle, just make this stream the current output. See the introduction of section 4.17.3 for details.
append(+File)
Similar to tell/1, but positions the file pointer at the end of File rather than truncating an existing file. The pipe construct is not accepted by this predicate.
seeing(?SrcDest)
Same as current_input/1, except that user is returned if the current input is the stream user_input to improve compatibility with traditional Edinburgh I/O. See the introduction of section 4.17.3 for details.
telling(?SrcDest)
Same as current_output/1, except that user is returned if the current output is the stream user_output to improve compatibility with traditional Edinburgh I/O. See the introduction of section 4.17.3 for details.
seen
Close the current input stream. The new input stream becomes user_input.
told
Close the current output stream. The new output stream becomes user_output.
\end{verbatim}
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4.17.4 Switching between Edinburgh and ISO I/O

The predicates below can be used for switching between the implicit and the explicit stream-based I/O predicates.

\[
\text{set_input}(+\text{Stream}) \quad \text{[ISO]}
\]
Set the current input stream to become \text{Stream}. Thus, \text{open(file, read, Stream), set_input(Stream)} is equivalent to \text{see(file)}.

\[
\text{set_output}(+\text{Stream}) \quad \text{[ISO]}
\]
Set the current output stream to become \text{Stream}. See also \text{with_output_to/2}.

\[
\text{current_input}(-\text{Stream}) \quad \text{[ISO]}
\]
Get the current input stream. Useful for getting access to the status predicates associated with streams.

\[
\text{current_output}(-\text{Stream}) \quad \text{[ISO]}
\]
Get the current output stream.

4.17.5 Adding IRI schemas

The file handling predicates may be hooked to deal with IRIs. An IRI starts with \langle\text{scheme}⟩://, where \langle\text{scheme}⟩ is a non-empty sequence of lowercase ASCII letters. After detecting the scheme the file manipulation predicates call a hook that is registered using \text{register_iri_scheme/3}.

Hooking the file operations using extensible IRI schemas allows us to place any resource that is accessed through Prolog I/O predicates on arbitrary devices such as web servers or the ZIP archive used to store program resources (see section 14.2). This is typically combined with \text{file_search_path/2} declarations to switch between accessing a set of resources from local files, from the program resource database, from a web-server, etc.

\[
\text{register_iri_scheme}(+\text{Scheme}, :\text{Hook}, +\text{Options})
\]
Register \text{Hook} to be called by all file handling predicates if a name that starts with \text{Scheme://} is encountered. The \text{Hook} is called by \text{call/4} using the \text{operation}, the \text{IRI} and a term that receives the \text{result} of the operation. The following operations are defined:

\[
\text{open}(\text{Mode},\text{Options})
\]
Called by \text{open/3,4}. The result argument must be unified with a stream.

\[
\text{access}(\text{Mode})
\]
Called by \text{access_file/2}, \text{exists_file/1 (Mode is file)} and \text{exists_directory/1 (Mode is directory)}. The result argument must be unified with a boolean.

\[
\text{time}
\]
Called by \text{time_file/2}. The result must be unified with a time stamp.

\[
\text{size}
\]
Called by \text{size_file/2}. The result must be unified with an integer representing the size in bytes.
4.17.6 Write onto atoms, code-lists, etc.

**with_output_to(+Output, :Goal)**

Run *Goal* as *once/1*, while characters written to the current output are sent to *Output*. The predicate is SWI-Prolog-specific, inspired by various posts to the mailinglist. It provides a flexible replacement for predicates such as *sformat/3*, *swritef/3*, *term_to_atom/2*, *atom_number/2* converting numbers to atoms, etc. The predicate *format/3* accepts the same terms as output argument.

Applications should generally avoid creating atoms by breaking and concatenating other atoms, as the creation of large numbers of intermediate atoms generally leads to poor performance, even more so in multithreaded applications. This predicate supports creating difference lists from character data efficiently. The example below defines the DCG rule *term//1* to insert a term in the output:

```prolog
term(Term, In, Tail) :-
    with_output_to(codes(In, Tail), write(Term)).
?- phrase(term(hello), X).
```

*Output* takes one of the shapes below. Except for the first, the system creates a temporary stream using the *wchar_t* internal encoding that points at a memory buffer. The encoding cannot be changed and an attempt to call *set_stream/2* using *encoding(Encoding)* results in a *permission_error* exception.

**A Stream handle or alias**

Temporarily switch current output to the given stream. Redirection using *with_output_to/2* guarantees the original output is restored, also if *Goal* fails or raises an exception. See also *call_cleanup/2*.

**atom(-Atom)**

Create an atom from the emitted characters. Please note the remark above.

**string(-String)**

Create a string object as defined in section 5.2.

**codes(-Codes)**

Create a list of character codes from the emitted characters, similar to *atom_codes/2*.

**codes(-Codes, -Tail)**

Create a list of character codes as a difference list.

**chars(-Chars)**

Create a list of one-character atoms from the emitted characters, similar to *atom_chars/2*.

**chars(-Chars, -Tail)**

Create a list of one-character atoms as a difference list.
4.17.7 Fast binary term I/O

The predicates in this section provide fast binary I/O of arbitrary Prolog terms, including cyclic terms and terms holding attributed variables. Library fastrw is a SICSTus/Ciao compatible library that extends the core primitives described below.

The binary representation the same as used by `PL_record_external()`. The use of these primitives instead of using `write_canonical/2` has advantages and disadvantages. Below are the main considerations:

- Using `write_canonical/2` allows or exchange of terms with other Prolog systems. The format is stable and, as it is text based, it can be inspected and corrected.
- Using the binary format improves the performance roughly 3 times.
- The size of both representations is comparable.
- The binary format can deal with cycles, sharing and attributes. Special precautions are needed to transfer such terms using `write_canonical/2`. See `term_factorized/3` and `copy_term/3`.
- In the current version, reading the binary format has only incomplete consistency checks. This implies a user must be able to trust the source as crafted messages may compromise the reading Prolog system.

`fast_term_serialized(?Term, ?String)`
(De-)serialize `Term` to/from `String`.

`fast_write(+Output, +Term)`
Write `Term` using the fast serialization format to the `Output` stream. `Output must` be a binary stream.

`fast_read(+Input, -Term)`
Read `Term` using the fast serialization format from the `Input` stream. `Input must` be a binary stream.

4.18 Status of streams

`wait_for_input(+ListStreams, -ReadyList, +TimeOut)`
[det]
Wait for input on one of the streams in `ListStreams` and return a list of streams on which input is available in `ReadyList`. Each element of `ListStreams` is either a stream or an integer. Integers are consider waitable OS handles. This can be used to (also) wait for handles that are not associated with Prolog streams such as UDP sockets. See `tcp_setopt/2`.

This predicate waits for at most `TimeOut` seconds. `TimeOut` may be specified as a floating point number to specify fractions of a second. If `TimeOut` equals `infinite`, `wait_for_input/3` waits indefinitely. If `TimeOut` is 0 or 0.0 this predicate returns without waiting.

This predicate can be used to implement timeout while reading and to handle input from multiple sources and is typically used to wait for multiple (network) sockets. On Unix systems it may

---

62 BUG: The predicate `fast_read/2` may crash on arbitrary input.
63 Prior to 7.3.23, the integer value ‘0’ was the same as `infinite`.
be used on any stream that is associated with a system file descriptor. On Windows it can only be used on sockets. If ListOfStreams contains a stream that is not associated with a supported device, a domain_error(waitable_stream, Stream) is raised.

The example below waits for input from the user and an explicitly opened secondary terminal stream. On return, Inputs may hold user_input or P4 or both.

?- open('/dev/tty4', read, P4),
   wait_for_input([user_input, P4], Inputs, 0).

When available, the implementation is based on the poll() system call. The poll() puts no additional restriction on the number of open files the process may have. It does limit the time to $2^{31} - 1$ milliseconds (a bit less than 25 days). Specifying a too large timeout raises a representation_error(timeout) exception. If poll() is not supported by the OS, select() is used. The select() call can only handle file descriptors up to FD_SETSIZE. If the set contains a descriptor that exceeds this limit a representation_error('FD_SETSIZE') is raised.

Note that wait_for_input/3 returns streams that have data waiting. This does not mean you can, for example, call read/2 on the stream without blocking as the stream might hold an incomplete term. The predicate set_stream/2 using the option timeout(Seconds) can be used to make the stream generate an exception if no new data arrives within the timeout period.

Suppose two processes communicate by exchanging Prolog terms. The following code makes the server immune for clients that write an incomplete term:

```prolog
...,
  tcp_accept(Server, Socket, _Peer),
  tcp_open(Socket, In, Out),
  set_stream(In, timeout(10)),
  catch(read(In, Term), _, (close(Out), close(In), fail)),
  ...,
```

<table>
<thead>
<tr>
<th>Predicate</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>byte_count(+Stream, -Count)</td>
<td>Byte position in Stream. For binary streams this is the same as character_count/2. For text files the number may be different due to multi-byte encodings or additional record separators (such as Control-M in Windows).</td>
</tr>
<tr>
<td>character_count(+Stream, -Count)</td>
<td>Unify Count with the current character index. For input streams this is the number of characters read since the open; for output streams this is the number of characters written. Counting starts at 0.</td>
</tr>
<tr>
<td>line_count(+Stream, -Count)</td>
<td>Unify Count with the number of lines read or written. Counting starts at 1.</td>
</tr>
<tr>
<td>line_position(+Stream, -Count)</td>
<td>Unify Count with the position on the current line. Note that this assumes the position is 0 after the open. Tabs are assumed to be defined on each 8-th character, and backspaces are assumed to reduce the count by one, provided it is positive.</td>
</tr>
</tbody>
</table>
4.19 Primitive character I/O

See section 4.2 for an overview of supported character representations.

*nl*  
Write a newline character to the current output stream. On Unix systems `nl 0` is equivalent to `put(10)`.

*nl(Stream)*  
Write a newline to Stream.

*put(Char)*  
Write Char to the current output stream. Char is either an integer expression evaluating to a character code or an atom of one character. Deprecated. New code should use `put_char/1` or `put_code/1`.

*put(Stream, Char)*  
Write Char to Stream. See `put/1` for details.

*put_byte(Byte)*  
Write a single byte to the output. Byte must be an integer between 0 and 255.

*put_byte(Stream, Byte)*  
Write a single byte to Stream. Byte must be an integer between 0 and 255.

*put_char(Char)*  
Write a character to the current output, obeying the encoding defined for the current output stream. Note that this may raise an exception if the encoding of the output stream cannot represent Char.

*put_char(Stream, Char)*  
Write a character to Stream, obeying the encoding defined for Stream. Note that this may raise an exception if the encoding of Stream cannot represent Char.

*put_code(Code)*  
Similar to `put_char/1`, but using a character code. Code is a non-negative integer. Note that this may raise an exception if the encoding of the output stream cannot represent Code.

*put_code(Stream, Code)*  
Same as `put_code/1` but directing Code to Stream.

*tab(Amount)*  
Write Amount spaces on the current output stream. Amount should be an expression that evaluates to a positive integer (see section 4.27).

*tab(Stream, Amount)*  
Write Amount spaces to Stream.

*flush_output*  
Flush pending output on current output stream. `flush_output/0` is automatically generated by `read/1` and derivatives if the current input stream is `user` and the cursor is not at the left margin.
flush_output(+Stream)  [ISO]
Flush output on the specified stream. The stream must be open for writing.

ttyflush
Flush pending output on stream user. See also flush_output/[0,1].

get_byte(-Byte)  [ISO]
Read the current input stream and unify the next byte with Byte (an integer between 0 and 255).
Byte is unified with -1 on end of file.

get_byte(+Stream, -Byte)  [ISO]
Read the next byte from Stream and unify Byte with an integer between 0 and 255.

get_code(-Code)  [ISO]
Read the current input stream and unify Code with the character code of the next character.
Code is unified with -1 on end of file. See also get_char/1.

get_code(+Stream, -Code)  [ISO]
Read the next character code from Stream.

get_char(-Char)  [ISO]
Read the current input stream and unify Char with the next character as a one-character atom.
See also atom_chars/2. On end-of-file, Char is unified to the atom end_of_file.

get_char(+Stream, -Char)  [ISO]
Unify Char with the next character from Stream as a one-character atom. See also get_char/2, get_byte/2 and get_code/2.

get0(-Char)  [deprecated]
Edinburgh version of the ISO get_code/1 predicate. Note that Edinburgh Prolog didn’t support wide characters and therefore technically speaking get0/1 should have been mapped to get_byte/1. The intention of get0/1, however, is to read character codes.

get0(+Stream, -Char)  [deprecated]
Edinburgh version of the ISO get_code/2 predicate. See also get0/1.

get(-Char)  [deprecated]
Read the current input stream and unify the next non-blank character with Char. Char is unified with -1 on end of file. The predicate get/1 operates on character codes. See also get0/1.

get(+Stream, -Char)  [deprecated]
Read the next non-blank character from Stream. See also get/1, get0/1 and get0/2.

peek_byte(-Byte)  [ISO]
peek_byte(+Stream, -Byte)  [ISO]
peek_code(-Code)  [ISO]
peek_code(+Stream, -Code)  [ISO]
peek_char(-Char)  [ISO]
peek_char(+Stream, -Char)  [ISO]
Read the next byte/code/char from the input without removing it. These predicates do not
modify the stream’s position or end-of-file status. These predicates require a buffered stream (see set_stream/2) and raise a permission error if the stream is unbuffered or the buffer is too small to hold the longest multi-byte sequence that might need to be buffered.

**peek_string(+Stream, +Len, -String)**
Read the next Len characters (if the stream is a text stream) or bytes (if the stream is binary) from Stream without removing the data. If Len is larger that the stream buffer size, the buffer size is increased to Len. String can be shorter than Len if the stream contains less data. This predicate is intended to guess the content type of data read from non-repositionable streams.

**skip(+Code)**
Read the input until Code or the end of the file is encountered. A subsequent call to get_code/1 will read the first character after Code.

**skip(+Stream, +Code)**
Skip input (as skip/1) on Stream.

**get_single_char(-Code)**
Get a single character from input stream ‘user’ (regardless of the current input stream). Unlike get_code/1, this predicate does not wait for a return. The character is not echoed to the user’s terminal. This predicate is meant for keyboard menu selection, etc. If SWI-Prolog was started with the --no-tty option this predicate reads an entire line of input and returns the first non-blank character on this line, or the character code of the newline (10) if the entire line consisted of blank characters. See also with_tty_RAW/1.

**with_tty_RAW(:Goal)**
Run goal with the user input and output streams set in raw mode, which implies the terminal makes the input available immediately instead of line-by-line and input that is read is not echoed. As a consequence, line editing does not work. See also get_single_char/1.

**at_end_of_stream**
Succeeds after the last character of the current input stream has been read. Also succeeds if there is no valid current input stream.

**at_end_of_stream(+Stream)**
Succeeds after the last character of the named stream is read, or Stream is not a valid input stream. The end-of-stream test is only available on buffered input streams (unbuffered input streams are rarely used; see open/4).

**set_end_of_stream(+Stream)**
Set the size of the file opened as Stream to the current file position. This is typically used in combination with the open-mode update.

**copy_stream_data(+StreamIn, +StreamOut, +Len)**
Copy Len codes from StreamIn to StreamOut. Note that the copy is done using the semantics of get_code/2 and put_code/2, taking care of possibly recoding that needs to take place between two text files. See section 2.19.1.

**copy_stream_data(+StreamIn, +StreamOut)**
Copy all (remaining) data from StreamIn to StreamOut.
CHAPTER 4. BUILT-IN PREDICATES

fill_buffer(+Stream) [det]
  Fill the Stream's input buffer. Subsequent calls try to read more input until the buffer is completely filled. This predicate is used together with read_pending_codes/3 to process input with minimal buffering.

read_pending_codes(+StreamIn, -Codes, ?Tail)
  Read input pending in the input buffer of StreamIn and return it in the difference list Codes-Tail. That is, the available characters codes are used to create the list Codes ending in the tail Tail. On encountering end-of-file, both Codes and Tail are unified with the empty list ([]).

This predicate is intended for efficient unbuffered copying and filtering of input coming from network connections or devices. It also enables the library pure_input, which processes input from files and streams using a DCG.

The following code fragment realises efficient non-blocking copying of data from an input to an output stream. The at_end_of_stream/1 call checks for end-of-stream and fills the input buffer. Note that the use of a get_code/2 and put_code/2 based loop requires a flush_output/1 call after each put_code/2. The copy_stream_data/2 does not allow for inspection of the copied data and suffers from the same buffering issues.

```prolog
copy(In, Out) :-
  repeat,
  fill_buffer(In),
  read_pending_codes(In, Chars, Tail),
  \+ \+ ( Tail = [],
     format(Out, '˜s', [Chars]),
     flush_output(Out)
   ),
  ( Tail == [] -> !
    ; fail
  ).
```

read_pending_chars(+StreamIn, -Chars, ?Tail)
  As read_pending_codes/3, but returns a difference list of one-character atoms.

4.20 Term reading and writing

This section describes the basic term reading and writing predicates. The predicates format/[1,2] and writef/2 provide formatted output. Writing to Prolog data structures such as atoms or code-lists is supported by with_output_to/2 and format/3.

Reading is sensitive to the Prolog flag character_escapes, which controls the interpretation of the \ character in quoted atoms and strings.

write_term(+Term, +Options) [ISO]
  The predicate write_term/2 is the generic form of all Prolog term-write predicates. Valid options are:
attributes(Atom)
Define how attributed variables (see section 8.1) are written. The default is determined by
the Prolog flag write_attributes. Defined values are ignore (ignore the attribute),
dots (write the attributes as {...}), write (simply hand the attributes recursively to
write_term/2) and portray (hand the attributes to attr_portray_hook/2).

back_quotes(Atom)
Fulfills the same role as the back_quotes prolog flag. Notably, the value string
causes string objects to be printed between back quotes and symbol_char causes the
backquote to be printed unquoted. In all other cases the backquote is printed as a quoted
atom.

brace_terms(Bool)
If true (default), write {}(X) as {X}. See also dotlists and ignore_ops.

blobs(Atom)
Define how non-text blobs are handled. By default, this is left to the write handler specified with the blob type. Using portray, portray/1 is called for each blob encountered. See section 12.4.9.

cycles(Bool)
If true (default), cyclic terms are written as @((Template, Substitutions), where Substitutions is a list Var = Value. If cycles is false, max_depth is not given, and Term is cyclic, write_term/2 raises a domain_error. See also the cycles option in read_term/2.

dotlists(Bool)
If true (default false), write lists using the dotted term notation rather than the list notation. Note that as of version 7, the list constructor is ’[|]’. Using dotlists(true), write_term/2 writes a list using ’.’ as constructor. This is intended for communication with programs such as other Prolog systems, that rely on this notation. See also the option no_lists(true) to use the actual SWI-Prolog list functor.

fullstop(Bool)
If true (default false), add a fullstop token to the output. The dot is preceded by a space if needed and followed by a space (default) or newline if the nl(true) option is also given.

ignore_ops(Bool)
If true, the generic term representation ((functor)(⟨args⟩ . . . )) will be used for all terms.

---

64 The cycles option and the cyclic term representation using the @-term are copied from SICStus Prolog. However, the default in SICStus is set to false and SICStus writes an infinite term if not protected by, e.g., the depth_limit option.
65 Copied from ECLiPSe.
66 Compatible with ECLiPSe.
Otherwise (default), operators will be used where appropriate. 67

**max_depth(Integer)**

If the term is nested deeper than *Integer*, print the remainder as ellipses (...). A 0 (zero) value (default) imposes no depth limit. This option also delimits the number of printed items in a list. Example:

```
?- write_term(a(s(s(s(0)))), [a,b,c,d,e,f]), [max_depth(3)]).
a(s(s(...)), [a, b|...])
true.
```

Used by the top level and debugger to limit screen output. See also the Prolog flags `answer_write_options` and `debugger_write_options`.

**module(Module)**

Define the reference module (default `user`). This defines the default value for the character escapes option as well as the operator definitions to use. If *Module* does not exist it is *not* created and the `user` module is used. See also `op/3` and `read_term/2`, providing the same option.

**nl(Bool)**

Add a newline to the output. See also the `fullstop` option.

**no_lists(Bool)**

Do not use list notation. This is similar to `dotlists(true)`, but uses the SWI-Prolog list functor, which is by default ’[[ ]]’ instead of the ISO Prolog ’.’. Used by `display/1`.

**numbervars(Bool)**

If *true*, terms of the format `$\text{VAR}(N)$`, where *N* is an integer that fits in 64-bit, 68 will be written as a variable name. For *N* in 0..25 it emits A..Z. For higher numbers it emits An..Zn, where *n* is *N//26. For negative numbers it emits S_\text{N}, which is used for representing shared sub-terms and cyclic terms.

If *N* is an atom it is written without quotes. This extension allows for writing variables with user-provided names. The default is *false*. See also `numbervars/3` and the option `variable_names`.

**partial(Bool)**

If *true* (default *false*), do not reset the logic that inserts extra spaces that separate tokens where needed. This is intended to solve the problems with the code below. Calling `write_value(.)` writes ..., which cannot be read. By adding `partial(true)` to the option list, it correctly emits . . . Similar problems appear when emitting operators using multiple calls to `write_term/3`.

```
write_value(Value) :-
    write_term(Value, [partial(true)]),
    write(‘.’), nl.
```

---

67 In traditional systems this flag also stops the syntactic sugar notation for lists and brace terms. In SWI-Prolog, these are controlled by the separate options `dotlists` and `brace_terms`.

68 Larger integers are ignored. As no term that fits into memory can have that many variables, this is not a restriction.
In addition, if the priority is not 1200 or 999 this assumes we are printing an operant of an operator. If Term is an atom that is also an operator it will always be embraced.69

portray(Bool)
Same as portrayed(Bool). Deprecated.

portray_goal(:Goal)
Implies portray(true), but calls Goal rather than the predefined hook portray/1. Goal is called through call/3, where the first argument is Goal, the second is the term to be printed and the 3rd argument is the current write option list. The write option list is copied from the write_term call, but the list is guaranteed to hold an option priority that reflects the current priority.

portrayed(Bool)
If true, the hook portray/1 is called before printing a term that is not a variable. If portray/1 succeeds, the term is considered printed. See also print/1. The default is false. This option is an extension to the ISO write_term options.

priority(Integer)
An integer between 0 and 1200 representing the ‘context priority’. Default is 1200. Can be used to write partial terms appearing as the argument to an operator. For example:

```
format(’˜w = ’, [VarName]),
write_term(Value, [quoted(true), priority(699)])
```

quoted(Bool)
If true, atoms and strings that need quotes will be quoted. The default is false. If character_escapes is true (default) characters in the quoted atom or string are escaped using backslash (\) sequences. To the minimum, the quote itself, newlines and backslash characters are escaped to make the output valid for read/1. All unassigned unicode characters and characters in the Unicode separator (Z*) and control (C*) classes except for the ASCII space (\u0020) are escaped. For those characters for which an ISO Prolog single character escape, e.g., \t is defined, this is used. Otherwise the output depends on the option character_escapes_unicode. If this flag applies (default) the widely accepted \uXXXX or \UXXXXXXXX is used. Otherwise the ISO Prolog \x<hex>\ syntax is used.

quote_non_ascii(Bool)
Quote an atom that contains non-ASCII, i.e., larger than 127 code points. The Prolog standard only describes non-quoted atom syntax containing ASCII characters. While SWI-Prolog extends this to Unicode (see section 2.16.1), transferring atoms holding non-ASCII text to other Prolog implementations may cause problems. This flag is used by write_canonical/1.

spacing(+Spacing)
Determines whether and where extra white space is added to enhance readability. The default is standard, adding only space where needed for proper tokenization by read_term/3. Currently, the only other value is next_argument, adding a space after a comma used to separate arguments in a term or list.

---

69 If the priority is 1200 it is assumed to be a toplevel term and if the priority is 999 it is assumed to be a list element or argument of a compound term.
variable_names(+List)

Assign names to variables in Term. List is a list of terms Name = Var, where Name is an atom that represents a valid Prolog variable name. Terms where Var is bound or is a variable that does not appear in Term are ignored. Raises an error if List is not a list, one of the members is not a term Name = Var, Name is not an atom or Name does not represent a valid Prolog variable name.

The implementation binds the variables from List to a term ‘$VAR’(Name). Like write_canonical/1, terms that where already bound to ‘$VAR’(X) before write_term/2 are printed normally, unless the option numbervars(true) is also provided. If the option numbervars(true) is used, the user is responsible for avoiding collisions between assigned names and numbered names. See also the variable_names option of read_term/2.

Possible variable attributes (see section 8.1) are ignored. In most cases one should use copy_term/3 to obtain a copy that is free of attributed variables and handle the associated constraints as appropriate for the use-case.

write_term(+Stream, +Term, +Options) [ISO]

As write_term/2, but output is sent to Stream rather than the current output.

write_length(+Term, -Length, +Options) [semidet]

True when Length is the number of characters emitted for write_term(Term, Options). In addition to valid options for write_term/2, it processes the option:

max_length(+MaxLength)

If provided, fail if Length would be larger than MaxLength. The implementation ensures that the runtime is limited when computing the length of a huge term with a bounded maximum.

write_canonical(+Term) [ISO]

Write Term on the current output stream using standard parenthesised prefix notation (i.e., ignoring operator declarations). Atoms that need quotes are quoted. Terms written with this predicate can always be read back, regardless of current operator declarations. Equivalent to write_term/2 using the options ignore_ops, quoted, quote_non_ascii, brace_terms(false) and numbervars after numbervars/4 using the singletons option.

Note that due to the use of numbervars/4, non-ground terms must be written using a single write_canonical/1 call. This used to be the case anyhow, as garbage collection between multiple calls to one of the write predicates can change the _⟨NNN⟩ identity of the variables.

write_canonical(+Stream, +Term) [ISO]

Write Term in canonical form on Stream.

write(+Term) [ISO]

Write Term to the current output, using brackets and operators where appropriate.

write(+Stream, +Term) [ISO]

Write Term to Stream.
### 4.20. TERM READING AND WRITING

#### writeq(+Term)
Write `Term` to the current output, using brackets and operators where appropriate. Atoms that need quotes are quoted. Terms written with this predicate can be read back with `read/1` provided the currently active operator declarations are identical.

#### writeq(+Stream, +Term)
Write `Term` to `Stream`, inserting quotes.

#### writeln(+Term)
Equivalent to `write(Term), nl.`. The output stream is locked, which implies no output from other threads can appear between the term and newline.

#### writeln(+Stream, +Term)
Equivalent to `write(Stream, Term), nl(Stream)`.. The output stream is locked, which implies no output from other threads can appear between the term and newline.

#### print(+Term)
Print a term for debugging purposes. The predicate `print/1` acts as if defined as below.

```prolog
print(Term) :-
    current_prolog_flag(print_write_options, Options), !,
    write_term(Term, Options).
print(Term) :-
    write_term(Term, [ portray(true),
                      numbervars(true),
                      quoted(true)
                     ]).
```

The `print/1` predicate is used primarily through the \`p escape sequence of `format/2`, which is commonly used in the recipes used by `print_message/2` to emit messages.

The classical definition of this predicate is equivalent to the ISO predicate `write_term/2` using the options `portray(true)` and `numbervars(true)`. The `portray(true)` option allows the user to implement application-specific printing of terms printed during debugging to facilitate easy understanding of the output. See also `portray/1` and `portray_text`. SWI-Prolog adds `quoted(true)` to (1) facilitate the copying/pasting of terms that are not affected by `portray/1` and to (2) allow numbers, atoms and strings to be more easily distinguished, e.g., 42, '42' and "42".

#### print(+Stream, +Term)
Print `Term` to `Stream`.

#### portray(+Term)
A dynamic predicate, which can be defined by the user to change the behaviour of `print/1` on (sub)terms. For each subterm encountered that is not a variable `print/1` first calls `portray/1` using the term as argument. For lists, only the list as a whole is given to `portray/1`. If `portray/1` succeeds `print/1` assumes the term has been written.

#### read(-Term)
Read the next Prolog term from the current input stream and unify it with `Term`. On reaching
end-of-file Term is unified with the atom end_of_file. This is the same as read_term/2 using an empty option list.

[NOTE] You might have found this while looking for a predicate to read input from a file or the user. Quite likely this is not what you need in this case. This predicate is for reading a Prolog term which may span multiple lines and must end in a full stop (dot character followed by a layout character). The predicates for reading and writing Prolog terms are particularly useful for storing Prolog data in a file or transferring them over a network communication channel (socket) to another Prolog process. The libraries provide a wealth of predicates to read data in other formats. See e.g., readutil, pure_input or libraries from the extension packages to read XML, JSON, YAML, etc.

read(+Stream, -Term)  [ISO]
Read the next Prolog term from Stream. See read/1 and read_term/2 for details.

read_clause(+Stream, -Term, +Options)
Equivalent to read_term/3, but sets options according to the current compilation context and optionally processes comments. Defined options:

syntax_errors(+Atom)
See read_term/3, but the default is dec10 (report and restart).

term_position(-TermPos)
Same as for read_term/3.

subterm_positions(-TermPos)
Same as for read_term/3.

variable_names(-Bindings)
Same as for read_term/3.

process_comment(+Boolean)
If true (default), call prolog:comment_hook(Comments, TermPos, Term) if this multifile hook is defined (see prolog:comment_hook/3). This is used to drive PlDoc.

comments(-Comments)
If provided, unify Comments with the comments encountered while reading Term. This option implies process_comment(false).

The singletons option of read_term/3 is initialised from the active style-checking mode. The module option is initialised to the current compilation module (see prolog_load_context/2).

read_term(-Term, +Options)  [ISO]
Read a term from the current input stream and unify the term with Term. The reading is controlled by options from the list of Options. If this list is empty, the behaviour is the same as for read/1. The options are upward compatible with Quintus Prolog. The argument order is according to the ISO standard. Syntax errors are always reported using exception-handling (see catch/3). Options:

backquoted_string(Bool)
If true, read ‘...’ to a string object (see section 5.2). The default depends on the Prolog flag back_quotes.
4.20. TERM READING AND WRITING

**character_escapes(Bool)**
Defines how to read \ escape sequences in quoted atoms. See the Prolog flag character_escapes in current_prolog_flag/2. (SWI-Prolog).

**comments(-Comments)**
Unify Comments with a list of Position-Comment, where Position is a stream position object (see stream_position_data/3) indicating the start of a comment and Comment is a string object containing the text including delimiters of a comment. It returns all comments from where the read_term/2 call started up to the end of the term read.

**cycles(Bool)**
If true (default false), re-instantiate templates as produced by the corresponding write_term/2 option. Note that the default is false to avoid misinterpretation of @(Template, Substitutions), while the default of write_term/2 is true because emitting cyclic terms without using the template construct produces an infinitely large term (read: it will generate an error after producing a huge amount of output).

**dotlists(Bool)**
If true (default false), read .(a,[]) as a list, even if lists are internally constructed a different functor ([[Head, Tail]]. This is primarily intended to read the output from write_canonical/1 from other Prolog systems. See section 5.1.

**double_quotes(Atom)**
Defines how to read ”…” strings. See the Prolog flag double_quotes. (SWI-Prolog).

**module(Module)**
Specify Module for operators, character_escapes flag and double_quotes flag. The value of the latter two is overruled if the corresponding read_term/3 option is provided. If no module is specified, the current ‘source module’ is used. If the options is provided but the target module does not exist, module user is used because new modules by default inherit from user

**quasi_quotations(-List)**
If present, unify List with the quasi quotations (see section A.41) instead of evaluating quasi quotations. Each quasi quotation is a term quasi_quotation(+Syntax, +Quotation, +VarDict, -Result), where Syntax is the term in {{Syntax||..|}}, Quotation is a list of character codes that represent the quotation, VarDict is a list of Name=Variable and Result is a variable that shares with the place where the quotation must be inserted. This option is intended to support tools that manipulate Prolog source text.

**singletons(Vars)**
As variable_names, but only reports the variables occurring only once in the Term read (ISO). If Vars is the constant warning, singleton variables are reported using print_message/2. The variables appear in the order they have been read. The latter option provides backward compatibility and is used to read terms from source files. Not all singleton variables are reported as a warning. See section 2.16.1 for the rules that apply for warning about a singleton variable.70

**syntax_errors(Atom)**
If error (default), throw an exception on a syntax error. Other values are fail, which

---

70As of version 7.7.17, all variables starting with an underscore except for the truly anonymous variable are returned in Vars. Older versions only reported those that would have been reported if warning is used.
causes a message to be printed using `print_message/2`, after which the predicate fails, `quiet` which causes the predicate to fail silently, and `dec10` which causes syntax errors to be printed, after which `read_term/[2,3]` continues reading the next term. Using `dec10`, `read_term/[2,3]` never fails. (Quintus, SICStus).

**subterm_positions(TermPos)**

Describes the detailed layout of the term. The formats for the various types of terms are given below. All positions are character positions. If the input is related to a normal stream, these positions are relative to the start of the input; when reading from the terminal, they are relative to the start of the term.

*From-To*  
Used for primitive types (atoms, numbers, variables).

**string_position(From, To)**  
Used to indicate the position of a string enclosed in double quotes (").

**brace_term_position(From, To, Arg)**  
Term of the form `{ ... }`, as used in DCG rules. Arg describes the argument.

**list_position(From, To, Elms, Tail)**  
A list. Elms describes the positions of the elements. If the list specifies the tail as \langle TailTerm \rangle, Tail is unified with the term position of the tail, otherwise with the atom `none`.

**term_position(From, To, FFrom, FTo, SubPos)**  
Used for a compound term not matching one of the above. `FFrom` and `FTo` describe the position of the functor. `SubPos` is a list, each element of which describes the term position of the corresponding subterm.

**dict_position(From, To, TagFrom, TagTo, KeyValuePosList)**  
Used for a dict (see section 5.4). The position of the key-value pairs is described by `KeyValuePosList`, which is a list of `key_value_position/7` terms. The `key_value_position/7` terms appear in the order of the input. Because maps to not preserve ordering, the key is provided in the position description.

**key_value_position(From, To, SepFrom, SepTo, Key, KeyPos, ValuePos)**  
Used for key-value pairs in a map (see section 5.4). It is similar to the `term_position/5` that would be created, except that the key and value positions do not need an intermediate list and the key is provided in `Key` to enable synchronisation of the file position data with the data structure.

**parentheses_term_position(From, To, ContentPos)**  
Used for terms between parentheses. This is an extension compared to the original Quintus specification that was considered necessary for secure refactoring of terms.

**quasi_quotation_position(From, To, SyntaxTerm, SyntaxPos, ContentPos)**  
Used for quasi quotations. Given the input `{{|Syntax||Content|}}`, `SyntaxTerm` is the parsed term representation from `Syntax`, e.g., `{|string(X)||Hello {{X}}|}` produces `Syntax string(X)` and `SyntaxPos` describes the layout of this term. `ContentPos` is always a term `From-To` describing the character range of `Content`.\(^{71}\)

---

\(^{71}\)The layout of the term produced by the quasi quotation parser is not available. Future versions may provide an interface that allows contributing a layout term.
4.20. TERM READING AND WRITING

\(\text{term\_position}(\text{Pos})\)

Unifies \(\text{Pos}\) with the starting position of the term read. \(\text{Pos}\) is of the same format as used by \text{stream\_property}/2.

\(\text{var\_prefix}(\text{Bool})\)

If \text{true}, demand variables to start with an underscore. See section 2.16.1.

\(\text{variables}(\text{Vars})\)

Unify \(\text{Vars}\) with a list of variables in the term. The variables appear in the order they have been read. See also \text{term\_variables}/2. (ISO).

\(\text{variable\_names}(\text{Vars})\)

Unify \(\text{Vars}\) with a list of \('\text{Name} = \text{Var}'\), where \(\text{Name}\) is an atom describing the variable name and \(\text{Var}\) is a variable that shares with the corresponding variable in \(\text{Term}\). (ISO). The variables appear in the order they have been read.

\(\text{read\_term}(+\text{Stream}, -\text{Term}, +\text{Options})\) [ISO]

Read term with options from \(\text{Stream}\). See \text{read\_term}/2.

\(\text{read\_term\_from\_atom}(+\text{Atom}, -\text{Term}, +\text{Options})\)

Use \text{read\_term}/3 to read the next term from \(\text{Atom}\). \(\text{Atom}\) is either an atom or a string object (see section 5.2). It is not required for \(\text{Atom}\) to end with a full-stop. This predicate supersedes \text{atom\_to\_term}/3.

\(\text{read\_term\_with\_history}(-\text{Term}, +\text{Options})\)

Read a term while providing history substitutions. \text{read\_term\_with\_history}/2 is used by the top level to read the user’s actions. In addition to the options recognised by \text{read\_term}/2, the following options are recognised:

\(\text{prompt}(+\text{Prompt})\)

Define the prompt to use. The default is \(\sim!\ ?\sim\). A sequence \(\sim!\) is replaced by the current history event number.

\(\text{show}(+\text{Command})\)

Using \(\text{Command}\) lists the saved history events. Default is \text{!history}.

\(\text{help}(+\text{Command})\)

Using \(\text{Command}\) shows help on the history system. Default is \text{!help}.

\(\text{no\_save}(+\text{Commands})\)

Do not save the command into the history if it appears in the list \(\text{Commands}\).

\(\text{module}(+\text{Module})\)

Defines the module from which to extract module-specific syntax such as operators and handling of the various quotes. Default is the \text{typein} module which is set using \text{module}/1 and is initially set to \text{user}.

\(\text{input}(+\text{Stream})\)

Stream from which to read \(\text{Term}\). Default is \text{user\_input}.

Most applications will use the \text{read\_term}/2 option \text{variable\_names} to get access to the names of the variables in \(\text{Term}\). SWI-Prolog calls \text{read\_term\_with\_history}/2 as follows:
prompt(-Old, +New)
Set prompt associated with reading from the user_input stream. Old is first unified with the current prompt. On success the prompt will be set to New (an atom). A prompt is printed if data is read from user_input, the cursor is at the left margin and the user_input is considered to be connected to a terminal. See the tty(Bool) property of stream_property/2 and set_stream/2.

The default prompt is ‘|: ’. Note that the toplevel loop (see prolog/0) sets the prompt for the first prompt (see prompt1/1) to ‘?- ’, possibly decorated by the history event number, break level and debug mode. If the first line does not complete the term, subsequent lines are prompted for using the prompt as defined by prompt/2.

prompt1(+Prompt)
Sets the prompt for the next line to be read. Continuation lines will be read using the prompt defined by prompt/2.

4.21 Analysing and Constructing Terms

functor(?Term, ?Name, ?Arity)
[ISO]
True when Term is a term with functor Name/Arity. If Term is a variable it is unified with a new term whose arguments are all different variables (such a term is called a skeleton). If Term is atomic, Arity will be unified with the integer 0, and Name will be unified with Term. Raises instantiation_error if Term is unbound and Name/Arity is insufficiently instantiated.

SWI-Prolog also supports terms with arity 0, as in a() (see section 5). Such terms must be processed using functor/4 or compound_name arity/3. The predicate functor functor/3 and =../2 raise a domain_error when faced with these terms. Without this precaution a round trip of a term with arity 0 over functor/3 would create an atom.

functor(?Term, ?Name, ?Arity, ?Type)
As functor/3, but designed to work with zero-arity terms (e.g., a(), see section 5). Type is one of atom, compound, callable or atomic. Type must be instantiated if Name is an atom and Arity is 0 (zero). In other cases Type may be a variable. This predicate is true if Term (either initially or after haveing been created from Name and Type) and Type are related as below

- If Term is compound (including zero-arity compounds), Type must be compound or callable. If Type is unbound is is unified with compound.
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• If Term is an atom, Type must be atom or callable. If Type is unbound is is unified with atom.
• Else Type is unified with atomic.

This predicate provides a safe round trip for zero-arity compounds and atoms. It can also be used as a variant of functor/3 that only processes compound or callable terms. See also compound/1, callable/1 and compound_name arity/3.

arg(?Arg, +Term, ?Value) [ISO]

Term should be instantiated to a term, Arg to an integer between 1 and the arity of Term. Value is unified with the Arg-th argument of Term. Arg may also be unbound. In this case Value will be unified with the successive arguments of the term. On successful unification, Arg is unified with the argument number. Backtracking yields alternative solutions.\(^72\)

The predicate arg/3 fails silently if Arg = 0 or Arg > arity and raises the exception domain_error(not_less_than_zero, Arg) if Arg < 0.

?- Term =.. ?List

List is a list whose head is the functor of Term and the remaining arguments are the arguments of the term. Either side of the predicate may be a variable, but not both. This predicate is called ‘Univ’.

?- foo(hello, X) =.. List.
List = [foo, hello, X]

?- Term =.. [baz, foo(1)].
Term = baz(foo(1))

SWI-Prolog also supports terms with arity 0, as in a() (see section 5). Such terms must be processed using compound_name arguments/3. This predicate raises a domain error as shown below. See also functor/3.

?- a() =.. L.
ERROR: Domain error: ‘compound_non_zero_arity’ expected, found ‘a()’

compound_name arity(?Compound, ?Name, ?Arity)

Version of functor/3 that only works for compound terms and can examine and create compound terms with zero arguments (e.g, name()). See also compound_name arguments/3. See also functor/4.

compound_name arguments(?Compound, ?Name, ?Arguments)

Rationalized version of =../2 that can compose and decompose compound terms with zero arguments. See also compound_name arity/3.

\(^72\)The instantiation pattern (-, +, ?) is an extension to ‘standard’ Prolog. Some systems provide genarg/3 that covers this pattern.
numbervars(+Term, +Start, -End)

Unify the free variables in \( \text{Term} \) with a term \( \$\text{VAR}(N) \), where \( N \) is the number of the variable. Counting starts at \( \text{Start} \). \( \text{End} \) is unified with the number that should be given to the next variable.\(^{73}\) The example below illustrates this. Note that the toplevel prints \( \$\text{VAR}(0) \) as \( A \) due to the numbervars(true) option used to print answers.

\[
? \leftarrow \text{Term} = f(X, Y, X), \\
\text{numbervars}(\text{Term}, 0, \text{End}), \\
\text{write}_\text{canonical}(\text{Term}), \text{nl}.
\]

\[
f(\$\text{VAR}(0), \$\text{VAR}(1), \$\text{VAR}(0))
\]

\[
\text{Term} = f(A, B, A), \\
X = A, \\
Y = B, \\
\text{End} = 2.
\]

See also the numbervars option to write_term/3 and numbervars/4.

numbervars(+Term, +Start, -End, +Options)

As numbervars/3, providing the following options:

functor_name(+Atom)

Name of the functor to use instead of \( \$\text{VAR} \).

attvar(+Action)

What to do if an attributed variable is encountered. Options are skip, which causes numbervars/3 to ignore the attributed variable, bind which causes it to treat it as a normal variable and assign the next \( \$\text{VAR}(N) \) term to it, or (default) error which raises a type_error exception.\(^{74}\)

singletons(+Bool)

If true (default false), numbervars/4 does singleton detection. Singleton variables are unified with \( \$\text{VAR}('\_') \), causing them to be printed as \( _ \) by write_term/2 using the numbervars option. This option is exploited by portray_clause/2 and write_canonical/2.\(^{75}\)

var_number(@Term, -VarNumber)

True if \( \text{Term} \) is numbered by numbervars/3 and \( \text{VarNumber} \) is the number given to this variable. This predicate avoids the need for unification with \( \$\text{VAR}(X) \) and opens the path for replacing this valid Prolog term by an internal representation that has no textual equivalent.

term_variables(+Term, -List) \[ISO\]

Unify \( \text{List} \) with a list of variables, each sharing with a unique variable of \( \text{Term} \).\(^{76}\) The variables

\(^{73}\)BUG: Only tagged integers are supported (see the Prolog flag max_tagged_integer). This suffices to count all variables that can appear in the largest term that can be represented, but does not support arbitrary large integer values for \( \text{Start} \). On overflow, a representation_error(tagged_integer) exception is raised.

\(^{74}\)This behaviour was decided after a long discussion between David Reitter, Richard O’Keefe, Bart Demoen and Tom Schrijvers.

\(^{75}\)BUG: Currently this option is ignored for cyclic terms.

\(^{76}\)This predicate used to be called free_variables/2. The name term_variables/2 is more widely used. The old predicate is still available from the library backcomp.
in *List* are ordered in order of appearance traversing *Term* depth-first and left-to-right. See also *term* variables/3 and nonground/2. For example:

```prolog
?- term_variables(a(X, b(Y, X), Z), L).
L = [X, Y, Z].
```

### nonground(+Term, -Var)

True when *Var* is a variable in *Term*. Fails if *Term* is *ground* (see ground/1). This predicate is intended for coroutining to trigger a wakeup if *Term* becomes ground, e.g., using when/2. The current implementation always returns the first variable in depth-first left-right search. Ideally it should return a random member of the set of variables (see *term* variables/2) to realise logarithmic complexity for the ground trigger. Compatible with ECLiPSe and hProlog.

### term* variables(+Term, -List, ?Tail)

Difference list version of *term* variables/2. That is, *Tail* is the tail of the variable list *List*.

### term* singletons(+Term, -List)

Unify *List* with a list of variables, each sharing with a variable that appears only once in *Term*.77 Note that, if a variable appears in a shared subterm, it is *not* considered singleton. Thus, *A* is *not* a singleton in the example below. See also the singleton option of numbervars/4.

```prolog
?- S = a(A), term_singletons(t(S,S), L).
L = [ ].
```

### is* most* general* term(@Term)

True if *Term* is a callable term where all arguments are non-sharing variables or *Term* is a list whose members are all non-sharing variables. This predicate is used to reason about call subsumption for tabling and is compatible with XSB. See also subsumes_term/2. Examples:

<table>
<thead>
<tr>
<th>Example</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>is_most_general_term(1) false</td>
</tr>
<tr>
<td>2</td>
<td>is_most_general_term(p) true</td>
</tr>
<tr>
<td>3</td>
<td>is_most_general_term(p(.,)) true</td>
</tr>
<tr>
<td>4</td>
<td>is_most_general_term(p(.,a)) false</td>
</tr>
<tr>
<td>5</td>
<td>is_most_general_term(p(X,X)) false</td>
</tr>
<tr>
<td>6</td>
<td>is_most_general_term([]) true</td>
</tr>
<tr>
<td>7</td>
<td>is_most_general_term([.,]) false</td>
</tr>
<tr>
<td>8</td>
<td>is_most_general_term([.,.]) true</td>
</tr>
<tr>
<td>9</td>
<td>is_most_general_term([X,X]) false</td>
</tr>
</tbody>
</table>

### copy_term(+In, -Out)

Create a version of *In* with renamed (fresh) variables and unify it to *Out*. Attributed variables

77BUG: In the current implementation *Term* must be acyclic. If not, a representation_error is raised.
(see section 8.1) have their attributes copied. The implementation of \texttt{copy_term/2} can deal with infinite trees (cyclic terms). As pure Prolog cannot distinguish a ground term from another ground term with exactly the same structure, ground sub-terms are \textit{shared} between \textit{In} and \textit{Out}. Sharing ground terms does affect \texttt{setarg/3}. SWI-Prolog provides \texttt{duplicate_term/2} to create a true copy of a term.

\textbf{copy_term(+VarsIn, +In, -VarsOut, -Out)}

Similar to \texttt{copy_term/2}, but only rename the variables in \textit{VarsIn} that appear in \textit{In}.\textsuperscript{78} Variables in \textit{In} that do not appear in \textit{VarsIn} are \textit{shared} between \textit{In} and \textit{Out}. Sub terms that only contain such shared variables are shared as a whole between \textit{In} and \textit{Out}. \textit{VarsIn} is often a list, but can be arbitrary term. For example:

\begin{verbatim}
?- copy_term([X], q(X,Y), Vars, Term).
Vars = [_A],
Term = q(_A, Y).
\end{verbatim}

Note that if \textit{VarsIn} and \textit{In} do not share any variables, \textit{Out} is equivalent to \textit{In} and \textit{VarsOut} is a copy (as \texttt{copy_term/2}) of \textit{VarsIn}. If \textit{In} does not contain any variables not in \textit{VarsIn} the result is the same as \texttt{copy_term(VarsIn-In, VarsOut-Out)}.

\textbf{copy_term_nat(+VarsIn, +In, -VarsOut, -Out)}

As \texttt{copy_term/4}, using the attributed variable semantics of \texttt{copy_term_nat/2}. This implies that attributed variables that appear in \textit{VarsIn} appear as renamed plain variables in \textit{VarsOut} and \textit{Out}. Attributed variables in \textit{In} that do not appear in \textit{VarsIn} are shared between \textit{In} and \textit{Out}.

\section*{4.21.1 Non-logical operations on terms}

Prolog is not able to \textit{modify} instantiated parts of a term. Lacking that capability makes the language much safer, but unfortunately there are problems that suffer severely in terms of time and/or memory usage. Always try hard to avoid the use of these primitives, but they can be a good alternative to using dynamic predicates. See also section 4.33, discussing the use of global variables.

\textbf{setarg(+Arg, +Term, +Value)}

Extra-logical predicate. Assigns the \textit{Arg}-th argument of the compound term \textit{Term} with the given \textit{Value}. The assignment is undone if backtracking brings the state back into a position before the \texttt{setarg/3} call. If the designated argument of \textit{Term} is a variable, this variable is unified with \textit{Value} using normal unification, i.e., \texttt{setarg/3} behaves as \texttt{arg/3} in this case. Note that this may produce a cyclic term if \textit{Value} contains this variable. See also \texttt{nb_setarg/3}.

This predicate may be used for destructive assignment to terms, using them as an extra-logical storage bin. Always try hard to avoid the use of \texttt{setarg/3} as it is not supported by many Prolog systems and one has to be very careful about unexpected copying as well as unexpected noncopying of terms. A good practice to improve somewhat on this situation is to make sure that terms whose arguments are subject to \texttt{setarg/3} have one unused and unshared variable in addition to the used arguments. This variable avoids unwanted sharing in, e.g., \texttt{copy_term/2}.

\textsuperscript{78}This predicate is based on a similar predicate in s(CASP) by Joaquin Arias.
and causes the term to be considered as non-ground. An alternative is to use `put_attr/3` to attach information to attributed variables (see section 8.1).

**nb_setarg(+Arg, +Term, +Value)**

Assigns the Arg-th argument of the compound term Term with the given Value as `setarg/3`, but on backtracking the assignment is not reversed. If Value is not atomic, it is duplicated using `duplicate_term/2`. This predicate uses the same technique as `nb_setval/2`. We therefore refer to the description of `nb_setval/2` for details on non-backtrackable assignment of terms. This predicate is compatible with GNU-Prolog `setarg(A,T,V,false)`, removing the type restriction on Value. See also `nb_linkarg/3`. Below is an example for counting the number of solutions of a goal. Note that this implementation is thread-safe, reentrant and capable of handling exceptions. Realising these features with a traditional implementation based on `assert/retract or flag/3` is much more complicated.

```prolog
:- meta_predicate
    succeeds_n_times(0, -).

succeeds_n_times(Goal, Times) :-
    Counter = counter(0),
    ( Goal,
      arg(1, Counter, N0),
      N is N0 + 1,
      nb_setarg(1, Counter, N),
      fail
    ;
      arg(1, Counter, Times)
    ).
```

**nb_linkarg(+Arg, +Term, +Value)**

As `nb_setarg/3`, but like `nb_linkval/2` it does not duplicate Value. Use with extreme care and consult the documentation of `nb_linkval/2` before use.

**duplicate_term(+In, -Out)**

Version of `copy_term/2` that also copies ground terms and therefore ensures that destructive modification using `setarg/3` does not affect the copy. See also `nb_setval/2`, `nb_linkval/2`, `nb_setarg/3` and `nb_linkarg/3`.

**same_term(@T1, @T2)**

True if T1 and T2 are equivalent and will remain equivalent, even if `setarg/3` is used on either of them. This means T1 and T2 are the same variable, equivalent atomic data or a compound term allocated at the same address.

### 4.22 Analysing and Constructing Atoms

These predicates convert between certain Prolog atomic values on one hand and lists of *character codes* (or, for `atom_chars/2`, *characters*) on the other. The Prolog atomic values can be atoms, *characters* (which are atoms of length 1), SWI-Prolog strings, as well as numbers (integers, floats and non-integer rationals).
The character codes, also known as code values, are integers. In SWI-Prolog, these integers are Unicode code points.\footnote{BUG: On Windows the range is limited to UCS-2, 0..65535.}

To ease the pain of all text representation variations in the Prolog community, all SWI-Prolog predicates behave as \textit{flexible as possible}. This implies the ‘list-side’ accepts both a character-code-list and a character-list and the ‘atom-side’ accepts all atomic types (atom, number and string). For example, the predicates \texttt{atom_codes/2}, \texttt{number_codes/2} and \texttt{name/2} behave the same in mode (+,-), i.e., ‘listwards’, from a constant to a list of character codes. When converting the other way around:

- \texttt{atom_codes/2} will generate an atom;
- \texttt{number_codes/2} will generate a number or throw an exception;
- \texttt{name/2} will generate a number if possible and an atom otherwise.

\begin{verbatim}
atom_codes(?Atom, ?CodeList)
\end{verbatim}

\[\text{ISO}\]

Convert between an atom and a list of character codes (integers denoting characters).

- If \texttt{Atom} is instantiated, it will be translated into a list of character codes, which are unified with \texttt{CodeList}.
- If \texttt{Atom} is uninstantiated and \texttt{CodeList} is a list of character codes, then \texttt{Atom} will be unified with an atom constructed from this list.

\begin{verbatim}
?- atom_codes(hello, X).
\end{verbatim}

The ‘listwards’ call to \texttt{atom_codes/2} can also be written (functionally) using backquotes instead:

\begin{verbatim}
?- Cs = 'hello'.
\end{verbatim}

Backquoted strings can be mostly found in the body of DCG rules that process lists of character codes.

Note that this is the default interpretation for backquotes. It can be changed on a per-module basis by setting the value of the Prolog flag \texttt{back_quotes}.

\begin{verbatim}
atom_chars(?Atom, ?CharList)
\end{verbatim}

\[\text{ISO}\]

Similar to \texttt{atom_codes/2}, but \texttt{CharList} is a list of characters (atoms of length 1) rather than a list of character codes (integers denoting characters).

\begin{verbatim}
?- atom_chars(hello, X).
X = [h, e, l, l, o]
\end{verbatim}
char_code(?Atom, ?Code) [ISO]
Convert between a single character (an atom of length 1), and its character code (an integer denoting the corresponding character). The predicate alternatively accepts an SWI-Prolog string of length 1 at Atom place.

number_chars(?Number, ?CharList) [ISO]
Similar to atom_chars/2, but converts between a number and its representation as a list of characters (atoms of length 1).

- If CharList is a proper list, i.e., not unbound or a partial list, CharList is parsed according to the Prolog syntax for numbers and the resulting number is unified with Number. A syntax_error exception is raised if CharList is instantiated to a ground, proper list but does not represent a valid Prolog number.
- Otherwise, if Number is indeed a number, Number is serialized and the result is unified with CharList.

Following the ISO standard, the Prolog syntax for number allows for leading white space (including newlines) and does not allow for trailing white space. Prolog syntax-based conversion can also be achieved using format/3 and read_from_chars/2.

number_codes(?Number, ?CodeList) [ISO]
As number_chars/2, but converts to a list of character codes rather than characters. In the mode (-,+), both predicates behave identically to improve handling of non-ISO source.

atom_number(?Atom, ?Number)
Realises the popular combination of atom_codes/2 and number_codes/2 to convert between atom and number (integer, float or non-integer rational) in one predicate, avoiding the intermediate list. Unlike the ISO standard number_codes/2 predicates, atom_number/2 fails silently in mode (+,-) if Atom does not represent a number.

name(?Atomic, ?CodeList)
CodeList is a list of character codes representing the same text as Atomic. Each of the arguments may be a variable, but not both.

- When CodeList describes an integer or floating point number and Atomic is a variable, Atomic will be unified with the numeric value described by CodeList (e.g., name(N, "300"), 400 is N + 100 succeeds).
- If CodeList is not a representation of a number, Atomic will be unified with the atom with the name given by the character code list.
- If Atomic is an atom or number, the unquoted print representation of it as a character code list is unified with CodeList.

80)ISO also allows for Prolog comments in leading white space. We–and most other implementations–believe this is incorrect. We also believe it would have been better not to allow for white space, or to allow for both leading and trailing white space.
This predicate is part of the Edinburgh tradition. It should be considered deprecated although, given its long tradition, it is unlikely to be removed from the system. It still has some value for converting input to a number or an atom (depending on the syntax). New code should consider the ISO predicates atom_codes/2, number_codes/2 or the SWI-Prolog predicate atom_number/2.

**term_to_atom(ENTITY1, ENTITY2)**

True if ENTITY2 describes a term that unifies with ENTITY1. When ENTITY2 is instantiated, ENTITY2 is parsed and the result unified with ENTITY1. If ENTITY2 has no valid syntax, a syntax_error exception is raised. Otherwise ENTITY1 is “written” on ENTITY2 using write_term/2 with the option quoted(true). See also format/3, with_output_to/2 and term_string/2.

**atom_to_term(ENTITY1, ENTITY2, ENTITY3)**

[deprecated]

Use ENTITY1 as input to read_term/2 using the option variable_names and return the read term in ENTITY2 and the variable bindings in ENTITY3. ENTITY3 is a list of Name = Var couples, thus providing access to the actual variable names. See also read_term/2. If ENTITY1 has no valid syntax, a syntax_error exception is raised. New code should use read_term_from_atom/3.

**atomic_concat(ENTITY1, ENTITY2, ENTITY3)**

[ISO]

ENTITY3 forms the concatenation of ENTITY1 and ENTITY2. At least two of the arguments must be instantiated to atoms. This predicate also allows for the mode (-,-,+), non-deterministically splitting the 3rd argument into two parts (as append/3 does for lists). SWI-Prolog allows for atomic arguments. Portable code must use atomic_concat/3 if non-atom arguments are involved.

**atomic_concat(ENTITY1, ENTITY2, ENTITY3)**

[commons]

ENTITY3 represents the text after converting ENTITY1 and ENTITY2 to text and concatenating the result:

?- atomic_concat(\text{name}, 42, X).
X = name42.

**atomic_list_concat(ENTITY1, ENTITY2, ENTITY3)**

[commons]

ENTITY3 is a list of strings, atoms, integers, floating point numbers or non-integer rationals. Succeeds if ENTITY2 can be unified with the concatenated elements of ENTITY1. Equivalent to atomic_list_concat(ENTITY1, "\text{ }, \text{ }, \text{ }").

**atomic_list_concat(ENTITY1, ENTITY2, ENTITY3)**

[commons]

Creates an atom just like atomic_list_concat/2, but inserts \text{Separator} between each pair of inputs. For example:

?- atomic_list_concat([\text{gnu}, \text{ gnat}], ', ', A).
A = 'gnu, gnat'

The ‘atomwards’ transformation is usually called a string join operation in other programming languages.
The SWI-Prolog version of this predicate can also be used to split atoms by instantiating Separator and Atom as shown below. We kept this functionality to simplify porting old SWI-Prolog code where this predicate was called `concat_atom/3`. When used in mode (-,+,+), Separator must be a non-empty atom. See also `split_string/4`.

```prolog
?- atomic_list_concat(L, -, 'gnu-gnat').
L = [gnu, gnat]
```

**atom_length(+Atom, -Length)**  
[ISO]  
True if `Atom` is an atom of `Length` characters. The SWI-Prolog version accepts all atomic types, as well as code-lists and character-lists. New code should avoid this feature and use `write_length/3` to get the number of characters that would be written if the argument was handed to `write_term/3`.

```prolog
atom_length(Atom, Length).
```

**atom_prefix(+Atom, +Prefix)**  
[deprecated]  
True if `Atom` starts with the characters from `Prefix`. Its behaviour is equivalent to `?- sub_atom(Atom, 0, _, _, Prefix)`.

[ISO]  
ISO predicate for breaking atoms. It maintains the following relation: `SubAtom` is a sub-atom of `Atom` that starts at (0-based index) `Before`, has `Length` characters, and `Atom` contains `After` characters after the match. The implementation minimises non-determinism and creation of atoms. This is a flexible predicate that can do search, prefix- and suffix-matching, etc.

Pick out a sub-atom of length 3 starting a 0-based index 2:

```prolog
?- sub_atom('aaxyzbbb', 2, 3, After, SubAtom).
After = 3,
SubAtom = xyz.
```

On backtracking, matches are delivered in order left-to-right (i.e. `Before` increases monotonically):

```prolog
?- sub_atom('xAATGATGAXATGAXATGAX', Before, Length, After, 'ATGAX').
Before = 1, Length = 4, After = 14 ;
Before = Length, Length = 4, After = 11 ;
Before = 9, Length = 4, After = 6 ;
Before = 14, Length = 4, After = 1 ;
false.
```

See also `sub_string/5`, the corresponding predicate for SWI-Prolog strings.

**sub_atom_icasechk(+Haystack, ?Start, +Needle)**  
[semidet]  
True when `Needle` is a sub atom of `Haystack` starting at `Start`. The match is ‘half case insensitive’, i.e., uppercase letters in `Needle` only match themselves, while lowercase letters in
Needle match case insensitively. Start is the first 0-based offset inside Haystack where Needle matches.\textsuperscript{81}

### 4.23 Localization (locale) support

SWI-Prolog provides (currently limited) support for localized applications.

- The predicates `char_type/2` and `code_type/2` query character classes depending on the locale.
- The predicates `collation_key/2` and `locale_sort/2` can be used for locale dependent sorting of atoms.
- The predicate `format_time/3` can be used to format time and date representations, where some of the specifiers are locale dependent.
- The predicate `format/2` provides locale-specific formatting of numbers. This functionality is based on a more fine-grained localization model that is the subject of this section.

A locale is a (optionally named) read-only object that provides information to locale specific functions.\textsuperscript{82} The system creates a default locale object named `default` from the system locale. This locale is used as the initial locale for the three standard streams as well as the main thread. Locale sensitive output predicates such as `format/3` get their locale from the stream to which they deliver their output. New streams get their locale from the thread that created the stream. Threads get their locale from the thread that created them.

**locale_create(-Locale, +Default, +Options)**

Create a new locale object. `Default` is either an existing locale or a string that denotes the name of a locale provided by the system, such as "en\textunderscore EN\textunderscore UTF\textunderscore 8". The values read from the default locale can be modified using `Options`. `Options` provided are:

- **alias(+Atom)**
  
  Give the locale a name.

- **decimal_point(+Atom)**
  
  Specify the decimal point to use.

- **thousands\_sep(+Atom)**
  
  Specify the string that delimits digit groups. Only effective is `grouping` is also specified.

- **grouping(+List)**
  
  Specify the grouping of digits. Groups are created from the right (least significant) digits, left of the decimal point. `List` is a list of integers, specifying the number of digits in each group, counting from the right. If the last element is `repeat(Count)`, the remaining digits are grouped in groups of size `Count`. If the last element is a normal integer, digits further to the left are not grouped.

---

\textsuperscript{81} This predicate replaces `apropos_match/2`, used by the help system, while extending it with locating the (first) match and performing case insensitive prefix matching. We are still not happy with the name and interface.

\textsuperscript{82} The locale interface described in this section and its effect on `format/2` and reading integers from digit groups was discussed on the SWI-Prolog mailinglist. Most input in this discussion is from Ulrich Neumerkel and Richard O'Keefe. The predicates in this section were designed by Jan Wielemaker.
4.24. CHARACTER PROPERTIES

For example, the English locale uses

```
[ decimal_point('.'), thousands_sep(','), grouping([repeat(3)]) ]
```

Named locales exist until they are destroyed using `locale.destroy/1` and they are no longer referenced. Unnamed locales are subject to (atom) garbage collection.

`locale_destroy(+Locale)`

Destroy a locale. If the locale is named, this removes the name association from the locale, after which the locale is left to be reclaimed by garbage collection.

`locale_property(?Locale, ?Property)`

True when `Locale` has `Property`. Properties are the same as the `Options` described with `locale.create/3`.

`set_locale(+Locale)`

Set the default locale for the current thread, as well as the locale for the standard streams (`user_input`, `user_output`, `user_error`, `current_output` and `current_input`). This locale is used for new streams, unless overruled using the `locale(Locale)` option of `open/4` or `set_stream/2`.

`current_locale(-Locale)`

True when `Locale` is the locale of the calling thread.

4.24 Character properties

SWI-Prolog offers two comprehensive predicates for classifying characters and character codes. These predicates are defined as built-in predicates to exploit the C-character classification’s handling of `locale` (handling of local character sets). These predicates are fast, logical and deterministic if applicable.

In addition, there is the library `ctypes` providing compatibility with some other Prolog systems. The predicates of this library are defined in terms of `code_type/2`.

`char_type(?Char, ?Type)`

Tests or generates alternative `Types` or `Chars`. The character types are inspired by the standard C `<ctype.h>` primitives. The types are sensitive to the active `locale`, see `setlocale/3`. Most of the `Types` are mapped to the Unicode classification functions from `<wctype.h>`, e.g., `alnum` uses `iswalnum()`. The types `prolog_var_start`, `prolog_atom_start`, `prolog_identifier_continue` and `prolog_symbol` are based on the locale-independent built-in classification routines that are also used by `read/1` and friends.

Note that the mode `(-,+)` is only efficient if the `Type` has a parameter, e.g., `char_type(C, digit(8))`. If `Type` is a atomic, the whole unicode range (0..0x1ffff) is generated and tested against the character classification function.

`alnum`

`Char` is a letter (upper- or lowercase) or digit.

`alpha`

`Char` is a letter (upper- or lowercase).
csym

Char is a letter (upper- or lowercase), digit or the underscore (_). These are valid C and Prolog symbol characters.

csymf

Char is a letter (upper- or lowercase) or the underscore (_). These are valid first characters for C and Prolog symbols.

ascii

Char is a 7-bit ASCII character (0..127).

white

Char is a space or tab, i.e. white space inside a line.

cntrl

Char is an ASCII control character (0..31), ASCII DEL character (127), or non-ASCII character in the range 128..159 or 8232..8233.

digit

Char is a digit, i.e., Char is in 0...9. See also decimal.

digit(Weight)

Char is a digit with value Weight. I.e. char_type(X, digit(6)) yields X = ’6’. Useful for parsing numbers.

xdigit(Weight)

Char is a hexadecimal digit with value Weight. I.e. char_type(a, xdigit(X)) yields X = ’10’. Useful for parsing numbers.

decimal

Char is a decimal digit in any script. This implies it has the Unicode general category Nd).

decimal(Weight)

Char is a decimal digit in any script with Weight 0...9.

print

Char is printable character.

graph

Char produces a visible mark on a page when printed. Note that the space is not included!

lower

Char is a lowercase letter.

lower(Upper)

Char is a lowercase version of Upper. Only true if Char is lowercase and Upper uppercase.

to_lower(Upper)

Char is a lowercase version of Upper. For non-letters, or letter without case, Char and Lower are the same. See also upcase/atom/2 and downcase/atom/2.

upper

Char is an uppercase letter.

upper(Lower)

Char is an uppercase version of Lower. Only true if Char is uppercase and Lower lowercase.
4.24. CHARACTER PROPERTIES

4.24.1 Case conversion

There is nothing in the Prolog standard for converting case in textual data. The SWI-Prolog predicates `code_type/2` and `char_type/2` can be used to test and convert individual characters. We have started some additional support:

```
downcase_atom(+AnyCase, -LowerCase)
```

Converts the characters of `AnyCase` into lowercase as `char_type/2` does (i.e. based on

```
to_upper(Lower)
```

*Char* is an uppercase version of *Lower*. For non-letters, or letter without case, *Char* and *Lower* are the same. See also `upcase_atom/2` and `downcase_atom/2`.

```
punct
```

*Char* is a punctuation character. This is a graph character that is not a letter or digit.

```
space
```

*Char* is some form of layout character (tab, vertical tab, newline, etc.).

```
end_of_file
```

*Char* is -1.

```
end_of_line
```

*Char* ends a line (ASCII: 10..13).

```
ewline
```

*Char* is a newline character (10).

```
period
```

*Char* counts as the end of a sentence (.,!,?).

```
quote
```

*Char* is a quote character (", ", ").

```
paren(Close)
```

*Char* is an open parenthesis and *Close* is the corresponding close parenthesis.

```
prolog_var_start
```

*Char* can start a Prolog variable name.

```
prolog_atom_start
```

*Char* can start a unquoted Prolog atom that is not a symbol.

```
prolog_identifier_continue
```

*Char* can continue a Prolog variable name or atom.

```
prolog_symbol
```

*Char* is a Prolog symbol character. Sequences of Prolog symbol characters glue together to form an unquoted atom. Examples are =.., \=, etc.

```
code_type(?Code, ?Type)
```

As `char_type/2`, but uses character codes rather than one-character atoms. Please note that both predicates are as flexible as possible. They handle either representation if the argument is instantiated and will instantiate only with an integer code or a one-character atom, depending of the version used. See also the Prolog flag `double_quotes, atom_chars/2` and `atom_codes/2`.

---

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the defined locale if Prolog provides locale support on the hosting platform) and unifies the lowercase atom with LowerCase.

**upcase_atom(+AnyCase, -UpperCase)**

Converts, similar to downcase_atom/2, an atom to uppercase.

### 4.24.2 White space normalization

**normalize_space(-Out, +In)**

Normalize white space in In. All leading and trailing white space is removed. All non-empty sequences for Unicode white space characters are replaced by a single space (\u0020) character. Out uses the same conventions as with_output_to/2 and format/3.

### 4.24.3 Language-specific comparison

This section deals with predicates for language-specific string comparison operations.

**collation_key(+Atom, -Key)**

Create a Key from Atom for locale-specific comparison. The key is defined such that if the key of atom A precedes the key of atom B in the standard order of terms, A is alphabetically smaller than B using the sort order of the current locale.

The predicate collation_key/2 is used by locale_sort/2 from library(sort). Please examine the implementation of locale_sort/2 as an example of using this call.

The Key is an implementation-defined and generally unreadable string. On systems that do not support locale handling, Key is simply unified with Atom.

**locale_sort(+List, -Sorted)**

Sort a list of atoms using the current locale. List is a list of atoms or string objects (see section 5.2). Sorted is unified with a list containing all atoms of List, sorted to the rules of the current locale. See also collation_key/2 and setlocale/3.

### 4.25 Operators

Operators are defined to improve the readability of source code. For example, without operators, to write $2*3+4*5$ one would have to write $+(\times2,3),\times4,5)$. In Prolog, a number of operators have been predefined. All operators, except for the comma (,) can be redefined by the user.

Some care has to be taken before defining new operators. Defining too many operators might make your source ‘natural’ looking, but at the same time using many operators can make it hard to understand the limits of your syntax.

In SWI-Prolog, operators are local to the module in which they are defined. Operators can be exported from modules using a term op(Precedence, Type, Name) in the export list as specified by module/2. Many modern Prolog systems have module specific operators. Unfortunately, there is no established interface for exporting and importing operators. SWI-Prolog’s convention has been adopted by YAP.

The module table of the module user acts as default table for all modules and can be modified explicitly from inside a module to achieve compatibility with other Prolog that do not have module-local operators:
Although operators are module-specific and the predicates that define them (op/3) or rely on them such as current_op/3, read/1 and write/1 are module sensitive, they are not proper meta-predicates. If they were proper meta predicates read/1 and write/1 would use the module from which they are called, breaking compatibility with other Prolog systems. The following rules apply:

1. If the module is explicitly specified by qualifying the third argument (op/3, current_op/3) or specifying a module(Module) option (read_term/3, write_term/3), this module is used.

2. While compiling, the module into which the compiled code is loaded applies.

3. Otherwise, the typein module applies. This is normally user and may be changed using module/1.

In SWI-Prolog, a quoted atom never acts as an operator. Note that the portable way to stop an atom acting as an operator is to enclose it in parentheses like this: (myop). See also section 5.3.1.

\textbf{op(+Precedence, +Type, :Name)}

[ISO]

Declare \texttt{Name} to be an operator of type \texttt{Type} with precedence \texttt{Precedence}. \texttt{Name} can also be a list of names, in which case all elements of the list are declared to be identical operators. \texttt{Precedence} is an integer between 0 and 1200. Precedence 0 removes the declaration. \texttt{Type} is one of: xf, yf, xfx, xfy, yfx, fy or fx. The ‘f’ indicates the position of the functor, while x and y indicate the position of the arguments. ‘y’ should be interpreted as “on this position a term with precedence lower or equal to the precedence of the functor should occur”. For ‘x’ the precedence of the argument must be strictly lower. The precedence of a term is 0, unless its principal functor is an operator, in which case the precedence is the precedence of this operator.

A term enclosed in parentheses (...) has precedence 0.

The predefined operators are shown in table 4.2. Operators can be redefined, unless prohibited by one of the limitations below. Applications must be careful with (re-)defining operators because changing operators may cause (other) files to be interpreted \textbf{differently}. Often this will lead to a syntax error. In other cases, text is read silently into a different term which may lead to subtle and difficult to track errors.

- It is not allowed to redefine the comma (’, ’).
- The bar (|) can only be (re-)defined as infix operator with priority not less than 1001.

In SWI-Prolog, operators are \textit{local} to a module (see also section 6.9). Keeping operators in modules and using controlled import/export of operators as described with the \texttt{module/2} directive keep the issues manageable. The module \texttt{system} provides the operators from table 4.2 and these operators cannot be modified. Files that are loaded from the SWI-Prolog directories
resolve operators and predicates from this system module rather than user, which makes the semantics of the library and development system modules independent of operator changes to the user module. See section 4.25 for details about the relation between operators and modules.

**current_op(?Precedence, ?Type, ?:Name)**

True if Name is currently defined as an operator of type Type with precedence Precedence. See also op/3. Note that an unqualified Name does not resolve to the calling context but, when compiling, to the compiler’s target module and otherwise to the typein module. See section 4.25 for details.

### 4.26 Character Conversion

Although I wouldn’t really know why you would like to use these features, they are provided for ISO compliance.

**char_conversion(+CharIn, +CharOut)**

Define that term input (see read_term/3) maps each character read as CharIn to the character CharOut. Character conversion is only executed if the Prolog flag char_conversion is
4.27. ARITHMETIC

set to true and not inside quoted atoms or strings. The initial table maps each character onto itself. See also current_char_conversion/2.

\[\text{current_char_conversion}(\text{?CharIn}, \text{?CharOut})\]  
[ISO]
Queries the current character conversion table. See char_conversion/2 for details.

4.27  Arithmetic

Arithmetic can be divided into some special purpose integer predicates and a series of general predicates for integer, floating point and rational arithmetic as appropriate. The general arithmetic predicates all handle expressions. An expression is either a simple number or a function. The arguments of a function are expressions. The functions are described in section 4.27.2.

4.27.1  Special purpose integer arithmetic

The predicates in this section provide more logical operations between integers. They are not covered by the ISO standard, although they are ‘part of the community’ and found as either library or built-in in many other Prolog systems.

\[\text{between}(+Low, +High, ?Value)\]
\[\text{Low and High are integers, High } \geq \text{ Low. If Value is an integer, Low } \leq \text{ Value } \leq \text{ High. When Value is a variable it is successively bound to all integers between Low and High. If High is inf or infinite, between/3 is true iff Value } \geq \text{ Low, a feature that is particularly interesting for generating integers from a certain value.}\]

\[\text{succ(?Int1, ?Int2)}\]
\[\text{True if Int2 } = \text{ Int1 } + 1 \text{ and Int1 } \geq 0. \text{ At least one of the arguments must be instantiated to a natural number. This predicate raises the domain error not_less_than_zero if called with a negative integer. E.g. succ(X, 0) fails silently and succ(X, -1) raises a domain error.}\]

\[\text{plus(?Int1, ?Int2, ?Int3)}\]
\[\text{True if Int3 } = \text{ Int1 } + \text{ Int2. At least two of the three arguments must be instantiated to integers.}\]

\[\text{divmod(+Dividend, +Divisor, -Quotient, -Remainder)}\]
\[\text{This predicate is a shorthand for computing both the Quotient and Remainder of two integers in a single operation. This allows for exploiting the fact that the low level implementation for computing the quotient also produces the remainder. Timing confirms that this predicate is almost twice as fast as performing the steps independently. Semantically, divmod/4 is defined as below.}\]

```prolog
divmod(Dividend, Divisor, Quotient, Remainder) :-
    Quotient is Dividend div Divisor,
    Remainder is Dividend mod Divisor.
```

\[\text{divmod}(\text{Dividend, Divisor, Quotient, Remainder})\]

\[\text{We prefer infinite, but some other Prolog systems already use inf for infinity; we accept both for the time being.}\]

\[\text{The behaviour to deal with natural numbers only was defined by Richard O’Keefe to support the common count-down-to-zero in a natural way. Up to 5.1.8, succ/2 also accepted negative integers.}\]
Note that this predicate is only available if SWI-Prolog is compiled with unbounded integer support. This is the case for all packaged versions.

\[ \text{nth_integer_root_and_remainder}(+N, +I, -Root, -Remainder) \]

True when \( Root^N + Remainder = I \). \( N \) and \( I \) must be integers.\(^85\) \( N \) must be one or more. If \( I \) is negative and \( N \) is odd, \( Root \) and \( Remainder \) are negative, i.e., the following holds for \( I < 0 \):

\[
\begin{align*}
&\text{I} < 0, \\
&\text{N mod 2} \not\equiv 0, \\
&\text{nth_integer_root_and_remainder(N, I, Root, Remainder),} \\
&\text{IPos is -I,} \\
&\text{nth_integer_root_and_remainder(N, IPos, RootPos, RemainderPos),} \\
&\text{Root =:= -RootPos,} \\
&\text{Remainder =:= -RemainderPos.}
\end{align*}
\]

### 4.27.2 General purpose arithmetic

The general arithmetic predicates are optionally compiled (see `set_prolog_flag/2` and the `-O` command line option). Compiled arithmetic reduces global stack requirements and improves performance. Unfortunately compiled arithmetic cannot be traced, which is why it is optional.

\[ +\text{Expr1} > +\text{Expr2} \]  

True if expression \( \text{Expr1} \) evaluates to a larger number than \( \text{Expr2} \).

\[ +\text{Expr1} < +\text{Expr2} \]  

True if expression \( \text{Expr1} \) evaluates to a smaller number than \( \text{Expr2} \).

\[ +\text{Expr1} =< +\text{Expr2} \]  

True if expression \( \text{Expr1} \) evaluates to a smaller or equal number to \( \text{Expr2} \).

\[ +\text{Expr1} =< +\text{Expr2} \]  

True if expression \( \text{Expr1} \) evaluates to a larger or equal number to \( \text{Expr2} \).

\[ +\text{Expr1} \not\equiv +\text{Expr2} \]  

True if expression \( \text{Expr1} \) evaluates to a number non-equal to \( \text{Expr2} \).

\[ -\text{Number is} +\text{Expr} \]

True when \( \text{Number} \) is the value to which \( \text{Expr} \) evaluates. Typically, \( \text{is}/2 \) should be used with unbound left operand. If equality is to be tested, \( =:=/2 \) should be used. For example:

\(^85\)This predicate was suggested by Markus Triska. The final name and argument order is by Richard O’Keefe. The decision to include the remainder is by Jan Wielemaker. Including the remainder makes this predicate about twice as slow if \( Root \) is not exact.
### 4.27. ARITHMETIC

?- 1 is sin(pi/2).
Fails! \( \sin(\pi/2) \) evaluates to the float 1.0, which does not unify with the integer 1.

?- 1 =:= sin(pi/2).
Succeeds as expected.

**Arithmetic types**

SWI-Prolog defines the following numeric types:

- **integer**
  
  If SWI-Prolog is built using the *GNU multiple precision arithmetic library* (GMP), integer arithmetic is *unbounded*, which means that the size of integers is limited by available memory only. Without GMP, SWI-Prolog integers are 64-bits, regardless of the native integer size of the platform. The type of integer support can be detected using the Prolog flags `bounded`, `min_integer` and `max_integer`. As the use of GMP is default, most of the following descriptions assume unbounded integer arithmetic.

  Internally, SWI-Prolog has three integer representations. Small integers (defined by the Prolog flag `max_tagged_integer`) are encoded directly. Larger integers are represented as 64-bit values on the global stack. Integers that do not fit in 64 bits are represented as serialised GNU MPZ structures on the global stack. Integers that do not fit in 64 bits are represented as serialised GNU MPZ structures on the global stack.

- **rational number**
  
  Rational numbers \((Q)\) are quotients of two integers \((N/M)\). Rational arithmetic is only provided if GMP is used (see above). Rational numbers satisfy the type tests `rational/1`, `number/1` and `atomic/1` and may satisfy the type test `integer/1`, i.e., integers are considered rational numbers. Rational numbers are always kept in canonical representation, which means \(M\) is positive and \(N\) and \(M\) have no common divisors. Rational numbers are introduced into the computation using the functions `rational/1`, `rationalize/1` or the `rdiv/2` (rational division) function. If the Prolog flag `prefer_rationals` is true (default), division \((/2)\) and integer power \((^/2)\) also produce a rational number.

- **float**
  
  Floating point numbers are represented using the C type `double`. On most of today’s platforms these are 64-bit IEEE floating point numbers.

  Arithmetic functions that require integer arguments accept, in addition to integers, rational numbers with (canonical) denominator ‘1’. If the required argument is a float the argument is converted to float. Note that conversion of integers to floating point numbers may raise an overflow exception. In all other cases, arguments are converted to the same type using the order below.

  
  \[ \text{integer} \rightarrow \text{rational number} \rightarrow \text{floating point number} \]

**Rational number examples**

The use of rational numbers with unbounded integers allows for exact integer or fixed point arithmetic under addition, subtraction, multiplication, division and exponentiation \((^/2)\). Support for rational numbers depends on the Prolog flag `prefer_rationals`. If this is true (default), the number division function \((/2)\) and exponentiation function \((^/2)\) generate a rational number on integer and rational arguments and `read/1` and friends `read [-+][0-9_]+/[0-9_]+` into a rational number. See also section 2.16.1. Here are some examples.
A is 2/6  A = 1/3
A is 4/3 + 1  A = 7/3
A is 4/3 + 1.5  A = 2.83333
A is 4/3 + rationalize(1.5)  A = 17/6

Note that floats cannot represent all decimal numbers exactly. The function rational/1 creates an exact equivalent of the float, while rationalize/1 creates a rational number that is within the float rounding error from the original float. Please check the documentation of these functions for details and examples.

Rational numbers can be printed as decimal numbers with arbitrary precision using the format/3 floating point conversion:

?- A is 4/3 + rational(1.5),
   format('˜50f˜n', [A]).
2.833333333333333333333333333333333333333333333333
A = 17/6

Rational numbers or floats

SWI-Prolog uses rational number arithmetic if the Prolog flag prefer_rationals is true and if this is defined for a function on the given operants. This results in perfectly precise answers. Unfortunately rational numbers can get really large and, if a precise answer is not needed, a big waste of memory and CPU time. In such cases one should use floating point arithmetic. The Prolog flag max_rational_size provides a tripwire to detect cases where rational numbers get big and react on these events.

Floating point arithmetic can be forced by forcing a float into an argument at any point, i.e., the result of a function with at least one float is always float except for the float-to-integer rounding and truncating functions such as round/1, rational/1 or float_integer_part/1.

Float arithmetic is typically forced by using a floating point constant as initial value or operant. Alternatively, the float/1 function forces conversion of the argument.

IEEE 754 floating point arithmetic

The Prolog ISO standard defines that floating point arithmetic returns a valid floating point number or raises an exception. IEEE floating point arithmetic defines two modes: raising exceptions and propagating the special float values NaN, Inf, −Inf and −0.0. SWI-Prolog implements a part of the ECLiPSe proposal to support non-exception based processing of floating point numbers. There are four flags that define handling the four exceptional events in floating point arithmetic, providing the choice between error and returning the IEEE special value. Note that these flags only apply for floating point arithmetic. For example rational division by zero always raises an exception.

<table>
<thead>
<tr>
<th>Flag</th>
<th>Default</th>
<th>Alternative</th>
</tr>
</thead>
<tbody>
<tr>
<td>float_overflow</td>
<td>error</td>
<td>infinity</td>
</tr>
<tr>
<td>float_zero_div</td>
<td>error</td>
<td>infinity</td>
</tr>
<tr>
<td>float_undefined</td>
<td>error</td>
<td>nan</td>
</tr>
<tr>
<td>float_underflow</td>
<td>ignore</td>
<td>error</td>
</tr>
</tbody>
</table>
The Prolog flag `float_rounding` and the function `roundtoward/2` control the rounding mode for floating point arithmetic. The default rounding is `to_nearest` and the following alternatives are provided: `to_positive`, `to_negative` and `to_zero`.

```prolog
float_class(+Float, -Class) [det]
Wraps C99 fpclassify() to access the class of a floating point number. Raises a type error if `Float` is not a float. Defined classes are below.

nan
`Float` is “Not a number”. See `nan/0`. May be produced if the Prolog flag `float_undefined` is set to `nan`. Although IEEE 754 allows NaN to carry a payload and have a sign, SWI-Prolog has only a single NaN values. Note that two NaN terms compare equal in the standard order of terms (==/2, etc.), they compare non-equal for arithmetic (=:=/2, etc.).

infinite
`Float` is positive or negative infinity. See `inf/0`. May be produced if the Prolog flag `float_overflow` or the flag `float_zero_div` is set to `infinity`.

zero
`Float` is zero (0.0 or -0.0)

subnormal
`Float` is too small to be represented in normalized format. May not be produced if the Prolog flag `float_underflow` is set to `error`.

normal
`Float` is a normal floating point number.

float_parts(+Float, -Mantissa, -Base, -Exponent) [det]
True when `Mantissa` is the normalized fraction of `Float`, `Base` is the radix and `Exponent` is the exponent. This uses the C function frexp(). If `Float` is NaN or ±Inf `Mantissa` has the same value and `Exponent` is 0 (zero). In the current implementation `Base` is always 2. The following relation is always true:

\[
Float =:= Mantissa \times Base^{Exponent}
\]

bounded_number(?Low, ?High, +Num) [det]
True if `Low` < `Num` < `High`. Raises a type error if `Num` is not a number. This predicate can be used both to check and generate bounds across the various numeric types. Note that a number cannot be bounded by itself and NaN, Inf, and -Inf are not bounded numbers.

If `Low` and/or `High` are variables they will be unified with `tightest` values that still meet the bounds criteria. The generated bounds will be integers if `Num` is an integer; otherwise they will be floats (also see `nexttoward/2` for generating float bounds). Some examples:

?- bounded_number(0,10,1).
true.

?- bounded_number(0.0,1.0,1r2).
true.
Floating point arithmetic precision

SWI-Prolog represents floats using the C `double` type. On virtually all modern hardware this implies it uses 64-bit IEEE 754 floating point numbers. See also section 4.27.2. All floating point arithmetic is performed using C. Different C compilers, different C math libraries and different hardware floating point support may yield different results for the same expression on different instances of SWI-Prolog.

Arithmetic Functions

Arithmetic functions are terms which are evaluated by the arithmetic predicates described in section 4.27.2. There are four types of arguments to functions:

- `Expr` Arbitrary expression, returning either a floating point value or an integer.
- `IntExpr` Arbitrary expression that must evaluate to an integer.
- `RatExpr` Arbitrary expression that must evaluate to a rational number.
- `FloatExpr` Arbitrary expression that must evaluate to a floating point.

For systems using bounded integer arithmetic (default is unbounded, see section 4.27.2 for details), integer operations that would cause overflow automatically convert to floating point arithmetic.

SWI-Prolog provides many extensions to the set of floating point functions defined by the ISO standard. The current policy is to provide such functions on ‘as-needed’ basis if the function is widely supported elsewhere and notably if it is part of the C99 mathematical library. In addition, we try to maintain compatibility with other Prolog implementations.

\[
\begin{align*}
& \text{\texttt{\(-\)}} +\text{Expr} \\
& \text{Result} = -\text{Expr} \quad [\text{ISO}] \\
& \text{\texttt{\(+\)}} +\text{Expr} \\
& \text{Result} = \text{Expr}. \text{ Note that if } + \text{ is followed by a number, the parser discards the +. I.e.} \\
& \text{?- integer(+1) succeeds.}
\end{align*}
\]
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\[ +Expr1 + +Expr2 \]
\[ Result = Expr1 + Expr2 \] [ISO]

\[ +Expr1 - +Expr2 \]
\[ Result = Expr1 - Expr2 \] [ISO]

\[ +Expr1 \times +Expr2 \]
\[ Result = Expr1 \times Expr2 \] [ISO]

\[ +Expr1 / +Expr2 \]
\[ Result = \frac{Expr1}{Expr2} \]

If the flag iso is true or one of the arguments is a float, both arguments are converted to float and the return value is a float. Otherwise the result type depends on the Prolog flag prefer.rationals. If true, the result is always a rational number. If false the result is rational if at least one of the arguments is rational. Otherwise (both arguments are integer) the result is integer if the division is exact and float otherwise. See also section 4.27.2, // / /2, and rdiv / 2.

The current default for the Prolog flag prefer.rationals is false. Future version may switch this to true, providing precise results when possible. The pitfall is that in general rational arithmetic is slower and can become very slow and produce huge numbers that require a lot of (global stack) memory. Code for which the exact results provided by rational numbers is not needed should force float results by making one of the operators float, for example by dividing by 10.0 rather than 10 or by using float / 1. Note that when one of the arguments is forced to a float the division is a float operation while if the result is forced to the float the division is done using rational arithmetic.

\[ +IntExpr1 \mod +IntExpr2 \]
\[ Result = IntExpr1 - (IntExpr1 \div IntExpr2) \times IntExpr2, \]

where \( \div \) is floored division.

\[ +IntExpr1 \rem +IntExpr2 \]
Remainder of integer division. Behaves as if defined by
\[ Result = IntExpr1 - (IntExpr1 \// IntExpr2) \times IntExpr2 \]

\[ +IntExpr1 \div // +IntExpr2 \]
Integer division, defined as \( Result = \text{rnd}_1(Expr1/Expr2) \). The function \( \text{rnd}_1 \) is the default rounding used by the C compiler and available through the Prolog flag integer.rounding.function. In the C99 standard, C-rounding is defined as towards_zero.86

\( \text{div}(+IntExpr1, +IntExpr2) \)
Integer division, defined as \( Result = (IntExpr1 - IntExpr1 \mod IntExpr2) \div IntExpr2 \). In other words, this is integer division that rounds towards -infinity. This function guarantees behaviour that is consistent with mod / 2, i.e., the following holds for every pair of integers \( X, Y \) where \( Y \neq 0 \).

\[
Q \text{ is } \text{div}(X, Y), \\
M \text{ is } \text{mod}(X, Y), \\
X =: Y \times Q + M.
\]

86Future versions might guarantee rounding towards zero.

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+\texttt{RatExpr rdiv +RatExpr}
Rational number division. This function is only available if SWI-Prolog has been compiled with rational number support. See section 4.27.2 for details.

+\texttt{IntExpr1 gcd +IntExpr2}
Result is the greatest common divisor of \texttt{IntExpr1} and \texttt{IntExpr2}. The GCD is always a positive integer. If either expression evaluates to zero the GCD is the result of the other expression.

+\texttt{IntExpr1 lcm +IntExpr2}
Result is the least common multiple of \texttt{IntExpr1}, \texttt{IntExpr2}.\footnote{BUG: If the system is compiled for bounded integers only \texttt{lcm/2} produces an integer overflow if the product of the two expressions does not fit in a 64 bit signed integer. The default build with unbounded integer support has no such limit.} If either expression evaluates to zero the LCM is zero.

\texttt{abs(+Expr)}
Evaluate \texttt{Expr} and return the absolute value of it.

\texttt{sign(+Expr)} \textit{[ISO]}
Evaluate to -1 if \texttt{Expr} < 0, 1 if \texttt{Expr} > 0 and 0 if \texttt{Expr} = 0. If \texttt{Expr} evaluates to a float, the return value is a float (e.g., -1.0, 0.0 or 1.0). In particular, note that sign(-0.0) evaluates to 0.0. See also \texttt{copysign/2}.

\texttt{copysign(+Expr1, +Expr2)} \textit{[ISO]}
Evaluate to \texttt{X}, where the absolute value of \texttt{X} equals the absolute value of \texttt{Expr1} and the sign of \texttt{X} matches the sign of \texttt{Expr2}. This function is based on copysign() from C99, which works on double precision floats and deals with handling the sign of special floating point values such as -0.0. Our implementation follows C99 if both arguments are floats. Otherwise, \texttt{copysign/2} evaluates to \texttt{Expr1} if the sign of both expressions matches or -\texttt{Expr1} if the signs do not match. Here, we use the extended notion of signs for floating point numbers, where the sign of -0.0 and other special floats is negative.

\texttt{nexttoward(+Expr1, +Expr2)}
Evaluates to floating point number following \texttt{Expr1} in the direction of \texttt{Expr2}. This relates to \texttt{epsilon/0} in the following way:

\begin{verbatim}
?- epsilon =:= nexttoward(1,2)-1.
true.
\end{verbatim}

\texttt{roundtoward(+Expr1, +RoundMode)}
Evaluate \texttt{Expr1} using the floating point rounding mode \texttt{RoundMode}. This provides a local alternative to the Prolog flag \texttt{float_rounding}. This function can be nested. The supported values for \texttt{RoundMode} are the same as the flag values: \texttt{to_nearest}, \texttt{to_positive}, \texttt{to_negative} or \texttt{to_zero}.

Note that floating point arithmetic is provided by the C compiler and C runtime library. Unfortunately most C libraries do not correctly implement the rounding modes for notably the trigonometry and exponential functions. There exist correct libraries such as \texttt{crlibm}, but these
libraries are large, most of them are poorly maintained or have an incompatible license. C run-
time libraries do a better job using the default `to nearest` rounding mode. SWI-Prolog now
assumes this mode is correct and translates upward rounding to be the `nexttoward/2` in-
finity and downward rounding `nexttoward/2` `-infinity`. If the “to nearest” rounding mode is
correct, this ensures that the true value is between the downward and upward rounded values, al-
though the generated interval is larger than needed. Unfortunately this is not the case as shown
in Accuracy of Mathematical Functions in Single, Double, Extended Double and Quadruple
Precision by Vincenzo Innocente and Paul Zimmermann.

\[ \text{max}(+Expr1, +Expr2) \]  
Evaluate to the larger of \(Expr1\) and \(Expr2\). Both arguments are compared after converting to
the same type, but the return value is in the original type. For example, \(\text{max}(2.5, 3)\) compares
the two values after converting to float, but returns the integer 3. If both values are numerical
equal the returned max is of the type used for the comparison. For example, the max of 1 and
1.0 is 1.0 because both numbers are converted to float for the comparison. However, the special
float -0.0 is smaller than 0.0 as well as the integer 0.

\[ \text{min}(+Expr1, +Expr2) \]  
Evaluate to the smaller of \(Expr1\) and \(Expr2\). See \text{max}/2 for a description of type handling.

\[ (+\text{Char}, []) \]  
A list of one element evaluates to the character code of this element.\(^{88}\) This implies "a"
evaluates to the character code of the letter 'a' (97) using the traditional mapping of double
quoted string to a list of character codes. \(\text{Char}\) is either a valid code point (non-negative integer
up to the Prolog flag `max_char_code`) or a one-character atom. Arithmetic evaluation also
translates a string object (see section 5.2) of one character length into the character code for
that character. This implies that expression '"a"' works if the Prolog flag `double_quotes` is
set to one of `codes`, `chars` or `string`.

Getting access to character codes this way originates from DEC10 Prolog. ISO has the 0'a
syntax and the predicate `char_code/2`. Future versions may drop support for \(X\) is '"a"'.

\[ \text{random}(+IntExpr) \]  
Evaluate to a random integer \(i\) for which \(0 \leq i < \text{IntExpr}\). The system has two implemen-
tations. If it is compiled with support for unbounded arithmetic (default) it uses the GMP
library random functions. In this case, each thread keeps its own random state. The default
algorithm is the Mersenne Twister algorithm. The seed is set when the first random number in
a thread is generated. If available, it is set from `/dev/random`.\(^{89}\) Otherwise it is set from the
system clock. If unbounded arithmetic is not supported, random numbers are shared between
threads and the seed is initialised from the clock when SWI-Prolog was started. The predicate
\text{set_random/1} can be used to control the random number generator.

\textbf{Warning!} Although properly seeded (if supported on the OS), the Mersenne Twister algorithm
does not produce cryptographically secure random numbers. To generate cryptographically
secure random numbers, use crypto_random_bytes/2 from library crypto provided by the ssl package.

\(^{88}\)The function is documented as `.2`. Using SWI-Prolog v7 and later the actual functor is `[]/2`.
\(^{89}\)On Windows the state is initialised from CryptGenRandom().
random_float
Evaluate to a random float I for which 0.0 < i < 1.0. This function shares the random state with random/1. All remarks with the function random/1 also apply for random_float/0. Note that both sides of the domain are open. This avoids evaluation errors on, e.g., log/1 or //2 while no practical application can expect 0.0.\footnote{Richard O’Keefe said: “If you are generating IEEE doubles with the claimed uniformity, then 0 has a 1 in 2^{53} = 1 in 9, 007, 199, 54, 740, 992 chance of turning up. No program that expects [0.0,1.0) is going to be surprised when 0.0 fails to turn up in a few millions of millions of trials, now is it? But a program that expects (0.0,1.0) could be devastated if 0.0 did turn up.”}

\begin{verbatim}
?- A is rational(0.25).
A is 1 rdiv 4
?
A is rational(0.1).
?- A = 3602879701896397 rdiv 36028797018963968

For every normal float X the relation X =:= rational(X) holds.

This function raises an evaluation_error(\textit{undefined}) if \textit{Expr} is NaN and evaluation_error(rational\_overflow) if \textit{Expr} is Inf.
\end{verbatim}

\begin{verbatim}
\textbf{rational} (+Expr)
\end{verbatim}
Convert the \textit{Expr} to a rational number or integer. The function returns the input on integers and rational numbers. For floating point numbers, the returned rational number \textit{exactly} represents the float. As floats cannot exactly represent all decimal numbers the results may be surprising. In the examples below, doubles can represent 0.25 and the result is as expected, in contrast to the result of \textit{rational}(0.1). The function \textit{rationalize}/1 remedies this. See section 4.27.2 for more information on rational number support.

\begin{verbatim}
?- A is rational(0.25).
A is 1 rdiv 4
?
A is rational(0.1).
?- A = 3602879701896397 rdiv 36028797018963968

For every normal float X the relation X =:= rational(X) holds.

This function raises an evaluation_error(\textit{undefined}) if \textit{Expr} is NaN and evaluation_error(rational\_overflow) if \textit{Expr} is Inf.
\end{verbatim}

\begin{verbatim}
\textbf{rationalize} (+Expr)
\end{verbatim}
Convert the \textit{Expr} to a rational number or integer. The function is similar to \textit{rational}/1, but the result is only accurate within the rounding error of floating point numbers, generally producing a much smaller denominator.\footnote{The names \textit{rational}/1 and \textit{rationalize}/1 as well as their semantics are inspired by Common Lisp. \footnote{The implementation of \textit{rationalize} as well as converting a rational number into a float is copied from ECLiPSe and covered by the \textit{Cisco-style Mozilla Public License Version 1.1}.}
?- A is rationalize(0.25).
A = 1 rdiv 4
?- A is rationalize(0.1).
A = 1 rdiv 10

For every normal float \( X \) the relation \( X =:= \text{rationalize}(X) \) holds.
This function raises the same exceptions as \text{rational}/1 on non-normal floating point numbers.

\text{numerator}(+\text{RationalExpr})
If \text{RationalExpr} evaluates to a rational number or integer, evaluate to the top/left value. Evaluates to itself if \text{RationalExpr} evaluates to an integer. See also \text{denominator}/1. The following is true for any rational \( X \).

\[ X =:= \text{numerator}(X)/\text{denominator}(X). \]

\text{denominator}(+\text{RationalExpr})
If \text{RationalExpr} evaluates to a rational number or integer, evaluate to the bottom/right value. Evaluates to 1 (one) if \text{RationalExpr} evaluates to an integer. See also \text{numerator}/1. The following is true for any rational \( X \).

\[ X =:= \text{numerator}(X)/\text{denominator}(X). \]

\text{float_fractional_part}(+\text{Expr}) \hspace{1cm} \text{[ISO]}
Fractional part of a floating point number. Negative if \text{Expr} is negative, rational if \text{Expr} is rational and 0 if \text{Expr} is integer. The following relation is always true: \( X \text{is float_fractional_part}(X) + \text{float_integer_part}(X) \).

\text{float_integer_part}(+\text{Expr}) \hspace{1cm} \text{[ISO]}
Integer part of floating point number. Negative if \text{Expr} is negative, \text{Expr} if \text{Expr} is integer.

\text{truncate}(+\text{Expr}) \hspace{1cm} \text{[ISO]}
Truncate \text{Expr} to an integer. If \text{Expr} \geq 0 this is the same as \text{floor}(\text{Expr}). For \text{Expr} < 0 this is the same as \text{ceiling}(\text{Expr}). That is, \text{truncate}/1 rounds towards zero.

\text{floor}(+\text{Expr}) \hspace{1cm} \text{[ISO]}
Evaluate \text{Expr} and return the largest integer smaller or equal to the result of the evaluation.

\text{ceiling}(+\text{Expr}) \hspace{1cm} \text{[ISO]}
Evaluate \text{Expr} and return the smallest integer larger or equal to the result of the evaluation.

\text{ceil}(+\text{Expr})
Same as \text{ceiling}/1 (backward compatibility).
CHAPTER 4. BUILT-IN PREDICATES

\( +\text{IntExpr1} \gg \text{IntExpr2} \)  
Bitwise shift \text{IntExpr1} by \text{IntExpr2} bits to the right. The operation performs \textit{arithmetic shift}, which implies that the inserted most significant bits are copies of the original most significant bits.

\( +\text{IntExpr1} \ll \text{IntExpr2} \)  
Bitwise shift \text{IntExpr1} by \text{IntExpr2} bits to the left.

\( +\text{IntExpr1} \lor \text{IntExpr2} \)  
Bitwise ‘or’ \text{IntExpr1} and \text{IntExpr2}.

\( +\text{IntExpr1} \land \text{IntExpr2} \)  
Bitwise ‘and’ \text{IntExpr1} and \text{IntExpr2}.

\( +\text{IntExpr1} \oplus \text{IntExpr2} \)  
Bitwise ‘exclusive or’ \text{IntExpr1} and \text{IntExpr2}.

\( \lnot +\text{IntExpr} \)  
Bitwise negation. The returned value is the one’s complement of \text{IntExpr}.

\( \text{sqrt}(+\text{Expr}) \)  
Result = \sqrt{\text{Expr}}.

\( \text{sin}(+\text{Expr}) \)  
Result = \sin \text{Expr}. \text{Expr} is the angle in radians.

\( \text{cos}(+\text{Expr}) \)  
Result = \cos \text{Expr}. \text{Expr} is the angle in radians.

\( \text{tan}(+\text{Expr}) \)  
Result = \tan \text{Expr}. \text{Expr} is the angle in radians.

\( \text{asin}(+\text{Expr}) \)  
Result = \arcsin \text{Expr}. Result is the angle in radians.

\( \text{acos}(+\text{Expr}) \)  
Result = \arccos \text{Expr}. Result is the angle in radians.

\( \text{atan}(+\text{Expr}) \)  
Result = \arctan \text{Expr}. Result is the angle in radians.

\( \text{atan2}(+\text{YExpr}, +\text{XExpr}) \)  
Result = \arctan \frac{\text{YExpr}}{\text{XExpr}}. Result is the angle in radians. The return value is in the range \([-\pi \ldots \pi]\). Used to convert between rectangular and polar coordinate system.

Note that the ISO Prolog standard demands \texttt{atan2(0.0,0.0)} to raise an evaluation error, whereas the C99 and POSIX standards demand this to evaluate to 0.0. SWI-Prolog follows C99 and POSIX.

\( \text{atan}(+\text{YExpr}, +\text{XExpr}) \)  
Same as \texttt{atan2/2} (backward compatibility).
4.27. ARITHMETIC

\[ \sinh(\text{Expr}) \]
\[ \text{Result} = \sinh \text{Expr}. \text{The hyperbolic sine of } X \text{ is defined as } \frac{e^X - e^{-X}}{2}. \]

\[ \cosh(\text{Expr}) \]
\[ \text{Result} = \cosh \text{Expr}. \text{The hyperbolic cosine of } X \text{ is defined as } \frac{e^X + e^{-X}}{2}. \]

\[ \tanh(\text{Expr}) \]
\[ \text{Result} = \tanh \text{Expr}. \text{The hyperbolic tangent of } X \text{ is defined as } \frac{\sinh X}{\cosh X}. \]

\[ \text{asinh}(\text{Expr}) \]
\[ \text{Result} = \text{arcsinh}(\text{Expr}) \text{ (inverse hyperbolic sine)}. \]

\[ \text{acosh}(\text{Expr}) \]
\[ \text{Result} = \text{arccosh}(\text{Expr}) \text{ (inverse hyperbolic cosine)}. \]

\[ \text{atanh}(\text{Expr}) \]
\[ \text{Result} = \text{arctanh}(\text{Expr}). \text{ (inverse hyperbolic tangent)}. \]

\[ \log(\text{Expr}) \]
\[ \text{Natural logarithm. Result} = \ln \text{Expr} \]

\[ \log_{10}(\text{Expr}) \]
\[ \text{Base-10 logarithm. Result} = \log \text{Expr} \]

\[ \exp(\text{Expr}) \]
\[ \text{Result} = e^{\text{Expr}} \]

\[ +\text{Expr1} \times +\text{Expr2} \]
\[ \text{Result} = \text{Expr1} \times \text{Expr2}. \text{The result is a float, unless SWI-Prolog is compiled with unbounded integer support and the inputs are integers and produce an integer result. The integer expressions } 0^I, 1^I \text{ and } -1^I \text{ are guaranteed to work for any integer } I. \text{ Other integer base values generate a resource error if the result does not fit in memory.} \]

The ISO standard demands a float result for all inputs and introduces \(^{1/2}\) for integer exponentiation. The function float/1 can be used on one or both arguments to force a floating point result. Note that casting the input result in a floating point computation, while casting the output performs integer exponentiation followed by a conversion to float.

\[ +\text{Expr1} \div +\text{Expr2} \]
\[ \text{Result} = \text{Expr1} \div \text{Expr2}. \text{The result is a float, unless SWI-Prolog is compiled with unbounded integer support and the inputs are integers and produce an integer result. The integer expressions } 0^I, 1^I \text{ and } -1^I \text{ are guaranteed to work for any integer } I. \text{ Other integer base values generate a resource error if the result does not fit in memory.} \]

The ISO standard demands a float result for all inputs and introduces \(^{1/2}\) for integer exponentiation. The function float/1 can be used on one or both arguments to force a floating point result. Note that casting the input result in a floating point computation, while casting the output performs integer exponentiation followed by a conversion to float.
### Built-in Predicates

<table>
<thead>
<tr>
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<td>Int or Rational</td>
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<tr>
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<td>Rational</td>
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</tr>
<tr>
<td>Float</td>
<td>Int</td>
<td>**/2</td>
<td>Float</td>
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<tr>
<td>Float</td>
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<td>**/2</td>
<td>Float</td>
<td>Float</td>
</tr>
<tr>
<td>Int</td>
<td>Int</td>
<td>^/2</td>
<td>Int or Rational</td>
<td>Int or error</td>
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<td>Int</td>
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<tr>
<td>Rational</td>
<td>Int</td>
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<tr>
<td>Float</td>
<td>Float</td>
<td>^/2</td>
<td>Float</td>
<td>Float</td>
</tr>
</tbody>
</table>

**powm(+IntExprBase, +IntExprExp, +IntExprMod)**

\[ \text{Result} = (\text{IntExprBase}^{\text{IntExprExp}}) \mod \text{IntExprMod}. \]

Only available when compiled with unbounded integer support. This formula is required for Diffie-Hellman key-exchange, a technique where two parties can establish a secret key over a public network. \(\text{IntExprBase}\) and \(\text{IntExprExp}\) must be non-negative \((\geq 0)\), \(\text{IntExprMod}\) must be positive \((> 0)\).\(^{93}\)

**lgamma(+Expr)**

Return the natural logarithm of the absolute value of the Gamma function.\(^{94}\)

**erf(+Expr)**

**Wikipedia:** “In mathematics, the error function (also called the Gauss error function) is a special function (non-elementary) of sigmoid shape which occurs in probability, statistics and partial differential equations.”

**erfc(+Expr)**

**Wikipedia:** “The complementary error function.”

**pi**

Evaluate to the mathematical constant \(\pi\ (3.14159\ldots)\).\(^{[ISO]}\)

**e**

Evaluate to the mathematical constant \(e\ (2.71828\ldots)\).

**epsilon**

Evaluate to the difference between the float 1.0 and the first larger floating point number. Deprecated. The function `nexttoward/2` provides a better alternative.

**inf**

Evaluate to positive infinity. See section 2.16.1 and section 4.27.2. This value can be negated using \(-/1\).

**nan**

Evaluate to Not a Number. See section 2.16.1 and section 4.27.2.

\(^{93}\)The underlying GMP `mpz_powm()` function allows negative values under some conditions. As the conditions are expensive to pre-compute, error handling from GMP is non-trivial and negative values are not needed for Diffie-Hellman key-exchange we do not support these.

\(^{94}\)Some interfaces also provide the sign of the Gamma function. We cannot do that in an arithmetic function. Future versions may provide a predicate `1gamma/3` that returns both the value and the sign.
4.28. MISC ARITHMETIC SUPPORT PREDICATES

**cputime**
Evaluate to a floating point number expressing the CPU time (in seconds) used by Prolog up till now. See also `statistics/2` and `time/1`.

**eval(+Expr)**
Evaluate `Expr`. Although ISO standard dictates that `‘A=1+2, B is A’` works and unifies `B` to 3, it is widely felt that source level variables in arithmetic expressions should have been limited to numbers. In this view the eval function can be used to evaluate arbitrary expressions.\(^95\)

**Bitvector functions** The functions below are not covered by the standard. The `msb/1` function also appears in hProlog and SICStus Prolog. The `getbit/2` function also appears in ECLiPSe, which also provides `setbit(Vector,Index)` and `clrbit(Vector,Index)`. The others are SWI-Prolog extensions that improve handling of —unbounded— integers as bit-vectors.

**msb(+IntExpr)**
Return the largest integer \( N \) such that \((\text{IntExpr} \gg N) \\&\& 1 =:= 1\). This is the (zero-origin) index of the most significant 1 bit in the value of `IntExpr`, which must evaluate to a positive integer. Errors for 0, negative integers, and non-integers.

**lsb(+IntExpr)**
Return the smallest integer \( N \) such that \((\text{IntExpr} \gg N) \\&\& 1 =:= 1\). This is the (zero-origin) index of the least significant 1 bit in the value of `IntExpr`, which must evaluate to a positive integer. Errors for 0, negative integers, and non-integers.

**popcount(+IntExpr)**
Return the number of 1s in the binary representation of the non-negative integer `IntExpr`.

**getbit(+IntExprV, +IntExprI)**
Evaluates to the bit value (0 or 1) of the `IntExprI`-th bit of `IntExprV`. Both arguments must evaluate to non-negative integers. The result is equivalent to \((\text{IntExprV} \gg \text{IntExprI}) \\&\& 1\), but more efficient because materialization of the shifted value is avoided. Future versions will optimise \((\text{IntExprV} \gg \text{IntExprI}) \\&\& 1\) to a call to `getbit/2`, providing both portability and performance.\(^96\)

**4.28 Misc arithmetic support predicates**

**set_random(+Option)**
Controls the random number generator accessible through the `functions random/1` and `random_float/0`. Note that the library `random` provides an alternative API to the same random primitives.

**seed(+Seed)**
Set the seed of the random generator for this thread. `Seed` is an integer or the atom `random`. If `random`, repeat the initialization procedure described with the function `random/1`. Here is an example:

---

\(^95\)The `eval/1` function was first introduced by ECLiPSe and is under consideration for YAP.

\(^96\)This issue was fiercely debated at the ISO standard mailinglist. The name `getbit` was selected for compatibility with ECLiPSe, the only system providing this support. Richard O’Keefe disliked the name and argued that efficient handling of the above implementation is the best choice for this functionality.
?- set_random(seed(111)), A is random(6).
A = 5.
?- set_random(seed(111)), A is random(6).
A = 5.

\[ \text{state}(\text{+State}) \]
Set the generator to a state fetched using the state property of \text{random.property/1}. Using other values may lead to undefined behaviour.\textsuperscript{97}

\[ \text{random.property}(\text{?Option}) \]
True when \text{Option} is a current property of the random generator. Currently, this predicate provides access to the state. This predicate is not present on systems where the state is inaccessible.

\[ \text{state}(\text{-State}) \]
Describes the current state of the random generator. State is a normal Prolog term that can be asserted or written to a file. Applications should make no other assumptions about its representation. The only meaningful operation is to use as argument to \text{set_random/1} using the \text{state(State)} option.\textsuperscript{98}

\[ \text{current_arithmetic_function}(\text{?Head}) \]
True when \text{Head} is an evaluable function. For example:

\[ \text{?- current_arithmetic_function(sin(_)).} \]
\text{true}.\textsuperscript{99}

4.29 Built-in list operations

Most list operations are defined in the library \text{lists} described in section A.24. Some that are implemented with more low-level primitives are built-in and described here.

\[ \text{is_list}(\text{+Term}) \]
True if \text{Term} is bound to the empty list \([\ ]\) or a compound term with name ‘\([ | ]\)’\textsuperscript{99} and arity 2 and the second argument is a list.\textsuperscript{100} This predicate acts as if defined by the definition below on acyclic terms. The implementation safely \text{fails} if \text{Term} represents a cyclic list.

\textsuperscript{97}The limitations of the underlying (GMP) library are unknown, which makes it impossible to validate the \text{State}.
\textsuperscript{98}BUG: GMP provides no portable mechanism to fetch and restore the state. The current implementation works, but the state depends on the platform. I.e., it is generally not possible to reuse the state with another version of GMP or on a CPU with different datasizes or endian-ness.
\textsuperscript{99}The traditional list functor name is the dot (‘\(.’\)). This is still the case of the command line option --traditional is given. See also section 5.1.
\textsuperscript{100}In versions before 5.0.1, \text{is_list/1} just checked for \([\ ]\) or \([_\ ]\) and \text{proper_list/1} had the role of the current \text{is_list/1}. The current definition conforms to the de facto standard. Assuming proper coding standards, there should only be very few cases where a quick-and-dirty \text{is_list/1} is a good choice. Richard O’Keefe pointed at this issue.
4.29. BUILT-IN LIST OPERATIONS

```prolog
is_list(X) :-
    var(X), !,
    fail.
is_list([]).
is_list([_|T]) :-
    is_list(T).
```

**memberchk(?Elem, +List)**

True when `Elem` is an element of `List`. This ‘chk’ variant of `member/2` is semi deterministic and typically used to test membership of a list. Raises a type error if scanning `List` encounters a non-list. Note that `memberchk/2` does not perform a full list typecheck. For example, `memberchk(a, [a|b])` succeeds without error. If `List` is cyclic and `Elem` is not a member of `List`, `memberchk/2` eventually raises a type error.

**length(?List, ?Length)**

True if `Length` represents the number of elements in `List`. This predicate is a true relation and can be used to find the length of a list or produce a list (holding variables) of length `Length`. The predicate is non-deterministic, producing lists of increasing length if `List` is a partial list and `Length` is a variable.

```prolog
?- length(List, 4).
List = [_27940, _27946, _27952, _27958].

?- length(List, Length).
List = [], Length = 0 ;
List = [_24698], Length = 1 ;
List = [_24698, _25826], Length = 2
...
```

It raises errors if `Length` is bound to a non-integer or a negative integer or if `List` is neither a list nor a partial list. This error condition includes cyclic lists.

```prolog
?- A=[1, 2, 3|A], length(A, L).
ERROR: Type error: ‘list’ expected ...
```

Covering an edge case, the predicate fails if the tail of `List` is equivalent to `Length`.

```prolog
?- List=[1, 2, 3|Length], length(List, Length).
false.
```

---

101 *Eventually* here means it will scan as many elements as the longest list that may exist given the current stack usage before raising the exception.

102 ISO demands failure here. We think an error is more appropriate.

103 This is logically correct. An exception would be more appropriate, but to our best knowledge, current practice in Prolog does not describe a suitable candidate exception term.
sort(+List, -Sorted)

True if Sorted can be unified with a list holding the elements of List, sorted to the standard order of terms (see section 4.6). Duplicates are removed. The implementation is in C, using natural merge sort.\textsuperscript{104} The sort/2 predicate can sort a cyclic list, returning a non-cyclic version with the same elements.

Note that List may contain non-ground terms. If Sorted is unbound at call-time, for each consecutive pair of elements in Sorted, the relation E1 @< E2 will hold. However, unifying a variable in Sorted may cause this relation to become invalid, even unifying a variable in Sorted with another (older) variable. See also section 4.6.1.

sort(+Key, +Order, +List, -Sorted)

True when Sorted can be unified with a list holding the elements of List. Key determines which part of each element in List is used for comparing two term and Order describes the relation between each set of consecutive elements in Sorted.\textsuperscript{105}

If Key is the integer zero (0), the entire term is used to compare two elements. Using Key=0 can be used to sort arbitrary Prolog terms. Other values for Key can only be used with compound terms or dicts (see section 5.4). An integer key extracts the Key-th argument from a compound term. An integer or atom key extracts the value from a dict that is associated with the given key. A type_error is raised if the list element is of the wrong type and an existence_error is raised if the compound has not enough argument or the dict does not contain the requested key.

Deeper nested elements of structures can be selected by using a list of keys for the Key argument.

The Order argument is described in the table below:\textsuperscript{106}

<table>
<thead>
<tr>
<th>Order</th>
<th>Ordering</th>
<th>Duplicate handling</th>
</tr>
</thead>
<tbody>
<tr>
<td>@&lt;</td>
<td>ascending</td>
<td>remove</td>
</tr>
<tr>
<td>@=&lt;</td>
<td>ascending</td>
<td>keep</td>
</tr>
<tr>
<td>@&gt;</td>
<td>descending</td>
<td>remove</td>
</tr>
<tr>
<td>@&gt;=</td>
<td>descending</td>
<td>keep</td>
</tr>
</tbody>
</table>

The sort is stable, which implies that, if duplicates are kept, the order of duplicates is not changed. If duplicates are removed, only the first element of a sequence of duplicates appears in Sorted.

This predicate supersedes most of the other sorting primitives, for example:

\begin{verbatim}
sort(List, Sorted) :- sort(0, @<, List, Sorted).
msort(List, Sorted) :- sort(0, @=<, List, Sorted).
keysort(Pairs, Sorted) :- sort(1, @=<, Pairs, Sorted).
\end{verbatim}

\textsuperscript{104}Contributed by Richard O’Keefe.
\textsuperscript{105}The definition of this predicate was established after discussion with Joachim Schimpf from the ECLiPSe team. ECLiPSe currently only accepts @<, @=<, @> and @>= for the Order argument but this is likely to change. SWI-Prolog extends this predicate to deal with dicts.
\textsuperscript{106}For compatibility with ECLiPSe, the values @<, @=<, @> and @>= are allowed as synonyms.
The following example sorts a list of rows, for example resulting from `csv_read_file/2`) ascending on the 3th column and descending on the 4th column:

```
sort(4, @>=, Rows0, Rows1),
sort(3, @=<, Rows1, Sorted).
```

See also `sort/2` (ISO), `msort/2`, `keysort/2`, `predsort/3` and `order_by/2`.

**msort(+List, -Sorted)**
Equivalent to `sort/2`, but does not remove duplicates. Raises a `type_error` if `List` is a cyclic list or not a list.

**keysort(+List, -Sorted)**
Sorted of pairs. `List` must be a list of `Key-Value` pairs, terms whose principal functor is `(-)/2`. `List` is sorted on `Key` according to the standard order of terms (see section 4.6.1). Duplicates are not removed. Sorting is stable with regard to the order of the `Values`, i.e., the order of multiple elements that have the same `Key` is not changed.

The `keysort/2` predicate is often used together with library `pairs`. It can be used to sort lists on different or multiple criteria. For example, the following predicates sorts a list of atoms according to their length, maintaining the initial order for atoms that have the same length.

```
:- use_module(library(pairs)).

sort_atoms_by_length(Atoms, ByLength) :-
  map_list_to_pairs(atom_length, Atoms, Pairs),
  keysort(Pairs, Sorted),
  pairs_values(Sorted, ByLength).
```

**predsort(+Pred, +List, -Sorted)**
Sorts similar to `sort/2`, but determines the order of two terms by calling `Pred(-Delta, +E1, +E2)`. This call must unify `Delta` with one of `<`, `>`, or `=`. Duplicates are removed (i.e., equivalence classes of elements as defined by `Pred` are collapsed to a single element in `Sorted`) if the built-in predicate `compare/3` is used, the result is the same as `sort/2`. See also `keysort/2`.

### 4.30 Finding all Solutions to a Goal

**findall(+Template, :Goal, -Bag)**
Create a list of the instantiations `Template` gets successively on backtracking over `Goal` and unify the result with `Bag`. Succeeds with an empty list if `Goal` has no solutions.

`findall/3` is equivalent to `bagof/3` with all `free` variables appearing in `Goal` scoped to the `Goal` with an existential (caret) operator (`^`), except that `bagof/3` fails when `Goal` has no solutions.
findall(+Template, :Goal, -Bag, +Tail)
As findall/3, but returns the result as the difference list Bag-Tail. The 3-argument version is defined as

findall(Templ, Goal, Bag) :-
    findall(Templ, Goal, Bag, [])

findnsols(+N, @Template, :Goal, -List)  [nondet]
findnsols(+N, @Template, :Goal, -List, ?Tail)  [nondet]
As findall/3 and findall/4, but generates at most N solutions. If N solutions are returned, this predicate succeeds with a choice point if Goal has a choice point. Backtracking returns the next chunk of (at most) N solutions. In addition to passing a plain integer for N, a term of the form count(N) is accepted. Using count(N), the size of the next chunk can be controlled using nb_setarg/3. The non-deterministic behaviour used to implement the chunk option in pengines. Based on Ciao, but the Ciao version is deterministic. Portability can be achieved by wrapping the goal in once/1. Below are three examples. The first illustrates standard chunking of answers. The second illustrates that the chunk size can be adjusted dynamically and the last illustrates that no choice point is left if Goal leaves no choice-point after the last solution.

?- findnsols(5, I, between(1, 12, I), L).
L = [1, 2, 3, 4, 5] ;
L = [6, 7, 8, 9, 10] ;
L = [11, 12].

?- State = count(2),
   findnsols(State, I, between(1, 12, I), L),
   nb_setarg(1, State, 5).
State = count(5), L = [1, 2] ;
State = count(5), L = [3, 4, 5, 6, 7] ;
State = count(5), L = [8, 9, 10, 11, 12].

?- findnsols(4, I, between(1, 4, I), L).
L = [1, 2, 3, 4].

bagof(+Template, :Goal, -Bag)  [ISO]
Unify Bag with the alternatives of Template. If Goal has free variables besides the one sharing with Template, bagof/3 will backtrack over the alternatives of these free variables, unifying Bag with the corresponding alternatives of Template. The construct +Var^Goal tells bagof/3 not to bind Var in Goal. bagof/3 fails if Goal has no solutions.

The example below illustrates bagof/3 and the ^ operator. The variable bindings are printed together on one line to save paper.

2 ?- listing(foo).
foo(a, b, c).
4.31. FORALL

```prolog
foo(a, b, d).
foo(b, c, e).
foo(b, c, f).
foo(c, c, g).
true.

3 ?- bagof(C, foo(A, B, C), Cs).
A = a, B = b, C = G308, Cs = [c, d] ;
A = b, B = c, C = G308, Cs = [e, f] ;
A = c, B = c, C = G308, Cs = [g].

4 ?- bagof(C, A^foo(A, B, C), Cs).
A = G324, B = b, C = G326, Cs = [c, d] ;
A = G324, B = c, C = G326, Cs = [e, f, g].

5 ?-
```

**setof (+Template, +Goal, -Set)**

Equivalent to `bagof/3`, but sorts the result using `sort/2` to get a sorted list of alternatives without duplicates.

### 4.31 Forall

**forall (:Cond, :Action)**

For all alternative bindings of `Cond, Action` can be proven. The example verifies that all arithmetic statements in the given list are correct. It does not say which is wrong if one proves wrong.

```prolog
?- forall(member(Result = Formula, [2 = 1 + 1, 4 = 2 * 2]),
        Result =:= Formula).
```

The predicate `forall/2` is implemented as `\+ ( Cond, \+ Action)`, i.e., *There is no instantiation of Cond for which Action is false.* The use of double negation implies that `forall/2` does not change any variable bindings. It proves a relation. The `forall/2` control structure can be used for its side-effects. E.g., the following asserts relations in a list into the dynamic database:

```prolog
?- forall(member(Child-Parent, ChildPairs),
           assertz(child_of(Child, Parent))).
```

Using `forall/2` as `forall(Generator, SideEffect)` is preferred over the classical failure driven loop as shown below because it makes it explicit which part of the construct is the generator and which part creates the side effects. Also, unexpected failure of the side effect causes the construct to fail. Failure makes it evident that there is an issue with the code, while a failure driven loop would succeed with an erroneous result.
If your intent is to create variable bindings, the `forall/2` control structure is inadequate. Possibly you are looking for `maplist/2, findall/3 or foreach/2`.

### 4.32 Formatted Write

The current version of SWI-Prolog provides two formatted write predicates. The `writef` family (`writef/1, writef/2, swritef/3`), is compatible with Edinburgh C-Prolog and should be considered deprecated. The `format` family (`format/1, format/2, format/3`), was defined by Quintus Prolog and currently available in many Prolog systems, although the details vary.

#### 4.32.1 Writef

**writef(+Atom)**

Equivalent to `writef(Atom, [])`. See `writef/2` for details.

**writef(+Format, +Arguments)**

Formatted write. `Format` is an atom whose characters will be printed. `Format` may contain certain special character sequences which specify certain formatting and substitution actions. `Arguments` provides all the terms required to be output.

Escape sequences to generate a single special character:

<table>
<thead>
<tr>
<th>Escape</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>\n</td>
<td>Output a newline character (see also <code>nl/[0,1]</code>)</td>
</tr>
<tr>
<td>\l</td>
<td>Output a line separator (same as <code>\n</code>)</td>
</tr>
<tr>
<td>\r</td>
<td>Output a carriage return character (ASCII 13)</td>
</tr>
<tr>
<td>\t</td>
<td>Output the ASCII character TAB (9)</td>
</tr>
<tr>
<td>\</td>
<td>The character \ is output</td>
</tr>
<tr>
<td>%</td>
<td>The character % is output</td>
</tr>
<tr>
<td>\nnn</td>
<td>where ⟨nnn⟩ is an integer (1-3 digits); the character with code ⟨nnn⟩ is output (NB: ⟨nnn⟩ is read as decimal)</td>
</tr>
</tbody>
</table>

Note that `\l`, `\nnn` and `\\` are interpreted differently when character escapes are in effect. See section 2.16.1.

Escape sequences to include arguments from `Arguments`. Each time a `%` escape sequence is found in `Format` the next argument from `Arguments` is formatted according to the specification.
4.32. FORMATTED WRITE

%t    | print/1 the next item (mnemonic: term)
%w    | write/1 the next item
%q    | writeq/1 the next item
%d    | Write the term, ignoring operators. See also write_term/2. Mnemonic: old Edinburgh display/1
%p    | print/1 the next item (identical to %t)
%n    | Put the next item as a character (i.e., it is a character code)
%r    | Write the next item N times where N is the second item (an integer)
%s    | Write the next item as a String (so it must be a list of characters)
%f    | Perform a ttyflush/0 (no items used)
%Nc   | Write the next item Centered in \( N \) columns
%Nr   | Write the next item Right justified in \( N \) columns. \( N \) is a decimal number with at least one digit. The item must be an atom, integer, float or string.

swritef(-String, +Format, +Arguments)  
[deprecated]  
Equivalent to writef/2, but “writes” the result on String instead of the current output stream. Example:

?- swritef(S, '%15L%w', ['Hello', 'World']).
S = "Hello World"

swritef(-String, +Format)  
[deprecated]  
Equivalent to swritef(String, Format, []).

4.32.2 Format

The format family of predicates is the most versatile and portable\(^{107}\) way to produce textual output.

format(+Format)  
Defined as ‘format(Format) :- format(Format, []).’. See format/2 for details.

format(+Format, :Arguments)  
\( Format \) is an atom, list of character codes, or a Prolog string. \( Arguments \) provides the arguments required by the format specification. If only one argument is required and this single argument is not a list, the argument need not be put in a list. Otherwise the arguments are put in a list.

\(^{107}\)Unfortunately not covered by any standard.
Special sequences start with the tilde (˜), followed by an optional numeric argument, optionally followed by a colon modifier (:) followed by a character describing the action to be undertaken. A numeric argument is either a sequence of digits, representing a positive decimal number, a sequence ‘⟨character⟩’, representing the character code value of the character (only useful for ˜t) or a asterisk (*), in which case the numeric argument is taken from the next argument of the argument list, which should be a positive integer. E.g., the following three examples all pass 46 (.) to ˜t:

?- format(‘˜w 46t ˜w72|˜n’, [‘Title’, ‘Page’]).
?- format(‘˜w .t ˜w72|˜n’, [‘Title’, ‘Page’]).
?- format(‘˜w *t ˜w72|˜n’, [‘Title’, 46, ‘Page’]).

Some format expressions may call back Prolog, i.e., ˜p, ˜W, ˜@ and user defined extensions registered with format_predicate/2. Output written to the stream current_output is merged into the format/2 output. If there is no pending rubber (˜t) and the the position notation aligns, only the output is switched. Otherwise the output is captured in a temporary memory buffer and emitted after the callback finishes. The system attempts to preserve the position and alignment promises. It sets the tty property of the temporary stream to reflect the main stream and uses the position information of the temporary stream to update its notion of the position. Notable ansi_format/3 cooperates properly in callbacks. Numeric conversion (d, D, e, E, f, g and G) accept an arithmetic expression as argument. This is introduced to handle rational numbers transparently (see section 4.27.2). The floating point conversions allow for unlimited precision for printing rational numbers in decimal form. E.g., the following will write as many 3’s as you want by changing the ‘50’.

?- format(‘˜50f’, [10 rdiv 3]).
3.33333333333333333333333333333333333333333333333333

˜ Output the tilde itself.

a Output the next argument, which must be an atom. This option is equivalent to w, except that it requires the argument to be an atom.

c Interpret the next argument as a character code and add it to the output. This argument must be a valid Unicode character code. Note that the actually emitted bytes are defined by the character encoding of the output stream and an exception may be raised if the output stream is not capable of representing the requested Unicode character. See section 2.19.1 for details.

d Output next argument as a decimal number. It should be an integer. If a numeric argument is specified, a dot is inserted argument positions from the right (useful for doing fixed point arithmetic with integers, such as handling amounts of money).

The colon modifier (e.g., ˜ : d) causes the number to be printed according to the locale of the output stream. See section 4.23.

108 The colon modifiers is a SWI-Prolog extension, proposed by Richard O’Keefe.
109 As of version 8.3.30
4.32. FORMATTED WRITE

D Same as d, but makes large values easier to read by inserting a comma every three digits left or right of the dot. This is the same as \~:d, but using the fixed English locale.

e Output next argument as a floating point number in exponential notation. The numeric argument specifies the precision. Default is 6 digits. Exact representation depends on the C library function printf(). This function is invoked with the format %.(precision)e.

E Equivalent to e, but outputs a capital E to indicate the exponent.

f Floating point in non-exponential notation. The numeric argument defines the number of digits right of the decimal point. If the numeric argument is zero (0), the value is printed as an integer. If the colon modifier (:) is used, the float is formatted using conventions from the current locale, which may define the decimal point as well as grouping of digits left of the decimal point.

g Floating point in e or f notation, whichever is shorter.

G Floating point in E or f notation, whichever is shorter.

i Ignore next argument of the argument list. Produces no output.

I Emit a decimal number using Prolog digit grouping (the underscore, \_). The argument describes the size of each digit group. The default is 3. See also section 2.16.1. For example:

```
?- A is 1<<100, format(\~10I', [A]).
1_2676506002_2822940149_6703205376
```

k Give the next argument to write_canonical/1.

n Output a newline character.

N Only output a newline if the last character output on this stream was not a newline. Not properly implemented yet.

p Give the next argument to print/1.

q Give the next argument to writeq/1.

r Print integer in radix numeric argument notation (default 8). Thus \~16r prints its argument hexadecimal. The argument should be in the range [2, \ldots, 36]. Lowercase letters are used for digits above 9. The colon modifier may be used to form locale-specific digit groups.

R Same as r, but uses uppercase letters for digits above 9.

s Output text from a list of character codes, characters, string (see string/1 and section 5.2) or atom from the next argument. If an numeric argument is given the string is truncated to this number of characters.

@ Interpret the next argument as a goal and execute it. Output written to the current_output stream is inserted at this place. Goal is called in the module calling format/3. This option is not present in the original definition by Quintus, but supported by some other Prolog systems. The goal is executed as \+ \+ Goal, i.e., bindings created by the goal are discarded.

t All remaining space between 2 tab stops is distributed equally over \~t statements between the tab stops. This space is padded with spaces by default. If an argument is supplied, it is taken to be the character code of the character used for padding. This can be used to do
left or right alignment, centering, distributing, etc. See also ~| and ~+ to set tab stops. A tab stop is assumed at the start of each line.

Set a tab stop on the current position. If an argument is supplied set a tab stop on the position of that argument. This will cause all ~t’s to be distributed between the previous and this tab stop.

If the current column is at or past the requested tabstop and the modifier (:) is used, a newline is inserted and the padding character of the last ~t is used to pad to the requested position.

Set a tab stop (as ~-) relative to the last tab stop or the beginning of the line if no tab stops are set before the ~+. This constructs can be used to fill fields. The partial format sequence below prints an integer right-aligned and padded with zeros in 6 columns. The ... sequences in the example illustrate that the integer is aligned in 6 columns regardless of the remainder of the format specification.

\[
\text{format(‘...|~’0t~d~6+...', [..., Integer, ...])}
\]

\[\text{\texttt{w \ Give the next argument to \texttt{write/1}.}}\]

\[\text{\texttt{W \ Give the next two arguments to \texttt{write_term/2}. \ For example,}}\]

\[
\text{format(‘\texttt{W’}, \texttt{[Term, [numbervars(true)]]}). \ This option is SWI-Prolog specific.}
\]

\[\text{Example:}
\]

\[
\text{simple_statistics :-}
\begin{align*}
\&\langle \text{obtain statistics}\rangle & \% \text{left to the user} \\
\&\text{format(‘\texttt{tStatistics|t~72|n\n},} \\
\&\text{format(‘\texttt{Runtime: ~t ~2f~34| Inferences: ~t ~D~72|n’,} \\
\&\texttt{[RunT, Inf]),} \\
\&\ldots.
\end{align*}
\]

\[\text{will output}
\]

\[
\begin{array}{c}
\text{Statistics} \\
\text{Runtime: .................. 3.45 Inferences: ............ 60,345}
\end{array}
\]

\[\text{\textbf{format(+Output, +Format, :Arguments)}}\]

As \texttt{format/2}, but write the output on the given \texttt{Output}. The de-facto standard only allows \texttt{Output} to be a stream. The SWI-Prolog implementation allows all valid arguments for \texttt{with_output_to/2}.\footnote{Earlier versions defined \texttt{sformat/3}. These predicates have been moved to the library \texttt{backcomp}.} For example:

\[
\text{?- format(atom(A), ‘\texttt{~D’}, [1000000]).} \\
A = ‘1,000,000’
\]
4.32.3 Programming Format

format_predicate(+Char, +Head)

If a sequence ‘˜c’ (tilde, followed by some character) is found, the format/3 and friends first check whether the user has defined a predicate to handle the format. If not, the built-in formatting rules described above are used. Char is either a character code or a one-character atom, specifying the letter to be (re)defined. Head is a term, whose name and arity are used to determine the predicate to call for the redefined formatting character. The first argument to the predicate is the numeric argument of the format command, or the atom default if no argument is specified. The remaining arguments are filled from the argument list. The example below defines ‘˜T’ to print a timestamp in ISO8601 format (see format_time/3). The subsequent block illustrates a possible call.

```prolog
:- format_predicate('T', format_time(_Arg,_Time)).

format_time(_Arg, Stamp) :-
    must_be(number, Stamp),
    format_time(current_output, '%FT%T%z', Stamp).
```

?- get_time(Now),
    format('Now, it is ‘˜T’\n', [Now]).
Now, it is 2012-06-04T19:02:01+0200
Now = 1338829321.6620328.

current_format_predicate(?Code, ?:Head)

True when ‘˜Code’ is handled by the user-defined predicate specified by Head.

4.33 Global variables

Global variables are associations between names (atoms) and terms. They differ in various ways from storing information using assert/1 or recorda/3.

- The value lives on the Prolog (global) stack. This implies that lookup time is independent of the size of the term. This is particularly interesting for large data structures such as parsed XML documents or the CHR global constraint store.

- They support both global assignment using nb_setval/2 and backtrackable assignment using b_setval/2.

- Only one value (which can be an arbitrary complex Prolog term) can be associated to a variable at a time.

- Their value cannot be shared among threads. Each thread has its own namespace and values for global variables.

- Currently global variables are scoped globally. We may consider module scoping in future versions.
Both \texttt{b_setval/2} and \texttt{nb_setval/2} implicitly create a variable if the referenced name does not already refer to a variable.

Global variables may be initialised from directives to make them available during the program lifetime, but some considerations are necessary for saved states and threads. Saved states do not store global variables, which implies they have to be declared with \texttt{initialization/1} to recreate them after loading the saved state. Each thread has its own set of global variables, starting with an empty set. Using \texttt{thread_initialization/1} to define a global variable it will be defined, restored after reloading a saved state and created in all threads that are created after the registration. Finally, global variables can be initialised using the exception hook \texttt{exception/3}. See also \texttt{nb_current/2} and \texttt{nb_delete/1}.

\texttt{b_setval(+Name, +Value)}

Associate the term \texttt{Value} with the atom \texttt{Name} or replace the currently associated value with \texttt{Value}. On backtracking the assignment is reversed. If the variable \texttt{Name} did not exist before calling \texttt{b_setval/2}, backtracking causes the variable to be deleted.\footnote{Prior to version 8.3.28 backtracking over the variable creation caused the variable to get the value \texttt{[]}, i.e., the empty list. If this is desirable use \texttt{nb_setval(Var, \texttt{[]})} before \texttt{b_setval/2}.}

\texttt{b_getval(+Name, -Value)}

Get the value associated with the global variable \texttt{Name} and unify it with \texttt{Value}. Note that this unification may further instantiate the value of the global variable. If this is undesirable the normal precautions (double negation or \texttt{copy_term/2}) must be taken. The \texttt{b_getval/2} predicate generates errors if \texttt{Name} is not an atom or the requested variable does not exist.

\texttt{nb_setval(+Name, +Value)}

Associates a copy of \texttt{Value} created with \texttt{duplicate_term/2} with the atom \texttt{Name}. Note that this can be used to set an initial value other than \texttt{[]} prior to backtrackable assignment.

\texttt{nb_getval(+Name, -Value)}

The \texttt{nb_getval/2} predicate is a synonym for \texttt{b_getval/2}, introduced for compatibility and symmetry. As most scenarios will use a particular global variable using either non-backtrackable or backtrackable assignment, using \texttt{nb_getval/2} can be used to document that the variable is non-backtrackable. Raises \texttt{existence_error(variable, Name)} if the variable does not exist. Alternatively, \texttt{nb_current/2} can used to query a global variable. This version \textit{fails} if the variable does not exist rather than raising an exception.

\texttt{nb_linkval(+Name, +Value)}

Associates the term \texttt{Value} with the atom \texttt{Name} without copying it. This is a fast special-purpose variation of \texttt{nb_setval/2} intended for expert users only because the semantics on backtracking to a point before creating the link are poorly defined for compound terms. The principal term is always left untouched, but backtracking behaviour on arguments is undone if the original assignment was \texttt{trailed} and left alone otherwise, which implies that the history that created the term affects the behaviour on backtracking. Consider the following example:

\begin{verbatim}
demo_nb_linkval :-
  T = nice(N),
  \{ N = world,
      nb_linkval(myvar, T),
\}
\end{verbatim}

\texttt{nb_current(+Name, -Value)}

Query the value associated with the global variable \texttt{Name}. Note that this can be used to instead of \texttt{nb_getval/2} to query a global variable. This version \textit{fails} if the variable does not exist rather than raising an exception.

\texttt{nb_delete(+Name)}

Delete the global variable \texttt{Name}. Note that this is a fast special-purpose variation of \texttt{nb_setval/2} without copying it. This is a fast special-purpose variation of \texttt{nb_setval/2} intended for expert users only because the semantics on backtracking to a point before creating the link are poorly defined for compound terms. The principal term is always left untouched, but backtracking behaviour on arguments is undone if the original assignment was \texttt{trailed} and left alone otherwise, which implies that the history that created the term affects the behaviour on backtracking. Consider the following example:

\begin{verbatim}
demo_nb_delete :-
  T = nice(N),
  \{ N = world,
      nb_linkval(myvar, T),
  \}
\end{verbatim}
fail
; nb_getval(myvar, V),
writeln(V)
).

nb_current(?Name, ?Value)
Enumerate all defined variables with their value. The order of enumeration is undefined. Note that nb_current/2 can be used as an alternative for nb_getval/2 to request the value of a variable and fail silently if the variable does not exists. Note that if the variable is not defined, exception/3 is called attempting to define it. As of version 8.3.28, a failure of exception/3 to define the variable causes the variable to be defined with a reserved valued to avoid subsequent calls to exception/3.

nb_delete(+Name)
Delete the named global variable. Succeeds also if the named variable does not exist. Deleting a global variable ensures the variable is associated to a reserved value to avoid subsequent calls to exception/3. Note that this implies that the resources associated with a global variable are never fully reclaimed.

4.33.1 Compatibility of SWI-Prolog Global Variables

Global variables have been introduced by various Prolog implementations recently. The implementation of them in SWI-Prolog is based on hProlog by Bart Demoen. In discussion with Bart it was decided that the semantics of hProlog nb_setval/2, which is equivalent to nb_linkval/2, is not acceptable for normal Prolog users as the behaviour is influenced by how built-in predicates that construct terms (read/1, =../2, etc.) are implemented.

GNU-Prolog provides a rich set of global variables, including arrays. Arrays can be implemented easily in SWI-Prolog using functor/3 and setarg/3 due to the unrestricted arity of compound terms.

4.34 Terminal Control

The following predicates form a simple access mechanism to the Unix termcap library to provide terminal-independent I/O for screen terminals. These predicates are only available on Unix machines. The SWI-Prolog Windows console accepts the ANSI escape sequences.

tty_get_capability(+Name, +Type, -Result)
Get the capability named Name from the termcap library. See termcap(5) for the capability names. Type specifies the type of the expected result, and is one of string, number or bool. String results are returned as an atom, number results as an integer, and bool results as the atom on or off. If an option cannot be found, this predicate fails silently. The results are only computed once. Successive queries on the same capability are fast.

tty_goto(+X, +Y)
Goto position (X, Y) on the screen. Note that the predicates line_count/2 and line_position/2 will not have a well-defined behaviour while using this predicate.
tty_put(+Atom, +Lines)

Put an atom via the termcap library function tputs(). This function decodes padding information in the strings returned by tty_get_capability/3 and should be used to output these strings. Lines is the number of lines affected by the operation, or 1 if not applicable (as in almost all cases).

tty_size(-Rows, -Columns)

Determine the size of the terminal. Platforms:

Unix  If the system provides ioctl calls for this, these are used and tty_size/2 properly reflects the actual size after a user resize of the window. The ioctl is issued on the file descriptor associated with the user_input stream. As a fallback, the system uses tty_get_capability/3 using li and co capabilities. In this case the reported size reflects the size at the first call and is not updated after a user-initiated resize of the terminal.

Windows Getting the size of the terminal is provided for swipl-win.exe. The requested value reflects the current size. For the multithreaded version the console that is associated with the user_input stream is used.

4.35  Operating System Interaction

The predicates in this section provide basic access to the operating system that has been part of the Prolog legacy tradition. Note that more advanced access to low-level OS features is provided by several libraries from the clib package, notably library process, socket, unix and filesex.

shell(+Command)

Equivalent to 'shell(Command, 0)'. See shell/2 for details.

shell(+Command, -Status)

Execute Command on the operating system. Command is given to the Bourne shell (/bin/sh). Status is unified with the exit status of the command.

On Windows, shell/[1,2] executes the command using the CreateProcess() API and waits for the command to terminate. If the command ends with a & sign, the command is handed to the WinExec() API, which does not wait for the new task to terminate. See also win_exec/2 and win_shell/2. Please note that the CreateProcess() API does not imply the Windows command interpreter (cmd.exe and therefore commands that are built in the command interpreter can only be activated using the command interpreter. For example, a file can be copied using the command below.

?- shell('cmd.exe /C copy file1.txt file2.txt').

Note that many of the operations that can be achieved using the shell built-in commands can easily be achieved using Prolog primitives. See make_directory/1, delete_file/1, rename_file/2, etc. The clib package provides filesex, implementing various high level file operations such as copy_file/2. Using Prolog primitives instead of shell commands improves the portability of your program.
The library *process* provides *process_create/3* and several related primitives that support more fine-grained interaction with processes, including I/O redirection and management of asynchronous processes.

**getenv(+Name, -Value)**
Get environment variable. Fails silently if the variable does not exist. Please note that environment variable names are case-sensitive on Unix systems and case-insensitive on Windows.

**setenv(+Name, +Value)**
Set an environment variable. *Name* and *Value* must be instantiated to atoms or integers. The environment variable will be passed to shell/[0-2] and can be requested using *getenv/2*. They also influence *expand_file_name/2*. Environment variables are shared between threads. Depending on the underlying C library, *setenv/2* and *unsetenv/1* may not be thread-safe and may cause memory leaks. Only changing the environment once and before starting threads is safe in all versions of SWI-Prolog.

**unsetenv(+Name)**
Remove an environment variable from the environment. Some systems lack the underlying *unsetenv()* library function. On these systems *unsetenv/1* sets the variable to the empty string.

**setlocale(+Category, -Old, +New)**
Set/Query the *locale* setting which tells the C library how to interpret text files, write numbers, dates, etc. *Category* is one of *all*, *collate*, *ctype*, *messages*, *monetary*, *numeric* or *time*. For details, please consult the C library locale documentation. See also section 2.19.1. Please note that the locale is shared between all threads and thread-safe usage of *setlocale/3* is in general not possible. Do locale operations before starting threads or thoroughly study threading aspects of locale support in your environment before using in multi-threaded environments. Locale settings are used by *format_time/3, collation_key/2* and *locale_sort/2*.

The *messages* locale defines the language used by *print_message/2*. Note that this locale is not available on all operating system. Notably Windows does not support this category. See *win_get_user_preferred_ui_languages/2*.

### 4.35.1 Windows-specific Operating System Interaction

The predicates in this section are only available on the Windows version of SWI-Prolog. Their use is discouraged if there are portable alternatives. For example, *win_exec/2* and *win_shell/2* can often be replaced by the more portable *shell/2* or the more powerful *process_create/3*.

**win_exec(+Command, +Show)**
Windows only. Spawns a Windows task without waiting for its completion. *Show* is one of the Win32 SW_* constants written in lowercase without the SW_*: *hide*, *maximize*, *minimize*, *restore*, *show*, *showdefault*, *showmaximized*, *showminimized*, *showminnoactive*, *showna*, *shownoactive*, *shownormal*. In addition, *iconic* is a synonym for *minimize* and *normal* for *shownormal*.

**win_shell(+Operation, +File, +Show)**
Windows only. Opens the document *File* using the Windows shell rules for doing so. *Operation*
is one of open, print or explore or another operation registered with the shell for the given document type. On modern systems it is also possible to pass a URL as File, opening the URL in Windows default browser. This call interfaces to the Win32 API `ShellExecute()`. The Show argument determines the initial state of the opened window (if any). See `win_exec/2` for defined values.

```
win_shell(+Operation, +File)
    Same as win_shell(Operation, File, normal).
```

```
win_registry_get_value(+Key, +Name, -Value)
    Windows only. Fetches the value of a Windows registry key. Key is an atom formed as a path name describing the desired registry key. Name is the desired attribute name of the key. Value is unified with the value. If the value is of type DWORD, the value is returned as an integer. If the value is a string, it is returned as a Prolog atom. Other types are currently not supported. The default 'root' is HKEY_CURRENT_USER. Other roots can be specified explicitly as HKEY_CLASSES_ROOT, HKEY_CURRENT_USER, HKEY_LOCAL_MACHINE or HKEY_USERS. The example below fetches the extension to use for Prolog files (see README.TXT on the Windows version):

```prolog
?- win_registry_get_value('HKEY_LOCAL_MACHINE/Software/SWI/Prolog', 'fileExtension', Ext).
Extended = pl
```

```
win_folder(?Name, -Directory)
    True if Name is the Windows 'CSIDL' of Directory. If Name is unbound, all known Windows special paths are generated. Name is the CSIDL after deleting the leading CSIDL and mapping the constant to lowercase. Check the Windows documentation for the function SHGetSpecialFolderPath() for a description of the defined constants. This example extracts the 'My Documents' folder:

```prolog
?- win_folder(personal, MyDocuments).
MyDocuments = 'C:/Documents and Settings/jan/My Documents'
```

```
win_add_dll_directory(+AbsDir)
    This predicate adds a directory to the search path for dependent DLL files. If possible, this is achieved with win_add_dll_directory/2. Otherwise, %PATH% is extended with the provided directory. AbsDir may be specified in the Prolog canonical syntax. See prolog_to_os_filename/2. Note that use_foreign_library/1 passes an absolute path to the DLL if the destination DLL can be located from the specification using absolute_file_name/3. This predicate is available from library shlib and can be autoloaded.
```
win_add_dll_directory(+AbsDir, -Cookie)
This predicate adds a directory to the search path for dependent DLL files. If the call is successful it unifies Cookie with a handle that must be passed to win_remove_dll_directory/1 to remove the directory from the search path. Error conditions:

- This predicate fails if Windows does not yet support the underlying primitives. These are available in recently patched Windows 7 systems and later.
- This predicate throws an exception if the provided path is invalid or the underlying Windows API returns an error.

If open_shared_object/2 is passed an absolute path to a DLL on a Windows installation that supports AddDllDirectory() and friends, SWI-Prolog uses LoadLibraryEx() with the flags LOAD_LIBRARY_SEARCH_DLL_LOAD_DIR and LOAD_LIBRARY_SEARCH_DEFAULT_DIRS. In this scenario, directories from %PATH% are not searched. Additional directories can be added using win_add_dll_directory/2.

win_remove_dll_directory(-Cookie)
Remove a DLL search directory installed using win_add_dll_directory/2.

win_process_modules(-FileNames)
This predicate is a wrapper around EnumProcessModules(). FileNames is unified with a list of absolute paths for all modules of the Windows process. Modules are the main executable file and all DLLs loaded into the process, except data DLLs. The returned file names are in canonical Prolog representation. This predicate may be used to debug loading a DLL from an unexpected location and as a helper for packaging all dependencies when creating a distribution. According to the Windows documentation this API may return incorrect results if DLLs are loaded or unloaded while EnumProcessModules() is in progress. See also qsave_program/2.

win_get_user_preferred_ui_languages(+Format, -Languages)
Unifies Languages with a list of the user preferred languages (Windows Display Languages) in order of preference. If Format is name, the list elements are atoms. See Language Names for details. If Format is id, Languages is a list of numeric language ids represented as Prolog integers. This predicate provides Windows alternative to setlocale/3 using the category messages.

4.35.2 Apple specific Operating System Interaction
Non-portable Apple MacOS specific predicates are prefixed woth apple_

apple_current_locale_identifier(-Identifier)
Unify Identifier with the value for CFLocaleGetIdentifier() of the Apple current locale. The Identifier is an atom that consists of the primary language identifier, e.g., en for english followed by an underscore and an identifier for the Region in the MacOS Language & Region preferences. For example, with the primary language set to “English (UK)” and the Region to “United Kingdom” we get en_GB. This relates to the locale identifier en_GB.UTF-8. Unfortunately it is not that simple. For example, we can combine the primary language

---

\[112\] Windows 7 with up-to-date patches or Windows 8.
“English (UK)” with the Region “Netherlands” to end up with en_NL which is not a valid MacOS locale.

4.35.3 Dealing with time and date

Representing time in a computer system is surprisingly complicated. There are a large number of time representations in use, and the correct choice depends on factors such as compactness, resolution and desired operations. Humans tend to think about time in hours, days, months, years or centuries. Physicists think about time in seconds. But, a month does not have a defined number of seconds. Even a day does not have a defined number of seconds as sometimes a leap-second is introduced to synchronise properly with our earth’s rotation. At the same time, resolution demands a range from better than pico-seconds to millions of years. Finally, civilizations have a wide range of calendars. Although there exist libraries dealing with most of this complexity, our desire to keep Prolog clean and lean stops us from fully supporting these.

For human-oriented tasks, time can be broken into years, months, days, hours, minutes, seconds and a timezone. Physicists prefer to have time in an arithmetic type representing seconds or fraction thereof, so basic arithmetic deals with comparison and durations. An additional advantage of the physicist’s approach is that it requires much less space. For these reasons, SWI-Prolog uses an arithmetic type as its prime time representation.

Many C libraries deal with time using fixed-point arithmetic, dealing with a large but finite time interval at constant resolution. In our opinion, using a floating point number is a more natural choice as we can use a natural unit and the interface does not need to be changed if a higher resolution is required in the future. Our unit of choice is the second as it is the scientific unit. We have placed our origin at 1970-01-01T0:0:0Z for compatibility with the POSIX notion of time as well as with older time support provided by SWI-Prolog.

Where older versions of SWI-Prolog relied on the POSIX conversion functions, the current implementation uses libtai to realise conversion between time-stamps and calendar dates for a period of 10 million years.

Time and date data structures

We use the following time representations

TimeStamp

A TimeStamp is a floating point number expressing the time in seconds since the Epoch at 1970-01-01.

date(Y,M,D,H,Mn,S,Off,TZ,DST)

We call this term a date-time structure. The first 5 fields are integers expressing the year, month (1..12), day (1..31), hour (0..23) and minute (0..59). The S field holds the seconds as a floating point number between 0.0 and 60.0. Off is an integer representing the offset relative to UTC in seconds, where positive values are west of Greenwich. If converted from local time (see stamp_date_time/3), TZ holds the name of the local timezone. If the timezone is not known, TZ is the atom - . DST is true if daylight saving time applies to the current time, false if daylight saving time is relevant but not effective, and - if unknown or the timezone has no daylight saving time.

\[\text{113}\] Using Julian days is a choice made by the Eclipse team. As conversion to dates is needed for a human readable notation of time and Julian days cannot deal naturally with leap seconds, we decided for the second as our unit.
4.35. OPERATING SYSTEM INTERACTION

\[\text{date}(Y,M,D)\]
Date using the same values as described above. Extracted using \text{date_time_value}/3.

\[\text{time}(H,Mn,S)\]
Time using the same values as described above. Extracted using \text{date_time_value}/3.

Time and date predicates

\text{get\_time}(-\text{TimeStamp})
Return the current time as a \text{TimeStamp}. The granularity is system-dependent. See section 4.35.3.

\text{stamp\_date\_time}(+\text{TimeStamp}, -\text{DateTime}, +\text{TimeZone})
Convert a \text{TimeStamp} to a \text{DateTime} in the given timezone. See section 4.35.3 for details on the data types. \text{TimeZone} describes the timezone for the conversion. It is one of local to extract the local time, 'UTC' to extract a UTC time or an integer describing the seconds west of Greenwich.

\text{date\_time\_stamp}(+\text{DateTime}, -\text{TimeStamp})
Compute the timestamp from a date/9 term. Values for month, day, hour, minute or second need not be normalized. This flexibility allows for easy computation of the time at any given number of these units from a given timestamp. Normalization can be achieved following this call with \text{stamp\_date\_time}/3. This example computes the date 200 days after 2006-07-14:

\begin{verbatim}
?- date_time_stamp(date(2006,7,214,0,0,0,0,-,-), Stamp),
    stamp_date_time(Stamp, D, 0),
    date_time_value(date, D, Date).
Date = date(2007, 1, 30)
\end{verbatim}

When computing a time stamp from a local time specification, the UTC offset (arg 7), TZ (arg 8) and DST (arg 9) argument may be left unbound and are unified with the proper information. The example below, executed in Amsterdam, illustrates this behaviour. On the 25th of March at 01:00, DST does not apply. At 02:00, the clock is advanced by one hour and thus both 02:00 and 03:00 represent the same time stamp.

\begin{verbatim}
1  ?- date_time_stamp(date(2012,3,25,1,0,0,UTCOff,TZ,DST), Stamp).
   UTCOff = -3600,
   TZ = 'CET',
   DST = false,
   Stamp = 1332633600.0.
2  ?- date_time_stamp(date(2012,3,25,2,0,0,UTCOff,TZ,DST), Stamp).
   UTCOff = -7200,
   TZ = 'CEST',
   DST = true,
   Stamp = 1332637200.0.
\end{verbatim}
3 ?- date_time_stamp(date(2012,3,25,3,0,0,UTCOff,TZ,DST),
                   Stamp).
UTCOff = -7200,
TZ = 'CEST',
DST = true,
Stamp = 1332637200.0.

Note that DST and offset calculation are based on the POSIX function mktime(). If mktime() returns an error, a representation_error dst is generated.

date_time_value(?Key, +DateTime, ?Value)
Extract values from a date/9 term. Provided keys are:

<table>
<thead>
<tr>
<th>key</th>
<th>value</th>
</tr>
</thead>
<tbody>
<tr>
<td>year</td>
<td>Calendar year as an integer</td>
</tr>
<tr>
<td>month</td>
<td>Calendar month as an integer 1..12</td>
</tr>
<tr>
<td>day</td>
<td>Calendar day as an integer 1..31</td>
</tr>
<tr>
<td>hour</td>
<td>Clock hour as an integer 0..23</td>
</tr>
<tr>
<td>minute</td>
<td>Clock minute as an integer 0..59</td>
</tr>
<tr>
<td>second</td>
<td>Clock second as a float 0.0..60.0</td>
</tr>
<tr>
<td>utc_offset</td>
<td>Offset to UTC in seconds (positive is west)</td>
</tr>
<tr>
<td>time_zone</td>
<td>Name of timezone; fails if unknown</td>
</tr>
<tr>
<td>daylight_saving</td>
<td>Bool (true) if dst is in effect</td>
</tr>
<tr>
<td>date</td>
<td>Term date(Y,M,D)</td>
</tr>
<tr>
<td>time</td>
<td>Term time(H,M,S)</td>
</tr>
</tbody>
</table>

format_time(+Out, +Format, +StampOrDateTime)
Modelled after POSIX strftime(), using GNU extensions. Out is a destination as specified with with_output_to/2. Format is an atom or string with the following conversions. Conversions start with a percent (%) character. StampOrDateTime is either a numeric time-stamp, a term date(Y,M,D,H,M,S,O,TZ,DST) or a term date(Y,M,D).

a  The abbreviated weekday name according to the current locale. Use format_time/4 for POSIX locale.

A  The full weekday name according to the current locale. Use format_time/4 for POSIX locale.

b  The abbreviated month name according to the current locale. Use format_time/4 for POSIX locale.

B  The full month name according to the current locale. Use format_time/4 for POSIX locale.

c  The preferred date and time representation for the current locale.

C  The century number (year/100) as a 2-digit integer.

\[114\] Descriptions taken from Linux Programmer’s Manual.
4.35. OPERATING SYSTEM INTERACTION

\(\text{c} \) The day of the month as a decimal number (range 01 to 31).

\(\text{D} \) Equivalent to \%m/%d/%y. (For Americans only. Americans should note that in other countries \%d/%m/%y is rather common. This means that in an international context this format is ambiguous and should not be used.)

\(\text{e} \) Like \%d, the day of the month as a decimal number, but a leading zero is replaced by a space.

\(\text{E} \) Modifier. Not implemented.

\(\text{f} \) Number of microseconds. The \(\text{f} \) can be prefixed by an integer to print the desired number of digits. E.g., \%3f prints milliseconds. This format is not covered by any standard, but available with different format specifiers in various incarnations of the strftime() function.

\(\text{F} \) Equivalent to \%Y-%m-%d (the ISO 8601 date format).

\(\text{g} \) Like \%G, but without century, i.e., with a 2-digit year (00-99).

\(\text{G} \) The ISO 8601 year with century as a decimal number. The 4-digit year corresponding to the ISO week number (see \%V). This has the same format and value as \%y, except that if the ISO week number belongs to the previous or next year, that year is used instead.

\(\text{V} \) The ISO 8601:1988 week number of the current year as a decimal number, range 01 to 53, where week 1 is the first week that has at least 4 days in the current year, and with Monday as the first day of the week. See also \%U and \%W.

\(\text{h} \) Equivalent to \%b.

\(\text{H} \) The hour as a decimal number using a 24-hour clock (range 00 to 23).

\(\text{I} \) The hour as a decimal number using a 12-hour clock (range 01 to 12).

\(\text{j} \) The day of the year as a decimal number (range 001 to 366).

\(\text{k} \) The hour (24-hour clock) as a decimal number (range 0 to 23); single digits are preceded by a blank. (See also \%H.)

\(\text{l} \) The hour (12-hour clock) as a decimal number (range 1 to 12); single digits are preceded by a blank. (See also \%I.)

\(\text{m} \) The month as a decimal number (range 01 to 12).

\(\text{M} \) The minute as a decimal number (range 00 to 59).

\(\text{n} \) A newline character.

\(\text{O} \) Modifier to select locale-specific output. Not implemented.

\(\text{p} \) Either ‘AM’ or ‘PM’ according to the given time value, or the corresponding strings for the current locale. Noon is treated as ‘pm’ and midnight as ‘am’.\(^{115}\)

\(\text{P} \) Like \%p but in lowercase: ‘am’ or ‘pm’ or a corresponding string for the current locale.

\(\text{r} \) The time in a.m. or p.m. notation. In the POSIX locale this is equivalent to ‘%I:%M:%S %p’.

\(\text{R} \) The time in 24-hour notation (\%H:\%M). For a version including the seconds, see \%T below.

\(\text{s} \) The number of seconds since the Epoch, i.e., since 1970-01-01 00:00:00 UTC.

\(^{115}\) Despite the above claim, some locales yield \text{am} or \text{pm} in lower case.
The second as a decimal number (range 00 to 60). (The range is up to 60 to allow for occasional leap seconds.)

A tab character.

The time in 24-hour notation (%H:%M:%S).

The day of the week as a decimal, range 1 to 7, Monday being 1. See also %w.

The week number of the current year as a decimal number, range 00 to 53, starting with the first Sunday as the first day of week 01. See also %V and %W.

The day of the week as a decimal, range 0 to 6, Sunday being 0. See also %u.

The week number of the current year as a decimal number, range 00 to 53, starting with the first Monday as the first day of week 01.

The preferred date representation for the current locale without the time.

The preferred time representation for the current locale without the date.

The year as a decimal number without a century (range 00 to 99).

The year as a decimal number including the century.

The timezone as hour offset from GMT using the format HHmm. Required to emit RFC822-conforming dates (using ‘%a, %d %b %Y %T %z’). Our implementation supports %:z, which modifies the output to HH:mm as required by XML-Schema. Note that both notations are valid in ISO 8601. The sequence %:z is compatible to the GNU date(1) command.

The timezone or name or abbreviation.

The date and time in date(1) format.

A literal ‘%’ character.

The table below gives some format strings for popular time representations. RFC1123 is used by HTTP. The full implementation of http_timestamp/2 as available from http/http_header is here.

<table>
<thead>
<tr>
<th>Standard</th>
<th>Format string</th>
</tr>
</thead>
<tbody>
<tr>
<td>xsd</td>
<td>‘%FT%T%:z’</td>
</tr>
<tr>
<td>ISO8601</td>
<td>‘%FT%T%z’</td>
</tr>
<tr>
<td>RFC822</td>
<td>‘%a, %d %b %Y %T %z’</td>
</tr>
<tr>
<td>RFC1123</td>
<td>‘%a, %d %b %Y %T GMT’</td>
</tr>
</tbody>
</table>

format_time(+Out, +Format, +StampOrDateTime, +Locale)

Format time given a specified Locale. This predicate is a work-around for lacking proper portable and thread-safe time and locale handling in current C libraries. In its current
implementation the only value allowed for Locale is posix, which currently only modifies
the behaviour of the a, A, b and B format specifiers. The predicate is used to be able to emit
POSIX locale week and month names for emitting standardised time-stamps such as RFC1123.

\textbf{parse\_time(+Text, -Stamp)}

Same as \texttt{parse\_time(Text, \_Format, Stamp)}. See \texttt{parse\_time/3}.

\textbf{parse\_time(+Text, ?Format, -Stamp)}

Parse a textual time representation, producing a time-stamp. Supported formats for Text are
in the table below. If the format is known, it may be given to reduce parse time and avoid
ambiguities. Otherwise, Format is unified with the format encountered.

<table>
<thead>
<tr>
<th>Name</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>rfc_1123</td>
<td>Fri, 08 Dec 2006 15:29:44 GMT</td>
</tr>
<tr>
<td></td>
<td>Fri, 08 Dec 2006 15:29:44 +0000</td>
</tr>
<tr>
<td>iso_8601</td>
<td>2006-12-08T17:29:44+02:00</td>
</tr>
<tr>
<td></td>
<td>20061208T172944+0200</td>
</tr>
<tr>
<td></td>
<td>2006-12-08T15:29Z</td>
</tr>
<tr>
<td></td>
<td>2006-12-08</td>
</tr>
<tr>
<td></td>
<td>20061208</td>
</tr>
<tr>
<td></td>
<td>2006-12</td>
</tr>
<tr>
<td></td>
<td>2006-W49-5</td>
</tr>
<tr>
<td></td>
<td>2006-342</td>
</tr>
</tbody>
</table>

\textbf{day\_of\_the\_week(+Date,-DayOfTheWeek)}

Computes the day of the week for a given date. \texttt{Day} = \texttt{date(Year, Month, Day)}. Days of
the week are numbered from one to seven: Monday = 1, Tuesday = 2, \ldots, Sunday = 7.

\subsection*{4.35.4 Controlling the \texttt{swipl-win.exe} console window}

The Windows executable \texttt{swipl-win.exe} console has a number of predicates to control the appear-
ance of the console. Being totally non-portable, we do not advise using it for your own application,
but use XPCE or another portable GUI platform instead. We give the predicates for reference here.

\textbf{window\_title(-Old, +New)}

Unify \texttt{Old} with the title displayed in the console and change the title to \texttt{New}.

\textbf{win\_window\_pos(+ListOfOptions)}

Interface to the MS-Windows \texttt{SetWindowPos()} function, controlling size, position and
stacking order of the window. \texttt{ListOfOptions} is a list that may hold any number of the terms
below:

\texttt{size(W, H)}

Change the size of the window. \texttt{W} and \texttt{H} are expressed in character units.

\texttt{position(X, Y)}

Change the top-left corner of the window. The values are expressed in pixel units.

\textsuperscript{116}BUG: This predicate should have been called \texttt{win\_window\_title} for consistent naming.
zorder(ZOrder)
Change the location in the window stacking order. Values are bottom, top, topmost and notopmost. Topmost windows are displayed above all other windows.

show(Bool)
If true, show the window, if false hide the window.

activate
If present, activate the window.

win_window_color(+Which, +RGB)
Change the color of the console window. Which is one of foreground, background, selection_foreground or selection_background. RGB is a term rgb(Red,Green,Blue) where the components are values between 0 and 255. The defaults are established using the Windows API GetSysColor().

win_has_menu
True if win_insert_menu/2 and win_insert_menu_item/4 are present.

win_insert_menu(+Label, +Before)
Insert a new entry (pulldown) in the menu. If the menu already contains this entry, nothing is done. The Label is the label and, using the Windows convention, a letter prefixed with & is underlined and defines the associated accelerator key. Before is the label before which this one must be inserted. Using – adds the new entry at the end (right). For example, the call below adds an Application entry just before the Help menu.

win_insert_menu(’&Application’, ’&Help’)

win_insert_menu_item(+Pulldown, +Label, +Before, :Goal)
Add an item to the named Pulldown menu. Label and Before are handled as in win_insert_menu/2, but the label – inserts a separator. Goal is called if the user selects the item.

4.36 File System Interaction

The predicates in this section provide interaction with the file system and (syntactic) operations on file names. SWI-Prolog file system interaction is based on the POSIX standard. On Windows we use the Unicode (wide character) versions of the C runtime library functions.

The file operations define a large set of error conditions. Errors are mapped to Prolog exceptions using a generic function that receives the action (e.g., make_directory), type (e.g., directory), the term that describes the object (name) of the file system and the errno value. Unfortunately, the resulting exceptions are often misleading. For example, calling make_directory/1 such that it must create mutiple directories (e.g., d1/d2/d3) returns an existence error on the directory d1/d2/d3 rather than the missing component. On Windows the situation is even worse because many of its runtime functions distinguish only a few error codes. For example, _wmkdir() only produces EEXIST or ENOENT and all failures except for an already existing target result in an existence_error exception. We can only improve on this situation by implementing the translation of errno to a Prolog exception specifically for each file operation and perform additional tests to distinguish the different
error conditions that are represented by the same \texttt{errno} value. This is hard, in particular because this translation needs to depend on the OS and specific file system limitations.

SWI-Prolog uses the Windows Unicode functions to access the file system. Internally all Prolog’s file handling is based on \texttt{C char*} strings. On POSIX systems these strings use \textit{multibyte encodings} according to the current \texttt{locale} (nowadays often UTF-8). On Windows the encoding is fixed to UTF-8 and a wrapper around the low-level file functions translates this to UTF-16 \footnote{Before 8.5.16 to UCS-2, allowing only for Unicode code points up to 0xffff.} before calling the Win32 \texttt{*W()} or C runtime \texttt{.w*()} functions.

Windows absolute file paths are traditionally limited to 260 characters (\texttt{PATH\_MAX}). More recent versions of Windows support long files. Many of the Unicode file functions support longer paths. For others, support for long paths can be forced by prefixing the path with “\\?\" (“\\?UNC\" for UNC paths (//server/path)). This syntax does \textit{not} allow for relative paths. Thus, SWI-Prolog file functions use \texttt{GetFullPathName()} to arrive at absolute canonical paths and apply the appropriate prefix before calling Windows low-level functions.

Unfortunately the support is not very robust. Some functions still apply length limits while others do not work with the above mentioned prefix. The result depends on the Windows version, several Windows registry entries and the file system. Exceeding the length limit is often reported as non-existence of the target file or directory.

\begin{verbatim}
access_file(+File, +Mode)
True if \textit{File} exists and can be accessed by this Prolog process under mode \textit{Mode}. \textit{Mode} is one of the atoms \texttt{read}, \texttt{write}, \texttt{append}, \texttt{execute}, \texttt{search}, \texttt{exist}, or \texttt{none}. Fails silently otherwise. \textit{File} may also be the name of a directory. \texttt{access_file(File, none)} simply succeeds without testing anything.

If \textit{Mode} is \texttt{write} or \texttt{append}, this predicate also succeeds if the file does not exist and the user has write access to the directory of the specified location.

The mode \texttt{execute} is only intended for use with regular files and the mode \texttt{search} only with directories. However, the two modes are currently equivalent and both can be used with either files or directories. This may change in the future, so the results of checking \texttt{execute access} on directories or \texttt{search access} on regular files should not be relied on.

The behaviour is backed up by the POSIX \texttt{access()} API. The Windows replacement (\texttt{.waccess()}) returns incorrect results because it does not consider ACLs (Access Control Lists). The Prolog flag \texttt{win\_file\_access\_check} may be used to control the level of checking performed by Prolog. Please note that checking access never provides a guarantee that a subsequent open succeeds without errors due to inherent concurrency in file operations. It is generally more robust to try and open the file and handle possible exceptions. See \texttt{open/4} and \texttt{catch/3}.
\end{verbatim}

\begin{verbatim}
exists_file(+File)
True if \textit{File} exists and is a regular file. This does not imply the user has read or write access to the file. See also \texttt{exists\_directory/1} and \texttt{access\_file/2}.
\end{verbatim}

\begin{verbatim}
file\_directory\_name(+File, -Directory)
Extracts the directory part of \textit{File}. This predicate removes the longest match for the regular expression /*[\^/]*\*/. If the result is empty it binds \texttt{Directory} to / if the first character of \textit{File} is / and . otherwise. The behaviour is consistent with the POSIX \texttt{dirname} program. \footnote{Before SWI-Prolog 7.7.13 trailing / where not removed, translation /a/b/ into /a/b. Volker Wysk pointed at this incorrect behaviour.}
\end{verbatim}
See also directory_file_path/3 from filesex. The system ensures that for every valid Path using the Prolog (POSIX) directory separators, following is true on systems with a sound implementation of same_file/2. See also prolog_to_os_filename/2.

.. code-block:: swi-prolog

```prolog
    .
    file_directory_name(Path, Dir),
    file_base_name(Path, File),
    directory_file_path(Dir, File, Path2),
    same_file(Path, Path2).
```

**file_base_name(+Path, -File)**

Extracts the file name part from a path. Similar to file_directory_name/2 the extraction is based on the regex `/*([^/]*)/*/`, now capturing the non-/ segment. If the segment is empty it unifies File with / if Path starts with / and the empty atom (’’’) otherwise. The behaviour is consistent with the POSIX basename program.

**same_file(+File1, +File2)**

True if both filenames refer to the same physical file. That is, if File1 and File2 are the same string or both names exist and point to the same file (due to hard or symbolic links and/or relative vs. absolute paths). On systems that provide stat() with meaningful values for st_dev and st_ino, same_file/2 is implemented by comparing the device and inode identifiers.

On Windows, same_file/2 uses GetFileInformationByHandle() and compares the volume serial number and file index.

**exists_directory(+Directory)**

True if Directory exists and is a directory. This does not imply the user has read, search or write permission for the directory.

**delete_file(+File)**

Remove File from the file system. Note that on POSIX systems the remove() call works on read-only files as long as the containing directory has write access. The Windows remove() call raises a permission error if the file is read-only. SWI-Prolog removes the read-only attribute if remove() fails and tries again. If the file still cannot be removed it restores the read-only attribute and delete_file/1 raises a permission error. As a consequence a read-only file that cannot be removed is briefly read-write. Also note that while an open file can be removed on POSIX systems (where it is actually deleted when closed), deleting an open file on Windows is not possible.

**rename_file(+File1, +File2)**

Rename File1 as File2. The semantics is compatible to the semantics of the POSIX rename() system call as far as the operating system allows. Notably, if File2 exists, the operation succeeds (except for possible permission errors) and is atomic (meaning there is no window where File2 does not exist). Note that File2 cannot be an existing directory. To move a file

---

119 On some systems, Path and Path2 refer to the same entry in the file system, but same_file/2 may fail.

120 Before SWI-Prolog 7.7.13, if argPath ended with a / File was unified with the empty atom.

121 As of version 8.5.16. Earlier versions only compare the canonical name obtained using GetFullPathName().

122 The POSIX semantics describe one exception: a directory can be moved to an existing empty directory.
to another directory one must create File2 from the target directory and the base name of File1. See file_base_name/2.

The rename() system call has a large number of error conditions. Errors are mapped to Prolog exceptions using a generic conversion based on the File1 argument. As a result, the errors may be confusing. Future versions may improve on this.

size_file(+File, -Size)
   Unify Size with the size of File in bytes.

time_file(+File, -Time)
   Unify the last modification time of File with Time. Time is a floating point number expressing the seconds elapsed since Jan 1, 1970. See also convert_time/[2,8] and get_time/1.

absolute_file_name(+File, -Absolute)
   Expand a local filename into an absolute path. The absolute path is canonicalised: references to .., and repeated directory separators (/) are deleted. This predicate ensures that expanding a filename returns the same absolute path regardless of how the file is addressed. Notably, if a file appears in multiple directories due to symbolic or hard links absolute_file_name/2 returns the same absolute filename. SWI-Prolog uses absolute filenames to register source files independent of the current working directory.

This predicate has a different history than absolute_file_name/3 and should primarily be used to get an absolute canonical name from a relative name. If File is a term Alias(Relative) is behaviour is defined as below, i.e., if an accessible file can be found using the provided search path this is returned. Otherwise it returns the the expansion of the alias path. Users are advised to use absolute_file_name/3 with appropriate options for resolving an Alias(Relative) term.

```
absolute_file_name(Spec, AbsFile) :-
   absolute_file_name(Spec, File, [access(read), file_errors(fail)]), !,
   AbsFile = File.

absolute_file_name(Spec, AbsFile) :-
   absolute_file_name(Spec, AbsFile, []).
```

See also absolute_file_name/3, file_search_path/2, and expand_file_name/2.

absolute_file_name(+Spec, -Absolute, +Options)
   Convert the given file specification into an absolute path. Spec is a term Alias(Relative) (e.g., (library(lists)), a relative filename or an absolute filename. The primary intention of this predicate is to resolve files specified as Alias(Relative), which use file_search_path/2 to look up the possibilities for Alias. This predicate only returns non-directories, unless the option file_type(directory) is specified or the requested access is none. Supported Options are:

\[123\] The SICStus implementation behaves as absolute_file_name/3 with an empty option list.
extensions(ListOfExtensions)
List of file extensions to try. Default is exam["]. For each extension, absolute_file_name/3 will first add the extension and then verify the conditions imposed by the other options. If the condition fails, the next extension on the list is tried. Extensions may be specified both as .ext or plain ext.

relative_to(+FileOrDir)
Resolve the path relative to the given directory or the directory holding the given file. Without this option, paths are resolved relative to the working directory (see working_directory/2) or, if Spec is atomic and absolute_file_name/[2,3] is executed in a directive, it uses the current source file as reference.

access(Mode)
Imposes the condition access_file(File, Mode). Mode is one of read, write, append, execute, search, exist or none. See also access_file/2. The default is none which, if file_type is not specified as directory or regular, returns absolute file names that result from expanding aliases without inspecting the actual file system.

file_type(Type)
Defines extensions. Current mapping: txt implies ["], prolog implies [’.pl’, ‘’], executable implies [’.so’, ‘’] and qlf implies [’.qlf’, ‘’]. The Type directory implies [‘’] and causes this predicate to generate (only) directories. The Type regular is the opposite of directory and is the default if no file type is specified and the effective access mode is none.
The file type source is an alias for prolog for compatibility with SICStus Prolog. See also prolog_file_type/2.

file_errors(fail/error)
If error (default), throw an existence_error exception if the file cannot be found. If fail, stay silent.\(^{124}\)

solutions(first/all)
If first (default), the predicate leaves no choice point. Otherwise a choice point will be left and backtracking may yield more solutions.

expand(Boolean)
If true (default is false) and Spec is atomic, call expand_file_name/2 followed by member/2 on Spec before proceeding. This is a SWI-Prolog extension intended to minimise porting effort after SWI-Prolog stopped expanding environment variables and the ~ by default. This option should be considered deprecated. In particular the use of wildcard patterns such as * should be avoided.

The Prolog flag verbose_file_search can be set to true to help debugging Prolog’s search for files. See also file_search_path/2.

This predicate is derived from Quintus Prolog. In Quintus Prolog, the argument order was absolute_file_name(+Spec, +Options, -Path). The argument order has been changed for compatibility with ISO and SICStus. The Quintus argument order is still accepted.

is_absolute_file_name(+File)
True if File specifies an absolute path name. On Unix systems, this implies the path starts

\(^{124}\)Silent operation was the default up to version 3.2.6.
with a ‘/’. For Microsoft-based systems this implies the path starts with ⟨letter⟩:.
This predicate is intended to provide platform-independent checking for absolute paths. See also
absolute_file_name/2 and prolog_to_os_filename/2.

file_name_extension(?Base, ?Extension, ?Name)
This predicate is used to add, remove or test filename extensions. The main reason for its
introduction is to deal with different filename properties in a portable manner. If the file system
is case-insensitive, testing for an extension will also be done case-insensitive. Extension may
be specified with or without a leading dot (.). If an Extension is generated, it will not have a
leading dot.

directory_files(+Directory, -Entries)
Unify Entries with a list of entries in Directory. Each member of Entries is an atom denoting an
entry relative to Directory. Entries contains all entries, including hidden files and, if supplied
by the OS, the special entries . and .. See also expand_file_name/2.125

expand_file_name(+WildCard, -List)
Unify List with a sorted list of files or directories matching WildCard. The normal Unix wild-
card constructs ‘?’, ‘*’, ‘[...]’ and ‘{...}’ are recognised. The interpretation of ‘{...}’
is slightly different from the C shell (csh(1)). The comma-separated argument can be arbitrary
patterns, including ‘{...}’ patterns. The empty pattern is legal as well: ‘\{.pl, \}’ matches
either ‘.pl’ or the empty string.
If the pattern contains wildcard characters, only existing files and directories are returned. Expanding a ‘pattern’ without wildcard characters returns the argument, regardless of whether or not it exists.
Before expanding wildcards, the construct \$\arg{var} is expanded to the value of the
environment variable var, and a possible leading ~ character is expanded to the user’s home
directory.126

prolog_to_os_filename(?PrologPath, ?OsPath)
Convert between the internal Prolog path name conventions and the operating system path
name conventions. The internal conventions follow the POSIX standard, which implies that
this predicate is equivalent to =/2 (unify) on POSIX (e.g., Unix) systems. On Windows systems
it changes the directory separator from \ into /.

read_link(+File, -Link, -Target)
If File points to a symbolic link, unify Link with the value of the link and Target to the file the
link is pointing to. Target points to a file, directory or non-existing entry in the file system, but
never to a link. Fails if File is not a link. Fails always on systems that do not support symbolic
links.

tmp_file(+Base, -TmpName) [deprecated]
Create a name for a temporary file. Base is an identifier for the category of file. The TmpName

---

125 This predicate should be considered a misnomer because it returns entries rather than files. We stick to this name for compatibility with, e.g., SICStus, Ciao and YAP.
126 On Windows, the home directory is determined as follows: if the environment variable HOME exists, this is used. If the variables HOMEDRIVE and HOMEPATH exist (Windows-NT), these are used. At initialisation, the system will set the environment variable HOME to point to the SWI-Prolog home directory if neither HOME nor HOMEPATH and HOMEDRIVE are defined.

---
is guaranteed to be unique. If the system halts, it will automatically remove all created temporary files. \textit{Base} is used as part of the final filename. Portable applications should limit themselves to alphanumeric characters.

Because it is possible to guess the generated filename, attackers may create the filesystem entry as a link and possibly create a security issue. New code should use \texttt{tmp_file_stream/3}.

\textbf{tmp_file_stream(+Encoding, -FileName, -Stream)}

\textbf{tmp_file_stream(-FileName, -Stream, +Options)}

Create a temporary filename \texttt{FileName}, open it for writing and unify \texttt{Stream} with the output stream. If the OS supports it, the created file is only accessible to the current user and the file is created using the \texttt{open()-flag O_EXCL}, which guarantees that the file did not exist before this call. The following options are processed:

\textbf{encoding(+Encoding)}

Encoding of \texttt{Stream}. Default is the value of the Prolog flag \texttt{encoding}. The value \texttt{binary} opens the file in binary mode.

\textbf{extension(+Ext)}

Ensure the created file has the given extension. Default is no extension. Using an extension may be necessary to run external programs on the file.

This predicate is a safe replacement of \texttt{tmp_file/2}. Note that in those cases where the temporary file is needed to store output from an external command, the file must be closed first. E.g., the following downloads a file from a URL to a temporary file and opens the file for reading (on Unix systems you can delete the file for cleanup after opening it for reading):

\begin{verbatim}
open_url(URL, In) :-
    tmp_file_stream(text, File, Stream),
    close(Stream),
    process_create(curl, ['-o', File, URL], []),
    open(File, read, In),
    delete_file(File). % Unix-only
\end{verbatim}

Temporary files created using this call are removed if the Prolog process terminates \textit{gracefully}. Calling \texttt{delete_file/1} using \texttt{FileName} removes the file and removes the entry from the administration of files-to-be-deleted.

\textbf{make_directory(+Directory)}

Create a new directory (folder) on the filesystem. Raises an exception on failure. On Unix systems, the directory is created with default permissions (defined by the process \texttt{umask} setting).

\textbf{delete_directory(+Directory)}

Delete directory (folder) from the filesystem. Raises an exception on failure. Please note that in general it will not be possible to delete a non-empty directory.

\textbf{working_directory(-Old, +New)}

Unify \texttt{Old} with an absolute path to the current working directory and change working directory
4.37. USER TOP-LEVEL MANIPULATION

to New. Use the pattern working_directory(CWD, CWD) to get the current directory. See also absolute_file_name/2 and chdir/1.\textsuperscript{127} Note that the working directory is shared between all threads. Applications are strongly encouraged not to change the working directory or change the working directory once during the initialization.

\texttt{chdir(+Path)}

Compatibility predicate. New code should use working_directory/2.

4.37 User Top-level Manipulation

\textbf{break}

Recursively start a new Prolog top level. This Prolog top level shares everything from the environment it was started in. Debugging is switched off on entering a break and restored on leaving one. The break environment is terminated by typing the system’s end-of-file character (control-D). If that is somehow not functional, the term end_of_file. can be entered to return from the break environment. If the –t toplevel command line option is given, this goal is started instead of entering the default interactive top level (prolog/0).

Notably the gui based versions (swipl-win on Windows and MacOS) provide the menu Run/New thread that opens a new toplevel that runs concurrently with the initial toplevel. The concurrent toplevel can be used to examine the program, in particular global dynamic predicates. It can not access global variables or thread-local dynamic predicates (see thread_local/1) of the main thread.

\textbf{abort}

Abort the Prolog execution and restart the top level. If the –t toplevel command line option is given, this goal is restarted instead of entering the default interactive top level.

Aborting is implemented by throwing the reserved exception ’$aborted’. This exception can be caught using catch/3, but the recovery goal is wrapped with a predicate that prunes the choice points of the recovery goal (i.e., as once/1) and re-throws the exception. This is illustrated in the example below, where we press control-C and ‘a’. See also section 4.10.1.

\begin{verbatim}
?- catch((repeat,fail), E, true).
^CAction (h for help) ? abort
% Execution Aborted
\end{verbatim}

\textbf{halt} \hspace{1cm} \texttt{[ISO]}

Terminate Prolog execution with default exit code using \texttt{halt/1}. The default exit code is normally 0, but can be 1 if one of the Prolog flags on_error or on_warning is set to status and there have been errors or warnings.

\texttt{halt(+Status)} \hspace{1cm} \texttt{[ISO]}

Terminate Prolog execution with Status. This predicate calls PL_halt() which preforms the following steps:

\begin{itemize}
\item BUG: Some of the file I/O predicates use local filenames. Changing directory while file-bound streams are open causes wrong results on telling/1, seeing/1 and current_stream/3.
\end{itemize}
1. Set the Prolog flag `exit_status` to `Status`.

2. Call all hooks registered using `at_halt/1`. If `Status` equals 0 (zero), any of these hooks calls `cancel_halt/1`, termination is cancelled.

3. Call all hooks registered using `PL_at_halt()`. In the future, if any of these hooks returns non-zero, termination will be cancelled. Currently, this only prints a warning.

4. Perform the following system cleanup actions:
   - Cancel all threads, calling `thread_at_exit/1` registered termination hooks. Threads not responding within 1 second are cancelled forcefully.
   - Flush I/O and close all streams except for standard I/O.
   - Reset the terminal if its properties were changed.
   - Remove temporary files and incomplete compilation output.
   - Reclaim memory.

5. Call `exit(Status)` to terminate the process

`halt/1` has been extended in SWI-Prolog to accept the arg `abort`. This performs as `halt/1` above except that:

- Termination cannot be cancelled with `cancel_halt/1`.
- `abort()` is called instead of `exit(Status)`.

**prolog**

This goal starts the default interactive top level. Queries are read from the stream `user_input`. See also the Prolog flag `history`. The `prolog/0` predicate is terminated (succeeds) by typing the end-of-file character (typically control-D).

The following two hooks allow for expanding queries and handling the result of a query. These hooks are used by the top level variable expansion mechanism described in section 2.9.

**expand_query(+Query, -Expanded, +Bindings, -ExpandedBindings)**

Hook in module `user`, normally not defined. `Query` and `Bindings` represents the query read from the user and the names of the free variables as obtained using `read_term/3`. If this predicate succeeds, it should bind `Expanded` and `ExpandedBindings` to the query and bindings to be executed by the top level. This predicate is used by the top level (`prolog/0`). See also `expand_answer/2` and `term_expansion/2`.

**expand_answer(+Bindings, -ExpandedBindings)**

Hook in module `user`, normally not defined. Expand the result of a successfully executed top-level query. `Bindings` is the query `<Name> = <Value>` binding list from the query. `ExpandedBindings` must be unified with the bindings the top level should print.

### 4.38 Creating a Protocol of the User Interaction

SWI-Prolog offers the possibility to log the interaction with the user on a file. All Prolog interaction, including warnings and tracer output, are written to the protocol file.

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128 A similar facility was added to Edinburgh C-Prolog by Wouter Jansweijer.
4.39 DEBUGGING AND TRACING PROGRAMS

4.39. DEBUGGING AND TRACING PROGRAMS

protocol(+File)
Start protocolling on file File. If there is already a protocol file open, then close it first. If File exists it is truncated.

protocola(+File)
Equivalent to protocol/1, but does not truncate the File if it exists.

noprotocol
Stop making a protocol of the user interaction. Pending output is flushed on the file.

protocolling(-File)
True if a protocol was started with protocol/1 or protocola/1 and unifies File with the current protocol output file.

4.39 Debugging and Tracing Programs

This section is a reference to the debugger interaction predicates. A more use-oriented overview of the debugger is in section 2.10.

If you have installed XPCE, you can use the graphical front-end of the tracer. This front-end is installed using the predicate guitracer/0.

trace
Start the tracer. trace/0 itself cannot be seen in the tracer. Note that the Prolog top level treats trace/0 special; it means ‘trace the next goal’.

tracing
True if the tracer is currently switched on. tracing/0 itself cannot be seen in the tracer.

notrace
Stop the tracer. notrace/0 itself cannot be seen in the tracer.

trace(+Pred)
Equivalent to trace(Pred, +all).

trace(+Pred, +Ports)
Put a trace point on all predicates satisfying the predicate specification Pred. Ports is a list of port names (call, redo, exit, fail). The atom all refers to all ports. If the port is preceded by a − sign, the trace point is cleared for the port. If it is preceded by a +, the trace point is set. Tracing a predicate is achieved by wrapping the predicate using wrap_predicate/4.

Each time a port (of the 4-port model) is passed that has a trace point set, the goal is printed. Unlike trace/0, however, the execution is continued without asking for further information. Examples:

?- trace(hello).
Trace all ports of hello with any arity in any module.

?- trace(foo/2, +fail).
Trace failures of foo/2 in any module.

?- trace(bar/1, -all).
Stop tracing bar/1.
notrace(_Goal)

Call _Goal, but suspend the debugger while _Goal is executing. The current implementation cuts the choice points of _Goal after successful completion. See once/1. Later implementations may have the same semantics as call/1.

debug

Start debugger. In debug mode, Prolog stops at spy and break points, disables last-call optimisation and aggressive destruction of choice points to make debugging information accessible. Implemented by the Prolog flag debug.

Note that the min_free parameter of all stacks is enlarged to 8 K cells if debugging is switched off in order to avoid excessive GC. GC complicates tracing because it renames the \langle NN \rangle variables and replaces unreachable variables with the atom <garbage_collected>. Calling nodebug/0 does not reset the initial free-margin because several parts of the top level and debugger disable debugging of system code regions. See also set_prolog_stack/2.

nodebug

Stop debugger. Implemented by the Prolog flag debug. See also debug/0.

debugging

Print debug status and spy points on current output stream. See also the Prolog flag debug.

spy(+Pred)

Put a spy point on all predicates meeting the predicate specification Pred. See section A.23.

nospy(+Pred)

Remove spy point from all predicates meeting the predicate specification Pred.

nospyall

Remove all spy points from the entire program.

leash(?Ports)

Set/query leashing (ports which allow for user interaction). Ports is one of +Name, -Name, ?Name or a list of these. +Name enables leashing on that port, -Name disables it and ?Name succeeds or fails according to the current setting. Recognised ports are call, redo, exit, fail and unify. The special shorthand all refers to all ports, full refers to all ports except for the unify port (default). half refers to the call, redo and fail port.

visible(+Ports)

Set the ports shown by the debugger. See leash/1 for a description of the Ports specification. Default is full.

unknown(-Old, +New)

Edinburgh-Prolog compatibility predicate, interfacing to the ISO Prolog flag unknown. Values are trace (meaning error) and fail. If the unknown flag is set to warning, unknown/2 reports the value as trace.

style_check(+Spec)

Modify/query style checking options. Spec is one of the terms below or a list of these.

• +Style enables a style check
4.39. DEBUGGING AND TRACING PROGRAMS

- Style disables a style check
- ?(Style) queries a style check (note the brackets). If Style is unbound, all active style check options are returned on backtracking.

Loading a file using load_files/2 or one of its derived predicates reset the style checking options to their value before loading the file, scoping the option to the remainder of the file and all files loaded after changing the style checking.

singleton(true)
The predicate read_clause/3 (used by the compiler to read source code) warns on variables appearing only once in a term (clause) which have a name not starting with an underscore. See section 2.16.1 for details on variable handling and warnings.

no_effect(true)
This warning is generated by the compiler for BIPs (built-in predicates) that are inlined by the compiler and for which the compiler can prove that they are meaningless. An example is using ==/2 against a not-yet-initialised variable as illustrated in the example below. This comparison is always false.

```prolog
always_false(X) :-
    X == Y,
    write(Y).
```

var_branches(false)
Verifies that if a variable is introduced in a branch and used after the branch, it is introduced in all branches. This code aims at bugs following the skeleton below, where \( p(\text{Next}) \) may be called with Next unbound.

```prolog
p(Arg) :-
    \{ Cond
    -> Next = value1
    ; true
    \},
    p(Next).
```

If a variable V is intended to be left unbound, one can use V=. This construct is removed by the compiler and thus has no implications for the performance of your program.

This check was suggested together with semantic singleton checking. The SWI-Prolog libraries contain about a hundred clauses that are triggered by this style check. Unlike semantic singleton analysis, only a tiny fraction of these clauses proved faulty. In most cases, the branches failing to bind the variable fail or raise an exception or the caller handles the case where the variable is unbound. The status of this style check is unclear. It might be removed in the future or it might be enhanced with a deeper analysis to be more precise.

discontiguous(true)
Warn if the clauses for a predicate are not together in the same source file. It is advised to disable the warning for discontiguous predicates using the discontiguous/1 directive.
charset(false)
Warn on atoms and variable names holding non-ASCII characters that are not quoted.
See also section 2.16.1.

4.40 Debugging and declaring determinism

A common issue with Prolog programs of a procedural nature is to guarantee deterministic behaviour and debug possible problems with determinism. SWI-Prolog provides several mechanisms to make writing, debugging and maintaining deterministic code easier. One of them is Single Sided Unification using =/>2 rules as described in section 5.6. This section deals with annotating your program.

If a program does not behave according to these annotations it raises an error/2 exception where the formal term is determinism_error(Pred, Declared, Observed, DeclType), where Declared is currently always det, Observed is one of fail or nondet and DeclType is one of property (det/1), guard ($/0) or goal ($/1). Using trap/1 or gtrap/1 we can ask Prolog to start the debugger in such events using

?- gtrap(determinism_error(_,_,_,_)).

WARNING: The primitives in this section are experimental. The naming and exact semantics may change. If you are interested in this, please follow and contribute to discussion on the Discourse forum.

det(+PredicateIndicators) [experimental,directive]
Declare a number of predicates as det, deterministic. As a result, both failure and success with a choicepoint is considered an error. The behaviour if the declaration is violated is controlled with the Prolog flag determinism_error. The default is to raise an exception (error). Consider the following program:

:- det(p/1).
p(1).
p(2).

Now, a call ?- p(1). behaves normally. However:

?- p(X).
ERROR: Deterministic procedure p/1 succeeded with a choicepoint
ERROR: In:
ERROR: [10] p(1)

?- p(a).
ERROR: Deterministic procedure p/1 failed
ERROR: In:
ERROR: [10] p(a)
4.41. Obtaining Runtime Statistics

The predicate `statistics/2` is built-in. More high level predicates are available from library `statistics`. See section A.48.

```
statistics(+Key, -Value)
```

Unify system statistics determined by `Key` with `Value`. The possible keys are given in the table 4.3. This predicate supports additional keys for compatibility reasons. These keys are described in table 4.4. CPU time results are based on `clock_gettime()`, `times()` or wall time since the process was started (in that order of preference). On Windows `GetProcessTimes()` is used. Both `clock_gettime()` and `GetProcessTimes()` provide a nanosecond resolution interface. The actual resolution depends on the platform.

Violations throw an `error/2` exception `determinism_error(Pred, Declared, Observed, property)`.

\$ \quad \text{[experimental]}

The `$/0$` constructs acts similar to the `!/0`, but in addition declares that the remainder of the clause body shall succeed deterministically. It exploits the same underlying mechanism as the `det/1` declaration. See also `$/1$.

Violations throw an `error/2` exception `determinism_error(Pred, Declared, Observed, guard)`.

\$(:Goal) \quad \text{[experimental]}

Verify that `Goal` succeeds deterministically. This predicate has no effect if `Goal` succeeds without a choicepoint. Otherwise the result depends on the Prolog flag `determinism_error`:

- `silent`  
  Act as `once/1`.
- `warning`  
  Print a warning and act as `once/1`.
- `error`  
  Raise a `determinism_error` exception.

Note that if `$/1$` is used for the last call, last call optimization is not effective. This behaviour ensures consistent errors or warnings. Last call optimization with determinism checking can be realised using `$\ldots\$, $, $, $\ldots$, i.e. by executing `$/0$` before the last call rather than wrapping the last call in `$/1$`.

Violations throw an `error/2` exception `determinism_error(Pred, Declared, Observed, goal)`.

A deterministic predicate may call normal predicates. No error is triggered as long as the deterministic predicate either ignores a possible failure, e.g., using `\+/1` and prunes possible choice points created by called predicates. If the last predicate is a normal predicate the requirement to succeed deterministically is transferred to the new goal. As last-call optimization causes the information which predicate initially claimed to be deterministic to be lost, the error is associated with the called predicate. Debug mode (see `debug/0` or the Prolog flag `debug`) may be used to avoid last call optimization and find the call stack that causes the issue.
Native keys (times as float in seconds)

<table>
<thead>
<tr>
<th>Key</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>agc</td>
<td>Number of atom garbage collections performed</td>
</tr>
<tr>
<td>agc_gained</td>
<td>Number of atoms removed</td>
</tr>
<tr>
<td>agc_time</td>
<td>Time spent in atom garbage collections</td>
</tr>
<tr>
<td>atoms</td>
<td>Total number of defined atoms</td>
</tr>
<tr>
<td>atom_space</td>
<td>Bytes used to represent atoms</td>
</tr>
<tr>
<td>c_stack</td>
<td>System (C-) stack limit. 0 if not known.</td>
</tr>
<tr>
<td>cgc</td>
<td>Number of clause garbage collections performed</td>
</tr>
<tr>
<td>cgc_gained</td>
<td>Number of clauses reclaimed</td>
</tr>
<tr>
<td>cgc_time</td>
<td>Time spent in clause garbage collections</td>
</tr>
<tr>
<td>clauses</td>
<td>Total number of clauses in the program</td>
</tr>
<tr>
<td>codes</td>
<td>Total size of (virtual) executable code in words</td>
</tr>
<tr>
<td>cputime</td>
<td>(User) CPU time since thread was started</td>
</tr>
<tr>
<td>epoch</td>
<td>Time stamp when thread was started</td>
</tr>
<tr>
<td>errors</td>
<td>Number of error messages printed</td>
</tr>
<tr>
<td>functors</td>
<td>Total number of defined name/arity pairs</td>
</tr>
<tr>
<td>functor_space</td>
<td>Bytes used to represent functors</td>
</tr>
<tr>
<td>global</td>
<td>Allocated size of the global stack in bytes</td>
</tr>
<tr>
<td>globalused</td>
<td>Number of bytes in use on the global stack</td>
</tr>
<tr>
<td>globallimit</td>
<td>Size to which the global stack is allowed to grow</td>
</tr>
<tr>
<td>global_shifts</td>
<td>Number of global stack expansions</td>
</tr>
<tr>
<td>heapused</td>
<td>Bytes of heap in use by Prolog (0 if not maintained)</td>
</tr>
<tr>
<td>inferences</td>
<td>Total number of passes via the call and redo ports since Prolog was started</td>
</tr>
<tr>
<td>modules</td>
<td>Total number of defined modules</td>
</tr>
<tr>
<td>local</td>
<td>Allocated size of the local stack in bytes</td>
</tr>
<tr>
<td>local_shifts</td>
<td>Number of local stack expansions</td>
</tr>
<tr>
<td>locallimit</td>
<td>Size to which the local stack is allowed to grow</td>
</tr>
<tr>
<td>localused</td>
<td>Number of bytes in use on the local stack</td>
</tr>
<tr>
<td>table_space_used</td>
<td>Amount of bytes in use by the thread’s answer tables</td>
</tr>
<tr>
<td>trail</td>
<td>Allocated size of the trail stack in bytes</td>
</tr>
<tr>
<td>trail_shifts</td>
<td>Number of trail stack expansions</td>
</tr>
<tr>
<td>traillimit</td>
<td>Size to which the trail stack is allowed to grow</td>
</tr>
<tr>
<td>trailused</td>
<td>Number of bytes in use on the trail stack</td>
</tr>
<tr>
<td>shift_time</td>
<td>Time spent in stack-shifts</td>
</tr>
<tr>
<td>stack</td>
<td>Total memory in use for stacks in all threads</td>
</tr>
<tr>
<td>predicates</td>
<td>Total number of predicates. This includes predicates that are undefined or not yet resolved.</td>
</tr>
<tr>
<td>indexes_created</td>
<td>Number of clause index tables creates.</td>
</tr>
<tr>
<td>indexes_destroyed</td>
<td>Number of clause index tables destroyed.</td>
</tr>
<tr>
<td>process_epoch</td>
<td>Time stamp when Prolog was started</td>
</tr>
<tr>
<td>process_cputime</td>
<td>(User) CPU time since Prolog was started</td>
</tr>
<tr>
<td>thread_cputime</td>
<td>MT-version: Seconds CPU time used by finished threads. The implementation requires non-portable functionality. Currently works on Linux, MacOSX, Windows and probably some more.</td>
</tr>
<tr>
<td>threads</td>
<td>MT-version: number of active threads</td>
</tr>
<tr>
<td>threads_created</td>
<td>MT-version: number of created threads</td>
</tr>
<tr>
<td>engines</td>
<td>MT-version: number of existing engines</td>
</tr>
<tr>
<td>engines_created</td>
<td>MT-version: number of created engines</td>
</tr>
<tr>
<td>threads_peak</td>
<td>MT-version: highest id handed out. This is a fair but possibly not 100% accurate value for the highest number of threads since the process was created.</td>
</tr>
</tbody>
</table>
Compatibility keys (times in milliseconds)

<table>
<thead>
<tr>
<th>Key</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>runtime</td>
<td>[ CPU time, CPU time since last ] (milliseconds, excluding time spent in garbage collection)</td>
</tr>
<tr>
<td>system_time</td>
<td>[ System CPU time, System CPU time since last ] (milliseconds)</td>
</tr>
<tr>
<td>real_time</td>
<td>[ Wall time, Wall time since last ] (integer seconds. See <code>get_time/1</code>)</td>
</tr>
<tr>
<td>walltime</td>
<td>[ Wall time since start, Wall time since last ] (milliseconds, SICStus compatibility)</td>
</tr>
<tr>
<td>memory</td>
<td>[ Total unshared data, free memory ] (Used is based on <code>ru_idrss</code> from <code>getrusage()</code>. Free is based on <code>RLIMIT_DATA</code> from <code>getrlimit()</code>. Both are reported as zero if the OS lacks support. Free is -1 if <code>getrlimit()</code> is supported but returns infinity.)</td>
</tr>
<tr>
<td>stacks</td>
<td>[ global use, local use ]</td>
</tr>
<tr>
<td>program</td>
<td>[ heap use, 0 ]</td>
</tr>
<tr>
<td>global_stack</td>
<td>[ global use, global free ]</td>
</tr>
<tr>
<td>local_stack</td>
<td>[ local use, local free ]</td>
</tr>
<tr>
<td>trail</td>
<td>[ trail use, trail free ]</td>
</tr>
<tr>
<td>garbage_collection</td>
<td>[ number of GC, bytes gained, time spent, bytes left ] The last column is a SWI-Prolog extension. It contains the sum of the memory left after each collection, which can be divided by the count to find the average working set size after GC. Use [Count, Gained, Time</td>
</tr>
<tr>
<td>stack_shifts</td>
<td>[ global shifts, local shifts, time spent ]</td>
</tr>
<tr>
<td>atoms</td>
<td>[ number, memory use, 0 ]</td>
</tr>
<tr>
<td>atom_garbage_collection</td>
<td>[ number of AGC, bytes gained, time spent ]</td>
</tr>
<tr>
<td>clause_garbage_collection</td>
<td>[ number of CGC, clauses gained, time spent ]</td>
</tr>
<tr>
<td>core</td>
<td>Same as memory</td>
</tr>
</tbody>
</table>

Table 4.4: Compatibility keys for `statistics/2`. Time is expressed in milliseconds.
4.42 Execution profiling

This section describes the hierarchical execution profiler. This profiler is based on ideas from gprof described in [Graham et al., 1982]. The profiler consists of two parts: the information-gathering component built into the kernel,\(^1\) and a presentation component which is defined in the statistics library. The latter can be hooked, which is used by the XPCE module swi/pce_profile to provide an interactive graphical frontend for the results.

4.42.1 Profiling predicates

The following predicates are defined to interact with the profiler.

**profile(:Goal)**

Execute Goal just like once/1, collecting profiling statistics, and call show_profile([]). With XPCE installed this opens a graphical interface to examine the collected profiling data.

**profile(:Goal, +Options)**

Execute Goal just like once/1. Collect profiling statistics according to Options and call show_profile/1 with Options. The default collects CPU profiling and opens a graphical interface when provided, printing the ‘plain’ time usage of the top 25 predicates as aallback. Options are described below. Remaining options are passed to show_profile/1.

**time(+Which)**

If Which is cpu (default), collect CPU timing statistics. If wall, collect wall time statistics based on a 5 millisecond sampling rate. Wall time statistics can be useful if Goal calls blocking system calls.

**show_profile(+Options)**

This predicate first calls prolog:show_profile_hook/1. If XPCE is loaded, this hook is used to activate a GUI interface to visualise the profile results. If not, a report is printed to the terminal according to Options:

**top(+N)**

Show the only top N predicates. Default is 25.

**cumulative(+Bool)**

If true (default false), include the time spent in children in the time reported for a predicate.

**profiler(-Old, +New)**

Query or change the status of the profiler. The status is one of

false

The profiler is not activated.

cputime

The profiler collects CPU statistics.

---

\(^1\)There are two implementations; one based on setitimer() using the SIGPROF signal and one using Windows Multi Media (MM) timers. On other systems the profiler is not provided.
4.42. EXECUTION PROFILING

Figure 4.1: Execution profiler showing the activity of the predicate chat:inv_map_list/5.

**walltime**

The profiler collects wall time statistics.

The value `true` is accepted as a synonym for `cputime` for compatibility reasons.

**reset_profiler**

Switches the profiler to `false` and clears all collected statistics.

**noprofile(+Name/+Arity, ...)**

Declares the predicate `Name/Arity` to be invisible to the profiler. The time spent in the named predicate is added to the caller, and the callees are linked directly to the caller. This is particularly useful for simple meta-predicates such as `call/1, ignore/1, catch/3`, etc.

### 4.42.2 Visualizing profiling data

Browsing the annotated call-tree as described in section 4.42.3 itself is not very attractive. Therefore, the results are combined per predicate, collecting all `callers` and `callees` as well as the propagation of time and activations in both directions. Figure 4.1 illustrates this. The central yellowish line is the ‘current’ predicate with counts for time spent in the predicate (‘Self’), time spent in its children (‘Siblings’), activations through the call and redo ports. Above that are the `callers`. Here, the two time fields indicate how much time is spent serving each of the callers. The columns sum to the time in the yellowish line. The caller `<recursive>` is the number of recursive calls. Below the yellowish lines are the callees, with the time spent in the callee itself for serving the current predicate and the time spent in the callees of the callee (‘Siblings’), so the whole time-block adds up to the ‘Siblings’ field of the current predicate. The ‘Access’ fields show how many times the current predicate accesses each of the callees.

The predicates have a menu that allows changing the view of the detail window to the given caller or callee, showing the documentation (if it is a built-in) and/or jumping to the source.

The statistics shown in the report field of figure 4.1 show the following information:

- **samples**

  Number of times the call-tree was sampled for collecting time statistics. On most hardware, the resolution of `SIGPROF` is 1/100 second. This number must be sufficiently large to get reliable timing figures. The `Time` menu allows viewing time as samples, relative time or absolute time.
• **sec**
  Total user CPU time with the profiler active.

• **predicates**
  Total count of predicates that have been called at least one time during the profile.

• **nodes**
  Number of nodes in the call-tree.

• **distortion**
  How much of the time is spent building the call-tree as a percentage of the total execution time.
  Timing samples while the profiler is building the call-tree are not added to the call-tree.

### 4.42.3 Information gathering

While the program executes under the profiler, the system builds a *dynamic* call-tree. It does this using three hooks from the kernel: one that starts a new goal (*profCall*), one that tells the system which goal is resumed after an *exit* (*profExit*) and one that tells the system which goal is resumed after a *fail* (i.e., which goal is used to *retry* (*profRedo*)). The *profCall()* function finds or creates the subnode for the argument predicate below the current node, increments the call-count of this link and returns the sub-node which is recorded in the Prolog stack-frame. Choice-points are marked with the current profiling node. *profExit()* and *profRedo()* pass the profiling node where execution resumes.

Just using the above algorithm would create a much too big tree due to recursion. For this reason the system performs detection of recursion. In the simplest case, recursive procedures increment the ‘recursive’ count on the current node. Mutual recursion, however, is not easily detected. For example, *call/1* can call a predicate that uses *call/1* itself. This can be viewed as a recursive invocation, but this is generally not desirable. Recursion is currently assumed if the same predicate with the same parent appears higher in the call-graph. Early experience with some non-trivial programs are promising.

The last part of the profiler collects statistics on the CPU time used in each node. On systems providing `setitimer()` with `SIGPROF`, it ‘ticks’ the current node of the call-tree each time the timer fires. On Windows, a MM-timer in a separate thread checks 100 times per second how much time is spent in the profiled thread and adds this to the current node. See section 4.42.3 for details.

### Profiling in the Windows Implementation

Profiling in the Windows version is similar, but as profiling is a statistical process it is good to be aware of the implementation\(^\text{130}\) for proper interpretation of the results.

Windows does not provide timers that fire asynchronously, frequent and proportional to the CPU time used by the process. Windows does provide multi-media timers that can run at high frequency. Such timers, however, run in a separate thread of execution and they are fired on the wall clock rather than the amount of CPU time used. The profiler installs such a timer running, for saving CPU time, rather inaccurately at about 100 Hz. Each time it is fired, it determines the CPU time in milliseconds used by Prolog since the last time it was fired. If this value is non-zero, active predicates are incremented with this value.

---
\(^{130}\)We hereby acknowledge Lionel Fourquaux, who suggested the design described here after a newsnet enquiry.
4.43 Memory Management

4.43.1 Garbage collection

**garbage_collect**
Invoke the global and trail stack garbage collector. Normally the garbage collector is invoked automatically if necessary. Explicit invocation might be useful to reduce the need for garbage collections in time-critical segments of the code. After the garbage collection `trim_stacks/0` is invoked to release the collected memory resources.

**garbage_collect_atoms**
Reclaim unused atoms. Normally invoked after `agc_margin` (a Prolog flag) atoms have been created. On multithreaded versions the actual collection is delayed until there are no threads performing normal garbage collection. In this case `garbage_collect_atoms/0` returns immediately. Note that there is no guarantee it will ever happen, as there may always be threads performing garbage collection.

**garbage_collect_clauses**
Reclaim retracted clauses. During normal operation, retracting a clause implies setting the erased generation to the current generation of the database and increment the generation. Keeping the clause around is both needed to realise the logical update view and deal with the fact that other threads may be executing the clause. Both static and dynamic code is processed this way.

The clause garbage collector (CGC) scans the environment stacks of all threads for referenced dirty predicates and at which generation this reference accesses the predicate. It then removes the references for clauses that have been retracted before the oldest access generation from the clause list as well as the secondary clauses indexes of the predicate. If the clause list is not being scanned, the clause references and ultimately the clause itself is reclaimed.

The clause garbage collector is called under three conditions, (1) after reloading a source file, (2) if the memory occupied by retracted but not yet reclaimed clauses exceeds 12.5% of the program store, or (3) if skipping dead clauses in the clause lists becomes too costly. The cost of clause garbage collection is proportional with the total size of the local stack of all threads (the scanning phase) and the number of clauses in all ‘dirty’ predicates (the reclaiming phase).

**set_prolog_gc_thread(+Status)**
Control whether or not atom and clause garbage collection are executed in a dedicated thread. The default is `true`. Values for `Status` are `true`, `false` and `stop`. The latter stops the gc thread but allows it to be recreated lazily. This is use by e.g., `fork/1` to avoid forking a multi-threaded application. See also `gc_thread`.

**trim_stacks**
Release stack memory resources that are not in use at this moment, returning them to the operating system. It can be used to release memory resources in a backtracking loop, where the iterations require typically seconds of execution time and very different, potentially large, amounts of stack space. Such a loop can be written as follows:

Up to version 7.3.11, dynamic code was handled using reference counts.
The Prolog top-level loop is written this way, reclaiming memory resources after every user query. See also `trim_heap/0` and `thread_idle/2`.

`set_prolog_stack(+Stack, +KeyValue)`
Set a parameter for one of the Prolog runtime stacks. `Stack` is one of `local`, `global` or `trail`. The table below describes the `Key(Value)` pairs.

Current settings can be retrieved with `prolog_stack_property/2`.

`min_free(+Cells)`
Minimum amount of free space after trimming or shifting the stack. Setting this value higher can reduce the number of garbage collections and stack-shifts at the cost of higher memory usage. The amount is reported and specified in `cells`. A cell is 4 bytes in the 32-bit version and 8 bytes on the 64-bit version. See `address_bits`. See also `trim_stacks/0` and `debug/0`.

`low(+Cells)`
`factor(+Number)`
These two figures determine whether, if the stacks are low, a stack shift (expansion) or garbage collection is performed. This depends on these two parameters, the current stack usage and the amount of stack used after the last garbage collection. A garbage collection is started if `used > factor \times lastused + low`.

`sparse(+Cells)`
All stacks trigger overflow before actually reaching the limit, so the resulting error can be handled gracefully. The spare stack is used for `print_message/2` from the garbage collector and for handling exceptions. The default suffices, unless the user redefines related hooks. Do not specify large values for this because it reduces the amount of memory available for your real task.

Related hooks are `message_hook/3` (redefining GC messages), `prolog_trace_interception/4` and `prolog_exception_hook/4`.

`prolog_stack_property(?Stack, ?KeyValue)`
True if `KeyValue` is a current property of `Stack`. See `set_prolog_stack/2` for defined properties.

The total space limit for all stacks is controlled using the prolog flag `stack_limit`.

### 4.43.2 Heap memory (malloc)

SWI-Prolog’s memory management is based on the C runtime `malloc()` function and related functions. The characteristics of the `malloc()` implementation may affect performance and overall memory usage.
of the system. For most Prolog programs the performance impact of the allocator is small. The impact on total memory usage can be significant though, in particular for multi-threaded applications. This is due to two aspects of SWI-Prolog memory management:

- The Prolog stacks are allocated using malloc(). The stacks can be extremely large. SWI-Prolog assumes malloc() will use a mechanism that allows returning this memory to the OS. Most todays allocators satisfy this requirement.

- Atoms and clauses are allocated by the thread that requires them, but this memory is freed by the thread running the atom or clause garbage collector (see garbage_collect_atoms/0 and garbage_collect_clauses/0). Normally these run in the thread gc, which means that all deallocation happens in this thread. Notably the ptmalloc implementation used by the GNU C library (glibc) seems to handle this poorly.

Starting with version 8.1.27, SWI-Prolog by default links against tcmalloc when available. Note that changing the allocator can only be done by linking the main executable (swipl) to an alternative library. When embedded (see section 12.4.24) the main program that embeds libswipl must be linked with tcmalloc. On ELF based systems (Linux), this effect can also be achieved using the environment variable LD_PRELOAD:

```
% LD_PRELOAD=/path/to/libtcmalloc.so swipl ...
```

SWI-Prolog attempts to detect the currently active allocator and sets the Prolog flag malloc if the detection succeeds. regardless of the malloc implementation, trim_heap/0 is provided.

`trim_heap` [det]

his predicate attempts to return heap memory to the operating system. There is no portable way of doing so. If the system detects tcmalloc it calls MallocExtension_ReleaseFreeMemory(). If the system detects ptmalloc as provided by the GNU runtime library it calls malloc_trim(). In other cases this predicate simply succeeds. See also trim_stacks/0

TCMalloc control predicates

If SWI-Prolog core detects that tcmalloc is the current allocator and provides the following additional predicates.

`malloc_property(\Property)` [nondet]

True when \Property is a property of the current allocator. The properties are defined by the allocator. The properties of tcmalloc are defined in gperftools/malloc_extension.h:

- `generic.current_allocated_bytes`(\-Int)
  Number of bytes currently allocated by application.

- `generic.heap_size`(\-Int)
  Number of bytes in the heap (= current_allocated_bytes + fragmentation + freed memory regions).

---

132 Multi-threaded applications may suffer from allocators that do not effectively avoid false sharing that affect CPU cache behaviour or operate using a single lock to provide thread safety. Such allocators should be rare in modern OSes.

133 Documentation copied from the header.
‘tcmalloc.max_total_thread_cache_bytes’(-Int)
Upper limit on total number of bytes stored across all thread caches.

‘tcmalloc.current_total_thread_cache_bytes’(-Int)
Number of bytes used across all thread caches.

‘tcmalloc.central_cache_free_bytes’(-Int)
Number of free bytes in the central cache that have been assigned to size classes. They always count towards virtual memory usage, and unless the underlying memory is swapped out by the OS, they also count towards physical memory usage.

‘tcmalloc.transfer_cache_free_bytes’(-Int)
Number of free bytes that are waiting to be transferred between the central cache and a thread cache. They always count towards virtual memory usage, and unless the underlying memory is swapped out by the OS, they also count towards physical memory usage.

‘tcmalloc.thread_cache_free_bytes’(-Int)
Number of free bytes in thread caches. They always count towards virtual memory usage, and unless the underlying memory is swapped out by the OS, they also count towards physical memory usage.

‘tcmalloc.pageheap_free_bytes’(-Int)
Number of bytes in free, mapped pages in page heap. These bytes can be used to fulfill allocation requests. They always count towards virtual memory usage, and unless the underlying memory is swapped out by the OS, they also count towards physical memory usage. This property is not writable.

‘tcmalloc.pageheap_unmapped_bytes’(-Int)
Number of bytes in free, unmapped pages in page heap. These are bytes that have been released back to the OS, possibly by one of the MallocExtension "Release" calls. They can be used to fulfill allocation requests, but typically incur a page fault. They always count towards virtual memory usage, and depending on the OS, typically do not count towards physical memory usage.

set_malloc(+Property) [det]
Set properties described in malloc_property/1. Currently the only writable property is tcmalloc.max_total_thread_cache_bytes. Setting an unknown property raises a domain_error and setting a read-only property raises a permission_error exception.

thread_idle(:Goal, +Duration) [semidet]
Indicates to the system that the calling thread will idle for some time while calling Goal as once/1. This call releases resources to the OS to minimise the footprint of the calling thread while it waits. Despite the name this predicate is always provided, also if the system is not configured with tcmalloc or is single threaded. Duration is one of

short
Calls trim_stacks/0 and, if tcmalloc is used, calls MallocExtension_MarkThreadTemporarilyIdle() which empties the thread’s malloc cache but preserves the cache itself.

long
Calls garbage_collect/0 and trim_stacks/0 and, if tcmalloc is used, calls MallocExtension_MarkThreadIdle() which releases all thread-specific allocation data structures.
4.44 Windows DDE interface

The predicates in this section deal with MS-Windows ‘Dynamic Data Exchange’ or DDE protocol.134 A Windows DDE conversation is a form of interprocess communication based on sending reserved window events between the communicating processes.

Failing DDE operations raise an error of the structure below, where Operation is the name of the (partial) operation that failed and Message is a translation of the operator error code. For some errors, Context provides additional comments.

\[
\text{error(dde_error(Operation, Message, Context))}
\]

4.44.1 DDE client interface

The DDE client interface allows Prolog to talk to DDE server programs. We will demonstrate the use of the DDE interface using the Windows PROGMAN (Program Manager) application:

\[
\begin{align*}
1 \text{ ?- open_dde_conversation(progman, progman, C).} \\
\text{C = 0} \\
2 \text{ ?- dde_request(0, groups, X)} \\
\text{--> Unifies X with description of groups} \\
3 \text{ ?- dde_execute(0, '[CreateGroup("DDE Demo")]').} \\
\text{true.} \\
4 \text{ ?- close_dde_conversation(0).} \\
\text{true.}
\end{align*}
\]

For details on interacting with progman, use the SDK online manual section on the Shell DDE interface. See also the Prolog library(progman), which may be used to write simple Windows setup scripts in Prolog.

\begin{itemize}
\item **open_dde_conversation**(Service, Topic, Handle)
  
  Open a conversation with a server supporting the given service name and topic (atoms). If successful, Handle may be used to send transactions to the server. If no willing server is found this predicate fails silently.

\item **close_dde_conversation**(Handle)
  
  Close the conversation associated with Handle. All opened conversations should be closed when they’re no longer needed, although the system will close any that remain open on process termination.
\end{itemize}

\[^{134}\text{This interface is contributed by Don Dwiggins.}\]
**dde_request(+Handle, +Item, -Value)**
Request a value from the server. *Item* is an atom that identifies the requested data, and *Value* will be a string (CF\_TEXT data in DDE parlance) representing that data, if the request is successful.

**dde_execute(+Handle, +Command)**
Request the DDE server to execute the given command string. Succeeds if the command could be executed and fails with an error message otherwise.

**dde_poke(+Handle, +Item, +Command)**
Issue a POKE command to the server on the specified *Item. command* is passed as data of type CF\_TEXT.

### 4.44.2 DDE server mode

The library(dde) defines primitives to realise simple DDE server applications in SWI-Prolog. These features are provided as of version 2.0.6 and should be regarded as prototypes. The C part of the DDE server can handle some more primitives, so if you need features not provided by this interface, please study library(dde).

**dde_register_service(+Template, +Goal)**
Register a server to handle DDE request or DDE execute requests from other applications. To register a service for a DDE request, *Template* is of the form:

```
+Service(+Topic, +Item, +Value)
```

*Service* is the name of the DDE service provided (like progman in the client example above). *Topic* is either an atom, indicating *Goal* only handles requests on this topic, or a variable that also appears in *Goal*. *Item* and *Value* are variables that also appear in *Goal*. *Item* represents the request data as a Prolog atom.\(^{135}\)

The example below registers the Prolog current_prolog_flag/2 predicate to be accessible from other applications. The request may be given from the same Prolog as well as from another application.

```
?- dde_register_service(prolog(current_prolog_flag, F, V),
                       current_prolog_flag(F, V)).
?- open_dde_conversation(prolog, current_prolog_flag, Handle),
   dde_request(Handle, home, Home),
   close_dde_conversation(Handle).
```

**Handling DDE execute requests** is very similar. In this case the template is of the form:

```
+Service(+Topic, +Item)
```

\(^{135}\)Up to version 3.4.5 this was a list of character codes. As recent versions have atom garbage collection there is no need for this anymore.
Passing a Value argument is not needed as execute requests either succeed or fail. If Goal fails, a ‘not processed’ is passed back to the caller of the DDE request.

**dde_unregister_service(+Service)**

Stop responding to Service. If Prolog is halted, it will automatically call this on all open services.

**dde_current_service(-Service, -Topic)**

Find currently registered services and the topics served on them.

**dde_current_connection(-Service, -Topic)**

Find currently open conversations.

4.45 Miscellaneous

**dwim_match(+Atom1, +Atom2)**

True if Atom1 matches Atom2 in the ‘Do What I Mean’ sense. Both Atom1 and Atom2 may also be integers or floats. The two atoms match if:

- They are identical
- They differ by one character (spy ≡ spu)
- One character is inserted/deleted (debug ≡ deug)
- Two characters are transposed (trace ≡ tarce)
- ‘Sub-words’ are glued differently (existsfile ≡ existsFile ≡ exists_file)
- Two adjacent sub-words are transposed (existsFile ≡ fileExists)

**dwim_match(+Atom1, +Atom2, -Difference)**

Equivalent to dwim_match/2, but unifies Difference with an atom identifying the difference between Atom1 and Atom2. The return values are (in the same order as above): equal, mismatched_char, inserted_char, transposed_char, separated and transposed_word.

**wildcard_match(+Pattern, +String)**

**wildcard_match(+Pattern, +String, +Options)**

True if String matches the wildcard pattern Pattern. Pattern is very similar to the Unix csh pattern matcher. The patterns are given below:

? Matches one arbitrary character.
*

Matches any number of arbitrary characters.

[...] Matches one of the characters specified between the brackets.

(\texttt{char1})-(\texttt{char2}) indicates a range.

\{\ldots\} Matches any of the patterns of the comma-separated list between the braces.

**Example:**

?- wildcard_match(’[a-zA-Z]*.\{pro,pl\}[^$]’, ’a_hello.pl$’).
true.
The wildcard_match/3 version processes the following option:

**case_sensitive(+Boolean)**
When false (default true), match case insensitively.

**sleep(+Time)**
Suspend execution *Time* seconds. *Time* is either a floating point number or an integer. Granularity is dependent on the system’s timer granularity. A negative time causes the timer to return immediately. On most non-realtime operating systems we can only ensure execution is suspended for at least *Time* seconds.

On Unix systems the sleep/1 predicate is realised —in order of preference— by nanosleep(), usleep(), select() if the time is below 1 minute, or sleep(). On Windows systems Sleep() is used.
This chapter describes extensions to the Prolog language introduced with SWI-Prolog version 7 in 2014. The changes bring more modern syntactical conventions to Prolog such as key-value maps, called *dicts*, as primary citizens and a restricted form of *functional notation*. They also extend Prolog basic types with strings, providing a natural notation to textual material as opposed to identifiers (atoms) and lists.

These extensions make the syntax more intuitive to new users, simplify the integration of domain specific languages (DSLs) and facilitate a more natural Prolog representation for popular exchange languages such as XML and JSON.

While many programs run unmodified in SWI-Prolog version 7, some require modifications, especially those that pass double quoted strings to general purpose list processing predicates. See section 5.2.4 and section 5.2.5 for information and tools on porting. We provide a tool (list_strings/0) that we used to port a huge code base in half a day.

### 5.1 Lists are special

As of version 7, SWI-Prolog lists can be distinguished unambiguously at runtime from */2* terms and the atom ‘[]’.

<table>
<thead>
<tr>
<th>Traditional list</th>
<th>SWI-Prolog 7 list</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>.'   </code>/ \ 1 <code>.'  </code>/ \ 2 <code>['  </code>/ \ 3 `['</td>
<td><code>['   </code>/ \ 1 <code>['   </code>/ \ 2 <code>['   </code>/ \ 3 `['</td>
</tr>
<tr>
<td>terminated with</td>
<td>terminated with</td>
</tr>
<tr>
<td>the atom ‘[]’,</td>
<td>a special constant</td>
</tr>
<tr>
<td>indistinguishable from text</td>
<td>which is printed as []</td>
</tr>
</tbody>
</table>

The constant `[]` is special constant that is not an atom. It has the following properties:

<table>
<thead>
<tr>
<th><code>atom([]).</code></th>
<th>fails</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>atomic([]).</code></td>
<td>succeeds</td>
</tr>
<tr>
<td><code>[] == '[]'.</code></td>
<td>fails</td>
</tr>
<tr>
<td><code>[] == []</code>.</td>
<td>succeeds</td>
</tr>
</tbody>
</table>
The ‘cons’ operator for creating list cells has changed from the pretty atom ‘.’ to the ugly atom ‘[|]’, so we can use the ‘.’ for other purposes, notably functional notation on dicts. See section 5.4.1.

This modification has minimal impact on typical Prolog code. It does affect foreign code (see section 12) that uses the normal atom and compound term interface for manipulating lists. In most cases this can be avoided by using the dedicated list functions. For convenience, the macros ATOM_nil and ATOM_dot are provided by SWI-Prolog.h.

Another place that is affected is write_canonical/1. Impact is minimized by using the list syntax for lists. The predicates read_term/2 and write_term/2 support the option dotlists(true), which causes read_term/2 to read .(a,[]) as [a] and write_term/2 to write [a] as .(a,[]).

5.1.1 Motivating ‘[|]’ and [] for lists

Representing lists the conventional way using ./2 as list cell and the atom ‘[]’ as list terminator both (independently) pose conflicts, while these conflicts are easily avoided.

- Using ./2 prevents using this commonly used symbol as an operator because a.B cannot be distinguished from [a|B]. Freeing ./2 provides us with a unique term that we can use for functional notation on dicts as described in section 5.4.1.

- Using the atom ‘[]’ as list terminator prevents dynamic distinction between atoms and the empty list. As a result, we cannot use type polymorphism that involve both atoms and lists. For example, we cannot use multi lists (arbitrary deeply nested lists) of atoms. Multi lists of atoms are in some situations a good representation of a flat list that is assembled from sub sequences. The alternative, using difference lists or DCGs, is often less natural and sometimes requires ‘opening’ proper lists (i.e., copying the list while replacing the terminating atom ‘[]’ with a variable) that have to be added to the sequence. The ambiguity of atom and list is particularly painful when mapping external data representations that do not suffer from this ambiguity.

At the same time, avoiding atom ‘[]’ as a list terminator makes the various text representations unambiguous, which allows us to write predicates that require a textual argument to accept any of atoms, strings, lists of character codes or characters. Traditionally, the empty list, as an atom, is afflicted with an ambiguous interpretation as it can stand for any of the strings "[]" and "".

5.2 The string type and its double quoted syntax

As of SWI-Prolog version 7, text enclosed in double quotes (e.g., "Hello world") is read as objects of the type string. Strings are distinct from lists, which makes it possible to recognize them at runtime and print them using the string syntax:

?- write("Hello world!").
Hello world!

?- writeq("Hello world!").
"Hello world!"

A string is a compact representation of a character sequence that lives on the global (term) stack. Strings are represented by sequences of Unicode character codes including the character code 0
## 5.2. THE STRING TYPE AND ITS DOUBLE QUOTED SYNTAX

<table>
<thead>
<tr>
<th>Mode</th>
<th>double_quotes</th>
<th>back_quotes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Version 7 default</td>
<td>string</td>
<td>codes</td>
</tr>
<tr>
<td>--traditional</td>
<td>codes</td>
<td>symbol_char</td>
</tr>
</tbody>
</table>

Table 5.1: Mapping of double and back quoted text in the two modes.

The length of strings is limited by the available space on the global (term) stack (see `set_prolog_stack/2`). Section 5.2.3 motivates the introduction of strings and mapping double quoted text to this type.

Whereas in version 7, double-quoted text is mapped to strings, *back-quoted* text (as in `text`) is mapped to a list of *character codes*, i.e. integers that are Unicode code points. In a traditional setting, back-quoted would be mapped to a list of *characters* (also known as *chars*), which are atoms of length 1.

The settings for the flags that control how double- and back-quoted text is read is summarised in table 5.1. Programs that aim for compatibility should realise that the ISO standard defines back-quoted text, but does not define the `back_quotes` Prolog flag and does not define the term that is produced by back-quoted text.

### 5.2.1 Representing text: strings, atoms and code lists

With the introduction of strings as a Prolog data type, there are three main ways to represent text: using strings, using atoms and using lists of character codes. As a fourth way, one may also use lists of chars. This section explains what to choose for what purpose. Both strings and atoms are *atomic* objects: you can only look inside them using dedicated predicates, while lists of character codes or chars are compound data structures forming an extended structure that must follow a convention.

**Lists of character codes** is what you need if you want to *parse* text using Prolog grammar rules (DCGs, see `phrase/3`). Most of the text reading predicates (e.g., `read_line_to_codes/2`) return a list of character codes because most applications need to parse these lines before the data can be processed. As said above, the *back-quoted* text notation (`'hello'`) can be used to easily specify a list of character codes. The `0'c` notation can be used to specify a single character code.

**Atoms** are *identifiers*. They are typically used in cases where identity comparison is the main operation and that are typically not composed nor taken apart. Examples are RDF resources (URIs that identify something), system identifiers (e.g., `'Boeing 747'`), but also individual words in a natural language processing system. They are also used where other languages would use *enumerated types*, such as the names of days in the week. Unlike enumerated types, Prolog atoms do not form a fixed set and the same atom can represent different things in different contexts.

**Strings** typically represents text that is processed as a unit most of the time, but which is not an identifier for something. Format specifications for `format/3` is a good example. Another example is a descriptive text provided in an application. Strings may be composed and decomposed using e.g., `string_concat/3` and `sub_string/5` or converted for parsing using `string_codes/2` or created from codes generated by a generative grammar rule, also using `string_codes/2`. 
5.2.2 Predicates that operate on strings

Strings are manipulated using a set of predicates that mirrors the set of predicates used for manipulating atoms. In addition to the list below, `string/1` performs the type check for this type and is described in section 4.5.

SWI-Prolog’s string primitives are being synchronized with ECLiPSe. We expect the set of predicates documented in this section to be stable, although it might be expanded. In general, SWI-Prolog’s text manipulation predicates accept any form of text as input argument - they accept `anytext` input. `anytext` comprises:

- atoms
- strings
- lists of character codes
- list of characters
- number types: integers, floating point numbers and non-integer rationals. Under the hood, these must first be formatted into a text representation according to some inner convention before they can be used.

The predicates produce the type indicated by the predicate name as output. This policy simplifies migration and writing programs that can run unmodified or with minor modifications on systems that do not support strings. Code should avoid relying on this feature as much as possible for clarity as well as to facilitate a more strict mode and/or type checking in future releases.

**atom_string(?Atom, ?String)**

Bi-directional conversion between an atom and a string. At least one of the two arguments must be instantiated. An initially uninstantiated variable on the “string side” is always instantiated to a string. An initially uninstantiated variable on the “atom side” is always instantiated to an atom. If both arguments are instantiated, their list-of-character representations must match, but the types are not enforced. The following all succeed:

```prolog
atom_string("x","x").
atom_string('x','x').
atom_string(3.1415,3.1415).
atom_string('3r2','3r2').
atom_string(3r2,'3r2').
atom_string(6r4,3r2).
```

**number_string(?Number, ?String)**

Bi-directional conversion between a number and a string. At least one of the two arguments must be instantiated. Besides the type used to represent the text, this predicate differs in several ways from its ISO cousin.\(^1\)

---

\(^1\)Note that SWI-Prolog’s syntax for numbers is not ISO compatible either.
5.2. THE STRING TYPE AND ITS DOUBLE QUOTED SYNTAX

• If String does not represent a number, the predicate fails rather than throwing a syntax
error exception.
• Leading white space and Prolog comments are not allowed.
• Numbers may start with + or -.
• It is not allowed to have white space between a leading + or - and the number.
• Floating point numbers in exponential notation do not require a dot before exponent, i.e.,
"1e10" is a valid number.

Unlike other predicates of this family, if instantiated, String cannot be an atom.

The corresponding ‘atom-handling’ predicate is atom_number/2, with reversed argument
order.

term_string(?Term, ?String)
Bi-directional conversion between a term and a string. If String is instantiated, it is parsed and
the result is unified with Term. Otherwise Term is ‘written’ using the option quoted(true) and
the result is converted to String.

term_string(?Term, ?String, +Options)
As term_string/2, passing Options to either read_term/2 or write_term/2. For
example:

?- term_string(Term, 'a(A)', [variable_names(VNames)]).
Term = a(_9674),
VNames = ['A'=_9674].

string_chars(?String, ?Chars)
Bi-directional conversion between a string and a list of characters. At least one of the two
arguments must be instantiated.

See also: atom_chars/2.

string_codes(?String, ?Codes)
Bi-directional conversion between a string and a list of character codes. At least one of the two
arguments must be instantiated.

string_bytes(?String, ?Bytes, +Encoding)
True when the (Unicode) String is represented by Bytes in Encoding. If String is instantiated
it may represent text as an atom, string, list of character codes or list or characters. Bytes
is always a list of integers in the range 0...255. At least one of String or Bytes must be
instantiated. This predicate is notably intended as an intermediate step to perform byte
oriented operations on text. Examples are (base64) encoding, encryption, computing a (secure)
hash, etc. Encoding is typically utf8. All valid stream encodings except for wchar_t are
supported. See section 2.19.1. Note that this translation is only provided for strings. Creating
an atom from bytes requires atom_string/2.2

Strings are an efficient intermediate and this conversion is needed only in some uncommon scenarios.

\[\text{SWI-Prolog 9.1 Reference Manual}\]
text_to_string(+Text, -String)  [det]
Converts Text to a string. Text is anytext excluding the number types. When running in
--traditional mode, ‘[[]]’ is ambiguous and interpreted as an empty string.

string_length(+String, -Length)
Unify Length with the number of characters in String. This predicate is functionally equivalent
to atom_length/2 and also accepts anytext as its first argument. Number types must first be
formatted into strings before the length of their string representation can be determined.

string_code(?Index, +String, ?Code)
True when Code represents the character at the 1-based Index position in String. If Index is
unbound the string is scanned from index 1. Raises a domain error if Index is negative. Fails
silently if Index is zero or greater than the length of String. The mode string_code(-,+,+)
is deterministic if the searched-for Code appears only once in String. See also sub_string/5.

get_string_code(+Index, +String, -Code)
Semi-deterministic version of string_code/3. In addition, this version provides strict range
checking, throwing a domain error if Index is less than 1 or greater than the length of String.
ECLiPSe provides this to support String[Index] notation.

string_concat(?String1, ?String2, ?String3)
Similar to atom_concat/3, but the unbound argument will be unified with a string object
rather than an atom. Also, if both String1 and String2 are unbound and String3 is bound to text,
it breaks String3, unifying the start with String1 and the end with String2 as append does with
lists. Note that this is not particularly fast on long strings, as for each redo the system has to
create two entirely new strings, while the list equivalent only creates a single new list-cell and
moves some pointers around.

split_string(+String, +SepChars, +PadChars, -SubStrings)  [det]
Break String into SubStrings. The SepChars argument provides the characters that act as
separators and thus the length of SubStrings is one more than the number of separators found if
SepChars and PadChars do not have common characters. If SepChars and PadChars are equal,
sequences of adjacent separators act as a single separator. Leading and trailing characters for
each substring that appear in PadChars are removed from the substring. The input arguments
can be either atoms, strings or char/code lists. Compatible with ECLiPSe. Below are some
examples:
A simple split wherever there is a ‘.’:

?- split_string("a.b.c.d", ".", ",", L).
L = ["a", "b", "c", "d"].

Consider sequences of separators as a single one:

?- split_string("/home//jan///nice/path", "/", "/", L).
L = ["home", "jan", "nice", "path"].

Split and remove white space:
5.2. THE STRING TYPE AND ITS DOUBLE QUOTED SYNTAX

?- split_string("SWI-Prolog, 7.0", ",", " ", L).
L = ["SWI-Prolog", "7.0"].

Only remove leading and trailing white space (trim the string):

?- split_string(" SWI-Prolog ", ",", "\s\t\n", L).
L = ["SWI-Prolog"].

In the typical use cases, SepChars either does not overlap PadChars or is equivalent to handle multiple adjacent separators as a single (often white space). The behaviour with partially overlapping sets of padding and separators should be considered undefined. See also read_string/5.

sub_string(+String, ?Before, ?Length, ?After, ?SubString)
This predicate is functionally equivalent to sub_atom/5, but operates on strings. Note that this implies the string input arguments can be either strings or atoms. If SubString is unbound (output) it is unified with a string. The following example splits a string of the form ⟨name⟩=⟨value⟩ into the name part (an atom) and the value (a string).

name_value(String, Name, Value) :-
    sub_string(String, Before, _, After, ";"),
    !, sub_atom(String, 0, Before, _, Name),
    sub_string(String, _, After, 0, Value).

atomics_to_string(+List, -String)
List is a list of strings, atoms, or number types. Succeeds if String can be unified with the concatenated elements of List. Equivalent to atomics_to_string(List, ",", String).

atomics_to_string(+List, +Separator, -String)
Creates a string just like atomics_to_string/2, but inserts Separator between each pair of inputs. For example:

?- atomics_to_string([gnu, "gnat", 1], ",", A).
A = "gnu, gnat, 1"

string_upper(+String, -UpperCase)
Convert String to upper case and unify the result with UpperCase.

string_lower(+String, LowerCase)
Convert String to lower case and unify the result with LowerCase.

read_string(+Stream, ?Length, -String)
Read at most Length characters from Stream and return them in the string String. If Length is unbound, Stream is read to the end and Length is unified with the number of characters read. Note that characters must be read as Unicode code points, not bytes.
read_string(+Stream, +SepChars, +PadChars, -Sep, -String)
Read a string from Stream, providing functionality similar to split_string/4. The predicate performs the following steps:

1. Skip all characters that match PadChars
2. Read up to a character that matches SepChars or end of file
3. Discard trailing characters that match PadChars from the collected input
4. Unify String with a string created from the input and Sep with the code of the separator character read. If input was terminated by the end of the input, Sep is unified with -1.

The predicate read_string/5 called repeatedly on an input until Sep is -1 (end of file) is equivalent to reading the entire file into a string and calling split_string/4, provided that SepChars and PadChars are not partially overlapping. Below are some examples:

Read a line:
```
read_string(Input, "\n", "\r", Sep, String)
```

Read a line, stripping leading and trailing white space:
```
read_string(Input, "\n", "\r\t ", Sep, String)
```

Read up to ‘,’ or ‘)’, unifying Sep with 0’, i.e. Unicode 44, or 0’), i.e. Unicode 41:
```
read_string(Input, ",", "\\t ", Sep, String)
```

open_string(+String, -Stream)
True when Stream is an input stream that accesses the content of String. String can be any text representation, i.e., string, atom, list of codes or list of characters. The created Stream has the reposition property (see stream_property/2). Note that the internal encoding of the data is either ISO Latin 1 or UTF-8.

5.2.3 Why has the representation of double quoted text changed?
Prolog defines two forms of quoted text. Traditionally, single quoted text is mapped to atoms while double quoted text is mapped to a list of character codes (integers) or characters (atoms of length 1). Representing text using atoms is often considered inadequate for several reasons:

- It hides the conceptual difference between text and program symbols. Where content of text often matters because it is used in I/O, program symbols are merely identifiers that match with the same symbol elsewhere. Program symbols can often be consistently replaced, for example to obfuscate or compact a program.

---

3Behaviour that is fully compatible would require unlimited look-ahead.
5.2. THE STRING TYPE AND ITS DOUBLE QUOTED SYNTAX

- Atoms are globally unique identifiers. They are stored in a shared table. Volatile strings represented as atoms come at a significant price due to the required cooperation between threads for creating atoms. Reclaiming temporary atoms using Atom garbage collection is a costly process that requires significant synchronisation.

- Many Prolog systems (not SWI-Prolog) put severe restrictions on the length of atoms or the maximum number of atoms.

Representing text as lists, be it of character codes or characters, also comes at a price:

- It is not possible to distinguish (at runtime) a list of integers or atoms from a string. Sometimes this information can be derived from (implicit) typing. In other cases the list must be embedded in a compound term to distinguish the two types. For example, `s("hello world")` could be used to indicate that we are dealing with a string.

Lacking runtime information, debuggers and the toplevel can only use heuristics to decide whether to print a list of integers as such or as a string (see `portray_text/1`).

While experienced Prolog programmers have learned to cope with this, we still consider this an unfortunate situation.

- Lists are expensive structures, taking 2 cells per character (3 for SWI-Prolog in its current form). This stresses memory consumption on the stacks while pushing them on the stack and dealing with them during garbage collection is unnecessarily expensive.

5.2.4 Adapting code for double quoted strings

We observe that in many programs, most strings are only handled as a single unit during their lifetime. Examining real code tells us that double quoted strings typically appear in one of the following roles:

A DCG literal Although represented as a list of codes is the correct representation for handling in DCGs, the DCG translator can recognise the literal and convert it to the proper representation. Such code need not be modified.

A format string This is a typical example of text that is conceptually not a program identifier. Format is designed to deal with alternative representations of the format string. Such code need not be modified.

Getting a character code The construct `[X] = "a"` is a commonly used template for getting the character code of the letter ‘a’. ISO Prolog defines the syntax `0’a` for this purpose. Code using this must be modified. The modified code will run on any ISO compliant Prolog Processor.

As argument to list predicates to operate on strings Here, we might see code similar to `append("name:", Rest, Codes)`. Such code needs to be modified. In this particular example, the following is a good portable alternative: `phrase("name:", Codes, Rest)`

Checks for a character to be in a set Such tests are often performed with code such as this: `memberchk(C, "~!@#$")`. This is a rather inefficient check in a traditional Prolog system because it pushes a list of character codes cell-by-cell onto the Prolog stack and then traverses this list cell-by-cell to see whether one of the cells unifies with C. If the test is successful,
the string will eventually be subject to garbage collection. The best code for this is to write a
predicate as below, which pushes nothing on the stack and performs an indexed lookup to see
whether the character code is in `my_class`.

```prolog
my_class(0'~).
my_class(0'!).
...
```

An alternative to reach the same effect is to use term expansion to create the clauses:

```prolog
term_expansion(my_class(_), Clauses) :-
    findall(my_class(C),
            string_code(_, "~!@#$", C),
            Clauses).
my_class(_).
```

Finally, the predicate `string_code/3` can be exploited directly as a replacement for the
`memberchk/2` on a list of codes. Although the string is still pushed onto the stack, it is more
compact and only a single entity.

### 5.2.5 Predicates to support adapting code for double quoted strings

The predicates in this section can help adapting your program to the new convention for handling
double quoted strings. We have adapted a huge code base with which we were not familiar in about
half a day.

**list_strings**

This predicate may be used to assess compatibility issues due to the representation of double
quoted text as string objects. See section 5.2 and section 5.2.3. To use it, load your program
into Prolog and run `list_strings/0`. The predicate lists source locations of string objects
encountered in the program that are not considered safe. Such string need to be examined
manually, after which one of the actions below may be appropriate:

- Rewrite the code. For example, change `[X] = "a"` into `X = 0’a`.
- If a particular module relies heavily on representing strings as lists of character code,
  consider adding the following directive to the module. Note that this flag only applies to
  the module in which it appears.

  ```prolog
  :- set_prolog_flag(double_quotes, codes).
  ```

- Use a back quoted string (e.g., `text`). Note that this will not make your code run re-
gardless of the `--traditional` command line option and code exploiting this mapping
  is also not portable to ISO compliant systems.

- If the strings appear in facts and usage is safe, add a clause to the multifile predicate
  `check:string_predicate/1` to silence `list_strings/0` on all clauses of that
  predicate.
• If the strings appear as an argument to a predicate that can handle string objects, add a clause to the multifile predicate `check:valid_string_goal/1` to silence `list_strings/0`.

`check:string_predicate(:PredicateIndicator)`
Declare that `PredicateIndicator` has clauses that contain strings, but that this is safe. For example, if there is a predicate `help_info/2`, where the second argument contains a double quoted string that is handled properly by the predicates of the applications’ help system, add the following declaration to stop `list_strings/0` from complaining:

```prolog
:- multifile check:string_predicate/1.
check:string_predicate(user:help_info/2).
```

`check:valid_string_goal(:Goal)`
Declare that calls to `Goal` are safe. The module qualification is the actual module in which `Goal` is defined. For example, a call to `format/3` is resolved by the predicate `system:format/3`, and the code below specifies that the second argument may be a string (system predicates that accept strings are defined in the library):

```prolog
:- multifile check:valid_string_goal/1.
check:valid_string_goal(system:format(_,S,_)) :- string(S).
```

## 5.3 Syntax changes since SWI-Prolog 7

### 5.3.1 Operators and quoted atoms

As of SWI-Prolog version 7, quoted atoms lose their operator property. This means that expressions such as `A = 'dynamic'/1` are valid syntax, regardless of the operator definitions. From questions on the mailinglist this is what people expect.\(^4\) To accommodate for real quoted operators, a quoted atom that *needs* quotes can still act as an operator.\(^5\) A good use-case for this is a unit library\(^6\), which allows for expressions such as below.

```
?- Y isu 600kcal - 1h*200’W’.
Y = 1790400.0’J’.
```

\(^4\)We believe that most users expect an operator declaration to define a new token, which would explain why the operator name is often quoted in the declaration, but not while the operator is used. We are afraid that allowing for this easily creates ambiguous syntax. Also, many development environments are based on tokenization. Having dynamic tokenization due to operator declarations would make it hard to support Prolog in such editors.

\(^5\)Suggested by Joachim Schimpf.

\(^6\)[https://groups.google.com/d/msg/comp.lang.prolog/ozqdzI-gi_g/2Gl6GYLIS0IJ](https://groups.google.com/d/msg/comp.lang.prolog/ozqdzI-gi_g/2Gl6GYLIS0IJ)
5.3.2 Compound terms with zero arguments

As of SWI-Prolog version 7, the system supports compound terms that have no arguments. This implies that e.g., name() is valid syntax. This extension aims at functions on dicts (see section 5.4) as well as the implementation of domain specific languages (DSLs). To minimise the consequences, the classic predicates functor/3 and =../2 have not been modified. The predicates compound_name arity/3 and compound_name arguments/3 have been added. These predicates operate only on compound terms and behave consistently for compounds with zero arguments. Code that generalises a term using the sequence below should generally be changed to use compound_name arity/3.

```prolog
...,
functor(Specific, Name, Arity),
functor(General, Name, Arity),
...,
```

Replacement of =../2 by compound_name arguments/3 is typically needed to deal with code that follow the skeleton below.

```prolog
...,
Term0 =.. [Name|Args0],
maplist(convert, Args0, Args),
Term =.. [Name|Args],
...,
```

For predicates, goals and arithmetic functions (evaluable terms), ⟨name⟩ and ⟨name⟩() are equivalent. Below are some examples that illustrate this behaviour.

```prolog
go() :- format('Hello world\n').
?- go().
Hello world
?- go.
Hello world
?- Pi is pi().
Pi = 3.141592653589793.
?- Pi is pi.
Pi = 3.141592653589793.
```

Note that the canonical representation of predicate heads and functions without arguments is an atom. Thus, clause(go(), Body) returns the clauses for go/0, but clause(-Head, -Body, +Ref) unifies Head with an atom if the clause specified by Ref is part of a predicate with zero arguments.
5.3.3 Block operators

Introducing curly bracket and array subscripting. The symbols [] and {} may be declared as an operator, which has the following effect:

[ ]
This operator is typically declared as a low-priority yf postfix operator, which allows for array[index] notation. This syntax produces a term [ ]([index],array).

{ }
This operator is typically declared as a low-priority xf postfix operator, which allows for head(arg) { body } notation. This syntax produces a term {}({body},head(arg)).

Below is an example that illustrates the representation of a typical ‘curly bracket language’ in Prolog.

?- op(100, xf, {}).  
?- op(100, yf, []).  
?- op(1100, yf, ;).  

?- displayq(func(arg)  
   { a[10] = 5;  
     update();  
   },  
   {};({;([]([10],a),5),;update()}),func(arg))

5.4 Dicts: structures with named arguments

SWI-Prolog version 7 introduces dicts as an abstract object with a concrete modern syntax and functional notation for accessing members and as well as access functions defined by the user. The syntax for a dict is illustrated below. Tag is either a variable or an atom. As with compound terms, there is no space between the tag and the opening brace. The keys are either atoms or small integers (up to max_tagged_integer). The values are arbitrary Prolog terms which are parsed using the same rules as used for arguments in compound terms.

Tag{Key1:Value1, Key2:Value2, ...}

A dict can not hold duplicate keys. The dict is transformed into an opaque internal representation that does not respect the order in which the key-value pairs appear in the input text. If a dict is written, the keys are written according to the standard order of terms (see section 4.6.1). Here are some examples, where the second example illustrates that the order is not maintained and the third illustrates an anonymous dict.

---

7Introducing block operators was proposed by Jose Morales. It was discussed in the Prolog standardization mailing list, but there were too many conflicts with existing extensions (ECLiPSe and B-Prolog) and doubt about their need to reach an agreement. Increasing need to get to some solution resulted in what is documented in this section. These extensions are also implemented in recent versions of YAP.
Dicts can be unified following the standard symmetric Prolog unification rules. As dicts use an internal canonical form, the order in which the named keys are represented is not relevant. This behaviour is illustrated by the following example.

```
?- point{x:1, y:2} = Tag{y:2, x:X}.
Tag = point,
X = 1.
```

**Note** In the current implementation, two dicts unify only if they have the same set of keys and the tags and values associated with the keys unify. In future versions, the notion of unification between dicts could be modified such that two dicts unify if their tags and the values associated with common keys unify, turning both dicts into a new dict that has the union of the keys of the two original dicts.

### 5.4.1 Functions on dicts

The infix operator dot \((\text{op}(100, \text{yfx}, .))\) is used to extract values and evaluate functions on dicts. Functions are recognised if they appear in the argument of a goal in the source text, possibly nested in a term. The keys act as field selector, which is illustrated in this example.

```
?- X = point{x:1,y:2}.x.
X = 1.

?- Pt = point{x:1,y:2}, write(Pt.y).
2
Pt = point{x:1,y:2}.

?- X = point{x:1,y:2}.C.
X = 1,
C = x ;
X = 2,
C = y.
```

The compiler translates a goal that contains \(./2\) terms in its arguments into a conjunction of calls to \(./3\) defined in the system module. Terms functor \(2\) that appears in the head are replaced with a variable and calls to \(./3\) are inserted at the start of the body. Below are two examples, where the first extracts the \(x\) key from a dict and the second extends a dict containing an address with the postal code, given a `find_postal_code/4` predicate.
dict_x(X, X.x).

add_postal_code(Dict, Dict.put(postal_code, Code)) :-
    find_postal_code(Dict.city, Dict.street, Dict.house_number, Code).

Note that expansion of ./2 terms implies that such terms cannot be created by writing them explicitly in your source code. Such terms can still be created with functor/3, =../2, compound_name arity/3 and compound_name arguments/3.\(^8\)

.(+Dict, +Function, -Result)

This predicate is called to evaluate ./2 terms found in the arguments of a goal. This predicate evaluates the field extraction described above, raising an exception if Function is an atom (key) and Dict does not contain the requested key. If Function is a compound term, it checks for the predefined functions on dicts described in section 5.4.1 or executes a user defined function as described in section 5.4.1.

User defined functions on dicts

The tag of a dict associates the dict to a module. If the dot notation uses a compound term, this calls the goal below.

\(\langle module\rangle:\langle name\rangle(Arg1, ..., +Dict, -Value)\)

Functions are normal Prolog predicates. The dict infrastructure provides a more convenient syntax for representing the head of such predicates without worrying about the argument calling conventions. The code below defines a function \(\text{multiply}(\text{Times})\) on a point that creates a new point by multiplying both coordinates. and \(\text{len}\)\(^9\) to compute the length from the origin. The . and := operators are used to abstract the location of the predicate arguments. It is allowed to define multiple a function with multiple clauses, providing overloading and non-determinism.

:- module(point, []).

M.multiply(F) := point{x:X, y:Y} :-
    X is M.x*F,
    Y is M.y*F.

M.len() := Len :-
    Len is sqrt(M.x**2 + M.y**2).

\(^8\)Traditional code is unlikely to use ./2 terms because they were practically reserved for usage in lists. We do not provide a quoting mechanism as found in functional languages because it would only be needed to quote ./2 terms, such terms are rare and term manipulation provides an escape route.

\(^9\)as \text{length} would result in a predicate \text{length}/2, this name cannot be used. This might change in future versions.
After these definitions, we can evaluate the following functions:

```
?- X = point{x:1, y:2}.multiply(2).
    X = point{x:2, y:4}.

?- X = point{x:1, y:2}.multiply(2).len().
    X = 4.47213595499958.
```

**Predefined functions on dicts**

Dicts currently define the following reserved functions:

- **get(?KeyPath)**
  - Return the value associates with `KeyPath`. `KeyPath` is either a single key or a term `Key1/Key2/...`. Each key is either an atom, small integer or a variable. While Dict.Key throws an existence error, this function *fails* silently if a key does not exist in the target dict. See also :/>2, which can be used to test for existence and unify multiple key values from a dict. For example:

  ```prolog
  ?- write(t{a:x}.get(a)).
      x
  ?- write(t{a:x}.get(b)).
      false.
  ?- write(t{a:t{b:x}}.get(a/b)).
      x
  ```

- **put(+New)**
  - Evaluates to a new dict where the key-values in `New` replace or extend the key-values in the original dict. See put_dict/3.

- **get(?KeyPath, +Default)**
  - Same as get/1, but if no match is found the function evaluates to `Default`. If `KeyPath` contains variables possible choice points are respected and the function only evaluates to `Default` if the pattern has no matches.

- **put(+KeyPath, +Value)**
  - Evaluates to a new dict where the `KeyPath-Value` replaces or extends the key-values in the original dict. `KeyPath` is either a key or a term `KeyPath/Key`, replacing the value associated with `Key` in a sub-dict of the dict on which the function operates. See put_dict/4. Below are some examples:

  ```prolog
  ?- A = _{}.put(a, 1).
      A = _G7359{a:1}.
  ```

10 Note that we do not use the "." functor here, because the ".//2" would evaluate.
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?- A = _{a:1}.put(a, 2).
A = _G7377{a:2}.

?- A = _{a:1}.put(b/c, 2).
A = _G1395{a:1, b:_G1584{c:2}}.

?- A = _{a:1}.put(a/b, 2).
A = _G1395{a:_G1578{b:2}}.

5.4.2 Predicates for managing dicts

This section documents the predicates that are defined on dicts. We use the naming and argument conventions of the traditional assoc.

\[ \text{is} \_ \text{dict}(@\text{Term}) \]
True if Term is a dict. This is the same as \text{is} \_ \text{dict}(\text{Term},_.).

\[ \text{is} \_ \text{dict}(@\text{Term}, -\text{Tag}) \]
True if Term is a dict of Tag.

\[ \text{get} \_ \text{dict}(?\text{Key}, +\text{Dict}, -\text{Value}) \]
Unify the value associated with Key in dict with Value. If Key is unbound, all associations in Dict are returned on backtracking. The order in which the associations are returned is undefined. This predicate is normally accessed using the functional notation Dict.Key. See section 5.4.1.

Fails silently if Key does not appear in Dict. This is different from the behavior of the functional ‘.’-notation, which throws an existence error in that case.

\[ \text{get} \_ \text{dict}(+\text{Key}, +\text{Dict}, -\text{Value}, -\text{NewDict}, +\text{NewValue}) \] [semidet]
Create a new dict after updating the value for Key. Fails if Value does not unify with the current value associated with Key. Dict is either a dict or a list the can be converted into a dict.

Has the behavior as if defined in the following way:

\[
\begin{align*}
\text{get} \_ \text{dict}(\text{Key}, \text{Dict}, \text{Value}, \text{NewDict}, \text{NewValue}) :- \\
\quad \text{get} \_ \text{dict}(\text{Key}, \text{Dict}, \text{Value}), \\
\quad \text{put} \_ \text{dict}(\text{Key}, \text{Dict}, \text{NewValue}, \text{NewDict}).
\end{align*}
\]

\[ \text{dict} \_ \text{create}(-\text{Dict}, +\text{Tag}, +\text{Data}) \]
Create a dict in Tag from Data. Data is a list of attribute-value pairs using the syntax Key:Value, Key=Value, Key–Value or Key(Value). An exception is raised if Data is not a proper list, one of the elements is not of the shape above, a key is neither an atom nor a small integer or there is a duplicate key.
dict_pairs(?Dict, ?Tag, ?Pairs)
   Bi-directional mapping between a dict and an ordered list of pairs (see section A.32).

put_dict(+New, +DictIn, -DictOut)
   DictOut is a new dict created by replacing or adding key-value pairs from New to Dict. New is either a dict or a valid input for dict_create/3. This predicate is normally accessed using the functional notation. Below are some examples:

   ?- A = point{x:1, y:2}.put(_{x:3}).
      A = point{x:3, y:2}.

   ?- A = point{x:1, y:2}.put([x=3]).
      A = point{x:3, y:2}.

   ?- A = point{x:1, y:2}.put([x=3,z=0]).
      A = point{x:3, y:2, z:0}.

put_dict(+Key, +DictIn, +Value, -DictOut)
   DictOut is a new dict created by replacing or adding Key-Value to DictIn. For example:

   ?- A = point{x:1, y:2}.put(x, 3).
      A = point{x:3, y:2}.

   This predicate can also be accessed by using the functional notation, in which case Key can also be a *path* of keys. For example:

   ?- Dict = _{}.put(a/b, c).
      Dict = _6096{a:_6200{b:c}}.

del_dict(+Key, +DictIn, ?Value, -DictOut)
   True when Key-Value is in DictIn and DictOut contains all associations of DictIn except for Key.

+Select :- +From [semidet]
   True when Select is a ‘sub dict’ of From: the tags must unify and all keys in Select must appear with unifying values in From. From may contain keys that are not in Select. This operation is frequently used to *match* a dict and at the same time extract relevant values from it. For example:

   plot(Dict, On) :-
      _{x:X, y:Y, z:Z} :- Dict, !,
      plot_xyz(X, Y, Z, On).
   plot(Dict, On) :-
      _{x:X, y:Y} :- Dict, !,
      plot_xy(X, Y, On).
5.4. DICTS: STRUCTURES WITH NAMED ARGUMENTS

The goal \texttt{Select :< From} is equivalent to \texttt{select_dict(Select, From, _)}.

\texttt{select_dict(+Select, +From, -Rest)}

True when the tags of \texttt{Select} and \texttt{From} have been unified, all keys in \texttt{Select} appear in \texttt{From} and the corresponding values have been unified. The key-value pairs of \texttt{From} that do not appear in \texttt{Select} are used to form an anonymous dict, which is unified with \texttt{Rest}. For example:

\begin{verbatim}
?- select_dict(P{x:0, y:Y}, point{x:0, y:1, z:2}, R).
P = point, Y = 1, R = _G1705{z:2}.
\end{verbatim}

See also :</2 to ignore \texttt{Rest} and >:/2 for a symmetric partial unification of two dicts.

\texttt{+Dict1 :< +Dict2}

This operator specifies a \textit{partial unification} between \texttt{Dict1} and \texttt{Dict2}. It is true when the tags and the values associated with all \textit{common} keys have been unified. The values associated to keys that do not appear in the other dict are ignored. Partial unification is symmetric. For example, given a list of dicts, find dicts that represent a point with X equal to zero:

\begin{verbatim}
member(Dict, List), Dict :< point{x:0, y:Y}.
\end{verbatim}

See also :</2 and \texttt{select_dict/3}.

\textbf{Destructive assignment in dicts}

This section describes the destructive update operations defined on dicts. These actions can only update keys and not add or remove keys. If the requested key does not exist the predicate raises \texttt{existence_error(key, Key, Dict)}. Note the additional argument.

Destructive assignment is a non-logical operation and should be used with care because the system may copy or share identical Prolog terms at any time. Some of this behaviour can be avoided by adding an additional unbound value to the dict. This prevents unwanted sharing and ensures that \texttt{copy_term/2} actually copies the dict. This pitfall is demonstrated in the example below:

\begin{verbatim}
?- A = a{a:1}, copy_term(A,B), b_set_dict(a, A, 2).
A = B, B = a{a:2}.
?- A = a{a:1,dummy:_}, copy_term(A,B), b_set_dict(a, A, 2).
A = a{a:2, dummy:_G3195}, B = a{a:1, dummy:_G3391}.
\end{verbatim}

\texttt{b_set_dict(+Key, !Dict, +Value)}

Destructively update the value associated with \texttt{Key} in \texttt{Dict} to \texttt{Value}. The update is trailed and undone on backtracking. This predicate raises an existence error if \texttt{Key} does not appear in \texttt{Dict}. The update semantics are equivalent to \texttt{setarg/3} and \texttt{b_setval/2}.
nb_set_dict(+Key, !Dict, +Value)  [det]
Destructively update the value associated with Key in Dict to a copy of Value. The update is not undone on backtracking. This predicate raises an existence error if Key does not appear in Dict. The update semantics are equivalent to nb_setarg/3 and nb_setval/2.

nb_link_dict(+Key, !Dict, +Value)  [det]
Destructively update the value associated with Key in Dict to Value. The update is not undone on backtracking. This predicate raises an existence error if Key does not appear in Dict. The update semantics are equivalent to nb_linkarg/3 and nb_linkval/2. Use with extreme care and consult the documentation of nb_linkval/2 before use.

5.4.3 When to use dicts?

Dicts are a new type in the Prolog world. They compete with several other types and libraries. In the list below we have a closer look at these relations. We will see that dicts are first of all a good replacement for compound terms with a high or not clearly fixed arity, library record and option processing.

**Compound terms** Compound terms with positional arguments form the traditional way to package data in Prolog. This representation is well understood, fast and compound terms are stored efficiently. Compound terms are still the representation of choice, provided that the number of arguments is low and fixed or compactness or performance are of utmost importance.

A good example of a compound term is the representation of RDF triples using the term rdf(Subject, Predicate, Object) because RDF triples are defined to have precisely these three arguments and they are always referred to in this order. An application processing information about persons should probably use dicts because the information that is related to a person is not so fixed. Typically we see first and last name. But there may also be title, middle name, gender, date of birth, etc. The number of arguments becomes unmanageable when using a compound term, while adding or removing an argument leads to many changes in the program.

**Library record** Using library record relieves the maintenance issues associated with using compound terms significantly. The library generates access and modification predicates for each field in a compound term from a declaration. The library provides sound access to compound terms with many arguments. One of its problems is the verbose syntax needed to access or modify fields which results from long names for the generated predicates and the restriction that each field needs to be extracted with a separate goal. Consider the example below, where the first uses library record and the second uses dicts.

```prolog
...,  
person_first_name(P, FirstName), 
person_last_name(P, LastName), 
format('Dear ˜w ˜w,˜n˜n', [FirstName, LastName]). 
...,  
format('Dear ˜w ˜w,˜n˜n', [Dict.first_name, Dict.last_name]).
```

Records have a fixed number of arguments and (non-)existence of an argument must be represented using a value that is outside the normal domain. This lead to unnatural code. For
example, suppose our person also has a title. If we know the first name we use this and else we use the title. The code samples below illustrate this.

```
salutation(P) :-
    person_first_name(P, FirstName), nonvar(FirstName), !,
    person_last_name(P, LastName),
    format('Dear ~w ~w,~n~n', [FirstName, LastName]).

salutation(P) :-
    person_title(P, Title), nonvar(Title), !,
    person_last_name(P, LastName),
    format('Dear ~w ~w,~n~n', [Title, LastName]).

salutation(P) :-
    {first_name:FirstName, last_name:LastName} :< P, !,
    format('Dear ~w ~w,~n~n', [FirstName, LastName]).

salutation(P) :-
    {title:Title, last_name:LastName} :< P, !,
    format('Dear ~w ~w,~n~n', [Title, LastName]).
```

**Library assoc** This library implements a balanced binary tree. Dicts can replace the use of this library if the association is fairly static (i.e., there are few update operations), all keys are atoms or (small) integers and the code does not rely on ordered operations.

**Library option** Option lists are introduced by ISO Prolog, for example for `read_term/3`, `open/4`, etc. The `option` library provides operations to extract options, merge options lists, etc. Dicts are well suited to replace option lists because they are cheaper, can be processed faster and have a more natural syntax.

**Library pairs** This library is commonly used to process large name-value associations. In many cases this concerns short-lived data structures that result from `findall/3`, `maplist/3` and similar list processing predicates. Dicts may play a role if frequent random key lookups are needed on the resulting association. For example, the skeleton ‘create a pairs list’, ‘use `list_to_assoc/2` to create an assoc’, followed by frequent usage of `get_assoc/3` to extract key values can be replaced using `dict_pairs/3` and the dict access functions. Using dicts in this scenario is more efficient and provides a more pleasant access syntax.

### 5.4.4 A motivation for dicts as primary citizens

Dicts, or key-value associations, are a common data structure. A good old example are *property lists* as found in Lisp, while a good recent example is formed by JavaScript *objects*. Traditional Prolog does not offer native property lists. As a result, people are using a wide range of data structures for key-value associations:

- Using compound terms and positional arguments, e.g., `point(1,2)`.
- Using compound terms with library `record`, which generates access predicates for a term using positional arguments from a description.
• Using lists of terms \texttt{Name=Value, Name=\ldots, Name=Value} or \texttt{Name(Value)}.

• Using library \texttt{assoc} which represents the associations as a balanced binary tree.

This situation is unfortunate. Each of these have their advantages and disadvantages. E.g., compound terms are compact and fast, but inflexible and using positional arguments quickly breaks down. Library \texttt{record} fixes this, but the syntax is considered hard to use. Lists are flexible, but expensive and the alternative key-value representations that are used complicate the matter even more. Library \texttt{assoc} allows for efficient manipulation of changing associations, but the syntactical representation of an assoc is complex, which makes them unsuitable for e.g., options lists as seen in predicates such as \texttt{open/4}.

\subsection*{5.4.5 Implementation notes about dicts}

Although dicts are designed as an abstract data type and we deliberately reserve the possibility to change the representation and even use multiple representations, this section describes the current implementation.

Dicts are currently represented as a compound term using the functor \texttt{dict}. The first argument is the tag. The remaining arguments create an array of sorted key-value pairs. This representation is compact and guarantees good locality. Lookup is order $\log N$, while adding values, deleting values and merging with other dicts has order $N$. The main disadvantage is that changing values in large dicts is costly, both in terms of memory and time.

Future versions may share keys in a separate structure or use a binary trees to allow for cheaper updates. One of the issues is that the representation must either be kept canonical or unification must be extended to compensate for alternate representations.

\subsection*{5.5 Integration of strings and dicts in the libraries}

While lacking proper string support and dicts when designed, many predicates and libraries use interfaces that must be classified as suboptimal. Changing these interfaces is likely to break much more code than the changes described in this chapter. This section discusses some of these issues. Roughly, there are two cases. There where key-value associations or text is required as input, we can facilitate the new features by overloading the accepted types. Interfaces that produce text or key-value associations as their output however must make a choice. We plan to resolve that using either options that specify the desired output or provide an alternative library.

\subsection*{5.5.1 Dicts and option processing}

System predicates and predicates based on library \texttt{options} process dicts as an alternative to traditional option lists.

\subsection*{5.5.2 Dicts in core data structures}

Some predicates now produce structured data using compound terms and access predicates. We consider migrating these to dicts. Below is a tentative list of candidates. Portable code should use the provided access predicates and not rely on the term representation.

• Stream position terms
5.6. SINGLE SIDED UNIFICATION RULES

• Date and time records

5.5.3 Dicts, strings and XML

The XML representation could benefit significantly from the new features. In due time we plan to provide an set of alternative predicates and options to existing predicates that can be used to exploit the new types. We propose the following changes to the data representation:

• The attribute list of the element(Name, Attributes, Content) will become a dict.
• Attribute values will remain atoms
• CDATA in element content will be represented as strings

5.5.4 Dicts, strings and JSON

The JSON representation could benefit significantly from the new features. In due time we plan to provide an set of alternative predicates and options to existing predicates that can be used to exploit the new types. We propose the following changes to the data representation:

• Instead of using json(KeyValueList), the new interface will translate JSON objects to a dict. The type of this dict will be json.
• String values in JSON will be mapped to strings.
• The values true, false and null will be represented as atoms

5.5.5 Dicts, strings and HTTP

The HTTP library and related data structures would profit from exploiting dicts. Below is a list of data structures that might be affected by future changes. Code can be made more robust by using the option library functions for extracting values from these structures.

• The HTTP request structure
• The HTTP parameter interface
• URI components
• Attributes to HTML elements

5.6 Single Sided Unification rules

For the execution of a normal Prolog clause, the goal term is unified with the head of the clause. This allows us to write facts such as below and use this relation in all four possible modes. This is the basis of SLD resolution that turns Prolog into a logic programming language.

```prolog
parent('Bob', 'Susan').
```
In practice though, Prolog is both a logic programming language and a language for expressing computations in a near *procedural* style. The first is used to solve (notably) combinatorial problems while the latter is used for I/O, data transformation and the many non-logical operations that are involved in many applications.

Many Prolog programmers experience writing procedural style Prolog as fighting non-determinism and dealing with hard to debug silent failures because no clause matches some goal. Below are two typical queries on library predicates that have a procedural nature, i.e., are *single moded*.

```prolog
?- sum_list(a, X).
false.

?- sum_list([1|T], X).
T = [], X = 1 ;
ERROR: Arguments are not sufficiently instantiated
```

The definition of `sum_list/2` is it appears in library(lists) is below. This implementation can be considered elegant. Note that `sum_list/2` has only one meaningful mode: (+,-). A general (logical) implementation would allow for a partial list or a list holding one or more variables. With a proper list that holds a single variable we can still make a sound logical implementation. In all other cases the number of solutions is infinite and even *uncountable* for a partial list, making the predicate useless as a *generator* of solutions.

```prolog
sum_list(Xs, Sum) :-
  sum_list(Xs, 0, Sum).

sum_list([], Sum, Sum).
sum_list([X|Xs], Sum0, Sum) :-
  Sum1 is Sum0 + X,
  sum_list(Xs, Sum1, Sum).
```

If we want to avoid the above dubious behaviour we have two options. First, we can verify that the first argument is a list before entering the recursion, changing the first clause as below. The disadvantage is that we process the list twice.

```prolog
sum_list(Xs, Sum) :-
  must_be(list, Xs),
  sum_list(Xs, 0, Sum).
```

Alternatively, we can rewrite the second clause to verify the list on the fly. That leads to the code below. Most likely the overhead of this alternative compared to the above is even worse in many Prolog implementations. Most people would also consider this code rather inelegant.

```prolog
sum_list(Var, _, _) :-
  var(Var),
```

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instantiation_error(Var).
sum_list([], Sum, Sum) :- !.
sum_list([X|Xs], Sum0, Sum) :- !,
    Sum1 is Sum0 + X,
    sum_list(Xs, Sum1, Sum).
sum_list(NoList, _, _) :-
    type_error(list, NoList).

Another example is a relation \texttt{max/3}, expressing the maximum of two numbers. A classical textbook definition could be as below. This code has two drawbacks. First it leaves an open choice points in most Prolog implementations if \texttt{X} is the largest and second it compares the two numbers twice. Some Prolog systems detect this particular case, but in general it needs two know that one test is the strict negation of the other.

\begin{verbatim}
max(X,Y,X) :- X >= Y.
max(X,Y,Y) :- Y > X.
\end{verbatim}

As a result people use a cut and might come up with the \textbf{wrong} solution below. Consider the query \texttt{?- max(5,2,2)} to see why this code is broken.

\begin{verbatim}
max(X,Y,X) :- X >= Y, !.
max(_,Y,Y).
\end{verbatim}

A correct solution is below, \textit{delaying} binding the output until after the cut.

\begin{verbatim}
max(X,Y,M) :- X >= Y, !, M = X.
max(_,Y,Y).
\end{verbatim}

Some people may prefer using if-then-else as below. This is arguable the cleanest efficient solution in standard Prolog.

\begin{verbatim}
max(X,Y,M) :- ( X >= Y -> M = X ; M = Y ).
\end{verbatim}

As we have seen from these examples, writing procedural code in Prolog requires us to follow the two basic principles below. Both principles have been properly described in \textit{The Craft of Prolog} [O’Keefe, 1990].

- Structure every clause as \texttt{Head :- Guard, !, Body}. Every clause has the cut as early as possible. \texttt{Guard} can be empty. The last clause often does not need a cut.
- Avoid that the head unification binds values in the goal term. We see this may lead to undesirable results such as \texttt{sum_list(L,S)} binding \texttt{L} to ‘[]’ and \texttt{S} to ‘0’ as well as loss of \textit{steadfastness}, causing \texttt{max(5,2,2)} to succeed. The first requires additional \texttt{var/1} or \texttt{nonvar/1} tests. The second requires delaying unification until after the cut.
Picat provides the $\Rightarrow/2$ alternative for the Prolog neck ($:\sim/2$) to force the above practices. A Picat rule has the following shape:

\[
\text{Head, Guard } \Rightarrow \text{ Body.}
\]

This is semantically equivalent to the Prolog clause below. The subsumes_term/2 guarantees the clause head is more generic than the goal term and thus unifying the two does not affect any of the arguments of the goal. This implies all output unification _must_ be done after the head unification.

\[
p(V1,V2,\ldots,Vn) :- \\
\quad \text{Pattern} = p(A1,A2,\ldots,An), \\
\quad \text{Args} = p(V1,V2,\ldots,Vn), \\
\quad \text{subsumes_term(Pattern, Args)}, \\
\quad \text{Pattern} = \text{Args}, \\
\quad \text{Guard}, \\
\quad !, \\
\quad \text{Body}.
\]

SWI-Prolog as of version 8.3.19 support $\Rightarrow/2$ as an alternative to normal Prolog clauses. The construct comes with the following properties.

- A predicate either uses $:\sim/2$ for all its clauses or $\Rightarrow/2$. Mixing is not allowed and raises a permission error for a clause that does not use the same neck as the first clause.
- Unlike Picat, it is an error if no clause matches.

Given $\Rightarrow/2$ rules, we can rewrite sum_list/2 as below. The first clause can be written using $:\sim/2$ or $\Rightarrow/2$. As the head is the most general head and there is only one clause these are fully equivalent. The sum_list/3 helper needs a small modification: we need to delay the unification against Sum to the body. The last clause is equivalent.

\[
\text{sum_list}(Xs, Sum) \Rightarrow \\
\quad \text{sum_list}(Xs, 0, Sum).
\]

\[
\text{sum_list}([], Sum0, Sum) \Rightarrow \\
\quad \text{Sum} = \text{Sum0}.
\]

\[
\text{sum_list}([X|Xs], Sum0, Sum) \Rightarrow \\
\quad \text{Sum1} = \text{Sum0} + X, \\
\quad \text{sum_list}(Xs, \text{Sum1}, Sum).
\]

Given this definition, sum_list(L,S) no longer matches a rule and neither does e.g., sum_list(a,S). Both raise an error. Currently the error is defined as below.

\[
\text{existence_error(matching_rule, Head)}
\]

Should silent failure be desired if no rule matches, this is easily encoding by adding a rule at the end using the most general head and fail/0 as body:

\[
\text{sum_list}(_,_,_) \Rightarrow \text{fail}.
\]
5.6. SINGLE SIDED UNIFICATION RULES

5.6.1 Single Sided Unification Guards

Using the construction `Head, Guard => Body`, the `Guard` is executed after the single sided head unification. If the `Guard` succeeds the clause executes a cut (`! /0`) and proceeds normally. There are no restrictions on the guard code. A well behaved guard is a test. Notably:

- Though not enforced\(^{11}\), guard code shall not instantiate variables in the `Head` because this breaks the promise of SSU and may make the node non-steadfast.
- It is bad style (but again, not enforced) to have any type of side effects (output, database change, etc.)
- Typically, guard calls are semidet. Non-deterministic calls are allowed. If the guard succeeds with choicepoints these are pruned before the body is entered.

As a special exception, explicit unification against a variable in the head is moved into the head. See section 2.18.3. In the example below, the `X = f(I)` is moved into the head and (thus) is executed using single sided unification.

```
p(X), X = f(I), integer(I) => q(X).
```

**Warning** Moving the guard unification into the head changes the semantics of the unification. This may be defended by the rules above that claim one should not unify against the head arguments in the guard. Future versions may use a dedicated operator to indicate that the unification may be moved into the head.

5.6.2 Consequences of `=>` single sided unification rules

The `=>/2` construct is handled by the low-level compiler if no `guard` is present. If a guard is present it is currently compiled into the construct below. The Picat `?=>/2 neck` operator is like `=>/2`, but does not commit to this rule. We are not yet sure whether or not SWI-Prolog will remain supporting `?=>/2`.\(^{12}\)

```
Head ?=> Guard, !, Body.
```

The main consequence is that `clause/2` cannot distinguish between a normal clause and a `=>/2` clause. In the current implementation it operates on both without distinguishing the two. This implies e.g., `cross referencing` still works. Meta interpretation however does not work. In future versions `clause/2` may fail on these rules. As an alternative we provide `rule/2,3`.

```
rule(:Head, -Rule)
rule(:Head, -Rule, -Ref)
```

`true` when `Rule` is a rule/clause that implements `Head`. `Rule` is a complete rule term. For a normal clause this is a term `Head :- Body` and for a single sided unification rule it is a term `Head => Body`.

---

\(^{11}\)We do not know about an efficient way to enforce unification against head arguments

\(^{12}\)`?=>/2` is currently implemented but not defined as an operator.
5.6.3 SSU: Future considerations

The current implementation is a rather simple. Single sided unification is achieved doing normal head unification and backtrack if this unification bound variables in the goal term. Future versions are likely to backtrack as soon as we find a variable in the goal that needs to be unified.

It is likely that in due time significant parts of the libraries will be migrated to use SSU rules, turning many silent failures on type errors into errors.

5.7 Remaining issues

The changes and extensions described in this chapter resolve many limitations of the Prolog language we have encountered. Still, there are remaining issues for which we seek solutions in the future.

Text representation Although strings resolve this issue for many applications, we are still faced with the representation of text as lists of characters which we need for parsing using DCGs. The ISO standard provides two representations, a list of character codes (‘codes’ for short) and a list of one-character atoms (‘chars’ for short). There are two sets of predicates, named *_code(s) and *_char(s) that provide the same functionality (e.g., atom_codes/2 and atom_chars/2) using their own representation of characters. Codes can be used in arithmetic expressions, while chars are more readable. Neither can unambiguously be interpreted as a representation for text because codes can be interpreted as a list of integers and chars as a list of atoms.

We have not found a convincing way out. One of the options could be the introduction of a ‘char’ type. This type can be allowed in arithmetic and with the 0’(char) syntax we have a concrete syntax for it.

Arrays Although lists are generally a much cleaner alternative for Prolog, real arrays with direct access to elements can be useful for particular tasks. The problem of integrating arrays is twofold. First of all, there is no good one-size-fits-all data representation for arrays. Many tasks that involve arrays require mutable arrays, while Prolog data is immutable by design. Second, standard Prolog has no good syntax support for arrays. SWI-Prolog version 7 has ‘block operators’ (see section 5.3.3) which can resolve the syntactic issues. Block operators have been adopted by YAP.

Lambda expressions Although many alternatives\(^{13}\) have been proposed, we still feel uneasy with them.

Loops Many people have explored routes to avoid the need for recursion in Prolog for simple iterations over data. ECLiPSe have proposed logical loops [Schimpf, 2002], while B-Prolog introduced declarative loops and list comprehension [Zhou, 2010]. The above mentioned lambda expressions, combined with maplist/2 can achieve similar results.

\(^{13}\) See e.g., http://www.complang.tuwien.ac.at/ulrich/Prolog-inedit/ISO-Hiord
A Prolog module is a collection of predicates which defines a public interface by means of a set of provided predicates and operators. Prolog modules are defined by an ISO standard. Unfortunately, the standard is considered a failure and, as far as we are aware, not implemented by any concrete Prolog implementation. The SWI-Prolog module system syntax is derived from the Quintus Prolog module system. The Quintus module system has been the starting point for the module systems of a number of mainstream Prolog systems, such as SICStus, Ciao and YAP. The underlying primitives of the SWI-Prolog module system differ from the mentioned systems. These primitives allow for multiple modules in a file, hierarchical modules, emulation of other modules interfaces, etc.

This chapter motivates and describes the SWI-Prolog module system. Novices can start using the module system after reading section 6.2 and section 6.3. The primitives defined in these sections suffice for basic usage until one needs to export predicates that call or manage other predicates dynamically (e.g., use `call/1`, `assert/1`, etc.). Such predicates are called `meta predicates` and are discussed in section 6.5. Section 6.6 to section 6.9 describe more advanced issues. Starting with section 6.10, we discuss more low-level aspects of the SWI-Prolog module system that are used to implement the visible module system, and can be used to build other code reuse mechanisms.

### 6.1 Why Use Modules?

In classic Prolog systems, all predicates are organised in a single namespace and any predicate can call any predicate. Because each predicate in a file can be called from anywhere in the program, it becomes very hard to find the dependencies and enhance the implementation of a predicate without risking to break the overall application. This is true for any language, but even worse for Prolog due to its frequent need for ‘helper predicates’.

A Prolog module encapsulates a set of predicates and defines an interface. Modules can import other modules, which makes the dependencies explicit. Given explicit dependencies and a well-defined interface, it becomes much easier to change the internal organisation of a module without breaking the overall application.

Explicit dependencies can also be used by the development environment. The SWI-Prolog library `prolog_xref` can be used to analyse completeness and consistency of modules. This library is used by the built-in editor PceEmacs for syntax highlighting, jump-to-definition, etc.

### 6.2 Defining a Module

Modules are normally created by loading a module file. A module file is a file holding a `module/2` directive as its first term. The `module/2` directive declares the name and the public (i.e., externally visible) predicates of the module. The rest of the file is loaded into the module. Below is an example...
of a module file, defining reverse/2 and hiding the helper predicate rev/3. A module can use all built-in predicates and, by default, cannot redefine system predicates.

```prolog
:- module(reverse, [reverse/2]).

reverse(List1, List2) :-
    rev(List1, [], List2).

rev([], List, List).
rev([Head|List1], List2, List3) :-
    rev(List1, [Head|List2], List3).
```

The module is named reverse. Typically, the name of a module is the same as the name of the file by which it is defined without the filename extension, but this naming is not enforced. Modules are organised in a single and flat namespace and therefore module names must be chosen with some care to avoid conflicts. As we will see, typical applications of the module system rarely use the name of a module explicitly in the source text.

```prolog
:- module(+Module, +PublicList).
```

This directive can only be used as the first term of a source file. It declares the file to be a module file, defining a module named Module. Note that a module name is an atom. The module exports the predicates of PublicList. PublicList is a list of predicate indicators (name/arity or name//arity pairs) or operator declarations using the format op(Precedence, Type, Name). Operators defined in the export list are available inside the module as well as to modules importing this module. See also section 4.25.

Compatible to Ciao Prolog, if Module is unbound, it is unified with the basename without extension of the file being loaded.

```prolog
:- module(+Module, +PublicList, +Dialect).
```

Same as module/2. The additional Dialect argument provides a list of language options. Each atom in the list Dialect is mapped to a use_module/1 goal as given below. See also section C. The third argument is supported for compatibility with the Prolog Commons project.

```prolog
:- use_module(library(dialect/LangOption)).
```

### 6.3 Importing Predicates into a Module

Predicates can be added to a module by importing them from another module. Importing adds predicates to the namespace of a module. An imported predicate can be called exactly the same as a locally defined predicate, although its implementation remains part of the module in which it has been defined.

Importing the predicates from another module is achieved using the directives use_module/1 or use_module/2. Note that both directives take filename(s) as arguments. That is, modules are imported based on their filename rather than their module name.
6.3. IMPORTING PREDICATES INTO A MODULE

**use_module(+Files)**
Load the file(s) specified with `Files` just like `ensure_loaded/1`. The files must all be module files. All exported predicates from the loaded files are imported into the module from which this predicate is called. This predicate is equivalent to `ensure_loaded/1`, except that it raises an error if `Files` are not module files.

The imported predicates act as *weak symbols* in the module into which they are imported. This implies that a local definition of a predicate overrides (clobbers) the imported definition. If the flag `warn_override_implicit_import` is true (default), a warning is printed. Below is an example of a module that uses `library(lists)`, but redefines `flatten/2`, giving it a totally different meaning:

```prolog
:- module(shapes, []).
:- use_module(library(lists)).
flatten(cube, square).
flatten(ball, circle).
```

Loading the above file prints the following message:

```
Warning: /home/janw/Bugs/Import/t.pl:5:
  Local definition of shapes:flatten/2
  overrides weak import from lists
```

This warning can be avoided by (1) using `use_module/2` to only import the predicates from the `lists` library that are actually used in the ‘shapes’ module, (2) using the `except([flatten/2])` option of `use_module/2`, (3) use `:- abolish(flatten/2)`. before the local definition or (4) setting `warn_override_implicit_import` to false. Globally disabling this warning is only recommended if overriding imported predicates is common as a result of design choices or the program is ported from a system that silently overrides imported predicates.

Note that it is always an error to import two modules with `use_module/1` that export the same predicate. Such conflicts must be resolved with `use_module/2` as described above.

**use_module(+File, +ImportList)**
Load `File`, which must be a module file, and import the predicates as specified by `ImportList`. `ImportList` is a list of predicate indicators specifying the predicates that will be imported from the loaded module. `ImportList` also allows for renaming or import-everything-except. See also the `import` option of `load_files/2`. The first example below loads `member/2` from the `lists` library and `append/2` under the name `list_concat`, which is how this predicate is named in YAP. The second example loads all exports from `library option` except for `meta_options/3`. These renaming facilities are generally used to deal with portability issues with as few changes as possible to the actual code. See also section C and section 6.8.

```prolog
:- use_module(library(lists), [ member/2, append/2 as list_concat]
```
In most cases a module is imported because some of its predicates are being used. However, sometimes a module is imported for other reasons, e.g., for its declarations. In such cases it is best practice to use `use_module/2` with empty ImportList. This distinguishes an imported module that is used, although not for its predicates, from a module that is needlessly imported.

The `module/2`, `use_module/1` and `use_module/2` directives are sufficient to partition a simple Prolog program into modules. The SWI-Prolog graphical cross-referencing tool `gxref/0` can be used to analyse the dependencies between non-module files and propose module declarations for each file.

### 6.4 Controlled autoloading for modules

SWI-Prolog by default support autoloading from its standard library. Autoloading implies that when a predicate is found missing during execution the library is searched and the predicate is imported lazily using `use_module/2`. See section 2.14 for details.

The advantage of autoloading is that it requires less typing while it reduces the startup time and reduces the memory footprint of an application. It also allows moving old predicates or emulation thereof the module `backcomp` without affecting existing code. This procedure keeps the libraries and system clean. We make sure that there are not two modules that provide the same predicate as autoloader predicate.

Nevertheless, a disadvantage of this autoloader is that the dependencies of a module on the libraries are not explicit and tooling such as PceEmacs or `gxref/0` are required to find these dependencies. Some users want explicit control over which library predicates are accessed from where, preferably by using `use_module/2` which explicitly states which predicates are imported from which library.¹

Large applications typically contain source files that are not immediately needed and often are not needed at all in many runs of the program. This can be solved by creating an application-specific autoloader library, but with multiple parties providing autoloadeable predicates the maintenance becomes fragile. For these two reasons we added `autoload/1` and `autoload/2` that behave similar to `use_module/[1,2]`, but do not perform the actual loading. The generic autoloader now proceeds as follows if a missing predicate is encountered:

1. Check `autoload/2` declarations. If one specifies the predicate, import it using `use_module/2`.

2. Check `autoload/1` declarations. If the specified file is loaded, check its export list. Otherwise read the module declaration of the target file to find the exports. If the target predicate is found, import it using `use_module/2`.

3. Perform autoloading from the library if the `autoload` is true.

```prolog
autoload(File)
autoload(File, +Exports)
```

¹Note that built-in predicates still add predicates for general use to all name spaces.
Declare that possibly missing predicates in the module in which this declaration occurs are to be resolved by using `use_module/2` on `File` to (possibly) load the file and make the target predicate available. The `autoload/2` variant is tried before `autoload/1`. It is not allowed for two `autoload/2` declarations to provide the same predicate and it is not allowed to define a predicate provided in this way locally. See also `require/1`, which allows specifying predicates for autoloading from their default location.

Predicates made available using `autoload/2` behave as defined predicates, which implies that any operation on them will perform autoloading if necessary. Notably `predicate_property/2, current_predicate/1` and `clause/2` are supported.

Currently, neither the existence of `File`, nor whether it actually exports the given predicates (autoload/2) is verified when the file is loaded. Instead, the declarations are verified when searching for a missing predicate.

If the Prolog flag `autoload` is set to `false`, these declarations are interpreted as `use_module/[1,2]`.

### 6.5 Defining a meta-predicate

A meta-predicate is a predicate that calls other predicates dynamically, modifies a predicate, or reasons about properties of a predicate. Such predicates use either a compound term or a predicate indicator to describe the predicate they address, e.g., `assert(name(jan))` or `abolish(name/1)`. With modules, this simple schema no longer works as each module defines its own mapping from name+arity to predicate. This is resolved by wrapping the original description in a term `<module>:<term>`, e.g., `assert(person:name(jan))` or `abolish(person:name/1)`.

Of course, when calling `assert/1` from inside a module, we expect to assert to a predicate local to this module. In other words, we do not wish to provide this `:/2` wrapper by hand. The `meta_predicate/1` directive tells the compiler that certain arguments are terms that will be used to look up a predicate and thus need to be wrapped (qualified) with `<module>:<term>`, unless they are already wrapped.

In the example below, we use this to define `maplist/3` inside a module. The argument ‘2’ in the `meta_predicate` declaration means that the argument is module-sensitive and refers to a predicate with an arity that is two more than the term that is passed in. The compiler only distinguishes the values 0..9 and `:`, which denote module-sensitive arguments, from `+`, `-` and `?`, which denote `modes`. The values 0..9 are used by the `cross-referencer` and syntax highlighting. Note that the helper predicate `maplist/3` does not need to be declared as a meta-predicate because the `maplist/3` wrapper already ensures that `Goal` is qualified as `<module>:Goal`. See the description of `meta_predicate/1` for details.

```prolog
:- module(maplist, [maplist/3]).
:- meta_predicate maplist(2, ?, ?).

%% maplist(:Goal, +List1, ?List2)
% True if Goal can successfully be applied to all successive pairs of elements from List1 and List2.
maplist(Goal, L1, L2) :-
```

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maplist_(L1, L2, Goal).
maplist_([], [], _).
maplist_([H0|T0], [H|T], Goal) :-
call(Goal, H0, H),
maplist_(T0, T, Goal).

meta_predicate +Head, ...

Define the predicates referenced by the comma-separated list Head as meta-predicates. Each argument of each head is a meta argument specifier. Defined specifiers are given below. Only 0..9, :, ^ and // are interpreted; the mode declarations +, -, * and ? are ignored.

0..9
The argument is a term that is used to reference a predicate with \( N \) more arguments than the given argument term. For example: \( \text{call}(0) \) or \( \text{maplist}(1, +) \).

:   The argument is module-sensitive, but does not directly refer to a predicate. For example: \( \text{consult}(:) \).

^   This extension is used to denote the possibly ^-annotated goal of \( \text{setof}/3, \text{bagof}/3, \text{aggregate}/3 \) and \( \text{aggregate}/4 \). It is processed similar to ‘0’, but leaving the ^/2 intact.

//   The argument is a DCG body. See \text{phrase}/3.

-   

?   

*   

+   

All these have the same semantics, declaring the argument to be not module sensitive. The * notation is an alias for ? for compatibility with e.g., Logtalk. The specific mode has merely documentation value. See section 4.1.1 for details.

Each argument that is module-sensitive (i.e., marked 0..9, : or ^) is qualified with the context module of the caller if it is not already qualified. The implementation ensures that the argument is passed as \( \langle \text{module}\rangle: \langle \text{term}\rangle \), where \( \langle \text{module}\rangle \) is an atom denoting the name of a module and \( \langle \text{term}\rangle \) itself is not a \( :/2 \) term where the first argument is an atom. Below is a simple declaration and a number of queries.

:- meta_predicate
   meta(0, +).
6.6 Overruling Module Boundaries

The module system described so far is sufficient to distribute programs over multiple modules. There are, however, cases in which we would like to be able to overrule this schema and explicitly call a predicate in some module or assert explicitly into some module. Calling in a particular module is useful for debugging from the user’s top level or to access multiple implementations of the same interface that reside in multiple modules. Accessing the same interface from multiple modules cannot be achieved using importing because importing a predicate with the same name and arity from two modules results in a name conflict. Asserting in a different module can be used to create models dynamically in a new module. See section 6.13.

Direct addressing of modules is achieved using a :/2 explicitly in a program and relies on the module qualification mechanism described in section 6.5. Here are a few examples:

?- assert(world:done). % asserts done/0 into module world
?- world:asserta(done). % the same
?- world:done. % calls done/0 in module world

Note that the second example is the same due to the Prolog flag colon_sets_calling_context. The system predicate asserta/1 is called in the module world, which is possible because system predicates are visible in all modules. At the same time, the calling context is set to world. Because meta arguments are qualified with the calling context, the resulting call is the same as the first example.
6.6.1 Explicit manipulation of the calling context

Quintus’ derived module systems have no means to separate the lookup module (for finding predicates) from the calling context (for qualifying meta arguments). Some other Prolog implementations (e.g., ECLiPSe and IF/Prolog) distinguish these operations, using @/2 for setting the calling context of a goal. This is provided by SWI-Prolog, currently mainly to support compatibility layers.

@/2(\text{Goal}, \text{+Module})

Execute \text{Goal}, setting the calling context to \text{Module}. Setting the calling context affects meta-predicates, for which meta arguments are qualified with \text{Module} and transparent predicates (see \text{module_transparent/1}). It has no implications for other predicates.

For example, the code \text{asserta(done)@world} is the same as \text{asserta(world:done)}. Unlike in \text{world:asserta(done)}, \text{asserta/1} is resolved in the current module rather than the module \text{world}. This makes no difference for system predicates, but usually does make a difference for user predicates.

Not that SWI-Prolog does not define @ as an operator. Some systems define this construct using \text{op(900, xfx, @)}.

6.7 Interacting with modules from the top level

Debugging often requires interaction with predicates that reside in modules: running them, setting spy points on them, etc. This can be achieved using the ⟨\text{module}:⟨term⟩⟩ construct explicitly as described above. In SWI-Prolog, you may also wish to omit the module qualification. Setting a spy point (spy/1) on a plain predicate sets a spy point on any predicate with that name in any module. Editing (edit/1) or calling an unqualified predicate invokes the DWIM (Do What I Mean) mechanism, which generally suggests the correct qualified query.

Mainly for compatibility, we provide \text{module/1} to switch the module with which the interactive top level interacts:

\text{module(+Module)}

The call \text{module (Module)} may be used to switch the default working module for the interactive top level (see \text{prolog/0}). This may be used when debugging a module. The example below lists the clauses of \text{file_of_label/2} in the module \text{tex}.

\begin{verbatim}
1 ?- module(tex).
true.
tex: 2 ?- listing(file_of_label/2).
...
\end{verbatim}

6.8 Composing modules from other modules

The predicates in this section are intended to create new modules from the content of other modules. Below is an example to define a \text{composite} module. The example exports all public predicates of \text{module_1, module_2 and module_3}, \text{pred/1} from \text{module_4}, all predicates from \text{module_5} except \text{do_not_use/1} and all predicates from \text{module_6} while renaming \text{pred/1} into \text{mypred/1}.
6.9. OPERATORS AND MODULES

:- module(my_composite, []).
:- reexport([ module_1,
             module_2,
             module_3
           ]).
:- reexport(module_4, [ pred/1 ]).
:- reexport(module_5, except([do_not_use/1])).
:- reexport(module_6, except([pred/1 as mypred])).

reexport(+Files)
Load and import predicates as use_module/1 and re-export all imported predicates. The
reexport declarations must immediately follow the module declaration.

reexport(+File, +Import)
Import from File as use_module/2 and re-export the imported predicates. The reexport
declarations must immediately follow the module declaration.

6.9 Operators and modules

Operators (section 4.25) are local to modules, where the initial table behaves as if it is copied
from the module user (see section 6.11). A specific operator can be disabled inside a mod-
ule using :- op(0, Type, Name). Inheritance from the public table can be restored using
:- op(-1, Type, Name).

In addition to using the op/3 directive, operators can be declared in the module/2 directive as
shown below. Such operator declarations are visible inside the module, and importing such a module
makes the operators visible in the target module. Exporting operators is typically used by modules
that implement sub-languages such as chr (see chapter 9). The example below is copied from the
library clpfd.

:- module(clpfd,
          [ op(760, yfx, #<==>),
            op(750, xfy, #==>),
            op(750, yfx, #<==),
            op(740, yfx, #/),
            ...
            (#<==>)/2,
            (#==>)/2,
            (#<==])/2,
            (#\)/2,
            ...
          ]).
6.10 Dynamic importing using import modules

Until now we discussed the public module interface that is, at least to some extent, portable between Prolog implementations with a module system that is derived from Quintus Prolog. The remainder of this chapter describes the underlying mechanisms that can be used to emulate other module systems or implement other code-reuse mechanisms.

In addition to built-in predicates, imported predicates and locally defined predicates, SWI-Prolog modules can also call predicates from its import modules. Each module has a (possibly empty) list of import modules. In the default setup, each new module has a single import module, which is user for all normal user modules and system for all system library modules. Module user imports from system where all built-in predicates reside. These special modules are described in more detail in section 6.11.

In general, the import relations between modules form an acyclic directed graph. The import relation affects the following mechanisms:

Predicate visibility When looking for a specific predicate definition the system starts in the target module. If the predicate is undefined there it walks the module import relations depth-first left-to-right searching for a module that defines the predicate. The first encountered definition is used. Note that using the default setup this means it searches the user and system modules (in that order).

Operators Operators are also searched through the import relations. System operators are defined in the module system. The user may define operators in user to make them globally visible for compatibility with e.g., SICStus Prolog that has no local operators. Normally operators are defined in a module and, when applicable, exported using the module/2 module header.

The unknown flag This flag controls the response to encountering an undefined predicate in the target module.

Term and goal expansion The hooks term_expansion/2 and goal_expansion/2 (see section 4.3.1) are chained over the import modules that define these hooks. This implies we collect all modules that provide definitions for these hook predicates by traversing the import module relation depth-first and left-to-right. Next, we perform the transformations in a pipeline, starting at the target module.

The list of import modules for a specific module can be manipulated and queried using the following predicates, as well as using set_module/1.

import_module(+Module, -Import) [nondet]
True if Module inherits directly from Import. All normal modules only import from user, which imports from system. The predicates add_import_module/3 and delete_import_module/2 can be used to manipulate the import list. See also default_module/2.

default_module(+Module, -Default) [multi]
True if predicates and operators in Default are visible in Module. Modules are returned in the same search order used for predicates and operators. That is, Default is first unified with Module, followed by the depth-first transitive closure of import_module/2.
add_import_module(+Module, +Import, +StartOrEnd)

If Import is not already an import module for Module, add it to this list at the start or end depending on StartOrEnd. See also import_module/2 and delete_import_module/2.

delete_import_module(+Module, +Import)

Delete Import from the list of import modules for Module. Fails silently if Import is not in the list.

6.11 Reserved Modules and using the ‘user’ module

As mentioned above, SWI-Prolog contains two special modules. The first one is the module system. This module contains all built-in predicates. Module system has no import module, i.e., is a root of the module graph. The second special module is the module user. This module forms the initial working space of the user. Initially it is empty. The import module of module user is system, making all built-in predicates available.

All normal application modules import from the module user. This implies they can use all predicates imported into user without explicitly importing them. If an application loads all modules from the user module using use_module/1, one achieves a scoping system similar to the C-language, where every module can access all exported predicates without any special precautions.

All library modules (see module_property/2) import directly from system. Library modules are modules loaded from the SWI-Prolog installation. As they import from system, the functionality of a library is not affected by operator or predicate definitions in the user module.

6.12 An alternative import/export interface

The use_module/1 predicate from section 6.3 defines import and export relations based on the filename from which a module is loaded. If modules are created differently, such as by asserting predicates into a new module as described in section 6.13, this interface cannot be used. The interface below provides for import/export from modules that are not created using a module file.

export(+PredicateIndicator, . . .)

Add predicates to the public list of the context module. This implies the predicate will be imported into another module if this module is imported with use_module/[1,2]. Note that predicates are normally exported using the directive module/2. export/1 is meant to handle export from dynamically created modules.

import(+PredicateIndicator, . . .)

Import predicates PredicateIndicator into the current context module. PredicateIndicator must specify the source module using the ⟨module⟩:(pi) construct. Note that predicates are normally imported using one of the directives use_module/[1,2]. The import/1 alternative is meant for handling imports into dynamically created modules. See also export/1 and export_list/2.

Unfortunately some hooks are traditionally defined in the user module
6.13 Dynamic Modules

So far, we discussed modules that were created by loading a module file. These modules have been introduced to facilitate the development of large applications. The modules are fully defined at load-time of the application and normally will not change during execution. Having the notion of a set of predicates as a self-contained world can be attractive for other purposes as well. For example, assume an application that can reason about multiple worlds. It is attractive to store the data of a particular world in a module, so we extract information from a world simply by invoking goals in this world.

Dynamic modules can easily be created. Any built-in predicate that tries to locate a predicate in a specific module will create this module as a side-effect if it did not yet exist. For example:

```prolog
?- assert(world_a:consistent),
     set_prolog_flag(world_a:unknown, fail).
```

These calls create a module called ‘world_a’ and make the call ‘world_a:consistent’ succeed. Undefined predicates will not raise an exception for this module (see unknown).

Import and export from a dynamically created world can be achieved using `import/1` and `export/1` or by specifying the import module as described in section 6.10.

```prolog
?- world_b:export(solve/2). % exports solve/2 from world_b
?- world_c:import(world_b:solve/2). % and import it to world_c
```

6.14 Transparent predicates: definition and context module

The ‘module-transparent’ mechanism is still underlying the actual implementation. Direct usage by programmers is deprecated. Please use `meta_predicate/1` to deal with meta-predicates.

The qualification of module-sensitive arguments described in section 6.5 is realised using transparent predicates. It is now deprecated to use this mechanism directly. However, studying the underlying mechanism helps to understand SWI-Prolog’s modules. In some respect, the transparent mechanism is more powerful than meta-predicate declarations.

Each predicate of the program is assigned a module, called its definition module. The definition module of a predicate is always the module in which the predicate was originally defined. Each active goal in the Prolog system has a context module assigned to it.

The context module is used to find predicates for a Prolog term. By default, the context module is the definition module of the predicate running the goal. For transparent predicates, however, this is the context module of the goal inherited from the parent goal. Below, we implement `maplist/3` using the transparent mechanism. The code of `maplist/3` and `maplist_/3` is the same as in section 6.5, but now we must declare both the main predicate and the helper as transparent to avoid changing the context module when calling the helper.

```prolog
:- module(maplist, maplist/3).
:- module_transparent
    maplist/3,
    maplist_/3.
```
maplist(Goal, L1, L2) :-
    maplist_(L1, L2, G).

maplist_([], [], _).
maplist_(([H0|T0], [H|T], Goal) :-
    call(Goal, H0, H),
    maplist_(T0, T, Goal).

Note that any call that translates terms into predicates is subject to the transparent mechanism, not just the terms passed to module-sensitive arguments. For example, the module below counts the number of unique atoms returned as bindings for a variable. It works as expected. If we use the directive :- module_transparent count_atom_results/3. instead, atom_result/2 is called wrongly in the module calling count_atom_results/3. This can be solved using strip_module/3 to create a qualified goal and a non-transparent helper predicate that is defined in the same module.

:- module(count_atom_results, [ count_atom_results/3 ]).
:- meta_predicate count_atom_results(-,0,-).

count_atom_results(A, Goal, Count) :-
    setof(A, atom_result(A, Goal), As), !,
    length(As, Count).
count_atom_results(_, _, 0).

atom_result(Var, Goal) :-
    call(Goal),
    atom(Var).

The following predicates support the module-transparent interface:

:- module_transparent(+Preds)
    Preds is a comma-separated list of name/arity pairs (like dynamic/1). Each goal associated with a transparent-declared predicate will inherit the context module from its parent goal.

context_module(-Module)
    Unify Module with the context module of the current goal. context_module/1 itself is, of course, transparent.

strip_module(+Term, -Module, -Plain)
    Used in module-transparent predicates or meta-predicates to extract the referenced module and plain term. If Term is a module-qualified term, i.e. of the format Module:Plain, Module and Plain are unified to these values. Otherwise, Plain is unified to Term and Module to the context module.
6.15 Module properties

The following predicates can be used to query the module system for reflexive programming:

\texttt{current\_module(?Module)}

True if \textit{Module} is a currently defined module. This predicate enumerates all modules, whether
loaded from a file or created dynamically. Note that modules cannot be destroyed in the current
version of SWI-Prolog.

\texttt{module\_property(?Module, ?Property)}

True if \textit{Property} is a property of \textit{Module}. Defined properties are:

\texttt{class(-Class)}

True when \textit{Class} is the class of the module. Defined classes are
user
    Default for user-defined modules.
\texttt{system}
    Module \texttt{system} and modules from \texttt{(home)/boot}.
\texttt{library}
    Other modules from the system directories.
\texttt{temporary}
    Module is temporary.
\texttt{test}
    Modules that create tests.
\texttt{development}
    Modules that only support the development environment.
\texttt{file(?File)}

True if \textit{Module} was loaded from \textit{File}.
\texttt{line\_count(-Line)}

True if \textit{Module} was loaded from the N-th line of file.
\texttt{exports(-ListOfPredicateIndicators)}

True if \textit{Module} exports the given predicates. Predicate indicators are in canonical form
(i.e., always using name/arity and never the DCG form name//arity). Future versions may
also use the DCG form. See also \texttt{predicate\_property/2}. Succeeds with an empty
list if the module exports no predicates.
\texttt{exported\_operators(-ListOfOperators)}

True if \textit{Module} exports the given operators. Each exported operator is represented as
a term \texttt{op(Pri,Assoc,Name)}. Succeeds with an empty list if the module exports no
operators.
\texttt{size(-Bytes)}

Total size in bytes used to represent the module. This includes the module itself, its
(hash) tables and the summed size of all predicates defined in this module. See also the
\texttt{size(Bytes)} property in \texttt{predicate\_property/2}.
\texttt{program\_size(-Bytes)}

Memory (in bytes) used for storing the predicates of this module. This figure includes the
predicate header and clauses.
program_space(-Bytes)
If present, this number limits the program_size. See set_module/1.

last_modified_generation(-Generation)
Integer expression the last database generation where a clause was added or removed from
a predicate that is implemented in this module. See also predicate_property/2.

set_module:(Property)
Modify properties of the module. Currently, the following properties may be modified:

base(+Base)
Set the default import module of the current module to Module. Typically, Module is one
of user or system. See section 6.10.

class(+Class)
Set the class of the module. See module_property/2.

program_space(+Bytes)
Maximum amount of memory used to store the predicates defined inside the module.
Raises a permission error if the current usage is above the requested limit. Setting the
limit to 0 (zero) removes the limit. An attempt to assert clauses that causes the limit to
be exceeded causes a resource_error(program_space) exception. See assertz/1
and module_property/2.

6.16 Compatibility of the Module System

The SWI-Prolog module system is largely derived from the Quintus Prolog module system, which
is also adopted by SICStus, Ciao and YAP. Originally, the mechanism for defining meta-predicates
in SWI-Prolog was based on the module_transparent/1 directive and strip_module/3.
Since 5.7.4 it supports the de-facto standard meta_predicate/1 directive for implementing meta-
predicates, providing much better compatibility.

The support for the meta_predicate/1 mechanism, however, is considerably different.
On most systems, the caller of a meta-predicate is compiled differently to provide the required
(module):(term) qualification. This implies that the meta-declaration must be available to the com-
piler when compiling code that calls a meta-predicate. In practice, this implies that other systems pose
the following restrictions on meta-predicates:

• Modules that provide meta-predicates for a module to be compiled must be loaded explicitly by
that module.

• The meta-predicate directives of exported predicates must follow the module/2 directive im-
mediately.

• After changing a meta-declaration, all modules that call the modified predicates need to be
recompiled.

In SWI-Prolog, meta-predicates are also module-transparent, and qualifying the module-sensitive
arguments is done inside the meta-predicate. As a result, the caller need not be aware that it is calling
a meta-predicate and none of the above restrictions hold for SWI-Prolog. However, code that aims at
portability must obey the above rules.

Other differences are listed below.
• If a module does not define a predicate, it is searched for in the *import modules*. By default, the import module of any user-defined module is the *user* module. In turn, the *user* module imports from the module *system* that provides all built-in predicates. The auto-import hierarchy can be changed using `add_import_module/3` and `delete_import_module/2`.

This mechanism can be used to realise a simple object-oriented system or a hierarchical module system.

• Operator declarations are local to a module and may be exported. In Quintus and SICStus all operators are global. YAP and Ciao also use local operators. SWI-Prolog provides global operator declarations from within a module by explicitly qualifying the operator name with the *user* module. I.e., operators are inherited from the *import modules* (see above).

```prolog
:- op(precedence, type, user:(operatorname)).
```
This chapter describes SWI-Prolog’s support for *Tabled execution* for one or more Prolog predicates, also called *SLG resolution*. Tabling a predicate provides two properties:

1. Re-evaluation of a tabled predicate is avoided by *memoizing* the answers. This can realise huge performance enhancements as illustrated in section 7.1. It also comes with two downsides: the memoized answers are not automatically updated or invalidated if the world (set of predicates on which the answers depend) changes and the answer tables must be stored (in memory).

2. *Left recursion*, a goal calling a *variant* of itself recursively and thus *looping* under the normal Prolog SLD resolution is avoided by suspending the variant call and resuming it with answers from the table. This is illustrated in section 7.2.

Tabling is particularly suited to simplify inference over a highly entangled set of predicates that express axioms and rules in a static (not changing) world. When using SLD resolution for such problems, it is hard to ensure termination and avoid frequent recomputation of intermediate results. A solution is to use Datalog style bottom-up evaluation, i.e., applying rules on the axioms and derived facts until a fixed point is reached. However, bottom-up evaluation typically derives many facts that are never used. Tabling provides a *goal oriented* resolution strategy for such problems and is enabled simply by adding a *table/1* directive to the program.

### 7.1 Example 1: using tabling for memoizing

As a first classical example we use tabling for *memoizing* intermediate results. We use Fibonacci numbers to illustrate the approach. The Fibonacci number \( I \) is defined as the sum of the Fibonacci numbers for \( I - 1 \) and \( I - 2 \), while the Fibonacci number of 0 and 1 are both defined to be 1. This can be translated naturally into Prolog:

```prolog
fib(0, 1) :- !.
fib(1, 1) :- !.
fib(N, F) :-
    N > 1,
    N1 is N-1,
    N2 is N-2,
    fib(N1, F1),
    fib(N2, F2),
    F is F1+F2.
```

The complexity of executing this using SLD resolution however is \( 2^N \) and thus becomes prohibitively slow rather quickly, e.g., the execution time for \( N = 30 \) is already 0.4 seconds. Using tabling,
fib(N,F) for each value of \( N \) is computed only once and the algorithm becomes linear. Tabling effectively inverts the execution order for this case: it suspends the final addition (F is F1+F2) until the two preceding Fibonacci numbers have been added to the answer tables. Thus, we can reduce the complexity from the show-stopping \( 2^N \) to linear by adding a tabling directive and otherwise not changing the algorithm. The code becomes:

```
:- table fib/2.

fib(0, 1) :- !.
fib(1, 1) :- !.
fib(N, F) :-
    N > 1,
    N1 is N-1,
    N2 is N-2,
    fib(N1, F1),
    fib(N2, F2),
    F is F1+F2.
```

The price that we pay is that a table \( \text{fib}(I,F) \) is created for each \( I \) in 0..\( N \). The execution time for \( N = 30 \) is now 1 millisecond and computing the Fibonacci number for \( N = 1000 \) is doable (output edited for readability).

```
1 ?- time(fib(1000, X)).
% 52,991 inferences, 0.013 CPU in 0.013 seconds
X = 70330367711422815821835254877183549770181269836358
    73274260490508715453711819693357974224949456261173
    34877504492417659910881863632654502236471060120533
    74121273867339111198139373125598767690091902245245
    323403501.
```

In the case of Fibonacci numbers we can still rather easily achieve linear complexity using program transformation, where we use bottom-up instead of top-down evaluation, i.e., we compute \( \text{fib}(N,F) \) for growing \( N \), where we pass the last two Fibonacci numbers to the next iteration. Not having to create the tables and not having to suspend and resume goals makes this implementation about 25 times faster than the tabled one. However, even in this simple case the transformation is not obvious and it is far more difficult to recognise the algorithm as an implementation of Fibonacci numbers.

```
fib(0, 1) :- !.
fib(1, 1) :- !.
fib(N, F) :-
    fib(1,1,1,N,F).

fib(_F, F1, N, N, F1) :- !.
fib(F0, F1, I, N, F) :-
    F2 is F0+F1,
    I2 is I + 1,
    fib(F1, F2, I2, N, F).
```
7.2 Example 2: avoiding non-termination

SLD resolution easily results in an infinite loop due to left recursion, a goal that (indirectly) calls a variant of itself or cycles in the input data. Thus, if we have a series of connection/2 statements that define railway connections between two cities, we cannot use the most natural logical definition to express that we can travel between two cities:

```prolog
% :- table connection/2.
connection(X, Y) :-
    connection(X, Z),
    connection(Z, Y).
connection(X, Y) :-
    connection(Y, X).
connection('Amsterdam', 'Schiphol').
connection('Amsterdam', 'Haarlem').
connection('Schiphol', 'Leiden').
connection('Haarlem', 'Leiden').
```

After enabling tabling however, the above works just fine as illustrated in the session below. Where is the magic and what is the price we paid? The magic is, again, the fact that new goals to the tabled predicate suspend. So, all recursive goals are suspended. Eventually, a table for connection('Amsterdam', X) is created with the two direct connections from Amsterdam. Now, it resumes the first clause using the tabled solutions, continuing the last connection/2 subgoal with connection('Schiphol', X) and connection('Haarlem', X). These two go through the same process, creating new suspended recursive calls and creating tables for the connections from Schiphol and Haarlem. Eventually, we end up with a set of tables for each call variant that is involved in computing the transitive closure of the network starting in Amsterdam. However, if the Japanese rail network would have been in our data as well, we would not have produced tables for that.

```prolog
1 ?- connection('Amsterdam', X).
X = 'Haarlem' ;
X = 'Schiphol' ;
X = 'Amsterdam' ;
X = 'Leiden'.
```

Again, the fact that a simple table/1 directive turns the pure logical specification into a fairly efficient algorithm is a clear advantage. Without tabling the program needs to be stratified, introducing a base layer with the raw connections, a second layer that introduces the commutative property of a railway (if you can travel from A to B you can also travel from B to A) and a final layer that realises transitivity (if you can travel from A to B and from B to C you can also travel from A to C). The third and final layer must keep track which cities you have already visited to avoid traveling in circles. The transformed program however uses little memory (the list of already visited cities and the still open choices) and does not need to deal with maintaining consistency between the tables and ground facts.
7.3 Answer subsumption or mode directed tabling

Tabling as defined above has a serious limitation. Although the definition of `connection/2` from section 7.2 can compute the transitive closure of connected cities, it cannot provide you with a route to travel. The reason is that there are infinitely many routes if there are cycles in the network and each new route found will be added to the answer table and cause the tabled execution’s completion algorithm to search for more routes, eventually running out of memory.

The solution to this problem is called *mode directed tabling* or *answer subsumption*.\(^1\) In this execution model one or more arguments are *not* added to the table. Instead, we remember a single *aggregated* value for these arguments. The example below is derived from section 7.2 and returns the connection as a list of cities. This argument is defined as a *moded* argument using the `lattice(PI)` mode.\(^2\) This causes the tabling engine each time that it finds a new path to call `shortest/3` and keep the shortest route.

```
:- table
  connection(_,_,lattice(shortest/3)).

shortest(P1, P2, P):-
  length(P1, L1),
  length(P2, L2),
  ( L1 < L2 -> P = P1 ; P = P2).

connection(X, Y, [X,Y]) :-
  connection(X, Y).
connection(X, Y, P) :-
  connection(X, Z, P0),
  connection(Z, Y),
  append(P0, [Y], P).
```

The mode declaration scheme is equivalent to XSB with partial compatibility support for YAP and B-Prolog. The `lattice(PI)` mode is the most general mode. The YAP `all` (B-Prolog `@`) mode is not yet supported. The list below describes the supported modes and indicates the portability.

**Var**

* +
* index

A variable (XSB), the atom *index* (YAP) or a + (B-Prolog, YAP) declare that the argument is tabled normally.

**lattice(Pred)**

* Pred* denotes a predicate with arity 3. It may be specified as an predicate indicator (`Name/3`),

---

\(^1\)The term *answer subsumption* is used by XSB and *mode directed tabling* by YAP and B-Prolog. The idea is that some arguments are considered ‘outputs’, where multiple values for the same ‘input’ are combined. Possibly *answer aggregation* would have been a better name.

\(^2\)This mode is compatible to XSB Prolog.
plain predicate name (Name) or a head term Name(\_\_\_\_). On each answer, PI is called with three arguments: the current aggregated answer and the new answer are inputs. The last argument must be unified with a term that represents the new aggregated answer.

\(\text{po}(PI)\)

*Partial Ordering.* The new answer is added iff \(\text{call}(PI, +Old, +Answer)\) succeeds. For example, \(\text{po}('<'/2)\) accumulates the smallest result. In SWI-Prolog the arity (2) may be omitted, resulting in \(\text{po}(<)\).

- \texttt{first}

  The atom \texttt{-} (B-Prolog, YAP) and \texttt{first} (YAP) declare to keep the first answer for this argument.

- \texttt{last}

  The atom \texttt{last} (YAP) declares to keep the last answer.

- \texttt{min}

  The atom \texttt{min} (YAP) declares to keep the smallest answer according to the standard order of terms (see \(\text{~<~/2}\)). Note that in SWI-Prolog the standard order of terms orders numbers by value.

- \texttt{max}

  The atom \texttt{max} (YAP) declares to keep the largest answer according to the standard order of terms (see \(\text{~?>/2}\)). Note that in SWI-Prolog the standard order of terms orders numbers by value.

- \texttt{sum}

  The atom \texttt{sum} (YAP) declares to sum numeric answers.

### 7.4 Tabling for impure programs

Tabling guarantees logically correct results and termination provided the computation only involves terms of bounded size on *pure* Prolog programs, i.e., Prolog programs without side effects or pruning of choice points (cut, \(->/2\), etc.). Notably pruning choice points of an incomplete tabled goal may cause an incomplete table and thus cause subsequent queries for the same goal to return an incomplete set of answers. The current SWI-Prolog implementation provides several mechanisms to improve on this situation.

- **Dynamic Strongly Connected Components (SCC)**

  Tabled goals are completed as soon as possible. Each fresh tabled goal creates a scheduling component which the system attempts to solve immediately. If a subgoal of the fresh goal refers to an incomplete tabled goal the scheduling components for both goals are merged such that the related goals are completed together. Dynamic rather than static determination of strongly connected components guarantees that the components are minimal because only actually reached code needs to be considered rather than maximally reachable code.

  Minimal SCCs imply that goals are completed as early as possible. This implies that tabled goals may be embedded in e.g., \texttt{findall/3} or be used as a condition as long as there is no
dependency (loop) with goals outside the findall/3 or condition. For example, the code below misbehaves when called as \texttt{p(X)} because the argument of \texttt{findall/3} calls a variant of the goal that initiated the findall goal. A call \texttt{p(I)} however is ok as \texttt{p(I)} is not a variant of \texttt{p(X)}.

\begin{verbatim}
p(X) :-
    findall(Y, p(Y), Ys),
    ...
\end{verbatim}

- \textit{Early completion}
  Ground goals, i.e., goals without variables, are subject to early completion. This implies they are considered completed after the first solution.

### 7.5 Variant and subsumptive tabling

By default, SWI-Prolog (and other Prolog systems with tabling) create a table per call variant. A call (term) is a variant of another call (term) if there is a renaming of variables that makes the two terms equal. See \texttt{=@=/2} for details. Consider the following program:

\begin{verbatim}
:- table p/1.
p(X) :- p(Y), Y < 10000, X is Y+1.
p(1).
\end{verbatim}

Calling \texttt{p(X)} creates a table for this variant with 10,000 answers. Calling \texttt{p(42)} creates a new table where the recursive call (\texttt{p(Y)}) uses the previously created table to enumerate all values 1\ldots\texttt{10,000} before deriving \texttt{p(42)} is true. \textit{Early completion} (see section 7.4) in this case prevents enumerating all answers for \texttt{p(Y)} (1\ldots10,000). As a result, the query below runs in quadratic time and creates a 10,000 additional tables.

\begin{verbatim}
?- time(forall(between(1, 10000, X), p(X))).
% 150,370,553 inferences, 13.256 CPU in 13.256 seconds
\end{verbatim}

\textit{Subsumptive} tabling answers a query using answers from a more general table. In this case, this means it uses basically \texttt{trie_gen/2} to get the answer \texttt{p(42)} from the table \texttt{p(_)}. This leads to the program and results shown below.

\begin{verbatim}
:- table p/1 as subsumptive.
p(X) :- p(Y), Y < 10000, X is Y+1.
p(1).
\end{verbatim}

\begin{verbatim}
?- time(p(_)).
% 140,066 inferences, 0.015 CPU in 0.015 seconds
?- time(t).
% 170,005 inferences, 0.016 CPU in 0.016 seconds
\end{verbatim}
Subsumptive tabling can be activated in two ways. Per table assign the ... as subsumptive option and globally by setting the table.subsumptive flag to true.

One may wonder why subsumptive tabling is not the default. There are also some drawbacks:

- Subsumptive tabling only provides correct support if instances (more specific) queries indeed provides answers that are consistent with the more general query. This is true for pure programs, but not guaranteed for arbitrary Prolog programs.

- Finding more generic tables is more complicated and expensive than finding the call variant table and extracting the subset of answers that match the more specific query can be expensive.

- Using subsumptive tables can create more dependencies in the call graph which can slow down the table completion process. Larger dependent components also negatively impact the issues discussed in section 7.4.

7.6 Well Founded Semantics

According to Wikipedia, "Well Founded Semantics is one definition of how we can make conclusions from a set of logical rules". Well Founded Semantics (WFS) defines a three valued logic representing true, false and something that is neither true or false. This latter value is often referred to as bottom, undefined or unknown. SWI-Prolog uses undefined/0.

Well Founded Semantics allows for reasoning about programs with contradictions or multiple answer sets. It allows for obtaining true/false results for literals that do not depend on the sub program that has no unambiguous solution, propagating the notion of undefined to literals that cannot be resolved otherwise and obtaining the residual program that expresses why an answer is not unambiguous.

The notion of Well Founded Semantics is only relevant if the program uses negation as implemented by tnot/1. The argument of tnot/1, as the name implies, must be a goal associated with a tabled predicate (see table/1). In a nutshell, resolving a goal that implies tnot/1 is implemented as follows:

Consider the following partial body term:

```
...,
tnot(p),
q.
```

1. If \( p \) has an unconditional answer in its table, fail.

2. Else, delay the negation. If an unconditional answer arrives at some time, resume with failure.

3. If at the end of the traditional tabled evaluation we can still not decide on \( p \), execute the continuation (\( q \) above) while maintaining the delay list set to tnot(\( p \)). If executing the continuation results in an answer for some tabled predicate, record this answer as a conditional answer, in this case with the condition tnot(\( p \)).

4. If a conditional answer is added to a table, it is propagated to its followers, say \( f \), adding the pair \( \{ f, \text{answer} \} \) to the delay list. If this leads to an answer, the answer is conditional on this pair.
5. After the continuations of all unresolved \texttt{tnot/1} calls have been executed the various tables may have conditional answers in addition to normal answers.

6. If there are negative literals that have neither conditional answers nor unconditional answers, the condition \texttt{tnot}(g) is true. This conclusion is propagated by simplifying the conditions for all answers that depend on \texttt{tnot}(g). This may result in a definite \texttt{false} condition, in which case the answer is removed or a definite \texttt{true} condition in which case the answer is made unconditional. Both events can make other conditional answers definitely true or false, etc.

7. At the end of the simplifying process some answers may still be conditional. A final \textit{answer completion} step analyses the graph of depending nodes, eliminating \textit{positive loops}, e.g., “\texttt{p :- q. q :- p}”. The answers in such a loop are removed, possibly leading to more simplification. This process is executed until \textit{fixed point} is reached, i.e., no further positive loops exist and no further simplification is possible.

The above process may complete without any remaining conditional answers, in which case we are back in the normal Prolog world. It is also possible that some answers remain conditional. The most obvious case is represented by \texttt{undefined/0}. The toplevel responds with \texttt{undefined} instead of \texttt{true} if an answer is conditional.

\textbf{undefined}

\textit{Unknown} represents neither \texttt{true} nor \texttt{false} in the well formed model. It is implemented as

\begin{verbatim}
:- table undefined/0.

undefined :- tnot(undefined).
\end{verbatim}

Solving a set of predicates under well formed semantics results in a \textit{residual program}. This program contains clauses for all tabled predicates with condition answers where each clause head represents and answer and each clause body its condition. The condition is a disjunction of conjunctions where each literal is either a tabled goal or \texttt{tnot/1} of a tabled goal. The remaining model has at least a cycle through a negative literal (\texttt{tnot/1}) and has no single solution in the \textit{stable model semantics}, i.e., it either expresses a contradiction (as \texttt{undefined/0}, i.e., there is no stable model) or a multiple stable models as in the program below, where both \{p\} and \{q\} are stable models.

\begin{verbatim}
:- table p/0, q/0.

p :- tnot(q).
q :- tnot(p).
\end{verbatim}

Note that it is possible that some literals have the same truth value in all stable models but are still \texttt{undefined} under the stable model semantics.

The residual program is an explanation of why an answer is undefined. SWI-Prolog offers the following predicates to access the residual program.

\textbf{call\_residual\_program}(\texttt{:Goal, -Program})

True when \texttt{Goal} is an answer according to the Well Founded Semantics. If \texttt{Program} is the empty list, \texttt{Goal} is unconditionally true. Otherwise this is a program as described by \texttt{delays\_residual\_program/2}. 

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**call_delays**(Goal, -Condition)

True when Goal is an answer that is true when Condition can be satisfied. If Condition is true, Answer is unconditional. Otherwise it is a conjunction of goals, each of which is associated with a tabled predicate.

**delays_residual_program**(Condition, -Program)

Program is a list of clauses that represents the connected program associated with Condition. Each clause head represents a conditional answer from a table and each corresponding clause body is the condition that must hold for this answer to be true. The body is a disjunction of conjunctions. Each leaf in this condition is either a term tnot(Goal) or a plain Goal. Each Goal is associated with a tabled predicate. The program always contains at least one cycle that involves tnot/1.

**7.6.1 Well founded semantics and the toplevel**

The toplevel supports two modes for reporting that it is undefined whether the current answer is true. The mode is selected by the Prolog flag toplevel_list_wfs_residual_program. If true, the toplevel uses call_delays/2 and delays_residual_program/2 to find the conditional answers used and the residual program associated with these answers. It then prints the residual program, followed by the answer and the conditional answers. For undefined/0, this results in the following output:

```prolog
?- undefined.
% WFS residual program
    undefined :-
        tnot(undefined).
    undefined.
```

If the toplevel_list_wfs_residual_program is false, any undefined answer is a conjunction with undefined/0. See the program and output below.

```prolog
:- table p/0, q/0.
p :- tnot(q).
q :- tnot(p).

?- p.
% WFS residual program
    p :-
        tnot(q).
    q :-
        tnot(p).
    p.

?- set_prolog_flag(toplevel_list_wfs_residual_program, false).
true.
```
7.7 Incremental tabling

Incremental tabling maintains the consistency of a set of tabled predicates that depend on a set of dynamic predicates. Both the tabled and dynamic predicates must have the property incremental set. See dynamic/1 and table/1.

Incremental tabling causes the engine to connect the answer tries and incremental dynamic predicates in an Incremental Dependency Graph (IDG). Modifications (asserta/1, retract/1, retractall/1 and friends) of an incremental dynamic predicate mark all depending tables as invalid. Subsequent usage of these tables forces re-evaluation.

Re-evaluation of invalidated tables happens on demand, i.e., on access to an invalid table. First the dependency graph of invalid tables that lead to dynamic predicates is established. Next, tables are re-evaluated in bottom-up order. For each re-evaluated table the system determines whether the new table has changed. If the table has not changed, this event is propagated to the affected nodes of the IDG and no further re-evaluation may be needed. Consider the following program:

```prolog
:- table (p/1, q/1) as incremental.
:- dynamic([d/1], [incremental(true)]).

p(X) :- q(X).
q(X) :- d(X), X < 10.
d(1).
```

Executing this program creates tables for $X = 1$ for $p/1$ and $q/1$. After calling `assert(d(100))` the tables for $p/1$ and $q/1$ have an invalid count of 1. Re-running $p(X)$ first re-evaluates $q/1$ (bottom-up) which results to the same table as $X = 100$ does not lead to a new answer. Re-evaluation clears the invalid count for $q/1$ and, because the $q/1$ tables is not changed, decrements the invalid count of affected tables. This sets the invalid count for $p/1$ to zero, completing the re-evaluation.

Note that invalidating and re-evaluation is done at the level of tables. Notably asserting a clause invalidates all affected tables and may lead to re-evaluating of all these tables. Incremental tabling automates manual abolishing of invalid tables in a changing world and avoids unnecessary re-evaluation if indirectly affected tables prove unaffected because the answer set of dependent tables is unaffected by the change. This is the same policy as implemented in XSB [Swift, 2014]. Future versions may implement a more fine grained approach.

7.8 Monotonic tabling

Incremental tabling (section 7.7) maintains the consistency of tables that depend directly or indirectly on (incremental) dynamic predicates. This is done by invalidating dependent tables on an assert or retract and lazily re-evaluate invalid tables when their content is needed. Incremental tabling preserves
all normal tabling properties, including well founded semantics. The downside is that re-evaluation recomputes the table from scratch. This section deals with monotonic tabling, a mechanism that propagates the consequences of assert/1 and friends without recomputing the dependent tables from scratch. Unlike incremental tabling though, monotonic tabling can only deal with monotonic programs, in particular it does not deal with negation.

The example below defines the transitive closure of a bi-directional graph using monotonic tabling. This program builds tables for the connected/2 and maintains these tables when new facts are added for link/2.

```prolog
:- table connected/2 as monotonic.
:- dynamic link/2 as monotonic.
connected(X, Y) :-
  connected(Y, X).
connected(X, Z) :-
  connected(X, Y),
  connected(Y, Z).
connected(X, Y) :-
  link(X, Y).
```

abolish_monotonic_tables

Abolish all monotonic tables and their dependencies.

The list below describes properties of monotonic tabling and relation to other tabling primitives:

- When using retract/1 on a dynamic monotonic predicate, all dependent tables and dependency links are invalidated and marked for normal incremental update.

- abolish_all_tables/0 destroys all monotonic dependency relations.

- Dynamic predicates can be declared as both monotonic and incremental and it allowed to have both incremental and monotonic tabled predicates that depend on such dynamic predicates.

- A tabled predicate that depends on a monotonic tabled predicate must be tabled monotonic or incremental. If the dependent predicate is incremental a new answer invalidates the incremental table.

7.8.1 Eager and lazy monotonic tabling

There are two types of monotonic tabling. The default is eager, which implies that an asserted clause is immediately propagated through the dependency network. Possibly resulting new answers can be tracked as described in section 7.8.2. The alternative is lazy. A predicate is marked for lazy using the lazy option as shown below, or by setting the table_monotonic flag to lazy.

```prolog
:- table p/1 as (monotonic,lazy).
```
If a predicate is tabled as monotonic and lazy and an answer is added to one of the monotonic dynamic predicates, all dependent monotonic or incremental tables are invalidated and the answer is queued together with the dependency. A subsequent call to one of the invalidated tabled predicates re-evaluates the tables. For a monotonic table this implies pushing the queued answers through the dependencies. Removing a clause from one of a monotonic dynamic predicates invalidates all dependent tables and marks all these tables for forced reevaluation, which implies they are reevaluated using the same algorithm as used for incremental tabling.

Lazy monotonic tables may depend on eager monotonic tables. There is no point in making an eager monotonic table depend on a lazy monotonic table as one would have to reevaluate the lazy table to make the eager table consistent. Therefore, a dependency of an eager table on a lazy table is silently converted into a lazy dependency.

### 7.8.2 Tracking new answers to monotonic tables

The prolog\_listen/2 interface allows for tracking new facts that are added to monotonic tables. For example, we can print new possible connections from the above program using this code:

```
:- prolog\_listen(connected/2, connection\_change).
connection\_change(new\_answer, _\_\_\_:connected(From, To)) :-
    format(’\_\_p and \_\_p are now connected\n’, [From, To]).
```

Currently, failure of the hook are ignored. If the hook throws an exception this is propagated. The hook is executed outside the current tabling context.

After loading the connected/2 program and the above declarations we can observe the interaction below. Note that query 1 establishes the dependencies and fills the tables using normal tabling. In the current implementation, possibly discovered connections do not trigger the hook. Adding a single link/2 fact links both locations to itself and to each other in both directions. Adding a second fact extends the network.

1 ?- connected(_, _).
false.

2 ?- assert(link('Amsterdam', 'Haarlem')).
'Amsterdam' and 'Haarlem' are now connected
'Amsterdam' and 'Amsterdam' are now connected
'Haarlem' and 'Amsterdam' are now connected
'Haarlem' and 'Haarlem' are now connected
true.

3 ?- assert(link('Leiden', 'Haarlem')).
'Leiden' and 'Haarlem' are now connected
'Haarlem' and 'Leiden' are now connected
'Amsterdam' and 'Leiden' are now connected
'Leiden' and 'Amsterdam' are now connected

\[3\] The final behavior may be different in both aspects.

\[4\] This is likely to change in the future.
7.8. MONOTONIC TABLING

’Haarlem’ and ’Leiden’ are now connected
’Leiden’ and ’Haarlem’ are now connected
’Leiden’ and ’Amsterdam’ are now connected
’Amsterdam’ and ’Leiden’ are now connected
’Leiden’ and ’Leiden’ are now connected
true.

7.8.3 Monotonic tabling with external data

Monotonic tables depend on monotonic dynamic predicates. In some situations there is external dynamic data such as a database. One solution is to maintain a shadow copy of all the external data in a dynamic predicate. This wastes resources and introduces maintenance problems. The system allows to use this information directly from the external source. To do this, create a dynamic and monotonic predicate that accesses the data:

```prolog
:- dynamic my_data/2 as monotonic.
my_data(X, Y) :-
    <access external data>.
```

Any monotonic table that depends on `my_data/2` will be populated correctly and build a dependency. Next, if a new answer is added to the external data the user must call `incr_propagate_calls/1` from the Prolog library `increval`. Similarly, when an answer is removed from the external data we use `incr.invalidate_calls/1`. Both notification calls must be made after the external data has been updated, i.e., `my_data/2` must reflect the new situation before calling `incr.propagate_calls/1` or `incr.invalidate_calls/1`.

```prolog
:- use_module(library(increval)).

on_new_my_data(X, Y) :-
    incr_propagate_calls(my_data(X, Y)).

on_removed_my_data(X, Y) :-
    incr.invalidate_calls(my_data(X, Y)).
```

`incr.propagate_calls(:Answer)`

Activate the monotonic answer propagation similarly to when a new fact is asserted for a monotonic dynamic predicate. The `Answer` term must match a monotonic dynamic predicate. See section 7.8.3 for an example.

**Status** Monotonic tabling is experimental and incomplete. Notably support for `answer subsumption` and `call subsumption` is probably possible and may greatly improve the application domain and resource usage. Monotonic tabling should work with both shared and private tables. Concurrency issues have not yet been tested though.
### 7.9 Shared tabling

Tables can both be *private* to a thread or *shared* between all threads. Private tables are used only by the calling threads and are discarded as the thread terminates. Shared tables are used by all threads and can only be discarded explicitly. Tables are declared as shared using, e.g.,

```prolog
:- table (p/1, q/2) as shared.
```

A thread may find a table for a particular variant of a shared tabled predicate in any of the following states:

**Complete** If the table is complete we can simply use its answers.

**Fresh/non-existent** If the table is still fresh, claim ownership for it and start filling the table. When completed, the ownership relation is terminated.

**Incomplete** If the table is incomplete and owned by the calling thread, simply continue. If it is owned by another thread we wait for the table unless there is a cycle of threads waiting for each other's table. The latter situation would cause a deadlock and therefore we raise a deadlock exception. This exception causes the current SCC to be abandoned and gives other threads the opportunity to claim ownership of the tables that were owned by this thread. The thread that raised the exception and abandoned the SCC simply restarts the leader goal of the SCC. As other threads now have claimed more variants of the SCC it will, in most cases, wait for these threads instead of creating a new deadlock.

A thread that waits for a table may be faced with three results. If the table is complete it can use the answers. It is also possible that the thread that was filling the table raised an exception (either a deadlock or any other exception), in which case we find a fresh table for which we will try to claim ownership. Finally, some thread may have abolished the table. This situation is the same as when the owning thread raised an exception.

### 7.9.1 Abolishing shared tables

This section briefly explains the interaction between deleting shared tables and running threads. The core rule is that *abolishing a shared table has no effect on the semantics of the tabled predicates*. An attempt to abolish an incomplete table results in the table to be marked for destruction on completion. The thread that is completing the table continues to do so and continues execution with the computed table answers. Any other thread blocks, waiting for the table to complete. Once completed, the table is destroyed and the waiting threads see a fresh table.

The current implementation never reclaims shared tables. Instead, they remain part of the global variant table and only the answers of the shared table are reclaimed. Future versions may garbage collect such tables. See also `abolish_shared_tables/0`.

---

5Future versions may avoid waiting by converting the abolished shared table to a private table.
7.9.2 Status and future of shared tabling

Currently, shared tabling has many restrictions. The implementation does not verify that the limitations are met and violating these restrictions may cause incorrect results or crashes. Future versions are expected to resolve these issues.

- Shared tabling currently only handles the basic scenario and cannot yet deal with well formed semantics or incremental tabling.
- As described in section 7.9.1, abolishing shared tables may cause unnecessary waiting for threads to complete the table.
- Only the answers of shared tables can be reclaimed, not the answer table itself.

SWI-Prolog’s *continuation based* tabling offers the opportunity to perform completion using multiple threads.

7.10 Tabling restraints: bounded rationality and tripwires

Tabling avoids non-termination due to *self-recursion*. As Prolog allows for infinitely nested *compound terms* (*function symbols* in logic) and arbitrary numbers, the set of possible answers is not finite and thus there is no guaranteed termination.

This section describes *restraints* [Grosof & Swift, 2013] that can be enforced to specific or all tabled predicates. Currently there are three defined restraints, limiting (1) the size of (the arguments to) goals, (2) the size of the answer substitution added to a table and (3) the number of answers allowed in any table. If any of these events occurs we can specify the action taken. We distinguish two classes of actions. First, these events can trap a *tripwire* which can be handled using a hook or a predefined action such as raising an exception, printing a warning or enter a *break level*. This can be used for limiting resources, be notified of suspicious events (debugging) or dynamically adjust the (tabling) strategy of the program. Second, they may continue the computation that results in a partial answer (*bounded rationality*). Unlike just not exploring part of the space though, we use the third truth value of well founded semantics to keep track of answers that have not been affected by the restraints and those that have been affected.

The tripwire actions apply for all restraints. If a tripwire action is triggered, the system takes the steps below.

1. Call the `prolog:tripwire/2` hook.

2. If `prolog:tripwire/2` fails, take one of the predefined actions:

   - **warning**
     Print a message indicating the trapped tripwire and continue execution as normal, i.e., the final answer is the same as if no restraint was active.

   - **error**
     Throw an exception `error(resource_error(tripwire(Wire,Context)))`.

   - **suspend**
     Print a message and start a *break level* (see `break/0`).
prolog:tripwire(Wire, Context)  [multifile]
Called when tripwire Wire is trapped. Context provides additional context for interpreting the
tripwire. The hook can take one of three actions:

- Succeed. In this case the tripwire is considered handled and execution proceeds as if there
  was no tripwire. Note that tripwires only trigger at the exact value, which implies that
  a wire on a count will be triggered only once. The hook can install a new tripwire at a
  higher count.
- Fail. In this case the default action is taken.
- Throw an exception. Exceptions are propagated normally.

Radial restraints limit the sizes of subgoals or answers. Abstraction of a term according to the
size limit is implemented by size_abstract_term/3.

size_abstract_term(+Size, +Term, -Abstract)  [det]
The size of a term is defined as the number of compound subterms (function symbols) that
appear in term. Abstract is an abstract copy of Term where each argument is abstracted by
copying only the first Size function symbols and constants. Excess function symbols are
replaced by fresh variables.

This predicate is a helper for tabling where Term is the ret/N answer skeleton that is added to
the answer table. Examples:

<table>
<thead>
<tr>
<th>Size</th>
<th>Term</th>
<th>Abstract</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>ret(f(x), a)</td>
<td>ret(_, a)</td>
</tr>
<tr>
<td>1</td>
<td>ret(f(x), a)</td>
<td>ret(f(x), a)</td>
</tr>
<tr>
<td>1</td>
<td>ret(f(A), a)</td>
<td>ret(f(A), a)</td>
</tr>
<tr>
<td>1</td>
<td>ret(f(x), x(y(Z)))</td>
<td>ret(f(x), x(_))</td>
</tr>
</tbody>
</table>

radial_restraint  [undefined]
This predicate is undefined in the sense of well founded semantics (see section 7.6 and
undefined/0). Any answer that depends on this condition is undefined because either the
restraint on the subgoal size or answer size was violated.

7.10.1 Restriction subgoal size
Using the subgoal_abstract(Size) attribute, a tabled subgoal that is too large is abstracted
by replacing compound subterms of the goal with variables. In a nutshell, a goal p(s(s(s(s(0)))))) is
converted into the semantically equivalent subgoal if the subgoal size is limited to 3.

...,
p(s(s(s(X)))), X = s(s(0)),
...,

As a result of this, terms stored in the variant trie that maps goal variants into answer tables is limited.
Note that does not limit the number of answer tables as atomic values are never abstracted and there
are, for example, an infinite number of integers. Note that restraining the subgoal size does not affect
the semantics, provided more general queries on the predicate include all answers that more specific queries do. See also call substitution as described in section 7.5. In addition to the tripwire actions, the max_table_subgoal_size_action can be set to the value abstract:

abstract
Abstract the goal as described above and provide correctness by adding the required unification instructions after the goal.

7.10.2 Restraint answer size

Using the answer_abstract(Size) attribute, a tabled subgoal that produces answer substitutions (instances of the variables in the goal) whose size exceed Size are trapped. In addition to the tripwire actions, answer abstraction defines two additional modes for dealing with too large answers as defines by the Prolog flag max_table_answer_size_action:

fail
Ignore the too large answer. Note that this is semantically incorrect.

bounded_rationality
In this mode, the large answer is abstracted in the same way as subgoals are abstracted (see section 7.10.1). This is semantically incorrect, but our third truth value undefined is used to remedy this problem. In other words, the abstracted value is added to the table as undefined and all conclusions that depend on usage of this abstracted value are thus undefined unless they can also be proved some other way.

7.10.3 Restraint answer count

Finally, using “as max_answers(Count)” or the Prolog flag max_answers_for_subgoal, the number of answers in a table is restrained. In addition to the tripwire actions this restraint supports the action bounded_rationality. If the restraint is reached in the bounded rationality mode the system takes the following actions:

- Ignore the answer that triggered the restraint.
- Prune the choice points of the tabled goal to avoid more answers.
- Add an new answer to the table that does not bind any variables, i.e., an empty answer substitution. This answer is conditional on answer_count_restraint/0.

answer_count_restraint [undefined]
This predicate is undefined in the sense of well founded semantics (see section 7.6 and undefined/0). Any answer that depends on this condition is undefined because the max_answers restraint on some table was violated.

The program and subsequent query below illustrate the behavior.

\[6\]The action complete_soundly is supported as a synonym for XSB compatibility
7.11 Tabling predicate reference

`:table(:Specification)`

Prepare the predicates specified by `Specification` for tabled execution. `Specification` is a `comma-list`, each member specifying tabled execution for a specific predicate. The individual specification is either a `predicate indicator` (name/arity or name/arity) or head specifying tabling with `answer subsumption`.

Although `table/1` is normally used as a directive, SWI-Prolog allows calling it as a runtime predicate to prepare an existing predicate for tabled execution. The predicate `htable/1` can be used to remove the tabling instrumentation from a predicate.

The example below prepares the predicate `edge/2` and the non-terminal `statement//1` for tabled execution.

`:table edge/2, statement//1.`

Below is an example declaring a predicate to use tabling with `answer subsumption`. Answer subsumption or `mode directed tabling` is discussed in section 7.3.

`:table connection(_,_,min).`

Additional tabling options can be provided using a term `as/2`, which can be applied to a single specification or a comma list of specifications. The options themselves are a comma-list of one or more of the following atoms:

`variant`

Default. Create a table for each call variant.
subsumptive
Instead of creating a new table for each call variant, check whether there is a completed table for a more general goal and if this is the case extract the answers from this table. See section 7.5.

shared
Declare that the table shall be shared between threads. See section 7.9

private
Declare that the table shall be local to the calling thread. See section 7.9

incremental
Declare that the table depends on other tables and incremental dynamic predicates. See section 7.7.

dynamic
Declare that the predicate is dynamic. Often used together with incremental.

This syntax is closely related to the table declarations used in XSB Prolog. Where in XSB as is an operator with priority above the priority of the comma, it is an operator with priority below the comma in SWI-Prolog. Therefore, multiple predicates or options must be enclosed in parenthesis. For example:

```
:- table p/1 as subsumptive.
:- table (q/1, r/2) as subsumptive.
```

**tnot(:Goal)**
The tnot/1 predicate implements tabled negation. This predicate realises Well Founded Semantics. See section 7.6 for details.

**not_exists(:Goal)**
Handles tabled negation for non-ground (floundering) Goal as well as non tabled goals. If Goal is ground and tabled not exists/1 calls tnot/1. Otherwise it used tabled_call(Goal) to create a table and subsequently uses tnot/1 on the created table.

Logically, not_exists(p(X)) is defined as tnot(∃X(p(X)))

Note that each Goal variant populates a table for tabled_call/1. Applications may need to abolish such tables to limit memory usage or guarantee consistency ‘after the world changed’.

**tabled_call(:Goal)**
Helper predicate for not_exists/1. Defined as below. The helper is public because application may need to abolish its tables.

```
:- table tabled_call/1 as variant.
tabled_call(Goal) :- call(Goal).
```

**current_table(:Variant, -Trie)**
True when Trie is the answer table for Variant.
**utable**: (*Specification*)
Remove the tables and tabling instrumentation for the specified predicates. *Specification* is compatible with `table/1`, although tabling with *answer subsumption* may be removed using a name/arity specification. The `utable/1` predicate is first of all intended for examining the effect of various tabling scenarios on a particular program interactively from the toplevel.

Note that although using `utable/1` followed by `table/1` may be used to flush all tables associated with the given predicate(s), flushing tables should be done using one of the table abolish predicates both for better performance and compatibility with other Prolog implementations: `abolish_all_tables/0`, `abolish_private_tables/0`, `abolish_shared_tables/0`, `abolish_module_tables/1` or `abolish_table_subgoals/1`. For example, to remove all tables for `p/3`, run the goal below. The predicate `functor/3` may be used to create a *head term* from a given name and arity.

```
?- abolish_table_subgoals(p(_,_,_)).
```

**abolish_all_tables**
Remove all tables, both *private* and *shared* (see section 7.9). Since the introduction of *incremental tabling* (see section 7.7) abolishing tables is rarely required to maintain consistency of the tables with a changed environment. Tables may be abolished regardless of the current state of the table. *Incomplete* tables are flagged for destruction when they are completed. See section 7.9.1 for the semantics of destroying shared tables and the following predicates for destroying a subset of the tables: `abolish_private_tables/0`, `abolish_shared_tables/0`, `abolish_table_subgoals/1` and `abolish_module_tables/1`.

**abolish_private_tables**
Abolish all tables that are private to this thread.

**abolish_shared_tables**
Abolish all tables that are shared between threads. See also section 7.9.1

**abolish_table_subgoals**: (*Subgoal*)
Abolish all tables that unify with *SubGoal*. Tables that have undefined answers that depend of the abolished table are abolished as well (recursively). For example, given the program below, `abolish_table_subgoals(und)` will also abolish the table for `p/0` because its answer refers to `und/0`.

```
p :- und.
und :- tnot(und).
```

**abolish_module_tables**: (+*Module*)
Remove all tables that belong to predicates in *Module*.

**abolish_nonincremental_tables**

**abolish_nonincremental_tables**: (+*Options*)
Similar to `abolish_all_tables/0`, but does not abolish *incremental* tables as their consistency is maintained by the system. Options:
7.12 About the tabling implementation

The SWI-Prolog implementation uses Delimited continuations (see section 4.9 to realise suspension of variant calls. The initial version was written by Benoit Desouter and described in [Desouter et al., 2015]. We moved the main data structures required for tabling, the answer tables (see section 4.14.4) and the worklist to SWI-Prolog’s C core. Mode directed tabling (section 7.3) is based on a prototype implementation by Fabrizio Riguzzi.

The implementation of dynamic SCCs, dynamically stratified negation and Well Founded Semantics was initiated by Benjamin Grosof from Kyndi and was realised with a lot of help by Theresa Swift, David Warren and Fabrizio Riguzzi, as well as publications about XSB [Sagonas & Swift, 1998, Sagonas et al., 2000].

The table/1 directive causes the creation of a wrapper calling the renamed original predicate. For example, the program in section 7.2 is translated into the following program. We give this information to improve your understanding of the current tabling implementation. Future versions are likely to use a more low-level translation that is not based on wrappers.

```prolog
connection(A, B) :-
    start_tabling(user:connection(A, B),
        'connection tabled'(A, B)).

'connection tabled'(X, Y) :-
    connection(X, Z),
    connection(Z, Y).

'connection tabled'(X, Y) :-
    connection(Y, X).

'connection tabled'('Amsterdam', 'Schiphol').
'connection tabled'('Amsterdam', 'Haarlem').
'connection tabled'('Schiphol', 'Leiden').
'connection tabled'('Haarlem', 'Leiden').
```

Status of tabling

The current implementation is merely a first prototype. It needs several enhancements before we can consider it a serious competitor to Prolog systems with mature tabling such as XSB, YAP and B-Prolog. In particular,

- The performance needs to be improved.
- Memory usage needs to be reduced.
- Tables must be shared between threads, both to reduce space and avoid recomputation.

\[\text{BUG: XSB marks such tables for deletion after completion. That is not yet implemented.}\]
• Tables must be invalidated and reclaimed automatically.
• Notably XSB supports incremental tabling and well-founded semantics under negation.
This chapter describes the extensions primarily designed to support constraint logic programming (CLP), an important declarative programming paradigm with countless practical applications.

CLP(\(X\)) stands for constraint logic programming over the domain \(X\). Plain Prolog can be regarded as CLP(\(H\)), where \(H\) stands for Herbrand terms. Over this domain, =/2 and dif/2 are the most important constraints that express, respectively, equality and disequality of terms. Plain Prolog can thus be regarded as a special case of CLP.

There are dedicated constraint solvers for several important domains:

- CLP(FD) for integers (section A.9)
- CLP(B) for Boolean variables (section A.8)
- CLP(Q) for rational numbers (section A.10)
- CLP(R) for floating point numbers (section A.10).

In addition, CHR (chapter 9) provides a general purpose constraint handling language to reason over user-defined constraints.

Constraints blend in naturally into Prolog programs, and behave exactly like plain Prolog predicates in those cases that can also be expressed without constraints. However, there are two key differences between constraints and plain Prolog predicates:

- Constraints can delay checks until their truth can be safely decided. This feature can significantly increase the generality of your programs, and preserves their relational nature.

- Constraints can take into account everything you state about the entities you reason about, independent of the order in which you state it, both before and also during any search for concrete solutions. Using available information to prune parts of the search space is called constraint propagation, and it is performed automatically by the available constraint solvers for their respective domains. This feature can significantly increase the performance of your programs.

Due to these two key advantages over plain Prolog, CLP has become an extremely important declarative programming paradigm in practice.

Among its most important and typical instances is CLP(FD), constraint logic programming over integers. For example, using constraints, you can state in the most general way that a variable \(X\) is an integer greater than 0. If, later, \(X\) is bound to a concrete integer, the constraint solver automatically ensures this. If you in addition constrain \(X\) to integers less than 3, the constraint solver combines the existing knowledge to infer that \(X\) is either 1 or 2 (see below). To obtain concrete values for \(X\), you can ask the solver to label \(X\) and produce 1 and 2 on backtracking. See section A.9.
Contrast this with plain Prolog, which has no efficient means to deal with (integer) \( X > 0 \) and \( X < 3 \). At best it could translate \( X > 0 \) to \texttt{between(1, infinite, X)} and a similar primitive for \( X < 3 \). If the two are combined it has no choice but to generate and test over this infinite two-dimensional space.

Using constraints therefore makes your program more \textit{declarative} in that it frees you from some procedural aspects and limitations of Prolog.

When working with constraints, keep in mind the following:

- As with plain Prolog, \texttt{!} also destroys the declarative semantics of constraints. A cut after a goal that is delayed may prematurely prune the search space, because the truth of delayed goals is not yet established. There are several ways to avoid cuts in constraint logic programs, retaining both generality and determinism of your programs. See for example \texttt{zcompare/3}.

- Term-copying operations (\texttt{assertz/1}, \texttt{retract/1}, \texttt{findall/3}, \texttt{copy_term/2}, etc.) generally also copy constraints. The effect varies from ok, silent copying of huge constraint networks to violations of the internal consistency of constraint networks. As a rule of thumb, copying terms holding attributes must be deprecated. If you need to reason about a term that is involved in constraints, use \texttt{copy_term/3} to obtain the constraints as Prolog goals, and use these goals for further processing.

All of the mentioned constraint solvers are implemented using the attributed variables interface described in section 8.1. These are lower-level predicates that are mainly intended for library authors, not for typical Prolog programmers.

8.1 Attributed variables

\textit{Attributed variables} provide a technique for extending the Prolog unification algorithm [Holzbaur, 1992] by hooking the binding of attributed variables. There is no consensus in the Prolog community on the exact definition and interface to attributed variables. The SWI-Prolog interface is identical to the one realised by Bart Demoen for hProlog [Demen, 2002]. This interface is simple and available on all Prolog systems that can run the Leuven CHR system (see chapter 9 and the Leuven CHR page).

Binding an attributed variable schedules a goal to be executed at the first possible opportunity. In the current implementation the hooks are executed immediately after a successful unification of the clause-head or successful completion of a foreign language (built-in) predicate. Each attribute is associated to a module, and the hook \texttt{attr_unify_hook/2} is executed in this module. The example below realises a very simple and incomplete finite domain reasoner:
8.1. ATTRIBUTED VARIABLES

```prolog
:- module(domain,
           [
             domain/2 % Var, ?Domain
           ]).
:- use_module(library(ordsets)).
domain(X, Dom) :-
  var(Dom), !,
  get_attr(X, domain, Dom).
domain(X, List) :-
  list_to_ord_set(List, Domain),
  put_attr(Y, domain, Domain),
  X = Y.

% An attributed variable with attribute value Domain has been
% assigned the value Y
attr_unify_hook(Domain, Y) :-
  ( get_attr(Y, domain, Dom2)
    -> ord_intersection(Domain, Dom2, NewDomain),
       NewDomain == []
    -> fail
    ; NewDomain = [Value]
    -> Y = Value
    ; put_attr(Y, domain, NewDomain)
  )
  ; var(Y)
  -> put_attr( Y, domain, Domain )
  ; ord_memberchk(Y, Domain)
).

% Translate attributes from this module to residual goals
attribute_goals(X) -->
  { get_attr(X, domain, List) },
  [domain(X, List)].
```

Before explaining the code we give some example queries:

?- domain(X, [a,b]), X = c fail
?- domain(X, [a,b]), domain(X, [a,c]). X = a
?- domain(X, [a,b,c]), domain(X, [a,c]). domain(X, [a,c])

The predicate `domain/2` fetches (first clause) or assigns (second clause) the variable a domain, a set of values the variable can be unified with. In the second clause, `domain/2` first associates the domain with a fresh variable (Y) and then unifies X to this variable to deal with the possibility that X already has a domain. The predicate `attr_unify_hook/2` (see below) is a hook called after a
variable with a domain is assigned a value. In the simple case where the variable is bound to a concrete value, we simply check whether this value is in the domain. Otherwise we take the intersection of the domains and either fail if the intersection is empty (first example), assign the value if there is only one value in the intersection (second example), or assign the intersection as the new domain of the variable (third example). The nonterminal attribute_goals/1 is used to translate remaining attributes to user-readable goals that, when called, reinstate these attributes or attributes that correspond to equivalent constraints.

Implementing constraint solvers (chapter 8) is the most common, but not the only use case for attributed variables: If you implement algorithms that require efficient destructive modifications, then using attributed variables is often a more convenient and somewhat more declarative alternative for \texttt{setarg/3} and related predicates whose sharing semantics are harder to understand. In particular, attributed variables make it easy to express graph networks and graph-oriented algorithms, since each variable can store pointers to further variables in its attributes. In such cases, the use of attributed variables should be confined within a module that exposes its functionality via more declarative interface predicates.

### 8.1.1 Attribute manipulation predicates

**attvar(@Term)**

Succeeds if Term is an attributed variable. Note that \texttt{var/1} also succeeds on attributed variables. Attributed variables are created with \texttt{put_attr/3}.

**put_attr(+Var, +Module, +Value)**

If Var is a variable or attributed variable, set the value for the attribute named Module to Value. If an attribute with this name is already associated with Var, the old value is replaced. Backtracking will restore the old value (i.e., an attribute is a mutable term; see also \texttt{setarg/3}). This predicate raises an uninstantiation error if Var is not a variable, and a type error if Module is not an atom.

**get_attr(+Var, +Module, -Value)**

Request the current value for the attribute named Module. If Var is not an attributed variable or the named attribute is not associated to Var this predicate fails silently. If Module is not an atom, a type error is raised.

**del_attr(+Var, +Module)**

Delete the named attribute. If Var loses its last attribute it is transformed back into a traditional Prolog variable. If Module is not an atom, a type error is raised. In all other cases this predicate succeeds regardless of whether or not the named attribute is present.

### 8.1.2 Attributed variable hooks

Attribute names are linked to modules. This means that certain operations on attributed variables cause hooks to be called in the module whose name matches the attribute name.

**attr_unify_hook(+AttValue, +VarValue)**

A hook that must be defined in the module to which an attributed variable refers. It is called after the attributed variable has been unified with a non-var term, possibly another attributed variable. AttValue is the attribute that was associated to the variable in this module and VarValue
is the new value of the variable. If this predicate fails, the unification fails. If \textit{VarValue} is another attributed variable the hook often combines the two attributes and associates the combined attribute with \textit{VarValue} using \texttt{put_attr/3}.

\textbf{To be done} The way in which this hook currently works makes the implementation of important classes of constraint solvers impossible or at least extremely impractical. For increased generality and convenience, simultaneous unifications as in \([X, Y]=[0, 1]\) should be processed sequentially by the Prolog engine, or a more general hook should be provided in the future. See \cite{Triska2016} for more information.

\texttt{attribute\_goals(+Var) //}

This nonterminal is the main mechanism in which residual constraints are obtained. It is called in every module where it is defined, and \textit{Var} has an attribute. Its argument is that variable. In each module, \texttt{attribute\_goals/1} must describe a list of Prolog goals that are declaratively equivalent to the goals that caused the attributes of that module to be present and in their current state. It is always possible to do this (since these attributes stem from such goals), and it is the responsibility of constraint library authors to provide this mapping without exposing any library internals. Ideally and typically, remaining relevant attributes are mapped to pure and potentially simplified Prolog goals that satisfy both of the following:

- They are declaratively equivalent to the constraints that were originally posted.
- They use only predicates that are themselves exported and documented in the modules they stem from.

The latter property ensures that users can reason about residual goals, and see for themselves whether a constraint library behaves correctly. It is this property that makes it possible to thoroughly test constraint solvers by contrasting obtained residual goals with expected answers.

This nonterminal is used by \texttt{copy\_term/3}, on which the Prolog top level relies to ensure the basic invariant of pure Prolog programs: The answer is \textit{declaratively equivalent} to the query.

The \texttt{copy\_term/3} primitive uses \texttt{attribute\_goals/1} inside a \texttt{findall/3} call. This implies that \texttt{attribute\_goals/1} can unify variables and modify attributes, for example, to tell other hooks that some attribute has already been taken care of. This nonterminal is also used by \texttt{frozen/2} which does \textit{not} create a copy. Ideally \texttt{attribute\_goals/1} should not modify anything to allow direct application in \texttt{frozen/2}. In the current implementation \texttt{frozen/2} backtracks over \texttt{attribute\_goals/1} to tolerate the current behavior. This work-around harms the performance of \texttt{frozen/2}. New implementations of \texttt{attribute\_goals/1} should avoid relying on backtracking when feasible. Future versions of \texttt{frozen/2} and \texttt{copy\_term/3} may require \texttt{attribute\_goals/1} not to modify any variables or attributes.

Note that instead of \textit{defaulty} representations, a Prolog \textit{list} is used to represent residual goals. This simplifies processing and reasoning about residual goals throughout all programs that need this functionality.

\texttt{project\_attributes(+QueryVars, +ResidualVars)}

A hook that can be defined in each module to project constraints on newly introduced variables back to the query variables. \textit{QueryVars} is the list of variables occurring in the query and \textit{ResidualVars} is a list of variables that have attributes attached. There may be variables that occur in both lists. If possible, \texttt{project\_attributes/2} should change the attributes so
that all constraints are expressed as residual goals that refer only to QueryVars, while other variables are existentially quantified.

\[\text{attr_portray_hook}(\text{+AttValue, +Var})\]  
Called by \text{write_term/2} and friends for each attribute if the option \text{attributes(portray)} is in effect. If the hook succeeds the attribute is considered printed. Otherwise \text{Module = ...} is printed to indicate the existence of a variable. This predicate is deprecated because it cannot work with pure interface predicates like \text{copy_term/3}. Use \text{attribute_goals/1} instead to map attributes to residual goals.

8.1.3 Operations on terms with attributed variables

\text{copy_term(+Term, -Copy, -Gs)} 
Create a regular term \text{Copy} as a copy of \text{Term} (without any attributes), and a list \text{Gs} of goals that represents the attributes. The goal \text{maplist(call, Gs)} recreates the attributes for \text{Copy}. The nonterminal attribute_goals/1, as defined in the modules the attributes stem from, is used to convert attributes to lists of goals.

This building block is used by the top level to report pending attributes in a portable and understandable fashion. This predicate is the preferred way to reason about and communicate terms with constraints.

The form \text{copy_term(Term, Term, Gs)} can be used to reason about the constraints in which \text{Term} is involved.

\text{copy_term_nat(+Term, -Copy)} 
As \text{copy_term/2}. Attributes, however, are not copied but replaced by fresh variables.

\text{term_attvars(+Term, -AttVars)} 
\text{AttVars} is a list of all attributed variables in \text{Term} and its attributes. That is, \text{term_attvars/2} works recursively through attributes. This predicate is cycle-safe. The goal \text{term_attvars(Term, [])} in an efficient test that \text{Term} has no attributes; scanning the term is aborted after the first attributed variable is found.

8.1.4 Special purpose predicates for attributes

Normal user code should deal with \text{put_attr/3}, \text{get_attr/3} and \text{del_attr/2}. The routines in this section fetch or set the entire attribute list of a variable. Use of these predicates is anticipated to be restricted to printing and other special purpose operations.

\text{getAttrs(+Var, -Attributes)} 
Get all attributes of \text{Var}. \text{Attributes} is a term of the form \text{att(Module, Value, MoreAttributes)}, where \text{MoreAttributes} is \text{[]} for the last attribute.

\text{putAttrs(+Var, -Attributes)} 
Set all attributes of \text{Var}. See \text{getAttrs/2} for a description of \text{Attributes}.

\text{delAttrs(+Var)} 
If \text{Var} is an attributed variable, delete all its attributes. In all other cases, this predicate succeeds without side-effects.
8.2 Coroutining

Coroutining allows us to delay the execution of Prolog goals until their truth can be safely decided.

Among the most important coroutining predicates is \texttt{dif/2}, which expresses disequality of terms in a sound way. The actual test is delayed until the terms are sufficiently different, or have become identical. For example:

\begin{verbatim}
?- dif(X, Y), X = a, Y = b.
X = a,
Y = b.
?- dif(X, Y), X = a, Y = a.
false.
\end{verbatim}

There are also lower-level coroutining predicates that are intended as building blocks for higher-level constraints. For example, we can use \texttt{freeze/2} to define a variable that can only be assigned an atom:

\begin{verbatim}
?- freeze(X, atom(X)), X = a.
X = a.
\end{verbatim}

In this case, calling \texttt{atom/1} earlier causes the whole query to fail:

\begin{verbatim}
?- atom(X), X = a.
false.
\end{verbatim}

If available, domain-specific constraints should be used in such cases. For example, to state that a variable can only assume even integers, use the CLP(FD) constraint \texttt{=/2}:

\begin{verbatim}
?- X mod 2 =/= 0.
X mod 2#=0.
\end{verbatim}

Importantly, domain-specific constraints can apply stronger propagation by exploiting logical properties of their respective domains. For example:

\begin{verbatim}
?- X mod 2 =/= 0, X in 1..3.
X = 2.
\end{verbatim}

Remaining constraints, such as \texttt{X mod 2#0} in the example above, are called residual goals. They are said to flounder, because their truth is not yet decided. Declaratively, the query is only true if all residual goals are satisfiable. Use \texttt{call_residue_vars/2} to collect all variables that are involved in constraints.

\texttt{dif(@A, @B)}

The \texttt{dif/2} predicate is a constraint that is true if and only if \texttt{A} and \texttt{B} are different terms. If \texttt{A} and \texttt{B} can never unify, \texttt{dif/2} succeeds deterministically. If \texttt{A} and \texttt{B} are identical, it fails
immediately. Finally, if $A$ and $B$ can unify, goals are delayed that prevent $A$ and $B$ to become equal. It is this last property that makes $\text{dif}/2$ a more general and more declarative alternative for $\neq/2$ and related predicates.

This predicate behaves as if defined by $\text{dif}(X, Y) :- \text{when}(\neq(X, Y), X \neq Y)$. See also $\neq/2$. The implementation can deal with cyclic terms.

The $\text{dif}/2$ predicate is realised using attributed variables associated with the module $\text{dif}$. It is an autoloaded predicate that is defined in the library $\text{dif}$.

**freeze(+Var, :Goal)**

Delay the execution of $\text{Goal}$ until $\text{Var}$ is bound (i.e., is not a variable or attributed variable). If $\text{Var}$ is bound on entry, $\text{freeze}/2$ is equivalent to $\text{call}/1$. The $\text{freeze}/2$ predicate is realised using an attributed variable associated with the module $\text{freeze}$. See also $\text{frozen}/2$.

**frozen(@Term, -Goal)** [det]

Unify $\text{Goal}$ with the goal or conjunction of goals delayed on some attributed variable in $\text{Term}$. If $\text{Term}$ is free of attributed variables, $\text{Goal}$ is unified to $\text{true}$. Note that $\text{frozen}/2$ reports all delayed goals, not only those delayed due to $\text{freeze}/2$. The goals are extracted using $\text{copy_term}/3$.

See also $\text{term_attvars}/2$ and $\text{call_residue_vars}/2$.

**when(@Condition, :Goal)**

Execute $\text{Goal}$ when $\text{Condition}$ becomes true. $\text{Condition}$ is one of $\neq(X, Y)$, $\text{nonvar}(X)$, $\text{ground}(X)$, $(\text{Cond1}, \text{Cond2})$ or $(\text{Cond1}, \text{Cond2})$. See also $\text{freeze}/2$ and $\text{dif}/2$. The implementation can deal with cyclic terms in $X$ and $Y$.

The $\text{when}/2$ predicate is realised using attributed variables associated with the module $\text{when}$. It is defined in the autoload library $\text{when}$.

**call_residue_vars(-Goal, -Vars)**

Find residual attributed variables left by $\text{Goal}$. This predicate is intended for reasoning about and debugging programs that use coroutining or constraints. To see why this predicate is necessary, consider a predicate that poses contradicting constraints on a variable, and where that variable does not appear in any argument of the predicate and hence does not yield any residual goals on the toplevel when the predicate is invoked. Such programs should fail, but sometimes succeed because the constraint solver is too weak to detect the contradiction. Ideally, delayed goals and constraints are all executed at the end of the computation. The meta predicate $\text{call_residue_vars}/2$ finds variables that are given attributes or whose attributes are modified by $\text{Goal}$, regardless of whether or not these variables are reachable from the arguments of $\text{Goal}$.

---

1 Versions prior to 8.3.7 only report goals delayed using $\text{freeze}/2$ on a plain variable. The new behaviour is compatible with SICStus.

2 The implementation of $\text{call_residue_vars}/2$ is completely redone in version 7.3.2 (7.2.1) after discussion with Bart Demoen. The current implementation no longer performs full scans of the stacks. The overhead is proportional to the number of attributed variables on the stack, dead or alive.
This chapter is written by Tom Schrijvers, K.U. Leuven, and adjustments by Jan Wielemaker.

The CHR system of SWI-Prolog is the *K.U.Leuven CHR system*. The runtime environment is written by Christian Holzbaur and Tom Schrijvers while the compiler is written by Tom Schrijvers. Both are integrated with SWI-Prolog and licensed under compatible conditions with permission from the authors.

The main reference for the K.U.Leuven CHR system is:


### 9.1 Introduction to CHR

Constraint Handling Rules (CHR) is a committed-choice rule-based language embedded in Prolog. It is designed for writing constraint solvers and is particularly useful for providing application-specific constraints. It has been used in many kinds of applications, like scheduling, model checking, abduction, and type checking, among many others.

CHR has previously been implemented in other Prolog systems (SICStus, Eclipse, Yap), Haskell and Java. This CHR system is based on the compilation scheme and runtime environment of CHR in SICStus.

In this documentation we restrict ourselves to giving a short overview of CHR in general and mainly focus on elements specific to this implementation. For a more thorough review of CHR we refer the reader to [Frühwirth, 2009]. More background on CHR can be found at [Frühwirth, ].

In section 9.2 we present the syntax of CHR in Prolog and explain informally its operational semantics. Next, section 9.3 deals with practical issues of writing and compiling Prolog programs containing CHR. Section 9.4 explains the (currently primitive) CHR debugging facilities. Section 9.4.3 provides a few useful predicates to inspect the constraint store, and section 9.5 illustrates CHR with two example programs. Section 9.6 describes some compatibility issues with older versions of this system and SICStus’ CHR system. Finally, section 9.7 concludes with a few practical guidelines for using CHR.
9.2 CHR Syntax and Semantics

9.2.1 Syntax of CHR rules

```
rules --> rule, rules ; [].
rule --> name, actual_rule, pragma, [atom(‘.’)].
name --> atom, [atom(‘@’)] ; [].
actual_rule --> simplification_rule.
actual_rule --> propagation_rule.
actual_rule --> simpagation_rule.
simplification_rule --> head, [atom(‘<=>’)], guard, body.
propagation_rule --> head, [atom(‘=>’)], guard, body.
simpagation_rule --> head, [atom(‘\’)], head, [atom(‘<=>’)],
                   guard, body.
head --> constraints.
constraints --> constraint, constraint_id.
constraints --> constraint, constraint_id,
               [atom(‘,’)], constraints.
constraint --> compound_term.
constraint_id --> [].
constraint_id --> [atom(‘#’)], variable.
constraint_id --> [atom(‘#’)], [atom(‘passive’)] .
guard --> [] ; goal, [atom(‘|’)].
body --> goal.
pragma --> [].
pragma --> [atom(‘pragma’)], actual_pragmas.
actual_pragmas --> actual pragma.
actual_pragmas --> actual pragma, [atom(‘,’)], actual_pragmas.
actual pragma --> [atom(‘passive’)], variable, [atom(‘’)].
```

Note that the guard of a rule may not contain any goal that binds a variable in the head of the rule with a non-variable or with another variable in the head of the rule. It may, however, bind variables that do not appear in the head of the rule, e.g. an auxiliary variable introduced in the guard.
9.2.2 Semantics of CHR

In this subsection the operational semantics of CHR in Prolog are presented informally. They do not differ essentially from other CHR systems.

When a constraint is called, it is considered an active constraint and the system will try to apply the rules to it. Rules are tried and executed sequentially in the order they are written.

A rule is conceptually tried for an active constraint in the following way. The active constraint is matched with a constraint in the head of the rule. If more constraints appear in the head, they are looked for among the suspended constraints, which are called passive constraints in this context. If the necessary passive constraints can be found and all match with the head of the rule and the guard of the rule succeeds, then the rule is committed and the body of the rule executed. If not all the necessary passive constraints can be found, or the matching or the guard fails, then the body is not executed and the process of trying and executing simply continues with the following rules. If for a rule there are multiple constraints in the head, the active constraint will try the rule sequentially multiple times, each time trying to match with another constraint.

This process ends either when the active constraint disappears, i.e. it is removed by some rule, or after the last rule has been processed. In the latter case the active constraint becomes suspended.

A suspended constraint is eligible as a passive constraint for an active constraint. The other way it may interact again with the rules is when a variable appearing in the constraint becomes bound to either a non-variable or another variable involved in one or more constraints. In that case the constraint is triggered, i.e. it becomes an active constraint and all the rules are tried.

Rule Types

There are three different kinds of rules, each with its specific semantics:

- **simplification**
  The simplification rule removes the constraints in its head and calls its body.

- **propagation**
  The propagation rule calls its body exactly once for the constraints in its head.

- **simpagation**
  The simpagation rule removes the constraints in its head after the \ and then calls its body. It is an optimization of simplification rules of the form:

  \[ constraints_1, constraints_2 <=> constraints_1, body \]

  Namely, in the simpagation form:

  \[ constraints_1 \backslash constraints_2 <=> body \]

  The \( constraints_1 \) constraints are not called in the body.

Rule Names

Naming a rule is optional and has no semantic meaning. It only functions as documentation for the programmer.

Pragmas

The semantics of the pragmas are:

- **passive(Identifier)**
  The constraint in the head of a rule Identifier can only match a passive constraint in that rule. There is an abbreviated syntax for this pragma. Instead of:
..., c # Id, ... <=> ... pragma passive(Id)

you can also write

..., c # passive, ... <=> ...

Additional pragmas may be released in the future.

:- chr_option(+Option, +Value)

It is possible to specify options that apply to all the CHR rules in the module. Options are specified with the chr_option/2 declaration:

:- chr_option(Option,Value).

and may appear in the file anywhere after the first constraints declaration.

Available options are:

check guard bindings

This option controls whether guards should be checked for (illegal) variable bindings or not. Possible values for this option are on to enable the checks, and off to disable the checks. If this option is on, any guard fails when it binds a variable that appears in the head of the rule. When the option is off (default), the behaviour of a binding in the guard is undefined.

optimize

This option controls the degree of optimization. Possible values are full to enable all available optimizations, and off (default) to disable all optimizations. The default is derived from the SWI-Prolog flag optimise, where true is mapped to full. Therefore the command line option -O provides full CHR optimization. If optimization is enabled, debugging must be disabled.

debug

This option enables or disables the possibility to debug the CHR code. Possible values are on (default) and off. See section 9.4 for more details on debugging. The default is derived from the Prolog flag generate_debug_info, which is true by default. See --no-debug. If debugging is enabled, optimization must be disabled.

9.3 CHR in SWI-Prolog Programs

9.3.1 Embedding CHR in Prolog Programs

The CHR constraints defined in a .pl file are associated with a module. The default module is user. One should never load different .pl files with the same CHR module name.
9.3.2 CHR Constraint declaration

\[
\text{\texttt{:- chr\_constraint(+Specifier)}}
\]

Every constraint used in CHR rules has to be declared with a \texttt{chr\_constraint/1} declaration by the constraint specifier. For convenience multiple constraints may be declared at once with the same \texttt{chr\_constraint/1} declaration followed by a comma-separated list of constraint specifiers.

A constraint specifier is, in its compact form, \(F/A\) where \(F\) and \(A\) are respectively the functor name and arity of the constraint, e.g.:

\[
\text{:- chr\_constraint foo/1.}
\]
\[
\text{:- chr\_constraint bar/2, baz/3.}
\]

In its extended form, a constraint specifier is \(c(A_1, \ldots, A_n)\) where \(c\) is the constraint’s functor, \(n\) its arity and the \(A_i\) are argument specifiers. An argument specifier is a mode, optionally followed by a type. Example:

\[
\text{:- chr\_constraint get\_value(+,?).}
\]
\[
\text{:- chr\_constraint domain(?int, +list(int)),
\text{\hspace{1cm} alldifferent(?list(int)).}
\]

Modes A mode is one of:

- The corresponding argument of every occurrence of the constraint is always unbound.

+ The corresponding argument of every occurrence of the constraint is always ground.

? The corresponding argument of every occurrence of the constraint can have any instantiation, which may change over time. This is the default value.

Types A type can be a user-defined type or one of the built-in types. A type comprises a (possibly infinite) set of values. The type declaration for a constraint argument means that for every instance of that constraint the corresponding argument is only ever bound to values in that set. It does not state that the argument necessarily has to be bound to a value.

The built-in types are:

\textbf{int}

The corresponding argument of every occurrence of the constraint is an integer number.

\textbf{dense\_int}

The corresponding argument of every occurrence of the constraint is an integer that can be used as an array index. Note that if this argument takes values in \([0, n]\), the array takes \(O(n)\) space.
float

...a floating point number.

number

...a number.

natural

...a positive integer.

any

The corresponding argument of every occurrence of the constraint can have any type. This is 
the default value.

:- chr_type(+TypeDeclaration)

User-defined types are algebraic data types, similar to those in Haskell or the discriminated 
unions in Mercury. An algebraic data type is defined using chr_type/1:

```prolog
:- chr_type type ---> body.
```

If the type term is a functor of arity zero (i.e. one having zero arguments), it names a monomorphic type. Otherwise, it names a polymorphic type; the arguments of the functor must be distinct type variables. The body term is defined as a sequence of constructor definitions separated by 
semi-colons.

Each constructor definition must be a functor whose arguments (if any) are types. Discriminated 
union definitions must be transparent: all type variables occurring in the body must also occur 
in the type.

Here are some examples of algebraic data type definitions:

```prolog
:- chr_type color ---> red ; blue ; yellow ; green.
:- chr_type tree ---> empty ; leaf(int) ; branch(tree, tree).
:- chr_type list(T) ---> [] ; [T | list(T)].
:- chr_type pair(T1, T2) ---> (T1 - T2).
```

Each algebraic data type definition introduces a distinct type. Two algebraic data types that 
have the same bodies are considered to be distinct types (name equivalence).

Constructors may be overloaded among different types: there may be any number of constructors with a given name and arity, so long as they all have different types.

Aliases can be defined using ==. For example, if your program uses lists of lists of integers, you can define an alias as follows:

```prolog
:- chr_type lli == list(list(int)).
```
Type Checking Currently two complementary forms of type checking are performed:

1. Static type checking is always performed by the compiler. It is limited to CHR rule heads and CHR constraint calls in rule bodies.

Two kinds of type error are detected. The first is where a variable has to belong to two types. For example, in the program:

```prolog
:-chr_type foo ---> foo.
:-chr_type bar ---> bar.
:-chr_constraint abc(?foo).
:-chr_constraint def(?bar).
foobar @ abc(X) <=> def(X).
```

the variable X has to be of both type foo and bar. This is reported as a type clash error:

```
CHR compiler ERROR:
  '--> Type clash for variable _ in rule foobar:
  expected type foo in body goal def(_, _)
  expected type bar in head def(_, _)
```

The second kind of error is where a functor is used that does not belong to the declared type. For example in:

```prolog
:- chr_type foo ---> foo.
:- chr_type bar ---> bar.
:- chr_constraint abc(?foo).
foo @ abc(bar) <=> true.
```

bar appears in the head of the rule where something of type foo is expected. This is reported as:

```
CHR compiler ERROR:
  '--> Invalid functor in head abc(bar) of rule foo:
  found 'bar',
  expected type 'foo'!
```

No runtime overhead is incurred in static type checking.

2. Dynamic type checking checks at runtime, during program execution, whether the arguments of CHR constraints respect their declared types. The when/2 co-routining library is used to delay dynamic type checks until variables are instantiated.

The kind of error detected by dynamic type checking is where a functor is used that does not belong to the declared type. For example, for the program:
we get the following error in an erroneous query:

?- abc(bar).
ERROR: Type error: 'foo' expected, found 'bar'
      (CHR Runtime Type Error)

Dynamic type checking is weaker than static type checking in the sense that it only checks the particular program execution at hand rather than all possible executions. It is stronger in the sense that it tracks types throughout the whole program.

Note that it is enabled only in debug mode, as it incurs some (minor) runtime overhead.

### 9.3.3 CHR Compilation

The SWI-Prolog CHR compiler exploits termexpansion/2 rules to translate the constraint handling rules to plain Prolog. These rules are loaded from the library chr. They are activated if the compiled file has the .chr extension or after finding a declaration in the following format:

```prolog
:- chr_constraint ...
```

It is advised to define CHR rules in a module file, where the module declaration is immediately followed by including the library(chr) library as exemplified below:

```prolog
:- module(zebra, [ zebra/0 ]).
:- use_module(library(chr)).
:- chr_constraint ...
```

Using this style, CHR rules can be defined in ordinary Prolog .pl files and the operator definitions required by CHR do not leak into modules where they might cause conflicts.

### 9.4 Debugging CHR programs

The CHR debugging facilities are currently rather limited. Only tracing is currently available. To use the CHR debugging facilities for a CHR file it must be compiled for debugging. Generating debug info is controlled by the CHR option debug, whose default is derived from the SWI-Prolog flag generate_debug_info. Therefore debug info is provided unless the --no-debug is used.
9.4. DEBUGGING CHR PROGRAMS

9.4.1 CHR debug ports

For CHR constraints the four standard ports are defined:

**call**
A new constraint is called and becomes active.

**exit**
An active constraint exits: it has either been inserted in the store after trying all rules or has been removed from the constraint store.

**fail**
An active constraint fails.

**redo**
An active constraint starts looking for an alternative solution.

In addition to the above ports, CHR constraints have five additional ports:

**wake**
A suspended constraint is woken and becomes active.

**insert**
An active constraint has tried all rules and is suspended in the constraint store.

**remove**
An active or passive constraint is removed from the constraint store.

**try**
An active constraint tries a rule with possibly some passive constraints. The try port is entered just before committing to the rule.

**apply**
An active constraint commits to a rule with possibly some passive constraints. The apply port is entered just after committing to the rule.

9.4.2 Tracing CHR programs

Tracing is enabled with the `chr_trace/0` predicate and disabled with the `chr_notrace/0` predicate.

When enabled the tracer will step through the `call`, `exit`, `fail`, `wake` and `apply` ports, accepting debug commands, and simply write out the other ports.

The following debug commands are currently supported:

CHR debug options:

```
<cr>  creep  c  creep
s  skip
G  ancestors
n  nodebug
b  break
```
a       abort
f       fail
?       help       h       help

Their meaning is:

**creep**
Step to the next port.

**skip**
Skip to exit port of this call or wake port.

**ancestors**
Print list of ancestor call and wake ports.

**nodebug**
Disable the tracer.

**break**
Enter a recursive Prolog top level. See break/0.

**abort**
Exit to the top level. See abort/0.

**fail**
Insert failure in execution.

**help**
Print the above available debug options.

### 9.4.3 CHR Debugging Predicates

The `chr` module contains several predicates that allow inspecting and printing the content of the constraint store.

**chr_trace**
Activate the CHR tracer. By default the CHR tracer is activated and deactivated automatically by the Prolog predicates `trace/0` and `notrace/0`.

**chr_notrace**
Deactivate the CHR tracer. By default the CHR tracer is activated and deactivated automatically by the Prolog predicates `trace/0` and `notrace/0`.

**chr_leash(+Spec)**
Define the set of CHR ports on which the CHR tracer asks for user intervention (i.e. stops). `Spec` is either a list of ports as defined in section 9.4.1 or a predefined ‘alias’. Defined aliases are: full to stop at all ports, none or off to never stop, and default to stop at the call, exit, fail, wake and apply ports. See also leash/1.
9.5. CHR EXAMPLES

**chr_show_store(+Mod)**
Prints all suspended constraints of module *Mod* to the standard output. This predicate is automatically called by the SWI-Prolog top level at the end of each query for every CHR module currently loaded. The Prolog flag `chr_toplevel_show_store` controls whether the top level shows the constraint stores. The value `true` enables it. Any other value disables it.

**find_chr_constraint(-Constraint)**
Returns a constraint in the constraint store. Via backtracking, all constraints in the store can be enumerated.

### 9.5 CHR Examples

Here are two example constraint solvers written in CHR.

- The program below defines a solver with one constraint, `leq/2`, which is a less-than-or-equal constraint, also known as a partial order constraint.

```prolog
:- module(leq, [leq/2]).
:- use_module(library(chr)).
:- chr_constraint leq/2.

reflexivity @ leq(X,X) <=> true.
antisymmetry @ leq(X,Y), leq(Y,X) <=> X = Y.
idempotence @ leq(X,Y) \ leq(X,Y) <=> true.
transitivity @ leq(X,Y), leq(Y,Z) ==> leq(X,Z).
```

When the above program is saved in a file and loaded in SWI-Prolog, you can call the `leq/2` constraints in a query, e.g.:

```prolog
?- leq(X,Y), leq(Y,Z).
leq(_G23837, _G23841)
leq(_G23838, _G23841)
leq(_G23837, _G23838)
true.
```

When the query succeeds, the SWI-Prolog top level prints the content of the CHR constraint store and displays the bindings generated during the query. Some of the query variables may have been bound to attributed variables, as you see in the above example.

- The program below implements a simple finite domain constraint solver.

```prolog
:- module(dom, [dom/2]).
:- use_module(library(chr)).

:- chr_constraint dom(?int,+list(int)).
:- chr_type list(T) ---> []; [T|list(T)].
```
dom(X,[]) <=> fail.
dom(X,[Y]) <=> X = Y.
dom(X,L) <=> nonvar(X) | memberchk(X,L).
dom(X,L1), dom(X,L2) <=> intersection(L1,L2,L3), dom(X,L3).

When the above program is saved in a file and loaded in SWI-Prolog, you can call the dom/2 constraints in a query, e.g.:

?- dom(A,[1,2,3]), dom(A,[3,4,5]).
A = 3.

9.6 CHR compatibility

9.6.1 The Old SICStus CHR implementation

There are small differences between the current K.U.Leuven CHR system in SWI-Prolog, older versions of the same system, and SICStus’ CHR system.

The current system maps old syntactic elements onto new ones and ignores a number of no longer required elements. However, for each a deprecated warning is issued. You are strongly urged to replace or remove deprecated features.

Besides differences in available options and pragmas, the following differences should be noted:

- *The constraints/1 declaration*
  This declaration is deprecated. It has been replaced with the chr_constraint/1 declaration.

- *The option/2 declaration*
  This declaration is deprecated. It has been replaced with the chr_option/2 declaration.

- *The handler/1 declaration*
  In SICStus every CHR module requires a handler/1 declaration declaring a unique handler name. This declaration is valid syntax in SWI-Prolog, but will have no effect. A warning will be given during compilation.

- *The rules/1 declaration*
  In SICStus, for every CHR module it is possible to only enable a subset of the available rules through the rules/1 declaration. The declaration is valid syntax in SWI-Prolog, but has no effect. A warning is given during compilation.

- *Guard bindings*
  The check_guard_bindings option only turns invalid calls to unification into failure. In SICStus this option does more: it intercepts instantiation errors from Prolog built-ins such as is/2 and turns them into failure. In SWI-Prolog, we do not go this far, as we like to separate concerns more. The CHR compiler is aware of the CHR code, the Prolog system, and the programmer should be aware of the appropriate meaning of the Prolog goals used in guards and bodies of CHR rules.
9.7. CHR PROGRAMMING TIPS AND TRICKS

9.6.2 The Old ECLiPSe CHR implementation

The old ECLiPSe CHR implementation features a label_with/1 construct for labeling variables in CHR constraints. This feature has long since been abandoned. However, a simple transformation is all that is required to port the functionality.

```prolog
label_with Constraint1 if Condition1.
...
label_with ConstraintN if ConditionN.
Constraint1 :- Body1.
...
ConstraintN :- BodyN.
```

is transformed into

```prolog
:- chr_constraint my_labeling/0.
my_labeling \ Constraint1 <=> Condition1 | Body1.
...
my_labeling \ ConstraintN <=> ConditionN | BodyN.
my_labeling <=> true.
```

Be sure to put this code after all other rules in your program! With my_labeling/0 (or another predicate name of your choosing) the labeling is initiated, rather than ECLiPSe’s chr_labeling/0.

9.7 CHR Programming Tips and Tricks

In this section we cover several guidelines on how to use CHR to write constraint solvers and how to do so efficiently.

- **Check guard bindings yourself**
  
  It is considered bad practice to write guards that bind variables of the head and to rely on the system to detect this at runtime. It is inefficient and obscures the working of the program.

- **Set semantics**
  
  The CHR system allows the presence of identical constraints, i.e. multiple constraints with the same functor, arity and arguments. For most constraint solvers, this is not desirable: it affects efficiency and possibly termination. Hence appropriate simpagation rules should be added of the form:

  \[
  \text{constraint} \
  \begin{array}{c}
  \text{constraint} \\
  \end{array}
  \Rightarrow \text{true}
  \]

- **Multi-headed rules**
  
  Multi-headed rules are executed more efficiently when the constraints share one or more variables.

- **Mode and type declarations**
  
  Provide mode and type declarations to get more efficient program execution. Make sure to disable debug (\texttt{--no-debug}) and enable optimization (\texttt{-O}).
• **Compile once, run many times**

Does consulting your CHR program take a long time in SWI-Prolog? Probably it takes the CHR compiler a long time to compile the CHR rules into Prolog code. When you disable optimizations the CHR compiler will be a lot quicker, but you may lose performance. Alternatively, you can just use SWI-Prolog’s `qcompile/1` to generate a `.qlf` file once from your `.pl` file. This `.qlf` file contains the generated code of the CHR compiler (be it in a binary format). When you consult the `.qlf` file, the CHR compiler is not invoked and consultation is much faster.

• **Finding Constraints**

The `find_chr_constraint/1` predicate is fairly expensive. Avoid it, if possible. If you must use it, try to use it with an instantiated top-level constraint symbol.

### 9.8 CHR Compiler Errors and Warnings

In this section we summarize the most important error and warning messages of the CHR compiler.

#### 9.8.1 CHR Compiler Errors

- **Type clash** for variable ... in rule ...

  This error indicates an inconsistency between declared types; a variable can not belong to two types. See static type checking.

- **Invalid functor** in head ... of rule ...

  This error indicates an inconsistency between a declared type and the use of a functor in a rule. See static type checking.

- **Cyclic alias** definition: ... == ...

  You have defined a type alias in terms of itself, either directly or indirectly.

- **Ambiguous type aliases** You have defined two overlapping type aliases.

- **Multiple definitions** for type

  You have defined the same type multiple times.

- **Non-ground type** in constraint definition: ...

  You have declared a non-ground type for a constraint argument.

- **Could not find type definition** for ...

  You have used an undefined type in a type declaration.

- **Illegal mode/type declaration** You have used invalid syntax in a constraint declaration.

- **Constraint multiply defined** There is more than one declaration for the same constraint.

- **Undeclared constraint** ... in head of ...

  You have used an undeclared constraint in the head of a rule. This often indicates a misspelled constraint name or wrong number of arguments.
9.8. CHR COMPILER ERRORS AND WARNINGS

Invalid pragma ... in ... Pragma should not be a variable.
   
   You have used a variable as a pragma in a rule. This is not allowed.

Invalid identifier ... in pragma passive in ...
   
   You have used an identifier in a passive pragma that does not correspond to an identifier in the head of the rule. Likely the identifier name is misspelled.

Unknown pragma ... in ...
   
   You have used an unknown pragma in a rule. Likely the pragma is misspelled or not supported.

Something unexpected happened in the CHR compiler
   
   You have most likely bumped into a bug in the CHR compiler. Please contact Tom Schrijvers to notify him of this error.
Multithreaded applications

Multithreaded applications

SWI-Prolog multithreading is based on standard C language multithreading support. It is not like ParLog or other parallel implementations of the Prolog language. Prolog threads have their own stacks and only share the Prolog heap: predicates, records, flags and other global non-backtrackable data. SWI-Prolog thread support is designed with the following goals in mind.

- **Multithreaded server applications**
  Today’s computing services often focus on (internet) server applications. Such applications often have need for communication between services and/or fast non-blocking service to multiple concurrent clients. The shared heap provides fast communication, and thread creation is relatively cheap.¹

- **Interactive applications**
  Interactive applications often need to perform extensive computation. If such computations are executed in a new thread, the main thread can process events and allow the user to cancel the ongoing computation. User interfaces can also use multiple threads, each thread dealing with input from a distinct group of windows. See also section 10.7.

- **Natural integration with foreign code**
  Each Prolog thread runs in a native thread of the operating system, automatically making them cooperate with MT-safe foreign code. In addition, any foreign thread can create its own Prolog engine for dealing with calling Prolog from C code.

SWI-Prolog multithreading is based on the POSIX thread standard [Butenhof, 1997] used on most popular systems except for MS-Windows. On Windows it uses the pthread-win32 emulation of POSIX threads mixed with the Windows native API for smoother and faster operation. The SWI-Prolog thread implementation has been discussed in the ISO WG17 working group and is largely adopted by YAP and XSB Prolog.²

10.1 Creating and destroying Prolog threads

**thread_create:** 
\[Goal, -Id\]

Shorthand for `thread_create(Goal, Id, [])`. See `thread_create/3`.

**thread_create:** 
\[Goal, -Id, +Options\]

Create a new Prolog thread (and underlying operating system thread) and start it by executing

---

¹ On an Intel i7-2600K, running Ubuntu Linux 12.04, SWI-Prolog 6.2 creates and joins 32,000 threads per second elapsed time.

² The latest version of the ISO draft can be found at [http://logtalk.org/plstd/threads.pdf](http://logtalk.org/plstd/threads.pdf). It appears to have dropped from the ISO WG17 agenda.
**Goal.** If the thread is created successfully, the thread identifier of the created thread is unified to *Id*.

*Id* is the *alias* name if the option `alias(name)` is given. Otherwise it is a *blob* of type `thread`. The anonymous blobs are subject to atom garbage collection. If a thread handle is garbage collected and the thread is not *detached*, it is *joined* if it has already terminated (see `thread_join/2`) and detached otherwise (see `thread_detach/1`).\(^3\) The thread identifier blobs are printed as `<thread>(I,Ptr)`, where *I* is the internal thread identifier and *Ptr* is the unique address of the identifier. The *I* is accepted as input argument for all thread APIs that accept a thread identifier for convenient interaction from the toplevel. See also `thread_property/2`.

**Options** is a list of options. The currently defined options are below. Stack size options can also take the value `inf` or `infinite`, which is mapped to the maximum stack size supported by the platform.

**affinity(+CpuSet)**
Specify that the thread should only run on the specified CPUs (cores). *CpuSet* is a list of integers between 0 (zero) and the known number of CPUs (see `cpu_count`). If *CpuSet* is empty a `domain_error` is raised. Referring to CPUs equal to or higher than the known number of CPUs returns an `existence_error`.

This option is currently implemented for systems that provide `pthread_attr_setaffinity_np()`. The option is silently ignored on other systems.\(^4\)

**alias(AliasName)**
Associate an ‘alias name’ with the thread. This name may be used to refer to the thread and remains valid until the thread is joined (see `thread_join/2`). If the OS supports it (e.g., Linux), the operating system thread is named as well.

**at_exit(+AtExit)**
Register *AtExit* as using `thread_at_exit/1` before entering the thread goal. Unlike calling `thread_at_exit/1` as part of the normal *Goal*, this ensures the *AtExit* is called. Using `thread_at_exit/1`, the thread may be signalled or run out of resources before `thread_at_exit/1` is reached. See `thread_at_exit/1` for details.

**debug(+Bool)**
Enable/disable debugging the new thread. If `false` (default `true`), the new thread is created with the property `debug(false)` and debugging is disabled before the new thread is started. The thread debugging predicates such as `tspy/1` and `tdebug/0` do not signal threads with the debug property set to `false`.\(^5\)

**detached(Bool)**
If `false` (default), the thread can be waited for using `thread_join/2`. `thread_join/2` must be called on this thread to reclaim all resources associated with the thread. If `true`, the system will reclaim all associated resources automatically.

\(^3\)Up to version 7.3.23, anonymous thread handles were integers. Using integers did not allow for safe checking of the thread’s status as the thread may have died and the handle may have been reused and did not allow for garbage collection to take care of forgotten threads.

\(^4\)BUG: There is currently no way to discover whether this option is supported.

\(^5\)Currently, the flag is only used as a hint for the various debugging primitives, i.e., the system does not really enforce that the target thread stays in `nodebug` mode.
after the thread finishes. Please note that thread identifiers are freed for reuse after a
detached thread finishes or a normal thread has been joined. See also thread_join/2
and thread_detach/1.

If a detached thread dies due to failure or exception of the initial goal, the thread prints a
message using print_message/2. If such termination is considered normal, the code
must be wrapped using ignore/1 and/or catch/3 to ensure successful completion.

\[
\text{inherit_from}(+\text{ThreadId})
\]
Inherit defaults from the given \text{ThreadId} instead of the calling thread.
This option was added to ensure that the \_\_\_\_\_\_\_\text{thread_pool_manager} (see\nthread_create_in_pool/4), which is created lazily, has a predictable state.
The following properties are inherited:

- The prompt (see prompt/2)
- The \text{typein} module (see module/1)
- The standard streams (user_input, etc.)
- The default encoding (see encoding)
- The default locale (see set_locale/1)
- All prolog flags
- The stack limit (see Prolog flag \text{stack_limit}).

\[
\text{queue_max_size}(\text{Size})
\]
Enforces a maximum to the number of terms in the input queue. See
message_queue_create/2 with the \text{max_size(o)}ption for details.

\[
\text{stack_limit}(\text{Bytes})
\]
Set the size limit for the Prolog stacks. See the Prolog flag \text{stack_limit}. The default is
inherited from the calling thread or the thread specified using \text{inherit_from}(\text{ThreadId}).

\[
\text{c_stack}(\text{K-Bytes})
\]
Set the limit to which the C stack of this thread may grow. The default, minimum and
maximum values are system-dependent.

The \text{Goal} argument is \text{copied} to the new Prolog engine. This implies that further instantiation
of this term in either thread does not have consequences for the other thread: Prolog threads do
not share data from their stacks.

\[
\text{thread_self}(-\text{Id})
\]
Get the Prolog thread identifier of the running thread. If the thread has an alias, the alias name
is returned.

\[
\text{thread_join}(+\text{Id})
\]
Calls thread_join/2 and succeeds if thread \text{Id} terminated with success. Otherwise the
exception \text{error(thread_error(Id, Status), \_)} is raised, where \text{Status} is the status as
returned by thread_join/2.

\[
\text{thread_join}(+\text{Id}, -\text{Status})
\]
Wait for the termination of the thread with the given \text{Id}. Then unify the result status of the
thread with \text{Status}. After this call, \text{Id} becomes invalid and all resources associated with the
thread are reclaimed. It is not allowed for two threads to join the same thread and the thread
10.1. CREATING AND DESTROYING PROLOG THREADS

being joined cannot be detached (see the detached(true) option for thread_create/3 and thread_detach/1).

A thread that has been completed without thread_join/2 being called on it is partly reclaimed: the Prolog stacks are released and the C thread is destroyed. A small data structure representing the exit status of the thread is retained until thread_join/2 is called on the thread. Defined values for Status are:

true
The goal has been proven successfully.

false
The goal has failed.

exception(Term)
The thread is terminated on an exception. See print_message/2 to turn system exceptions into readable messages.

exited(Term)
The thread is terminated on thread_exit/1 using the argument Term.

Note that the pthread primitive pthread_join() cannot be interrupted. Some systems provide pthread_timedjoin_np(). If this is provided thread_join/2 is implemented as a loop of timed joins with a 0.25 sec timeout while signals are being tested after each timeout. Such systems allow combining thread_join/2 with call_with_time_limit/2 as well as signalling threads blocked in thread_join/2 using thread_signal/2.

thread_alias(+Alias)
Set the alias name of the calling thread to Alias. An error is raised if the calling thread already has an alias or Alias is in use for a thread or message queue.

thread_detach(+Id)
Switch thread into detached state (see detached(Bool) option at thread_create/3) at runtime. Id is the identifier of the thread placed in detached state. This may be the result of thread_self/1.

One of the possible applications is to simplify debugging. Threads that are created as detached leave no traces if they crash. For non-detached threads the status can be inspected using thread_property/2. Threads nobody is waiting for may be created normally and detach themselves just before completion. This way they leave no traces on normal completion and their reason for failure can be inspected.

thread_exit(+Term) [deprecated]
Terminates the thread immediately, leaving exited(Term) as result state for thread_join/2. If the thread has the attribute detached(true) it terminates, but its exit status cannot be retrieved using thread_join/2, making the value of Term irrelevant. The Prolog stacks and C thread are reclaimed.

The current implementation does not guarantee proper releasing of all mutexes and proper cleanup in setup_call_cleanup/3, etc. Please use the exception mechanism (throw/1) to abort execution using non-standard control.\(^6\)

\(^6\)BUG: The Windows port does not properly cleanup for detached threads while the cleanup for other threads is executed.
thread_initialization(:Goal)
Run Goal when thread is started. This predicate is similar to initialization/1, but is intended for initialization operations of the runtime stacks, such as setting global variables as described in section 4.33. Goal is run on four occasions: at the call to this predicate, after loading a saved state, on starting a new thread and on creating a Prolog engine through the C interface. On loading a saved state, Goal is executed after running the initialization/1 hooks.

thread_at_exit(:Goal)
Run Goal just before releasing the thread resources. This is to be compared to at_halt/1, but only for the current thread. These hooks are run regardless of why the execution of the thread has been completed. When these hooks are run, the return code is already available through thread_property/2 using the result of thread_self/1 as thread identifier. Note that there are two scenarios for using exit hooks. Using thread_at_exit/1 is typically used if the thread creates a side-effect that must be reverted if the thread dies. Another scenario is where the creator of the thread wants to be informed when the thread ends. That cannot be guaranteed by means of thread_at_exit/1 because it is possible that the thread cannot be created or dies almost instantly due to a signal or resource error. The at_exit(Goal) option of thread_create/3 is designed to deal with this scenario.

The Goal is executed with signal processing disabled. This avoids that e.g., thread_signal(Thread, abort) kills the exit handler rather than the thread in the case the body of Thread has just finished when the signal arrives.

thread_setconcurrency(-Old, +New)
Determine the concurrency of the process, which is defined as the maximum number of concurrently active threads. ‘Active’ here means they are using CPU time. This option is provided if the thread implementation provides pthread_setconcurrency(). Solaris is a typical example of this family. On other systems this predicate unifies Old to 0 (zero) and succeeds silently.

thread_affinity(+ThreadID, -Current, +New)
True when Current is unified with the current thread affinity and the thread affinity is successfully set to New. The thread affinity specifies the set of CPUs on which this thread is allowed to run. The affinity is represented as a list of non-negative integers. See also the option affinity(+Affinity) of thread_create/3.

This predicate is only present if this functionality can be supported and has been ported to the target operating system. Currently, only Linux support is provided.

10.2 Monitoring threads
Normal multithreaded applications should not need the predicates from this section because almost any usage of these predicates is unsafe. For example checking the existence of a thread before signalling it is of no use as it may vanish between the two calls. Catching exceptions using catch/3 is the only safe way to deal with thread-existence errors.

These predicates are provided for diagnosis and monitoring tasks. See also section 10.5, describing more high-level primitives.
10.2. MONITORING THREADS

is_thread(@Term)
    True if Term is a handle to an existing thread.

thread_property(?Id, ?Property)
    True if thread Id has Property. Either or both arguments may be unbound, enumerating all
    relations on backtracking. Calling thread_property/2 does not influence any thread. See
    also thread_join/2. For threads that have an alias name, this name is returned in Id instead
    of the opaque thread identifier. Defined properties are:

    alias(Alias)
        Alias is the alias name of thread Id.

    detached(Boolean)
        Current detached status of the thread.

    id(Integer)
        Integer identifier for the thread. Can be used as argument to the thread predicates, but
        applications must be aware that these references are reused.

    status(Status)
        Current status of the thread. Status is one of:

    running
        The thread is running. This is the initial status of a thread. Please note that threads
        waiting for something are considered running too.

    suspended
        Only if the thread is an engine (see section 11). Indicates that the engine is currently
        not associated with an OS thread.

    false
        The Goal of the thread has been completed and failed.

    true
        The Goal of the thread has been completed and succeeded.

    exited(Term)
        The Goal of the thread has been terminated using thread_exit/1 with Term as
        argument. If the underlying native thread has exited (using pthread_exit()) Term is
        unbound.

    exception(Term)
        The Goal of the thread has been terminated due to an uncaught exception (see
        throw/1 and catch/3).

    engine(Boolean)
        If the thread is an engine (see chapter 11), Boolean is true. Otherwise the property is
        not present.

    thread(ThreadId)
        If the thread is an engine that is currently attached to a thread, ThreadId is the thread that
        executes the engine.

    size(Bytes)
        The amount of memory associated with this thread. This includes the thread structure, its
        stacks, its default message queue, its clauses in its thread local dynamic predicates (see
        thread_local/1) and memory used for representing thread-local answer tries (see
        section 7).
system_thread_id(Integer)

Thread identifier used by the operating system for the calling thread. Not available on all
OSes. This is the same as the Prolog flag system_thread_id for the calling thread.
Access to the system thread identifier can, on some systems, be used to gain additional
control over or information about Prolog threads.

See also thread_statistics/3 to obtain resource usage information and
message_queue_property/2 to get the number of queued messages for a thread.

thread_statistics(+Id, +Key, -Value)

Obtains statistical information on thread Id as statistics/2 does in single-threaded appli-
cations. This call supports all keys of statistics/2, although only stack sizes, cpu-time,
inferences, epoch, errors and warnings yield different values for each thread. For
errors and warnings statistics/2 gives the global process count and this predicate
gives the counts for the calling thread.7

mutex

Print usage statistics on internal mutexes and mutexes associated with dynamic predicates. For
each mutex two numbers are printed: the number of times the mutex was acquired and the num-
ber of collisions: the number of times the calling thread has to wait for the mutex. The output
is written to current_output and can thus be redirected using with_output_to/2.

10.3 Thread communication

10.3.1 Message queues

Prolog threads can exchange data using dynamic predicates, database records, and other globally
shared data. These provide no suitable means to wait for data or a condition as they can only be
checked in an expensive polling loop. Message queues provide a means for threads to wait for data or
conditions without using the CPU.

Each thread has a message queue attached to it that is identified by the thread. Additional queues
are created using message_queue_create/1. Explicitly created queues come in two flavours.
When given an alias, they must be destroyed by the user. Anonymous message queues are identified
by a blob (see section 12.4.9) and subject to garbage collection.

thread_send_message(+QueueOrThreadId, +Term)

Place Term in the given queue or default queue of the indicated thread (which can even be the
message queue of itself, see thread_self/1). Any term can be placed in a message queue,
but note that the term is copied to the receiving thread and variable bindings are thus lost. This
call returns immediately.

If more than one thread is waiting for messages on the given queue and at least one of these
is waiting with a partially instantiated Term, the waiting threads are all sent a wake-up signal,
starting a rush for the available messages in the queue. This behaviour can seriously harm
performance with many threads waiting on the same queue as all-but-the-winner perform a

7There is no portable interface to obtain thread-specific CPU time and some operating systems provide no access to this
information at all. On such systems the total process CPU is returned. Thread CPU time is supported on MS-Windows,
Linux and MacOSX.
useless scan of the queue. If there is only one waiting thread or all waiting threads wait with an
unbound variable, an arbitrary thread is restarted to scan the queue.\footnote{See the documentation for the POSIX thread functions pthread_cond_signal() v.s. pthread_cond_broadcast() for background information.}

\begin{verbatim}
thread_send_message(+Queue, +Term, +Options) \[semidet\]
As thread_send_message/2, but providing additional Options. These are to
deal with the case that the queue has a finite maximum size and is full: whereas
thread_send_message/2 will block until the queue has drained sufficiently to accept a
new message, thread_send_message/3 can accept a time-out or deadline analogously to
thread_get_message/3. The options are:

\begin{description}
  \item[deadline(+AbsTime)]
The call fails (silently) if no space has become available before \texttt{AbsTime}. See
get_time/1 for the representation of absolute time. If \texttt{AbsTime} is earlier then the
current time, \texttt{thread_send_message/3} fails immediately. Both resolution and
maximum wait time is platform-dependent.\footnote{The implementation uses MsgWaitForMultipleObjects() on MS-Windows and pthread_cond_timedwait() on other systems.}

  \item[timeout(+Time)]
\texttt{Time} is a float or integer and specifies the maximum time to wait in seconds. This is a
relative-time version of the \texttt{deadline} option. If both options are provided, the earlier
time is effective.

If \texttt{Time} is 0 or 0.0, \texttt{thread_send_message/3} examines the queue and sends the mes-
sage if space is available, but does not suspend if no space is available, failing immediately
instead.

If \texttt{Time} < 0, \texttt{thread_send_message/3} fails immediately without sending the mes-
sage.

\end{description}

thread_get_message(?Term)
Examines the thread message queue and if necessary blocks execution until a term that unifies
to \texttt{Term} arrives in the queue. After a term from the queue has been unified to \texttt{Term}, the term is
deleted from the queue.

Please note that non-unifying messages remain in the queue. After the following has been
executed, thread 1 has the term \texttt{b(gnu)} in its queue and continues execution using \texttt{A = gnat}.

\begin{verbatim}
  \begin{thread}
    \begin{verbatim}
    thread_get_message(a(A)) ,
    \end{verbatim}
  \end{thread}

  \begin{thread}
    \begin{verbatim}
    thread_send_message(Thread_1, b(gnu)) ,
    thread_send_message(Thread_1, a(gnat)) ,
    \end{verbatim}
  \end{thread}
\end{verbatim}

\texttt{Term} may contain attributed variables (see section 8), in which case only terms for which the
constraints successfully execute are returned. Handle constraints applies for all predicates that
extract terms from message queues. For example, we can get the even numbers from a queue
using this code:
get_matching_messages(Queue, Pattern, [H|T]) :-
    copy_term(Pattern, H),
    thread_get_message(Queue, H, [timeout(0)]),
    !,
    get_matching_messages(Queue, Pattern, T).
get_matching_messages(_, _, []).

even_numbers(Q, List) :-
    freeze(Even, Even mod 2 == 0),
    get_matching_messages(Q, Even, List).

See also thread:peek:peek_message/1.

thread:peek:peek_message(?Term)
Enter the thread message queue and compares the queued terms with Term until one
unifies or the end of the queue has been reached. If the first case the call suc-
ceeds, possibly instantiating Term. If no term from the queue unifies, this call fails. I.e.,
thread:peek:peek_message/1 never waits and does not remove any term from the queue. See
also thread:get:message/3.

message:queue:create(?Queue)
Equivalent to message:queue:create(Queue, []). For compatibility, calling
message:queue:create(+Atom) is equivalent to message:queue:create(Queue,
[alias(Atom)]). New code should use message:queue:create/2 to create a named queue.

message:queue:create(-Queue, +Options)
Create a message queue from Options. Defined options are:

alias(+Alias)
Create a message queue that is identified by the atom Alias. Message queues created this
way must be explicitly destroyed by the user. If the alias option is omitted, an Anonymous
queue is created that is identified by a blob (see section 12.4.9) and subject to garbage
collection. 10

max_size(+Size)
Maximum number of terms in the queue. If this number is reached,
thread:send:message/2 will suspend until the queue is drained. The option
can be used if the source, sending messages to the queue, is faster than the drain,
consuming the messages.

message:queue:destroy(+Queue) [det]
Destroy a message queue created with message:queue:create/1. A permission error
is raised if Queue refers to (the default queue of) a thread. Other threads that are waiting for
Queue using thread:get:message/2 receive an existence error.

10 Garbage collecting anonymous message queues is not part of the ISO proposal and most likely not a widely imple-
mented feature.
10.3. THREAD COMMUNICATION

thread_get_message(+Queue, ?Term)  [det]
As thread_get_message/1, operating on a given queue. It is allowed (but not advised) to get messages from the queue of other threads. This predicate raises an existence error exception if Queue doesn’t exist or is destroyed using message_queue_destroy/1 while this predicate is waiting.

thread_get_message(+Queue, ?Term, +Options)  [semidet]
As thread_get_message/2, but providing additional Options:

deadline(+AbsTime)
The call fails (silently) if no message has arrived before AbsTime. See get_time/1 for the representation of absolute time. If AbsTime is earlier then the current time, thread_get_message/3 fails immediately. Both resolution and maximum wait time is platform-dependent.\(^{11}\)

timeout(+Time)
Time is a float or integer and specifies the maximum time to wait in seconds. This is a relative-time version of the deadline option. If both options are provided, the earlier time is effective.

If Time is 0 or 0.0, thread_get_message/3 examines the queue but does not suspend if no matching term is available. Note that unlike thread_peek_message/2, a matching term is removed from the queue.

If Time < 0, thread_get_message/3 fails immediately without removing any message from the queue.

thread_peek_message(+Queue, ?Term)  [semidet]
As thread_peek_message/1, operating on a given queue. It is allowed to peek into another thread’s message queue, an operation that can be used to check whether a thread has swallowed a message sent to it.

message_queue_property(?Queue, ?Property)
True if Property is a property of Queue. Defined properties are:

alias(Alias)
Queue has the given alias name.

max_size(Size)
Maximum number of terms that can be in the queue. See message_queue_create/2. This property is not present if there is no limit (default).

size(Size)
Queue currently contains Size terms. Note that due to concurrent access the returned value may be outdated before it is returned. It can be used for debugging purposes as well as work distribution purposes.

waiting(-Count)
Number of threads waiting for this queue. This property is not present if no threads waits for this queue.

\(^{11}\) The implementation uses MsgWaitForMultipleObjects() on MS-Windows and pthread_cond_timedwait() on other systems.
The \texttt{size(\textit{Size})} property is always present and may be used to enumerate the created message queues. Note that this predicate does \textit{not enumerate} threads, but can be used to query the properties of the default queue of a thread.

\textbf{message\_queue\_set(+Queue, +Property)}

Set a property on the queue. Supported properties are:

\textbf{max\_size(+Size)}

Change the number of terms that may appear in the message queue before the next \texttt{thread\_send\_message/[2,3]} blocks on it. If the value is higher than the current maximum and the queue has writers waiting, wakeup the writers. The value can be lower than the current number of terms in the queue. In that case writers will block until the queue is drained below the new maximum.

Explicit message queues are designed with the \textit{worker-pool} model in mind, where multiple threads wait on a single queue and pick up the first goal to execute. Below is a simple implementation where the workers execute arbitrary Prolog goals. Note that this example provides no means to tell when all work is done. This must be realised using additional synchronisation.

\begin{verbatim}
%% create_workers(?Id, +N)
% Create a pool with Id and number of workers.
% After the pool is created, post_job/1 can be used to
% send jobs to the pool.

create_workers(Id, N) :-
    message_queue_create(Id),
    forall(between(1, N, _),
                thread_create(do_work(Id), _, [])).

do_work(Id) :-
    repeat,
                thread_get_message(Id, Goal),
        (    catch(Goal, E, print_message(error, E))
                -> true
                ;    print_message(error, goal_failed(Goal, worker(Id)))
        ),
    fail.

%% post_job(+Id, +Goal)
% Post a job to be executed by one of the pool’s workers.

post_job(Id, Goal) :-
    thread_send_message(Id, Goal).
\end{verbatim}
10.3. THREAD COMMUNICATION

10.3.2 Waiting for events

While message queues realizes communicating agents sharing the same program and optionally dynamic data, the predicate thread_wait/2 facilitates agents that communicate based on a shared blackboard. An important difference is were message queues require the sender and receiver to know about the queue used to communicate and every message can wakeup at most one thread, the blackboard model allows any number (including zero) of threads to listen to changes on the blackboard. Any module can act as a blackboard. The blackboard can be updated using the standard Prolog database update predicates (assert/1, retract/1 and friends).

Waiting is implemented using a POSIX condition variable and matching mutex. On a matching database change the condition variable is signalled using a broadcast, waking up all threads waiting in thread_wait/2. Multiple database updates can be grouped and cause a single wakeup using thread_update/2. This predicate also allows signalling the module condition variable without updating the database and controlling whether all or a single thread is activated.

The blackboard architecture is a good match for an intelligent agent system that has to react on a changing world. Input threads gather sensor data from the world and update a shared world view in a set of dynamic predicates in one or more modules. Agent threads listen to this data or a subset thereof and trigger actions. This is notably a good match with tabling, in particular incremental tabling (see section 7.7) and WellFounded Semantics (see section 7.6).12

**thread_wait**(:**Goal**, :**Options**)

Block execution of the calling thread until **Goal** becomes true. The application must be prepared to handle spurious calls to **Goal**, i.e., more calls than asked for based on the **Options** list. A possible exception in **Goal** is propagated and thus terminates thread_wait/2.

The wait is associated with a module. This module is derived from the **Options** argument.

The **Options** list specifies when **Goal** is re-evaluated and optionally when the call terminates due to a timeout.

**deadline**(+**AbsTime**)

**timeout**(+#**Time**)

Timeout and deadline handling. See thread_get_message/3 for details. This predicate fails when it terminates due to one of these options.

**retry_every**(+#**Time**)

Retry goal every **Time** seconds regardless of whether an event happened. The default is 1 second. This ensures that signals (see thread_signal/2) and time limits are respected with an optional delay.13

**db**(+#**Boolean**)

Wakeup on arbitrary changes to any dynamic predicate that is defined in the associated module. This is the default if **wait_preds**(+#**Preds**) is not provided.

**wait_preds**(+#**List**) Only call **Goal** if at least one of the predicates in **List** has been modified. Each element of **List** is a predicate indicator (**Name**/Arity or **Name**//Arity) that is resolved to a predicate in

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12 Future versions may provide additional triggers, for example to learn about invalidated tables. Please share your experience.

13 Some operating systems process such signals immediately, while others only check for such events synchronously.
the module this wait is associated with. If the element is \(+(P)\), \(Goal\) is only triggered if a clause was added (\(\text{assert/1}\)). If the element is \(-(P)\), \(Goal\) is only triggered if a clause was retracted (\(\text{retract/1}\) or \(\text{erase/1}\)). Default is to wakeup on both assert and retract.

\(\text{modified(-List)}\)

The \(List\) variable normally also appears in \(Goal\) and is unified with a list of predicates from the \(\text{wait.preds}\) option that have been modified. \(List\) must be unbound at entry.

\(\text{module(+Module)}\)

Specifies the module to act on explicitly.

The execution of \(Goal\) is synchronized between all threads calling this predicate on the same module, changes to dynamic predicates in this module and calls to \(\text{thread.update/2}\) on the same module.

This predicate raises a \text{permission.error} exception when called recursively or called from inside a transaction. See section 4.14.1 for details about interaction with transactions.

\(\text{thread.update(}Goal, :Options)\)

Update a module (typically using \(\text{assert/1}\) and/or \(\text{retract/1}\) and friends) and on completion signal threads waiting for this module using \(\text{thread.wait/2}\) to reevaluate their \(Goal\). \(Goal\) is synchronized between updating and waiting threads. \(Options:\)

\(\text{module(+Module)}\)

Determines the module to operate on. Default is the context module associated with the \(Options\) argument.

\(\text{notify(+Atom)}\)

Determines whether all waiting threads are activated (\(broadcast\), default) or a single thread (\(signal\)).

Compatibility The \(\text{thread.wait/2}\) predicate is modelled after the Qu-Prolog predicate \(\text{thread.wait.on.goal/2}\). It is largely compatible. Our current implementation does not support predicate time stamps.\(^{15}\) We made this predicate act on a specific module rather than the entire database. The timeout specification follows that of the other thread waiting predicates and may be combined with the \(\text{retry.ever}\) option. The default retry-time is also 1 second rather than \text{infinite}.

10.3.3 Signalling threads

The predicates in this section provide \text{signalling} between threads. A thread signal inserts any goal as an \text{interrupt} into the control flow of any target thread. The target thread processes the goal at the first safe opportunity. The mechanism was introduced with two goals in mind: (1) running a goal inside a thread for debugging purposes such as enabling the status or get access thread-specific data and (2) force a thread to abort its current goal by inserting an exception into its control flow.

Over time, more complicated use cases have been identified that may result in multiple signals that occur (nearly) simultaneous. As of version 8.5.1 the interface has been extended and the interaction with other built-in predicates has been specified in much more detail.

\(^{14}\)Note that \(+p/1\) is read as \(/(+(p),1)\).

\(^{15}\)See predicate \(\text{property/2}\), \text{property generation}. 
10.3. THREAD COMMUNICATION

thread_signal(+ThreadId, :Goal) [det]

Make thread ThreadId execute Goal at the first opportunity. The predicate thread_signal/2 itself places Goal into the signalled thread’s signal queue and returns immediately.

ThreadId executes Goal as an interrupt at the first opportunity. Defined opportunities are:

- At the call port of any predicate except for predicates with the property sig_atomic. Currently this only applies to sig_atomic/1.
- Before retrying a foreign predicate.
- Before backtracking to the next clause of a Prolog predicate.
- When a foreign predicate calls PL_handle_signals(). Foreign predicates that take long to complete should call PL_handle_signals() regularly and return with FALSE after PL_handle_signals() returned -1, indicating an exception was raised.
- Foreign predicates calling blocking system calls should attempt to make these system calls interruptible. To enable this on POSIX systems, SWI-Prolog sends a SIGUSR2 to the signalled thread while the handler is an empty function. This causes most blocking system calls to return with EINTR. See also the commandline option --sig-alert. On Windows, PL_handle_signals() is called when the user processes Windows messages.
- For some blocking (thread) APIs we use a timed version with a 0.25 sec timeout to achieve a polling loop.

If one or more signals are queued, the queue is processed. Processing the queue skips signals blocked due to sig_block/1 and stops after the queue does not contain any more non-blocked signals or processing a signal results in an exception. After an exception, other signals remain in the queue and will be processed after unwinding to the matching catch/3. Typically these queued signals will be processed during the Recover goal of the catch/3. Note that sig_atomic/1 may be used to protect the recovery goal.

The thread_signal/2 mechanism is primarily used by the system to insert debugging goals into the target thread (tspy/1, tbacktrace/1, etc.) or to interrupt a thread using e.g., thread_signal(Thread, abort). Predicates from library thread use signals to stop workers for e.g. concurrent_maplist/2 if some call fails. Applications may use it, typically for similar purposes such as asynchronously stopping tasks or inspecting the status of a task. Below we describe the behaviour of thread signalling in more detail. The following notes apply for Goal executing in ThreadId:

- The execution is protected by sig_atomic/1 and thus signal execution is not nested.
- If Goal succeeds, possible choice points are discarded. Changes to the Prolog stacks such as changes to backtrackable global variables remain.
- If Goal fails, no action is taken, i.e., failure is not considered a special condition.
- If Goal raises an exception the exception is propagated into the environment. This allows for forcefully stopping the target thread. The system uses this to implement abort/0 and call_with_time_limit/2.
- Code into which signals may be injected must make sure to use setup_call_cleanup/3 and friends to ensure proper cleanup in the case of an
exception. This is good practice anyway to guard against unpredicatable exceptions such as resource exhaustion.

- **Goal** may use stack inspection such as `prolog_frame_attribute/3` to determine what the thread is doing.

```
sig_pending(-List)                     [det]
    True when List contains all signals submitted using thread_signal/2 that are not yet processed. This includes signals blocked by sig_block/1.
```

```
sig_remove(:Pattern, -List)            [det]
    Remove all signals that unify with Pattern from the signal queue and make the removed signals available in List
```

```
sig_block(:Pattern)                   [det]
    Block thread signals queued using thread_signal/2 that match Pattern.
```

```
sig_unblock(:Pattern)                 [det]
    Remove any effect of sig_block/1 for patterns that are more specific (see subsumes_term/2). If any patterns are removed, reschedule blocked signals. Note that sig_unblock/1 normally causes all unblocked signals to be executed immediately.
```

```
sig_atomic(:Goal)                     [semidet]
    Execute Goal as once/1 while blocking both thread signals (see thread_signal/2) and OS signals (see on_signal/3). The system executes some goals while blocking signals. These are:
    
    - The goal injected using thread_signal/2, i.e., signals do not interrupt a running signal handler.
    - The Setup call of setup_call_cleanup/3 and friends.
    - The Cleanup call of call_cleanup/2 and friends.
    - Compiling a file or loading a quick load file.
```

The call port of `sig_atomic/1` does not handle signals. This may notably be used to prevent interruption of the `catch/3` Recover goal. For example, we may ensure the recovery goal of a timeout is called using the code below. Without this precaution another signal may run before `writeln/1` and raise an exception to prevent its execution. Note that `catch/3` should generally not be used for cleanup of resources in case of an exception and thus it is typically fine if its Recover goal is interrupted. Use `setup_call_cleanup/3` or one of the other predicates from the `call_cleanup/2` family for cleanup.

```
    
    ..., 
    catch(call_with_time_limit(Time, Goal),
        time_limit_exceeded,
        sig_atomic(writeln('Time limit exceeded'))).
```
10.3.4 Threads and dynamic predicates

Besides queues (section 10.3.1) threads can share and exchange data using dynamic predicates. The multithreaded version knows about two types of dynamic predicates. By default, a predicate declared `dynamic` (see `dynamic/1`) is shared by all threads. Each thread may assert, retract and run the dynamic predicate. Synchronisation inside Prolog guarantees the consistency of the predicate. Updates are logical: visible clauses are not affected by assert/retract after a query started on the predicate. In many cases primitives from section 10.4 should be used to ensure that application invariants on the predicate are maintained.

Besides shared predicates, dynamic predicates can be declared with the `thread_local/1` directive. Such predicates share their attributes, but the clause list is different in each thread.

```
thread_local +Functor/+Arity, ...
```

This directive is related to the `dynamic/1` directive. It tells the system that the predicate may be modified using `assert/1`, `retract/1`, etc., during execution of the program. Unlike normal shared dynamic data, however, each thread has its own clause list for the predicate. As a thread starts, this clause list is empty. If there are still clauses when the thread terminates, these are automatically reclaimed by the system (see also `volatile/1`). The `thread_local` property implies the properties `dynamic` and `volatile`.

Thread-local dynamic predicates are intended for maintaining thread-specific state or intermediate results of a computation.

It is not recommended to put clauses for a thread-local predicate into a file, as in the example below, because the clause is only visible from the thread that loaded the source file. All other threads start with an empty clause list.

```
:- thread_local
    foo/1.

foo(gnat).
```

**DISCLAIMER** Whether or not this declaration is appropriate in the sense of the proper mechanism to reach the goal is still debated. If you have strong feelings in favour or against, please share them in the SWI-Prolog mailing list.

10.4 Thread synchronisation

All internal Prolog operations are thread-safe. This implies that two Prolog threads can operate on the same dynamic predicate without corrupting the consistency of the predicate. This section deals with user-level mutexes (called monitors in ADA or critical sections by Microsoft). A mutex is a MUTual EXclusive device, which implies that at most one thread can hold a mutex.

Mutexes are used to realise related updates to the Prolog database. With ‘related’, we refer to the situation where a ‘transaction’ implies two or more changes to the Prolog database. For example, we have a predicate `address/2`, representing the address of a person and we want to change the address by retracting the old and asserting the new address. Between these two operations the database is invalid: this person has either no address or two addresses, depending on the assert/retract order.
The code below provides a solution to this problem based on \texttt{with_mutex/2}. It also illustrates the problem of mutexes. The predicate \texttt{with_mutex/2} behaves as \texttt{once/1} with respect to the guarded goal. This means that our predicate \texttt{address/2} is no longer a nice logical non-deterministic relation. This could be solved by explicit locking and unlocking a mutex using \texttt{setup_call_cleanup/3}, but at the risk of deadlocking the program if the choice point is left open by accident.

\begin{verbatim}
change_address(Id, Address) :-
    with_mutex(addressbook,
        ( retractall(address(Id, _)),
          asserta(address_db(Id, Address))
        )).

address(Id, Address) :-
    with_mutex(addressbook,
        address_db(Id, Address)).
\end{verbatim}

Message queues (see \texttt{message_queue_create/2}) often provide simpler and more robust ways for threads to communicate. Still, mutexes can be a sensible solution and are therefore provided.

\textbf{mutex_create(?MutexId)}

Create a mutex. If \texttt{MutexId} is an atom, a \texttt{named} mutex is created. If it is a variable, an anonymous mutex reference is returned. Anonymous mutexes are subject to (atom) garbage collection.

\textbf{mutex_create(-MutexId, +Options)}

Create a mutex using options. Defined options are:

\begin{itemize}
  \item \texttt{alias(Alias)}
    \begin{itemize}
      \item Set the alias name. Using \texttt{mutex_create(X, \{alias(name)\})} is preferred over the equivalent \texttt{mutex_create(name)}.
    \end{itemize}
\end{itemize}

\textbf{mutex_destroy(+MutexId)}

Destroy a mutex. If the mutex is not locked, it is destroyed and further access yields an \texttt{existence_error} exception. As of version 7.1.19, this behaviour is reliable. If the mutex is locked, the mutex is scheduled for \textit{delayed destruction}: it will be destroyed when it becomes unlocked.

\textbf{with_mutex(+MutexId, :Goal)}

Execute \texttt{Goal} while holding \texttt{MutexId}. If \texttt{Goal} leaves choice points, these are destroyed (as in \texttt{once/1}). The mutex is unlocked regardless of whether \texttt{Goal} succeeds, fails or raises an exception. An exception thrown by \texttt{Goal} is re-thrown after the mutex has been successfully unlocked. See also \texttt{mutex_create/1} and \texttt{setup_call_cleanup/3}.

Although described in the thread section, this predicate is also available in the single-threaded version, where it behaves simply as \texttt{once/1}.

\textbf{mutex_lock(+MutexId)}

Lock the mutex. Prolog mutexes are \textit{recursive} mutexes: they can be locked multiple times by
10.5. THREAD SUPPORT LIBRARY(THREADUTIL)  

the same thread. Only after unlocking it as many times as it is locked does the mutex become available for locking by other threads. If another thread has locked the mutex the calling thread is suspended until the mutex is unlocked.

If MutexId is an atom, and there is no current mutex with that name, the mutex is created automatically using mutex_create/1. This implies named mutexes need not be declared explicitly.

Please note that locking and unlocking mutexes should be paired carefully. Especially make sure to unlock mutexes even if the protected code fails or raises an exception. For most common cases, use with_mutex/2, which provides a safer way for handling Prolog-level mutexes. The predicate setup_call_cleanup/3 is another way to guarantee that the mutex is unlocked while retaining non-determinism.

mutex_trylock(+MutexId)  
As mutex_lock/1, but if the mutex is held by another thread, this predicate fails immediately.

mutex_unlock(+MutexId)  
Unlock the mutex. This can only be called if the mutex is held by the calling thread. If this is not the case, a permission_error exception is raised.

mutex_unlock_all  
Unlock all mutexes held by the current thread. This predicate should not be needed if mutex unlocking is guaranteed with with_mutex/2 or setup_call_cleanup/3.\footnote{The also deprecated thread_exit/1 bypasses the automatic cleanup.}

mutex_property(?MutexId, ?Property)  
True if Property is a property of MutexId. Defined properties are:

alias(Alias)  
Mutex has the defined alias name. See mutex_create/2 using the ‘alias’ option.

status(Status)  
Current status of the mutex. One of unlocked if the mutex is currently not locked, or locked(Owner, Count) if mutex is locked Count times by thread Owner. Note that unless Owner is the calling thread, the locked status can change at any time. There is no useful application of this property, except for diagnostic purposes.\footnote{BUG: As Owner and Count are fetched separately from the mutex, the values may be inconsistent.}

10.5 Thread support library(threadutil)

This library defines a couple of useful predicates for demonstrating and debugging multithreaded applications. This library is certainly not complete.

threads  
Lists all current threads and their status.

join_threads  
Join all terminated threads. For normal applications, dealing with terminated threads must be

part of the application logic, either detaching the thread before termination or making sure it will be joined. The predicate join_threads/0 is intended for interactive sessions to reclaim resources from threads that died unexpectedly during development.

interactor
Create a new console and run the Prolog top level in this new console. See also attach_console/0. In the Windows version a new interactor can also be created from the Run/New thread menu.

10.5.1 Debugging threads
Support for debugging threads is still very limited. Debug and trace mode are flags that are local to each thread. Individual threads can be debugged either using the graphical debugger described in section 3.5 (see tspy/1 and friends) or by attaching a console to the thread and running the traditional command line debugger (see attach_console/0). When using the graphical debugger, the debugger must be loaded from the main thread (for example using guitracer) before gtrace/0 can be called from a thread.

attach_console
If the current thread has no console attached yet, attach one and redirect the user streams (input, output, and error) to the new console window. On Unix systems the console is an xterm application. On Windows systems this requires the GUI version swipl-win.exe rather than the console-based swipl.exe.

This predicate has a couple of useful applications. One is to separate (debugging) I/O of different threads. Another is to start debugging a thread that is running in the background. If thread 10 is running, the following sequence starts the tracer on this thread:

?- thread_signal(10, (attach_console, trace)).

tdebug(+ThreadId)
Prepare ThreadId for debugging using the graphical tracer. This implies installing the tracer hooks in the thread and switching the thread to debug mode using debug/0. The call is injected into the thread using thread_signal/2. We refer to the documentation of this predicate for asynchronous interaction with threads. New threads created inherit their debug mode from the thread that created them.

tdebug
Call tdebug/1 in all running threads.

tnodebug(+ThreadId)
Disable debugging thread ThreadId.

tnodebug
Disable debugging in all threads.

tspy(:Spec, +ThreadId)
Set a spy point as spy/1 and enable the thread for debugging using tdebug/1. Note that a spy point is a global flag on a predicate that is visible from all threads. Spy points are honoured in all threads that are in debug mode and ignored in threads that are in nodebug mode.
tspy(:Spec)
    Set a spy point as spy/1 and enable debugging in all threads using tdebug/0. Note that removing spy points can be done using nospy/1. Disabling spy points in a specific thread is achieved by tnodebug/1.

10.5.2 Profiling threads

In the current implementation, at most one thread can be profiled at any moment. Any thread can call profile/1 to profile the execution of some part of its code. The predicate tprofile/1 allows for profiling the execution of another thread until the user stops collecting profile data.

tprofile(+ThreadId)
    Start collecting profile data in ThreadId and ask the user to hit ⟨return⟩ to stop the profiler. See section 4.42 for details on the execution profiler.

10.6 Multithreaded mixed C and Prolog applications

All foreign code linked to the multithreading version of SWI-Prolog should be thread-safe (reentrant) or guarded in Prolog using with_mutex/2 from simultaneous access from multiple Prolog threads. If you want to write mixed multithreaded C and Prolog applications you should first familiarise yourself with writing multithreaded applications in C (C++). If you are using SWI-Prolog as an embedded engine in a multithreaded application you can access the Prolog engine from multiple threads by creating an engine in each thread from which you call Prolog. Without creating an engine, a thread can only use functions that do not use the term_t type (for example PL_new_atom()).

The system supports two models. Section 10.6.1 describes the original one-to-one mapping. In this schema a native thread attaches a Prolog thread if it needs to call Prolog and detaches it when finished, as opposed to the model from section 10.6.2, where threads temporarily use a Prolog engine.

10.6.1 A Prolog thread for each native thread (one-to-one)

In the one-to-one model, the thread that called PL_initialise() has a Prolog engine attached. If another C thread in the system wishes to call Prolog it must first attach an engine using PL_thread_attach_engine() and call PL_thread_destroy_engine() after all Prolog work is finished. This model is especially suitable with long running threads that need to do Prolog work regularly. See section 10.6.2 for the alternative many-to-many model.

int PL_thread_self()
    Returns the integer Prolog identifier of the engine or -1 if the calling thread has no Prolog engine. This function is also provided in the single-threaded version of SWI-Prolog, where it returns -2.

int PL_unify_thread_id(term_t t, int i)
    Unify t with the Prolog thread identifier for thread i. Thread identifiers are normally returned from PL_thread_self(). Returns -1 if the thread does not exist or the unification fails.

int PL_thread_attach_engine(const PL_thread_attr_t *attr)
    Creates a new Prolog engine in the calling thread. If the calling thread already has an engine the
reference count of the engine is incremented. The attr argument can be NULL to create a thread with default attributes. Otherwise it is a pointer to a structure with the definition below.\(^\text{18}\) For any field with value ‘0’, the default is used. The cancel field may be filled with a pointer to a function that is called when PL_cleanup() terminates the running Prolog engines. If this function is not present or returns FALSE pthread_cancel() is used. The flags field defines the following flags:

**PL_THREAD_NO_DEBUG**

If this flag is present, the thread starts in normal no-debug status. By default, the debug status is inherited from the main thread.

**PL_THREAD_NOT_DETACHED**

By default the new thread is created in detached mode. With this flag it is created normally, allowing Prolog to join the thread.

```c
typedef struct
{ size_t stack_limit; /* Total stack limit (bytes) */
 size_t table_space; /* Total tabling space limit (bytes) */
 char * alias; /* alias name */
 int (*cancel)(int thread); /* cancel function */
 intptr_t flags; /* PL_THREAD_* flags */
 size_t max_queue_size; /* Max size of associated queue */
} PL_thread_attr_t;
```

The structure may be destroyed after PL_thread_attach_engine() has returned. On success it returns the Prolog identifier for the thread (as returned by PL_thread_self()). If an error occurs, -1 is returned. If this Prolog is not compiled for multithreading, -2 is returned.

```c
int PL_thread_destroy_engine()
```

Destroy the Prolog engine in the calling thread. Only takes effect if PL_thread_destroy_engine() is called as many times as PL_thread_attach_engine() in this thread. Returns TRUE on success and FALSE if the calling thread has no engine or this Prolog does not support threads.

Please note that construction and destruction of engines are relatively expensive operations. Only destroy an engine if performance is not critical and memory is a critical resource.

```c
int PL_thread_at_exit(void (*function)(void *), void *closure, int global)
```

Register a handle to be called as the Prolog engine is destroyed. The handler function is called with one void * argument holding closure. If global is TRUE, the handler is installed for all threads. Globally installed handlers are executed after the thread-local handlers. If the handler is installed local for the current thread only (global == FALSE) it is stored in the same FIFO queue as used by thread_at_exit/1.

### 10.6.2 Pooling Prolog engines (many-to-many)

In this model Prolog engines live as entities that are independent from threads. If a thread needs to call Prolog it takes one of the engines from the pool and returns the engine when done. This model is

\(^{18}\)The structure layout changed in version 7.7.14.
suitable in the following identified cases:

- **Compatibility with the single-threaded version**
  In the single-threaded version, foreign threads must serialise access to the one and only thread engine. Functions from this section allow sharing one engine among multiple threads.

- **Many native threads with infrequent Prolog work**
  Prolog threads are expensive in terms of memory and time to create and destroy them. For systems that use a large number of threads that only infrequently need to call Prolog, it is better to take an engine from a pool and return it there.

- **Prolog status must be handed to another thread**
  This situation has been identified by Uwe Lesta when creating a .NET interface for SWI-Prolog. .NET distributes work for an active internet connection over a pool of threads. If a Prolog engine contains the state for a connection, it must be possible to detach the engine from a thread and re-attach it to another thread handling the same connection.

```c
PL_engine_t PL_create_engine(PL_thread_attr_t *attributes)
Create a new Prolog engine. attributes is described with PL_thread_attach_engine(). Any thread can make this call after PL_initialise() returns success. The returned engine is not attached to any thread and lives until PL_destroy_engine() is used on the returned handle.

In the single-threaded version this call always returns NULL, indicating failure.

int PL_destroy_engine(PL_engine_t e)
Destroy the given engine. Destroying an engine is only allowed if the engine is not attached to any thread or attached to the calling thread. On success this function returns TRUE, on failure the return value is FALSE.

int PL_set_engine(PL_engine_t engine, PL_engine_t *old)
Make the calling thread ready to use engine. If old is non-NULL the current engine associated with the calling thread is stored at the given location. If engine equals PL_ENGINE_MAIN the initial engine is attached to the calling thread. If engine is PL_ENGINE_CURRENT the engine is not changed. This can be used to query the current engine. This call returns PL_ENGINE_SET if the engine was switched successfully, PL_ENGINE_INVAL if engine is not a valid engine handle and PL_ENGINE_INUSE if the engine is currently in use by another thread.

Engines can be changed at any time. For example, it is allowed to select an engine to initiate a Prolog goal, detach it and at a later moment execute the goal from another thread. Note, however, that the term_t, qid_t and fid_t types are interpreted relative to the engine for which they are created. Behaviour when passing one of these types from one engine to another is undefined.

In the single-threaded version this call only succeeds if engine refers to the main engine.
```

### 10.7 Multithreading and the XPCE graphics system

GUI applications written in XPCE can benefit from Prolog threads if they need to do expensive computations that would otherwise block the UI. The XPCE message passing system is guarded with a
single mutex, which synchronises both access from Prolog and activation through the GUI. In MS-Windows, GUI events are processed by the thread that created the window in which the event occurred, whereas in Unix/X11 they are processed by the thread that dispatches messages. In practice, the most feasible approach to graphical Prolog implementations is to control XPCE from a single thread and deploy other threads for (long) computations.

Traditionally, XPCE runs in the foreground (main) thread. We are working towards a situation where XPCE can run comfortably in a separate thread. A separate XPCE thread can be created using `pce_dispatch/1`. It is also possible to create this thread as the (pce) is loaded by setting the `xpce_threaded` to `true`.

Threads other than the thread in which XPCE runs are provided with two predicates to communicate with XPCE.

### `in_pce_thread(+Goal)`

Assuming XPCE is running in the foreground thread, this call gives background threads the opportunity to make calls to the XPCE thread. A call to `in_pce_thread/1` succeeds immediately, copying `Goal` to the XPCE thread. `Goal` is added to the XPCE event queue and executed synchronous to normal user events like typing and clicking.

### `in_pce_thread_sync(+Goal)`

Same as `in_pce_thread/1`, but wait for `Goal` to be completed. Success depends on the success of executing `Goal`. Variable bindings inside `Goal` are visible to the caller, but it should be noted that the values are being copied. If `Goal` throws an exception, this exception is re-thrown by `in_pce_thread/1`. If the calling thread is the ‘pce thread’, `in_pce_thread_sync/1` executes a direct meta-call. See also `in_pce_thread/1`.

Note that `in_pce_thread_sync/1` is expensive because it requires copying and thread communication. For example, `in_pce_thread_synctrue` runs at approximately 50,000 calls per second (AMD Phenom 9600B, Ubuntu 11.04).

### `pce_dispatch(+Options)`

Create a Prolog thread with the alias name `pce` for XPCE event handling. In the X11 version this call creates a thread that executes the X11 event-dispatch loop. In MS-Windows it creates a thread that executes a windows event-dispatch loop. The XPCE event-handling thread has the alias `pce`. `Options` specifies the thread attributes as `thread_create/3`. 
Where the term *coroutine* in Prolog typically refer to hooks triggered by *attributed variables* (section 8.1), SWI-Prolog provides two other forms of coroutines. Delimited continuations (see section 4.9) allow creating coroutines that run in the same Prolog engine by capturing and restarting the *continuation*. This section discusses *engines*, also known as *interactors*. The idea was developed by Paul Tarau [Tarau, 2011]. The API described in this chapter has been established together with Paul Tarau and Paulo Moura.

Engines are closely related to *threads* (section 10). An engine is a Prolog virtual machine that has its own stacks and (virtual) machine state. Unlike normal Prolog threads though, they are not associated with an operating system thread. Instead, you *ask* an engine for a next answer (*engine_next/2*). Asking an engine for the next answer attaches the engine to the calling operating system thread and cause it to run until the engine calls *engine_yield/1* or its associated goal completes with an answer, failure or an exception. After the engine yields or completes, it is detached from the operating system thread and the answer term is made available to the calling thread. Communicating with an engine is similar to communicating with a Prolog system though the terminal. In this sense engines are related to Pengines as provided by library *pengines*, but where Pengines aim primarily at accessing Prolog engines through the network, engines are in-process entities.

### 11.1 Examples using engines

We introduce engines by describing application areas and providing simple example programs. The predicates are defined in section 11.3. We identify the following application areas for engines.

1. Aggregating solutions from one or more goals. See section 11.1.1.

2. Access the terms produced in forward execution through backtracking without collecting all of them first. Section 11.1.1 illustrates this as well.

3. State accumulation and sharing. See section 11.1.2.

4. Scalable many-agent applications. See section 11.1.3.

#### 11.1.1 Aggregation using engines

Engines can be used to reason about solutions produced by a goal through backtracking. In this scenario we create an engine with the goal we wish to backtrack over and we enumerate all its solution using *engine_next/2*. This usage scenario competes with the all solution predicates (*findall/3*, *bagof/3*, etc.) and the predicates from library *aggregate*. Below we implement *findall/3* using engines.
The above is not a particularly attractive alternative for the built-in \texttt{findall/3}. It is mostly slower due to time required to create and destroy the engine as well as the (currently\footnote{The current implementation of engines is built on top of primitives that are not optimal for the engine use case. There is considerable opportunity to reduce the overhead.}) higher overhead of copying terms between engines than the overhead required by the dedicated representation used by \texttt{findall/3}.

It gets more interesting if we wish to combine answers from multiple backtracking predicates. Assume we have two predicates that, on backtracking, return ordered solutions and we wish to merge the two answer streams into a single ordered stream of answers. The solution in classical Prolog is below. It collects both answer sets, merges them using ordered set merging and extract the answers. The code is clean and short, but it doesn’t produce any answers before both generators are fully enumerated and it uses memory that is proportional to the combined set of answers.

$$\begin{align*}
\text{merge} & \text{(T1,G1, T2,G2, A) :-} \\
& \text{findall(T1, G1, L1),} \\
& \text{findall(T2, G2, L2),} \\
& \text{ord_union(L1, L2, Ordered),} \\
& \text{member(A, Ordered).}
\end{align*}$$

We can achieve the same using engines. We create two engines to generate the solutions to both our generators. Now, we can ask both for an answer, put the smallest in the answer set and ask the engine that created the smallest for its next answer, etc. This way we can create an ordered list of answers as above, but now without creating intermediate lists. We can avoid creating the intermediate list by introducing a third engine that controls the two generators and \texttt{yields} the answers rather than putting them in a list. This is a general example of turning a predicate that builds a set of terms into a non-deterministic predicate that produces the results on backtracking. The full code is below. Merging the answers of two generators, each generating a set of 10,000 integers is currently about 20\% slower than the code above, but the engine-based solution runs in constant space and generates the first solution immediately after both our generators have produced their first solution.

$$\begin{align*}
\text{:- meta_predicate merge(?,0, ?,0, -).}
\end{align*}$$
merge(T1,G1, T2,G2, A) :-
    engine_create(A, merge(T1,G1, T2,G2), E),
    repeat,
    (  engine_next(E, A)
    ->   true
    ;    !, fail
    ).

merge(T1,G1, T2,G2) :-
    engine_create(T1, G1, E1),
    engine_create(T2, G2, E2),
    (  engine_next(E1, S1)
    -> (  engine_next(E2, S2)
        -> order_solutions(S1, S2, E1, E2)
              ;     yield_remaining(S1, E1)
          )
        ;     engine_next(E2, S2),
              yield_remaining(S2, E2)
      ).

order_solutions(S1, S2, E1, E2) :- !,
    (  S1 @=< S2
    ->    engine_yield(S1),
         (  engine_next(E1, S11)
             -> order_solutions(S11, S2, E1, E2)
                   ;     yield_remaining(S2, E2)
         )
    ;     engine_yield(S2),
         (  engine_next(E2, S21)
             -> order_solutions(S1, S21, E1, E2)
                   ;     yield_remaining(S1, E1)
         )
    ).

yield_remaining(S, E) :-
    engine_yield(S),
    engine_next(E, S1),
    yield_remaining(S1, E).

11.1.2 State accumulation using engines

Applications that need to manage a state can do so by passing the state around in an additional argument, storing it in a global variable or update it in the dynamic database using `assertz/1` and `retract/1`. Both using an additional argument and a global variable (see `b_setval/2`), make the state subject to backtracking. This may or may not be desirable. If having a state is that subject to
backtracking is required, using an additional argument or backtrackable global variable is the right approach. Otherwise, non-backtrackable global variables (\texttt{nb.setval/2}) and dynamic database come into the picture, where global variables are always local to a thread and the dynamic database may or may not be shared between threads (see \texttt{thread.local/1}).

Engines bring an alternative that packages a state inside the engine where it is typically represented in a (threaded) Prolog variable. The state may be updated, while controlled backtracking to a previous state belongs to the possibilities. It can be accessed and updated by anyone with access to the engines’ handle. Using an engine to represent state has the following advantages:

- The programming style needed inside the engine is much more ‘Prolog friendly’, using \texttt{engine.fetch/1} to read a request and \texttt{engine.yield/1} to reply to it.
- The state is packaged and subject to (atom) garbage collection.
- The state may be accessed from multiple threads. Access to the state is synchronized without the need for explicit locks.

The example below implements a shared priority heap based on library \texttt{heaps}. The predicate \texttt{update_heap/1} shows the typical update loop for maintaining state inside an engine: fetch a command, update the state, yield with the reply and call the updater recursively. The update step is guarded against failure. For robustness one may also guard it against exceptions using \texttt{catch/3}. Note that \texttt{heap.get/3} passes the \texttt{Priority} and \texttt{Key} it wishes to delete from the heap such that if the unification fails, the heap remains unchanged.

The resulting heap is a global object with either a named or anonymous handle that evolves independently from the Prolog thread(s) that access it. If the heap is anonymous, it is subject to (atom) garbage collection.

```prolog
:- use_module(library(heaps)).

create_heap(E) :-
    empty_heap(H),
    engine_create(_, update_heap(H), E).

update_heap(H) :-
    engine_fetch(Command),
    ( update_heap(Command, Reply, H, H1) -> true
      ; H1 = H,
      Reply = false
    ),
    engine_yield(Reply),
    update_heap(H1).

update_heap(add(Priority, Key), true, H0, H) :-
    add_to_heap(H0, Priority, Key, H).
update_heap(get(Priority, Key), Priority-Key, H0, H) :-
    get_from_heap(H0, Priority, Key, H).
```
11.2. ENGINE RESOURCE USAGE

heap_add(Priority, Key, E) :-
    engine_post(E, add(Priority, Key), true).

heap_get(Priority, Key, E) :-
    engine_post(E, get(Priority, Key), Priority-Key).

11.1.3 Scalable many-agent applications

The final application area we touch are agent systems were we wish to capture an agent in a Prolog goal. Such systems can be implemented using threads (see section 10) that use thread_send_message/2 and thread_get_message/1 to communicate. The main problem is that each thread is associated by an operating system thread. OS threads are, depending on the OS, relatively expensive. Scalability of this design typically ends, depending on OS and hardware, somewhere between 1,000 and 100,000 agents.

Engines provide an alternative. A detached Prolog engine currently requires approximately 20 Kbytes memory on 64 bit hardware, growing with the size of the Prolog stacks. The Prolog stacks may be minimised by calling garbage_collect/0 followed by trim_stacks/0, providing a deep sleep mode. The set of agents, each represented by an engine can be controlled by a static or dynamic pool of threads. Scheduling the execution of agents and their communication is completely open and can be optimised to satisfy the requirements of the application.

This section needs an example. Preferably something that fits on one page and would not scale using threads. Engines might work nice to implement Antrank: An ant colony algorithm for ranking web pages.²

11.2 Engine resource usage

A Prolog engine consists of a virtual machine state that includes the Prolog stacks. An ‘empty’ engine requires about 20 KBytes of memory. This grows when the engine requires additional stack space. Anonymous engines are subject to atom garbage collection (see garbage_collect_atoms/0). Engines may be reclaimed immediately using engine_destroy/1. Calling engine_destroy/1 destroys the virtual machine state, while the handle itself is left to atom garbage collection. The virtual machine is reclaimed as soon as an engine produced its last result, failed or raised an exception. This implies that it is only advantageous to call engine_destroy/1 explicitly if you are not interested in further answers.

Engines that are expected to be left in inactive state for a prolonged time can be minimized by calling garbage_collect/0 and trim_stacks/0 (in that order) before calling engine_yield/1 or succeeding.

11.3 Engine predicate reference

This section documents the built-in predicates that deal with engines. In addition to these, most predicates dealing with threads and message queue can be used to access engines.

engine_create(+Template, :Goal, ?Engine) [det]
Create a new engine and unify Engine with a handle to it. Template and Goal form a pair similar to findall/3: the instantiation of Template becomes available through engine_next/2 after Goal succeeds. Options is a list of the following options. See thread_create/3 for details.

alias(+Name)
Give the engine a name. Name must be an atom. If this option is provided, Engine is unified with Name. The name space for engines is shared with threads and mutexes.

stack(+Bytes)
Set the stack limit for the engine. The default is inherited from the calling thread.

The Engine argument of engine_create/3 may be instantiated to an atom, creating an engine with the given alias.

engine_destroy(+Engine) [det]
Destroy Engine.

engine_next(+Engine, -Term) [semidet]
Ask the engine Engine to produce a next answer. On this first call on a specific engine, the Goal of the engine is started. If a previous call returned an answer through completion, this causes the engine to backtrack and finally, if the engine produces a previous result using engine_yield/1, execution proceeds after the engine_yield/1 call.

engine_next_reified(+Engine, -Term) [det]
Similar to engine_next/2, but instead of success, failure or or raising an exception, Term is unified with one of terms below. This predicate is provided primarily for compatibility with Lean Prolog.

the(Answer)
Goal succeeded with Template bound to Answer or Goal yielded with a term Answer.

no
Goal failed.

exception(Exception)
Goal raises the error Exception.

engine_post(+Engine, +Term) [det]
Make Term available to engine_fetch/1 inside the Engine. This call must be followed by a call to engine_next/2 and the engine must call engine_fetch/1.

engine_post(+Engine, +Term, -Reply) [det]
Combines engine_post/2 and engine_next/2.

engine_yield(+Term) [det]
Called from within the engine, causing engine_next/2 in the caller to return with Term. A subsequent call to engine_next/2 causes engine_yield/1 to 'return'. This predicate can only be called if the engine is not involved in a callback from C, i.e., when the engine calls a predicate defined in C that calls back Prolog it is not possible to use this predicate. Trying to do so results in a permission_error exception.
engine_fetch(Term) [det]
   Called from within the engine to fetch the term made available through engine_post/2 or engine_post/3. If no term is available an existence_error exception is raised.

engine_self(Engine) [det]
   Called from within the engine to get access to the handle to the engine itself.

is_engine(@Term) [semidet]
   True if Term is a reference to or the alias name of an existing engine.

current_engine(Engine) [nondet]
   True when Engine is an existing engine.
12

Foreign Language Interface

SWI-Prolog offers a powerful interface to C [Kernighan & Ritchie, 1978]. The main design objectives of the foreign language interface are flexibility and performance. A foreign predicate is a C function that has the same number of arguments as the predicate represented. C functions are provided to analyse the passed terms, convert them to basic C types as well as to instantiate arguments using unification. Non-deterministic foreign predicates are supported, providing the foreign function with a handle to control backtracking.

C can call Prolog predicates, providing both a query interface and an interface to extract multiple solutions from a non-deterministic Prolog predicate. There is no limit to the nesting of Prolog calling C, calling Prolog, etc. It is also possible to write the ‘main’ in C and use Prolog as an embedded logical engine.

12.1 Overview of the Interface

A special include file called SWI-Prolog.h should be included with each C source file that is to be loaded via the foreign interface. The installation process installs this file in the directory include in the SWI-Prolog home directory (?- current_prolog_flag(home, Home).). This C header file defines various data types, macros and functions that can be used to communicate with SWI-Prolog. Functions and macros can be divided into the following categories:

- Analysing Prolog terms
- Constructing new terms
- Unifying terms
- Returning control information to Prolog
- Registering foreign predicates with Prolog
- Calling Prolog from C
- Recorded database interactions
- Global actions on Prolog (halt, break, abort, etc.)

12.2 Linking Foreign Modules

Foreign modules may be linked to Prolog in two ways. Using static linking, the extensions, a (short) file defining main() which attaches the extension calls to Prolog, and the SWI-Prolog kernel distributed as a C library, are linked together to form a new executable. Using dynamic linking, the extensions
are linked to a shared library (.so file on most Unix systems) or dynamic link library (.DLL file on Microsoft platforms) and loaded into the running Prolog process.¹

12.2.1 What linking is provided?

The static linking schema can be used on all versions of SWI-Prolog. Whether or not dynamic linking is supported can be deduced from the Prolog flag open_shared_object (see current_prolog_flag/2). If this Prolog flag yields true, open_shared_object/2 and related predicates are defined. See section 12.2.3 for a suitable high-level interface to these predicates.

12.2.2 What kind of loading should I be using?

All described approaches have their advantages and disadvantages. Static linking is portable and allows for debugging on all platforms. It is relatively cumbersome and the libraries you need to pass to the linker may vary from system to system, though the utility program swipl-ld described in section 12.5 often hides these problems from the user.

Loading shared objects (DLL files on Windows) provides sharing and protection and is generally the best choice. If a saved state is created using qsave_program/[1,2], an initialization/1 directive may be used to load the appropriate library at startup.

Note that the definition of the foreign predicates is the same, regardless of the linking type used.

12.2.3 library(shlib): Utility library for loading foreign objects (DLLs, shared objects)

This section discusses the functionality of the (autoload) library(shlib), providing an interface to manage shared libraries. We describe the procedure for using a foreign resource (DLL in Windows and shared object in Unix) called mylib.

First, one must assemble the resource and make it compatible to SWI-Prolog. The details for this vary between platforms. The swipl-ld(1) utility can be used to deal with this in a portable manner. The typical commandline is:

```
swipl-ld -o mylib file.{c,o,cc,C} ...
```

Make sure that one of the files provides a global function install_mylib() that initialises the module using calls to PL_register_foreign(). Here is a simple example file mylib.c, which creates a Windows MessageBox:

```c
#include <windows.h>
#include <SWI-Prolog.h>

static foreign_t
pl_say_hello(term_t to)
{ char *a;
```

¹The system also contains code to load .o files directly for some operating systems, notably Unix systems using the BSD a.out executable format. As the number of Unix platforms supporting this quickly gets smaller and this interface is difficult to port and slow, it is no longer described in this manual. The best alternative would be to use the dld package on machines that do not have shared libraries.
if ( PL_get_atom_chars(to, &a) )
{
    MessageBox(NULL, a, "DLL test", MB_OK|MB_TASKMODAL);
    PL_succeed;
}
PL_fail;
}
install_t
install_mylib()
{
    PL_register_foreign("say_hello", 1, pl_say_hello, 0);
}

Now write a file mylib.pl:

:- module(mylib, [ say_hello/1 ]).
:- use_foreign_library(foreign(mylib)).

The file mylib.pl can be loaded as a normal Prolog file and provides the predicate defined in C.

use_foreign_library(+FileSpec)  [det]
use_foreign_library(+FileSpec, +Entry:atom)  [det]
Load and install a foreign library as load_foreign_library/1,2 and register the installation using initialization/2 with the option now. This is similar to using:

:- initialization(load_foreign_library(foreign(mylib))).

but using the initialization/1 wrapper causes the library to be loaded after loading of the file in which it appears is completed, while use_foreign_library/1 loads the library immediately. I.e. the difference is only relevant if the remainder of the file uses functionality of the C-library.

As of SWI-Prolog 8.1.22, use_foreign_library/1,2 is in provided as a built-in predicate that, if necessary, loads library(shlib). This implies that these directives can be used without explicitly loading library(shlib) or relying on demand loading.

qsave:compat_arch(Arch1, Arch2)  [semidet,multifile]
User definable hook to establish if Arch1 is compatible with Arch2 when running a shared object. It is used in saved states produced by qsave_program/2 to determine which shared object to load at runtime.

 See also foreign option in qsave_program/2 for more information.
12.2. LINKING FOREIGN MODULES

load_foreign_library(:FileSpec)  [det]
load_foreign_library(:FileSpec, +Entry:atom) [det]

Load a *shared object* or *DLL*. After loading the *Entry* function is called without arguments. The default entry function is composed from `=install_=`, followed by the file base-name. E.g., the load-call below calls the function *install_mylib()* if the platform prefixes extern functions with `=_=`, this prefix is added before calling.

```prolog
... load_foreign_library(foreign(mylib)), ...
```

FileSpec is a specification for absolute_file_name/3. If searching the file fails, the plain name is passed to the OS to try the default method of the OS for locating foreign objects. The default definition of file_search_path/2 searches `<prolog home>/lib/<arch>` on Unix and `<prolog home>/bin` on Windows.

See also use_foreign_library/1.2 are intended for use in directives.

unload_foreign_library(+FileSpec)  [det]
unload_foreign_library(+FileSpec, +Exit:atom) [det]

Unload a *shared object* or *DLL*. After calling the *Exit* function, the shared object is removed from the process. The default exit function is composed from `=uninstall_=`, followed by the file base-name.

current_foreign_library(?File, ?Public)

Query currently loaded shared libraries.

reload_foreign_libraries
Reload all foreign libraries loaded (after restore of a state created using qsave_program/2).

12.2.4 Low-level operations on shared libraries

The interface defined in this section allows the user to load shared libraries (`.so` files on most Unix systems, `.dll` files on Windows). This interface is portable to Windows as well as to Unix machines providing `dlopen(2)` (Solaris, Linux, FreeBSD, Irix and many more) or `shl_open(2)` (HP/UX). It is advised to use the predicates from section 12.2.3 in your application.

open_shared_object(+File, -Handle)

*File* is the name of a shared object file (DLL in MS-Windows). This file is attached to the current process, and *Handle* is unified with a handle to the library. Equivalent to `open_shared_object(File, Handle, [])`. See also `open_shared_object/3` and `load_foreign_library/1`.

On errors, an exception `shared_object(Action, Message)` is raised. *Message* is the return value from `dlerror()`.
open_shared_object(+File, -Handle, +Options)
   As open_shared_object/2, but allows for additional flags to be passed. Options is a list of atoms. now implies the symbols are resolved immediately rather than lazy (default). global implies symbols of the loaded object are visible while loading other shared objects (by default they are local). Note that these flags may not be supported by your operating system. Check the documentation of dlopen() or equivalent on your operating system. Unsupported flags are silently ignored.

close_shared_object(+Handle)
   Detach the shared object identified by Handle.

call_shared_object_function(+Handle, +Function)
   Call the named function in the loaded shared library. The function is called without arguments and the return value is ignored. Normally this function installs foreign language predicates using calls to PL_register_foreign().

12.2.5 Static Linking

Older versions of SWI-Prolog were shipped by default with a static library. In recent versions we no longer ship a static library because practically every OS properly supports dynamic linking without serious drawbacks and dynamic linking has several advantages. It is on many platforms required to be able to load SWI-Prolog foreign libraries (see use_foreign_library/1). Only on ELF based systems such as Linux we can load foreign libraries if the main executable is linked to export its global symbols (gcc -rdynamic option). Another advantage of dynamic libraries is that the user does not have to worry about libraries that this particular build of SWI-Prolog requires such as libgmp as well as OS specific libraries.

If one really wants a static library, use the CMake flag -DSWIPL_STATIC_LIB=ON while configuring a build from source. This causes building and installing libswipl_static.a. Note the .static postfix to avoid a name conflict on Windows between the import library and the static library.\(^2\)

12.3 Interface Data Types

12.3.1 Type term_t: a reference to a Prolog term

The principal data type is term_t. Type term_t is what Quintus calls QP_term_ref. This name indicates better what the type represents: it is a handle for a term rather than the term itself. Terms can only be represented and manipulated using this type, as this is the only safe way to ensure the Prolog kernel is aware of all terms referenced by foreign code and thus allows the kernel to perform garbage collection and/or stack-shifts while foreign code is active, for example during a callback from C.

A term reference is a C uintptr_t, representing the offset of a variable on the Prolog environment stack. A foreign function is passed term references for the predicate arguments, one for each argument. If references for intermediate results are needed, such references may be created using PL_new_term_ref() or PL_new_term_refs().

\(^2\)As is, the Windows build is cross-compiled using MinGW which produces libswipl_static.a. This file can, as far as we know, not be used by MSVC.
These references normally live till the foreign function returns control back to Prolog. Their scope can be explicitly limited using `PL_open_foreign_frame()` and `PL_close_foreign_frame()`.

A `term_t` always refers to a valid Prolog term (variable, atom, integer, float or compound term). A term lives either until backtracking takes us back to a point before the term was created, the garbage collector has collected the term, or the term was created after a `PL_open_foreign_frame()` and `PL_discard_foreign_frame()` has been called.

The foreign interface functions can either read, unify or write to term references. In this document we use the following notation for arguments of type `term_t`:

- `term_t +t` Accessed in read-mode. The `+` indicates the argument is ‘input’.
- `term_t -t` Accessed in write-mode.
- `term_t ?t` Accessed in unify-mode.

**WARNING** Term references that are accessed in ‘write’ (-) mode will refer to an invalid term if the term is allocated on the global stack and backtracking takes us back to a point before the term was written. Compound terms, dicts, large integers, rational numbers, floats and strings are all allocated on the global stack. Below is a typical scenario where this may happen. The first solution writes a term extracted from the solution into `a`. After the system backtracks due to `PL_next_solution()`, `a` becomes a reference to a term that no longer exists.

```c
term_t a = PL_new_term_ref();
...
query = PL_open_query(...);
while(PL_next_solution(query))
{ PL_get_arg(i, ..., a);
}
PL_close_query(query);
```

There are two solutions to this problem. One is to scope the term reference using `PL_open_foreign_frame()` and `PL_close_foreign_frame()` and makes sure it goes out of scope before backtracking happens. The other is to clear the term reference using `PL_put_variable()` before backtracking.

Term references are obtained in any of the following ways:

- **Passed as argument**
  The C functions implementing foreign predicates are passed their arguments as term references. These references may be read or unified. Writing to these variables causes undefined behaviour.

- **Created by `PL_new_term_ref()`**
  A term created by `PL_new_term_ref()` is normally used to build temporary terms or to be written by one of the interface functions. For example, `PL_get_arg()` writes a reference to the term argument in its last argument.

- **Created by `PL_new_term_refs(int n)`**
  This function returns a set of term references with the same characteristics as `PL_new_term_ref()`. See `PL_open_query()`.

---

3 This could have been avoided by trailing term references when data is written to them. This seriously hurts performance in some scenarios though. If this is desired, use `PL_put_variable()` followed by one of the `PL_unify_*()` functions.
• *Created by PL_copy_term_ref(term_t t)*

  Creates a new term reference to the same term as the argument. The term may be written to. See figure 12.2.

Term references can safely be copied to other C variables of type term_t, but all copies will always refer to the same term.

```c
void PL_copy_term_ref(term_t from)
{
    term_t t0 = PL_new_term_refs(2);
    term_t t1 = t0+1;
    ...
}
```

**term_t PL_new_term_ref()**

  Return a fresh reference to a term. The reference is allocated on the local stack. Allocating a term reference may trigger a stack-shift on machines that cannot use sparse memory management for allocation of the Prolog stacks. The returned reference describes a variable. Raise a resource exception and returns (term_t)0 on failure.

**term_t PL_new_term.refs(int n)**

  Return *n* new term references. The first term reference is returned. The others are *t + 1*, *t + 2*, etc. Raise a resource exception and returns (term_t)0 on failure. There are two reasons for using this function. PL_open_query() expects the arguments as a set of consecutive term references, and very time-critical code requiring a number of term references can be written as:

```c
pl_mypredicate(term_t a0, term_t a1)
{
    term_t t0 = PL_new_term_refs(2);
    term_t t1 = t0+1;
    ...
}
```

**term_t PL_copy_term_ref(term_t from)**

  Create a new term reference and make it point initially to the same term as *from*. This function is commonly used to copy a predicate argument to a term reference that may be written. Raise a resource exception and returns (term_t)0 on failure.

**void PL_reset_term.refs(term_t after)**

  Destroy all term references that have been created after *after*, including *after* itself. Any reference to the invalidated term references after this call results in undefined behaviour.

  Note that returning from the foreign context to Prolog will reclaim all references used in the foreign context. This call is only necessary if references are created inside a loop that never exits back to Prolog. See also PL_open_foreign_frame(), PL_close_foreign_frame() and PL_discard_foreign_frame().

### Interaction with the garbage collector and stack-shifter

Prolog implements two mechanisms for avoiding stack overflow: garbage collection and stack expansion. On machines that allow for it, Prolog will use virtual memory management to detect stack overflow and expand the runtime stacks. On other machines Prolog will reallocate the stacks and update all pointers to them. To do so, Prolog needs to know which data is referenced by C code. As all Prolog data known by C is referenced through term references (term_t), Prolog has all the information necessary to perform its memory management without special precautions from the C programmer.
12.3.2 Other foreign interface types

atom_t The type atom_t actually represents a blob (see section 12.4.9). Blobs are the super type of Prolog atoms, where atoms are blobs that represent textual content. Textual content is also represented by Prolog string (see section 5.2), which makes the general notion of string in Prolog ambiguous. The core idea behind blobs/atoms is to represent arbitrary content using a unique handle, such that comparing the handle is enough to prove equivalence of the content; i.e., given two different atom handles we know they represent different texts. This uniqueness feature allows the core engine to reason about atoms without considering their content. Strings (section 5.2) and blobs without the PL_BLOB_UNIQUE feature do not have this uniqueness property - to test for equality, the contents of the strings or blobs must be compared.

Because atoms are often used to represent (parts of) arbitrary input, intermediate results, and output of data processed by Prolog, it is necessary that atoms be subject to garbage collection (see garbage_collect_atoms/0). The garbage collection makes atoms ideal handles for arbitrary data structures, which are generalized as blobs. Blobs provide safe access to many internal Prolog data structures such as streams, clause references, etc.

functor_t A functor is the internal representation of a name/arity pair. They are used to find the name and arity of a compound term as well as to construct new compound terms. Like atoms they live for the whole Prolog session and are unique.

predicate_t Handle to a Prolog predicate. Predicate handles live forever (although they can lose their definition).

qid_t Query identifier. Used by PL_open_query(), PL_next_solution() and PL_close_query() to handle backtracking from C.

fid_t Frame identifier. Used by PL_open_foreign_frame() and PL_close_foreign_frame().

module_t A module is a unique handle to a Prolog module. Modules are used only to call predicates in a specific module.

foreign_t Return type for a C function implementing a Prolog predicate.

control_t Passed as additional argument to non-deterministic foreign functions. See PL_retry*() and PL_foreign_context*().

install_t Type for the install() and uninstall() functions of shared or dynamic link libraries. See section 12.2.3.

int64_t Actually part of the C99 standard rather than Prolog. As of version 5.5.6, Prolog integers are 64-bit on all hardware. The C99 type int64_t is defined in the stdint.h standard header and provides platform-independent 64-bit integers. Portable code accessing Prolog should use this type to exchange integer values. Please note that PL_get_long() can return FALSE on Prolog integers that cannot be represented as a C long. Robust code should not assume any of the integer fetching functions to succeed, even if the Prolog term is known to be an integer.
PL_ARITY_AS_SIZE

As of SWI-Prolog 7.3.12, the arity of terms has changed from `int` to `size_t`. To deal with this transition, all affecting functions have two versions, where the old name exchanges the arity as `int` and a new function with name `*_sz()` exchanges the arity as `size_t`. Up to 8.1.28, the default was to use the old `int` functions. As of 8.1.29/8.2.x, the default is to use `size_t` and the old behaviour can be restored by defining `PL_ARITY_AS_SIZE` to 0 (zero). This makes old code compatible, but the following warning is printed when compiling:

```
#warning "Term arity has changed from int to size_t."
#warning "Please update your code or use #define PL_ARITY_AS_SIZE 0."
```

To make the code compile silently again, change the types you use to represent arity from `int` to `size_t`. Please be aware that `size_t` is `unsigned`. At some point representing arity as `int` will be dropped completely.

12.4 The Foreign Include File

12.4.1 Argument Passing and Control

If Prolog encounters a foreign predicate at run time it will call a function specified in the predicate definition of the foreign predicate. The arguments `1,...,(arity)` pass the Prolog arguments to the goal as Prolog terms. Foreign functions should be declared of type `foreign_t`. Deterministic foreign functions have two alternatives to return control back to Prolog:

- `(return) foreign_t PL_succeed()`
  
  Succeed deterministically. `PL_succeed` is defined as `return TRUE`.

- `(return) foreign_t PL_fail()`
  
  Fail and start Prolog backtracking. `PL_fail` is defined as `return FALSE`.

Non-deterministic Foreign Predicates

By default foreign predicates are deterministic. Using the `PL_FA_NONDETERMINISTIC` attribute (see `PL_register_foreign()`) it is possible to register a predicate as a non-deterministic predicate. Writing non-deterministic foreign predicates is slightly more complicated as the foreign function needs context information for generating the next solution. Note that the same foreign function should be prepared to be simultaneously active in more than one goal. Suppose the `natural_number_below_n/2` is a non-deterministic foreign predicate, backtracking over all natural numbers lower than the first argument. Now consider the following predicate:

```
quotient_below_n(Q, N) :-
    natural_number_below_n(N, N1),
    natural_number_below_n(N, N2),
    Q =:= N1 / N2, !.
```

In this predicate the function `natural_number_below_n/2` simultaneously generates solutions for both its invocations.

Non-deterministic foreign functions should be prepared to handle three different calls from Prolog:
12.4. THE FOREIGN INCLUDE FILE

- **Initial call (PL_FIRST_CALL)**
  Prolog has just created a frame for the foreign function and asks it to produce the first answer.

- **Redo call (PL_REDO)**
  The previous invocation of the foreign function associated with the current goal indicated it was possible to backtrack. The foreign function should produce the next solution.

- **Terminate call (PL_PRUNED)**
  The choice point left by the foreign function has been destroyed by a cut. The foreign function is given the opportunity to clean the environment.

Both the context information and the type of call is provided by an argument of type `control_t` appended to the argument list for deterministic foreign functions. The macro `PL_foreign_control()` extracts the type of call from the control argument. The foreign function can pass a context handle using the `PL_retry*()` macros and extract the handle from the extra argument using the `PL_foreign_context*()` macro.

**(return) foreign_t PL_retry(intptr_t value)**

The foreign function succeeds while leaving a choice point. On backtracking over this goal the foreign function will be called again, but the control argument now indicates it is a ‘Redo’ call and the macro `PL_foreign_context()` returns the handle passed via `PL_retry()`. This handle is a signed value two bits smaller than a pointer, i.e., 30 or 62 bits (two bits are used for status indication). Defined as return `PL_retry(n)`. See also `PL_succeed()`.

**(return) foreign_t PL_retry_address(void *)**

As `PL_retry()`, but ensures an address as returned by `malloc()` is correctly recovered by `PL_foreign_context_address()`. Defined as return `PL_retry_address(n)`. See also `PL_succeed()`.

`int PL_foreign_control(control_t)`

Extracts the type of call from the control argument. The return values are described above. Note that the function should be prepared to handle the `PL_PRUNED` case and should be aware that the other arguments are not valid in this case.

`intptr_t PL_foreign_context(control_t)`

Extracts the context from the context argument. If the call type is `PL_FIRST_CALL` the context value is 0L. Otherwise it is the value returned by the last `PL_retry()` associated with this goal (both if the call type is `PL_REDO` or `PL_PRUNED`).

`void * PL_foreign_context_address(control_t)`

Extracts an address as passed in by `PL_retry_address()`.

`predicate_t PL_foreign_context_predicate(control_t)`

Fetch the Prolog predicate that is executing this function. Note that if the predicate is imported, the returned predicate refers to the final definition rather than the imported predicate; i.e., the module reported by `PL_predicate_info()` is the module in which the predicate is defined rather than the module where it was called. See also `PL_predicate_info()`.

Note: If a non-deterministic foreign function returns using `PL_succeed()` or `PL_fail()`, Prolog assumes the foreign function has cleaned its environment. No call with control argument `PL_PRUNED` will follow.

The code of figure 12.1 shows a skeleton for a non-deterministic foreign predicate definition.
typedef struct /* define a context structure */
{
...
} context;

foreign_t
my_function(term_t a0, term_t a1, control_t handle)
{
struct context * ctxt;

switch( PL_foreign_control(handle) )
{
    case PL_FIRST_CALL:
        if ( !(ctxt = malloc(sizeof *ctxt)) )
            return PL_resource_error("memory");
        <initialize ctxt>
        break;
    case PL_REDO:
        ctxt = PL_foreign_context_address(handle);
        break;
    case PL_PRUNED:
        ctxt = PL_foreign_context_address(handle);
        ...
        free(ctxt);
        return TRUE;
}

<find first/next solution from ctxt>
...
// We fail */
if ( <no_solution> )
{
    free(ctx);
    return FALSE;
}
// We succeed without a choice point */
if ( <last_solution> )
{
    free(ctx);
    return TRUE;
}
// We succeed with a choice point */
PL_retry_address(ctxt);
}

Figure 12.1: Skeleton for non-deterministic foreign functions
Yielding from foreign predicates

Starting with SWI-Prolog 8.5.5 we provide an experimental interface that allows using a SWI-Prolog engine for asynchronous processing. The idea is that an engine that calls a foreign predicate which would need to block may be suspended and later resumed. For example, consider an application that listens to a large number of network connections (sockets). SWI-Prolog offers three scenarios to deal with this:

1. Using a thread per connection. This model fits Prolog well as it allows to keep state in e.g. a DCG using `phrase_from_stream/2`. Maintaining an operating system thread per connection uses a significant amount of resources though.

2. Using `wait_for_input/3` a single thread can wait for many connections. Each time input arrives we must associate this with a state engine and advance this engine using a chunk of input of unknown size. Programming a state engine in Prolog is typically a tedious job. Although we can use delimited continuations (see section 4.9) in some scenarios this is not a universal solution.

3. Using the primitives from this section we can create an engine (see `PL_engine_create()`) to handle a connection with the same benefits as using threads. When the engine calls a foreign predicate that would need to block it calls `PL_yield_address()` to suspend the engine. An overall scheduler watches for ready connections and calls `PL_next_solution()` to resume the suspended engine. This approach allows processing many connections on the same operating system thread.

As is, these features can only used through the foreign language interface. It was added after discussion with with Mattijs van Otterdijk aiming for using SWI-Prolog together with Rust’s asynchronous programming support. Note that this feature is related to the engine API as described in section 11. It is different though. Where the Prolog engine API allows for communicating with a Prolog engine, the facilities of this section merely allow an engine to suspend, to be resumed later.

To prepare a query for asynchronous usage we first create an engine using `PL_create_engine()`. Next, we create a query in the engine using `PL_open_query()` with the flags `PL_Q_ALLOW_YIELD` and `PL_Q_EXT_STATUS`. A foreign predicate that needs to be capable of suspending must be registered using `PL_register_foreign()` and the flags `PL_FA_VARARGS` and `PL_FA_NONDETERMINISTIC`; i.e., only non-det predicates can yield. This is no restriction as non-det predicate can always return `TRUE` to indicate deterministic success. Finally, `PL_yield_address()` allows the predicate to yield control, preparing to resume similar to `PL_retry_address()` does for non-deterministic results. `PL_next_solution()` returns `PL_S_YIELD` if a predicate calls `PL_yield_address()` and may be resumed by calling `PL_next_solution()` using the same query id (`qid`). We illustrate the above using some example fragments.

First, let us create a predicate that can read the available input from a Prolog stream and yield if it would block. Note that our predicate must the `PL_FA_VARARGS` interface, which implies the first argument is in `a0`, the second in `a0+1`, etc.4

```prolog
/** read_or_block(+Stream, -String) is det.
 */
```

\(^4\)the other foreign interfaces do not support the yield API.
```c
#define BUFSIZE 4096

static foreign_t read_or_block(term_t a0, int arity, void *context)
{
    IOSTREAM *s;

    switch(PL_foreign_control(context))
    {
    case PL_FIRST_CALL:
        if ( PL_get_stream(a0, &s, SIO_INPUT) )
        {
            Sset_timeout(s, 0);
            break;
        }
        return FALSE;
    case PL_RESUME:
        s = PL_foreign_context_address(context);
        break;
    case PL_PRUNED:
        PL_release_stream(s);
        return TRUE;
    default:
        assert(0);
        return FALSE;
    }

    char buf[BUFSIZE];

    size_t n = Sfread(buf, sizeof buf[0], sizeof buf / sizeof buf[0], s);
    if ( n == 0 ) // timeout or error
    {
        if ( (s->flags&SIO_TIMEOUT) )
            PL_yield_address(s); // timeout: yield
        else
            return PL_release_stream(s); // raise error
    }
    else
    {
        PL_release_stream(s);
        return PL_unify_chars(a0+1, PL_STRING|REP_ISO_LATIN_1, n, buf);
    }
}

This function must be registered using PL_register_foreign():

```c
PL_register_foreign("read_or_block", 2, read_or_block,
    PL_FA_VARARGS|PL_FA_NONDETERMINISTIC);
```c

Next, create an engine to run handle_connection/1 on a Prolog stream. Note that we omitted most of the error checking for readability. Also note that we must make our engine current using PL_set_engine() before we can interact with it.
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```c
qid_t
start_connection(IOSTREAM *c)
{
  predicate_t p = PL_predicate("handle_connection", 1, "user");

  PL_engine_t e = PL_create_engine(NULL);
  PL_engine_t old;
  if ( PL_set_engine(e, &old) )
  {
    term_t av = PL_new_term_refs(1);
    PL_unify_stream(av+0, c);
    qid_t q = PL_open_query(e, NULL, PL_Q_NORMAL|PL_Q_ALLOW_YIELD|PL_Q_EXT_STATUS, p, av);
    PL_set_engine(old, NULL);
    return q;
  } /* else error */
}
```

Finally, our foreign code must manage this engine. Normally it will do so together with many other engines. First, we write a function that runs a query in the engine to which it belongs.\(^5\)

```c
int
PL_engine_next_solution(qid_t qid)
{
  PL_engine_t old;
  int rc;

  if ( PL_set_engine(PL_query_engine(qid), &old) == PL_ENGINE_SET )
  {
    rc = PL_next_solution(qid);
    PL_set_engine(old, NULL);
  } else
    rc = FALSE;

  return rc;
}
```

Now we can simply handle a connection using the loop below which restarts the query as long as it yields. Realistic code manages multiple queries and will (in this case) use the POSIX poll() or select() interfaces to activate the next query that can continue without blocking.

```c
int rc;
do
  { rc = PL_engine_next_solution(qid);
  } while( rc == PL_S_YIELD );
```

\(^5\)Possibly, future versions of `PL_next_solution()` may do that although the value is in general limited because interacting with the arguments of the query requires the query’s engine to be current anyway.
After the query completes it must be closed using `PL_close_query()` or `PL_cut_query()`. The engine may be destroyed using `PL_engine_destroy()` or reused for a new query.

**(return) `foreign_f PL_yield_address(void *)`**

Cause `PL_next_solution()` of the active query to return with `PL_S_YIELD`. A subsequent call to `PL_next_solution()` on the same query calls the foreign predicate again with the control status set to `PL_RESUME`, after which `PL_foreign_context_address()` retrieves the address passed to this function. The state of the Prolog engine is maintained, including `term_t` handles. If the passed address needs to be invalidated the predicate must do so when returning either `TRUE` or `FALSE`. If the engine terminates the predicate the predicate is called with status `PL_PRUNED`, in which case the predicate must cleanup.

**int `PL_can_yield(void)`**

Returns `TRUE` when called from inside a foreign predicate if the query that (indirectly) calls this foreign predicate can yield using `PL_yield_address()`. Returns `FALSE` when either there is no current query or the query cannot yield.

**Discussion**

Asynchronous processing has become popular with modern programming languages, especially those aiming at network communication. Asynchronous processing uses fewer resources than threads while avoiding most of the complications associated with thread synchronization if only a single thread is used to manage the various states. The lack of good support for destructive state updates in Prolog makes it attractive to use threads for dealing with multiple inputs. The fact that Prolog discourages using shared global data such as dynamic predicates typically makes multithreaded code easy to manage.

It is not clear how much scalability we gain using Prolog engines instead of Prolog threads. The only difference between the two is the operating system task. Prolog engines are still rather memory intensive, mainly depending on the stack sizes. Global garbage collection (atoms and clauses) need to process all the stacks of all the engines and thus limit scalability.

One possible future direction is to allow all (possibly) blocking Prolog predicates to use the yield facility and provide a Prolog API to manage sets of engines that use this type of yielding. As is, these features are designed to allow SWI-Prolog for cooperating with languages that provide asynchronous functions.

**12.4.2 Atoms and functors**

The following functions provide for communication using atoms and functors.

**atom_t `PL_new_atom(const char *)`**

Return an atom handle for the given C-string. This function always succeeds. The returned handle is valid as long as the atom is referenced (see section 12.4.2). Currently aborts the process with a *fatal error* on failure. Future versions may raise a resource exception and return `(atom_t)0`.

The following atoms are provided as macros, giving access to the empty list symbol and the name of the list constructor. Prior to version 7, `ATOM nil` is the same as `PL_new_atom("[]")` and `ATOM dot` is the same as `PL_new_atom("."`). This is no longer the case in SWI-Prolog version 7.

---

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\texttt{atom\_t ATOM\_nil(\textit{A})}

Tomic constant that represents the empty list. It is advised to use \texttt{PL\_get\_nil()}, \texttt{PL\_put\_nil()} or \texttt{PL\_unify\_nil()} where applicable.

\texttt{atom\_t ATOM\_dot(\textit{A})}

Tomic constant that represents the name of the list constructor. The list constructor itself is created using \texttt{PL\_new\_functor(ATOM\_dot,2)}. It is advised to use \texttt{PL\_get\_list()}, \texttt{PL\_put\_list()} or \texttt{PL\_unify\_list()} where applicable.

\texttt{atom\_t PL\_new\_atom\_mbchars(int rep, size\_t len, const char *s)}

This function generalizes \texttt{PL\_new\_atom()} and \texttt{PL\_new\_atom\_nchars()} while allowing for multiple encodings. The \textit{rep} argument is one of \texttt{REP\_ISO\_LATIN\_1}, \texttt{REP\_UTF8} or \texttt{REP\_MB}. If \textit{len} is \texttt{(size\_t)-1}, it is computed from \textit{s} using \texttt{strlen()}. Raises an exception if \textit{s} violates \textit{rep} and returns \texttt{(atom\_t)0}. For other error conditions, see \texttt{PL\_new\_atom()}.

\texttt{int PL\_atom\_mbchars(atom\_t atom, size\_t len, char *s, unsigned int flags)}

This function generalizes fetching the text associated with an atom. The encoding depends on the flags \texttt{REP\_UTF8}, \texttt{REP\_MB} or \texttt{REP\_ISO\_LATIN\_1}. Storage is defined by the \texttt{BUF\_*} flags as described with \texttt{PL\_get\_chars()}. The flag \texttt{CVT\_EXCEPTION} defines whether or not the function fails silently or raises a Prolog exception. This function may fail because \texttt{atom} is not a text atom but a \texttt{blob} (see section 12.4.9), conversion to the requested encoding is not possible or a resource error occurs.

\texttt{const char* PL\_atom\_chars(atom\_t atom)}

Deprecated. This function returns a pointer to the content represented by the atom or blob regardless of its type. New code that uses blobs should use the blob functions such as \texttt{PL\_blob\_data()} to get a pointer to the content, the size of the content, and the type of the content. Most applications that need to get text from a \texttt{term\_t} handle should use \texttt{PL\_atom\_nchars()}, \texttt{PL\_atom\_wchars()}, or \texttt{PL\_atom\_mbchars()}. If it is known that \texttt{atom} is a classical Prolog text atom, one can use \texttt{PL\_atom\_nchars()} to obtain the C string and its length (for ISO-Latin-1 atoms) or \texttt{PL\_atom\_wchars()} to obtain a C wide string (wchar\_t).

\texttt{functor\_t PL\_new\_functor(atom\_t name, int arity)}

Returns a functor identifier, a handle for the name/arity pair. The returned handle is valid for the entire Prolog session. Future versions may garbage collect functors as part of atom garbage collection. Currently aborts the process with a \texttt{fatal\_error} on failure. Future versions may raise a resource exception and return \texttt{(atom\_t)0}.

\texttt{atom\_t PL\_functor\_name(functor\_t f)}

Return an atom representing the name of the given functor.

\texttt{size\_t PL\_functor\_arity(functor\_t f)}

Return the arity of the given functor.

Atoms and atom garbage collection

With the introduction of atom garbage collection in version 3.3.0, atoms no longer live as long as the process. Instead, their lifetime is guaranteed only as long as they are referenced. In the single-threaded
version, atom garbage collections are only invoked at the *call-port*. In the multithreaded version (see chapter 10), they appear asynchronously, except for the invoking thread.

For dealing with atom garbage collection, two additional functions are provided:

```c
void PL_register_atom(atom_t atom)

Increment the reference count of the atom by one. PL_new_atom() performs this automatically, returning an atom with a reference count of at least one.\(^6\)

void PL_unregister_atom(atom_t atom)

Decrement the reference count of the atom. If the reference count drops below zero, an assertion error is raised.

Please note that the following two calls are different with respect to atom garbage collection:

```c
PL_unify_atom_chars(t, "text");
PL_unify_atom(t, PL_new_atom("text"));
```

The latter increments the reference count of the atom *text*, which effectively ensures the atom will never be collected. It is advised to use the *\_chars() or *\_nchars() functions whenever applicable.

### 12.4.3 Analysing Terms via the Foreign Interface

Each argument of a foreign function (except for the control argument) is of type *term_t*, an opaque handle to a Prolog term. Three groups of functions are available for the analysis of terms. The first just validates the type, like the Prolog predicates *var/1, atom/1*, etc., and are called *PL_is_*(). The second group attempts to translate the argument into a C primitive type. These predicates take a *term_t* and a pointer to the appropriate C type and return TRUE or FALSE depending on successful or unsuccessful translation. If the translation fails, the pointed-to data is never modified.

**Testing the type of a term**

```c
int PL_term_type(term_t)

Obtain the type of a term, which should be a term returned by one of the other interface predicates or passed as an argument. The function returns the type of the Prolog term. The type identifiers are listed below. Note that the extraction functions *PL_get_*() also validate the type and thus the two sections below are equivalent.

```c
if ( PL_is_atom(t) )
{ char *s;

    PL_get_atom_chars(t, &s);
    ...;
}
```

---

\(^6\)Otherwise asynchronous atom garbage collection might destroy the atom before it is used.
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```c
char *s;
if ( PL_get_atom_chars(t, &s) )
{ ...;
}
```

**Version 7** added `PL NIL`, `PL BLOB`, `PL LIST_PAIR` and `PL DICT`. Older versions classify `PL NIL` and `PL BLOB` as `PL ATOM`, `PL LIST_PAIR` as `PL TERM` and do not have dicts.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>PL VARIABLE</td>
<td>A variable or attributed variable</td>
</tr>
<tr>
<td>PL ATOM</td>
<td>A Prolog atom</td>
</tr>
<tr>
<td>PL NIL</td>
<td>The constant []</td>
</tr>
<tr>
<td>PL BLOB</td>
<td>A blob (see section 12.4.9)</td>
</tr>
<tr>
<td>PL STRING</td>
<td>A string (see section 5.2)</td>
</tr>
<tr>
<td>PL INTEGER</td>
<td>A integer</td>
</tr>
<tr>
<td>PL RATIONAL</td>
<td>A rational number</td>
</tr>
<tr>
<td>PL FLOAT</td>
<td>A floating point number</td>
</tr>
<tr>
<td>PL TERM</td>
<td>A compound term</td>
</tr>
<tr>
<td>PL LIST_PAIR</td>
<td>A list cell ([H</td>
</tr>
<tr>
<td>PL DICT</td>
<td>A dict (see section 5.4)</td>
</tr>
</tbody>
</table>

The functions `PL is⟨type⟩` are an alternative to `PL term type()`. The test `PL is variable(term)` is equivalent to `PL term type(term) == PL VARIABLE`, but the first is considerably faster. On the other hand, using a switch over `PL term type()` is faster and more readable then using an if-then-else using the functions below. All these functions return either TRUE or FALSE.

- **int PL is variable(term_t)**
  Returns non-zero if `term` is a variable.

- **int PL is ground(term_t)**
  Returns non-zero if `term` is a ground term. See also `ground/1`. This function is cycle-safe.

- **int PL is atom(term_t)**
  Returns non-zero if `term` is an atom.

- **int PL is string(term_t)**
  Returns non-zero if `term` is a string.

- **int PL is integer(term_t)**
  Returns non-zero if `term` is an integer.

- **int PL is rational(term_t)**
  Returns non-zero if `term` is a rational number (P/Q). Note that all integers are considered rational and this test thus succeeds for any term for which `PL is integer()` succeeds. See also `PL get mpz()` and `PL unify mpz()`.

- **int PL is float(term_t)**
  Returns non-zero if `term` is a float. Note that the corresponding `PL get float()` converts rationals (and thus integers).
int PL_is_callable(term_t)
  Returns non-zero if term is a callable term. See callable/1 for details.

int PL_is_compound(term_t)
  Returns non-zero if term is a compound term.

int PL_is_functor(term_t, functor_t)
  Returns non-zero if term is compound and its functor is functor. This test is equivalent to
  PL_get_functor(), followed by testing the functor, but easier to write and faster.

int PL_is_list(term_t)
  Returns non-zero if term is a compound term using the list constructor or the list terminator.
  See also PL_is_pair() and PL_skip_list().

int PL_is_pair(term_t)
  Returns non-zero if term is a compound term using the list constructor. See also
  PL_is_list() and PL_skip_list().

int PL_is_dict(term_t)
  Returns non-zero if term is a dict. See also PL_put_dict() and PL_get_dict_key().

int PL_is_atomic(term_t)
  Returns non-zero if term is atomic (not a variable or compound).

int PL_is_number(term_t)
  Returns non-zero if term is an rational (including integers) or float.

int PL_is_acyclic(term_t)
  Returns non-zero if term is acyclic (i.e. a finite tree).

Reading data from a term

The functions PL_get_*() read information from a Prolog term. Most of them take two arguments.
The first is the input term and the second is a pointer to the output value or a term reference. The
return value is TRUE or FALSE, indicating the success of the "get" operation. Most functions have a
related "_ex" function that raises an error if the argument is the operation cannot be completed. If the
Prolog term is not suitable, this is a type, domain or instantiation error. If the receiving C type cannot
represent the value this is a representation error.

For integers an alternative interface exists, which helps deal with the various integer types in C
and C++. They are convenient for use with _Generic selection or C++ overloading.

int PL_get_atom(term_t +t, atom_t *a)
  If t is an atom, store the unique atom identifier over a. See also PL_atom_chars() and
  PL_new_atom(). If there is no need to access the data (characters) of an atom, it is
  advised to manipulate atoms using their handle. As the atom is referenced by t, it will live
  at least as long as t does. If longer live-time is required, the atom should be locked using
  PL_register_atom().

int PL_get_atom_chars(term_t +t, char **s)
  If t is an atom, store a pointer to a 0-terminated C-string in s. It is explicitly not allowed
to modify the contents of this string. Some built-in atoms may have the string allocated in read-only memory, so ‘temporary manipulation’ can cause an error.

```c
int PL_get_string_chars(term_t *t, char **s, size_t *len)
```

If `t` is a string object, store a pointer to a 0-terminated C-string in `s` and the length of the string in `len`. Note that this pointer is invalidated by backtracking, garbage collection and stack-shifts, so generally the only safe operations are to pass it immediately to a C function that doesn’t involve Prolog.

```c
int PL_get_chars(term_t *t, char **s, unsigned flags)
```

Convert the argument term `t` to a 0-terminated C-string. `flags` is a bitwise disjunction from two groups of constants. The first specifies which term types should be converted and the second how the argument is stored. Below is a specification of these constants. BUF_STACK implies, if the data is not static (as from an atom), that the data is pushed on a stack. If BUF_MALLOC is used, the data must be freed using PL_free() when no longer needed.

With the introduction of wide characters (see section 2.19.1), not all atoms can be converted into a `char*`. This function fails if `t` is of the wrong type, but also if the text cannot be represented. See the REP_* flags below for details. See also PL_get_wchars().

- **CVT_ATOM**
  Convert if term is an atom.

- **CVT_STRING**
  Convert if term is a string.

- **CVT_LIST**
  Convert if term is a list of of character codes.

- **CVT_INTEGER**
  Convert if term is an integer.

- **CVT_FLOAT**
  Convert if term is a float. The characters returned are the same as `write/1` would write for the floating point number.

- **CVT_NUMBER**
  Convert if term is an integer or float.

- **CVT_ATOMIC**
  Convert if term is atomic.

- **CVT_VARIABLE**
  Convert variable to print-name

- **CVT_WRITE**
  Convert any term that is not converted by any of the other flags using `write/1`. If no BUF_* is provided, BUF_STACK is implied.

- **CVT_WRITE_CANonical**
  As CVT_WRITE, but using `write_canonical/2`.

- **CVT_WRITEQ**
  As CVT_WRITE, but using `writeq/2`.

- **CVT_ALL**
  Convert if term is any of the above, except for CVT_VARIABLE and CVT_WRITE*. 

CVT EXCEPTION
If conversion fails due to a type error, raise a Prolog type error exception in addition to failure.

BUF_DISCARDABLE
Data must copied immediately.

BUF_STACK
Data is stored on a stack. The older BUF_RING is an alias for BUF_STACK. See section 12.4.13.

BUF_MALLOC
Data is copied to a new buffer returned by PL_malloc(3). When no longer needed the user must call PL_free() on the data.

REP_ISO_LATIN_1
Text is in ISO Latin-1 encoding and the call fails if text cannot be represented. This flag has the value 0 and is thus the default.

REP_UTF8
Convert the text to a UTF-8 string. This works for all text.

REP_MB
Convert to default locale-defined 8-bit string. Success depends on the locale. Conversion is done using the wcrtomb() C library function.

```
int PL_get_list_chars(+term t, char **s, unsigned flags)
    Same as PL_get_chars (l, s, CVT_LIST—flags), provided flags contains none of the CVT_* flags.

int PL_get_integer(+term t, int *i)
    If t is a Prolog integer, assign its value over i. On 32-bit machines, this is the same as PL_get_long(), but avoids a warning from the compiler. See also PL_get_long() and PL_get_integer_ex().

int PL_get_long(term t +t, long *i)
    If i is a Prolog integer that can be represented as a long, assign its value over i. If t is an integer that cannot be represented by a C long, this function returns FALSE. If t is a floating point number that can be represented as a long, this function succeeds as well. See also PL_get_int64() and PL_get_long_ex().

int PL_get_int64(term t +t, int64_t *i)
    If i is a Prolog integer or float that can be represented as a int64_t, assign its value over i. See also PL_get_int64_ex().

int PL_get_uint64(term t +t, uint64_t *i)
    If t is a Prolog integer that can be represented as a uint64_t, assign its value over i. Note that this requires GMP support for representing uint64_t values with the high bit set. See also PL_get_uint64_ex().

int PL_getintptr(term t +t, intptr_t *i)
    Get an integer that is at least as wide as a pointer. On most platforms this is the same as PL_get_long(), but on Win64 pointers are 8 bytes and longs only 4. Unlike PL_get_pointer(), the value is not modified.
```
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int PL_get_bool(term_t +t, int *val)
If t has the value true, false, set val to the C constant TRUE or FALSE and return success, otherwise return failure. The values on, 1, off, const0 and are also accepted.

int PL_get_pointer(term_t +t, void **ptr)
Together with PL_put_pointer() and PL_unify_pointer(), these functions allow representing a C pointer as a Prolog integer. The integer value is derived from the pointer, but not equivalent. The translation aims at producing smaller integers that fit more often in the tagged integer range. Representing C pointers as integers is unsafe. The blob API described in section 12.4.9 provides a safe way for handling foreign resources that cooperates with Prolog garbage collection.

int PL_get_float(term_t +t, double *f)
If t is a float, integer or rational number, its value is assigned over f. Note that if t is an integer or rational conversion may fail because the number cannot be represented as a float.

int PL_get_functor(term_t +t, functor_t *f)
If t is compound or an atom, the Prolog representation of the name-arity pair will be assigned over f. See also PL_get_name arity() and PL_is_functor().

int PL_get_name arity(term_t +t, atom_t *name, size_t *arity)
If t is compound or an atom, the functor name will be assigned over name and the arity over arity (either or both may be NULL). See also PL_get_functor() and PL_is_functor().

int PL_get_compound_name arity(term_t +t, atom_t *name, size_t *arity)
If t is compound term, the functor name will be assigned over name and the arity over arity. This is the same as PL_get_name arity(), but this function fails if t is an atom.

int PL_get_module(term_t +t, module_t *module)
If t is an atom, the system will look up or create the corresponding module and assign an opaque pointer to it over module.

int PL_get_arg(size_t index, term_t +t, term_t -a)
If t is compound and index is between 1 and arity (inclusive), assign a with a term reference to the argument.

int _PL_get_arg(size_t index, term_t +t, term_t -a)
Same as PL_get_arg(), but no checking is performed, neither whether t is actually a term nor whether index is a valid argument index.

int PL_get_dict_key(atom_t key, term_t +dict, term_t -value)
If dict is a dict, get the associated value in value. Fails silently if key does not appear in dict or if if dict is not a dict.

Exchanging text using length and string
All internal text representation in SWI-Prolog is represented using char * plus length and allow for 0-bytes in them. The foreign library supports this by implementing a *nchars() function for each applicable *chars() function. Below we briefly present the signatures of these functions. For full documentation consult the *_chars() function.
int PL_get_atom_nchars(term_t t, size_t *len, char **s)
    See PL_get_atom_chars().

int PL_get_list_nchars(term_t t, size_t *len, char **s)
    See PL_get_list_chars().

int PL_get_nchars(term_t t, size_t *len, char **s, unsigned int flags)
    See PL_get_chars().

int PL_put_atom_nchars(term_t t, size_t len, const char *s)
    See PL_put_atom_chars().

int PL_put_string_nchars(term_t t, size_t len, const char *s)
    See PL_put_string_chars().

int PL_put_list_ncodes(term_t t, size_t len, const char *s)
    See PL_put_list_codes().

int PL_put_list_nchars(term_t t, size_t len, const char *s)
    See PL_put_list_chars().

int PL_unify_atom_nchars(term_t t, size_t len, const char *s)
    See PL_unify_atom_chars().

int PL_unify_string_nchars(term_t t, size_t len, const char *s)
    See PL_unify_string_chars().

int PL_unify_list_ncodes(term_t t, size_t len, const char *s)
    See PL_unify_codes().

int PL_unify_list_nchars(term_t t, size_t len, const char *s)
    See PL_unify_list_chars().

In addition, the following functions are available for creating and inspecting atoms:

atom_t PL_new_atom_nchars(size_t len, const char *s)
    Create a new atom as PL_new_atom(), but using the given length and characters. If len is
    (size_t)-1, it is computed from s using strlen(). See PL_new_atom() for error handling.

const char * PL_atom_nchars(atom_t a, size_t *len)
    Extract the text and length of an atom. If you do not need the length, pass NULL as the value
    of len. If PL_atom_nchars() is called for a blob, NULL is returned.

Wide-character versions

Support for exchange of wide-character strings is still under consideration. The functions dealing
with 8-bit character strings return failure when operating on a wide-character atom or Prolog string
object. The functions below can extract and unify both 8-bit and wide atoms and string objects. Wide
character strings are represented as C arrays of objects of the type pl_wchart_t, which is guaranteed
to be the same as wchar_t on platforms supporting this type. For example, on MS-Windows, this
represents a 16-bit UTF-16 string, while using the GNU C library (glibc) this represents 32-bit UCS4
characters.
atom_t PL_new_atom_wchars(size_t len, const pl wchar_t *s)
Create atom from wide-character string as PL_new_atom_nchars() does for ISO-Latin-1 strings. If s only contains ISO-Latin-1 characters a normal byte-array atom is created. If len is (size_t)-1, it is computed from s using wcslen(). See PL_new_atom() for error handling.

const pl wchar_t* PL_atom_wchars(atom_t atom, size_t *len)
Extract characters from a wide-character atom. Succeeds on any atom marked as ‘text’. If the underlying atom is a wide-character atom, the returned pointer is a pointer into the atom structure. If the atom is represented as an ISO-Latin-1 string, the returned pointer comes from Prolog’s ‘buffer stack’ (see section 12.4.13).

int PL_get_wchars(term_t t, size_t *len, pl wchar_t **s, unsigned flags)
Wide-character version of PL_get_chars(). The flags argument is the same as for PL_get_chars(). Note that this operation may return a pointer into Prolog’s ‘buffer stack’ (see section 12.4.13).

int PL_unify_wchars(term_t t, int type, size_t len, const pl wchar_t *s)
Unify t with a textual representation of the C wide-character array s. The type argument defines the Prolog representation and is one of PL_ATOM, PL_STRING, PL_CODE_LIST or PL_CHAR_LIST.

int PL_unify_wchars_diff(term_t +t, term_t -tail, int type, size_t len, const pl wchar_t *s)
Difference list version of PL_unify_wchars(), only supporting the types PL_CODE_LIST and PL_CHAR_LIST. It serves two purposes. It allows for returning very long lists from data read from a stream without the need for a resizing buffer in C. Also, the use of difference lists is often practical for further processing in Prolog. Examples can be found in packages/clib/readutil.c from the source distribution.

Reading a list
The functions from this section are intended to read a Prolog list from C. Suppose we expect a list of atoms; the following code will print the atoms, each on a line:

```c
foreign_t pl_write_atoms(term_t l)
{ term_t head = PL_new_term_ref(); /* the elements */
  term_t list = PL_copy_term_ref(l); /* copy (we modify list) */

  while( PL_get_list(list, head, list) )
  { char *s;

    if ( PL_get_atom_chars(head, &s) )
      printf("%s\n", s);
    else
      PL_fail;
  }

  return PL_get_nil(list); /* test end for [] */
}
```
Note that as of version 7, lists have a new representation unless the option \texttt{--traditional} is used. See section 5.1.

\begin{verbatim}
int PL_get_list(term_t +l, term_t -h, term_t -t)
    If \( l \) is a list and not the empty list, assign a term reference to the head to \( h \) and to the tail to \( t \).

int PL_get_head(term_t +l, term_t -h)
    If \( l \) is a list and not the empty list, assign a term reference to the head to \( h \).

int PL_get_tail(term_t +l, term_t -t)
    If \( l \) is a list and not the empty list, assign a term reference to the tail to \( t \).

int PL_get_nil(term_t +l)
    Succeeds if \( l \) represents the list termination constant.

int PL_skip_list(term_t +list, term_t -tail, size_t *len)
    This is a multi-purpose function to deal with lists. It allows for finding the length of a list, checking whether something is a list, etc. The reference \texttt{tail} is set to point to the end of the list, \texttt{len} is filled with the number of list-cells skipped, and the return value indicates the status of the list:

    \textbf{PL\_LIST}
    The list is a ‘proper’ list: one that ends in the list terminator constant and \texttt{tail} is filled with the terminator constant.

    \textbf{PL\_PARTIAL\_LIST}
    The list is a ‘partial’ list: one that ends in a variable and \texttt{tail} is a reference to this variable.

    \textbf{PL\_CYCLIC\_TERM}
    The list is cyclic (e.g. \( X = [a—X] \)). \texttt{tail} points to an arbitrary cell of the list and \texttt{len} is at most twice the cycle length of the list.

    \textbf{PL\_NOT\_A\_LIST}
    The term \texttt{list} is not a list at all. \texttt{tail} is bound to the non-list term and \texttt{len} is set to the number of list-cells skipped.

    It is allowed to pass 0 for \texttt{tail} and \texttt{NULL} for \texttt{len}.
\end{verbatim}

\textbf{Processing option lists and dicts}

\begin{verbatim}
int PL_scan_options(term_t options, int flags, const char* opttype, PL_option_t specs[], ...)
    Process an option list as we find with, e.g., write_term/2 and many other builtin predicates. This function takes an option list (or dict) and in the variadic argument list pointers that receive the option values. \texttt{PL\_scan\_options()} takes care of validating the list, ensuring the list is not cyclic, validating the option type and storing the converted values using the supplied pointers.

    Below is an example. While \texttt{PL\_option\_t} is a struct, its members are initialised using the \texttt{PL\_OPTION()} macro. The data structure is not constant because \texttt{PL\_scan\_options()} adds the option names as \texttt{atoms} to speed up option processing. The macro \texttt{PL\_OPTIONS\_END} terminates the option list.
\end{verbatim}
static PL_option_t mypred_options[] =
{ PL_OPTION("quoted", OPT_BOOL),
  PL_OPTION("length", OPT_SIZE),
  PL_OPTION("callback", OPT_TERM),
  PL_OPTIONS_END
};

static foreign_t
mypred(term_t a1, term_t options)
{ int quoted = FALSE;
  size_t length = 10;
  term_t callback = 0;

  if ( !PL_scan_options(options, 0, "mypred_options", mypred_options,
                         &quoted, &length, &callback) )
    return FALSE;

  <implement mypred>
}

The only defined value for flags is currently OPT_ALL, which causes this function to raise a domain error if an option is passed that is not in specs. Default in SWI-Prolog is to silently ignore unknown options, unless the Prolog flag iso is true. The opttype argument defines the type (group) of the options, e.g., "write_option". Option types are defined by the ISO standard. SWI-Prolog only uses this if OPT_ALL is specified, to raise a domain error of the indicated type if some option is unused. The type name is normally the name of the predicate followed by _option or the name of a representative of a group of predicates to which the options apply.

Defined option types and their corresponding pointer type are described below.

OPT_BOOL int
  Convert the option value to a bool. This converts the values described by PL_get_bool(). In addition, an option without a value (i.e., a plain atom that denotes the option name) can act as a boolean TRUE.

OPT_INT int
OPT_INT64 int64_t
OPT_UINT64 uint64_t
OPT_SIZE size_t
OPT_DOUBLE double
  Numeric values of various types. Raises an error if the Prolog value cannot be represented by the C type.

OPT_STRING char*
  Uses PL_get_chars() using the flags CVT_ALL|REP_UTF8|BUF_STACK|CVT_EXCEPTION. The buffered string must be guarded using PL_STRINGS_MARK() and PL_STRINGS_RELEASE().
OPT_ATOM atom_t
Accepts an atom. Note that if the C function that implements the predicate wishes to keep hold of the atom after it returns it must use PL_register_atom().

OPT_TERM term_t
Accepts an arbitrary Prolog term. The term handle is scoped by the foreign predicate invocation. Terms can be preserved using PL_record().

The ISO standard demands that if an option is repeated the last occurrence holds. This implies that PL_scan_options() must scan the option list to the end.

An example: defining write/1 in C

Figure 12.2 shows a simplified definition of write/1 to illustrate the described functions. This simplified version does not deal with operators. It is called display/1, because it mimics closely the behaviour of this Edinburgh predicate.

12.4.4 Constructing Terms

Terms can be constructed using functions from the PL_put_*() and PL_cons_*() families. This approach builds the term ‘inside-out’, starting at the leaves and subsequently creating compound terms. Alternatively, terms may be created ‘top-down’, first creating a compound holding only variables and subsequently unifying the arguments. This section discusses functions for the first approach. This approach is generally used for creating arguments for PL_call() and PL_open_query().

int PL_put_variable(term_t -t)
Put a fresh variable in the term, resetting the term reference to its initial state.\(^7\)

int PL_put_atom(term_t -t, atom_t a)
Put an atom in the term reference from a handle. See also PL_new_atom() and PL_atom_chars().

int PL_put_bool(term_t -t, int val)
Put one of the atoms true or false in the term reference. See also PL_put_atom(), PL_unify_bool() and PL_get_bool().

int PL_put_chars(term_t -t, int flags, size_t len, const char *chars)
New function to deal with setting a term from a char* with various encodings. The flags argument is a bitwise or specifying the Prolog target type and the encoding of chars. A Prolog type is one of PL_ATOM, PL_STRING, PL_CODE_LIST or PL_CHAR_LIST. A representation is one of REP_ISO_LATIN_1, REP_UTF8 or REP_MB. See PL_get_chars() for a definition of the representation types. If len is -1 chars must be zero-terminated and the length is computed from chars using strlen().

int PL_put_atom_chars(term_t -t, const char *chars)
Put an atom in the term reference constructed from the zero-terminated string. The string itself will never be referenced by Prolog after this function.

\(^7\)Older versions created a variable on the global stack.
foreign_t
pl_display(term_t t)
{ functor_t functor;
  int arity, len, n;
  char *s;

  switch( PL_term_type(t) )
  { case PL_VARIABLE:
    case PL_ATOM:
    case PL_INTEGER:
    case PL_FLOAT:
      PL_get_chars(t, &s, CVT_ALL);
      Sprintf("%s", s);
      break;
    case PL_STRING:
      PL_get_string_chars(t, &s, &len);
      Sprintf("\"%s\"", s);
      break;
    case PL_TERM:
      { term_t a = PL_new_term_ref();

        PL_get_name_arity(t, &name, &arity);
        Sprintf("%s\(", PL_atom_chars(name));
        for(n=1; n<=arity; n++)
          { PL_get_arg(n, t, a);
            if ( n > 1 )
              Sprintf("\", ");
            pl_display(a);
          }
        Sprintf("\)\n");
        break;
      }
    default:
      PL_fail; /* should not happen */
  }

  PL_succeed;
}
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int PL_put_string_chars(term_t -t, const char *chars)
Put a zero-terminated string in the term reference. The data will be copied. See also
PL_put_string_nchars().

int PL_put_string_nchars(term_t -t, size_t len, const char *chars)
Put a string, represented by a length/start pointer pair in the term reference. The data will be
copied. This interface can deal with 0-bytes in the string. See also section 12.4.23.

int PL_put_list_chars(term_t -t, const char *chars)
Put a list of ASCII values in the term reference.

int PL_put_integer(term_t -t, long i)
Put a Prolog integer in the term reference.

int PL_put_int64(term_t -t, int64_t i)
Put a Prolog integer in the term reference.

int PL_put_uint64(term_t -t, uint64_t i)
Put a Prolog integer in the term reference. Note that unbounded integer support is required for
uint64_t values with the highest bit set to 1. Without unbounded integer support, too large
values raise a representation_error exception.

int PL_put_pointer(term_t -t, void *ptr)
Put a Prolog integer in the term reference. Provided ptr is in the ‘malloc()-area’,
PL_get_pointer() will get the pointer back.

int PL_put_float(term_t -t, double f)
Put a floating-point value in the term reference.

int PL_put_functor(term_t -t, functor_t functor)
Create a new compound term from functor and bind t to this term. All arguments of the term
will be variables. To create a term with instantiated arguments, either instantiate the arguments
using the PL_unify_*() functions or use PL_cons_functor().

int PL_put_list(term_t -l)
As PL_put_functor(), using the list-cell functor. Note that on classical Prolog systems
or in SWI-Prolog using the option --traditional, this is ./2, while on SWI-Prolog
version 7 this is [ ]/2.

int PL_put_nil(term_t -l)
Put the list terminator constant in l. Always returns TRUE. Note that in classical Pro-
log systems or in SWI-Prolog using the option --traditional, this is the same as
PL_put_atom_chars("["]). See section 5.1.

int PL_put_term(term_t -t1, term_t +t2)
Make t1 point to the same term as t2. Under the unusual condition that t2 is a fresh term
reference this function requires a global stack cell and may thus return FALSE and leave a
resource exception in the environment.

int PL_cons_functor(term_t -t, functor_t f, ...)
Create a term whose arguments are filled from a variable argument list holding the same number
of term_t objects as the arity of the functor. To create the term animal(gnu, 50), use:
After this sequence, the term references \( a1 \) and \( a2 \) may be used for other purposes.

```c
int PL_cons_functor_v(term_t h, functor_t f, term_t a0)
Create a compound term like PL_cons_functor(), but \( a0 \) is an array of term references as returned by PL_new_term_refs(). The length of this array should match the number of arguments required by the functor.

int PL_cons_list(term_t l, term_t +h, term_t +t)
Create a list (cons-) cell in \( l \) from the head \( h \) and tail \( t \). The code below creates a list of atoms from a char **. The list is built tail-to-head. The PL_unify_*() functions can be used to build a list head-to-tail.

```
a resource error exception in the environment), −1 if some key or the tag is invalid and −2 if there are duplicate keys.

### 12.4.5 Unifying data

The functions of this section *unify* terms with other terms or translated C data structures. Except for `PL_unify()`, these functions are specific to SWI-Prolog. They have been introduced because they shorten the code for returning data to Prolog and at the same time make this more efficient by avoiding the need to allocate temporary term references and reduce the number of calls to the Prolog API. Consider the case where we want a foreign function to return the host name of the machine Prolog is running on. Using the `PL_get_*()` and `PL_put_*()` functions, the code becomes:

```c
foreign_t
pl_hostname(term_t name)
{
    char buf[100];

    if ( gethostname(buf, sizeof(buf)) )
    {
        term_t tmp = PL_new_term_ref();

        PL_put_atom_chars(tmp, buf);
        return PL_unify(name, tmp);
    }

    PL_fail;
}
```

Using `PL_unify_atom_chars()`, this becomes:

```c
foreign_t
pl_hostname(term_t name)
{
    char buf[100];

    if ( gethostname(buf, sizeof(buf)) )
        return PL_unify_atom_chars(name, buf);

    PL_fail;
}
```

Note that unification functions that perform multiple bindings may leave part of the bindings in case of failure. See `PL_unify()` for details.

```c
int PL_unify(term_t *t1, term_t *t2)
{
    Unify two Prolog terms and return TRUE on success.

    Care is needed if `PL_unify()` returns FAIL and the foreign function does not immediately return to Prolog with FAIL. Unification may perform multiple changes to either t1 or t2. A failing unification may have created bindings before failure is detected. *Already created bindings are not undone.* For example, calling `PL_unify()` on `a(X, a)` and `a(c, b)` binds `X` to `c` and
```
fails when trying to unify $a$ to $b$. If control remains in C or even if we want to return success to Prolog, we must undo such bindings. This is achieved using `PL_open_foreign_frame()` and `PL_rewind_foreign_frame()`, as shown in the snippet below.

```c
{ fid_t fid = PL_open_foreign_frame();

    ...

    if ( !PL_unify(t1, t2) )
        PL_rewind_foreign_frame(fid);

    ...

    PL_close_foreign_frame(fid);
}
```

In addition, `PL_unify()` may have failed on an exception, typically a resource (stack) overflow. This can be tested using `PL_exception()`, passing 0 (zero) for the query-id argument. Foreign functions that encounter an exception must return `FAIL` to Prolog as soon as possible or call `PL_clear_exception()` if they wish to ignore the exception.

```c
int PL_unify_atom(term_t ?t, atom_t a)
    Unify $t$ with the atom $a$ and return non-zero on success.

int PL_unify_bool(term_t ?t, int a)
    Unify $t$ with either false or true, according to whether $a$ is zero or non-zero. If $t$ is instantiated, off and on are also accepted.

int PL_unify_chars(term_t ?t, int flags, size_t len, const char *chars)
    New function to deal with unification of `char*` with various encodings to a Prolog representation. The `flags` argument is a bitwise or specifying the Prolog target type and the encoding of `chars`. A Prolog type is one of `PL_ATOM`, `PL_STRING`, `PL_CODE_LIST` or `PL_CHAR_LIST`. A representation is one of `REP_ISO_LATIN1`, `REP_UTF8` or `REP_MB`. See `PL_get_chars()` for a definition of the representation types. If `len` is -1 `chars` must be zero-terminated and the length is computed from `chars` using `strlen()`.

If `flags` includes `PL_DIFF_LIST` and type is one of `PL_CODE_LIST` or `PL_CHAR_LIST`, the text is converted to a difference list. The tail of the difference list is $t + 1$.

```c
int PL_unify_atom_chars(term_t ?t, const char *chars)
    Unify $t$ with an atom created from `chars` and return non-zero on success.

int PL_unify_list_chars(term_t ?t, const char *chars)
    Unify $t$ with a list of ASCII characters constructed from `chars`.

void PL_unify_string_chars(term_t ?t, const char *chars)
    Unify $t$ with a Prolog string object created from the zero-terminated string `chars`. The data will be copied. See also `PL_unify_string_nchars()`.

int PL_unify_integer(term_t ?t, intptr_t n)
    Unify $t$ with a Prolog integer from $n$. 
```
int PL_unify_int64(term_t ?t, int64_t n)
    Unify t with a Prolog integer from n.

int PL_unify_uint64(term_t ?t, uint64_t n)
    Unify t with a Prolog integer from n. Note that unbounded integer support is required if n does not fit in a signed int64_t. If unbounded integers are not supported a representation_error is raised.

int PL_unify_float(term_t ?t, double f)
    Unify t with a Prolog float from f.

int PL_unify_pointer(term_t ?t, void *ptr)
    Unify t with a Prolog integer describing the pointer. See also PL_put_pointer() and PL_get_pointer().

int PL_unify_functor(term_t ?t, functor_t f)
    If t is a compound term with the given functor, just succeed. If it is unbound, create a term and bind the variable, else fail. Note that this function does not create a term if the argument is already instantiated. If f is a functor with arity 0, t is unified with an atom. See also PL_unify_compound().

int PL_unify_compound(term_t ?t, functor_t f)
    If t is a compound term with the given functor, just succeed. If it is unbound, create a term and bind the variable, else fail. Note that this function does not create a term if the argument is already instantiated. If f is a functor with arity 0, t is unified with compound without arguments. See also PL_unify_functor().

int PL_unify_list(term_t ?l, term_t -h, term_t -t)
    Unify l with a list-cell (/.2). If successful, write a reference to the head of the list into h and a reference to the tail of the list into t. This reference may be used for subsequent calls to this function. Suppose we want to return a list of atoms from a char **. We could use the example described by PL_put_list(), followed by a call to PL_unify(), or we can use the code below. If the predicate argument is unbound, the difference is minimal (the code based on PL_put_list() is probably slightly faster). If the argument is bound, the code below may fail before reaching the end of the word list, but even if the unification succeeds, this code avoids a duplicate (garbage) list and a deep unification.

```c
foreign_t
pl_get_environ(term_t env)
{
    term_t l = PL_copy_term_ref(env);
    term_t a = PL_new_term_ref();
    extern char **environ;
    char **e;

    for(e = environ; *e; e++)
    {
        if ( !PL_unify_list(l, a, l) ||
             !PL_unify_atom_chars(a, *e) )
            PL_fail;
    }
}```
```c
return PL_unify_nil(l);
}
```

```c
int PL_unify_nil(term_t ?l)
    Unify $l$ with the atom $[]$.

int PL_unify_arg(int index, term_t ?t, term_t ?a)
    Unifies the $index$-th argument (1-based) of $t$ with $a$.

int PL_unify_term(term_t ?t, ...)
    Unify $t$ with a (normally) compound term. The remaining arguments are a sequence of a type identifier followed by the required arguments. This predicate is an extension to the Quintus and SICStus foreign interface from which the SWI-Prolog foreign interface has been derived, but has proved to be a powerful and comfortable way to create compound terms from C. Due to the vararg packing/unpacking and the required type-switching this interface is slightly slower than using the primitives. Please note that some bad C compilers have fairly low limits on the number of arguments that may be passed to a function.

Special attention is required when passing numbers. C ‘promotes’ any integral smaller than int to int. That is, the types char, short and int are all passed as int. In addition, on most 32-bit platforms int and long are the same. Up to version 4.0.5, only PL_INTEGER could be specified, which was taken from the stack as long. Such code fails when passing small integral types on machines where int is smaller than long. It is advised to use PL_SHORT, PL_INT or PL_LONG as appropriate. Similarly, C compilers promote float to double and therefore PL_FLOAT and PL_DOUBLE are synonyms.

The type identifiers are:

PL_VARIABLE none
    No op. Used in arguments of PL_FUNCTOR.

PL_BOOL int
    Unify the argument with true or false.

PL_ATOM atom_t
    Unify the argument with an atom, as in PL_unify_atom().

PL_CHARS const char *
    Unify the argument with an atom constructed from the C char *, as in PL_unify_atom_chars().

PL_NCHARS size_t, const char *
    Unify the argument with an atom constructed from length and char* as in PL_unifyAtom_nchars().

PL_UTF8_CHARS const char *
    Create an atom from a UTF-8 string.

PL_UTF8_STRING const char *
    Create a packed string object from a UTF-8 string.
PL_MBCHARS const char *
Create an atom from a multi-byte string in the current locale.

PL_MBCODES const char *
Create a list of character codes from a multi-byte string in the current locale.

PL_MBSTRING const char *
Create a packed string object from a multi-byte string in the current locale.

PL_NWCHARS size_t, const wchar_t *
Create an atom from a length and a wide character pointer.

PL_NWCODES size_t, const wchar_t *
Create a list of character codes from a length and a wide character pointer.

PL_NWSTRING size_t, const wchar_t *
Create a packed string object from a length and a wide character pointer.

PL_SHORT short
Unify the argument with an integer, as in PL_unify_integer(). As short is promoted to int, PL_SHORT is a synonym for PL_INT.

PL_INTEGER long
Unify the argument with an integer, as in PL_unify_integer().

PL_INT int
Unify the argument with an integer, as in PL_unify_integer().

PL_LONG long
Unify the argument with an integer, as in PL_unify_integer().

PL_INT64 int64_t
Unify the argument with a 64-bit integer, as in PL_unify_int64().

PL_INTPTR intptr_t
Unify the argument with an integer with the same width as a pointer. On most machines this is the same as PL_LONG, but on 64-bit MS-Windows pointers are 64 bits while longs are only 32 bits.

PL_DOUBLE double
Unify the argument with a float, as in PL_unify_float(). Note that, as the argument is passed using the C vararg conventions, a float must be casted to a double explicitly.

PL_FLOAT double
Unify the argument with a float, as in PL_unify_float().

PL_POINTER void *
Unify the argument with a pointer, as in PL_unify_pointer().

PL_STRING const char *
Unify the argument with a string object, as in PL_unify_string_chars().

PL_TERM term_t
Unify a subterm. Note this may be the return value of a PL_new_term_ref() call to get access to a variable.

PL_FUNCTOR functor, ...
Unify the argument with a compound term. This specification should be followed by exactly as many specifications as the number of arguments of the compound term.
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PL_FUNCTOR_CHARS  
  const char *name, int arity, ...
Create a functor from the given name and arity and then behave as PL_FUNCTOR.

PL_LIST  
  int length, ...
Create a list of the indicated length. The remaining arguments contain the elements of the list.

For example, to unify an argument with the term language(dutch), the following skeleton may be used:

```c
static functor_t FUNCTOR_language1;

static void
init_constants()
{
  FUNCTOR_language1 = PL_new_functor(PL_new_atom("language"),1);
}

foreign_t
pl_get_lang(term_t r)
{
  return PL_unify_term(r,
    PL_FUNCTOR, FUNCTOR_language1,
    PL_CHARS, "dutch");
}

install_t
install()
{
  PL_register_foreign("get_lang", 1, pl_get_lang, 0);
  init_constants();
}
```

int PL_chars_to_term(const char *chars, term_t t)
Parse the string chars and put the resulting Prolog term into t. chars may or may not be closed using a Prolog full-stop (i.e., a dot followed by a blank). Returns FALSE if a syntax error was encountered and TRUE after successful completion. In addition to returning FALSE, the exception-term is returned in t on a syntax error. See also term_to_atom/2.

The following example builds a goal term from a string and calls it.

```c
int
call_chars(const char *goal)
{
  fid_t fid = PL_open_foreign_frame();
  term_t g = PL_new_term_ref();
  BOOL rval;

  if ( PL_chars_to_term(goal, g )
    rval = PL_call(goal, NULL);
  else
```
```c
rval = FALSE;
PL_discard_foreign_frame(fid);
return rval;
}
...
call_chars("consult(load)");
...
```

PL\_chars\_to\_term() is defined using PL\_put\_term\_from\_chars() which can deal with not null-terminated strings as well as strings using different encodings:

```c
int
PL_chars_to_term(const char *s, term_t t)
{ return PL_put_term_from_chars(t, REP_ISO_LATIN_1, (size_t)-1, s);
}
```

int **PL\_wchars\_to\_term**(*const pl\_wchar\_t \*chars, term\_t \*t*)
Wide character version of PL\_chars\_to\_term().

char * **PL\_quote**(*int chr, const char *string*)
Return a quoted version of string. If chr is ‘\’’, the result is a quoted atom. If chr is ‘”’, the result is a string. The result string is stored in the same ring of buffers as described with the BUF\_STACK argument of PL\_get\_chars();
In the current implementation, the string is surrounded by chr and any occurrence of chr is doubled. In the future the behaviour will depend on the character escapes Prolog flag.

### 12.4.6 Convenient functions to generate Prolog exceptions

The typical implementation of a foreign predicate first uses the PL\_get\_\*() functions to extract C data types from the Prolog terms. Failure of any of these functions is normally because the Prolog term is of the wrong type. The \_*\_ex() family of functions are wrappers around (mostly) the PL\_get\_\*() functions, such that we can write code in the style below and get proper exceptions if an argument is uninstantiated or of the wrong type. Section 12.4.7 documents an alternative API to fetch values for the C basic types.

```c
/** set\_size(\+Name:atom, \+Width:int, \+Height:int) is det.

static foreign_t
set\_size(term\_t name, term\_t width, term\_t height)
{ char *\n;
  int w, h;

  if ( !PL\_get\_chars(name, &n, CVT_ATOM|CVT\_EXCEPTION) ||
      !PL\_get\_integer\_ex(with, &w) ||
      !PL\_get\_integer\_ex(height, &h) )
```
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```c
return FALSE;
...
}
```

```c
int PL_get_atom_ex(term_t t, atom_t *a)
As PL_get_atom(), but raises a type or instantiation error if t is not an atom.

int PL_get_integer_ex(term_t t, int *i)
As PL_get_integer(), but raises a type or instantiation error if t is not an integer, or a representation error if the Prolog integer does not fit in a C int.

int PL_get_long_ex(term_t t, long *i)
As PL_get_long(), but raises a type or instantiation error if t is not an atom, or a representation error if the Prolog integer does not fit in a C long.

int PL_get_int64_ex(term_t t, int64_t *i)
As PL_get_int64(), but raises a type or instantiation error if t is not an integer, or a representation error if the Prolog integer does not fit in a C int64_t.

int PL_get_uint64_ex(term_t t, uint64_t *i)
As PL_get_uint64(), but raises a type, domain or instantiation error if t is not an integer or t is less than zero, or a representation error if the Prolog integer does not fit in a C int64_t.

int PL_get_intptr_ex(term_t t, intptr_t *i)
As PL_get_intptr(), but raises a type or instantiation error if t is not an atom, or a representation error if the Prolog integer does not fit in a C intptr_t.

int PL_get_size_ex(term_t t, size_t *i)
As PL_get_size(), but raises a type or instantiation error if t is not an atom, or a representation error if the Prolog integer does not fit in a C size_t.

int PL_get_bool_ex(term_t t, int *i)
As PL_get_bool(), but raises a type or instantiation error if t is not a valid boolean value (true, false, on, constoff, 1 or 0). Note that the pointer is to an int because C has no bool type.

int PL_get_float_ex(term_t t, double *f)
As PL_get_float(), but raises a type or instantiation error if t is not a float.

int PL_get_char_ex(term_t t, int *p, int *eof)
Get a character code from t, where t is either an integer or an atom with length one. If *eof is TRUE and t is -1, *p is filled with -1. Raises an appropriate error if the conversion is not possible.

int PL_get_pointer_ex(term_t t, void **addrp)
As PL_get_pointer(), but raises a type or instantiation error if t is not a pointer.
int PL_get_list_ex(term t l, term t h, term t t)
   As PL_get_list(), but raises a type or instantiation error if t is not a list.

int PL_get_nil_ex(term t l)
   As PL_get_nil(), but raises a type or instantiation error if t is not the empty list.

int PL_unify_list_ex(term t l, term t h, term t t)
   As PL_unify_list(), but raises a type error if t is not a variable, list-cell or the empty list.

int PL_unify_nil_ex(term t l)
   As PL_unify_nil(), but raises a type error if t is not a variable, list-cell or the empty list.

int PL_unify_bool_ex(term t l, int val)
   As PL_unify_bool(), but raises a type error if t is not a variable or a boolean.

The second family of functions in this section simplifies the generation of ISO compatible error terms. Any foreign function that calls this function must return to Prolog with the return code of the error function or the constant FALSE. If available, these error functions add the name of the calling predicate to the error context. See also PL_raise_exception().

int PL_instantiation_error(term t culprit)
   Raise instantiation_error. Culprit is ignored, but should be bound to the term that is insufficiently instantiated. See instantiation_error/1.

int PL_uninstantiation_error(term t culprit)
   Raise uninstantiation_error(culprit). This should be called if an argument that must be unbound at entry is bound to culprit. This error is typically raised for a pure output arguments such as a newly created stream handle (e.g., the third argument of open/3).

int PL_representation_error(const char *resource)
   Raise representation_error(resource). See representation_error/1.

int PL_type_error(const char *expected, term t culprit)
   Raise type_error(expected, culprit). See type_error/2.

int PL_domain_error(const char *expected, term t culprit)
   Raise domain_error(expected, culprit). See domain_error/2.

int PL_existence_error(const char *type, term t culprit)
   Raise existence_error(type, culprit). See type_error/2.

int PL_permission_error(const char *operation, const char *type, term t culprit)
   Raise permission_error(operation, type, culprit). See permission_error/3.

int PL_resource_error(const char *resource)
   Raise resource_error(resource). See resource_error/1.

int PL_syntax_error(const char *message, IOSTREAM *in)
   Raise syntax_error(message). If arg is not NULL, add information about the current position of the input stream.
### 12.4.7 Foreign language wrapper support functions

In addition to the functions described in section 12.4.3, there is a family of functions that is used for automatic generation of wrapper functions, for example using the Prolog library `qpforeign` that provides a Quintus/SICStus compatible foreign language interface.

The `PL_cvt_i_*()` family of functions is suitable for use with a `Generic` selector or C++ overloading.\(^8\)

Note that the documentation on this API is incomplete. Also note that many of these functions are equivalent to the `PL_get_*_ex()` functions described in section 12.4.6.

```c
int PL_cvt_i_bool(term t p, int *c)
    Equivalent to `PL_get_bool_ex()` . Note that the pointer is to an `int` because C has no `bool` type. The return value is either 0 or 1.

int PL_cvt_i_char(term t p, char *c)
int PL_cvt_i_schar(term t p, signed char *c)
int PL_cvt_i_uchar(term t p, unsigned char *c)
int PL_cvt_i_short(term t p, short *s)
int PL_cvt_i_ushort(term t p, unsigned short *s)
int PL_cvt_i_int(term t p, int *c)
int PL_cvt_i_uint(term t p, unsigned int *c)
int PL_cvt_i_long(term t p, long *c)
int PL_cvt_i_ulong(term t p, unsigned long *c)
int PL_cvt_i_llong(term t p, long long *c)
int PL_cvt_i_ullong(term t p, unsigned long long *c)
int PL_cvt_i_int32(term t p, int32_t *c)
int PL_cvt_i_uint32(term t p, uint32_t *c)
int PL_cvt_i_int64(term t p, int64_t *c)
int PL_cvt_i_uint64(term t p, uint64_t *c)
int PL_cvt_i_size_t(term t p, size_t *c)

Convert a Prolog integer into a C integer of the specified size. Generate an exception and return `FALSE` if the conversion is impossible because the Prolog term is not an integer or the C type cannot represent the value of the Prolog integer.
```

### 12.4.8 Serializing and deserializing Prolog terms

```c
int PL_put_term_from_chars(term t t, int flags, size_t len, const char *s)
    Parse the text from the C-string `s` holding `len` bytes and put the resulting term in `t`. `len` can be `(size_t)-1`, assuming a 0-terminated string. The `flags` argument controls the encoding and is currently one of `REP_UTF8` (string is UTF8 encoded), `REP_MB` (string is encoded in the current locale) or 0 (string is encoded in ISO latin 1). The string may, but is not required, to be closed by a full stop (.)

    If parsing produces an exception the behaviour depends on the `CVT_EXCEPTION` flag. If present, the exception is propagated into the environment. Otherwise, the exception is placed in `r` and the return value is `FALSE`.\(^9\).
```

---

\(^8\)_Generic needs to take into account that there’s no `bool` type in C but there is in C++. An overloaded integer() method is provided in the C++ interface.

\(^9\)The `CVT_EXCEPTION` was added in version 8.3.12

---

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12.4.9 BLOBS: Using atoms to store arbitrary binary data

SWI-Prolog atoms as well as strings can represent arbitrary binary data of arbitrary length. This facility is attractive for storing foreign data such as images in an atom. An atom is a unique handle to this data and the atom garbage collector is able to destroy atoms that are no longer referenced by the Prolog engine. This property of atoms makes them attractive as a handle to foreign resources, such as Java atoms, Microsoft's COM objects, etc., providing safe combined garbage collection.

To exploit these features safely and in an organised manner, the SWI-Prolog foreign interface allows creating ‘atoms’ with additional type information. The type is represented by a structure holding C function pointers that tell Prolog how to handle releasing the atom, writing it, sorting it, etc. Two atoms created with different types can represent the same sequence of bytes. Atoms are first ordered on the rank number of the type and then on the result of the \texttt{compare()} function. Rank numbers are assigned when the type is registered. This implies that the results of inequality comparisons between blobs of different types is undefined and can change if the program is run twice (the ordering within a blob type will not change, of course).

While the blob is alive, neither its handle nor the location of the contents (see \texttt{PL_blob_data()}) change. If the blob’s type has the \texttt{PL_BLOB_UNIQUE} feature, the content of the blob must remain unmodified. Blobs are only reclaimed by the atom garbage collector. In this case the atom garbage collector calls the \texttt{release()} function associated with the blob type and reclaims the memory allocated for the content unless this is owned by the creator of the blob indicated by the \texttt{PL_BLOB_NOCOPY} flag. After an \texttt{atom_t} value is reclaimed by the atom garbage collector, the value may be reused for allocating a new blob or atom.

If foreign code stores the \texttt{atom_t} handle in some permanent location it must make sure the handle is registered to prevent it from being garbage collected. If the handle is obtained from a \texttt{term_t} object it is not registered because it is protected by the \texttt{term_t} object. This applies to e.g., \texttt{PL_get_atom()}. Functions that create a handle from data such as \texttt{PL_new_atom()} return a registered handle to prevent the asynchronous atom garbage collector from reclaiming it immediately. Note that many of the API functions create an atom or blob handle and use this to fill a \texttt{term_t} object, e.g., \texttt{PL_unify_blob()}, \texttt{PL_unify_chars()}, etc. In this scenario the handle is protected by the \texttt{term_t} object. Registering and unregistering \texttt{atom_t} handles is done by \texttt{PL_register_atom()} and \texttt{PL_unregister_atom()}.

Note that during program shutdown using \texttt{PL_cleanup()}, all atoms and blobs are reclaimed as described above. These objects are reclaimed regardless of their registration count. The order in which the atoms or blobs are reclaimed under \texttt{PL_cleanup()} is undefined. However, when these objects are reclaimed using \texttt{garbage_collect_atoms/0}, registration counts are taken into account.

Defining a BLOB type

The type \texttt{PL_blob_t} represents a structure with the layout displayed below. The structure contains additional fields at the …for internal bookkeeping as well as future extensions.

```c
typedef struct PL_blob_t
{
  uintptr_t magic;        /* PL_BLOB_MAGIC */
 uintptr_t flags;         /* Bitwise or of PL_BLOB_* */
  const char * name;      /* name of the type */
  int (*release)(atom_t a);    
  int (*compare)(atom_t a, atom_t b);
  };
```

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For each type, exactly one such structure should be allocated. Its first field must be initialised to \texttt{PL\_BLOB\_MAGIC}. The \texttt{flags} is a bitwise \texttt{or} of the following constants:

**\texttt{PL\_BLOB\_TEXT}**
If specified, the blob is assumed to contain text and is considered a normal Prolog atom. The (currently) two predefined blob types that represent atoms have this flag set. User-defined blobs may not specify this, even if they contain only text. Applications should \emph{not} use the blob API to create normal text atoms or get access to the text represented by normal text atoms. Most applications should use \texttt{PL\_get\_nchars()} and \texttt{PL\_unify\_chars()} to get text from Prolog terms or create Prolog terms that represent text.

**\texttt{PL\_BLOB\_UNIQUE}**
If specified the system ensures that the blob-handle is a unique reference for a blob with the given type, length and content. If this flag is not specified, each lookup creates a new blob. Uniqueness is determined by comparing the bytes in the blobs unless \texttt{PL\_BLOB\_NOCOPY} is also specified, in which case the pointers are compared.

**\texttt{PL\_BLOB\_NOCOPY}**
By default the content of the blob is copied. Using this flag the blob references the external data directly. The user must ensure the provided pointer is valid as long as the atom lives. If \texttt{PL\_BLOB\_UNIQUE} is also specified, uniqueness is determined by comparing the pointer rather than the data pointed at. Using \texttt{PL\_BLOB\_UNIQUE|PL\_BLOB\_NOCOPY} can be used to make a blob reference an arbitrary pointer where the pointer data may be reclaimed in the release() handler.

**\texttt{PL\_BLOB\_WCHAR}**
If \texttt{PL\_BLOB\_TEXT} is also set, then the text is made up of \texttt{pl\_wchar\_t} items and the blob’s length is the number of bytes (that is, the number of characters times \texttt{sizeof(pl\_wchar\_t)}). As \texttt{PL\_BLOB\_TEXT}, this flag should not be set in user-defined blobs.

The \texttt{name} field represents the type name as available to Prolog. See also \texttt{current\_blob/2}. The other fields are function pointers that must be initialised to proper functions or \texttt{NULL} to get the default behaviour of built-in atoms. Below are the defined member functions:

void \texttt{acquire(atom\_t a)}
Called if a new blob of this type is created through \texttt{PL\_put\_blob()} or \texttt{PL\_unify\_blob()}. Note this this call is done as part of creating the blob. The call to \texttt{PL\_unify\_blob()} may fail if the unification fails or cannot be completed due to a resource error. \texttt{PL\_put\_blob()} has no such error conditions. This callback is typically used to store the \texttt{atom\_t} handle into the content of the blob. Given a pointer to the content, we can now use \texttt{PL\_unify\_atom()} to bind a Prolog term with a reference to the pointed to object. If the content of the blob
can be modified (PL_BLOB_UNIQUE is not present) this is the only way to get access to the atom_t handle that belongs to this blob. If PL_BLOB_UNIQUE is provided and respected, PL_unify_blob() given the same pointer and length will produce the same atom_t handle.

```
int release(atom_t a)
    The blob (atom) a is about to be released. This function can retrieve the data of the blob using PL_blob_data(). If it returns FALSE, the atom garbage collector will not reclaim the atom. The release( ) function is called when the atom is reclaimed by the atom garbage collector. For critical resources such as file handles or significant memory resources it may be desirable to have an explicit call to dispose (most of) the resources. For example, close/1 reclaims the file handle and most of the resources associated with a stream, leaving only a tiny bit of content to the garbage collector. See also setup_call_cleanup/3.

int compare(atom_t a, atom_t b)
    Compare the blobs a and b, both of which are of the type associated to this blob type. Return values are as memcmp(): < 0 if a is less than b, = 0 if both are equal, and > 0 otherwise. The default implementation is a bitwise comparison of the blobs’ contents. If you cannot guarantee that the blobs all have unique contents, then you should incorporate the blob address (the system guarantees that blobs are not shifted in memory after they are allocated). The following minimal compare function gives a stable total ordering:

```
static int compare_my_blob(atom_t a, atom_t b)
{ const struct my_blob_data *blob_a = PL_blob_data(a, NULL, NULL);
    const struct my_blob_data *blob_b = PL_blob_data(b, NULL, NULL);
    return (blob_a > blob_b) ? 1 : (blob_a < blob_b) ? -1 : 0;
}
```

```
int write(IOSTREAM *s, atom_t a, int flags)
    Write the content of the blob a to the stream s respecting the flags. The flags are a bitwise or of zero or more of the PL_WRT_* flags defined in SWI-Prolog.h. This prototype is available if the undocumented SWI-Stream.h is included before SWI-Prolog.h. This function can retrieve the data of the blob using PL_blob_data().

If this function is not provided, write/1 emits the content of the blob for blobs of type PL_BLOB_TEXT or a string of the format <#hex data> for binary blobs.

If a blob type is registered from a loadable object (shared object or DLL) the blob type must be deregistered before the object may be released.

int PL_unregister_blob_type(PL_blob_t *type)
    Unlink the blob type from the registered type and transform the type of possible living blobs to unregistered, avoiding further reference to the type structure, functions referred by it, as well as the data. This function returns TRUE if no blobs of this type existed and FALSE otherwise. PL_unregister_blob_type() is intended for the uninstall() hook of foreign modules, avoiding further references to the module.
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Accessing blobs

The blob access functions are similar to the atom accessing functions. Blobs being atoms, the atom functions operate on blobs and vice versa. For clarity and possible future compatibility issues, however, it is not advised to rely on this.

int PL_is_blob(term_t t, PL_blob_t **type)
Succeeds if $t$ refers to a blob, in which case $type$ is filled with the type of the blob.

int PL_unify_blob(term_t t, void *blob, size_t len, PL_blob_t *type)
Unify $t$ to a blob constructed from the given data and associated with the given type. This performs the following steps:

1. If the $type$ has PL_BLOB_UNIQUE set, search the blob database for a blob of the same type with the same content. If found, unify $t$ with the existing handle.
2. If not found or PL_BLOB_UNIQUE is not set, create a new blob handle. If PL_BLOB_NOCOPY is set, associate it to the given memory; else, copy the memory to a new area owned by the blob. Call the acquire() function of the $type$.
3. Unify $t$ with the existing or new handle. This succeeds if $t$ is already bound to the existing blob handle. If $t$ is a variable, it succeeds if sufficient resources are available to perform the unification; if $t$ is bound to something else, this fails.

It is possible that a blob referencing critical resources is created after which the unification fails. Typically these resources are eventually reclaimed because the new blob is not referenced and reclaimed by the atom garbage collector. As described with the release() function, it can be desirable to reclaim the critical resources after the failing PL_unify_blob() call.

int PL_put_blob(term_t t, void *blob, size_t len, PL_blob_t *type)
Store the described blob in $t$. The return value indicates whether a new blob was allocated (FALSE) or the blob is a reference to an existing blob (TRUE). Reporting new/existing can be used to deal with external objects having their own reference counts. If the return is TRUE this reference count must be incremented, and it must be decremented on blob destruction callback. See also PL_put_atom_nchars().

int PL_get_blob(term_t t, void **blob, size_t *len, PL_blob_t **type)
If $t$ holds a blob or atom, get the data and type and return TRUE. Otherwise return FALSE. Each result pointer may be NULL, in which case the requested information is ignored.

void *PL_blob_data(atom_t a, size_t *len, PL_blob_t **type)
Get the data and type associated to a blob. This function is mainly used from the callback functions described in section 12.4.9. Note that if the release() hook is called from PL_cleanup(), blobs are releases regardless of whether or not they are referenced and the order in which blobs are released is undefined (the order depends on the ordering in the atom hash table). PL_blob_data() may be called safely on a blob that has already been released. If this happens during PL_cleanup() the return value is guaranteed to be NULL. During normal execution it may return the content of a newly allocated blob that reused the released handle.
12.4.10 Exchanging GMP numbers

If SWI-Prolog is linked with the GNU Multiple Precision Arithmetic Library (GMP, used by default), the foreign interface provides functions for exchanging numeric values to GMP types. To access these functions the header `<gmp.h>` must be included before `<SWI-Prolog.h>`. Foreign code using GMP linked to SWI-Prolog asks for some considerations.

- SWI-Prolog normally rebinds the GMP allocation functions using `mp_set_memory_functions()`. This means SWI-Prolog must be initialised before the foreign code touches any GMP function. You can call `PL_action(PL_GMP_SET_ALLOC_FUNCTIONS, TRUE)` to force Prolog’s GMP initialization without doing the rest of the Prolog initialization. If you do not want Prolog rebinding the GMP allocation, call `PL_action(PL_GMP_SET_ALLOC_FUNCTIONS, FALSE)` before initializing Prolog.

- On Windows, each DLL has its own memory pool. To make exchange of GMP numbers between Prolog and foreign code possible you must either let Prolog rebind the allocation functions (default) or you must recompile SWI-Prolog to link to a DLL version of the GMP library.

Here is an example exploiting the function `mpz_nextprime()`:

```c
#include <gmp.h>
#include <SWI-Prolog.h>

static foreign_t
next_prime(term_t n, term_t prime)
{ mpz_t mpz;
  int rc;

  mpz_init(mpz);
  if ( PL_get_mpz(n, mpz) )
    { mpz_nextprime(mpz, mpz);
      rc = PL_unify_mpz(prime, mpz);
    } else
      rc = FALSE;

  mpz_clear(mpz);
  return rc;
}

install_t
install()
{ PL_register_foreign("next_prime", 2, next_prime, 0);
}
```

```c
int PL_get_mpz(term_t t, mpz_t mpz)
If t represents an integer, mpz is filled with the value and the function returns TRUE. Otherwise
```
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mpz is untouched and the function returns FALSE. Note that mpz must have been initialised before calling this function and must be cleared using mpz_clear() to reclaim any storage associated with it.

int PL_get_mpq(term_t t, mpq_t mpq)
If t is an integer or rational number (term rdiv/2), mpq is filled with the normalised rational number and the function returns TRUE. Otherwise mpq is untouched and the function returns FALSE. Note that mpq must have been initialised before calling this function and must be cleared using mpq_clear() to reclaim any storage associated with it.

int PL_unifympz(term_t t, mpz_t mpz)
Unify t with the integer value represented by mpz and return TRUE on success. The mpz argument is not changed.

int PL_unifympq(term_t t, mpq_t mpq)
Unify t with a rational number represented by mpq and return TRUE on success. Note that t is unified with an integer if the denominator is 1. The mpq argument is not changed.

12.4.11 Calling Prolog from C

The Prolog engine can be called from C. There are two interfaces for this. For the first, a term is created that could be used as an argument to call/1, and then PL_call() is used to call Prolog. This system is simple, but does not allow to inspect the different answers to a non-deterministic goal and is relatively slow as the runtime system needs to find the predicate. The other interface is based on PL_open_query(), PL_next_solution() and PL_cut_query() or PL_close_query(). This mechanism is more powerful, but also more complicated to use.

Predicate references

This section discusses the functions used to communicate about predicates. Though a Prolog predicate may be defined or not, redefined, etc., a Prolog predicate has a handle that is neither destroyed nor moved. This handle is known by the type predicate_t.

predicate_t PL_pred(functor_t f, module_t m)
Return a handle to a predicate for the specified name/arity in the given module. If the module argument m is NULL, the current context module is used. If the target predicate does not exist a handle to a new undefined predicate is returned. The predicate may fail, returning (predicate_t) 0 after setting a resource exception, if the target module has a limit on the program space, see set_module/1. Currently aborts the process with a fatal error when out of memory. Future versions may raise a resource exception and return (predicate_t) 0.

predicate_t PL_predicate(const char *name, int arity, const char *module)
Same as PL_pred(), but provides a more convenient interface to the C programmer.

void PL_predicate_info(predicate_t p, atom_t *n, size_t *a, module_t *m)
Return information on the predicate p. The name is stored over n, the arity over a, while m receives the definition module. Note that the latter need not be the same as specified with PL_predicate(). If the predicate is imported into the module given to PL_predicate(), this function will return the module where the predicate is defined. Any of the arguments n, a and m can be NULL.
Initiating a query from C

This section discusses the functions for creating and manipulating queries from C. Note that a foreign context can have at most one active query. This implies that it is allowed to make strictly nested calls between C and Prolog (Prolog calls C, calls Prolog, calls C, etc.), but it is not allowed to open multiple queries and start generating solutions for each of them by calling PL_next_solution(). Be sure to call PL_cut_query() or PL_close_query() on any query you opened before opening the next or returning control back to Prolog.

qid_t PL_open_query(module_t ctx, int flags, predicate_t p, term_t +t0)

Opens a query and returns an identifier for it. ctx is the context module of the goal. When NULL, the context module of the calling context will be used, or user if there is no calling context (as may happen in embedded systems). Note that the context module only matters for meta-predicates. See meta_predicate/1, context_module/1 and module_transparent/1. The p argument specifies the predicate, and should be the result of a call to PL_pred() or PL_predicate(). Note that it is allowed to store this handle as global data and reuse it for future queries. The term reference t0 is the first of a vector of term references as returned by PL_new_term_refs(n). Raise a resource exception and returns (qid_t) 0 on failure.

The flags arguments provides some additional options concerning debugging and exception handling. It is a bitwise or of the following values:

- **PL_Q_NORMAL**
  Normal operation. The debugger inherits its settings from the environment. If an exception occurs that is not handled in Prolog, a message is printed and the tracer is started to debug the error.\(^\text{10}\)

- **PL_Q_NODEBUG**
  Switch off the debugger while executing the goal. This option is used by many calls to hook-predicates to avoid tracing the hooks. An example is print/1 calling portray/1 from foreign code.

- **PL_Q_CATCH_EXCEPTION**
  If an exception is raised while executing the goal, do not report it, but make it available for PL_exception().

- **PL_Q_PASS_EXCEPTION**
  As PL_Q_CATCH_EXCEPTION, but do not invalidate the exception-term while calling PL_close_query(). This option is experimental.

- **PL_Q_ALLOW_YIELD**
  Support the I_YIELD instruction for engine-based coroutining. See $engine_yield/2 in boot/init.pl for details.

- **PL_Q_EXT_STATUS**
  Make PL_next_solution() return extended status. Instead of only TRUE or FALSE extended status as illustrated in the following table:

---

\(^{10}\)Do not pass the integer 0 for normal operation, as this is interpreted as PL_Q_NODEBUG for backward compatibility reasons.
Extended Normal
PL_S_EXCEPTION FALSE Exception available through PL_exception()
PL_S_FALSE FALSE Query failed
PL_S_TRUE TRUE Query succeeded with choicepoint
PL_S_LAST TRUE Query succeeded without choicepoint

PL_open_query() can return the query identifier ‘0’ if there is not enough space on the environment stack. This function succeeds, even if the referenced predicate is not defined. In this case, running the query using PL_next_solution() will return an existence error. See PL_exception().

The example below opens a query to the predicate is_a/2 to find the ancestor of ‘me’. The reference to the predicate is valid for the duration of the process and may be cached by the client.

```c
char *
ancestor(const char *me)
{
  term_t a0 = PL_new_term_refs(2);
  static predicate_t p;
  
  if ( !p )
    p = PL_predicate("is_a", 2, "database");
  
  PL_put_atom_chars(a0, me);
  PL_open_query(NULL, PL_Q_NORMAL, p, a0);
  ...
}
```

int PL_next_solution(qid_t qid)
Generate the first (next) solution for the given query. The return value is TRUE if a solution was found, or FALSE to indicate the query could not be proven. This function may be called repeatedly until it fails to generate all solutions to the query.

int PL_cut_query(qid_t qid)
Discards the query, but does not delete any of the data created by the query. It just invalidates qid, allowing for a new call to PL_open_query() in this context. PL_cut_query() may invoke cleanup handlers (see setup_call_cleanup/3) and therefore may experience exceptions. If an exception occurs the return value is FALSE and the exception is accessible through PL_exception(0).

int PL_close_query(qid_t qid)
As PL_cut_query(), but all data and bindings created by the query are destroyed.

qid_t PL_current_query(void)
Returns the query id of of the current query or 0 if the current thread is not executing any queries.
PL_engine_t PL_query_engine(qid_t qid)
Return the engine to which qid belongs. Note that interacting with a query or the Prolog terms associated with a query requires the engine to be current. See PL_set_engine().

int PL_call_predicate(module_t m, int flags, predicate_t pred, term_t +t0)
Shorthand for PL_open_query(), PL_next_solution(), PL_cut_query(), generating a single solution. The arguments are the same as for PL_open_query(), the return value is the same as PL_next_solution().

int PL_call(term_t t, module_t m)
Call term t just like the Prolog predicate once/1. t is called in the module m, or in the context module if m == NULL. Returns TRUE if the call succeeds, FALSE otherwise. Figure 12.3 shows an example to obtain the number of defined atoms. All checks are omitted to improve readability.

12.4.12 Discarding Data
The Prolog data created and term references needed to set up the call and/or analyse the result can in most cases be discarded right after the call. PL_close_query() allows for destroying the data, while leaving the term references. The calls below may be used to destroy term references and data. See figure 12.3 for an example.

fid_t PL_open_foreign_frame()
Create a foreign frame, holding a mark that allows the system to undo bindings and destroy data created after it, as well as providing the environment for creating term references. This function is called by the kernel before calling a foreign predicate. Raise a resource exception and returns (fid_t)0 on failure.

void PL_close_foreign_frame(fid_t id)
Discard all term references created after the frame was opened. All other Prolog data is retained. This function is called by the kernel whenever a foreign function returns control back to Prolog.

void PL_discard_foreign_frame(fid_t id)
Same as PL_close_foreign_frame(), but also undo all bindings made since the open and destroy all Prolog data.

void PL_rewind_foreign_frame(fid_t id)
Undo all bindings and discard all term references created since the frame was created, but do not pop the frame. That is, the same frame can be rewound multiple times, and must eventually be closed or discarded.

It is obligatory to call either of the two closing functions to discard a foreign frame. Foreign frames may be nested.

12.4.13 String buffering
Many of the functions of the foreign language interface involve strings. Some of these strings point into static memory like those associated with atoms. These strings are valid as long as the atom is
12.4. THE FOREIGN INCLUDE FILE

```c
int count_atoms()
{
    fid_t fid = PL_open_foreign_frame();
    term_t goal = PL_new_term_ref();
    term_t a1 = PL_new_term_ref();
    term_t a2 = PL_new_term_ref();
    functor_t s2 = PL_new_functor(PL_new_atom("statistics"), 2);
    int atoms;

    PL_put_atom_chars(a1, "atoms");
    PL_cons_functor(goal, s2, a1, a2);
    PL_call(goal, NULL); /* call it in current module */

    PL_get_integer(a2, &atoms);
    PL_discard_foreign_frame(fid);

    return atoms;
}
```

Figure 12.3: Calling Prolog

protected against atom garbage collection, which generally implies the atom must be locked using `PL_register_atom()` or be part of an accessible term. Other strings are more volatile. Several functions provide a `BUF_*` flag that can be set to either `BUF_STACK` (default) or `BUF_MALLOC`. Strings returned by a function accepting `BUF_MALLOC` must be freed using `PL_free()`. Strings returned using `BUF_STACK` are pushed on a stack that is cleared when a foreign predicate returns control back to Prolog. More fine grained control may be needed if functions that return strings are called outside the context of a foreign predicate or a foreign predicate creates many strings during its execution. Temporary strings are scoped using these macros:

void `PL_STRINGS_MARK()`
void `PL_STRINGS_RELEASE()`

These macros must be paired and create a C `block {...}`. Any string created using `BUF_STACK` after `PL_STRINGS_MARK()` is released by the corresponding `PL_STRINGS_RELEASE()`. These macros should be used like below

```c
...
PL_STRINGS_MARK();
<operations involving strings>
PL_STRINGS_RELEASE();
...
```

The Prolog flag `string_stack_tripwire` may be used to set a *tripwire* to help finding places where scoping strings may help reducing resources.
12.4.14 Foreign Code and Modules

Modules are identified via a unique handle. The following functions are available to query and manipulate modules.

```
module_t PL_context()
    Return the module identifier of the context module of the currently active foreign predicate. If there is no currently active predicate it returns a handle to the user module.

int PL_strip_module(term_t +raw, module_t *m, term_t -plain)
    Utility function. If raw is a term, possibly holding the module construct ⟨module⟩:⟨rest⟩, this function will make plain a reference to ⟨rest⟩ and fill module * with ⟨module⟩. For further nested module constructs the innermost module is returned via module *. If raw is not a module construct, raw will simply be put in plain. The value pointed to by m must be initialized before calling PL_strip_module(), either to the default module or to NULL. A NULL value is replaced by the current context module if raw carries no module. The following example shows how to obtain the plain term and module if the default module is the user module:

    { module m = PL_new_module(PL_new_atom("user"));
        term_t plain = PL_new_term_ref();

        PL_strip_module(term, &m, plain);

        ...
    }
```

atom_t PL_module_name(module_t module)
    Return the name of module as an atom.

module_t PL_new_module(atom_t name)
    Find an existing module or create a new module with the name name. Currently aborts the process with a fatal error on failure. Future versions may raise a resource exception and return (module_t)0.

12.4.15 Prolog exceptions in foreign code

This section discusses PL_exception() and PL_raise_exception(), the interface functions to detect and generate Prolog exceptions from C code. PL_raise_exception() from the C interface registers the exception term and returns FALSE. If a foreign predicate returns FALSE, while an exception term is registered, a Prolog exception will be raised by the virtual machine. This implies for a foreign function that implements a predicate and wishes to raise an exception, the function shall call PL_raise_exception(), perform any necessary cleanup and return the return code of PL_raise_exception() or explicitly FALSE. Calling PL_raise_exception() outside the context of a function implementing a foreign predicate results in undefined behaviour.

Note that many of the C API functions may call PL_raise_exception() and return FALSE. The user shall test for this, cleanup and make the foreign function return FALSE.

PL_exception() may be used to inspect the currently registered exception. It is normally called after a call to PL_next_solution() returns FALSE, and returns a term reference to an
exception term if an exception is pending, and \( (\text{term}_t)0 \) otherwise. It may also be called after, e.g., \texttt{PL unify()} to distinguish a normal failing unification from a unification that raised an resource error exception.

If a C function implementing a predicate that calls Prolog should use \texttt{PL open query()} with the flag \texttt{PL Q PASS EXCEPTION} and make the function return \texttt{FALSE} if \texttt{PL next solution()} returns \texttt{FALSE} and \texttt{PL exception()} indicates an exception is pending.

Both for C functions implementing a predicate and when Prolog is called while the main control of the process is in C, user code should always check for exceptions. As explained above, C functions implementing a predicate should normally cleanup and return with \texttt{FALSE}. If the C function whishes to continue it may call \texttt{PL clear exception()}. Note that this may cause any exeption to be ignored, including \texttt{time outs} and \texttt{abort}. Typically the user should check the exeption details before ignoring an exception. If the C code does not implement a predicate it normally prints the exception and calls \texttt{PL clear exception()} to discard it. Exceptions may be printed by calling \texttt{print message/2} through the C interface.

int \texttt{PL raise exception(term t exception)}

Generate an exception (as \texttt{throw/1}) and return \texttt{FALSE}. This function is rarely used directly. Instead, errors are typically raised using the functions in section 12.4.6 or the C api functions that end in \texttt{ex} such as \texttt{PL get atom ex()}. Below we give an example returning an exception from a foreign predicate the verbose way. Note that the exception is raised in a sequence of actions connected using \&\&. This ensures that a proper exception is raised should any of the calls used to build or raise the exception themselves raise an exception. In this simple case \texttt{PL new term ref()} is guaranteed to succeed because the system guarantees at least 10 available term references before entering the foreign predicate. \texttt{PL unify term()} however may raise a resource exception for the global stack.

```c
foreign_t pl_hello(term_t to)
{
  char *s;

  if ( PL_get_atom_chars(to, &s) )
  {
    sprintf("Hello \\
$s"
  "\n", s);

    return TRUE;
  } else
  {
    term_t except;

    return ( (except=PL_new_term_ref()) &&
     PL_unify_term(except,
     PL_FUNCTOR_CHARS, "type_error", 2,
     PL_CHARS, "atom",
     PL_TERM, to) &&
     PL_raise_exception(except) );
  }
}
```

For reference, the preferred implementation of the above is below. The \texttt{CVT EXCEPTION} tells
the system to generate an exception if the conversion fails. The other CVT flags define the admissible types and REP_MB requests the string to be provided in the current locale representation. This implies that Unicode text is printed correctly if the current environment can represent it. If not, a representation_error is raised.

```c
foreign_t
pl_hello(term_t to)
{
    char *s;

    if ( PL_get_chars(to, &s, CVT_ATOM|CVT_STRING|CVT_EXCEPTION|REP_MB) )
    {
        Sprintf("Hello\"%s\"\n", s);

        return TRUE;
    }

    return FALSE;
}
```

```c
int PL_throw(term_t exception)
    Similar to PL_raise_exception(), but returns using the C longjmp() function to the innermost PL_next_solution(). This function is deprecated as it does not provide the opportunity to cleanup.

term_t PL_exception(qid_t qid)
    If PL_next_solution() fails, this can be due to normal failure of the Prolog call, or because an exception was raised using throw/1. This function returns a handle to the exception term if an exception was raised, or (term_t)0 if the Prolog goal simply failed. If there is an exception, PL_exception() returns a term reference that contains the exception term.

    Additionally, PL_exception(0) returns the pending exception in the current query or (term_t)0 if no exception is pending. This can be used to check the error status after a failing call to, e.g., one of the unification functions.

void PL_clear_exception(void)
    Tells Prolog that the encountered exception must be ignored. This function must be called if control remains in C after a previous API call fails with an exception.\[11\]

12.4.16 Catching Signals (Software Interrupts)

SWI-Prolog offers both a C and Prolog interface to deal with software interrupts (signals). The Prolog mapping is defined in section 4.12. This subsection deals with handling signals from C.

If a signal is not used by Prolog and the handler does not call Prolog in any way, the native signal interface routines may be used.

Any handler that wishes to call one of the Prolog interface functions should call PL_sigaction() to install the handler. PL_signal() provides a deprecated interface that is

\[11\] This feature is non-portable. Other Prolog systems (e.g., YAP) have no facilities to ignore raised exceptions, and the design of YAP’s exception handling does not support such a facility.

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notably not capable of properly restoring the old signal status if the signal was previously handled by Prolog.

```c
int PL_sigaction(int sig, pl_sigaction_t *act, pl_sigaction_t *oldact)
```

Install or query the status for signal `sig`. The signal is an integer between 1 and 64, where the where the signals up to 32 are mapped to OS signals and signals above that are handled by Prolog’s synchronous signal handling. The `pl_sigaction_t` is a struct with the following definition:

```c
typedef struct pl_sigaction {
    void (*sa_cfunction)(int); /* traditional C function */
    predicate_t sa_predicate;  /* call a predicate */
    int sa_flags;              /* additional flags */
} pl_sigaction_t;
```

The `sa_flags` is a bitwise or of `PLSIG_THROW`, `PLSIG_SYNC` and `PLSIG_NOFREE`. Signal handling is enabled if `PLSIG_THROW` is provided, `sa_cfunction` or `sa_predicate` is provided. `sa_predicate` is a predicate handle for a predicate with arity 1. If no action is provided the signal handling for this signal is restored to the default before `PL_initialise()` was called.

Finally, 0 (zero) may be passed for `sig`. In that case the system allocates a free signal in the Prolog range (32...64). Such signal handler are activated using `PL_thread_raise()`.

```c
void (*)() PL_signal(sig, func)
```

This function is equivalent to the BSD-Unix `signal()` function, regardless of the platform used. The signal handler is blocked while the signal routine is active, and automatically reactivated after the handler returns.

After a signal handler is registered using this function, the native signal interface redirects the signal to a generic signal handler inside SWI-Prolog. This generic handler validates the environment, creates a suitable environment for calling the interface functions described in this chapter and finally calls the registered user-handler.

By default, signals are handled asynchronously (i.e., at the time they arrive). It is inherently dangerous to call extensive code fragments, and especially exception related code from asynchronous handlers. The interface allows for synchronous handling of signals. In this case the native OS handler just schedules the signal using `PL_raise()`, which is checked by `PL_handle_signals()` at the call- and redo-port. This behaviour is realised by or-ing `sig` with the constant `PLSIGSYNC.12`

Signal handling routines may raise exceptions using `PL_raise_exception()`. The use of `PL_throw()` is not safe. If a synchronous handler raises an exception, the exception is delayed to the next call to `PL_handle_signals()`;

```c
int PL_raise(int sig)
```

Register `sig` for synchronous handling by Prolog. Synchronous signals are handled at the call-port or if foreign code calls `PL_handle_signals()`. See also `thread_signal/2`.

---

12 A better default would be to use synchronous handling, but this interface preserves backward compatibility.
int PL_handle_signals(void)
Handle any signals pending from PL_raise(). PL_handle_signals() is called at each pass through the call- and redo-port at a safe point. Exceptions raised by the handler using PL_raise_exception() are properly passed to the environment.

The user may call this function inside long-running foreign functions to handle scheduled interrupts. This routine returns the number of signals handled. If a handler raises an exception, the return value is -1 and the calling routine should return with FALSE as soon as possible.

int PL_get_signum_ex(term t t, int *sig)
Extract a signal specification from a Prolog term and store as an integer signal number in sig. The specification is an integer, a lowercase signal name without SIG or the full signal name. These refer to the same: 9, kill and SIGKILL. Leaves a typed, domain or instantiation error if the conversion fails.

12.4.17 Miscellaneous
Term Comparison
int PL_compare(term t t1, term t t2)
Compares two terms using the standard order of terms and returns -1, 0 or 1. See also compare/3.

int PL_same_compound(term t t1, term t t2)
Yields TRUE if t1 and t2 refer to physically the same compound term and FALSE otherwise.

Recorded database
In some applications it is useful to store and retrieve Prolog terms from C code. For example, the XPCE graphical environment does this for storing arbitrary Prolog data as slot-data of XPCE objects.

Please note that the returned handles have no meaning at the Prolog level and the recorded terms are not visible from Prolog. The functions PL_recorded() and PL_erase() are the only functions that can operate on the stored term.

Two groups of functions are provided. The first group (PL_record() and friends) store Prolog terms on the Prolog heap for retrieval during the same session. These functions are also used by recorda/3 and friends. The recorded database may be used to communicate Prolog terms between threads.

record_t PL_record(term t t +t)
Record the term t into the Prolog database as recorda/3 and return an opaque handle to the term. The returned handle remains valid until PL_erase() is called on it. PL_recorded() is used to copy recorded terms back to the Prolog stack. Currently aborts the process with a fatal error on failure. Future versions may raise a resource exception and return (record_t)0.

record_t PL_duplicate_record(record t record)
Return a duplicate of record. As records are read-only objects this function merely increments the records reference count. Returns (record_t)0 if the record is an external record (see PL_record_external()).
int PL_recorded(record_t record, term_t *t)
    Copy a recorded term back to the Prolog stack. The same record may be used to copy multiple
    instances at any time to the Prolog stack. Returns TRUE on success, and FALSE if there
    is not enough space on the stack to accommodate the term. See also PL_record() and
    PL_erase().

void PL_erase(record_t record)
    Remove the recorded term from the Prolog database, reclaiming all associated memory re-
    sources.

The second group (headed by PL_record_external()) provides the same functionality, but
the returned data has properties that enable storing the data on an external device. It has been designed
for fast and compact storage of Prolog terms in an external database. Here are the main features:

• Independent of session
    Records can be communicated to another Prolog session and made visible using
    PL_recorded_external().

• Binary
    The representation is binary for maximum performance. The returned data may contain zero
    bytes.

• Byte-order independent
    The representation can be transferred between machines with different byte order.

• No alignment restrictions
    There are no memory alignment restrictions and copies of the record can thus be moved freely.
    For example, it is possible to use this representation to exchange terms using shared memory
    between different Prolog processes.

• Compact
    It is assumed that a smaller memory footprint will eventually outperform slightly faster repre-
    sentations.

• Stable
    The format is designed for future enhancements without breaking compatibility with older
    records.

char * PL_record_external(term_t *t, size_t *len)
    Record the term t into the Prolog database as recorda/3 and return an opaque handle to
    the term. The returned handle remains valid until PL_erase_external() is called on it.
    Currently aborts the process with a fatal error on failure. Future versions may raise a resource
    exception and return (record_t)0.

    It is allowed to copy the data and use PL_recorded_external() on the copy. The user
    is responsible for the memory management of the copy. After copying, the original may be
    discarded using PL_erase_external().

    PL_recorded_external() is used to copy such recorded terms back to the Prolog stack.
int \textbf{PL\_recorded\_external}(\texttt{const char *record, term\_t \_t})

Copy a recorded term back to the Prolog stack. The same record may be used to copy multiple instances at any time to the Prolog stack. See also \texttt{PL\_record\_external()} and \texttt{PL\_erase\_external()}.

int \textbf{PL\_erase\_external}(\texttt{char *record})

Remove the recorded term from the Prolog database, reclaiming all associated memory resources.

\section*{Database}

int \textbf{PL\_assert}(\texttt{term\_t \_t, module\_t \_m, int flags})

Provides direct access to \texttt{asserta/1} and \texttt{assertz/1} by asserting \texttt{t} into the database in the module \texttt{m}. Defined flags are:

\begin{itemize}
  \item \texttt{PL\_ASSERTZ} \\
  \hspace{1em} Add the new clause as last. Calls \texttt{assertz/1}. This macro is defined as 0 and thus the default.
  \item \texttt{PL\_ASSERTA} \\
  \hspace{1em} Add the new clause as first. Calls \texttt{asserta/1}.
  \item \texttt{PL\_CREATE\_THREAD\_LOCAL} \\
  \hspace{1em} If the predicate is not defined, create it as thread-local. See \texttt{thread\_local/1}.
  \item \texttt{PL\_CREATE\_INCREMENTAL} \\
  \hspace{1em} If the predicate is not defined, create it as \texttt{incremental} see \texttt{table/1} and section \texttt{7.7}.
\end{itemize}

On success this function returns \texttt{TRUE}. On failure \texttt{FALSE} is returned and an exception is left in the environment that describes the reason of failure. See \texttt{PL\_exception()}.

This predicate bypasses creating a Prolog callback environment and is faster than setting up a call to \texttt{assertz/1}. It may be used together with \texttt{PL\_chars\_to\_term()}, but the typical use case will create a number of clauses for the same predicate. The fastest way to achieve this is by creating a term that represents the invariable structure of the desired clauses using variables for the variable sub terms. Now we can loop over the data, binding the variables, asserting the term and undoing the bindings. Below is an example loading words from a file that contains a word per line.

```c
#include <SWI-Prolog.h>
#include <stdio.h>
#include <string.h>
#define MAXWLEN 256

static foreign_t
load_words(term_t name)
{
    char *fn;

    if ( PL_get_file_name(name, &fn, PL_FILE_READ) )
    {
        FILE *fd = fopen(fn, "r");
```
Getting file names

The function `PL_get_file_name()` provides access to Prolog filenames and its file-search mechanism described with `absolute_file_name/3`. Its existence is motivated to realise a uniform interface to deal with file properties, search, naming conventions, etc., from foreign code.

```c
int PL_get_file_name(term_t spec, char **name, int flags)
```

Translate a Prolog term into a file name. The name is stored in the buffer stack described with the `PL_get_chars()` option `BUF_STACK`. Conversion from the internal UNICODE
encoding is done using standard C library functions. flags is a bit-mask controlling the conversion process. Options are:

**PL_FILE_ABSOLUTE**
- Return an absolute path to the requested file.

**PL_FILE_OSPATH**
- Return the name using the hosting OS conventions. On MS-Windows, \ is used to separate directories rather than the canonical /.

**PL_FILE_SEARCH**
- Invoke absolute_file_name/3. This implies rules from file_search_path/2 are used.

**PL_FILE_EXIST**
- Demand the path to refer to an existing entity.

**PL_FILE_READ**
- Demand read-access on the result.

**PL_FILE_WRITE**
- Demand write-access on the result.

**PL_FILE_EXECUTE**
- Demand execute-access on the result.

**PL_FILE_NOERRORS**
- Do not raise any exceptions.

```c
int PL_get_file_nameW(term_t spec, wchar_t **name, int flags)
```
Same as PL_get_file_name(), but returns the filename as a wide-character string. This is intended for Windows to access the Unicode version of the Win32 API. Note that the flag PL_FILE_OSPATH must be provided to fetch a filename in OS native (e.g., C:\x\y) notation.

### Dealing with Prolog flags from C

Foreign code can set or create Prolog flags using PL_set_prolog_flag(). See set_prolog_flag/2 and create_prolog_flag/3. To retrieve the value of a flag you can use PL_current_prolog_flag().

```c
int PL_set_prolog_flag(const char *name, int type, ...)
```
Set/create a Prolog flag from C. name is the name of the affected flag. type is one of the values below, which also dictates the type of the final argument. The function returns TRUE on success and FALSE on failure. This function can be called before PL_initialise(), making the flag available to the Prolog startup code.

**PL_BOOL**
- Create a boolean (true or false) flag. The argument must be an int.

**PL_ATOM**
- Create a flag with an atom as value. The argument must be of type const char *.

**PL_INTEGER**
- Create a flag with an integer as value. The argument must be of type intptr_t *.
12.4. THE FOREIGN INCLUDE FILE

```c
int PL_current_prolog_flag(atom_t name, int type, void *value)
```

Retrieve the value of a Prolog flag from C. `name` is the name of the flag as an `atom_t` (see `current_prolog_flag/2`). `type` specifies the kind of value to be retrieved, it is one of the values below. `value` is a pointer to a location where to store the value. The user is responsible for making sure this memory location is of the appropriate size/type (see the returned types below to determine the size/type). The function returns `TRUE` on success and `FALSE` on failure.

- **PL_ATOM**
  Retrieve a flag whose value is an `atom`. The returned value is an atom handle of type `atom_t`.

- **PL_INTEGER**
  Retrieve a flag whose value is an `integer`. The returned value is an integer of type `int64_t`.

- **PL_FLOAT**
  Retrieve a flag whose value is a `float`. The returned value is a floating point number of type `double`.

- **PL_TERM**
  Retrieve a flag whose value is a `term`. The returned value is a term handle of type `term_t`.

12.4.18 Errors and warnings

`PL_warning()` prints a standard Prolog warning message to the standard error (`user_error`) stream. Please note that new code should consider using `PL_raise_exception()` to raise a Prolog exception. See also section 4.10.

```c
int PL_warning(format, a1, ...)
```

Print an error message starting with ‘[WARNING: ’, followed by the output from `format`, followed by a ‘]’ and a newline. Then start the tracer. `format` and the arguments are the same as for `printf(2)`. Always returns `FALSE`.

12.4.19 Environment Control from Foreign Code

```c
int PL_action(int, ...)
```

Perform some action on the Prolog system. `int` describes the action. Remaining arguments depend on the requested action. The actions are listed below:

- **PL_ACTION_TRACE**
  Start Prolog tracer (`trace/0`). Requires no arguments.

- **PL_ACTION_DEBUG**
  Switch on Prolog debug mode (`debug/0`). Requires no arguments.

- **PL_ACTION_BACKTRACE**
  Print backtrace on current output stream. The argument (an `int`) is the number of frames printed.
PL_ACTION_HALT
Halt Prolog execution. This action should be called rather than Unix exit() to give Prolog
the opportunity to clean up. This call does not return. The argument (an int) is the exit
code. See halt/1.

PL_ACTION_ABORT
Generate a Prolog abort (abort/0). This call does not return. Requires no arguments.

PL_ACTION_BREAK
Create a standard Prolog break environment (break/0). Returns after the user types the
end-of-file character. Requires no arguments.

PL_ACTION_GUIAPP
Windows: Used to indicate to the kernel that the application is a GUI application if the
argument is not 0, and a console application if the argument is 0. If a fatal error occurs,
the system uses a windows messagebox to report this on a GUI application, and otherwise
simply prints the error and exits.

PL_ACTION_TRADITIONAL
Same effect as using --traditional. Must be called before PL_initialise().

PL_ACTION_WRITE
Write the argument, a char * to the current output stream.

PL_ACTION_FLUSH
Flush the current output stream. Requires no arguments.

PL_ACTION_ATTACH_CONSOLE
Attach a console to a thread if it does not have one. See attach_console/0.

PL_GMP_SET_ALLOC_FUNCTIONS
Takes an integer argument. If TRUE, the GMP allocations are immediately bound to the
Prolog functions. If FALSE, SWI-Prolog will never rebind the GMP allocation functions.
See mp_set_memory_functions() in the GMP documentation. The action returns FALSE
if there is no GMP support or GMP is already initialised.

unsigned int PL_version_info(int key)
Query version information. This function may be called before PL_initialise(). If the
key is unknown the function returns 0. See section 2.22 for a more in-depth discussion on bi-
nary compatibility. Versions upto SWI-Prolog 8.5.2 defined this function as PL_version().
It was renamed to avoid a conflict with Perl affecting Yaswi. PL_version() is provided as a
macro for compatibility. Defined keys are:

PL_VERSION_SYSTEM
SWI-Prolog version as 10,000 × major + 100 × minor + patch.

PL_VERSION_FLI
Incremented if the foreign interface defined in this chapter changes in a way that breaks
backward compatibility.

PL_VERSION_REC
Incremented if the binary representation of terms as used by PL_record_external() and
fast_write/2 changes.

PL_VERSION_QLF
Incremented if the QLF file format changes.
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| PL_QUERY_ARGC | Return an integer holding the number of arguments given to Prolog from Unix. |
| PL_QUERYARGV | Return a char ** holding the argument vector given to Prolog from Unix. |
| PL_QUERY_SYMBOLFILE | Return a char * holding the current symbol file of the running process. |
| PL_MAX_INTEGER | Return a long, representing the maximal integer value represented by a Prolog integer. |
| PL_MIN_INTEGER | Return a long, representing the minimal integer value. |
| PL_QUERY_VERSION | Return a long, representing the version as \(10,000 \times M + 100 \times m + p\), where \(M\) is the major, \(m\) the minor version number and \(p\) the patch level. For example, 20717 means 2.7.17. |
| PL_QUERY_ENCODING | Return the default stream encoding of Prolog (of type IOENC). |
| PL_QUERY_USER_CPU | Get amount of user CPU time of the process in milliseconds. |

Table 12.1: PL_query() options

**PL_VERSION_QLF_LOAD**
Represents the oldest loadable QLF file format version.

**PL_VERSION_VM**
A hash that represents the VM instructions and their arguments.

**PL_VERSION_BUILT_IN**
A hash that represents the names, arities and properties of all built-in predicates defined in C. If this function is called before PL_initialise() it returns 0.

12.4.20 Querying Prolog

```c
long PL_query(int)
```
Obtain status information on the Prolog system. The actual argument type depends on the information required. \(int\) describes what information is wanted.\(^{13}\) The options are given in table 12.1.

12.4.21 Registering Foreign Predicates

```c
int PL_register_foreign_in_module(char *mod, char *name, int arity, foreign_t (*f)(), int flags, ...)
```
Register the C function \(f\) to implement a Prolog predicate. After this call returns successfully a predicate with name \(name\) (a char *) and arity \(arity\) (a C int) is created in module \(mod\). If \(mod\) is NULL, the predicate is created in the module of the calling context, or if no context is present in the module \(user\).

\(^{13}\)Returning pointers and integers as a long is bad style. The signature of this function should be changed.
When called in Prolog, Prolog will call function. flags form a bitwise or’ed list of options for the installation. These are:

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>PL_FA_META</td>
<td>Provide meta-predicate info (see below)</td>
</tr>
<tr>
<td>PL_FA_TRANSPARENT</td>
<td>Predicate is module transparent (deprecated)</td>
</tr>
<tr>
<td>PL_FA_NONDETERMINISTIC</td>
<td>Predicate is non-deterministic. See also PL_retry().</td>
</tr>
<tr>
<td>PL_FA_NOTRACE</td>
<td>Predicate cannot be seen in the tracer</td>
</tr>
<tr>
<td>PL_FA_VARARGS</td>
<td>Use alternative calling convention.</td>
</tr>
</tbody>
</table>

If PL_FA_META is provided, PL_register_foreign_in_module() takes one extra argument. This argument is of type const char*. This string must be exactly as long as the number of arguments of the predicate and filled with characters from the set 0-9:ˆ+-?.

See meta_predicate/1 for details. PL_FA_TRANSPARENT is implied if at least one meta-argument is provided (0-9:ˆ). Note that meta-arguments are not always passed as ⟨module⟩:⟨term⟩. Always use PL_strip_module() to extract the module and plain term from a meta-argument.\(^\text{14}\)

Predicates may be registered either before or after PL_initialise(). When registered before initialisation the registration is recorded and executed after installing the system predicates and before loading the saved state.

Default calling (i.e. without PL_FA_VARARGS) function is passed the same number of term_t arguments as the arity of the predicate and, if the predicate is non-deterministic, an extra argument of type control_t (see section 12.4.1). If PL_FA_VARARGS is provided, function is called with three arguments. The first argument is a term_t handle to the first argument. Further arguments can be reached by adding the offset (see also PL_new_termRefs()). The second argument is the arity, which defines the number of valid term references in the argument vector. The last argument is used for non-deterministic calls. It is currently undocumented and should be defined of type void*. Here is an example:

```c
static foreign_t
atom_checksum(term_t a0, int arity, void* context)
{
    char *s;

    if (PL_get_atom_chars(a0, &s))
    {
        int sum;

        for(sum=0; *s; s++)
            sum += *s&0xff;

        return PL_unify_integer(a0+1, sum&0xff);
    }

    return FALSE;
}
install_t
```

\(^{14}\)It is encouraged to pass an additional NULL pointer for non-meta-predicates.
install()
{ PL_register_foreign("atom_checksum", 2,
    atom_checksum, PL_FA_VARARGS);
}

int PL_register_foreign(const char *name, int arity, foreign t (*function)(), int flags, ...)
Same as PL_register_foreign_in_module(), passing NULL for the module.

void PL_register_extensions_in_module(const char *module, PL_extension *e)
Register a series of predicates from an array of definitions of the type PL_extension in the
given module. If module is NULL, the predicate is created in the module of the calling context,
or if no context is present in the module user. The PL_extension type is defined as

typedef struct PL_extension
{ char *predicate_name; /* Name of the predicate */
  short arity; /* Arity of the predicate */
  pl_function_t function; /* Implementing functions */
  short flags; /* Or of PL_FA_... */
} PL_extension;

For details, see PL_register_foreign_in_module(). Here is an example of its usage:

static PL_extension predicates[] = {
{ "foo", 1, pl_foo, 0 },
{ "bar", 2, pl_bar, PL_FA_NONDETERMINISTIC },
{ NULL, 0, NULL, 0 }
};

main(int argc, char **argv)
{ PL_register_extensions_in_module("user", predicates);

  if ( !PL_initialise(argc, argv) )
    PL_halt(1);

  ...
}

void PL_register_extensions( PL_extension *e)
Same as PL_register_extensions_in_module() using NULL for the module argument.

12.4.22 Foreign Code Hooks
For various specific applications some hooks are provided.
PL_dispatch_hook_t PL_dispatch_hook(PL_dispatch_hook_t)
If this hook is not NULL, this function is called when reading from the terminal. It is supposed
to dispatch events when SWI-Prolog is connected to a window environment. It can return
two values: PL_DISPATCH_INPUT indicates Prolog input is available on file descriptor 0
or PL_DISPATCH_TIMEOUT to indicate a timeout. The old hook is returned. The type
PL_dispatch_hook_t is defined as:

```c
typedef int (*PL_dispatch_hook_t)(void);
```

void PL_abort_hook(PL_abort_hook_t)
Install a hook when abort/0 is executed. SWI-Prolog abort/0 is implemented using C
setjmp()/longjmp() construct. The hooks are executed in the reverse order of their registra-
tion after the longjmp() took place and before the Prolog top level is reinvoked. The type
PL_abort_hook_t is defined as:

```c
typedef void (*PL_abort_hook_t)(void);
```

int PL_abort_unhook(PL_abort_hook_t)
Remove a hook installed with PL_abort_hook(). Returns FALSE if no such hook is found,
TRUE otherwise.

void PL_on_halt(int (*f)(int, void *), void *closure)
Register the function f to be called if SWI-Prolog is halted. The function is called with two
arguments: the exit code of the process (0 if this cannot be determined) and the closure
argument passed to the PL_on_halt() call. Handlers must return 0. Other return values
are reserved for future use. See also at_halt/1.15 These handlers are called before system
cleanup and can therefore access all normal Prolog resources. See also PL_exit_hook().

void PL_exit_hook(int (*f)(int, void *), void *closure)
Similar to PL_on_halt(), but the hooks are executed by PL_halt() instead of
PL_cleanup() just before calling exit().

PL_agc_hook_t PL_agc_hook(PL_agc_hook_t new)
Register a hook with the atom-garbage collector (see garbage_collect_atoms/0) that is
called on any atom that is reclaimed. The old hook is returned. If no hook is currently defined,
NULL is returned. The argument of the called hook is the atom that is to be garbage collected.
The return value is an int. If the return value is zero, the atom is not reclaimed. The hook
may invoke any Prolog predicate.

The example below defines a foreign library for printing the garbage collected atoms for debug-
ning purposes.

```c
#include <SWI-Stream.h>
#include <SWI-Prolog.h>
```

15BUG: Although both PL_on_halt() and at_halt/1 are called in FIFO order, all at_halt/1 handlers are called
before all PL_on_halt() handlers.
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static int atom_hook(atom_t a)
{ Sdprintf("AGC: deleting %s\n", PL_atom_chars(a));
    return TRUE;
}

static PL_agc_hook_t old;

install_t install()
{ old = PL_agc_hook(atom_hook);
}

install_t uninstall()
{ PL_agc_hook(old);
}

12.4.23 Storing foreign data

When combining foreign code with Prolog, it can be necessary to make data represented in the foreign language available to Prolog. For example, to pass it to another foreign function. At the end of this section, there is a partial implementation of using foreign functions to manage bit-vectors. Another example is the SGML/XML library that manages a ‘parser’ object, an object that represents the current state of the parser and that can be directed to perform actions such as parsing a document or make queries about the document content.

This section provides some hints for handling foreign data in Prolog. There are four options for storing such data:

• **Natural Prolog data**
  Uses the representation one would choose if no foreign interface was required. For example, a bitvector representing a list of small integers can be represented as a Prolog list of integers.

• **Opaque packed data on the stacks**
  It is possible to represent the raw binary representation of the foreign object as a Prolog string (see section 5.2). Strings may be created from foreign data using PL_put_string_nchars() and retrieved using PL_get_string_chars(). It is good practice to wrap the string in a compound term with arity 1, so Prolog can identify the type. The hook portray/1 rules may be used to streamline printing such terms during development.

• **Opaque packed data in a blob**
  Similar to the above solution, binary data can be stored in an atom. The blob interface (section 12.4.9) provides additional facilities to assign a type and hook-functions that act on creation and destruction of the underlying atom.
• **Natural foreign data, passed as a pointer**
  An alternative is to pass a pointer to the foreign data. Again, the pointer is often wrapped in a compound term.

The choice may be guided using the following distinctions

• **Is the data opaque to Prolog**
  With ‘opaque’ data, we refer to data handled in foreign functions, passed around in Prolog, but where Prolog never examines the contents of the data itself. If the data is opaque to Prolog, the selection will be driven solely by simplicity of the interface and performance.

• **What is the lifetime of the data**
  With ‘lifetime’ we refer to how it is decided that the object is (or can be) destroyed. We can distinguish three cases:

1. The object must be destroyed on backtracking and normal Prolog garbage collection (i.e., it acts as a normal Prolog term). In this case, representing the object as a Prolog string (second option above) is the only feasible solution.

2. The data must survive Prolog backtracking. This leaves two options. One is to represent the object using a pointer and use explicit creation and destruction, making the programmer responsible. The alternative is to use the blob-interface, leaving destruction to the (atom) garbage collector.

3. The data lives as during the lifetime of a foreign function that implements a predicate. If the predicate is deterministic, foreign automatic variables are suitable. If the predicate is non-deterministic, the data may be allocated using malloc() and a pointer may be passed. See section 12.4.1.

**Examples for storing foreign data**

In this section, we outline some examples, covering typical cases. In the first example, we will deal with extending Prolog’s data representation with integer sets, represented as bit-vectors. Then, we discuss the outline of the DDE interface.

**Integer sets** with not-too-far-apart upper- and lower-bounds can be represented using bit-vectors. Common set operations, such as union, intersection, etc., are reduced to simple and’ing and or’ing the bit-vectors. This can be done using Prolog’s unbounded integers.

For really demanding applications, foreign representation will perform better, especially time-wise. Bit-vectors are naturally expressed using string objects. If the string is wrapped in bitvector/1, the lower-bound of the vector is 0 and the upper-bound is not defined; an implementation for getting and putting the sets as well as the union predicate for it is below.

```c
#include <SWI-Prolog.h>

#define max(a, b) ((a) > (b) ? (a) : (b))
#define min(a, b) ((a) < (b) ? (a) : (b))

static functor_t FUNCTOR_bitvector1;
```
static int
get_bitvector(term_t in, int *len, unsigned char **data)
{
  if ( PL_is_functor(in, FUNCTOR_bitvector1) )
  {
    term_t a = PL_new_term_ref();

    PL_get_arg(1, in, a);
    return PL_get_string(a, (char **)data, len);
  }

  PL_fail;
}

static int
unify_bitvector(term_t out, int len, const unsigned char *data)
{
  if ( PL_unify_functor(out, FUNCTOR_bitvector1) )
  {
    term_t a = PL_new_term_ref();

    PL_get_arg(1, out, a);

    return PL_unify_string_nchars(a, len, (const char *)data);
  }

  PL_fail;
}

static foreign_t
pl_bitvector_union(term_t t1, term_t t2, term_t u)
{
  unsigned char *s1, *s2;
  int l1, l2;

  if ( get_bitvector(t1, &l1, &s1) &&
       get_bitvector(t2, &l2, &s2) )
  {
    int l = max(l1, l2);
    unsigned char *s3 = alloca(l);

    if ( s3 )
    {
      int n;
      int ml = min(l1, l2);

      for(n=0; n<ml; n++)
        s3[n] = s1[n] | s2[n];
      for( ; n < l1; n++)
        s3[n] = s1[n];
      for( ; n < l2; n++)
        s3[n] = s2[n];
  
  return s3;
  }

  return PL_fail;
}
The DDE interface (see section 4.44) represents another common usage of the foreign interface: providing communication to new operating system features. The DDE interface requires knowledge about active DDE server and client channels. These channels contain various foreign data types. Such an interface is normally achieved using an open/close protocol that creates and destroys a handle. The handle is a reference to a foreign data structure containing the relevant information.

There are a couple of possibilities for representing the handle. The choice depends on responsibilities and debugging facilities. The simplest approach is to use `PL_unify_pointer()` and `PL_get_pointer()`. This approach is fast and easy, but has the drawbacks of (untyped) pointers: there is no reliable way to detect the validity of the pointer, nor to verify that it is pointing to a structure of the desired type. The pointer may be wrapped into a compound term with arity 1 (i.e., `dde_channel(⟨Pointer⟩)`), making the type-problem less serious.

Alternatively (used in the DDE interface), the interface code can maintain a (preferably variable length) array of pointers and return the index in this array. This provides better protection. Especially for debugging purposes, wrapping the handle in a compound is a good suggestion.

12.4.24 Embedding SWI-Prolog in other applications

With embedded Prolog we refer to the situation where the ‘main’ program is not the Prolog application. Prolog is sometimes embedded in C, C++, Java or other languages to provide logic based services in a larger application. Embedding loads the Prolog engine as a library to the external language. Prolog itself only provides for embedding in the C language (compatible with C++). Embedding in Java is achieved using JPL using a C-glue between the Java and Prolog C interfaces.

The most simple embedded program is below. The interface function `PL_initialise()` must be called before any of the other SWI-Prolog foreign language functions described in this chapter, except for `PL_initialise_hook()`, `PL_new_atom()`, `PL_new_functor()` and `PL_register_foreign()`. `PL_initialise()` interprets all the command line arguments, except for the -t toplevel flag that is interpreted by `PL_toplevel()`.
int main(int argc, char **argv)
{
    if ( !PL_initialise(argc, argv) )
        PL_halt(1);
    PL_halt(PL_toplevel() ? 0 : 1);
}

int PL_initialise(int argc, char **argv)

Initialises the SWI-Prolog heap and stacks, restores the Prolog state, loads the system and personal initialisation files, runs the initialization/1 hooks and finally runs the initialization goals registered using -g goal.

Special consideration is required for argv[0]. On Unix, this argument passes the part of the command line that is used to locate the executable. Prolog uses this to find the file holding the running executable. The Windows version uses this to find a module of the running executable. If the specified module cannot be found, it tries the module libswipl.dll, containing the Prolog runtime kernel. In all these cases, the resulting file is used for two purposes:

- See whether a Prolog saved state is appended to the file. If this is the case, this state will be loaded instead of the default boot.prc file from the SWI-Prolog home directory. See also qsave_progranm/[1,2] and section 12.5.
- Find the Prolog home directory. This process is described in detail in section 12.6.

PL_initialise() returns 1 if all initialisation succeeded and 0 otherwise.\textsuperscript{16}

In most cases, argc and argv will be passed from the main program. It is allowed to create your own argument vector, provided argv[0] is constructed according to the rules above. For example:

```c
int main(int argc, char **argv)
{
    char *av[10];
    int ac = 0;

    av[ac++] = argv[0];
    av[ac++] = "-x";
    av[ac++] = "mystate";
    av[ac] = NULL;

    if ( !PL_initialise(ac, av) )
        PL_halt(1);
    ...
}
```

\textsuperscript{16}BUG: Various fatal errors may cause PL_initialise() to call PL_halt(1), preventing it from returning at all.
Please note that the passed argument vector may be referred from Prolog at any time and should therefore be valid as long as the Prolog engine is used.

A good setup in Windows is to add SWI-Prolog’s `bin` directory to your `PATH` and either pass a module holding a saved state, or "libswipl.dll" as `argv[0]`. If the Prolog state is attached to a DLL (see the `−dll` option of `swipl-ld`), pass the name of this DLL.

```c
int PL_w initialise(int argc, wchar_t **argv)
```

Wide character version of `PL initialise()`. Can be used in Windows combined with the `wmain()` entry point.

```c
int PL_is_initialised(int *argc, char ***argv)
```

Test whether the Prolog engine is already initialised. Returns `FALSE` if Prolog is not initialised and `TRUE` otherwise. If the engine is initialised and `argc` is not `NULL`, the argument count used with `PL initialise()` is stored in `argc`. Same for the argument vector `argv`.

```c
int PL_set_resource_db_mem(const unsigned char *data, size_t size)
```

This function must be called at most once and before calling `PL initialise()`. The memory area designated by `data` and `size` must contain the resource data and be in the format as produced by `qsave program/2`. The memory area is accessed by `PL initialise()` as well as calls to `open resource/3`.\(^{17}\)

For example, we can include the bootstrap data into an embedded executable using the steps below. The advantage of this approach is that it is fully supported by any OS and you obtain a single file executable.

1. Create a saved state using `qsave program/2` or

   ```bash
   % swipl -o state -c file.pl ...
   ```

2. Create a C source file from the state using e.g., the Unix utility `xxd(1):

   ```bash
   % xxd -i state > state.h
   ```

3. Embed Prolog as in the example below. Instead of calling the toplevel you probably want to call your application code.

   ```c
   #include <SWI-Prolog.h>
   #include "state.h"

   int main(int argc, char **argv)
   { if ( !PL_set_resource_db_mem(state, state_len) ||
       !PL initialise(argc, argv) )
     PL_halt(1);
   return PL_toplevel();
   }
   ```

\(^{17}\)This implies that the data must remain accessible during the lifetime of the process if `open resource/3` is used. Future versions may provide a function to detach the resource database and cause `open resource/3` to raise an exception.
Alternative to `xxd`, it is possible to use inline assembler, e.g. the `gcc incbin` instruction. Code for `gcc` was provided by Roberto Bagnara on the SWI-Prolog mailinglist. Given the state in a file `state`, create the following assembler program:

```assembly
.globl _state
.globl _state_end
_state:
    .incbin "state"
_state_end:
```

Now include this as follows:

```c
#include <SWI-Prolog.h>
#if __linux
#define STATE _state
#define STATE_END _state_end
#else
#define STATE state
#define STATE_END state_end
#endif
extern unsigned char STATE[];
extern unsigned char STATE_END[];

int main(int argc, char **argv)
{ if ( !PL_set_resource_db_mem(STATE, STATE_END - STATE) ||
    !PL_initialise(argc, argv) )
    PL_halt(1);
return PL_toplevel();
}
```

As Jose Morales pointed at https://github.com/graphitemaster/incbin, which contains a portability layer on top of the above idea.

```c
int PL_toplevel()
Runs the goal of the -t toplevel switch (default prolog/0) and returns 1 if successful, 0 otherwise.
```

```c
int PL_cleanup(int status_and_flags)
This function may be called instead of PL_halt() to cleanup Prolog without exiting the process. It performs the reverse of PL_initialise(). It runs the PL_on_halt() and at_halt/1 handlers, closes all streams (except for the standard I/O streams, which are flushed only), restores all signal handlers and reclaims all memory unless asked not to. status_and_flags accepts the following flags:
```
PL_CLEANUP_NO_RECLAIM_MEMORY
Do not reclaim memory. This is the default when called from PL_halt() for the release versions because the OS will do so anyway.

PL_CLEANUP_NO_CANCELE
Do not allow Prolog and foreign halt hooks to cancel the cleanup.

The return value of PL_cleanup() is one of the following:

PL_CLEANUP_CANCELED
A Prolog or foreign halt hook cancelled the cleanup. Note that some of the halt hooks may have been executed.

PL_CLEANUP_SUCCESS
Cleanup completed successfully. Unless PL_CLEANUP_NO_RECLAIM.Memory was specified this implies most of the memory was reclaimed and Prolog may be reinitialized in the same process using PL_initialise().

PL_CLEANUP_FAILED
Cleanup failed. This happens if the user requested to reclaim all memory but this failed because the system was not able to join all Prolog threads and could therefore not reclaim the memory.

PL_CLEANUP_RECURSIVE
PL_cleanup() was called from a hook called by the cleanup process.

PL_cleanup() allows deleting and restarting the Prolog system in the same process. In versions older than 8.5.9 this did not work. As of version 8.5.9, it works for the basic Prolog engine. Many of the plugins that contain foreign code do not implement a suitable uninstall handler and will leak memory and possibly other resources. Note that shutting Prolog down and reinitializing it is slow. For almost all scenarios there are faster alternatives such as reloading modified code, using temporary modules, using threads, etc.

void PL_cleanup_fork()
Stop intervaltimer that may be running on behalf of profile/1. The call is intended to be used in combination with fork():

```c
if ( (pid=fork()) == 0 )
{ PL_cleanup_fork();
  <some exec variation>
}
```

The call behaves the same on Windows, though there is probably no meaningful application.

int PL_halt(int status)
Clean up the Prolog environment using PL_cleanup() and if successful call exit() with the status argument. Returns FALSE if exit was cancelled by PL_cleanup().
Threading, Signals and embedded Prolog

This section applies to Unix-based environments that have signals or multithreading. The Windows version is compiled for multithreading, and Windows lacks proper signals.

We can distinguish two classes of embedded executables. There are small C/C++ programs that act as an interfacing layer around Prolog. Most of these programs can be replaced using the normal Prolog executable extended with a dynamically loaded foreign extension and in most cases this is the preferred route. In other cases, Prolog is embedded in a complex application that—like Prolog—wants to control the process environment. A good example is Java. Embedding Prolog is generally the only way to get these environments together in one process image. Java VMs, however, are by nature multithreaded and appear to do signal handling (software interrupts).

On Unix systems, SWI-Prolog installs handlers for the following signals:

**SIGUSR2** has an empty signal handler. This signal is sent to a thread after sending a thread-signal (see `thread_signal/2`). It causes blocking system calls to return with EINTR, which gives them the opportunity to react to thread-signals.

In some cases the embedded system and SWI-Prolog may both use SIGUSR2 without conflict. If the embedded system redefines SIGUSR2 with a handler that runs quickly and no harm is done in the embedded system due to spurious wakeup when initiated from Prolog, there is no problem. If SWI-Prolog is initialised after the embedded system it will call the handler set by the embedded system and the same conditions as above apply. SWI-Prolog’s handler is a simple function only chaining a possibly previously registered handler. SWI-Prolog can handle spurious SIGUSR2 signals.

**SIGINT** is used by the top level to activate the tracer (typically bound to control-C). The first control-C posts a request for starting the tracer in a safe, synchronous fashion. If control-C is hit again before the safe route is executed, it prompts the user whether or not a forced interrupt is desired.

**SIGTERM, SIGABRT and SIGQUIT** are caught to cleanup before killing the process again using the same signal.

**SIGSEGV, SIGILL, SIGBUS, SIGFPE and SIGSYS** are caught by to print a backtrace before killing the process again using the same signal.

**SIGHUP** is caught and causes the process to exit with status 2 after cleanup.

The --no-signals option can be used to inhibit all signal processing except for SIGUSR2. The handling of SIGUSR2 is vital for dealing with blocking system call in threads. The used signal may be changed using the --sigalert=NUM option or disabled using --sigalert=0.

12.5 Linking embedded applications using swipl-ld

The utility program swipl-ld (Win32: swipl-ld.exe) may be used to link a combination of C files and Prolog files into a stand-alone executable. swipl-ld automates most of what is described in the previous sections.

In normal usage, a copy is made of the default embedding template .../swipl/include/stub.c. The main() routine is modified to suit your application. PL_initialise() must be
passed the program name \((\text{argv[0]})\) (Win32: the executing program can be obtained using GetModuleFileName()). The other elements of the command line may be modified. Next, \texttt{swipl-ld} is typically invoked as:

\begin{verbatim}
swipl-ld -o output stubfile.c [other-c-or-o-files] [plfiles]
\end{verbatim}

\texttt{swipl-ld} will first split the options into various groups for both the C compiler and the Prolog compiler. Next, it will add various default options to the C compiler and call it to create an executable holding the user’s C code and the Prolog kernel. Then, it will call the SWI-Prolog compiler to create a saved state from the provided Prolog files and finally, it will attach this saved state to the created emulator to create the requested executable.

Below, it is described how the options are split and which additional options are passed.

\textbf{-help}  
Print brief synopsis.

\textbf{-pl prolog}  
Select the Prolog to use. This Prolog is used for two purposes: get the home directory as well as the compiler/linker options and create a saved state of the Prolog code.

\textbf{-ld linker}  
Linker used to link the raw executable. Default is to use the C compiler (Win32: \texttt{link.exe}).

\textbf{-cc C compiler}  
Compiler for .c files found on the command line. Default is the compiler used to build SWI-Prolog accessible through the Prolog flag \texttt{c.c} (Win32: \texttt{cl.exe}).

\textbf{-c++ C++-compiler}  
Compiler for C++ source file (extensions .cpp, .cxx, .cc or .C) found on the command line. Default is \texttt{c++} or \texttt{g++} if the C compiler is \texttt{gcc} (Win32: \texttt{cl.exe}).

\textbf{-nostate}  
Just relink the kernel, do not add any Prolog code to the new kernel. This is used to create a new kernel holding additional foreign predicates on machines that do not support the shared-library (DLL) interface, or if building the state cannot be handled by the default procedure used by \texttt{swipl-ld}. In the latter case the state is created separately and appended to the kernel using \texttt{cat \langle kernel\rangle \langle state\rangle > \langle out\rangle} (Win32: \texttt{copy /b \langle kernel\rangle+\langle state\rangle \langle out\rangle}).

\textbf{-shared}  
Link C, C++ or object files into a shared object (DLL) that can be loaded by the \texttt{load_foreign_library/1} predicate. If used with \texttt{-c} it sets the proper options to compile a C or C++ file ready for linking into a shared object.

\textbf{-dll}  
\textit{Windows only.} Embed SWI-Prolog into a DLL rather than an executable.

\textbf{-c}  
Compile C or C++ source files into object files. This turns \texttt{swipl-ld} into a replacement for the C or C++ compiler, where proper options such as the location of the include directory are passed automatically to the compiler.
Invoke the C preprocessor. Used to make swipl-ld a replacement for the C or C++ compiler.

Additional options passed to Prolog when creating the saved state. The first character immediately following pl-options is used as separator and translated to spaces when the argument is built. Example: -pl-options,-F,xpce passes -F xpce as additional flags to Prolog.

Passes options to the linker, similar to -pl-options.

Passes options to the C/C++ compiler, similar to -pl-options.

Select verbose operation, showing the various programs and their options.

Reserved to specify the final output file.

Specifies a library for the C compiler. By default, -lswipl (Win32: libpl.lib) and the libraries needed by the Prolog kernel are given.

Specifies a library directory for the C compiler. By default the directory containing the Prolog C library for the current architecture is passed.

These options are passed to the C compiler. By default, the include directory containing SWI-Prolog.h is passed. swipl-ld adds two additional * -Ddef flags:

Indicates the code is to be connected to SWI-Prolog.

Indicates the creation of an embedded program.

Passed as input files to the C compiler.

Passed as input files to the Prolog compiler to create the saved state.

All other options. These are passed as linker options to the C compiler.

The following is a very simple example going through all the steps outlined above. It provides an arithmetic expression evaluator. We will call the application calc and define it in the files calc.c and calc.pl. The Prolog file is simple:
calc(Atom) :-
    term_to_atom(Expr, Atom),
    A is Expr,
    write(A),
    nl.

The C part of the application parses the command line options, initialises the Prolog engine, locates the `calc/1` predicate and calls it. The coder is in figure 12.4.

The application is now created using the command line below. The option `-goal true` sets the Prolog initialization goal to suppress the banner. Note that the `-o calc` does not specify an extension. If the platform uses a file extension for executables, `swipl-ld` will add this (e.g., `.exe` on Windows).

```
% swipl-ld -goal true -o calc calc.c calc.pl
```

The created program `calc` is a native executable with the Prolog code attached to it. Note that the program typically depends on the shared object `libswipl` and, depending on the platform and configuration, on several external shared objects.

```
% ./calc pi/2
1.5708
```

### 12.6 The Prolog ‘home’ directory

Executables embedding SWI-Prolog should be able to find the ‘home’ directory of the development environment unless a self-contained saved state has been added to the executable (see `qsave_program/[1,2]` and section 12.5).

If Prolog starts up, it will try to locate the development environment. To do so, it will try the following steps until one succeeds:

1. If the `--home=DIR` is provided, use this.
2. If the environment variable `SWI_HOME_DIR` is defined and points to an existing directory, use this.
3. If the environment variable `SWIPL` is defined and points to an existing directory, use this.
4. Locate the primary executable or (Windows only) a component (module) thereof and check whether the parent directory of the directory holding this file contains the file `swipl`. If so, this file contains the (relative) path to the home directory. If this directory exists, use this. This is the normal mechanism used by the binary distribution.
5. If the precompiled path exists, use it. This is only useful for a source installation.

If all fails and there is no state attached to the executable or provided Windows module (see `PL_initialise()`, SWI-Prolog gives up. If a state is attached, the current working directory is used.

The `file_search_path/2` alias `swi` is set to point to the home directory located.
```c
#include <stdio.h>
#include <string.h>
#include <SWI-Prolog.h>

#define MAXLINE 1024

int main(int argc, char **argv)
{
    char expression[MAXLINE];
    char *e = expression;
    char *program = argv[0];
    char *plav[2];
    int n;

    /* combine all the arguments in a single string */
    for(n=1; n<argc; n++)
    {
        if ( n != 1 )
            *e++ = ' ';
        strcpy(e, argv[n]);
        e += strlen(e);
    }

    /* make the argument vector for Prolog */
    plav[0] = program;
    plav[1] = NULL;

    /* initialise Prolog */
    if ( !PL_initialise(1, plav) )
        PL_halt(1);

    /* Lookup calc/1 and make the arguments and call */
    { predicate_t pred = PL_predicate("calc", 1, "user");
        term_t h0 = PL_new_term_refs(1);
        int rval;
        PL_put_atom_chars(h0, expression);
        rval = PL_call_predicate(NULL, PL_Q_NORMAL, pred, h0);
        PL_halt(rval ? 0 : 1);
    }

    return 0;
}
```

Figure 12.4: C source for the calc application
12.7 Example of Using the Foreign Interface

Below is an example showing all stages of the declaration of a foreign predicate that transforms atoms possibly holding uppercase letters into an atom only holding lowercase letters. Figure 12.5 shows the C source file, figure 12.6 illustrates compiling and loading of foreign code.

```c
/* Include file depends on local installation */
#include <SWI-Prolog.h>
#include <string.h>
#include <ctype.h>

foreign_t
pl_lowercase(term_t u, term_t l)
{
    char *copy;
    char *s, *q;
    int rval;

    if ( !PL_get_atom_chars(u, &s) )
        return PL_warning("lowercase/2: instantiation fault");
    copy = malloc(strlen(s)+1);
    if ( !copy )
        return PL_resource_error("memory");

    for( q=copy; *s; q++, s++ )
        *q = (isupper(*s) ? tolower(*s) : *s);
    *q = '\0';

    rval = PL_unify_atom_chars(l, copy);
    free(copy);

    return rval;
}

install_t
install()
{
    PL_register_foreign("lowercase", 2, pl_lowercase, 0);
}
```

Figure 12.5: Lowercase source file
Figure 12.6: Compiling the C source and loading the object file

```prolog
% gcc -I/usr/local/lib/swipl-\plversion/include -fpic -c lowercase.c
% gcc -shared -o lowercase.so lowercase.o
% swipl
Welcome to SWI-Prolog (...)
...
1 ?- load_foreign_library(lowercase).
   true.
2 ?- lowercase('Hello World!', L).
   L = 'hello world!'.
```
12.8 Notes on Using Foreign Code

12.8.1 Foreign debugging functions

The functions in this section are primarily intended for debugging foreign extensions or embedded Prolog. Violating the constraints of the foreign interface often leads to crashes in a subsequent garbage collection. If this happens, the system needs to be compiled for debugging using `cmake -DCMAKE_BUILD_TYPE=Debug`, after which all functions and predicates listed below are available to use from the debugger (e.g. `gdb`) or can be placed at critical location in your code or the system code.

```c
void PL_backtrace(int depth, int flags)
Dump a Prolog backtrace to the user_error stream. Depth is the number of frames to dump. Flags is a bitwise or of the following constants:

PL_BT_SAFE
(0x1) Do not try to print goals. Instead, just print the predicate name and arity. This reduces the likelihood to crash if `PL_backtrace()` is called in a damaged environment.

PL_BT_USER
(0x2) Only show ‘user’ frames. Default is to also show frames of hidden built-in predicates.
```

```c
char * PL_backtrace_string(int depth, int flags)
As `PL_backtrace()`, but returns the stack as a string. The string uses UTF-8 encoding. The returned string must be freed using `PL_free()`. This function is was added to get stack traces from running servers where I/O is redirected or discarded. For example, using `gdb`, a stack trace is printed in the gdb console regardless of Prolog I/O redirection using the following command:

```gdb
(gdb) printf "%s", PL_backtrace_string(25,0)
```

The source distribution provides the script `scripts/swipl-bt` that exploits `gdb` and `PL_backtrace_string()` to print stack traces in various formats for a SWI-Prolog process, given its process id.

```c
int PL_check_data(term t data)
Check the consistency of the term data. Returns TRUE this is actually implemented in the current version and FALSE otherwise. The actual implementation only exists if the system is compiled with the cflag `-DO_DEBUG` or `-DO_MAINTENANCE`. This is not the default.
```

```c
int PL_check_stacks()
Check the consistency of the runtime stacks of the calling thread. Returns TRUE this is actually implemented in the current version and FALSE otherwise. The actual implementation only exists if the system is compiled with the cflag `-DO_DEBUG` or `-DO_MAINTENANCE`. This is not the default.
```

The Prolog kernel sources use the macro `DEBUG (Topic, Code)`. These macros are disabled in the production version and must be enabled by recompiling the system as described above. Specific topics
can be enabled and disabled using the predicates `prolog_debug/1` and `prolog_nodebug/1`. In addition, they can be activated from the command line using command line option `-d topics`, where `topics` is a comma-separated list of debug topics to enable. For example, the code below adds many consistency checks and prints messages if the Prolog signal handler dispatches signals.

```
$ swipl -d chk_secure,msg_signal
```

`prolog_debug(+Topic)`
`prolog_nodebug(+Topic)`

Enable/disable a debug topic. `Topic` is an atom that identifies the desired topic. The available topics are defined in `src/pl-debug.h`. Please search the sources to find out what is actually printed and when. We highlight one topic here:

`chk_secure(A)`

dd many expensive consistency checks to the system. This should typically be used when the system crashes, notably in the garbage collector. Garbage collection crashes are in most cases caused by invalid data on the Prolog stacks. This debug topic may help locating how the invalid data was created.

These predicates require the system to be compiled for debugging using `cmake -DCMAKE_BUILD_TYPE=Debug`.

```
int PL_prolog_debug(const char *topic)
int PL_prolog_nodebug(const char *topic)
```

(De)activate debug topics. The `topics` argument is a comma-separated string of topics to enable or disable. Matching is case-insensitive. See also `prolog_debug/1` and `prolog_nodebug/1`.

These functions require the system to be compiled for debugging using `cmake -DCMAKE_BUILD_TYPE=Debug`.

### 12.8.2 Memory Allocation

SWI-Prolog’s heap memory allocation is based on the `malloc(3)` library routines. SWI-Prolog provides the functions below as a wrapper around `malloc()`. Allocation errors in these functions trap SWI-Prolog’s fatal-error handler, in which case `PL_malloc()` or `PL_realloc()` do not return.

Portable applications must use `PL_free()` to release strings returned by `PL_get_chars()` using the `BUF_MALLOC` argument. Portable applications may use both `PL_malloc()` and friends or `malloc()` and friends but should not mix these two sets of functions on the same memory.

```
void *PL_malloc(size_t bytes)
void *PL_realloc(void *mem, size_t size)
```

Allocate `bytes` of memory. On failure SWI-Prolog’s fatal-error handler is called and `PL_malloc()` does not return. Memory allocated using these functions must use `PL_realloc()` and `PL_free()` rather than `realloc()` and `free()`.

Change the size of the allocated chunk, possibly moving it. The `mem` argument must be obtained from a previous `PL_malloc()` or `PL_realloc()` call.
void PL_free(void *mem)
    Release memory. The mem argument must be obtained from a previous PL_malloc() or PL_realloc() call.

12.8.3 Compatibility between Prolog versions

Great care is taken to ensure binary compatibility of foreign extensions between different Prolog versions. Only the much less frequently used stream interface has been responsible for binary incompatibilities.

Source code that relies on new features of the foreign interface can use the macro PLVERSION to find the version of SWI-Prolog.h and PL_query() using the option PL_QUERY_VERSION to find the version of the attached Prolog system. Both follow the same numbering schema explained with PL_query().

12.8.4 Foreign hash tables

As of SWI-Prolog 8.3.2 the foreign API provides access to the internal thread-safe and lock-free hash tables that associate pointers or objects that fit in a pointer such as atoms (atom_t). An argument against providing these functions is that they have little to do with Prolog. The argument in favor is that it is hard to implement efficient lock-free tables without low-level access to the underlying Prolog threads and exporting this interface has a low cost.

The functions below can only be called if the calling thread is associated with a Prolog thread. Failure to do so causes the call to be ignored or return the failure code where applicable.

hash_table_t PL_new_hash_table(int size, void (*free_symbol)(void *, void *))
    Create a new table for size key-value pairs. The table is resized when needed. If you know the table will hold 10,000 key-value pairs, providing a suitable initial size avoids resizing. The free_symbol function is called whenever a key-value pair is removed from the table. This can be NULL.

int PL_free_hash_table(hash_table_t table)
    Destroy the hash table. First calls PL_clear_hash_table().

void* PL_lookup_hash_table(hash_table_t table, void *key)
    Return the value matching key or NULL if key does not appear in the table.

void* PL_add_hash_table(hash_table_t table, void *key, void *value, int flags)
    Add key-value to the table. The behaviour if key is already in the table depends on flags. If 0, this function returns the existing value without updating the table. If PL_HT_UPDATE the old value is replaced and the function returns the old value. If PL_HT_NEW, a message and backtrace are printed and the function returns NULL if key is already in the table.

void* PL_del_hash_table(hash_table_t table, void *key)
    Delete key from the table, returning the old associated value or NULL.

int PL_clear_hash_table(hash_table_t table)
    Delete all key-value pairs from the table. Call free_symbol for each deleted pair.
12.8. NOTES ON USING FOREIGN CODE

hash_table_enum_t PL_new_hash_table_enum(hash_table_t table)

Return a table enumerator (cursor) that can be used to enumerate all key-value pairs using PL_advance_hash_table_enum(). The enumerator must be discarded using PL_free_hash_table_enum(). It is safe for another thread to add symbols while the table is being enumerated, but undefined whether or not these new symbols are visible. If another thread deletes a key that is not yet enumerated it will not be enumerated.

void PL_free_hash_table_enum(hash_table_enum_t e)

Discard an enumerator object created using PL_new_hash_table_enum(). Failure to do so causes the table to use more and more memory on subsequent modifications.

int PL_advance_hash_table_enum(hash_table_enum_t e, void **key, void **value)

Get the next key-value pair from a cursor.

12.8.5 Debugging and profiling foreign code (valgrind, asan)

This section is only relevant for Unix users on platforms supported by valgrind. Valgrind is an excellent binary instrumentation platform. Unlike many other instrumentation platforms, valgrind can deal with code loaded through dlopen().

The callgrind tool can be used to profile foreign code loaded under SWI-Prolog. Compile the foreign library adding -g option to gcc or swipl-ld. By setting the environment variable VALGRIND to yes, SWI-Prolog will not release loaded shared objects using dlclose(). This trick is required to get source information on the loaded library. Without, valgrind claims that the shared object has no debugging information.\(^\text{18}\) Here is the complete sequence using bash as login shell:

```
% VALGRIND=yes valgrind --tool=callgrind pl <args>
<prolog interaction>
% kcachegrind callgrind.out.<pid>
```

Instead of valgrind, you can use AddressSanitizer. Here is a short example for building with asan enabled and then running the resulting binary. When you exit swipl, a message is printed and any leaks are printed. During execution, other messages may be printed out, such as freeing an address twice or using freed or unallocated memory.

```
% cd build.sanitize
% cmake -G Ninja -DCMAKE_BUILD_TYPE=Sanitize ..
% ninja
% ASAN_OPTIONS=detect_leaks=1 build.sanitize/src/swipl
<prolog interaction>
% halt
Running LSAN memory leak check (reclaim_memory=1)
No leaks detected
```

\(^\text{18}\)Tested using valgrind version 3.2.3 on x64.
12.8.6 Name Conflicts in C modules

In the current version of the system all public C functions of SWI-Prolog are in the symbol table. This can lead to name clashes with foreign code. Someday I should write a program to strip all these symbols from the symbol table (why does Unix not have that?). For now I can only suggest you give your function another name. You can do this using the C preprocessor. If—for example—your foreign package uses a function warning(), which happens to exist in SWI-Prolog as well, the following macro should fix the problem:

```c
#define warning warning_
```

Note that shared libraries do not have this problem as the shared library loader will only look for symbols in the main executable for symbols that are not defined in the library itself.

12.8.7 Compatibility of the Foreign Interface

The term reference mechanism was first used by Quintus Prolog version 3. SICStus Prolog version 3 is strongly based on the Quintus interface. The described SWI-Prolog interface is similar to using the Quintus or SICStus interfaces, defining all foreign-predicate arguments of type `+term`. SWI-Prolog explicitly uses type `functor_t`, while Quintus and SICStus use `<name>` and `<arity>`. As the names of the functions differ from Prolog to Prolog, a simple macro layer dealing with the names can also deal with this detail. For example:

```c
#define QP_put_functor(t, n, a) 
    PL_put_functor(t, PL_new_functor(n, a))
```

The `PL_unify.*()` functions are lacking from the Quintus and SICStus interface. They can easily be emulated, or the put/unify approach should be used to write compatible code.

The `PL_open_foreign_frame() / PL_close_foreign_frame()` combination is lacking from both other Prologs. SICStus has `PL_new_termRefs(0)`, followed by `PL_reset_term_refs()`, that allows for discarding term references.

The Prolog interface for the graphical user interface package XPCE shares about 90% of the code using a simple macro layer to deal with different naming and calling conventions of the interfaces.

12.9 Foreign access to Prolog IO streams

The SWI-Prolog foreign language interface provides access to Prolog IO streams. This interface may be used to get hold of Prolog streams for reading and writing. In addition, this interface allows to define new stream types. For example, the Windows `swipl-win.exe` executable that runs Prolog in a Windows GUI redefines the Prolog standard IO streams (user_input, user_output and user_error) to read from and write to the GUI window.

The interface is built around the IOSTREAM type which plays a role similar to the POSIX FILE type. Most of the functions are modeled after their FILE counterpart, prefixed by S, e.g. `Sfwrite()`. The IOSTREAM type has considerably more features though. The IOSTREAM type is practically disconnected from the rest of the Prolog system. Prolog refers to streams either by alias (user_input, etc. or created using the alias(Name) option of open/4) or using a stream handle.
which is represented as a *blob* (see section 12.4.9). Foreign extensions that wish to access or define streams should include SWI-Stream.h in addition to SWI-Prolog.h as below. Both headers may be used with C as well as C++.

```c
#include <SWI-Stream.h>
#include <SWI-Prolog.h>
```

### 12.9.1 Get IO stream handles

There are several ways to get access to an IO Stream handle, basically get them from Prolog, get access to the standard streams and create a new stream. The *standard streams* are available as Sinput, Soutput and Serror. Note that these are thread specific. Creating a new stream is discussed with Snew(). Below are the functions to obtain a stream handle from a Prolog term, obtain and release ownership.

```c
int PL_get_stream(term_t t, IOSTREAM **s, int flags)
```

Get a stream handle from the Prolog term `t`. Returns TRUE on success and FALSE on failure, by default generating an exception. The `flags` argument is a bitwise disjunction of these flags:

- **SIO_INPUT**
  - Get an input stream. If `t` is a stream pair (see stream_pair/3), return the input channel.
  - If `t` is an output stream the function fails.

- **SIO_OUTPUT**
  - Get an output stream. See SIO_INPUT for details. If neither SIO_OUTPUT nor SIO_INPUT is given `t` may not be a pair.

- **SIO_NOERROR**
  - If the function fails no exception is produced.

The returned stream is owned by the calling thread using PL_acquire_stream().

```c
int PL_get_stream_from_blob(atom_t b, IOSTREAM **s, int flags)
```

Same as PL_get_stream(), but operates directly on the blob `b`. This allows for foreign code that wishes long term access to a stream to maintain a handle to the stream as a (registered) atom_t object rather than a IOSTREAM*.

```c
IOSTREAM * PL_acquire_stream(IOSTREAM *s)
```

Obtain ownership of `s` and return `s`. The application must call PL_release_stream() when done. Only one thread can own a stream and this call blocks if some other thread owns the stream. Note that PL_get_stream() acquires ownership. This function may be called multiple times by the same thread (recursive lock).

```c
int PL_release_stream(IOSTREAM *s)
```

Give up ownership acquired using PL_acquire_stream() or PL_get_stream(). If the stream is an an error state, return FALSE with an exception. Otherwise return TRUE.

Below is an example that writes “Hello World” to a stream provided by Prolog.
static foreign_t
hello_world(term_t to)
{ IOSTREAM *s;

    if ( PL_get_stream(to, &s, SIO_OUTPUT) )
    { Sfprintf(s, "Hello World!\n");
        return PL_release_stream(s);
    }

    return FALSE;
}

... // fragment from install function
PL_register_foreign("hello world", 1, hello_world, 0);

12.9.2 Creating an IO stream

A new stream is created using Snew(). Before we can create a stream we must create a function block of type IOFUNCTIONS that provide function pointers for the basic operations on the stream. This type is defined as follows:

```c
typedef struct io_functions
{
    Sread_function read; /* fill the buffer */
    Swrite_function write; /* empty the buffer */
    Sseek_function seek; /* seek to position */
    Sclose_function close; /* close stream */
    Scontrol_function control; /* Info/control */
    Sseek64_function seek64; /* seek to position (large files) */
} IOFUNCTIONS;
```

**ssize_t** (*Sread_function*)*(void *handle, char *buf, size_t bufsize)*
Read new data into *buf* that has size *bufsize*, return the number of bytes read or -1. Note that this is the same interface as the POSIX read() API. See section 12.9.4 for raising errors.

**ssize_t** (*Swrite_function*)*(void *handle, char *buf, size_t bufsize)*
Write the bytes from *buf* with contains *bufsize* bytes and return the number of bytes written or -1. The number of bytes written may be less than *bufsize*. Bytes that were not written remain in the stream’s output buffer. Note that this is the same interface as the POSIX write() API. See section 12.9.4 for raising errors.

**long** (*Sseek_function*)*(void *handle, long pos, int whence)*
Reposition the file pointer. These functions may be NULL if repositioning is not possible on this type or they may return -1 and set errno to EPIPE if the pointer cannot be repositioned on this instance. The function returns the new file position. See Sseek() for details on how repositioning is implemented. See section 12.9.4 for raising errors.

**int64_t** (*Sseek64_function*)*(void *handle, int64_t pos, int whence)*

---

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int (*Sclose_function)(void *handle)
Close the stream. This is used by Sclose(). Note that buffered output is first written using the Swrite_function(). See section 12.9.4 for raising errors.

int (*Sccontrol_function)(void *handle, int action, void *arg)
Obtain information about the stream or modify the stream. The function should return 0 on success and -1 on failure. If some action is not implemented the function should return -1:

SIO_GETPENDING, size_t*
Return the number of bytes that may be written without blocking. Used by Spending().

SIO_LASTERROR, char*
Called after an error is raised on a stream. May return a C string that sets error details using Sseterr().

SIO_SETENCODING, IOENC*
Called by Ssetenc() to change the encoding of the stream. If the call does not return 0 the encoding is not changed.

SIO_FLUSHOUTPUT, NULL
Called by Sflush() after flushing the stream’s output buffer. Note that this is only called on an explicit flush using Sflush() or flush_output/1. An implicit flush because the output buffer is full does not call this hook.

SIO_GETSIZE, int64_t*
Get the size of the underlying object in bytes. Used by Ssize().

SIO_GETFILENO, int*
If the stream is associated with an OS file handle, return this handle. Used by Sfileno().

SIO_GETWINSOCK, SOCKET*
Windows only. If the stream is associated to a Windows socket return this handle. Used by Swinsock().

Given an IOFUNCTIONS block we can create a new stream from a handle using Snew():

Iostream* Snew(void *handle, int flags, IOFUNCTIONS *functions)
Create an Iostream* from a handle, flags and a block of callback functions. The flags argument is a bitwise or of SIO_* flags. Flags that control the creation are:

SIO_INPUT
SIO_OUTPUT
One of these flags must be present to indicate whether this is an input or output stream.

SIO_NBUF
SIO_LBUF
SIO_FBUF
One of these flags must be present to select the buffering as one of unbuffered (SIO_NBUF), line buffered (SIO_LBUF) or fully buffered (SIO_FBUF)

SIO_TEXT
If given, this is a text stream and the encoding is set to the default encoding (see the Prolog flag encoding). Otherwise this is a binary stream and the encoding is set to ENC_OCTET.
SIO_RECORDPOS
If given, enable position maintenance on the stream. This is used by Stell(), Sseek(), stream_property/2 using the position property and related predicates.

SIO_NOMUTEX
Used internally to create a stream that cannot be owned or locked.

If the stream is associated with an OS file handle the system initializes the SIO_ISATTY flag (on POSIX systems) and if possible tells the OS not to inherit this stream to child processes.

The symbol Sfilefunctions is a IOFUNCTIONS struct that contains the callbacks for accessing a regular file. After opening an file using the POSIX open() API we can create a stream to this file using Snew():

```c
int fno = open(path, O_RDONLY);
IOSTREAM *s;

if ( fno >= 0 )
    s = Snew((void*)fno, SIO_INPUT|SIO_FBUF|SIO_RECORDPOS|SIO_TEXT, &Sfilefunctions);
...
```

Snew() can only fail if there is not enough memory. In that case the return value is NULL and errno is set to ENOMEM.

IOSTREAM* Sopen_pipe(const char *command, const char *type)
Start a process from command and connect the input or output to the returned stream. This wraps the POSIX popen() API. The type string starts with r or w and may be followed by b to create a binary stream. The default is to create a text stream using the platform conventions and locale.

IOSTREAM* Sopenmem(char **buffer, size_t *sizep, const char *mode)
Open a memory area as a stream. Output streams are automatically resized using realloc() if *size = 0 or the stream is opened with mode "wa". If the buffer is allocated or enlarged, this is achieved using malloc() or realloc(). In this case the returned buffer should be freed by the caller when done. Example:

```c
{ char buf[1024]; // don’t allocate for small stuff
  char *s = buf;
  IOSTREAM *fd;
  size_t size = sizeof(buf);

  fd = Sopenmem(&s, &size, "w");
  ...
  Sclose(fd);
  ...
  if ( s != buf ) // apparently moved
```
The mode is "r" or "w". The mode "rF" calls \texttt{PL\_free(*buffer)} at when closed.

\textbf{Note:} It is \textit{not} allowed to access streams created with this call from multiple threads. This is ok for all usage inside Prolog itself. This call is intended to use write and other output predicates to create strings.

\begin{verbatim}
void Sfree(void *ptr)

This function must be used to free objects that are allocated by the stream interface. Currently this only applies to strings allocated by \texttt{Sopenmem()}.

A stream can be made accessible from Prolog using \texttt{PL\_unify\_stream}:

\begin{verbatim}
int PL\_unify\_stream(term t, IOSTREAM *s)

Unify \texttt{t} with a \texttt{blob} that points at \texttt{s}. Note that a blob provides a unique and reliable reference to a stream. Blobs are subject to atom garbage collection. If an open stream is garbage collected the behaviour depends on the Prolog flag \texttt{agc\_close\_streams}. See also \texttt{Sgc\_close}.
\end{verbatim}

\subsection*{Interacting with foreign streams}

\begin{verbatim}
int Sset\_timeout(IOSTREAM *s, int milliseconds)

Set the timeout on an input stream to \texttt{milliseconds}. If this value is non-negative the the poll() or select() API is used to wait until input is available. If no input is available within the specified time an error is raised on the stream.

int Sunit\_size()

Returns the size of a code unit in bytes depending on the stream’s encoding. This returns 2 for the encodings \texttt{ENC\_UNICODE\_BE} and \texttt{ENC\_UNICODE\_LE}, \texttt{sizeof(wchar\_t)} for \texttt{ENC\_WCHAR} and 1 for all other encodings (including multibyte encodings such as \texttt{ENC\_UTF8}).

int Sputc(int c, IOSTREAM *s)

Emit a byte to \texttt{s}. Flushes the buffer on \texttt{\n} when in \texttt{SIO\_LBUF} buffering mode and updates the stream position information if enabled (\texttt{SIO\_RECORDPOS}). Returns 0 on success, -1 on error.

int Sgetc(IOSTREAM *s)

Read a byte from \texttt{s}. Fills the input buffer if buffering is enabled and the buffer is empty. Updates the stream position information if enabled (\texttt{SIO\_RECORDPOS}). Returns -1 on end of file or error. Use \texttt{S\_error()} or \texttt{S\_feof()} to distinguish end of file from an error. This is a C macro.

int Sfgetc(IOSTREAM *s)

Function equivalent to \texttt{S\_getc}.

int Sungetc(int c, IOSTREAM *s)

Put a byte back into the input buffer. Returns -1 if this is not possible. Deprecated. New code should use \texttt{Speek\_code()} because that reliably maintains the position information on the stream.
\end{verbatim}
int Sputcode(int c, IOSTREAM *s)
   Emit a Unicode code point to s. This function also performs newline encoding (see section 12.9.6). If the encoding of s cannot represent c, the behaviour depends on the the following flags. Only one of these flags may be enabled. If none of these flags is enabled an error is raised and the function returns -1.

   SIO_REPXML
       Emit as XML character entity, e.g. &u#4242;
   SIO_REPPL
       Emit as ISO escape, e.g., \x4242\n   SIO_REPPLU
       Emit as Unicode escape, e.g., \u4242 or \U42424242

   Updates the stream position information if enabled (SIO_RECORDPOS)

int Sgetcode(IOSTREAM *s)
   Read a Unicode code point from s. If it detects an invalid multibyte character a warning is emitted and the code point 0xfffd is returned. Other errors and end-of-file return -1; Use Sferror() or Sfeof() to distinguish end of file from an error.

int Speekcode(IOSTREAM *s)
   As Sgetcode(), but leaves the character in the input buffer and does not update the stream position. Returns -1 if the stream is not buffered (SIO_NBUF).

int Sputw(int w, IOSTREAM *s)
int Sgetw(IOSTREAM *s)
   Reads/writes an integer in native byte order. Deprecated.

int Sfread(void *data, size_t size, size_t elems, IOSTREAM *s)
int Sfwrite(const void *data, size_t size, size_t elems, IOSTREAM *s)
   Emulations of the POSIX fread() and fwrite() calls for Prolog streams. These functions read or write elems objects of size size and return the number of objects successfully read or written. Data exchange is binary (even if the stream is in text mode) and unlike read() and write(), these functions keep reading or writing until end-of-file (for Sfread()) or an error.

int Sfeof(IOSTREAM *s)
   Returns non-zero if the stream is at the end. It performs the following checks: (1) test the SIO_PEOF flag, (2) test whether the buffer is non-empty, (3) fill the buffer and return non-zero if the Sread function() returned 0 (zero).

int Sfpasteof(IOSTREAM *s)
   Returns non-zero when a read operation was performed after signalling end-of-file. On other words, reaching end-of-file first triggers Sfeof() and after another read triggers Sfpasteof().

int Ssetlocale(IOSTREAM *s, struct PLlocale *new_loc, struct PLlocale **old_loc)
   Change the locale associated with a stream. The current system does not provide a public C API for dealing with Prolog locale objects. See section 4.23.
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int Sflush(IOSTREAM *s)
Flush buffered output, returning 0 on success and -1 after a (write) error occurred. Calls Scontrol_function() using the action SIO_FLUSHOUTPUT after the buffer was successfully written.

int64_t Ssize(IOSTREAM *s)
Returns the size in bytes of the object associated to the stream or -1 if this is not known.

int Seek(IOSTREAM *s, long pos, int whence)
int Seek64(IOSTREAM *s, int64_t pos, int whence)
Reposition the file pointer in the object associated to s, returning 0 on success and -1 otherwise. If the stream is buffered and position information is maintained these functions readjust the buffer information if possible. Otherwise they call Sseek64_function() or Sseek_function() as a fallback iff pos can be represented as a C long. Whence is one of SIO_SEEK_SET, SIO_SEEK_CUR or SIO_SEEK_END, seeking relative to the start, current position or end.

long Stell(IOSTREAM *s)
int64_t Stell64(IOSTREAM *s)
Return the current position in the stream. This is obtained from the recorded position or based on information from the seek handlers, adjusted with the buffer information.

int Sclose(IOSTREAM *s)
Close the stream. This first locks the stream (see PL_acquire_stream()). When successful it flushes pending output and calls the Sclose_function() hook. Finally, the stream is unlocked and all memory associated to the stream is released. On success, the function returns 0. On failure a Prolog exception is raised and the return value is -1. Regardless of the return value, s becomes invalid after completion of Sclose(). See also Sgcclose().

int Sgcclose(IOSTREAM *s, int flags)
As Sclose(), but intended to be used from the atom garbage collector if a stream is closed because it is garbage. The SWI-Prolog atom garbage collector normally runs in a separate thread and thus may be unable to obtain a lock on s if some thread lost access to the stream while it is locked. For this situation flags may be SIO_CLOSE_TRYLOCK which causes Sgcclose() to return -1 with errno set to EDEADLK if the stream is locked. Alternatively, using SIO_CLOSE_FORCE the stream is closed and released without gaining a lock. This should be safe because the stream is garbage and thus no thread can use the lock.

In addition, Sgcclose() never raises a Prolog exception because Prolog interaction is not allowed from the blob release hook and there is no meaningful way to raise a Prolog exception from this context.

char* Sfgets(char *buf, int n, IOSTREAM *s)
Read a line of input as a sequence of bytes. The buf is n bytes long. On success, buf is returned and contains a 0-terminated C string that ends with a \n character. On end-of-file or an error, NULL is returned. If the input line is longer that n bytes buf is not 0-terminated.

int Sgets(char *buf)
Shorthand for Sfgets(buf, Slinesize, Sinput). Deletes the terminating \n character. Slinesize is a global variable that defines the length of the input buffer. Deprecated.
int Sread_pending(IOSTREAM *s, char *buf, size_t limit, int flags)
    Return the data buffered on an input stream. If flags includes SIO_RP_BLOCK, fill the buffer
    (possibly blocking) if the buffer is empty. Update the stream position information unless flags
    include SIO_RP_NOPoS. This function effectively provides functionality similar to POSIX
    read() on a stream. This function is used by read_pending_codes/3.

size_t Spending(IOSTREAM *s)
    Return the number of bytes that can be read from s without blocking. If there is buffered input,
    this is the number of bytes buffered. Otherwise it is the result of the Scontrol_function() using the action SIO_GETPENDING.

int Sfputs(const char *q, IOSTREAM *s)
    Emit a 0-terminated C string. The input string q is handled as a sequence of unsigned characters
    (code points 1...255).

int Sputs(const char *q)
    Equivalent to Sfputs(q, Soutput).

int Sfprintf(IOSTREAM *s, const char *fm, ...)
    Similar to POSIX fprintf(). This function largely accepts the same % escape sequences. The
    % character is followed by numeric arguments and modifier characters. The generic format of
    this is described by the regular expression [+0 #]*(\d*|\*) (. (\d*|\*))?. Here, + implies right alignment,
    - left alignment, 0 0-padding and, a space white-space padding and # modified output. The two optional numerical arguments are separated by a full stop and may
    be * to get them from the argument list. The first numerical argument specifies the field width
    and the second the precision for floating point numbers.

    This sequence is followed by optional type information. For integers this is one of l (long),
    ll (long long) or z (size_t). For strings this is one of L (ISO Latin 1), U (UTF-8) or W
    (wchar_t*).

    Finally we come to the format specifier. This is one of

    % Emit the % character itself.
    c Emit a Unicode code point.
    p Emit a pointer.
    d
    i Emit a a signed integer as decimal. The l (long), ll (long long) or z (size_t) denote
    the size.
    o
    u
    x
    X Emit a a unsigned integer as octal, decimal or hexadecimal.
    f
    e
    E
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g
G Emit a double.
s Emit a 0-terminated string.

This function returns the number of characters written. Note that due to multibyte encodings
the number of bytes written can be more.

int **Sprintf**(const char *fm, ...)
Similar to **Sfprintf()**, printing to **Soutput**

int **Syprintf**(IOSTREAM *s, const char *fm, va_list args)
Variadic argument list version of **Sprintf()**.

int **Sprintf**(char *buf, const char *fm, ...)
Print to a C string. Deprecated. Use **Ssnprintf()** instead.

int **Ssnprintf**(char *buf, size_t size, const char *fm, ...)
Print to a C string, emitting a maximum of size bytes. Returns the number of bytes written.
Currently buf uses ENC_ISO_LATIN_1 encoding. Future versions will probably change to ENC_UTF8.

int **Svprintf**(char *buf, const char *fm, va_list args)
Variadic argument list version of **Sprintf()**. Deprecated. Use **Svsnprintf()** instead.

int **Svsnprintf**(char *buf, size_t size, const char *fm, va_list args)
Variadic argument list version of **Ssnprintf()**.

int **Sdprintf**(const char *fm, ...)
Print to **Serror**. This function should be used for printing debug output from foreign code.

int **Svdprintf**(const char *fm, va_list args)
Variadic argument list version of **Sdprintf()**.

int **Sfileno**(IOSTREAM *s)
If the stream is associated to a POSIX file handle, return this handle. Returns -1 otherwise.

int **Swinsock**(IOSTREAM *s)
Windows only. If the stream is associated to a Windows socket handle, returns this handle.
Otherwise return INVALID_SOCKET

int **Sclosehook**(void (**hook)(IOSTREAM *))
Register a hook function to be called by **Sclose()** just before the stream is deallocated. This
is used internally to update the Prolog administration of open streams on **Sclose()**.
12.9.4 Foreign stream error handling

int Sferror(IOSTREAM *s)
Returns TRUE if the stream is in an error condition, FALSE if the stream is valid and in normal condition and -1 if the stream is invalid.

void Sclearerr(IOSTREAM *s)
Clear the error state of a stream. This includes the end-of-file state, pending warnings and errors and timeout.

int Sseterr(IOSTREAM *s, int which, const char *message)
Set an error or warning state on the stream. The which argument is one of SIO_WARN or SIO_FERR. This causes PL_release_stream() to print a message (SIO_WARN) or raise an exception (SIO_FERR).

int Sset_exception(IOSTREAM *s, term_t ex)
Associate a Prolog exception term with the stream or clear the associated exception if ex is 0 and set/clear the SIO_FERR condition on the stream. If an exception is associated PL_release_stream() raises this exception.

12.9.5 Foreign stream encoding

IOSTREAM has a field encoding that is managed at initialization from SIO_TEXT. The available encodings are defined as a C enum as below.

```c
typedef enum
{   ENC_UNKNOWN = 0,      /* invalid/unknown */
    ENC_OCTET,            /* raw 8 bit input */
    ENC_ASCII,            /* US-ASCII (0..127) */
    ENC_ISO_LATIN_1,      /* ISO Latin-1 (0..256) */
    ENC_ANSI,             /* default (multibyte) codepage */
    ENC_UTF8,             /* big endian unicode file */
    ENC_UNICODE_BE,       /* little endian unicode file */
    ENC_UNICODE_LE,       /* wchar_t */
    ENC_WCHAR
} IOENC;
```

Binary streams always have the encoding ENC_OCTET. The default encoding of a text stream depends on the Prolog flag encoding. The encoding is used by all functions that perform text I/O on a stream. The encoding can be changed at any moment using Ssetenc() which is available from Prolog using

```c
int Sset_filter(IOSTREAM *parent, IOSTREAM *filter)
Register filter as a stream that reads from or writes to the stream parent.

void Ssetbuffer(IOSTREAM *s, char *buf, size_t size)
Set the input or output buffer for s to size. The buf argument is either NULL, asking the system to allocate a buffer or points at a buffer of (at least) the indicated size long. The default buffer size is defined by the C macro SIO_BUFSIZE.
the `set_stream/2` encoding(\textit{Encoding}) property. Functions that explicitly manage the encoding are:

\begin{verbatim}
int Ssetenc(Iostream *s, Ioenc new_enc, Ioenc *old_enc)
  Set the encoding for \textit{s} to \textit{new_enc} and, if \textit{old_enc} is not NULL, return the old encoding. This function may fail, returning -1 if the Scontrol function of the stream returns -1 on the SIO_SETENCODING request. On success it returns 0. If \textit{new_enc} is \texttt{ENC_OCTET} the stream is switched to binary mode. Otherwise text mode is enabled.

int ScheckBOM(Iostream *s)
  This function may be called on a buffered input stream immediately after opening the stream. If the stream starts with a known \textit{Byte Order Mark} (BOM) the encoding is set accordingly and the flag SIO_BOM is set on the stream. Possibly resulting encodings are \texttt{ENC_UTF8}, \texttt{ENC_UNICODE_BE} and \texttt{ENC_UNICODE_LE}.

int SwriteBOM(Iostream *s)
  This function writes a \textit{Byte Order Mark} (BOM) to \textit{s} and should be called immediately after opening a stream for writing. If the encoding is one of \texttt{ENC_UTF8}, \texttt{ENC_UNICODE_BE} or \texttt{ENC_UNICODE_LE} it writes the code point \texttt{\u000b} (a zero-width white space) to the stream in the current encoding and sets the SIO_BOM flag on the stream.

int Scanrepresent(int c, Iostream *s)
  Returns 0 if the encoding of \textit{s} can represent the code point \textit{c} and -1 otherwise.
\end{verbatim}

### 12.9.6 Foreign stream line endings

Text streams have a field newline that controls the handling of the newline convention. Note that inside Prolog all lines end with a single newline (\texttt{\u000a}, \texttt{\n}) code point. The values are described below. The default depends on the OS and can be manipulated using the newline(\textit{Mode}) property of \texttt{set_stream/2}.

\texttt{SIO_NL_DETECT}

This mode may be enabled on an input stream. It causes the stream to read up to the first newline to set the newline mode accordingly.

\texttt{SIO_NL_POSIX}

Do not do any translation on input or output.

\texttt{SIO_NL_DOS}

Emit a newline (\texttt{\n}) as \texttt{\r\n}. Discard \texttt{\r} from the input.\footnote{The current implementation does not check that the character is followed by \texttt{\n}.}

### 12.9.7 Foreign stream position information

The Iostream has a field position that points at a structure of type IOPOS. This structure is defined as below.
typedef struct io_position
{
    int64_t byteno; /* byte-position in file */
    int64_t charno; /* character position in file */
    int lineno; /* lineno in file */
    int linepos; /* position in line */
    intptr_t reserved[2]; /* future extensions */
} IOPOS;

If a stream is created using the flag SIO_RECORDPOS the IO functions maintain the position information. Note that, supporting the ISO stream position data (see stream_property/2), both the byte and character position is maintained. These may differ if the stream uses a multibyte encoding.

The linepos is updated as follows: \n and \r reset the position to 0 (zero). The backspace (\b) decrements the position if it is positive. The tab (\t) tabs to the next multiple of 8. Any other character increments the line position by one. Future versions may change that, notably the tab width might no longer be hard coded.
Using SWI-Prolog in your browser (WASM)

Emscripten can compile C and C++ code to WebAssembly (WASM). WASM runs on a virtual machine that is provided by almost all modern browsers. This allows for compiling the SWI-Prolog source to WASM and run it in your browser. We keep up-to-date instructions for building the WASM version on the wiki page.

Currently the WASM version is a fairly comprehensive version of SWI-Prolog. It contains the core and a good selection of the packages, including many of the foreign packages.

13.1 Loading and initializing Prolog

The WASM SWI-Prolog distribution consists of three files:

swipl-web.js This is the main file that must be loaded using a `<script>` element. It defines a global function SWIPL that loads the other components and gives access to the SWI-Prolog system.

swipl-web.wasm This is the actual WASM binary containing the compiled C code of the core, foreign packages and required libraries.

swipl-web.data This data contains a file system that is mounted on `/swipl`. It contains the Prolog startup code and libraries.

Below is the skeleton for getting access to the Prolog system. We first define the global Module object, optionally with configuration parameters. We use a global variable because some of the Emscripten configuration parameters require access to the Module. SWIPL returns a Promise that resolves when the WASM system is loaded and initialized. This sets Module.prolog to an instance of the class Prolog that provides a high level interface from JavaScript.

```javascript
let Prolog;
const Module = {
  // Provide options for customization
};

SWIPL(Module).then((module) =>
{ Prolog = Module.prolog;

  // Start using Prolog
});
```
Module defines customization properties for the Emscripten module as well as for Prolog. We highlight the important properties below.

arguments
An Array of String objects that define the command line arguments for initializing Prolog. argv[0] is not part of this array. Few arguments are useful in this context. The -q may be used to suppress the Prolog banner.

locateFile
A Function that is used to translate swipl-web.wasm and swipl-web.data into a (relative) URL. Default is to find these resources in the same directory of the server. For example, to load swipl-web.wasm and swipl-web.data from /wasm use

```javascript
var Module = {
  ...
  locateFile: (file) => '/wasm/' + file
}
```

on_output
A Function that is called when Prolog writes to user_output or user_input. It is passed two arguments: a String containing the text to emit and one of the constant strings "stdout" or "stderr" to indicate the output stream. This uses the Emscripten Module.FS.init option to rebind the output and error streams, providing behaviour that is similar to the Emscripten properties print and printErr. However, our passed string contains the newline character and the handler is called when Prolog flushes the output. Normally the callback should insert a <span> element that has (at least) the following style:

```css
.stderr, .stdout {
  white-space: pre-wrap;
  font-family: monospace;
  overflow-wrap: anywhere;
}
```

Here is a simple implementation of print(), assuming the document has a <div id="output"> node.

```javascript
function print(line, cls) {
  const output = document.getElementById("output");
  const node = document.createElement('span');
  node.className = cls;
  node.textContent = line;
  output.appendChild(node);
}
```
13.2. CALLING PROLOG FROM JAVASCRIPT

13.1.1 Loading Prolog files

The WASM build ships with the Prolog library and thus Prolog libraries can be loaded as normal using \use_module/1, etc., for example, we can include the \lists library using this directive. Note that the normal autoloading of library code works in the WASM version.

\[:- \text{use_module(library(lists)).}\]

When Prolog is in asynchronous mode, i.e., called through \Prolog.forEach(), we can also load code from a URL. For example, we can load the \CHAT80 demo program directly from GitHub using

\[?- \text{consult('https://raw.githubusercontent.com/JanWielemaker/chat80/master/prolog/chat80.pl').}\]

Larger files can be loaded as .qlf files. See section 4.3.3 and qcompile/2. Notably we can create a single qlf file from an application using the include(user) option. Below we create a .qlf file from \CHAT80. The resulting chat80.qlf can be loaded from a URL using consult/1 as above.

\[?- \text{qcompile('chat80.pl', [include(user)])}.\]

There are three ways to load Prolog code from JavaScript: (1) loading from a string, (2) loading from <script> elements and (3) loading from URL. Note that all the loading methods return a Promise that is resolved when loading the data is completed.

Promise-Prolog.load_string(String, Id)

Load Prolog code from String, pretending it was loaded from the file Id. The Id is optional. When omitted it generates /string/1, /string/2, ....

Promise-Prolog.load_scripts()

Load all scripts from the current document that have their type set to text/prolog. The file reference for the loaded script is /script/Id, where Id is derived from (1) the id of the script, (2) the name of the script or (3) being the nth Prolog script in the document. When resolved, the promise returns an array with the names of the loaded scripts.

Promise-Prolog.consult(...Sources)

Load the given Sources. Each source is either a file from the local file system, e.g., library(lists) or a URL. The sources are downloaded and processed sequentially. This uses Prolog.forEach() calling load_files/1. The returned Promise returns 1 on success.

13.2 Calling Prolog from JavaScript

The Prolog class provides several methods for calling Prolog from JavaScript.

\(^1\)The \c continues the quoted atom from the next line after removing leading white space.
Boolean Prolog.call(Goal)

Processes a Prolog goal represented as a String and returns true or false. This simple calling pattern is intended for trivial goals such as setting a Prolog flag. For example, the call below limits the Prolog stacks to 10Mb.

```
Prolog.call("set_prolog_flag(stack_limit, 10 000 000)");
```

Query Prolog.query(Goal)

Create a Prolog query from a String, optionally binding Prolog variables embedded in Goal from properties of the Object Input. The returned object is an instance of class Query. This instance can be used as a JavaScript iterator. The value returned in each iteration is an Object with properties for each variable in Goal that is not in Input and does not start with an underscore. For example, we can iterate over the members of a list like below. Further details on class Query are provided in section 13.2.1. The translation of data between Prolog and JavaScript is described in section 13.2.2.

```
for(let r of Prolog.query("member(Elem,List)",

{List: ["aap", "noot", "mies"]})

{ console.log(r.Elem);
}
```

This interface is also practical for calling (fast) Prolog predicates to compute a single answer from an input using the Query.once() method. Assuming a Prolog predicate fib/2 that computes the nth Fibonacci number, we can call this using the code below. Note that if the fib/2 fails or raises an exception the object returned by Query.once() does not contain the Out key and thus our function returns undefined.

```
function fib(in, out)
{
return Prolog.query("fib(In,Out)", {In:in}).once().Out;
}
```

The .query() method is indented for fast queries that do not require the yield mechanism, i.e., the execution should not require asynchronous operations and the browser is not responsive during the execution.

Promise Prolog.forEach(Goal)
Promise Prolog.forEach(Goal, OnAnswer)
Promise Prolog.forEach(Goal, Input)
Promise Prolog.forEach(Goal, Input, OnAnswer)

This method executes Goal asynchronously. This implies that Goal may execute asynchronous operations and the browser remains responsive while executing Goal. Goal and Input are processed as with .query(). For each answer, OnAnswer is a Function that is called with a Object that holds the bindings for the output arguments of Goal.
The returned Promise is resolved when the query completes. The value passed to the .then() method of the Promise is the number of answers if OnAnswer is provided or an Array of answers if OnAnswer is omitted. If Goal raises an exception the Promise is rejected.

Multiple calls to Prolog can be activated at any time. Prolog processes such queries in LIFO (Last In, First Out) mode. If queries need to be processed sequentially use JavaScript await or the Promise.finally() method to wait for completion.

### 13.2.1 The JavaScript class Query

The method Prolog.query() returns an instance of the JavaScript class Query that may be used to explore the solutions of the query. The Query class implements the JavaScript iterator protocol.

Object Query.next()

Implements the iterator protocol. This returns an object holding the keys done and value. If exception handling is enabled it returns an object `{done:true, error:true, message:String}`.

Object Query.once()

Close the query after the first answer. Returns the .value of the object returned by .next() on success and the complete object on failure or error. In addition, on a logical result (no error), a field success is added with a boolean value. Thus, the return value may contain these keys:

- **{Bindings}**
  - Query succeeded. Objects holds a key for each output variable. In addition the success key is set to true.
  - **{success:false}**
    - Query failed. Note that the binding keys all start with an uppercase letter and this is thus not ambiguous.
  - **{error:true, message:String}**
    - Query raised an exception.

Object Query.close()

Closes the query. This can be used inside the iterator to stop further enumeration.

### 13.2.2 Translating data between JavaScript and Prolog

JavaScript and Prolog are both dynamically typed languages. The WASM module defines a faithful translation between JavaScript data and Prolog data that aims at completeness as well as keeping the data representation clean in the common cases. We describe the translation in two descriptions because round tripping does not always result in the original object.

**Translating JavaScript data to Prolog**

This section describes how data from JavaScript is translated into Prolog. The interface is primarily designed for passing JavaScript data as typically used to a natural Prolog representation. In addition a number of classes are provided to create Prolog specific data structures such as strings (as opposed to atoms), variables, compound terms, etc.
**Number**
Translate to a Prolog integer or floating point number.

**BigInt**
Translate to a Prolog integer.

**String**
Translate to a Prolog atom. Use `new Prolog.String(text)` to create a Prolog string. See below.

**Boolean**
Translate to one of the Prolog atoms `true` or `false`.

**undefined**
Translate the Prolog atom `undefined`.

**null**
Translate the Prolog atom `null`.

**Array**
Translate to a Prolog list.

**Objects holding the key $t$:Type**
Such objects are converted depending on the value for this key. The interface defines classes to simplify creating such objects.

- **s**
  Represent a Prolog string. The key `v` holds the text. May be created using `new Prolog.string(text)`. May be created using `new Prolog.String(text)`.

- **r**
  Represent a Prolog rational number. The keys `n` and `d` represent the numerator and denominator. For example, to represent `1r3`, use `{t:'r', n:1, d:3}`. May be created using `new Prolog.Rational(n, d)`, where `n` and `d` can be JavaScript numbers or big integers.

- **t**
  Represent a Prolog compound term. The object should hold exactly one key whose value is an array that holds the argument values. For example a term `point(1,2)` is constructed using `{t:'t', point:[1,2]}`. May be created using `new Prolog.Compound(functor, args)`.

- **v**
  Represent a variable. If the key `v` is present this identifies the variable. Two variables processed in the same translation with the same identifier represent the same Prolog variable. If the `v` key is omitted the variable will be unique. May be created using `new Prolog.Var(id)`.

- **l**
  Represent a Prolog list. As a JavaScript `Array` we only need this typed object to create a partial list. The `v` key contains the “normal” elements and the key `tail` contains the tail of the list. May be created using `new Prolog.List(array, tail)`.
13.2. CALLING PROLOG FROM JAVASCRIPT

Object of class **Object**
Plain JavaScript objects are translated into a Prolog `dict`. Note that JavaScript object keys are always strings and (thus) all dict keys are atoms. This, `{1:"one"}` is translated into `_{'1': one}`.

**ArrayBuffer**
Instances of `ArrayBuffer` are translated into a Prolog string that consists of characters in the range 0...255.

**Objects of a one class not being Object**
Instances of non-plain JavaScript objects are translated into a Prolog `blob`. Such objects are written as `<js_Class(id)>`. The Prolog interface allows for passing the objects back and calling methods on them. See section 13.3.

**Translating Prolog data to JavaScript**
Most of the translation from Prolog data to JavaScript is the reverse of the translation described in section 13.2.2. In some cases however reverse translation is ambiguous. For example, both 42 and 42n (a JavaScript `BigInt`) translate to a simple Prolog integer. The other way around, as JavaScript `Number` is a float, both Prolog 42 and 42.0 translate to 42 in JavaScript.

**Variable**
Translate to a JavaScript `Prolog.Variable` instance where the identifier is a unique number of each unique variable.

**Integer**
Translate to a JavaScript `Number` when possible or `BigInt` otherwise. Currently JavaScript `Number` can represent integers upto $2^{53}$ precisely.

**Rational**
Translate to a JavaScript `Prolog.Rational` instance.

**Float**
Translate to a JavaScript `Number`.

**Atom**
Translate to a JavaScript `String`.

**String**
Translate to a JavaScript `Prolog.String` instance.

**List**
When a *proper list* create a JavaScript `Array`, otherwise create a JavaScript `Prolog.List` instance.

**Compound term**
Create a JavaScript `Prolog.Compound` instance.

**Dict**
Create a plain JavaScript `Object` with the same keys. If the dict has a non-var `tag`, add a `$tag` property.
13.3 Accessing JavaScript from Prolog

This section describes how we can interact with JavaScript from Prolog. The interface is captured in a single predicate \( \text{=/2/} \).

\[ \text{Left := Right} \]

Depending on \text{Left}, this predicate implements two different actions. If \text{Left} is a Prolog variable, it evaluates the expression \text{Right} in JavaScript and unifies the result to \text{Left}. If \text{Left} is a term \text{Obj[Key]}, where \text{Key} is an atom, it accesses a JavaScript setter. The general form of an expression is \text{Expression[Callable]} or simply \text{Callable}. If \text{Callable} is compound it expresses a function (or method) call. Otherwise we call JavaScript \text{eval()}, except for these special values:

\text{window}

The main browser window itself (undefined when not in a browser).

\text{prolog}

The Prolog instance.

Prolog values are translated according to the rules in section 13.2.2 and the result is translated back to Prolog according to the rules in section 13.2.2. Because callables are translated to function calls, object properties or global variables we need an escape to pass them as data. This is achieved using the prefix operator \#. Note that lists are passed as JavaScript arrays rather than calls to the list functor. For convenience Prolog strings are by default translated to JavaScript \text{String} objects rather than Prolog.String instances. Below are some examples:

\begin{verbatim}
?- Res := myfunc([1,2,3]).
?- Max := 'Math'.max(10, 20).
?- Out := document.getElementById('output').
?- Par := document.createElement(p),
   Par.textContent := #Text.
?- Par.textContent := "aap" + " " + "noot".
\end{verbatim}

Some JavaScript expressions are not implemented as functions. The following “functions” are handled directly by the implementation.

\text{instanceof}

Returns the name of the class to which the object belongs. Same as \text{Obj.constructor.name}.

\text{instanceof(ClassName)}

Returns a \text{Boolean} indicating whether the object is an instance of \text{ClassName}. Note that the class name must be an atom and as JavaScript class names normally start with a capital, the names typically need to be quoted using single quotes. For example:

\begin{verbatim}
?- W := window, T := W.instanceof('Window').
W = <js_Window>(1),
T = true.
\end{verbatim}
13.3. ACCESSING JAVASCRIPT FROM PROLOG

\[-(Any)\]
\[\text{Numerical negation}\]
\[!(Any)\]
\[\text{Logical negation.}\]
\[+(Any, Any)\]
\[\neg(Any, Any)\]
\[\ast(Any, Any)\]
\[/(Any, Any)\]
\[\&\&(Any, Any)\]
\[||\&(Any, Any)\]

\[\&\&(Any, Any)\]
\[||\&(Any, Any)\]

\[\text{Binary operators. Note that some are not defined as Prolog operators and thus one must write e.g. A := \&\&(true, false). || is not a Prolog atom, so logical disjunction gets A := '||'(false, false).}\]

\[\text{is\_object}(\text{@Term})\]
\[\text{True if Term is a reference to a JavaScript object.}\]

\[\text{is\_object}(\text{@Term}, \text{?Class})\]
\[\text{True when Term is an instance of Class. If Class is unbound it is unified with the name of the constructor, otherwise a JavaScript Term instanceof Class is executed.}\]

\[\text{js\_script}(+\text{String}, +\text{Options})\]
\[\text{Evaluate String as JavaScript. This is designed to cooperate with string quasi quotations, so we can write e.g.,}\]

```
:- use_module(library(strings)).
:- js_script PROCUREMENTSTRING
function myfunc(a)
  ...
|}.
```

The implementation uses = : /2, calling the JavaScript function eval().

\[\text{fetch}(+\text{URL}, +\text{Type}, -\text{Data})\]
\[\text{Wrapper around JavaScript fetch(), conversion of the Response object and waiting for the Promise. Type is an atom or string that is used as method on the Response object. Examples are text, json, html or blob. The blob type returns the Data as a string of bytes, i.e., character codes in the range 0...255.}\]

\[\text{Asynchronous access to JavaScript from Prolog}\]

While section 13.3 describes synchronous calls from Prolog to JavaScript, we also need asynchronous calling to implement sleep/1, wait for user input, downloading documents from the web, etc. Asynchronous calling is achieved by yielding from the Prolog virtual machine. This can only be done
when Prolog is told to expect that the VM may yield. This is implemented by Prolog.forEach() as described in section 13.2.

**await(+Promise, -Result)**

Yield the Prolog VM, returning control back to JavaScript. When this is called from Prolog invoked using Prolog.forEach(), execution of await/2 completes when the Promise resolves and Result is unified with the value passed to the Promise.then() method. As an exception to the normal conversion rules, if the result is a single String, it is returned as a Prolog string rather than an atom. When the Promise is rejected await/2 throws an exception. Note that await/2 allows, for example, downloading a URL from Prolog:

```prolog
?- FP := fetch("test.pl"), await(FP, Response),
   TP := Response.text(), await(TP, T).
FP = <js_Promise>(4),
Response = <js_Response>(5),
TP = <js_Promise>(6),
T = "% :- debug(js) ...
```

Calls to await/2 may be asynchronously aborted by calling Prolog.abort() if Promise implements .abort(). See section 13.3 for implementing such a promise.

**is_async**

True when we can call await/2 in the current state. This implies Prolog has been called from JavaScript code that is prepared to deal with Prolog yielding and Prolog is not inside a callback from C (WASM).

### JavaScript Promise that can be aborted

A Promise resolves or is rejected. As Prolog waits for a specific promise on a call to await/2 we may want to abort long running operations. This may be achieved using the class Prolog.Promise which extends Promise. To make the promise abortable the executor function must have an abort property. Below is the code for Prolog.promise_sleep() that implements this schema. First we create the executor and use properties on the function itself to represent the necessary state information (here, the running timer). Next, we add an abort property the clears the timer and runs the reject callback of the Promise. Finally we return an instance of Prolog.Promise which implements .abort().

```javascript
promise_sleep(time)
{ const f = function(resolve, reject)
  { f.reject = reject;
    f.timer = setTimeout(() =>
      { f.timer = undefined;
        resolve(true);
      }, time*1000);
  }
  f.abort = function()
```

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{ if ( f.timer )
    { clearTimeout(f.timer);
      f.timer = undefined;
      f.reject("abort");
    }
}

return new Prolog.Promise(f);
Deploying applications

This chapter describes the features of SWI-Prolog for delivering applications using saved states.

14.1 Deployment options

There are several ways to make a Prolog application available to your users. By far the easiest way is to require the user to install SWI-Prolog and deliver the application as a directory holding source files, other resources the application may need and a Prolog Script file that provides the executable. See section 2.11.2. The two-step installation may be slightly less convenient for the end user, but enables the end-user to conveniently run your program on a different operating system or architecture. This mechanism is obviously not suitable if you want to keep the source of your program secret.

Another solution is to use saved states, the main topic of this chapter, together with the installed development system and disable autoloading requirements into the state using --no-autoload or the autoload(false) option of qsave_program/2. This allows creating the application as a single file, while avoiding the need to ensure that the state is self-contained. For large programs this technique typically reduces startup time by an order of magnitude. This mechanism is particularly suitable for in-house and cloud deployment. It provides some protection against inspecting the source. See section 14.6 for details.

The final solution is to make sure all required resources are present in the saved state. In this case the state may be added to the emulator and the application consists of the emulator with state and the shared objects/DLLs required to make the emulator work. If the emulator can be statically linked for the target platform this creates a single file executable that does not require SWI-Prolog installed on the target computer.

14.2 Understanding saved states

A SWI-Prolog saved state is a resource archive that contains the compiled program in a machine-independent format, startup options, optionally shared objects/DLLs and optionally additional resource files. As of version 7.7.13, the resource archive format is ZIP. A resource file is normally created using the commandline option -c:

```
swipl -o mystate option ... -c file.pl ...
```

The above causes SWI-Prolog to load the given Prolog files and call qsave_program/2 using options created from the option ... in the command above.

1Although the compiled code is independent from the CPU and operating system, 32-bit compiled code does not run on the 64-bit emulator, nor the other way around. Conditionally compiled code (see if/1) may also reduce platform independence.
A saved state may be executed in several ways. The basic mechanism is to use the -x:

```
swipl -x mystate app-arg ...
```

Saved states may have an arbitrary payload at the start. This allows combining a (shell) script or the emulator with the state to turn the state into a single file executable. By default a state starts with a shell script (Unix) or the emulator (Windows). The options emulator(File) and stand_alone(Boolean) control what is added at the start of the state. Finally, C/C++ programs that embed Prolog may use a static C string that embeds the state into the executable. See PL_set_resource_db_mem().

### 14.2.1 Creating a saved state

The predicates in this section support creating a saved state. Note that states are commonly created from the commandline using the -c, for example:

```
swipl -o mystate --foreign=save -c load.pl
```

Long (-- ) options are translated into options for qsave_program/2. This transformation uses the same conventions as used by argv_options/3, except that the transformation is guided by the option type. This implies that integer and callable options need to have valid syntax and boolean options may be abbreviated to simply --autoload or --no-autoload as shorthands for --autoload=true and -- autoload=false.

**qsave_program(+File, +Options)**

Saves the current state of the program to the file File. The result is a resource archive File containing expresses all Prolog data from the running program, all user-defined resources (see resource/2 and open_resource/2) and optionally all shared objects/DLLs required by the program for the current architecture. Depending on the stand_alone option, the resource is headed by the emulator, a Unix shell script or nothing. Options is a list of additional options:

- **stack_limit(+Bytes)**
  Sets default stack limit for the new process. See the command line option --stack-limit and the Prolog flag stack_limit.

- **goal(:Callable)**
  Initialization goal for the new executable (see -g). Two values have special meaning: prolog starts the Prolog toplevel and default runs halt/0 if there are initialization goals and the prolog/0 toplevel otherwise.

- **toplevel(:Callable)**
  Top-level goal for the new executable (see -t). Similar to initialization/2 using main, the default toplevel is to enter the Prolog interactive shell unless a goal has been specified using goal(Callable).

- **init_file(+Atom)**
  Default initialization file for the new executable. See -f.

---

2 As the default emulator is a short program while the true emulator is in a DLL this keeps the state short.
class(+Class)
    If runtime (default), read resources from the state and disconnect the code loaded into the state from the original source. If development, save the predicates in their current state and keep reading resources from their source (if present). See also open_resource/3.

autoload(+Boolean)
    If true (default), run autoload/0 first. If the class is runtime and autoload is true, the state is supposed to be self contained and autoloading is disabled in the restored state.

map(+File)
    Dump a human-readable trace of what has been saved in File.

op(+Action)
    One of save (default) to save the current operator table or standard to use the initial table of the emulator.

stand_alone(+Boolean)
    If true, the emulator is the first part of the state. If the emulator is started it tests whether a saved state is attached to itself and load this state. Provided the application has all libraries loaded, the resulting executable is completely independent from the runtime environment or location where it was built. See also section 2.11.2.

emulator(+File)
    File to use for the emulator or executable used by the startup script. Default is the running Prolog image after following symbolic links, e.g., /usr/lib/swipl/lib/x86_64-linux/swipl. To create a saved state based on the public executable such that it can run on multiple architectures one can use e.g.

    $ swipl -o myexe --emulator=$(which swipl) -c myload.pl

foreign(+Action)
    If save, include shared objects (DLLs) for the current architecture into the saved state. See current_foreign_library/2, and current_prolog_flag(arch, Arch). If the program strip is available, this is first used to reduce the size of the shared object. If a state is started, use_foreign_library/1 first tries to locate the foreign resource in the resource database. When found it copies the content of the resource to a temporary file and loads it. If possible (Unix), the temporary object is deleted immediately after opening.\(^3\)

    3This option is experimental and currently disabled by default. It will become the default if it proves robust.

    Creating a temporary file is the most portable way to load a shared object from a zip file but requires write access to the file system. Future versions may provide shortcuts for specific platforms that bypass the file system.

    4

If Action is of the form arch(ListOfArches) then the shared objects for the specified architectures are stored in the saved state. On the command line, the list of architectures can be passed as --foreign=(CommaSepArchesList). In order to obtain the shared object file for the specified architectures, qsave_program/2 calls a user defined hook: qsave:arch_shlib(+Arch, +FileSpec, -SoPath). This hook needs to unify SoPath with the absolute path to the shared object for the specified architecture. FileSpec is of the form foreign(Name).

$ swipl -o myexe --emulator=$(which swipl) -c myload.pl
At runtime, SWI-Prolog will try to load the shared library which is compatible with the 
current architecture, obtained by calling `current_prolog_flag(arch, Arch)`. An ar-
chitecture is compatible if one of the two following conditions is true (tried in order):

1. There is a shared object in the saved state file which matches the current architecture 
   name (from `current_prolog_flag(2)`) exactly.
2. The user definable `qsave:compat_arch(Arch1, Arch2)` hook succeeds.

This last one is useful when one wants to produce one shared object file that works for 
multiple architectures, usually compiling for the lowest common denominator of a certain 
CPU type. For example, it is common to compile for armv7 if even if the code will be 
running on newer arm CPUs. It is also useful to provide highly-optimized shared objects 
for particular architectures.

`undefined(+Value)`

Defines what happens if an undefined predicate is found during the code analysis. Values 
are `ignore` (default) or `error`. In the latter case creating the state is aborted with a 
message that indicates the undefines predicates and from where they are called.

`obfuscate(+Boolean)`

If `true` (default `false`), replace predicate names with generated symbols to make the 
code harder to assess for reverse engineering. See section 14.6.1.

`verbose(+Boolean)`

If `true` (default `false`), report progress and status, notably regarding auto loading.

`qsave_program(+File)`

Equivalent to `qsave_program(File, [])`.

`autoload_all`

Check the current Prolog program for predicates that are referred to, are undefined and have a 
definition in the Prolog library. Load the appropriate libraries.

This predicate is used by `qsave_program/[1, 2]` to ensure the saved state does not depend 
on availability of the libraries. The predicate `autoload_all/0` examines all clauses of the 
loaded program (obtained with `clause/2`) and analyzes the body for referenced goals. Such 
an analysis cannot be complete in Prolog, which allows for the creation of arbitrary terms at 
runtime and the use of them as a goal. The current analysis is limited to the following:

- Direct goals appearing in the body
- Arguments of declared meta-predicates that are marked with an integer (0..9). See 
  `meta_predicate/1`.

The analysis of meta-predicate arguments is limited to cases where the argument appears liter-
ally in the clause or is assigned using `=/2` before the meta-call. That is, the following fragment 
is processed correctly:

```prolog
..., Goal = prove(Theory), 
  forall(current_theory(Theory), 
     Goal)),
```
But, the calls to \texttt{prove_simple(Theory)} and \texttt{prove_complex(Theory)} in the example below are \textit{not} discovered by the analysis and therefore the modules that define these predicates must be loaded explicitly using \texttt{use_module/[1,2]}.

\begin{verbatim}
...,
    member(Goal, [ prove_simple(Theory),
                 prove_complex(Theory)
                 ]),
    forall(current_theory(Theory),
           Goal)),
\end{verbatim}

It is good practice to use \texttt{gxref/0} to make sure that the program has sufficient declarations such that the analysis tools can verify that all required predicates can be resolved and that all code is called. See \texttt{meta.predicate/1}, \texttt{dynamic/1}, \texttt{public/1} and \texttt{prolog:called_by/2}.

\texttt{volatile +Name/Arity, ...}

Declare that the clauses of specified predicates should \textit{not} be saved to the program. The volatile declaration is normally used to prevent the clauses of dynamic predicates that represent data for the current session from being saved in the state file.

\subsection*{14.2.2 Limitations of qsave\_program}

There are three areas that require special attention when using \texttt{qsave\_program/[1,2]}.

- If the program is an embedded Prolog application or uses the foreign language interface, care has to be taken to restore the appropriate foreign context. See section 14.2.3 for details.

- If the program uses directives (\texttt{:- goal, lines}) that perform other actions than setting predicate attributes (\texttt{dynamic/1}, \texttt{volatile/1}, etc.) or loading files (\texttt{use_module/1}, etc.). Goals that need to be executed when the state is started must use \texttt{initialization/1} (ISO standard) or \texttt{initialization/2} (SWI extension that provides more control over when the goal is executed). For example, \texttt{initialization/2} can be used to start the application:

\begin{verbatim}
:- initialization(go, main).
\end{verbatim}

- \texttt{Blobs} used as references to the database (see \texttt{clause/3}, \texttt{recorded/3}), streams, threads, etc. can not be saved. This implies that (dynamic) clauses may not contain such references at the moment the \texttt{qsave\_program/2} is called. Note that the required foreign context (stream, etc.) cannot be present in the state anyway, making it pointless to save such references. An attempt to save such objects results in a warning.

The \texttt{volatile/1} directive may be used to prevent saving the clauses of predicates that hold such references. The saved program must reinitialise such references using the normal program initialization techniques: use \texttt{initialization/1,2} directives, explicitly create them by the entry point or make the various components recreate the context lazily when required.
14.2.3 Runtimes and Foreign Code

Many applications use packages that include foreign language components compiled to shared objects or DLLs. This code is normally loaded using `use_foreign_library/1` and the `foreign` file search path. Below is an example from the `socket` library.

```prolog
:- use_foreign_library(foreign(socket)).
```

There are two options to handle shared objects in runtime applications. The first is to use the `foreign(save)` option of `qsave_program/2` or the `--foreign=save` command line option. This causes the dependent shared objects to be included into the resource archive. The `use_foreign_library/1` directive first attempts to find the foreign file in the resource archive. Alternatively, the shared objects may be placed in a directory that is distributed with the application. In this case the file search path `foreign` must be setup to point at this directory. For example, we can place the shared objects in the same directory as the executable using the definition below. This may be refined further by adding subdirectories depending on the architecture as available from the Prolog flag `arch`.

```prolog
:- multifile user:file_search_path/2.
user:file_search_path(foreign, Dir) :-
    current_prolog_flag(executable, Exe),
    file_directory_name(Exe, Dir).
```

14.3 State initialization

The `initialization/1` and `initialization/2` directive may be used to register goals to be executed at various points in the life cycle of an executable. Alternatively, one may consider lazy initialization which typically follows the pattern below. Single threaded code can avoid using `with_mutex/2`.

```prolog
:- dynamic x_done/0.
:- volatile x_done/0.

x(X) :-
    x_done,
    !,
    use_x(X).

x(X) :-
    with_mutex(x, create_x),
    use_x(X).

create_x :-
    x_done,
    !.
```
create_x :-
    <create x>
    asserta(x_done).

14.4 Using program resources

A *resource* is similar to a file. Resources, however, can be represented in two different formats: on files, as well as part of the resource *archive* of a saved state (see `qsave_program/2`) that acts as a *virtual file system* for the SWI-Prolog I/O predicates (see `open/4`, `register_iri_scheme/3`).

A resource has a *name*. The *source* data of a resource is a file. Resources are declared by adding clauses to the predicate `resource/2` or `resource/3`. Resources can be accessed from Prolog as files that start with `res://` or they can be opened using `open_resource/3`.

14.4.1 Resources as files

As of SWI-Prolog 7.7.13, resources that are compiled into the program can be accessed using the normal file handling predicates. Currently the following predicates transparently handle resources as read-only files:

- `open/3`, `open/4`
- `access_file/2`
- `exists_file/1`
- `exists_directory/1`
- `time_file/2`
- `size_file/2`

In addition, `open_shared_object/3`, underlying `use_foreign_library/1` handles *shared objects* or DLLs by copying them to a temporary file and opening this file. If the OS allows for it, the copied file is deleted immediately, otherwise it is deleted on program termination.

With the ability to open resources as if they were files we can use them for many tasks without changing the source code as required when using `open_resource/2`. Below we describe a typical scenario.

- Related resources are placed in one or more directories. Consider a web application where we have several directories holding icons. Add clauses to `file_search_path/2` that makes all icons accessible using the term `icon(file)`.

- Add a clause as below before creating the state. This causes all icons to be become available as `res://app/icon/file`.

  ```prolog
  resource(app/icon, icon(.)).
  ```

- Add a clause to `file_search_path/2` that make the icons available from the resource data. For example using the code below.
14.4. USING PROGRAM RESOURCES

:- asserta(user:file_search_path(icon, 'res://app/icon').)

14.4.2 Access resources using open_resource

Before the system had the ability to open resources as files, resources were opened using the predicates open_resource/2 or open_resource/3. These predicates provide somewhat better dynamic control over resources depending on whether the code is running from files or from a saved state. The main disadvantage is that having a separate open call requires rewriting code to make it work with resources rather than files.

`open_resource(+Name, -Stream)`

`open_resource(+Name, -Stream, +Options)`

Opens the resource specified by `Name`. If successful, `Stream` is unified with an input stream that provides access to the resource. The stream can be tuned using the `Options`, which is a subset of the options provided by `open/4`.

- `type(Type)`
- `encoding(Encoding)`
- `bom(Bool)`

Options that determine the binary/text type, encoding for text streams and whether or not the content should be checked for a BOM marker. The options have the same meaning as the corresponding options for `open/4`.

The predicate `open_resource/3` first checks `resource/2`. When successful it will open the returned resource source file. Otherwise it will look in the program’s resource database. When creating a saved state, the system normally saves the resource contents into the resource archive, but does not save the resource clauses.

This way, the development environment uses the files (and modifications) to the `resource/3` declarations and/or files containing resource info, thus immediately affecting the running environment, while the runtime system quickly accesses the system resources.

14.4.3 Declaring resources

`resource(:Name, +FileSpec)`

`resource(:Name, +FileSpec, +Options)`

These predicates are defined as dynamic predicates in the module `user`. Clauses for them may be defined in any module, including the user module. `Name` is the name of the resource (an atom). A resource name may contain any character, except for $ and :, which are reserved for internal usage by the resource library. `FileSpec` is a file specification that may exploit `file_search_path/2` (see `absolute_file_name/2`).

Often, resources are defined as unit clauses (facts), but the definition of this predicate also allows for rules. For proper generation of the saved state, it must be possible to enumerate the available resources by calling this predicate with all its arguments unbound.

If `FileSpec` points at a directory, the content of the directory is recursively added below `Name`. If `FileSpec` a term of the form `Alias(Name)`, all directories that match this specification are
enumerated and their content is added to the resource database. If an file appears in multiple results of this search path only the first file is added. Note that this is consistent with the normal behaviour where absolute_file_name/3 returns the first match. The Options can be used to control what is saved from a directory.

#include(+Patterns)
   Only include a file from a directory if it matches at least one of the members of Patterns.

exclude(+Patterns)
   Excludes a file from a directory if it matches at least one of the members of Patterns.

14.4.4 Managing resource files

As of version 7.7.13, SWI-Prolog resource files are zip(1) files. Prolog creates and accesses its resource files using the minizip project. The resource files may be examined and modified using any tool that can process zip files.

14.5 Debugging and updating deployed systems

SWI-Prolog provides several facilities to debug and update running (server) applications. The core to these facilities are:

- Hot-swap recompilation (section 4.3.2 and the library hotswap) allow, with some limitation, making modifications to running services. This includes adding debugging and logging statements.

- To make this useful some form of interaction is required. This can be implemented using signal handlers (Unix), specific HTTP services, generic HTTP services (e.g., SWISH) or networked interaction using the library prolog_server that allow interaction using netcat (nc) or telnet.

14.6 Protecting your code

Prolog in general, but SWI-Prolog in particular is an transparent environment. Prolog’s “code is data” point of view makes this natural as it simplifies development and debugging. Some users though want or need to protect their code against copying or reverse engineering.

There are three ways to distribute code: as source, as .qlf file and in a saved state. Both QLF files and saved states contain the code as virtual machine code. QLF files capture the predicates and directives, while saved state capture the current state of the program. From the viewpoint of protecting code there is no significant difference.

There are two aspects to protection. One is to make sure the attacker has no access to the code in any format and the other is to provide access to a non-human-readable version of the code. The second approach is known as code obfuscation. Code obfuscation typically remove layout and comments and rename all internal identifiers. If an attacker gets access to the SWI-Prolog virtual machine code this can be decompiled. The decompiled code does not include layout information variable names and comments. Other identifiers, notably predicate and module names are maintained. This provides some protection against understanding the source as Prolog code without meaningful variable names and comments is generally hard to follow.
For further protecting the code, there are several scenarios.

- If the user has unrestricted access to the file system on which the application is installed the user can always access the state or QLF file. This data can be loaded into a compatible emulator and be decompiled.

- If the user can run arbitrary Prolog code or shell commands the state can be protected by embedding it as a string in the executable deny read access to the executable. This requires a small C program that includes the string and uses `PL_set_resource_db_mem()` to register the string as the resource database. See `PL_set_resource_db_mem()` for details. This protection should be combined with the protect_static_code described below.

- Some extra protection can be provided using the Prolog flag `protect_static_code`, which disables decompilation of static predicates. Note that most Prolog implementations cannot decompile static code. Various SWI-Prolog tools depend on this ability though. Examples are `list undefined/0, autoload/0, show_coverage/1, etc.`

### 14.6.1 Obfuscating code in saved states

If the option `obfuscate(true)` is used with `qsave_program/2`, certain atoms in the saved state are renamed. The renaming is performed by library `obfuscate`. The current implementation is rather conservative, renaming atoms that are used only to define the functor that names a predicate. This is a safe operation, provided the application does not create new references to renamed predicates by reading additional source code or constructing the atom that names the predicate dynamically in some other way such as using `atom_concat/3`. Predicates that are called this way must be declared using `public/1`.

Note that more aggressive renaming is possible, but this requires more detailed analysis of the various roles played by some atom. Helpful and descriptive predicate names tend to be unique and are thus subject to this transformation. More general names tend to collide with other roles of the same atom and thus prevent renaming.

### 14.7 Finding Application files

If your application uses files that are not part of the saved program such as database files, configuration files, etc., the runtime version has to be able to locate these files. The `file_search_path/2` mechanism in combination with the `-p alias` command line argument provides a flexible mechanism for locating runtime files.
The SWI-Prolog library

This chapter documents the SWI-Prolog library. As SWI-Prolog provides auto-loading, there is little difference between library predicates and built-in predicates. Part of the library is therefore documented in the rest of the manual. Library predicates differ from built-in predicates in the following ways:

- User definition of a built-in leads to a permission error, while using the name of a library predicate is allowed.

- If autoloading is disabled explicitly or because trapping unknown predicates is disabled (see unknown/2 and current_prolog_flag/2), library predicates must be loaded explicitly.

- Using libraries reduces the footprint of applications that don’t need them.

The documentation of the library has just started. Material from the standard packages should be moved here, some material from other parts of the manual should be moved too and various libraries are not documented at all.

A.1 library(aggregate): Aggregation operators on backtrackable predicates

Compatibility Quintus, SICStus 4. The forall/2 is a SWI-Prolog built-in and term_variables/3 is a SWI-Prolog built-in with different semantics.

To be done
- Analysing the aggregation template and compiling a predicate for the list aggregation can be done at compile time.
- aggregate_all/3 can be rewritten to run in constant space using non-backtrackable assignment on a term.

This library provides aggregating operators over the solutions of a predicate. The operations are a generalisation of the bagof/3, setof/3 and findall/3 built-in predicates. Aggregations that can be computed incrementally avoid findall/3 and run in constant memory. The defined aggregation operations are counting, computing the sum, minimum, maximum, a bag of solutions and a set of solutions. We first give a simple example, computing the country with the smallest area:

```prolog
smallest_country(Name, Area) :-
    aggregate(min(A, N), country(N, A), min(Area, Name)).
```

There are four aggregation predicates (aggregate/3, aggregate/4, aggregate_all/3 and aggregate/4), distinguished on two properties.
aggregate vs. aggregate_all
The aggregate predicates use `setof/3 (aggregate/4)` or `bagof/3(aggregate/3)`, dealing with existential qualified variables `(Var^Goal)` and providing multiple solutions for the remaining free variables in `Goal`. The `aggregate_all/3` predicate uses `findall/3`, implicitly qualifying all free variables and providing exactly one solution, while `aggregate_all/4` uses `sort/2` over solutions that Discriminator (see below) generated using `findall/3`.

The Discriminator argument
The versions with 4 arguments deduplicate redundant solutions of `Goal`. Solutions for which both the template variables and Discriminator are identical will be treated as one solution. For example, if we wish to compute the total population of all countries, and for some reason `country(belgium, 11000000)` may succeed twice, we can use the following to avoid counting the population of Belgium twice:

```prolog
aggregate(sum(P), Name, country(Name, P), Total)
```

All aggregation predicates support the following operators below in Template. In addition, they allow for an arbitrary named compound term, where each of the arguments is a term from the list below. For example, the term `r(min(X), max(X))` computes both the minimum and maximum binding for X.

**count**
Count number of solutions. Same as `sum(1)`.

**sum(Expr)**
Sum of `Expr` for all solutions.

**min(Expr)**
Minimum of `Expr` for all solutions.

**min(Expr, Witness)**
A term `min(Min, Witness)`, where Min is the minimal version of `Expr` over all solutions, and `Witness` is any other template applied to solutions that produced Min. If multiple solutions provide the same minimum, `Witness` corresponds to the first solution.

**max(Expr)**
Maximum of `Expr` for all solutions.

**max(Expr, Witness)**
As `min(Expr, Witness)`, but producing the maximum result.

**set(X)**
An ordered set with all solutions for X.

**bag(X)**
A list of all solutions for X.

Acknowledgements
*The development of this library was sponsored by SecuritEase, http://www.securitease.com*
aggregate(+Template, :Goal, -Result)  [nondet]
Aggregate bindings in Goal according to Template. The aggregate/3 version performs
bagof/3 on Goal.

aggregate(+Template, +Discriminator, :Goal, -Result)  [nondet]
Aggregate bindings in Goal according to Template. The aggregate/4 version performs
setof/3 on Goal.

aggregate_all(+Template, :Goal, -Result)  [semidet]
Aggregate bindings in Goal according to Template. The aggregate_all/3 version per-
forms findall/3 on Goal. Note that this predicate fails if Template contains one or more of
min(X), max(X), min(X,Witness) or max(X,Witness) and Goal has no solutions,
i.e., the minimum and maximum of an empty set is undefined.

The Template values count, sum(X), max(X), min(X), max(X,W) and min(X,W) are
processed incrementally rather than using findall/3 and run in constant memory.

aggregate_all(+Template, +Discriminator, :Goal, -Result)  [semidet]
Aggregate bindings in Goal according to Template. The aggregate_all/4 version per-
forms findall/3 followed by sort/2 on Goal. See aggregate_all/3 to understand
why this predicate can fail.

foreach(:Generator, :Goal)
True when the conjunction of instances of Goal created from solutions for Generator is true.
Except for term copying, this could be implemented as below.

foreach(Generator, Goal) :-
    findall(Goal, Generator, Goals),
    maplist(call, Goals).

The actual implementation uses findall/3 on a template created from the variables shared
between Generator and Goal. Subsequently, it uses every instance of this template to instantiate
Goal, call Goal and undo only the instantiation of the template and not other instantiations
created by running Goal. Here is an example:

?- foreach(between(1,4,X), dif(X,Y)), Y = 5.
   Y = 5.
?- foreach(between(1,4,X), dif(X,Y)), Y = 3.
   false.

The predicate foreach/2 is mostly used if Goal performs backtrackable destructive assign-
ment on terms. Attributed variables (underlying constraints) are an example. Another example
of a backtrackable data structure is in library(hashtable). If we care only about the
side effects (I/O, dynamic database, etc.) or the truth value of Goal, forall/2 is a faster and
simpler alternative. If Goal instantiates its arguments it is will often fail as the argument cannot
be instantiated to multiple values. It is possible to incrementally grow an argument:

?- foreach(between(1,4,X), member(X, L)).
   L = [1,2,3,4|_].
A.2. LIBRARY(ANSI_TERM): PRINT DECORATED TEXT TO ANSI CONSOLES

Note that SWI-Prolog up to version 8.3.4 created copies of Goal using copy_term/2 for each iteration, this makes the current implementation unable to properly handle compound terms (in Goal's arguments) that share variables with the Generator. As a workaround you can define a goal that does not use compound terms, like in this example:

```prolog
mem(E,L) :- % mem/2 hides the compound argument from foreach/2
    member(r(E),L).
?- foreach( between(1,5,N), mem(N,L)).
```

free_variables(:Generator, +Template, +VarList0, -VarList)

Find free variables in bagof/setof template. In order to handle variables properly, we have to find all the universally quantified variables in the Generator. All variables as yet unbound are universally quantified, unless

1. they occur in the template
2. they are bound by X^P, setof/3, or bagof/3

free_variables(Generator, Template, OldList, NewList) finds this set using OldList as an accumulator.

author
- Richard O'Keefe
- Jan Wielemaker (made some SWI-Prolog enhancements)

license Public domain (from DEC10 library).

To be done
- Distinguish between control-structures and data terms.
- Exploit our built-in term:variables/2 at some places?

sandbox:safe_meta(+Goal, -Called)

Declare the aggregate meta-calls safe. This cannot be proven due to the manipulations of the argument Goal.

A.2 library(ansi_term): Print decorated text to ANSI consoles

See also http://en.wikipedia.org/wiki/ANSI_escape_code

This library allows for exploiting the color and attribute facilities of most modern terminals using ANSI escape sequences. This library provides the following:

- ansi_format/3 allows writing messages to the terminal with ansi attributes.
- It defines the hook prolog:message_line_element/2, which provides ansi attributes and hyperlinks for print_message/2.

The behavior of this library is controlled by two Prolog flags:


When true, activate the color output for this library. Otherwise simply call format/3.

---

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Emit terminal hyperlinks for `url(Location)` and `url(URL, Label)` elements of Prolog messages.

\[\text{ansi_format}(+\text{ClassOrAttributes}, +\text{Format}, +\text{Args})\] 

Format text with ANSI attributes. This predicate behaves as `format/2` using `Format` and `Args`, but if the current_output is a terminal, it adds ANSI escape sequences according to `Attributes`. For example, to print a text in bold cyan, do

\[\text{?- ansi_format}([\text{bold,fg(cyan)}], 'Hello \text{w}', [\text{world}]).\]

Attributes is either a single attribute, a list thereof or a term that is mapped to concrete attributes based on the current theme (see `prolog:console_color/2`). The attribute names are derived from the ANSI specification. See the source for `sgr_code/2` for details. Some commonly used attributes are:

**bold**

**underline**

\[\text{fg}(\text{Color}), \text{bg}(\text{Color}), \text{hfg}(\text{Color}), \text{hbg}(\text{Color})\]

For `fg(Color)` and `bg(Color)`, the colour name can be ‘#RGB’ or ‘#RRGGBB’

\[\text{fg8}(\text{Spec}), \text{bg8}(\text{Spec})\]

8-bit color specification. `Spec` is a colour name, `h(Color)` or an integer 0..255.

\[\text{fg}(R, G, B), \text{bg}(R, G, B)\]

24-bit (direct color) specification. The components are integers in the range 0..255.

Defined color constants are below. `default` can be used to access the default color of the terminal.

- black, red, green, yellow, blue, magenta, cyan, white

ANSI sequences are sent if and only if

- The current_output has the property tty(true) (see `stream_property/2`).
- The Prolog flag color_term is true.

\[\text{prolog:console_color}(+\text{Term}, -\text{AnsiAttributes})\] 

Hook that allows for mapping abstract terms to concrete ANSI attributes. This hook is used by `theme` files to adjust the rendering based on user preferences and context. Defaults are defined in the file boot/messages.pl.

See also `library(theme/dark)` for an example implementation and the `Term` values used by the system messages.
A.3. LIBRARY(APPLY): APPLY PREDICATES ON A LIST

prolog:message_line_element(+Stream, +Term)  [semidet,multifile]
    Hook implementation that deals with ansi(+Attr, +Fmt, +Args) in message specifications.

ansi_hyperlink(+Stream, +Location)  [det]
ansi_hyperlink(+Stream, +URL, +Label)  [det]
    Create a hyperlink for a terminal emulator. The file is fairly easy, but getting the line and column across is not as there seems to be no established standard. The current implementation emits, i.e., inserting a capital L before the line.

```
'file://AbsFileName[#LLine[:Column]]'
```

See also https://gist.github.com/egmontkob/eb114294efbcd5adb1944c9f3cb5feda

hyperlink(+Stream, +Spec)  [semidet,multifile]
    Multifile hook that may be used to redefine ansi_hyperlink/2,3. If this predicate succeeds the system assumes the link has been written to Stream.

    Arguments

    Spec is either url(Location) or url(URL, Label). See ansi_hyperlink/2,3 for details.

ansi_get_color(+Which, -RGB)  [semidet]
    Obtain the RGB color for an ANSI color parameter. Which is either a color alias or an integer ANSI color id. Defined aliases are foreground and background. This predicate sends a request to the console (user_output) and reads the reply. This assumes an xterm compatible terminal.

    Arguments

    RGB is a term rgb(Red,Green,Blue). The color components are integers in the range 0..65535.

A.3 library(apply): Apply predicates on a list

See also

- apply_macros.pl provides compile-time expansion for part of this library.
- Unit test code in src/Tests/library/test_apply.pl

To be done Add include/4, include/5, exclude/4, exclude/5

This module defines meta-predicates that apply a predicate on all members of a list.
All predicates support partial application in the Goal argument. This means that these calls are identical:

?- maplist(=, [foo, foo], [X, Y]).
?- maplist(=(foo), [X, Y]).
 Appendix A. The SWI-Prolog Library

**include**(\(\text{Goal}, +\text{List1}, \text{?List2}\)) \[\text{det}\]
Filter elements for which \(\text{Goal}\) succeeds. True if \(\text{List2}\) contains those elements \(\text{Xi}\) of \(\text{List1}\) for which \(\text{call(\text{Goal}, \text{Xi})}\) succeeds.

*See also* \(\text{exclude/3, partition/4, convlist/3}\).

*Compatibility* Older versions of SWI-Prolog had \(\text{sublist/3}\) with the same arguments and semantics.

**exclude**(\(\text{Goal}, +\text{List1}, \text{?List2}\)) \[\text{det}\]
Filter elements for which \(\text{Goal}\) fails. True if \(\text{List2}\) contains those elements \(\text{Xi}\) of \(\text{List1}\) for which \(\text{call(\text{Goal}, \text{Xi})}\) fails.

*See also* \(\text{include/3, partition/4}\).

**partition**(\(\text{Pred}, +\text{List}, \text{?Included}, \text{?Excluded}\)) \[\text{det}\]
Filter elements of \(\text{List}\) according to \(\text{Pred}\). True if \(\text{Included}\) contains all elements for which \(\text{call(\text{Pred}, \text{X})}\) succeeds and \(\text{Excluded}\) contains the remaining elements.

*See also* \(\text{include/3, exclude/3, partition/5}\).

**partition**(\(\text{Pred}, +\text{List}, \text{?Less}, \text{?Equal}, \text{?Greater}\)) \[\text{semidet}\]
Filter \(\text{List}\) according to \(\text{Pred}\) in three sets. For each element \(\text{Xi}\) of \(\text{List}\), its destination is determined by \(\text{call(\text{Pred}, \text{Xi}, \text{Place})}\), where \(\text{Place}\) must be unified to one of \(<, = \text{ or } >\). \(\text{Pred}\) must be deterministic.

*See also* \(\text{partition/4}\).

**maplist**(\(\text{Goal}, \text{?List1}\))
**maplist**(\(\text{Goal}, \text{?List1}, \text{?List2}\))
**maplist**(\(\text{Goal}, \text{?List1}, \text{?List2}, \text{?List3}\))
**maplist**(\(\text{Goal}, \text{?List1}, \text{?List2}, \text{?List3}, \text{?List4}\))
True if \(\text{Goal}\) is successfully applied on all matching elements of the list. The maplist family of predicates is defined as:

\[
\text{maplist(G, [X_{11}, \ldots, X_{1n}],}
\text{[X_{21}, \ldots, X_{2n}],}
\text{\ldots,}
\text{[X_{m1}, \ldots, X_{mn}]) :-}
\text{call(G, X_{11}, \ldots, X_{m1}),}
\text{call(G, X_{12}, \ldots, X_{m2}),}
\text{\ldots}
\text{call(G, X_{1n}, \ldots, X_{mn}).}
\]

This family of predicates is deterministic iff \(\text{Goal}\) is deterministic and \(\text{List1}\) is a proper list, i.e., a list that ends in \([\,]\).

**convlist**(\(\text{Goal}, +\text{ListIn}, -\text{ListOut}\)) \[\text{det}\]
Similar to maplist/3, but elements for which \(\text{call(\text{Goal}, \text{ElemIn}, \_)}\) fails are omitted from \(\text{ListOut}\). For example (using library(yall)):
A.3. LIBRARY(APPLY): APPLY PREDICATES ON A LIST

?- convlist([(X,Y)>>\{integer(X), Y is X^2\},
              [3, 5, foo, 2], L).
L = [9, 25, 4].

Compatibility  Also appears in YAP library(maplist) and SICStus library(lists).

foldl(\Goal, +\List, +\V0, -\V)
foldl(\Goal, +\List1, +\List2, +\V0, -\V)
foldl(\Goal, +\List1, +\List2, +\List3, +\V0, -\V)
foldl(\Goal, +\List1, +\List2, +\List3, +\List4, +\V0, -\V)

Fold an ensemble of \(m\) (0 \(<=\) \(m\) \(<=\) 4) lists of length \(n\) head-to-tail ("fold-left"), using columns of \(m\) list elements as arguments for \Goal. The foldl family of predicates is defined as follows, with \V0 an initial value and \V the final value of the folding operation:

\[
\text{foldl}(\text{G, } [X_{11}, \ldots, X_{1n}],
          [X_{21}, \ldots, X_{2n}],
          \ldots,
          [X_{m1}, \ldots, X_{mn}], \V0, \V) :-
\text{call}(\text{G, } X_{11}, \ldots, X_{m1}, \V0, \V1),
\text{call}(\text{G, } X_{12}, \ldots, X_{m2}, \V1, \V2),
\ldots
\text{call}(\text{G, } X_{1n}, \ldots, X_{mn}, \V<n-1>, \V).
\]

No implementation for a corresponding foldr is given. A foldr implementation would consist in first calling reverse/2 on each of the \(m\) input lists, then applying the appropriate foldl. This is actually more efficient than using a properly programmed-out recursive algorithm that cannot be tail-call optimized.

scanl(\Goal, +\List, +\V0, -\Values)
scanl(\Goal, +\List1, +\List2, +\V0, -\Values)
scanl(\Goal, +\List1, +\List2, +\List3, +\V0, -\Values)
scanl(\Goal, +\List1, +\List2, +\List3, +\List4, +\V0, -\Values)

Scan an ensemble of \(m\) (0 \(<=\) \(m\) \(<=\) 4) lists of length \(n\) head-to-tail ("scan-left"), using columns of \(m\) list elements as arguments for \Goal. The scanl family of predicates is defined as follows, with \V0 an initial value and \V the final value of the scanning operation:

\[
\text{scanl}(\text{G, } [X_{11}, \ldots, X_{1n}],
          [X_{21}, \ldots, X_{2n}],
          \ldots,
          [X_{m1}, \ldots, X_{mn}], \V0, [\V0, \V1, \ldots, \Vn]) :-
\text{call}(\text{G, } X_{11}, \ldots, X_{m1}, \V0, \V1),
\text{call}(\text{G, } X_{12}, \ldots, X_{m2}, \V1, \V2),
\ldots
\text{call}(\text{G, } X_{1n}, \ldots, X_{mn}, \V<n-1>, \Vn).
\]
scanl behaves like a foldl that collects the sequence of values taken on by the Vx accumulator into a list.

A.4 library(assoc): Association lists

Authors: Richard A. O’Keefe, L.Damas, V.S.Costa and Markus Triska

A.4.1 Introduction

An association list as implemented by this library is a collection of unique keys that are associated to values. Keys must be ground, values need not be.

An association list can be used to fetch elements via their keys and to enumerate its elements in ascending order of their keys.

This library uses AVL trees to implement association lists. This means that

- inserting a key
- changing an association
- fetching a single element

are all $O(\log(N))$ worst-case (and expected) time operations, where $N$ denotes the number of elements in the association list.

The logarithmic overhead is often acceptable in practice. Notable advantages of association lists over several other methods are:

- library(assoc) is written entirely in Prolog, making it portable to other systems
- the interface predicates fit the declarative nature of Prolog, avoiding destructive updates to terms
- AVL trees scale very predictably and can be used to represent sparse arrays efficiently.

A.4.2 Creating association lists

An association list is created with one of the following predicates:

empty_assoc(?Assoc) [semidet]

Is true if Assoc is the empty association list.

list_to_assoc(+Pairs, -Assoc) [det]

Create an association from a list Pairs of Key-Value pairs. List must not contain duplicate keys.

Errors domain_error(unique_key_pairs, List) if List contains duplicate keys

ord_list_to_assoc(+Pairs, -Assoc) [det]

Assoc is created from an ordered list Pairs of Key-Value pairs. The pairs must occur in strictly ascending order of their keys.

Errors domain_error(key_ordered_pairs, List) if pairs are not ordered.
A.4.3 Querying association lists

An association list can be queried with:

\textbf{get_assoc(+Key, +Assoc, -Value)} \hspace{1em} \text{[semidet]}

True if Key-Value is an association in Assoc.

\textbf{get_assoc(+Key, +Assoc0, ?Val0, ?Assoc, ?Val)} \hspace{1em} \text{[semidet]}

True if Key-Val0 is in Assoc0 and Key-Val is in Assoc.

\textbf{max_assoc(+Assoc, -Key, -Value)} \hspace{1em} \text{[semidet]}

True if Key-Value is in Assoc and Key is the largest key.

\textbf{min_assoc(+Assoc, -Key, -Value)} \hspace{1em} \text{[semidet]}

True if Key-Value is in assoc and Key is the smallest key.

\textbf{gen_assoc(?Key, +Assoc, ?Value)} \hspace{1em} \text{[nondet]}

True if Key-Value is an association in Assoc. Enumerates keys in ascending order on backtracking.

\textbf{See also get_assoc/3.}

A.4.4 Modifying association lists

Elements of an association list can be changed and inserted with:

\textbf{put_assoc(+Key, +Assoc0, +Value, -Assoc)} \hspace{1em} \text{[det]}

Assoc is Assoc0, except that Key is associated with Value. This can be used to insert and change associations.

\textbf{del_assoc(+Key, +Assoc0, ?Value, -Assoc)} \hspace{1em} \text{[semidet]}

True if Key-Value is in Assoc0. Assoc is Assoc0 with Key-Value removed.

\textbf{del_min_assoc(+Assoc0, ?Key, ?Val, -Assoc)} \hspace{1em} \text{[semidet]}

True if Key-Value is in Assoc0 and Key is the smallest key. Assoc is Assoc0 with Key-Value removed. Warning: This will succeed with no bindings for Key or Val if Assoc0 is empty.

\textbf{del_max_assoc(+Assoc0, ?Key, ?Val, -Assoc)} \hspace{1em} \text{[semidet]}

True if Key-Value is in Assoc0 and Key is the greatest key. Assoc is Assoc0 with Key-Value removed. Warning: This will succeed with no bindings for Key or Val if Assoc0 is empty.

A.4.5 Conversion predicates

Conversion of (parts of) an association list to \textit{lists} is possible with:

\textbf{assoc_to_list(+Assoc, -Pairs)} \hspace{1em} \text{[det]}

Translate Assoc to a list Pairs of Key-Value pairs. The keys in Pairs are sorted in ascending order.

\textbf{assoc_to_keys(+Assoc, -Keys)} \hspace{1em} \text{[det]}

True if Keys is the list of keys in Assoc. The keys are sorted in ascending order.
assoc_to_values(+Assoc, -Values)  \[det\]

True if Values is the list of values in Assoc. Values are ordered in ascending order of the key to which they were associated. Values may contain duplicates.

A.4.6 Reasoning about association lists and their elements

Further inspection predicates of an association list and its elements are:

is_assoc(+Assoc)  \[semidet\]

True if Assoc is an association list. This predicate checks that the structure is valid, elements are in order, and tree is balanced to the extent guaranteed by AVL trees. I.e., branches of each subtree differ in depth by at most 1. Does not validate that keys are sufficiently instantiated to ensure the tree remains valid if a key is further instantiated.

map_assoc(:Pred, +Assoc)  \[semidet\]

True if Pred(Value) is true for all values in Assoc.

map_assoc(:Pred, +Assoc0, ?Assoc)  \[semidet\]

Map corresponding values. True if Assoc is Assoc0 with Pred applied to all corresponding pairs of values.

A.5 library(broadcast): Broadcast and receive event notifications

The broadcast library was invented to realise GUI applications consisting of stand-alone components that use the Prolog database for storing the application data. Figure A.1 illustrates the flow of information using this design.

The broadcasting service provides two services. Using the ‘shout’ service, an unknown number of agents may listen to the message and act. The broadcaster is not (directly) aware of the implications. Using the ‘request’ service, listening agents are asked for an answer one-by-one and the broadcaster is allowed to reject answers using normal Prolog failure.
Shouting is often used to inform about changes made to a common database. Other messages can be “save yourself” or “show this”.

Requesting is used to get information while the broadcaster is not aware who might be able to answer the question. For example “who is showing X?”.

**broadcast(+Term)**

Broadcast Term. There are no limitations to Term, though being a global service, it is good practice to use a descriptive and unique principal functor. All associated goals are started and regardless of their success or failure, broadcast/1 always succeeds. Exceptions are passed.

**broadcast_request(+Term)**

Unlike broadcast/1, this predicate stops if an associated goal succeeds. Backtracking causes it to try other listeners. A broadcast request is used to fetch information without knowing the identity of the agent providing it. C.f. “Is there someone who knows the age of John?” could be asked using

```prolog
..., broadcast_request(age_of('John', Age)),
```

If there is an agent (listener) that registered an ‘age-of’ service and knows about the age of ‘John’ this question will be answered.

**listen(+Template, :Goal)**

Register a listen channel. Whenever a term unifying Template is broadcasted, call Goal. The following example traps all broadcasted messages as a variable unifies to any message. It is commonly used to debug usage of the library.

```prolog
?- listen(Term, writeln(Term), fail).
?- broadcast(hello(world)).
hello(world)
true.
```

**listen(+Listener, +Template, :Goal)**

Declare Listener as the owner of the channel. Unlike a channel opened using listen/2, channels that have an owner can terminate the channel. This is commonly used if an object is listening to broadcast messages. In the example below we define a ‘name-item’ displaying the name of an identifier represented by the predicate name_of/2.

```prolog
:- pce_begin_class(name_item, text_item).

variable(id, any, get, "Id visualised").

initialise(NI, Id:any) :-
    name_of(Id, Name),
    send_super(NI, initialise, name, Name,
      message(NI, set_name, @arg1)),
```
send(NI, slot, id, Id),
listen(NI, name_of(Id, Name),
    send(NI, selection, Name)).

unlink(NI) :-
    unlisten(NI),
    send_super(NI, unlink).

set_name(NI, Name:name) :-
    get(NI, id, Id),
    retractall(name_of(Id, _)),
    assert(name_of(Id, Name)),
    broadcast(name_of(Id, Name)).

:- pce_end_class.

unlisten(+Listener)
Deregister all entries created with listen/3 whose Listener unify.

unlisten(+Listener, +Template)
Deregister all entries created with listen/3 whose Listener and Template unify.

unlisten(+Listener, +Template, :Goal)
Deregister all entries created with listen/3 whose Listener, Template and Goal unify.

listening(?Listener, ?Template, ?Goal)
Examine the current listeners. This predicate is useful for debugging purposes.

A.6  library(charsio): I/O on Lists of Character Codes

Compatibility  The naming of this library is not in line with the ISO standard. We believe that the SWI-Prolog native predicates form a more elegant alternative for this library.

This module emulates the Quintus/SICStus library charsio.pl for reading and writing from/to lists of character codes. Most of these predicates are straight calls into similar SWI-Prolog primitives. Some can even be replaced by ISO standard predicates.

format_to_chars(+Format, +Args, -Codes)  [det]
Use format/2 to write to a list of character codes.

format_to_chars(+Format, +Args, -Codes, ?Tail)  [det]
Use format/2 to write to a difference list of character codes.

write_to_chars(+Term, -Codes)
Write a term to a code list. True when Codes is a list of character codes written by write/1 on Term.
write_to_chars(+Term, -Codes, ?Tail)
Write a term to a code list. Codes\Tail is a difference list of character codes produced by write/1 on Term.

atom_to_chars(+Atom, -Codes) [det]
Convert Atom into a list of character codes.

deprecated Use ISO atom_codes/2.

atom_to_chars(+Atom, -Codes, ?Tail) [det]
Convert Atom into a difference list of character codes.

number_to_chars(+Number, -Codes) [det]
Convert Atom into a list of character codes.

deprecated Use ISO number_codes/2.

number_to_chars(+Number, -Codes, ?Tail) [det]
Convert Number into a difference list of character codes.

read_from_chars(+Codes, -Term) [det]
Read Codes into Term.

Compatibility The SWI-Prolog version does not require Codes to end in a full-stop.

read_term_from_chars(+Codes, -Term, +Options) [det]
Read Codes into Term. Options are processed by read_term/3.

Compatibility sicstus

open_chars_stream(+Codes, -Stream) [det]
Open Codes as an input stream.

See also open_string/2.

with_output_to_chars(:Goal, -Codes) [det]
Run Goal as with once/1. Output written to current_output is collected in Codes.

with_output_to_chars(:Goal, -Codes, ?Tail) [det]
Run Goal as with once/1. Output written to current_output is collected in Codes\Tail.

with_output_to_chars(:Goal, -Stream, -Codes, ?Tail) [det]
Same as with_output_to_chars/3 using an explicit stream. The difference list Codes\Tail contains the character codes that Goal has written to Stream.
A.7 library(check): Consistency checking

See also
- gxref/0 provides a graphical cross referencer
- PceEmacs performs real time consistency checks while you edit
- library(prolog_xref) implements ‘offline’ cross-referencing
- library(prolog_codewalk) implements ‘online’ analysis

This library provides some consistency checks for the loaded Prolog program. The predicate make/0 runs listundefined/0 to find undefined predicates in ‘user’ modules.

check
[det]
Run all consistency checks defined by checker/2. Checks enabled by default are:

• listundefined/0 reports undefined predicates
• listtrivialfails/0 reports calls for which there is no matching clause.
• listredefined/0 reports predicates that have a local definition and a global definition. Note that these are not errors.
• listautoload/0 lists predicates that will be defined at runtime using the autoloader.

listundefined
[det]
listundefined(+Options)
Report undefined predicates. This predicate finds undefined predicates by decompiling and analyzing the body of all clauses. Options:

moduleclass(+Classes)
Process modules of the given Classes. The default for classes is [user]. For example, to include the libraries into the examination, use [user,library].

See also
- gxref/0 provides a graphical cross-referencer.
- make/0 calls listundefined/0

listautoload
[det]
Report predicates that may be auto-loaded. These are predicates that are not defined, but will be loaded on demand if referenced.

See also  autoload/0
To be done  This predicate uses an older mechanism for finding undefined predicates. Should be synchronized with listundefined.

listredefined
Lists predicates that are defined in the global module user as well as in a normal module; that is, predicates for which the local definition overrules the global default definition.

listcrossmodulecalls
[det]
List calls from one module to another using Module:Goal where the callee is not defined exported, public or multifile, i.e., where the callee should be considered private.
A.7. LIBRARY(CHECK): CONSISTENCY CHECKING

list_void Declarations
List predicates that have declared attributes, but no clauses.

list_trivial_fails(+Options)
List goals that trivially fail because there is no matching clause. Options:

module_class(+Classes)
Process modules of the given Classes. The default for classes is [user]. For example, to include the libraries into the examination, use [user,library].

trivial_fail_goal(:Goal)
Multifile hook that tells list_trivial_fails/0 to accept Goal as valid.

list_strings(+Options)
List strings that appear in clauses. This predicate is used to find portability issues for changing the Prolog flag double_quotes from codes to string, creating packed string objects. Warnings may be suppressed using the following multifile hooks:

- string_predicate/1 to stop checking certain predicates
- valid_string_goal/1 to tell the checker that a goal is safe.

See also Prolog flag double_quotes.

list_rationals(+Options)
List rational numbers that appear in clauses. This predicate is used to find portability issues for changing the Prolog flag rational_syntax to natural, creating rational numbers from <integer>/<nonneg>. Options:

module_class(+Classes)
Determined the modules classes processed. By default only user code is processed. See prolog_program_clause/2.

arithmetic(+Bool)
If true (default false) also warn on rationals appearing in arithmetic expressions.

See also Prolog flag rational_syntax and prefer_rationals.

list_format_errors(+Options)
List argument errors for format/2,3.

string_predicate(:PredicateIndicator)
Multifile hook to disable list_strings/0 on the given predicate. This is typically used for facts that store strings.

valid_string_goal(+Goal)
Multifile hook that qualifies Goal as valid for list_strings/0. For example, format("Hello world\n") is considered proper use of string constants.
checker(\Goal, +Message:text)  [nondet,multifile]

Register code validation routines. Each clause defines a \Goal which performs a consistency
check executed by check/0. \Message is a short description of the check. For example,
assuming the my_checks module defines a predicate list_format_mistakes/0:

\begin{verbatim}
:- multifile check:checker/2.
check:checker(my_checks:list_format_mistakes,
       "errors with format/2 arguments").
\end{verbatim}

The predicate is dynamic, so you can disable checks with retract/1. For example, to stop
reporting redefined predicates:

\begin{verbatim}
retract(check:checker(list_redefined,_)).
\end{verbatim}

A.8 library(clpb): CLP(B): Constraint Logic Programming over
Boolean Variables

author  Markus Triska

A.8.1 Introduction

This library provides CLP(B), Constraint Logic Programming over Boolean variables. It can be used
to model and solve combinatorial problems such as verification, allocation and covering tasks.
CLP(B) is an instance of the general CLP(X) scheme (section 8), extending logic programming
with reasoning over specialised domains.

The implementation is based on reduced and ordered Binary Decision Diagrams (BDDs).

Benchmarks and usage examples of this library are available from:
https://www.metalevel.at/clpb/

We recommend the following references for citing this library in scientific publications:

\begin{verbatim}
@inproceedings{Triska2016,
    author = "Markus Triska",
    title = "The \{Boolean\} Constraint Solver of \{SWI-Prolog\}: System Description",
    booktitle = "FLOPS",
    series = "LNCS",
    volume = 9613,
    year = 2016,
    pages = "45--61"
}

@article{Triska2018,
    title = "Boolean constraints in \{SWI-Prolog\}: A comprehensive system description",
    journal = "Science of Computer Programming",
    volume = "164",
}
\end{verbatim}
These papers are available from https://www.metalevel.at/swiclpb.pdf and https://www.metalevel.at/boolean.pdf respectively.

A.8.2 Boolean expressions

A Boolean expression is one of:

<table>
<thead>
<tr>
<th>Syntax</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>false</td>
</tr>
<tr>
<td>1</td>
<td>true</td>
</tr>
<tr>
<td>variable</td>
<td>unknown truth value</td>
</tr>
<tr>
<td>atom</td>
<td>universally quantified variable</td>
</tr>
<tr>
<td>~ Expr</td>
<td>logical NOT</td>
</tr>
<tr>
<td>Expr + Expr</td>
<td>logical OR</td>
</tr>
<tr>
<td>Expr * Expr</td>
<td>logical AND</td>
</tr>
<tr>
<td>Expr # Expr</td>
<td>exclusive OR</td>
</tr>
<tr>
<td>Var ^ Expr</td>
<td>existential quantification</td>
</tr>
<tr>
<td>Expr =:= Expr</td>
<td>equality</td>
</tr>
<tr>
<td>Expr == Expr</td>
<td>disequality (same as #)</td>
</tr>
<tr>
<td>Expr =&lt; Expr</td>
<td>less or equal (implication)</td>
</tr>
<tr>
<td>Expr =&gt; Expr</td>
<td>greater or equal</td>
</tr>
<tr>
<td>Expr &lt; Expr</td>
<td>less than</td>
</tr>
<tr>
<td>Expr &gt; Expr</td>
<td>greater than</td>
</tr>
<tr>
<td>card(Is,Exprs)</td>
<td>cardinality constraint (see below)</td>
</tr>
<tr>
<td>+(Exprs)</td>
<td>n-fold disjunction (see below)</td>
</tr>
<tr>
<td>*(Exprs)</td>
<td>n-fold conjunction (see below)</td>
</tr>
</tbody>
</table>

where Expr again denotes a Boolean expression.

The Boolean expression card(Is,Exprs) is true iff the number of true expressions in the list Exprs is a member of the list Is of integers and integer ranges of the form From-To. For example, to state that precisely two of the three variables X, Y and Z are true, you can use sat(card([2],[X,Y,Z])).

+(Exprs) and *(Exprs) denote, respectively, the disjunction and conjunction of all elements in the list Exprs of Boolean expressions.

Atoms denote parametric values that are universally quantified. All universal quantifiers appear implicitly in front of the entire expression. In residual goals, universally quantified variables always appear on the right-hand side of equations. Therefore, they can be used to express functional dependencies on input variables.
A.8.3 Interface predicates

The most frequently used CLP(B) predicates are:

\texttt{sat(+Expr)}

True iff the Boolean expression \texttt{Expr} is satisfiable.

\texttt{taut(+Expr, -T)}

If \texttt{Expr} is a tautology with respect to the posted constraints, succeeds with \texttt{T = 1}. If \texttt{Expr} cannot be satisfied, succeeds with \texttt{T = 0}. Otherwise, it fails.

\texttt{labeling(+Vs)}

Assigns truth values to the variables \texttt{Vs} such that all constraints are satisfied.

The unification of a CLP(B) variable \texttt{X} with a term \texttt{T} is equivalent to posting the constraint \texttt{sat(X=:=T)}.

A.8.4 Examples

Here is an example session with a few queries and their answers:

\begin{verbatim}
?- use_module(library(clpb)).
true.

?- sat(X*Y).
X = Y, Y = 1.

?- sat(X * ~X).
false.

?- taut(X * ~X, T).
T = 0,
sat(X=:=X).

?- sat(X^Y^(X+Y)).
sat(X=:=X),
sat(Y=:=Y).

?- sat(X*Y + X*Z), labeling([X,Y,Z]).
X = Z, Z = 1, Y = 0 ;
X = Y, Y = 1, Z = 0 ;
X = Y, Y = Z, Z = 1.

?- sat(X =< Y), sat(Y =< Z), taut(X =< Z, T).
T = 1,
sat(X=:=X*Y),
sat(Y=:=Y*Z).
\end{verbatim}
The pending residual goals constrain remaining variables to Boolean expressions and are declaratively equivalent to the original query. The last example illustrates that when applicable, remaining variables are expressed as functions of universally quantified variables.

A.8.5 Obtaining BDDs

By default, CLP(B) residual goals appear in (approximately) algebraic normal form (ANF). This projection is often computationally expensive. We can set the Prolog flag `clpb_residuals` to the value `bdd` to see the BDD representation of all constraints. This results in faster projection to residual goals, and is also useful for learning more about BDDs. For example:

```prolog
?- set_prolog_flag(clpb_residuals, bdd).
true.
?- sat(X#Y).
node(3)- (v(X, 0)->node(2);node(1)),
node(1)- (v(Y, 1)->true;false),
node(2)- (v(Y, 1)->false;true).
```

Note that this representation cannot be pasted back on the toplevel, and its details are subject to change. Use `copy_term/3` to obtain such answers as Prolog terms.

The variable order of the BDD is determined by the order in which the variables first appear in constraints. To obtain different orders, we can for example use:

```prolog
?- sat(+[1,Y,X]), sat(X#Y).
node(3)- (v(Y, 0)->node(2);node(1)),
node(1)- (v(X, 1)->true;false),
node(2)- (v(X, 1)->false;true).
```

A.8.6 Enabling monotonic CLP(B)

In the default execution mode, CLP(B) constraints are not monotonic. This means that adding constraints can yield new solutions. For example:

```prolog
?- sat(X=:1), X = 1+0.
false.
?- X = 1+0, sat(X=:1), X = 1+0.
X = 1+0.
```

This behaviour is highly problematic from a logical point of view, and it may render declarative debugging techniques inapplicable.

Set the flag `clpb_monotonic` to `true` to make CLP(B) monotonic. If this mode is enabled, then you must wrap CLP(B) variables with the functor `v/1`. For example:
A.8.7 Example: Pigeons

In this example, we are attempting to place $I$ pigeons into $J$ holes in such a way that each hole contains at most one pigeon. One interesting property of this task is that it can be formulated using only cardinality constraints (card/2). Another interesting aspect is that this task has no short resolution refutations in general.

In the following, we use Prolog DCG notation to describe a list $Cs$ of CLP(B) constraints that must all be satisfied.

\begin{verbatim}
:- use_module(library(clpb)).
:- use_module(library(clpfd)).
pigeon(I, J, Rows, Cs) :-
    length(Rows, I), length(Row, J),
    maplist(same_length(Row), Rows),
    transpose(Rows, TRows),
    phrase((all_cards(Rows,[1]),all_cards(TRows,[0,1])), Cs).

all_cards([], _) --> [].
all_cards([Ls|Lss], Cs) --> [card(Cs,Ls)], all_cards(Lss, Cs).
\end{verbatim}

Example queries:

\begin{verbatim}
?- pigeon(9, 8, Rows, Cs), sat(*(Cs)).
false.

?- pigeon(2, 3, Rows, Cs), sat(*(Cs)),
   append(Rows, Vs), labeling(Vs),
   maplist(portray_clause, Rows).
[0, 0, 1].
[0, 1, 0].
etc.
\end{verbatim}

A.8.8 Example: Boolean circuit

Consider a Boolean circuit that express the Boolean function XOR with 4 NAND gates. We can model such a circuit with CLP(B) constraints as follows:

\begin{verbatim}
:- use_module(library(clpb)).
\end{verbatim}
A.8. LIBRARY(CLPB): CLP(B): CONSTRAINT LOGIC PROGRAMMING OVER BOOLEAN VARIABLES

nand_gate(X, Y, Z) :- sat(Z =:= \neg(X \cdot Y)).

xor(X, Y, Z) :-
    nand_gate(X, Y, T1),
    nand_gate(X, T1, T2),
    nand_gate(Y, T1, T3),
    nand_gate(T2, T3, Z).

Using universally quantified variables, we can show that the circuit does compute XOR as intended:

?- xor(x, y, Z).
sat(Z=:=x\#y).

A.8.9 Acknowledgments

The interface predicates of this library follow the example of SICStus Prolog.
Use SICStus Prolog for higher performance in many cases.

A.8.10 CLP(B) predicate index

In the following, each CLP(B) predicate is described in more detail.
We recommend the following link to refer to this manual:
http://eu.swi-prolog.org/man/clpb.html

sat(+Expr) [semidet]
True iff Expr is a satisfiable Boolean expression.

taut(+Expr, -T) [semidet]
Tautology check. Succeeds with \( T = 0 \) if the Boolean expression Expr cannot be satisfied, and with \( T = 1 \) if Expr is always true with respect to the current constraints. Fails otherwise.

labeling(+Vs) [multi]
Enumerate concrete solutions. Assigns truth values to the Boolean variables Vs such that all stated constraints are satisfied.

sat_count(+Expr, -Count) [det]
Count the number of admissible assignments. Count is the number of different assignments of truth values to the variables in the Boolean expression Expr, such that Expr is true and all posted constraints are satisfiable.
A common form of invocation is sat_count(+[1|Vs], Count): This counts the number of admissible assignments to Vs without imposing any further constraints.

Examples:

?- sat(A =< B), Vs = [A,B], sat_count(+[1|Vs], Count).
Vs = [A, B],
Count = 3,
sat(A=:A*B).
?- length(Vs, 120),
    sat_count(+Vs, CountOr),
    sat_count(*(Vs), CountAnd).
Vs = [...],
CountOr = 1329227995784915872903807060280344575,
CountAnd = 1.

weighted_maximum(+Weights, +Vs, -Maximum)
Enumerate weighted optima over admissible assignments. Maximize a linear objective function over Boolean variables Vs with integer coefficients Weights. This predicate assigns 0 and 1 to the variables in Vs such that all stated constraints are satisfied, and Maximum is the maximum of \( \sum (\text{Weight}_i \times \text{V}_i) \) over all admissible assignments. On backtracking, all admissible assignments that attain the optimum are generated.
This predicate can also be used to minimize a linear Boolean program, since negative integers can appear in Weights.
Example:
?- sat(A#B), weighted_maximum([1,2,1], [A,B,C], Maximum).
A = 0, B = 1, C = 1, Maximum = 3.

random_labeling(+Seed, +Vs)
Select a single random solution. An admissible assignment of truth values to the Boolean variables in Vs is chosen in such a way that each admissible assignment is equally likely. Seed is an integer, used as the initial seed for the random number generator.

A.9 library(clpfd): CLP(FD): Constraint Logic Programming over Finite Domains

author  
Markus Triska

Development of this library has moved to SICStus Prolog.
Please see CLP(Z) for more information.

A.9.1 Introduction
This library provides CLP(FD): Constraint Logic Programming over Finite Domains. This is an instance of the general CLP(X) scheme (section 8), extending logic programming with reasoning over specialised domains. CLP(FD) lets us reason about integers in a way that honors the relational nature of Prolog.
Read The Power of Prolog to understand how this library is meant to be used in practice.
There are two major use cases of CLP(FD) constraints:

1. declarative integer arithmetic (section A.9.3)
2. solving combinatorial problems such as planning, scheduling and allocation tasks.
A.9. LIBRARY(CLPFD): CLP(FD): CONSTRAINT LOGIC PROGRAMMING OVER
FINITE DOMAINS

The predicates of this library can be classified as:

- **arithmetic** constraints like `=/2`, `>/2` and `\=/2` (section A.9.17)
- **the membership** constraints `in/2` and `ins/2` (section A.9.17)
- **the enumeration** predicates `indomain/1`, `label/1` and `labeling/2` (section A.9.17)
- **combinatorial** constraints like `all_distinct/1` and `global_cardinality/2` (section A.9.17)
- **reification** predicates such as `=<>/2` (section A.9.17)
- **reflection** predicates such as `fd_dom/2` (section A.9.17)

In most cases, **arithmetic constraints** (section A.9.2) are the only predicates you will ever need from this library. When reasoning over integers, simply replace low-level arithmetic predicates like `is/2` and `>/2` by the corresponding CLP(FD) constraints like `=/2` and `>/2` to honor and preserve declarative properties of your programs. For satisfactory performance, arithmetic constraints are implicitly rewritten at compilation time so that low-level fallback predicates are automatically used whenever possible.

Almost all Prolog programs also reason about integers. Therefore, it is highly advisable that you make CLP(FD) constraints available in all your programs. One way to do this is to put the following directive in your `<config>/init.pl` initialisation file:

```prolog
:- use_module(library(clpfd)).
```

All example programs that appear in the CLP(FD) documentation assume that you have done this. Important concepts and principles of this library are illustrated by means of usage examples that are available in a public git repository: [github.com/triska/clpfd](https://github.com/triska/clpfd)

If you are used to the complicated operational considerations that low-level arithmetic primitives necessitate, then moving to CLP(FD) constraints may, due to their power and convenience, at first feel to you excessive and almost like cheating. It isn’t. Constraints are an integral part of all popular Prolog systems, and they are designed to help you eliminate and avoid the use of low-level and less general primitives by providing declarative alternatives that are meant to be used instead.

When teaching Prolog, CLP(FD) constraints should be introduced before explaining low-level arithmetic predicates and their procedural idiosyncrasies. This is because constraints are easy to explain, understand and use due to their purely relational nature. In contrast, the modedness and directionality of low-level arithmetic primitives are impure limitations that are better deferred to more advanced lectures.

We recommend the following reference (PDF: metalevel.at/swiclpfd.pdf) for citing this library in scientific publications:

```bibtex
@inproceedings{Triska12,  
  author = {Markus Triska},  
  title = {The Finite Domain Constraint Solver of {SWI-Prolog}},  
  booktitle = {FLOPS},  
  series = {LNCS},  
  volume = {7294},  
}
```

SWI-Prolog 9.1 Reference Manual
A.9.2 Arithmetic constraints

In modern Prolog systems, arithmetic constraints subsume and supersede low-level predicates over integers. The main advantage of arithmetic constraints is that they are true relations and can be used in all directions. For most programs, arithmetic constraints are the only predicates you will ever need from this library.

The most important arithmetic constraint is \#=/2, which subsumes both (is)/2 and (=:=)/2 over integers. Use #=/2 to make your programs more general. See declarative integer arithmetic (section A.9.3).

In total, the arithmetic constraints are:

<table>
<thead>
<tr>
<th>Expr1 #= Expr2</th>
<th>Expr1 equals Expr2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expr1 #= Expr2</td>
<td>Expr1 is not equal to Expr2</td>
</tr>
<tr>
<td>Expr1 #&gt;= Expr2</td>
<td>Expr1 is greater than or equal to Expr2</td>
</tr>
<tr>
<td>Expr1 #=&lt; Expr2</td>
<td>Expr1 is less than or equal to Expr2</td>
</tr>
<tr>
<td>Expr1 #&gt; Expr2</td>
<td>Expr1 is greater than Expr2</td>
</tr>
<tr>
<td>Expr1 #&lt; Expr2</td>
<td>Expr1 is less than Expr2</td>
</tr>
</tbody>
</table>

\(Expr1\) and \(Expr2\) denote arithmetic expressions, which are:

| integer | Given value |
| variable | Unknown integer |
| ?(variable) | Unknown integer |
| Expr | Unary minus |
| Expr + Expr | Addition |
| Expr * Expr | Multiplication |
| Expr - Expr | Subtraction |
| Expr ∘ Expr | Exponentiation |
| min(Expr,Expr) | Minimum of two expressions |
| max(Expr,Expr) | Maximum of two expressions |
| Expr mod Expr | Modulo induced by floored division |
| Expr rem Expr | Modulo induced by truncated division |
| abs(Expr) | Absolute value |
| Expr // Expr | Truncated integer division |
| Expr div Expr | Floored integer division |

where \(Expr\) again denotes an arithmetic expression.

The bitwise operations \((\&)/1\), \((\&\&)/2\), \((\|)/2\), \((\|\|)/2\), \((\#)/2\), \((\_)/2\), \(\text{lsb}/1\), \(\text{msb}/1\), \(\text{popcount}/1\) and \((\text{xor})/2\) are also supported.
A.9.3 Declarative integer arithmetic

The arithmetic constraints (section A.9.2) #=/2, #>/2 etc. are meant to be used instead of the primitives (is)/2, (=:=)/2, (>)/2 etc. over integers. Almost all Prolog programs also reason about integers. Therefore, it is recommended that you put the following directive in your <config>/init.pl initialisation file to make CLP(FD) constraints available in all your programs:

```prolog
:- use_module(library(clpfd)).
```

Throughout the following, it is assumed that you have done this.

The most basic use of CLP(FD) constraints is evaluation of arithmetic expressions involving integers. For example:

```prolog
?- X #= 1+2.
X = 3.
```

This could in principle also be achieved with the lower-level predicate (is)/2. However, an important advantage of arithmetic constraints is their purely relational nature: Constraints can be used in all directions, also if one or more of their arguments are only partially instantiated. For example:

```prolog
?- 3 #= Y+2.
Y = 1.
```

This relational nature makes CLP(FD) constraints easy to explain and use, and well suited for beginners and experienced Prolog programmers alike. In contrast, when using low-level integer arithmetic, we get:

```prolog
?- 3 is Y+2.
ERROR: is/2: Arguments are not sufficiently instantiated
?- 3 =:= Y+2.
ERROR: =:=/2: Arguments are not sufficiently instantiated
```

Due to the necessary operational considerations, the use of these low-level arithmetic predicates is considerably harder to understand and should therefore be deferred to more advanced lectures.

For supported expressions, CLP(FD) constraints are drop-in replacements of these low-level arithmetic predicates, often yielding more general programs. See n_factorial/2 (section A.9.4) for an example.

This library uses goal_expansion/2 to automatically rewrite constraints at compilation time so that low-level arithmetic predicates are automatically used whenever possible. For example, the predicate:

```prolog
positive_integer(N) :- N #>= 1.
```

is executed as if it were written as:
positive_integer(N) :-
  ( integer(N)
  -> N #>= 1
  ; N #>= 1
  ).

This illustrates why the performance of CLP(FD) constraints is almost always completely satisfactory when they are used in modes that can be handled by low-level arithmetic. To disable the automatic rewriting, set the Prolog flag clpfd_goal_expansion to false.

If you are used to the complicated operational considerations that low-level arithmetic primitives necessitate, then moving to CLP(FD) constraints may, due to their power and convenience, at first feel to you excessive and almost like cheating. It isn’t. Constraints are an integral part of all popular Prolog systems, and they are designed to help you eliminate and avoid the use of low-level and less general primitives by providing declarative alternatives that are meant to be used instead.

A.9.4 Example: Factorial relation

We illustrate the benefit of using #=/2 for more generality with a simple example.

Consider first a rather conventional definition of n_factorial/2, relating each natural number N to its factorial F:

n_factorial(0, 1).
n_factorial(N, F) :-
  N #> 0,
  N1 #= N - 1,
  n_factorial(N1, F1),
  F #= N * F1.

This program uses CLP(FD) constraints instead of low-level arithmetic throughout, and everything that would have worked with low-level arithmetic also works with CLP(FD) constraints, retaining roughly the same performance. For example:

?- n_factorial(47, F).
F = 25862324151168180642964355153611979969197632389120000000000 ;
false.

Now the point: Due to the increased flexibility and generality of CLP(FD) constraints, we are free to reorder the goals as follows:

n_factorial(0, 1).
n_factorial(N, F) :-
  N #> 0,
  N1 #= N - 1,
  F #= N * F1,
  n_factorial(N1, F1).
In this concrete case, *termination* properties of the predicate are improved. For example, the following queries now both terminate:

```
?- n_factorial(N, 1).
N = 0 ;
N = 1 ;
false.
?- n_factorial(N, 3).
false.
```

To make the predicate terminate if *any* argument is instantiated, add the (implied) constraint \( F \neq 0 \) before the recursive call. Otherwise, the query `n_factorial(N, 0)` is the only non-terminating case of this kind.

The value of CLP(FD) constraints does *not* lie in completely freeing us from all procedural phenomena. For example, the two programs do not even have the same *termination properties* in all cases. Instead, the primary benefit of CLP(FD) constraints is that they allow you to try different execution orders and apply declarative debugging techniques *at all*! Reordering goals (and clauses) can significantly impact the performance of Prolog programs, and you are free to try different variants if you use declarative approaches. Moreover, since all CLP(FD) constraints always terminate, placing them earlier can at most improve, never worsen, the termination properties of your programs. An additional benefit of CLP(FD) constraints is that they eliminate the complexity of introducing \((\text{is})/2\) and \((\text{=:=})/2\) to beginners, since both predicates are subsumed by \(#=/2\) when reasoning over integers.

In the case above, the clauses are mutually exclusive if the first argument is sufficiently instantiated. To make the predicate deterministic in such cases while retaining its generality, you can use `zcompare/3` to reify a comparison, making the different cases distinguishable by pattern matching. For example, in this concrete case and others like it, you can use `zcompare(Comp, 0, N)` to obtain as `Comp` the symbolic outcome \((<, =, >)\) of 0 compared to \(N\).

### A.9.5 Combinatorial constraints

In addition to subsuming and replacing low-level arithmetic predicates, CLP(FD) constraints are often used to solve combinatorial problems such as planning, scheduling and allocation tasks. Among the most frequently used *combinatorial constraints* are `all_distinct/1`, `global_cardinality/2` and `cumulative/2`. This library also provides several other constraints like `disjoint2/1` and `automaton/8`, which are useful in more specialized applications.

### A.9.6 Domains

Each CLP(FD) variable has an associated set of admissible integers, which we call the variable’s *domain*. Initially, the domain of each CLP(FD) variable is the set of *all* integers. CLP(FD) constraints like \(\#=/=2\), \(\#>/2\) and \(\#\neq/=2\) can at most reduce, and never extend, the domains of their arguments. The constraints `in/2` and `ins/2` let us explicitly state domains of CLP(FD) variables. The process of determining and adjusting domains of variables is called constraint *propagation*, and it is performed automatically by this library. When the domain of a variable contains only one element, then the variable is automatically unified to that element.

Domains are taken into account when further constraints are stated, and by enumeration predicates like `labeling/2`. 
A.9.7  Example: Sudoku

As another example, consider Sudoku: It is a popular puzzle over integers that can be easily solved with CLP(FD) constraints.

```prolog
sudoku(Rows) :-
    length(Rows, 9), maplist(same_length(Rows), Rows),
    append(Rows, Vs), Vs ins 1..9,
    maplist(all_distinct, Rows),
    transpose(Rows, Columns),
    maplist(all_distinct, Columns),
    Rows = [As, Bs, Cs, Ds, Es, Fs, Gs, Hs, Is],
    blocks(As, Bs, Cs),
    blocks(Ds, Es, Fs),
    blocks(Gs, Hs, Is).
blocks([], [], []).
blocks([N1,N2,N3|Ns1], [N4,N5,N6|Ns2], [N7,N8,N9|Ns3]) :-
    all_distinct([N1,N2,N3,N4,N5,N6,N7,N8,N9]),
    blocks(Ns1, Ns2, Ns3).
problem(1, [[_,_,_,_,_,_,_,_,_],
            [_,_,_,_,_,3,_,8,5],
            [_,_,1,_,2,_,_,_,_],
            [_,_,_,5,_,7,_,_,_],
            [_,_,4,_,_,1,_,_,_],
            [_,_,9,_,_,_,_,_,_],
            [5,_,_,_,_,_,_,7,3],
            [_,_,2,_,1,_,_,_,_],
            [_,_,4,_,_,_,_,9]]).
```

Sample query:

```prolog
?- problem(1, Rows), sudoku(Rows), maplist(portray_clause, Rows).
[9, 8, 7, 6, 5, 4, 3, 2, 1].
[2, 4, 6, 1, 7, 3, 9, 8, 5].
[3, 5, 1, 9, 2, 8, 7, 4, 6].
[1, 2, 8, 5, 3, 7, 6, 9, 4].
[6, 3, 4, 8, 9, 2, 1, 5, 7].
[7, 9, 5, 4, 6, 1, 8, 3, 2].
[5, 1, 9, 2, 8, 6, 4, 7, 3].
[4, 7, 2, 3, 1, 9, 5, 6, 8].
[8, 6, 3, 7, 4, 5, 2, 1, 9].
Rows = [[9, 8, 7, 6, 5, 4, 3, 2|...], ... , [...|...]].
```

In this concrete case, the constraint solver is strong enough to find the unique solution without any search. For the general case, see search (section A.9.9).
A.9.8 Residual goals

Here is an example session with a few queries and their answers:

?- X #> 3.
X in 4..sup.

?- X #\= 20.
X in inf..19\21..sup.

?- 2*X #= 10.
X = 5.

?- X*X #= 144.
X in -12\12.

?- 4*X + 2*Y #= 24, X + Y #= 9, [X,Y] ins 0..sup.
X = 3,
Y = 6.

?- X #= Y #<==> B, X in 0..3, Y in 4..5.
B = 0,
X in 0..3,
Y in 4..5.

The answers emitted by the toplevel are called residual programs, and the goals that comprise each answer are called residual goals. In each case above, and as for all pure programs, the residual program is declaratively equivalent to the original query. From the residual goals, it is clear that the constraint solver has deduced additional domain restrictions in many cases.

To inspect residual goals, it is best to let the toplevel display them for us. Wrap the call of your predicate into \texttt{call_residue_vars/2} to make sure that all constrained variables are displayed. To make the constraints a variable is involved in available as a Prolog term for further reasoning within your program, use \texttt{copy_term/3}. For example:

?- X #= Y + Z, X in 0..5, copy_term([X,Y,Z], [X,Y,Z], Gs).
Gs = [clpfd: (X in 0..5), clpfd: (Y+Z#=X)],
X in 0..5,
Y+Z#=X.

This library also provides \texttt{reflection} predicates (like \texttt{fd_dom/2}, \texttt{fd_size/2} etc.) with which we can inspect a variable’s current domain. These predicates can be useful if you want to implement your own labeling strategies.

A.9.9 Core relations and search

Using CLP(FD) constraints to solve combinatorial tasks typically consists of two phases:
1. **Modeling.** In this phase, all relevant constraints are stated.

2. **Search.** In this phase, *enumeration predicates* are used to search for concrete solutions.

It is good practice to keep the modeling part, via a dedicated predicate called the **core relation**, separate from the actual search for solutions. This lets us observe termination and determinism properties of the core relation in isolation from the search, and more easily try different search strategies.

As an example of a constraint satisfaction problem, consider the cryptoarithmetic puzzle \texttt{SEND + MORE = MONEY}, where different letters denote distinct integers between 0 and 9. It can be modeled in CLP(FD) as follows:

```prolog
puzzle([S,E,N,D] + [M,O,R,E] = [M,O,N,E,Y]) :-
    Vars = [S,E,N,D,M,O,R,Y],
    Vars ins 0..9,
    all_different(Vars),
    S*1000 + E*100 + N*10 + D +
    M*1000 + O*100 + R*10 + E #= 
    M*10000 + O*1000 + N*100 + E*10 + Y,
    M #\= 0, S #\= 0.
```

Notice that we are *not* using \texttt{labeling/2} in this predicate, so that we can first execute and observe the modeling part in isolation. Sample query and its result (actual variables replaced for readability):

```prolog
?- puzzle(As+Bs=Cs).
As = [9, A2, A3, A4],
Bs = [1, 0, B3, A2],
Cs = [1, 0, A3, A2, C5],
A2 in 4..7,
all_different([9, A2, A3, A4, 1, 0, B3, C5]),
91*A2+A4+10*B3#=90*A3+C5,
A3 in 5..8,
A4 in 2..8,
B3 in 2..8,
C5 in 2..8.
```

From this answer, we see that this core relation **terminates** and is in fact **deterministic**. Moreover, we see from the residual goals that the constraint solver has deduced more stringent bounds for all variables. Such observations are only possible if modeling and search parts are cleanly separated.

Labeling can then be used to search for solutions in a separate predicate or goal:

```prolog
?- puzzle(As+Bs=Cs), label(As).
As = [9, 5, 6, 7],
Bs = [1, 0, 8, 5],
Cs = [1, 0, 6, 5, 2] ;
false.
```
A.9. LIBRARY(CLPFD): CLP(FD): CONSTRAINT LOGIC PROGRAMMING OVER
FINITE DOMAINS

In this case, it suffices to label a subset of variables to find the puzzle’s unique solution, since the
constraint solver is strong enough to reduce the domains of remaining variables to singleton sets. In
general though, it is necessary to label all variables to obtain ground solutions.

A.9.10 Example: Eight queens puzzle

We illustrate the concepts of the preceding sections by means of the so-called eight queens puzzle.
The task is to place 8 queens on an 8x8 chessboard such that none of the queens is under attack. This
means that no two queens share the same row, column or diagonal.

To express this puzzle via CLP(FD) constraints, we must first pick a suitable representation. Since
CLP(FD) constraints reason over integers, we must find a way to map the positions of queens to
integers. Several such mappings are conceivable, and it is not immediately obvious which we should
use. On top of that, different constraints can be used to express the desired relations. For such reasons,
modeling combinatorial problems via CLP(FD) constraints often necessitates some creativity and has
been described as more of an art than a science.

In our concrete case, we observe that there must be exactly one queen per column. The following
representation therefore suggests itself: We are looking for 8 integers, one for each column, where
each integer denotes the row of the queen that is placed in the respective column, and which are subject
to certain constraints.

In fact, let us now generalize the task to the so-called N queens puzzle, which is obtained by re-
placing 8 by N everywhere it occurs in the above description. We implement the above considerations
in the core relation n_queens/2, where the first argument is the number of queens (which is iden-
tical to the number of rows and columns of the generalized chessboard), and the second argument is a
list of N integers that represents a solution in the form described above.

n_queens(N, Qs) :-
  length(Qs, N),
  Qs ins 1..N,
  safe_queens(Qs).

safe_queens([]).
safe_queens([Q|Qs]) :- safe_queens(Qs, Q, 1), safe_queens(Qs).

safe_queens([], _, _).
safe_queens([Q|Qs], Q0, D0) :-
  Q0 #\= Q,
  abs(Q0 - Q) #\= D0,
  D1 #= D0 + 1,
  safe_queens(Qs, Q0, D1).

Note that all these predicates can be used in all directions: We can use them to find solutions, test
solutions and complete partially instantiated solutions.

The original task can be readily solved with the following query:

?- n_queens(8, Qs), label(Qs).
Qs = [1, 5, 8, 6, 3, 7, 2, 4].
Using suitable labeling strategies, we can easily find solutions with 80 queens and more:

```
?- n_queens(80, Qs), labeling([ff], Qs).
Qs = [1, 3, 5, 44, 42, 4, 50, 7, 68|...] .

?- time((n_queens(90, Qs), labeling([ff], Qs))).
% 5,904,401 inferences, 0.722 CPU in 0.737 seconds (98% CPU)
Qs = [1, 3, 5, 50, 42, 4, 49, 7, 59|...] .
```

Experimenting with different search strategies is easy because we have separated the core relation from the actual search.

**A.9.11 Optimisation**

We can use `labeling/2` to minimize or maximize the value of a CLP(FD) expression, and generate solutions in increasing or decreasing order of the value. See the labeling options `min(Expr)` and `max(Expr)`, respectively.

Again, to easily try different labeling options in connection with optimisation, we recommend to introduce a dedicated predicate for posting constraints, and to use `labeling/2` in a separate goal. This way, we can observe properties of the core relation in isolation, and try different labeling options without recompiling our code.

If necessary, we can use `once/1` to commit to the first optimal solution. However, it is often very valuable to see alternative solutions that are also optimal, so that we can choose among optimal solutions by other criteria. For the sake of purity and completeness, we recommend to avoid `once/1` and other constructs that lead to impurities in CLP(FD) programs.

Related to optimisation with CLP(FD) constraints are `library(simplex)` and CLP(Q) which reason about linear constraints over rational numbers.

**A.9.12 Reification**

The constraints `in/2`, `=/2`, `\=/2`, `<>/2`, `=<>/2`, and `>=/2` can be reified, which means reflecting their truth values into Boolean values represented by the integers 0 and 1. Let P and Q denote reifiable constraints or Boolean variables, then:

<table>
<thead>
<tr>
<th>P</th>
<th>Q</th>
<th>Truth Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>P #\ Q</td>
<td>True iff Q is false</td>
<td></td>
</tr>
<tr>
<td>P #/ Q</td>
<td>True iff either P or Q</td>
<td></td>
</tr>
<tr>
<td>P #\ Q</td>
<td>True iff both P and Q</td>
<td></td>
</tr>
<tr>
<td>P #\ Q</td>
<td>True iff either P or Q, but not both</td>
<td></td>
</tr>
<tr>
<td>P #=&lt;== Q</td>
<td>True iff P and Q are equivalent</td>
<td></td>
</tr>
<tr>
<td>P #=&gt;&gt; Q</td>
<td>True iff P implies Q</td>
<td></td>
</tr>
<tr>
<td>P #&lt;=Q</td>
<td>True iff Q implies P</td>
<td></td>
</tr>
</tbody>
</table>

The constraints of this table are reifiable as well.

When reasoning over Boolean variables, also consider using CLP(B) constraints as provided by `library(clpb)`.
A.9.13 Enabling monotonic CLP(FD)

In the default execution mode, CLP(FD) constraints still exhibit some non-relational properties. For example, *adding* constraints can yield new solutions:

```
?- X #= 2, X = 1+1.
false.
?- X = 1+1, X #= 2, X = 1+1.
X = 1+1.
```

This behaviour is highly problematic from a logical point of view, and it may render declarative debugging techniques inapplicable.

Set the Prolog flag `clpfd_monotonic` to `true` to make CLP(FD) monotonic: This means that *adding* new constraints *cannot* yield new solutions. When this flag is `true`, we must wrap variables that occur in arithmetic expressions with the functor `(?)/1` or `(#) /1`. For example:

```
?- set_prolog_flag(clpfd_monotonic, true).
ture.
?- #(X) #= #(Y) + #(Z).
#(Y)+ #(Z)#= #(X).
?- X #= 2, X = 1+1.
ERROR: Arguments are not sufficiently instantiated
```

The wrapper can be omitted for variables that are already constrained to integers.

A.9.14 Custom constraints

We can define custom constraints. The mechanism to do this is not yet finalised, and we welcome suggestions and descriptions of use cases that are important to you.

As an example of how it can be done currently, let us define a new custom constraint `oneground(X, Y, Z)`, where Z shall be 1 if at least one of X and Y is instantiated:

```
:- multifile clpfd:run_propagator/2.

oneground(X, Y, Z) :-
    clpfd:make_propagator(oneground(X, Y, Z), Prop),
    clpfd:init_propagator(X, Prop),
    clpfd:init_propagator(Y, Prop),
    clpfd:trigger_once(Prop).

clpfd:run_propagator(oneground(X, Y, Z), MState) :-
    ( integer(X) -> clpfd:kill(MState), Z = 1
    ; integer(Y) -> clpfd:kill(MState), Z = 1
    ; true
    ).
```
First, `clpfd:make_propagator/2` is used to transform a user-defined representation of the new constraint to an internal form. With `clpfd:init_propagator/2`, this internal form is then attached to X and Y. From now on, the propagator will be invoked whenever the domains of X or Y are changed. Then, `clpfd:trigger_once/1` is used to give the propagator its first chance for propagation even though the variables’ domains have not yet changed. Finally, `clpfd:run_propagator/2` is extended to define the actual propagator. As explained, this predicate is automatically called by the constraint solver. The first argument is the user-defined representation of the constraint as used in `clpfd:make_propagator/2`, and the second argument is a mutable state that can be used to prevent further invocations of the propagator when the constraint has become entailed, by using `clpfd:kill/1`. An example of using the new constraint:

```
?- oneground(X, Y, Z), Y = 5.
Y = 5,
Z = 1,
X in inf..sup.
```

**A.9.15 Applications**

CLP(FD) applications that we find particularly impressive and worth studying include:

- Michael Hendricks uses CLP(FD) constraints for flexible reasoning about *dates* and *times* in the *julian* package.

- Julien Cumin uses CLP(FD) constraints for integer arithmetic in *Brachylog*.

**A.9.16 Acknowledgments**

This library gives you a glimpse of what *SICStus Prolog* can do. The API is intentionally mostly compatible with that of SICStus Prolog, so that you can easily switch to a much more feature-rich and much faster CLP(FD) system when you need it. I thank Mats Carlsson, the designer and main implementor of SICStus Prolog, for his elegant example. I first encountered his system as part of the excellent *GUPU* teaching environment by Ulrich Neumerkel. Ulrich was also the first and most determined tester of the present system, filing hundreds of comments and suggestions for improvement. Tom Schrijvers has contributed several constraint libraries to SWI-Prolog, and I learned a lot from his coding style and implementation examples. Bart Demoen was a driving force behind the implementation of attributed variables in SWI-Prolog, and this library could not even have started without his prior work and contributions. Thank you all!

**A.9.17 CLP(FD) predicate index**

In the following, each CLP(FD) predicate is described in more detail.

We recommend the following link to refer to this manual:

http://eu.swi-prolog.org/man/clpfd.html

**Arithmetic constraints**

*Arithmetic* constraints are the most basic use of CLP(FD). Every time you use `(is)/2` or one of the low-level arithmetic comparisons `((<)/2, (>)/2` etc.) over integers, consider using CLP(FD)
constraints *instead*. This can at most *increase* the generality of your programs. See declarative integer arithmetic (section A.9.3).

\(?X \#= \?Y\)

The arithmetic expression \(X\) equals \(Y\). This is the most important arithmetic constraint (section A.9.2), subsuming and replacing both \((\text{is})/2\) and \((\text{=:=})/2\) over integers. See declarative integer arithmetic (section A.9.3).

\(?X \#\neq \?Y\)

The arithmetic expressions \(X\) and \(Y\) evaluate to distinct integers. When reasoning over integers, replace \((=\neq)/2\) by \(\#\neq/2\) to obtain more general relations. See declarative integer arithmetic (section A.9.3).

\(?X \#\geq \?Y\)

Same as \(Y \#\leq X\). When reasoning over integers, replace \((\geq)/2\) by \(\#\geq/2\) to obtain more general relations. See declarative integer arithmetic (section A.9.3).

\(?X \#\leq \?Y\)

The arithmetic expression \(X\) is less than or equal to \(Y\). When reasoning over integers, replace \((=\leq)/2\) by \(\#\leq/2\) to obtain more general relations. See declarative integer arithmetic (section A.9.3).

\(?X \#> \?Y\)

Same as \(Y \#< X\). When reasoning over integers, replace \((>/2\) by \(\#>/2\) to obtain more general relations. See declarative integer arithmetic (section A.9.3).

\(?X \#< \?Y\)

The arithmetic expression \(X\) is less than \(Y\). When reasoning over integers, replace \((<)/2\) by \(\#</2\) to obtain more general relations. See declarative integer arithmetic (section A.9.3).

In addition to its regular use in tasks that require it, this constraint can also be useful to eliminate uninteresting symmetries from a problem. For example, all possible matches between pairs built from four players in total:

\[
\text{?- Vs = [A,B,C,D], Vs ins 1..4,}
\text{ all_different(Vs),}
\text{ A \#< B, C \#< D, A \#< C,}
\text{ findall(pair(A,B)-pair(C,D), label(Vs), Ms).}
\text{Ms = [
\text{ pair(1, 2)-pair(3, 4),}
\text{ pair(1, 3)-pair(2, 4),}
\text{ pair(1, 4)-pair(2, 3).}
\text{]}
\]

**Membership constraints**

If you are using CLP(FD) to model and solve combinatorial tasks, then you typically need to specify the admissible domains of variables. The *membership constraints* \(\text{in}/2\) and \(\text{ins}/2\) are useful in such cases.

\(?\text{Var in +Domain}\)

\text{Var} is an element of \text{Domain}. \text{Domain} is one of:
**Integer**

Singleton set consisting only of Integer.

**Lower .. Upper**

All integers \( I \) such that \( \text{Lower} \leq I \leq \text{Upper} \). Lower must be an integer or the atom \text{inf}, which denotes negative infinity. Upper must be an integer or the atom \text{sup}, which denotes positive infinity.

**Domain1 \( \setminus \) Domain2**

The union of Domain1 and Domain2.

+\( Vars \) ins +\( Domain \)

The variables in the list \( Vars \) are elements of \( Domain \). See \( \text{in/2} \) for the syntax of \( Domain \).

**Enumeration predicates**

When modeling combinatorial tasks, the actual search for solutions is typically performed by enumeration predicates like \( \text{labeling/2} \). See the section about core relations and search for more information.

**indomain(?Var)**

Bind \( Var \) to all feasible values of its domain on backtracking. The domain of \( Var \) must be finite.

**label(+Vars)**

Equivalent to \( \text{labeling([], Vars)} \). See \( \text{labeling/2} \).

**labeling(+Options, +Vars)**

Assign a value to each variable in \( Vars \). Labeling means systematically trying out values for the finite domain variables \( Vars \) until all of them are ground. The domain of each variable in \( Vars \) must be finite. \( Options \) is a list of options that let you exhibit some control over the search process. Several categories of options exist:

The variable selection strategy lets you specify which variable of \( Vars \) is labeled next and is one of:

**leftmost**

Label the variables in the order they occur in \( Vars \). This is the default.

**ff**

First fail. Label the leftmost variable with smallest domain next, in order to detect infeasibility early. This is often a good strategy.

**ffc**

Of the variables with smallest domains, the leftmost one participating in most constraints is labeled next.

**min**

Label the leftmost variable whose lower bound is the lowest next.

**max**

Label the leftmost variable whose upper bound is the highest next.

The value order is one of:
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up
Try the elements of the chosen variable’s domain in ascending order. This is the default.

down
Try the domain elements in descending order.

The branching strategy is one of:

step
For each variable X, a choice is made between X = V and X ≠ V, where V is determined
by the value ordering options. This is the default.

down
For each variable X, a choice is made between X = V_1, X = V_2 etc., for all values V_i
of the domain of X. The order is determined by the value ordering options.

down
For each variable X, a choice is made between X ≠< M and X ≠> M, where M is the
midpoint of the domain of X.

At most one option of each category can be specified, and an option must not occur repeatedly.
The order of solutions can be influenced with:

- min(Expr)
- max(Expr)

This generates solutions in ascending/descending order with respect to the evaluation of the
arithmetic expression Expr. Labeling Vars must make Expr ground. If several such options are
specified, they are interpreted from left to right, e.g.:

?- [X,Y] ins 10..20, labeling([max(X),min(Y)], [X,Y]).

This generates solutions in descending order of X, and for each binding of X, solutions are
generated in ascending order of Y. To obtain the incomplete behaviour that other systems exhibit
with "maximize(Expr)" and "minimize(Expr)", use once/1, e.g.:

once(labeling([max(Expr)], Vars))

Labeling is always complete, always terminates, and yields no redundant solutions. See core
relations and search (section A.9.9) for usage advice.

Global constraints

A global constraint expresses a relation that involves many variables at once. The most fre-
quently used global constraints of this library are the combinatorial constraints all_distinct/1,
global_cardinality/2 and cumulative/2.

all_distinct(+Vars)
True iff Vars are pairwise distinct. For example, all_distinct/1 can detect that not all
variables can assume distinct values given the following domains:
all\_different(+Vars)

Like all\_distinct/1, but with weaker propagation. Consider using all\_distinct/1 instead, since all\_distinct/1 is typically acceptably efficient and propagates much more strongly.

sum(+Vars, +Rel, ?Expr)

The sum of elements of the list \textit{Vars} is in relation \textit{Rel} to \textit{Expr}. \textit{Rel} is one of #=, #\!, #<, #>, #=< or #>=. For example:

\[
\text{?- } [A,B,C] \text{ ins } 0..\text{sup}, \text{ sum}([A,B,C], #=, 100).
\]

\[
\text{A in } 0..100, \\
\text{A+B+C=}100, \\
\text{B in } 0..100, \\
\text{C in } 0..100.
\]

scalar\_product(+Cs, +Vs, +Rel, ?Expr)

True iff the scalar product of \textit{Cs} and \textit{Vs} is in relation \textit{Rel} to \textit{Expr}. \textit{Cs} is a list of integers, \textit{Vs} is a list of variables and integers. \textit{Rel} is #=, #\!, #<, #>, #=< or #>=.

lex\_chain(+Lists)

Lists are lexicographically non-decreasing.

tuples\_in(+Tuples, +Relation)

True iff all \textit{Tuples} are elements of \textit{Relation}. Each element of the list \textit{Tuples} is a list of integers or finite domain variables. \textit{Relation} is a list of lists of integers. Arbitrary finite relations, such as compatibility tables, can be modeled in this way. For example, if 1 is compatible with 2 and 5, and 4 is compatible with 0 and 3:

\[
\text{?- tuples\_in}([[X,Y]], \[[1,2],[1,5],[4,0],[4,3]]), X = 4. \\
\text{X = 4,} \\
\text{Y in } 0\backslash/3.
\]

As another example, consider a train schedule represented as a list of quadruples, denoting departure and arrival places and times for each train. In the following program, \textit{Ps} is a feasible journey of length 3 from A to D via trains that are part of the given schedule.

\[
\text{trains}([[1,2,0,1], \\
[2,3,4,5], \\
[2,3,0,1], \\
[3,4,5,6], \\
[3,4,2,3], \\
[0,1,0,1]])
\]
threepath(A, D, Ps) :-
    Ps = [[A, B, _T0, T1], [B, C, T2, T3], [C, D, T4, _T5]],
    T2 #> T1,
    T4 #> T3,
    trains(Ts),
    tuples_in(Ps, Ts).

In this example, the unique solution is found without labeling:

?- threepath(1, 4, Ps).
Ps = [[1, 2, 0, 1], [2, 3, 4, 5], [3, 4, 8, 9]].

serialized(+Starts, +Durations)
Describes a set of non-overlapping tasks. Starts = [S_1,...,S_n], is a list of variables or integers, Durations = [D_1,...,D_n] is a list of non-negative integers. Constrains Starts and Durations to denote a set of non-overlapping tasks, i.e.: S_i + D_i =< S_j or S_j + D_j =< S_i for all 1 =< i < j =< n. Example:

?- length(Vs, 3),
   Vs ins 0..3,
   serialized(Vs, [1,2,3]),
   label(Vs).
Vs = [0, 1, 3] ;
Vs = [2, 0, 3] ;
false.

See also Dorndorf et al. 2000, “Constraint Propagation Techniques for the Disjunctive Scheduling Problem”

element(?N, +Vs, ?V)
The N-th element of the list of finite domain variables Vs is V. Analogous to nth1/3.

global_cardinality(+Vs, +Pairs)
Global Cardinality constraint. Equivalent to global_cardinality(Vs, Pairs, []). See global_cardinality/3.
Example:

?- Vs = [1, 2, 3], global_cardinality(Vs, [1-2,3-_]), label(Vs).
Vs = [1, 1, 3] ;
Vs = [1, 3, 1] ;
Vs = [3, 1, 1].

global_cardinality(+Vs, +Pairs, +Options)
Global Cardinality constraint. Vs is a list of finite domain variables, Pairs is a list of Key-Num...
pairs, where Key is an integer and Num is a finite domain variable. The constraint holds iff each V in Vs is equal to some key, and for each Key-Num pair in Pairs, the number of occurrences of Key in Vs is Num. Options is a list of options. Supported options are:

**consistency(value)**
A weaker form of consistency is used.

**cost(Cost, Matrix)**
Matrix is a list of rows, one for each variable, in the order they occur in Vs. Each of these rows is a list of integers, one for each key, in the order these keys occur in Pairs. When variable v.i is assigned the value of key k.j, then the associated cost is Matrix_{ij}. Cost is the sum of all costs.

circuit(+Vs)
True iff the list Vs of finite domain variables induces a Hamiltonian circuit. The k-th element of Vs denotes the successor of node k. Node indexing starts with 1. Examples:

```prolog
?- length(Vs, _), circuit(Vs), label(Vs).
Vs = [ ] ;
Vs = [1] ;
Vs = [2, 1] ;
Vs = [2, 3, 1] ;
Vs = [3, 1, 2] ;
Vs = [2, 3, 4, 1].
```

cumulative(+Tasks)
Equivalent to cumulative(Tasks, [limit(1)]). See cumulative/2.

cumulative(+Tasks, +Options)
Schedule with a limited resource. Tasks is a list of tasks, each of the form task(S_i, D_i, E_i, C_i, T_i). S_i denotes the start time, D_i the positive duration, E_i the end time, C_i the non-negative resource consumption, and T_i the task identifier. Each of these arguments must be a finite domain variable with bounded domain, or an integer. The constraint holds iff at each time slot during the start and end of each task, the total resource consumption of all tasks running at that time does not exceed the global resource limit. Options is a list of options. Currently, the only supported option is:

**limit(L)**
The integer L is the global resource limit. Default is 1.

For example, given the following predicate that relates three tasks of durations 2 and 3 to a list containing their starting times:

```prolog
tasks_starts(Tasks, [S1,S2,S3]) :-
    Tasks = [task(S1,3,_,1,_),
             task(S2,2,_,1,_),
             task(S3,2,_,1,_)].
```
We can use `cumulative/2` as follows, and obtain a schedule:

```prolog
?- tasks_starts(Tasks, Starts), Starts ins 0..10,
cumulative(Tasks, [limit(2)]), label(Starts).
Tasks = [task(0, 3, 3, 1, _G36), task(0, 2, 2, 1, _G45), ...],
Starts = [0, 0, 2].
```

disjoint2(+Rectangles)
True iff `Rectangles` are not overlapping. `Rectangles` is a list of terms of the form `F(X_i, W_i, Y_i, H_i)`, where `F` is any functor, and the arguments are finite domain variables or integers that denote, respectively, the X coordinate, width, Y coordinate and height of each rectangle.

automaton(+Vs, +Nodes, +Arcs)
Describes a list of finite domain variables with a finite automaton. Equivalent to `automaton(Vs, _, Vs, Nodes, Arcs, [], [], _)`, a common use case of `automaton/8`. In the following example, a list of binary finite domain variables is constrained to contain at least two consecutive ones:

```prolog
two_consecutive_ones(Vs) :-
  automaton(Vs, [source(a),sink(c)],
            [arc(a,0,a), arc(a,1,b),
             arc(b,0,a), arc(b,1,c),
             arc(c,0,c), arc(c,1,c)]).
```

Example query:

```prolog
?- length(Vs, 3), two_consecutive_ones(Vs), label(Vs).
Vs = [0, 1, 1] ;
Vs = [1, 1, 0] ;
Vs = [1, 1, 1].
```

automaton(+Sequence, ?Template, +Signature, +Nodes, +Arcs, +Counters, +Initials, ?Finals)
Describes a list of finite domain variables with a finite automaton. True iff the finite automaton induced by `Nodes` and `Arcs` (extended with `Counters`) accepts `Signature`. `Sequence` is a list of terms, all of the same shape. Additional constraints must link `Sequence` to `Signature`, if necessary. `Nodes` is a list of `source(Node)` and `sink(Node)` terms. `Arcs` is a list of `arc(Node,Integer,Node)` and `arc(Node,Integer,Node,Exprs)` terms that denote the automaton’s transitions. Each node is represented by an arbitrary term. Transitions that are not mentioned go to an implicit failure node. `Exprs` is a list of arithmetic expressions, of the same length as `Counters`. In each expression, variables occurring in `Counters` symbolically refer to previous counter values, and variables occurring in `Template` refer to the current element of `Sequence`. When a transition containing arithmetic expressions is taken, each counter is updated according to the result of the corresponding expression. When a transition without arithmetic expressions is taken, all counters remain unchanged. `Counters` is a list of variables. `Initials` is a list of finite domain variables or integers denoting, in the same order, the initial value of each counter. These values are related to `Finals` according to the arithmetic expressions of the taken transitions.
The following example is taken from Beldiceanu, Carlsson, Debruyne and Petit: "Reformulation of Global Constraints Based on Constraints Checkers", Constraints 10(4), pp 339-362 (2005). It relates a sequence of integers and finite domain variables to its number of inflexions, which are switches between strictly ascending and strictly descending subsequences:

```prolog
sequence_inflexions(Vs, N) :-
    variables_signature(Vs, Sigs),
    automaton(Sigs, _, Sigs,
        [source(s), sink(i), sink(j), sink(s)],
        [arc(s,0,s), arc(s,1,j), arc(s,2,i),
        arc(i,0,i), arc(i,1,j,[C+1]), arc(i,2,i),
        arc(j,0,j), arc(j,1,j),
        arc(j,2,i,[C+1]),
        [C], [0], [N]].

variables_signature([], []).
variables_signature([V|Vs], Sigs) :-
    variables_signature_(Vs, V, Sigs).

variables_signature_([], _, []).
variables_signature_([V|Vs], Prev, [S|Sigs]) :-
    V #= Prev #<==> S #= 0,
    Prev #< V #<==> S #= 1,
    Prev #> V #<==> S #= 2,
    variables_signature_(Vs, V, Sigs).
```

Example queries:

```prolog
?- sequence_inflexions([1,2,3,3,2,1,3,0], N).
N = 3.
?- length(Ls, 5), Ls ins 0..1,
    sequence_inflexions(Ls, 3), label(Ls).
Ls = [0, 1, 0, 1, 0] ;
Ls = [1, 0, 1, 0, 1].
```

chain(+Zs, +Relation)

Zs form a chain with respect to Relation. Zs is a list of finite domain variables that are a chain with respect to the partial order Relation, in the order they appear in the list. Relation must be #=, #=<, #>=, #< or #>. For example:

```prolog
?- chain([X,Y,Z], #>=).
X#>=Y,
Y#>=Z.
```
Reification predicates

Many CLP(FD) constraints can be reified. This means that their truth value is itself turned into a CLP(FD) variable, so that we can explicitly reason about whether a constraint holds or not. See reification (section A.9.12).

\#\ + Q

Q does not hold. See reification (section A.9.12).

For example, to obtain the complement of a domain:

?- \#\ X in -3..0\10..80.
   X in inf.. -4\1..9\81..sup.

?P #<==> ?Q

P and Q are equivalent. See reification (section A.9.12).

For example:

?- X #= 4 #<==> B, X #\= 4.
   B = 0,
   X in inf..3\5..sup.

The following example uses reified constraints to relate a list of finite domain variables to the number of occurrences of a given value:

vs_n_num(Vs, N, Num) :-
   maplist(eq_b(N), Vs, Bs),
   sum(Bs, #=, Num).

eq_b(X, Y, B) :- X #= Y #<==> B.

Sample queries and their results:

?- Vs = [X,Y,Z], Vs ins 0..1, vs_n_num(Vs, 4, Num).
   Vs = [X, Y, Z],
   Num = 0,
   X in 0..1,
   Y in 0..1,
   Z in 0..1.

?- vs_n_num([X,Y,Z], 2, 3).
   X = 2,
   Y = 2,
   Z = 2.
\( P \implies Q \) implies \( P \). See reification (section A.9.12).

\( P \lor Q \) holds. See reification (section A.9.12).

\( P \lor Q \) holds. See reification (section A.9.12).

For example, the sum of natural numbers below 1000 that are multiples of 3 or 5:

\begin{verbatim}
?- findall(N, (N mod 3 \#= 0 \lor N mod 5 \#= 0, N in 0..999,
              indomain(N)),
       Ns),
  sum(Ns, \#=, Sum).
Ns = [0, 3, 5, 6, 9, 10, 12, 15, 18|...],
Sum = 233168.
\end{verbatim}

\( P \lor Q \) Either \( P \) holds or \( Q \) holds, but not both. See reification (section A.9.12).

\texttt{zcompare(Order, A, B)} Analogous to \texttt{compare/3}, with finite domain variables \( A \) and \( B \).

Think of \texttt{zcompare/3} as reifying an arithmetic comparison of two integers. This means that we can explicitly reason about the different cases within our programs. As in \texttt{compare/3}, the atoms \(<, >\) and \( =\) denote the different cases of the trichotomy. In contrast to \texttt{compare/3} though, \texttt{zcompare/3} works correctly for all modes, also if only a subset of the arguments is instantiated. This allows you to make several predicates over integers deterministic while preserving their generality and completeness. For example:

\begin{verbatim}
n_factorial(N, F) :-
    zcompare(C, N, 0),
    n_factorial_(C, N, F).

n_factorial_(\#, _, 1).
n_factorial_(>, N, F) :-
    F \#= F0*N,
    N1 \#= N - 1,
    n_factorial(N1, F0).
\end{verbatim}

This version of \texttt{n_factorial/2} is deterministic if the first argument is instantiated, because argument indexing can distinguish the different clauses that reflect the possible and admissible outcomes of a comparison of \( N \) against 0. Example:

\begin{verbatim}
?- n_factorial(30, F).
F = 265252859812191058636308480000000.
\end{verbatim}
Since there is no clause for $<$, the predicate automatically fails if $N$ is less than 0. The predicate can still be used in all directions, including the most general query:

```
?- n_factorial(N, F).
N = 0,  
F = 1 ; 
N = F, F = 1 ; 
N = F, F = 2 .
```

In this case, all clauses are tried on backtracking, and \texttt{zcompare/3} ensures that the respective ordering between $N$ and 0 holds in each case.

The truth value of a comparison can also be reified with \((\#<\#)/2\) in combination with one of the \textit{arithmetic constraints} (section A.9.2). See reification (section A.9.12). However, \texttt{zcompare/3} lets you more conveniently distinguish the cases.

**Reflection predicates**

Reflection predicates let us obtain, in a well-defined way, information that is normally internal to this library. In addition to the predicates explained below, also take a look at \texttt{call_residue_vars/2} and \texttt{copy_term/3} to reason about CLP(FD) constraints that arise in programs. This can be useful in program analyzers and declarative debuggers.

\textbf{fd\_var}(+\texttt{Var})

True iff \texttt{Var} is a CLP(FD) variable.

\textbf{fd\_inf}(+\texttt{Var}, -\texttt{Inf})

\texttt{Inf} is the infimum of the current domain of \texttt{Var}.

\textbf{fd\_sup}(+\texttt{Var}, -\texttt{Sup})

\texttt{Sup} is the supremum of the current domain of \texttt{Var}.

\textbf{fd\_size}(+\texttt{Var}, -\texttt{Size})

Reflect the current size of a domain. \texttt{Size} is the number of elements of the current domain of \texttt{Var}, or the atom \texttt{sup} if the domain is unbounded.

\textbf{fd\_dom}(+\texttt{Var}, -\texttt{Dom})

\texttt{Dom} is the current domain (see \texttt{in/2}) of \texttt{Var}. This predicate is useful if you want to reason about domains. It is \textit{not} needed if you only want to display remaining domains; instead, separate your model from the search part and let the toplevel display this information via residual goals.

For example, to implement a custom labeling strategy, you may need to inspect the current domain of a finite domain variable. With the following code, you can convert a \textit{finite} domain to a list of integers:

```
dom_integers(D, Is) :- phrase(dom_integers_(D), Is).
dom_integers_(I) --> { integer(I) }, [I].
```
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\[ \text{dom_integers\_}(L..U) \rightarrow \{ \text{numlist}(L, U, \text{Is}) \}, \text{Is}. \]
\[ \text{dom_integers\_}(D1\ldv D2) \rightarrow \text{dom_integers\_}(D1), \text{dom_integers\_}(D2). \]

Example:

\begin{verbatim}
?- X in 1..5, X #\= 4, fd_dom(X, D), dom_integers(D, Is).
D = 1..3\ldv 5,
Is = [1,2,3,5],
X in 1..3\ldv 5.
\end{verbatim}

\text{fd\_degree}(\text{+Var}, -\text{Degree}) \hspace{1cm} \text{[det]}

\text{Degree} is the number of constraints currently attached to \text{Var}.

FD set predicates

These predicates allow operating directly on the internal representation of CLP(FD) domains. In this context, such an internal domain representation is called an \text{FD set}.

Note that the exact term representation of FD sets is unspecified and will vary across CLP(FD) implementations or even different versions of the same implementation. FD set terms should be manipulated \textbf{only} using the predicates in this section. The behavior of other operations on FD set terms is undefined. In particular, you should \textbf{not} construct or deconstruct FD sets by unification, and you \textbf{cannot} reliably compare FD sets using unification or generic term equality/comparison predicates.

\text{?Var in set\_} \hspace{1cm} \text{+Set}

\text{Var} is an element of the FD set \text{Set}.

\text{fd\_set}(\text{?Var}, -\text{Set}) \hspace{1cm} \text{[det]}

\text{Set} is the FD set representation of the current domain of \text{Var}.

\text{is\_fdset}(\text{@Set}) \hspace{1cm} \text{[semidet]}

\text{Set} is currently bound to a valid FD set.

\text{empty\_fdset\_} \hspace{1cm} \text{-Set} \hspace{1cm} \text{[det]}

\text{Set} is the empty FD set.

\text{fdset\_parts}(\text{?Set}, \text{?Min}, \text{?Max}, \text{?Rest}) \hspace{1cm} \text{[semidet]}

\text{Set} is a non-empty FD set representing the domain \text{Min..Max} \ldv \text{Rest}, where \text{Min..Max} is a non-empty interval (see \text{fdset\_interval/3}) and \text{Rest} is another FD set (possibly empty).

If \text{Max} is \text{sup}, then \text{Rest} is the empty FD set. Otherwise, if \text{Rest} is non-empty, all elements of \text{Rest} are greater than \text{Max}+1.

This predicate should only be called with either \text{Set} or all other arguments being ground.

\text{empty\_interval}\hspace{1cm} \text{+Min, +Max} \hspace{1cm} \text{[semidet]}

\text{Min..Max} is an empty interval. \text{Min} and \text{Max} are integers or one of the atoms \text{inf} or \text{sup}.

\text{fdset\_interval}(\text{?Interval}, \text{?Min}, \text{?Max}) \hspace{1cm} \text{[semidet]}

\text{Interval} is a non-empty FD set consisting of the single interval \text{Min..Max}. \text{Min} is an integer or
the atom \texttt{inf} to denote negative infinity. \texttt{Max} is an integer or the atom \texttt{sup} to denote positive infinity.

Either \textit{Interval} or \textit{Min} and \textit{Max} must be ground.

\begin{verbatim}
fdset\_singleton(?Set, ?Elt) [semidet]
Set is the FD set containing the single integer Elt.
Either Set or Elt must be ground.

fdset\_min(+Set, -Min) [semidet]
Min is the lower bound (infimum) of the non-empty FD set \textit{Set}. Min is an integer or the atom \texttt{inf} if \textit{Set} has no lower bound.

fdset\_max(+Set, -Max) [semidet]
Max is the upper bound (supremum) of the non-empty FD set \textit{Set}. Max is an integer or the atom \texttt{sup} if \textit{Set} has no upper bound.

fdset\_size(+Set, -Size) [det]
Size is the number of elements of the FD set \textit{Set}, or the atom \texttt{sup} if \textit{Set} is infinite.

list\_to\_fdset(+List, -Set) [det]
\textit{Set} is an FD set containing all elements of \textit{List}, which must be a list of integers.

fdset\_to\_list(+Set, -List) [det]
\textit{List} is a list containing all elements of the finite FD set \textit{Set}, in ascending order.

range\_to\_fdset(+Domain, -Set) [det]
\textit{Set} is an FD set equivalent to the domain \textit{Domain}. \textit{Domain} uses the same syntax as accepted by \texttt{(in)/2}.

fdset\_to\_range(+Set, -Domain) [det]
\textit{Domain} is a domain equivalent to the FD set \textit{Set}. \textit{Domain} is returned in the same format as by \texttt{fd\_dom/2}.

fdset\_add\_element(+Set1, +Elt, -Set2) [det]
\textit{Set}2 is the same FD set as \textit{Set1}, but with the integer \textit{Elt} added. If \textit{Elt} is already in \textit{Set1}, the set is returned unchanged.

fdset\_del\_element(+Set1, +Elt, -Set2) [det]
\textit{Set}2 is the same FD set as \textit{Set1}, but with the integer \textit{Elt} removed. If \textit{Elt} is not in \textit{Set1}, the set returned unchanged.

fdset\_disjoint(+Set1, +Set2) [semidet]
The FD sets \textit{Set1} and \textit{Set2} have no elements in common.

fdset\_intersect(+Set1, +Set2) [semidet]
The FD sets \textit{Set1} and \textit{Set2} have at least one element in common.

fdset\_intersection(+Set1, +Set2, -Intersection) [det]
\textit{Intersection} is an FD set (possibly empty) of all elements that the FD sets \textit{Set1} and \textit{Set2} have in common.
\end{verbatim}
fdset_member(?Elt, +Set)  [nondet]
The integer Elt is a member of the FD set Set. If Elt is unbound, Set must be finite and all elements are enumerated on backtracking.

fdset_eq(+Set1, +Set2)  [semidet]
True if the FD sets Set1 and Set2 are equal, i.e. contain exactly the same elements. This is not necessarily the same as unification or a term equality check, because some FD sets have multiple possible term representations.

fdset_subset(+Set1, +Set2)  [semidet]
The FD set Set1 is a (non-strict) subset of Set2, i.e. every element of Set1 is also in Set2.

fdset_subtract(+Set1, +Set2, -Difference)  [det]
The FD set Difference is Set1 with all elements of Set2 removed, i.e. the set difference of Set1 and Set2.

fdset_union(+Set1, +Set2, -Union)  [det]
The FD set Union is the union of FD sets Set1 and Set2.

fdset_union(+Sets, -Union)  [det]
The FD set Union is the n-ary union of all FD sets in the list Sets. If Sets is empty, Union is the empty FD set.

fdset_complement(+Set, -Complement)  [det]
The FD set Complement is the complement of the FD set Set. Equivalent to fdset_subtract(inf..sup, Set, Complement).

FD miscellaneous predicates

The predicates in this section are not clp(fd) predicates. They ended up in this library for historical reasons and may be moved to other libraries in the future.

transpose(+Matrix, ?Transpose)  
Transpose a list of lists of the same length. Example:

?- transpose([[1,2,3],[4,5,6],[7,8,9]], Ts).
Ts = [[1, 4, 7], [2, 5, 8], [3, 6, 9]].

This predicate is useful in many constraint programs. Consider for instance Sudoku:

sudoku(Rows) :-
    length(Rows, 9), maplist(same_length(Rows), Rows),
    append(Rows, Vs), Vs ins 1..9,
    maplist(all_distinct, Rows),
    transpose(Rows, Columns),
    maplist(all_distinct, Columns),
    Rows = [As,Bs, Cs, Ds, Es, Fs, Gs, Hs, Is],
    blocks(As, Bs, Cs), blocks(Ds, Es, Fs), blocks(Gs, Hs, Is).
blocks([], [], []).  
blocks([N1,N2,N3|Ns1], [N4,N5,N6|Ns2], [N7,N8,N9|Ns3]) :-  
    all_distinct([N1,N2,N3,N4,N5,N6,N7,N8,N9]),  
    blocks(Ns1, Ns2, Ns3).

problem(1, [[_,_,_,_,_,_,_,_,_],  
             [_,_,_,_,_,3,_,8,5],  
             [_,_,1,_,2,_,_,_,_],  
             [_,_,_,5,_,7,_,_,_],  
             [_,_,4,_,_,1,_,_,_],  
             [_,9,_,_,_,_,_,_,_],  
             [5,_,_,_,_,_,7,3],  
             [_,_,2,_,1,_,_,_,_],  
             [_,_,_,4,_,_,_,9]]).

Sample query:

?- problem(1, Rows), sudoku(Rows), maplist(portray_clause, Rows).  
[9, 8, 7, 6, 5, 4, 3, 2, 1].  
[2, 4, 6, 1, 7, 3, 9, 8, 5].  
[3, 5, 1, 9, 2, 8, 7, 4, 6].  
[1, 2, 8, 5, 3, 7, 6, 9, 4].  
[6, 3, 4, 8, 9, 2, 1, 5, 7].  
[7, 9, 5, 4, 6, 1, 8, 3, 2].  
[5, 1, 9, 2, 8, 6, 4, 7, 3].  
[4, 7, 2, 3, 1, 9, 5, 6, 8].  
[8, 6, 3, 7, 4, 5, 2, 1, 9].  
Rows = [[9, 8, 7, 6, 5, 4, 3, 2|...], ... , [...|...]].

A.9.18 Closing and opening words about CLP(FD)

CLP(FD) constraints are one of the main reasons why logic programming approaches are picked over other paradigms for solving many tasks of high practical relevance. The usefulness of CLP(FD) constraints for scheduling, allocation and combinatorial optimization tasks is well-known both in academia and industry.

With this library, we take the applicability of CLP(FD) constraints one step further, following the road that visionary systems like SICStus Prolog have already clearly outlined: This library is designed to completely subsume and replace low-level predicates over integers, which were in the past repeatedly found to be a major stumbling block when introducing logic programming to beginners.

Embrace the change and new opportunities that this paradigm allows! Use CLP(FD) constraints in your programs. The use of CLP(FD) constraints instead of low-level arithmetic is also a good indicator to judge the quality of any introductory Prolog text.
A.10 library(clpqr): Constraint Logic Programming over Rationals and Reals

Author: Christian Holzbaur, ported to SWI-Prolog by Leslie De Koninck, K.U. Leuven

This CLP(Q,R) system is a port of the CLP(Q,R) system of Sicstus Prolog by Christian Holzbaur: Holzbaur C.: OFAI clp(q,r) Manual, Edition 1.3.3, Austrian Research Institute for Artificial Intelligence, Vienna, TR-95-09, 1995. This manual is roughly based on the manual of the above mentioned CLP(Q,R) implementation.

The CLP(Q,R) system consists of two components: the CLP(Q) library for handling constraints over the rational numbers and the CLP(R) library for handling constraints over the real numbers (using floating point numbers as representation). Both libraries offer the same predicates (with exception of \texttt{bb_inf/4} in CLP(Q) and \texttt{bb_inf/5} in CLP(R)). It is allowed to use both libraries in one program, but using both CLP(Q) and CLP(R) constraints on the same variable will result in an exception.

Please note that the \texttt{clpqr} library is not an \texttt{autoload} library and therefore this library must be loaded explicitly before using it:

\begin{verbatim}
:- use_module(library(clpq)).
\end{verbatim}

or

\begin{verbatim}
:- use_module(library(clpr)).
\end{verbatim}

A.10.1 Solver predicates

The following predicates are provided to work with constraints:

\begin{verbatim}
\{\}(+\textit{Constraints})
\end{verbatim}

Adds the constraints given by \textit{Constraints} to the constraint store.

\begin{verbatim}
entailed(+\textit{Constraint})
\end{verbatim}

Succeeds if \textit{Constraint} is necessarily true within the current constraint store. This means that adding the negation of the constraint to the store results in failure.

\begin{verbatim}
\texttt{inf(+Expression, -Inf)}
\end{verbatim}

Computes the infimum of \textit{Expression} within the current state of the constraint store and returns that infimum in \textit{Inf}. This predicate does not change the constraint store.

\begin{verbatim}
\texttt{sup(+Expression, -Sup)}
\end{verbatim}

Computes the supremum of \textit{Expression} within the current state of the constraint store and returns that supremum in \textit{Sup}. This predicate does not change the constraint store.

\begin{verbatim}
\texttt{minimize(+Expression)}
\end{verbatim}

Minimizes \textit{Expression} within the current constraint store. This is the same as computing the infimum and equating the expression to that infimum.

\footnote{\url{http://www.ai.univie.ac.at/cgi-bin/tr-online?number+95-09}}
### A.10. LIBRARY(CLPQR): CONSTRAINT LOGIC PROGRAMMING OVER RATIONALS AND REALS

**maximize(+Expression)**

Maximizes *Expression* within the current constraint store. This is the same as computing the supremum and equating the expression to that supremum.

**bb_inf(+Ints, +Expression, -Inf, -Vertex, +Eps)**

This predicate is offered in CLP(R) only. It computes the infimum of *Expression* within the current constraint store, with the additional constraint that in that infimum, all variables in *Ints* have integral values. *Vertex* will contain the values of *Ints* in the infimum. *Eps* denotes how much a value may differ from an integer to be considered an integer. E.g. when *Eps* = 0.001, then X = 4.999 will be considered as an integer (5 in this case). *Eps* should be between 0 and 0.5.

**bb_inf(+Ints, +Expression, -Inf, -Vertex)**

This predicate is offered in CLP(Q) only. It behaves the same as `bb_inf/5` but does not use an error margin.

**bb_inf(+Ints, +Expression, -Inf)**

The same as `bb_inf/5` or `bb_inf/4` but without returning the values of the integers. In CLP(R), an error margin of 0.001 is used.

**dump(+Target, +Newvars, -CodedAnswer)**

Returns the constraints on *Target* in the list *CodedAnswer* where all variables of *Target* have been replaced by *NewVars*. This operation does not change the constraint store. E.g. in

```prolog
dump([X,Y,Z],[x,y,z],Cons)
```

*Cons* will contain the constraints on X, Y and Z, where these variables have been replaced by atoms x, y and z.

### A.10.2 Syntax of the predicate arguments

The arguments of the predicates defined in the subsection above are defined in table A.1. Failing to meet the syntax rules will result in an exception.

### A.10.3 Use of unification

Instead of using the `{}/1` predicate, you can also use the standard unification mechanism to store constraints. The following code samples are equivalent:

- **Unification with a variable**
  ```prolog
  {X = Y}
  X = Y
  ```

- **Unification with a number**
  ```prolog
  {X = 5.0}
  X = 5.0
  ```
### CLP(Q,R) constraint BNF

| (Constraints) ::= | (Constraint) | single constraint |
| | (Constraint) , (Constraints) | conjunction |
| | (Constraint) ; (Constraints) | disjunction |
| (Constraint) ::= | (Expression) < (Expression) | less than |
| | (Expression) > (Expression) | greater than |
| | (Expression) =< (Expression) | less or equal |
| | <=((Expression), (Expression)) | less or equal |
| | (Expression) >= (Expression) | greater or equal |
| | (Expression) =\= (Expression) | not equal |
| | (Expression) == (Expression) | equal |
| | (Expression) = (Expression) | equal |

| (Expression) ::= | (Variable) | Prolog variable |
| | (Number) | Prolog number |
| | + (Expression) | unary plus |
| | - (Expression) | unary minus |
| | (Expression) + (Expression) | addition |
| | (Expression) - (Expression) | substraction |
| | (Expression) * (Expression) | multiplication |
| | (Expression) / (Expression) | division |
| | abs( (Expression) ) | absolute value |
| | sin( (Expression) ) | sine |
| | cos( (Expression) ) | cosine |
| | tan( (Expression) ) | tangent |
| | exp( (Expression) ) | exponent |
| | pow( (Expression) ) | exponent |
| | (Expression) ^ (Expression) | exponent |
| | min( (Expression), (Expression) ) | minimum |
| | max( (Expression), (Expression) ) | maximum |

Table A.1: CLP(Q,R) constraint BNF
### A.10.4 Non-linear constraints

The CLP(Q,R) system deals only passively with non-linear constraints. They remain in a passive state until certain conditions are satisfied. These conditions, which are called the isolation axioms, are given in table A.2.

### A.10.5 Status and known problems

The clpq and clpr libraries are ‘orphaned’, i.e., they currently have no maintainer.

- **Top-level output**
  
The top-level output may contain variables not present in the original query:

   ```prolog
   ?- {X+Y>=1}.
   {Y=1-X+_G2160, _G2160>=0}.
   ?-
   ```

   Nonetheless, for linear constraints this kind of answer means unconditional satisfiability.

- **Dumping constraints**
  
The first argument of `dump/3` has to be a list of free variables at call-time:

   ```prolog
   ?- {X=1},dump([X],[Y],L).
   ERROR:Unhandled exception: Unknown message: instantiation_error(dump([1],[_G11],_G6),1)
   ?-
   ```
A.11 library(csv): Process CSV (Comma-Separated Values) data

See also RFC 4180

To be done
- Implement immediate assert of the data to avoid possible stack overflows.
- Writing creates an intermediate code-list, possibly overflowing resources. This waits for pure output!

This library parses and generates CSV data. CSV data is represented in Prolog as a list of rows. Each row is a compound term, where all rows have the same name and arity.

csv_read_file(+File, -Rows)  [det]
csv_read_file(+File, -Rows, +Options)  [det]

Read a CSV file into a list of rows. Each row is a Prolog term with the same arity. Options is handed to csv//2. Remaining options are processed by phrase_from_file/3. The default separator depends on the file name extension and is \t for .tsv files and , otherwise.

Suppose we want to create a predicate table/6 from a CSV file that we know contains 6 fields per record. This can be done using the code below. Without the option arity(6), this would generate a predicate table/N, where N is the number of fields per record in the data.

```prolog
?- csv_read_file(File, Rows, [functor(table), arity(6)]),
   maplist(assert, Rows).
```

csv_read_stream(+Stream, -Rows, +Options)  [det]

Read CSV data from Stream. See also csv_read_row/3.

csv(?Rows) //  [det]
csv(?Rows, +Options) //  [det]

Prolog DCG to ‘read/write’ CSV data. Options:

separator(+Code)
The comma-separator. Must be a character code. Default is (of course) the comma. Character codes can be specified using the 0' notion. E.g., using separator(0';) parses a semicolon separated file.

ignore_quotes(+Boolean)
If true (default false), threat double quotes as a normal character.

strip(+Boolean)
If true (default false), strip leading and trailing blank space. RFC4180 says that blank space is part of the data.

skip_header(+CommentLead)
Skip leading lines that start with CommentLead. There is no standard for comments in CSV files, but some CSV files have a header where each line starts with #. After skipping comment lines this option causes csv//2 to skip empty lines. Note that an empty line may not contain white space characters (space or tab) as these may provide valid data.

convert(+Boolean)
If true (default), use name/2 on the field data. This translates the field into a number if possible.
A.11. LIBRARY(CSV): PROCESS CSV (COMMA-SEPARATED VALUES) DATA 589

case(+Action)
   If down, downcase atomic values. If up, upcase them and if preserve (default), do not change the case.

functor(+Atom)
   Functor to use for creating row terms. Default is row.

arity(?Arity)
   Number of fields in each row. This predicate raises a domain_error(row arity(Expected), Found) if a row is found with different arity.

match arity(+Boolean)
   If false (default true), do not reject CSV files where lines provide a varying number of fields (columns). This can be a work-around to use some incorrect CSV files.

csv_read_file_row(+File, -Row, +Options)  [nondet]
   True when Row is a row in File. First unifies Row with the first row in File. Backtracking yields the second, ... row. This interface is an alternative to csv_read_file/3 that avoids loading all rows in memory. Note that this interface does not guarantee that all rows in File have the same arity.

   In addition to the options of csv_read_file/3, this predicate processes the option:

line(-Line)
   Line is unified with the 1-based line-number from which Row is read. Note that Line is not the physical line, but rather the logical record number.

csv_read_row(+Stream, -Row, +CompiledOptions)  [det]
   Read the next CSV record from Stream and unify the result with Row. CompiledOptions is created from options defined for csv//2 using csv_options/2. Row is unified with end_of_file upon reaching the end of the input.

csv_options(-Compiled, +Options)  [det]
   Compiled is the compiled representation of the CSV processing options as they may be passed into csv//2, etc. This predicate is used in combination with csv_read_row/3 to avoid repeated processing of the options.

csv_write_file(+File, +Data)  [det]
csv_write_file(+File, +Data, +Options)  [det]
   Write a list of Prolog terms to a CSV file. Options are given to csv//2. Remaining options are given to open/4. The default separator depends on the file name extension and is \t for .tsv files and , otherwise.

csv_write_stream(+Stream, +Data, +Options)  [det]
   Write the rows in Data to Stream. This is similar to csv_write_file/3, but can deal with data that is produced incrementally. The example below saves all answers from the predicate data/3 to File.

save_data(File) :-
   setup_call_cleanup(

open(File, write, Out),
forall(data(C1,C2,C3),
  csv_write_stream(Out, [row(C1,C2,C3)], [])),
close(Out)).

A.12 library(dcg/basics): Various general DCG utilities

To be done  This is just a starting point. We need a comprehensive set of generally useful DCG primitives.

This library provides various commonly used DCG primitives acting on list of character codes. Character classification is based on code_type/2.

This module started its life as library(http/dcg_basics) to support the HTTP protocol. Since then, it was increasingly used in code that has no relation to HTTP and therefore this library was moved to the core library.

string_without(+EndCodes, -Codes) // [det]
Take as many codes from the input until the next character code appears in the list EndCodes. The terminating code itself is left on the input. Typical use is to read up to a defined delimiter such as a newline or other reserved character. For example:

```prolog
  ..., string_without("\n", RestOfLine)
```

Arguments

EndCodes is a list of character codes.

See also string//1.

string(-Codes) // [nondet]
Take as few as possible tokens from the input, taking one more each time on backtracking. This code is normally followed by a test for a delimiter. For example:

```prolog
  upto_colon(Atom) -->
    string(Codes), ":", !,
    { atom_codes(Atom, Codes) }.
```

See also string_without//2.

blanks // [det]
Skip zero or more white-space characters.

blank // [semidet]
Take next space character from input. Space characters include newline.

See also white//0
nonblanks(-Codes) //
   Take all graph characters

nonblank(-Code) //
   Code is the next non-blank (graph) character.

blanks_to_nl //
   Take a sequence of blank//0 codes if blanks are followed by a newline or end of the input.

whites //
   Skip white space inside a line.

   See also blanks//0 also skips newlines.

white //
   Take next white character from input. White characters do not include newline.

alpha_to_lower(?C) //
   Read a letter (class alpha) and return it as a lowercase letter. If C is instantiated and the DCG list is already bound, C must be lower and matches both a lower and uppercase letter. If the output list is unbound, its first element is bound to C. For example:

   ?- alpha_to_lower(0'a, 'AB', R).
      R = [66].
   ?- alpha_to_lower(C, 'AB', R).
      C = 97, R = [66].
   ?- alpha_to_lower(0'a, L, R).
      L = [97|R].

digits(?Chars) //
digit(?Char) //
integer(?Integer) //
   Number processing. The predicate digits//1 matches a possibly empty set of digits, digit//1 processes a single digit and integer processes an optional sign followed by a non-empty sequence of digits into an integer.

float(?Float) //
   Process a floating point number. The actual conversion is controlled by number_codes/2.

number(+Number) //
number(-Number) //
   Generate extract a number. Handles both integers and floating point numbers.

xinteger(+Integer) //
   Generate or extract an integer from a sequence of hexadecimal digits. Hexadecimal characters include both uppercase (A-F) and lowercase (a-f) letters. The value may be preceded by a sign (+/-)
**APPENDIX A. THE SWI-PROLOG LIBRARY**

**xdigit(-Weight) [semidet]**  
True if the next code is a hexadecimal digit with Weight. Weight is between 0 and 15. Hexadecimal characters include both uppercase (A-F) and lowercase (a-f) letters.

**xdigits(-WeightList) [det]**  
List of weights of a sequence of hexadecimal codes. WeightList may be empty. Hexadecimal characters include both uppercase (A-F) and lowercase (a-f) letters.

**eol**  
Matches end-of-line. Matching \r\n, \n or end of input (eos//0).

**eos**  
Matches end-of-input. The implementation behaves as the following portable implementation:

```
eos --> call(eos_).
eos_([], []).  
```

**To be done**  
This is a difficult concept and violates the context free property of DCGs. Explain the exact problems.

**remainder(-List) [semidet]**  
Unify List with the remainder of the input.

**prolog_var_name(-Name:atom) [semidet]**  
Matches a Prolog variable name. Primarily intended to deal with quasi quotations that embed Prolog variables.

**atom(+-Atom) [det]**  
Generate codes of Atom. Current implementation uses write/1, dealing with any Prolog term. Atom must be ground though.

**A.13 library(dcg/high_order): High order grammar operations**

This library provides facilities comparable maplist/3, ignore/1 and foreach/2 for DCGs.  
**STATUS:** This library is experimental. The interface and implementation may change based on feedback. Please send feedback to the mailinglist or the issue page of the swipl-devel.git repository.

**sequence(-Element, ?List) [nondet]**  
Match or generate a sequence of Element. This predicate is deterministic if List is fully instantiated and Element is deterministic. When parsing, this predicate is gready and does not prune choice points. For example:

```
?- phrase(sequence(digit, Digits), '123a', L).
Digits = "123",
L = [97] ;
Digits = [49, 50],
```

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sequence(\:Element, \:Sep, ?List) //

Match or generate a sequence of \( \text{Element} \) where each pair of elements is separated by \( \text{Sep} \). When parsing, a matched \( \text{Sep} \) commits. The final element is not committed. More formally, it matches the following sequence:

\[(\text{Element})? \cdot (\text{Sep}, \text{Element})^*\]

See also \text{sequence}//5.

sequence(\:Start, \:Element, \:Sep, \:End, ?List) //

Match or generate a sequence of \( \text{Element} \) enclosed by \( \text{Start} \) and \( \text{End} \), where each pair of elements is separated by \( \text{Sep} \). More formally, it matches the following sequence:

\[(\text{Start}), (\text{Element})?, (\text{Sep}, \text{Element})^*, (\text{End})\]

The example below matches a Prolog list of integers:

\[- \text{phrase}\{(\text{sequence}(\text{"\[\", \text{blanks}},)\),\n    \text{number}, (\text{"\", \text{blanks}},)\),\n    (\text{blanks,"\"]}), L),\n    \text{\text{"[1, 2, 3 \] a\"}}, \text{Tail}\).\n\]
\[L = [1, 2, 3],\nTail = [32, 97].\]

optional(\:Match, \:Default) //

Perform an optional match, executing \( \text{Default} \) if \( \text{Match} \) is not matched. This is comparable to ignore/1. Both \( \text{Match} \) and \( \text{Default} \) are DCG body terms. \( \text{Default} \) is typically used to instantiate the output variables of \( \text{Match} \), but may also be used to match a default representation. Using \( [] \) for \( \text{Default} \) succeeds without any additional actions if \( \text{Match} \) fails. For example:

\[- \text{phrase}\{(\text{optional}(\text{number}(X), \{X=0\}), \text{\text{"23\"}}, \text{Tail}).\n\]
\[X = 23,\nTail = [].\n\[- \text{phrase}\{(\text{optional}(\text{number}(X), \{X=0\}), \text{\text{"aap\"}}, \text{Tail}).\n\]
\[X = 0,\nTail = \text{\text{"aap\"}}.\n\]

foreach(\:Generator, \:Element) //
foreach(\:Generator, \:Element, \:Sep) //

Generate a list from the solutions of \( \text{Generator} \). This predicate collects all solutions of \( \text{Generator} \), applies \( \text{Element} \) for each solution and \( \text{Sep} \) between each pair of solutions. For example:
?- phrase(foreach(between(1,5,X), number(X), ", "), L).
L = "1, 2, 3, 4, 5".

A.14 library(debug): Print debug messages and test assertions

author Jan Wielemaker

This library is a replacement for format/3 for printing debug messages. Messages are assigned a topic. By dynamically enabling or disabling topics the user can select desired messages. Debug statements are removed when the code is compiled for optimization.

See manual for details. With XPCE, you can use the call below to start a graphical monitoring tool.

?- prolog_ide(debug_monitor).

Using the predicate assertion/1 you can make assumptions about your program explicit, trapping the debugger if the condition does not hold.

debugging(+Topic) [semidet]
debugging(-Topic) [nondet]
debugging(?Topic, ?Bool) [nondet]

Examine debug topics. The form debugging(+Topic) may be used to perform more complex debugging tasks. A typical usage skeleton is:

( debugging(mytopic)
  -> <perform debugging actions>
  ;  true
),
...

The other two calls are intended to examine existing and enabled debugging tokens and are typically not used in user programs.

debug(+Topic) [det]
nodebug(+Topic) [det]

Add/remove a topic from being printed. nodebug(_) removes all topics. Gives a warning if the topic is not defined unless it is used from a directive. The latter allows placing debug topics at the start of a (load-)file without warnings.

For debug/1, Topic can be a term Topic > Out, where Out is either a stream or stream-alias or a filename (atom). This redirects debug information on this topic to the given output.

list_debug_topics [det]
List currently known debug topics and their setting.
A.15. LIBRARY(DICTS): DICT UTILITIES

debug_message_context(+What)  [det]
   Specify additional context for debug messages.

   deprecated New code should use the Prolog flag message_context. This predicates adds or
   deletes topics from this list.

debug(+Topic, +Format, :Args)  [det]
   Format a message if debug topic is enabled. Similar to format/3 to user_error, but only
   prints if Topic is activated through debug/1. Args is a meta-argument to deal with goal for the
   @-command. Output is first handed to the hook prolog:debug_print_hook/3. If this fails, Format+Args is translated to text using the message-translation (see
   print_message/2) for the term debug(Format, Args) and then printed to ev-
   ry matching destination (controlled by debug/1) using print_message_lines/3.

   The message is preceded by ’% ’ and terminated with a newline.

   See also format/3.

prolog:debug_print_hook(+Topic, +Format, +Args)  [semidet,multifile]
   Hook called by debug/3. This hook is used by the graphical frontend that can be activated
   using prolog_ide/1:

   ?- prolog_ide(debug_monitor).

assertion(:Goal)  [det]
   Acts similar to C assert() macro. It has no effect if Goal succeeds. If Goal fails or throws
   an exception, the following steps are taken:

   • call prolog:assertion_failed/2. If prolog:assertion_failed/2 fails, then:
   – If this is an interactive toplevel thread, print a message, the stack-trace, and finally
     trap the debugger.
   – Otherwise, throw error(assertion_error(Reason, G),_)

prolog:assertion_failed(+Reason, +Goal)  [semidet,multifile]
   This hook is called if the Goal of assertion/1 fails. Reason is unified with either fail
   if Goal simply failed or an exception call otherwise. If this hook fails, the default behaviour
   is activated. If the hooks throws an exception it will be propagated into the caller of
   assertion/1.

A.15 library(dicts): Dict utilities

This library defines utilities that operate on lists of dicts, notably to make lists of dicts consistent by
adding missing keys, converting between lists of compounds and lists of dicts, joining and slicing lists
of dicts.
dicts_same_tag(+List, -Tag)  
    [semidet] 
    True when List is a list of dicts that all have the tag Tag.

dict_size(+Dict, -KeyCount)  
    [det] 
    True when KeyCount is the number of keys in Dict.

dict_keys(+Dict, -Keys)  
    [det] 
    True when Keys is an ordered set of the keys appearing in Dict.

dicts_same_keys(+List, -Keys)  
    [semidet] 
    True if List is a list of dicts that all have the same keys and Keys is an ordered set of these keys.

dicts_to_same_keys(+DictsIn, +OnEmpty, -DictsOut) 
    DictsOut is a copy of DictsIn, where each dict contains all keys appearing in all dicts of DictsIn. Values for keys that are added to a dict are produced by calling OnEmpty as below. The predicate dict_fill/4 provides an implementation that fills all new cells with a predefined value.

    call(:OnEmpty, +Key, +Dict, -Value)


dict_fill(+ValueIn, +Key, +Dict, -Value)  
    [det] 
    Implementation for the dicts_to_same_keys/3 OnEmpty closure that fills new cells with a copy of ValueIn. Note that copy_term/2 does not really copy ground terms. Below are two examples. Note that when filling empty cells with a variable, each empty cell is bound to a new variable.

    ?- dicts_to_same_keys([r{x:1}, r{y:2}], dict_fill(null), L).  
       L = [r{x:1, y:null}, r{x:null, y:2}].
    ?- dicts_to_same_keys([r{x:1}, r{y:2}], dict_fill(_), L).  
       L = [r{x:1, y:_G2005}, r{x:_G2036, y:2}].

    Use dict_no_fill/3 to raise an error if a dict is missing a key.

dicts_join(+Key, +DictsIn, -Dicts)  
    [semidet] 
    Join dicts in Dicts that have the same value for Key, provided they do not have conflicting values on other keys. For example:

    ?- dicts_join(x, [r{x:1, y:2}, r{x:1, z:3}, r{x:2,y:4}], L).  
       L = [r{x:1, y:2, z:3}, r{x:2, y:4}].

    Errors existence_error(key, Key, Dict) if a dict in Dicts1 or Dicts2 does not contain Key.

dicts_join(+Key, +Dicts1, +Dicts2, -Dicts)  
    [semidet] 
    Join two lists of dicts (Dicts1 and Dicts2) on Key. Each pair D1-D2 from Dicts1 and Dicts2 that have the same (==) value for Key creates a new dict D with the union of the keys from D1 and D2, provided D1 and D2 to not have conflicting values for some key. For example:
A.16. LIBRARY(ERROR): ERROR GENERATING SUPPORT

Errors existence_error(key, Key, Dict) if a dict in Dict1 or Dicts2 does not contain Key.

dicts_slice(+Keys, +DictsIn, -DictsOut) [det]
DictsOut is a list of Dicts only containing values for Keys.

dicts_to_compounds(?Dicts, +Keys, :OnEmpty, ?Compounds) [semidet]
True when Dicts and Compounds are lists of the same length and each element of Compounds is a compound term whose arguments represent the values associated with the corresponding keys in Keys. When converting from dict to row, OnEmpty is used to compute missing values. The functor for the compound is the same as the tag of the pair. When converting from dict to row and the dict has no tag, the functor row is used. For example:

?- Dicts = [{x:1}, {x:2, y:3}],
dicts_to_compounds(Dicts, [x], dict_fill(null), Compounds).
Compounds = [row(1), row(2)].
?- Dicts = [{x:1}, {x:2, y:3}],
dicts_to_compounds(Dicts, [x, y], dict_fill(null), Compounds).
Compounds = [row(1, null), row(2, 3)].
?- Compounds = [point(1,1), point(2,4)],
dicts_to_compounds(Dicts, [x, y], dict_fill(null), Compounds).
Dicts = [point(x:1, y:1), point(x:2, y:4)].

When converting from Dicts to Compounds Keys may be computed by dicts_same_keys/2.

A.16  library(error): Error generating support

author
- Jan Wielemaker
- Richard O’Keefe
- Ulrich Neumerkel

See also
- library(debug) and library(prolog_stack).
- print_message/2 is used to print (uncaught) error terms.

This module provides predicates to simplify error generation and checking. Its implementation is based on a discussion on the SWI-Prolog mailinglist on best practices in error handling. The utility predicate must_be/2 provides simple run-time type validation. The *_error predicates are simple wrappers around throw/1 to simplify throwing the most common ISO error terms.
**type_error(+ValidType, +Culprit)**
Tell the user that *Culprit* is not of the expected *ValidType*. This error is closely related to domain_error/2 because the notion of types is not really set in stone in Prolog. We introduce the difference using a simple example.

Suppose an argument must be a non-negative integer. If the actual argument is not an integer, this is a *type_error*. If it is a negative integer, it is a *domain_error*.

Typical borderline cases are predicates accepting a compound term, e.g., `point(X,Y)`. One could argue that the basic type is a compound-term and any other compound term is a domain error. Most Prolog programmers consider each compound as a type and would consider a compound that is not `point(_,_)` a *type_error*.

**domain_error(+ValidDomain, +Culprit)**
The argument is of the proper type, but has a value that is outside the supported values. See *type_error/2* for a more elaborate discussion of the distinction between type- and domain-errors.

**existence_error(+ObjectType, +Culprit)**
*Culprit* is of the correct type and correct domain, but there is no existing (external) resource of type *ObjectType* that is represented by it.

**existence_error(+ObjectType, +Culprit, +Set)**
*Culprit* is of the correct type and correct domain, but there is no existing (external) resource of type *ObjectType* that is represented by it in the provided set. The thrown exception term carries a formal term structured as follows:

```
existence_error(ObjectType, Culprit, Set)
```

**Compatibility** This error is outside the ISO Standard.

**permission_error(+Operation, +PermissionType, +Culprit)**
It is not allowed to perform *Operation* on (whatever is represented by) *Culprit* that is of the given *PermissionType* (in fact, the ISO Standard is confusing and vague about these terms’ meaning).

**instantiation_error(+FormalSubTerm)**
An argument is under-instantiated. I.e. it is not acceptable as it is, but if some variables are bound to appropriate values it would be acceptable.

**Arguments**

```
FormalSubTerm  is the term that needs (further) instantiation. Unfortunately, the
ISO error does not allow for passing this term along with the error,
but we pass it to this predicate for documentation purposes and to
allow for future enhancement.
```

**uninstantiation_error(+Culprit)**
An argument is over-instantiated. This error is used for output arguments whose value cannot be known upfront. For example, the goal `open(File, read, input)` cannot succeed because the system will allocate a new unique stream handle that will never unify with *input*.

**representation_error(+Flag)**
A representation error indicates a limitation of the implementation. SWI-Prolog has no such
limits that are not covered by other errors, but an example of a representation error in another Prolog implementation could be an attempt to create a term with an arity higher than supported by the system.

**syntax_error(+Culprit)**
A text has invalid syntax. The error is described by *Culprit*. According to the ISO Standard, *Culprit* should be an implementation-dependent atom.

To be done Deal with proper description of the location of the error. For short texts, we allow for Type(Text), meaning Text is not a valid Type. E.g. `syntax_error(number('1a'))` means that *1a* is not a valid number.

**resource_error(+Resource)**
A goal cannot be completed due to lack of resources. According to the ISO Standard, *Resource* should be an implementation-dependent atom.

**must_be(+Type, @Term) [det]**
True if *Term* satisfies the type constraints for *Type*. Defined types are atom, atomic, between, boolean, callable, chars, codes, text, compound, constant, float, integer, nonneg, positive_integer, negative_integer, nonvar, number, oneof, list, list_or_partial_list, symbol, var, rational, encoding, dict and string.

Most of these types are defined by an arity-1 built-in predicate of the same name. Below is a brief definition of the other types.
<table>
<thead>
<tr>
<th>Predicate</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>acyclic</td>
<td>Acyclic term (tree); see <code>acyclic_term/1</code></td>
</tr>
<tr>
<td>any</td>
<td>Any term</td>
</tr>
<tr>
<td>between(FloatL, FloatU)</td>
<td>Number [FloatL..FloatU]</td>
</tr>
<tr>
<td>between(IntL, IntU)</td>
<td>Integer [IntL..IntU]</td>
</tr>
<tr>
<td>boolean</td>
<td>One of <code>true</code> or <code>false</code></td>
</tr>
<tr>
<td>char</td>
<td>Atom of length 1</td>
</tr>
<tr>
<td>chars</td>
<td>Proper list of 1-character atoms</td>
</tr>
<tr>
<td>code</td>
<td>Representation Unicode code point</td>
</tr>
<tr>
<td>codes</td>
<td>Proper list of Unicode character codes</td>
</tr>
<tr>
<td>constant</td>
<td>Same as <code>atomic</code></td>
</tr>
<tr>
<td>cyclic</td>
<td>Cyclic term (rational tree); see <code>cyclic_term/1</code></td>
</tr>
<tr>
<td>dict</td>
<td>A dictionary term; see <code>is_dict/1</code></td>
</tr>
<tr>
<td>encoding</td>
<td>Valid name for a character encoding; see <code>current_encoding/1</code></td>
</tr>
<tr>
<td>list</td>
<td>A (non-open) list; see <code>is_list/1</code></td>
</tr>
<tr>
<td>negative_integer</td>
<td>Integer &lt; 0</td>
</tr>
<tr>
<td>nonneg</td>
<td>Integer &gt;= 0</td>
</tr>
<tr>
<td>oneof(L)</td>
<td>Ground term that is member of L</td>
</tr>
<tr>
<td>pair</td>
<td>Key-Value pair</td>
</tr>
<tr>
<td>positive_integer</td>
<td>Integer &gt; 0</td>
</tr>
<tr>
<td>proper_list</td>
<td>Same as <code>list</code></td>
</tr>
<tr>
<td>list(Type)</td>
<td>Proper list with elements of <code>Type</code></td>
</tr>
<tr>
<td>list_or_partial_list</td>
<td>A list or an open list (ending in a variable); see <code>is_list_or_partial_list/1</code></td>
</tr>
<tr>
<td>stream</td>
<td>A stream name or valid stream handle; see <code>is_stream/1</code></td>
</tr>
<tr>
<td>symbol</td>
<td>Same as <code>atom</code></td>
</tr>
<tr>
<td>text</td>
<td>One of <code>atom</code>, <code>string</code>, <code>chars</code> or <code>codes</code></td>
</tr>
<tr>
<td>type</td>
<td><code>Term</code> is a valid type specification</td>
</tr>
</tbody>
</table>

Note: The Windows version can only represent Unicode code points up to $2^{16}-1$. Higher values cause a representation error on most text handling predicates.

```
throws instantiation_error if `Term` is insufficiently instantiated and `type_error(Type, Term)` if `Term` is not of `Type`.
```

**is_of_type**(+Type, @Term) [semidet]

True if `Term` satisfies `Type`.

**has_type**(+Type, @Term) [semidet,multifile]

True if `Term` satisfies `Type`.

**current_encoding**(?Name) [nondet]

True if `Name` is the name of a supported encoding. See encoding option of e.g., `open/4`.

**current_type**(?Type, @Var, -Body) [nondet]

True when `Type` is a currently defined type and `Var` satisfies `Type` of the body term `Body` succeeds.
A.17 library(fastrw): Fast reading and writing of terms

Compatibility
The format is not compatible to SICStus/Ciao (which are not compatible either). Future versions of this library might implement a different encoding.

bug
The current implementation of fast_read/1 is not safe. It is guaranteed to safely read terms written using fast_write/1, but may crash on arbitrary input. The implementation does perform some basic sanity checks, including validation of the magic start byte.

To be done
Establish a portable binary format.

This library provides the SICStus and Ciao library(fastrw) interface. The idea behind this library is to design a fast serialization for Prolog terms. Ideally, this should be portable between Prolog implementation. Unfortunately there is no portably binary term format defined.

The current implementation is based on PL_record_external(), which provides a binary representation of terms that is processed efficiently and can handle subterm sharing, cycles and attributed variables. In other words, this library can handle any Prolog term except blobs such as stream handles, database references, etc. We try to keep the format compatible between versions, but this is not guaranteed. Conversion is always possible by reading a database using the old version, dump it using write_canonical/1 and read it into the new version.

This library is built upon the following built in predicates:

- fast_term_serialized/2 translates between a term and its serialization as a byte string.
- fast_read/2 and fast_write/2 read/write binary serializations.

fast_read(-Term)
The next term is read from current standard input and is unified with Term. The syntax of the term must agree with fast_read / fast_write format. If the end of the input has been reached, Term is unified with the term end_of_file.

fast_write(+Term)
Output Term in a way that fast_read/1 and fast_read/2 will be able to read it back.

fast_write_to_string(+Term, -String, ?Tail)
Perform a fast-write to the difference-slist String\ Tail.

A.18 library(gensym): Generate unique symbols

Gensym (Generate Symbols) is an old library for generating unique symbols (atoms). Such symbols are generated from a base atom which gets a sequence number appended. Of course there is no guarantee that catch22 is not an already defined atom and therefore one must be aware these atoms are only unique in an isolated context.

The SWI-Prolog gensym library is thread-safe. The sequence numbers are global over all threads and therefore generated atoms are unique over all threads.
gensym(+Base, -Unique)

Generate <Base>1, <Base>2, etc atoms on each subsequent call. Note that there is nothing that prevents other parts of the application to ‘invent’ the same identifier. The predicate gensym/2 is thread-safe in the sense that two threads generating identifiers from the same Base will never generate the same identifier.

See also uuid/1, term_hash/2, variant_shal/2 may be used to generate various unique or content-based identifiers safely.

reset_gensym

Reset gensym for all registered keys. This predicate is available for compatibility only. New code is strongly advised to avoid the use of reset_gensym or at least to reset only the keys used by your program to avoid unexpected side effects on other components.

reset_gensym(+Base)

Restart generation of identifiers from Base at <Base>1. Used to make sure a program produces the same results on subsequent runs. Use with care.

A.19 library(heaps): heaps/priority queues

author Lars Buitinck

Heaps are data structures that return the entries inserted into them in an ordered fashion, based on a priority. This makes them the data structure of choice for implementing priority queues, a central element of algorithms such as best-first/A* search and Kruskal’s minimum-spanning-tree algorithm.

This module implements min-heaps, meaning that items are retrieved in ascending order of key/priority. It was designed to be compatible with the SICStus Prolog library module of the same name. merge_heaps/3 and singleton_heap/3 are SWI-specific extension. The portray_heap/1 predicate is not implemented.

Although the data items can be arbitrary Prolog data, keys/priorities must be ordered by @=</2. Be careful when using variables as keys, since binding them in between heap operations may change the ordering.

The current version implements pairing heaps. These support insertion and merging both in constant time, deletion of the minimum in logarithmic amortized time (though delete-min, i.e., get_from_heap/3, takes linear time in the worst case).

add_to_heap(+Heap0, +Priority, ?Key, -Heap) [semidet]

Adds Key with priority Priority to Heap0, constructing a new heap in Heap.

delete_from_heap(+Heap0, -Priority, +Key, -Heap) [semidet]

Deletes Key from Heap0, leaving its priority in Priority and the resulting data structure in Heap. Fails if Key is not found in Heap0.

bug This predicate is extremely inefficient and exists only for SICStus compatibility.

empty_heap(?Heap) [semidet]

True if Heap is an empty heap. Complexity: constant.
A.20. LIBRARY(INCREASE): INCREMENTAL DYNAMIC PREDICATE MODIFICATION

singleton_heap(?Heap, ?Priority, ?Key) [semidet]
True if Heap is a heap with the single element Priority-Key.
Complexity: constant.

get_from_heap(?Heap0, ?Priority, ?Key, -Heap) [semidet]
Retrieves the minimum-priority pair Priority-Key from Heap0. Heap is Heap0 with that pair removed. Complexity: logarithmic (amortized), linear in the worst case.

heap_size(+Heap, -Size:int) [det]
Determines the number of elements in Heap. Complexity: constant.

heap_to_list(+Heap, -List:list) [det]
Constructs a list List of Priority-Element terms, ordered by (ascending) priority. Complexity: $O(n \log n)$.

is_heap(+X) [semidet]
Returns true if X is a heap. Validates the consistency of the entire heap. Complexity: linear.

list_to_heap(+List:list, -Heap) [det]
If List is a list of Priority-Element terms, constructs a heap out of List. Complexity: linear.

min_of_heap(+Heap, ?Priority, ?Key) [semidet]
Unifies Key with the minimum-priority element of Heap and Priority with its priority value. Complexity: constant.

min_of_heap(+Heap, ?Priority1, ?Key1, ?Priority2, ?Key2) [semidet]
Gets the two minimum-priority elements from Heap. Complexity: logarithmic (amortized).
Do not use this predicate; it exists for compatibility with earlier implementations of this library and the SICStus counterpart. It performs a linear amount of work in the worst case that a following get_from_heap has to re-do.

merge_heaps(+Heap0, +Heap1, -Heap) [det]
Merge the two heaps Heap0 and Heap1 in Heap. Complexity: constant.

A.20 library(increval): Incremental dynamic predicate modification

Compatibility XSB

This module emulates the XSB module increval. This module serves two goals: (1) provide alternatives for the dynamic clause manipulation predicates that propagate into the incremental tables and (2) query the dynamically maintained Incremental Dependency Graph (IDG).

The change propagation for incremental dynamic predicates. SWI-Prolog relies in prolog_listen/2 to forward any change to dynamic predicates to the table IDG and incr_assert/1 and friends thus simply call the corresponding database update.

is_incremental_subgoal(?SubGoal) [nondet]
This predicate non-deterministically unifies Subgoal with incrementally tabled subgoals that are currently table entries.
incr\_directly\_depends(:Goal1, :Goal2) [nondet]
True if Goal1 depends on Goal2 in the IDG.

Compatibility: In XSB, at least one of Goal 1 or Goal 2 must be bound. This implementation may be used with both arguments unbound.

incr\_trans\_depends(:Goal1, Goal2) [nondet]
True for each pair in the transitive closure of incr\_directly\_depends(G1, G2).

incr\_invalid\_subgoals(-List) [det]
List is a sorted list (set) of the incremental subgoals that are currently invalid.

incr\_is\_invalid(:Subgoal) [semidet]
True when Subgoal’s table is marked as invalid.

incr\_invalidate\_calls(:Goal) [det]
invalidate all tables for subgoals of Goal as well as tables that are affected by these.

incr\_invalidate\_call(:Goal) [det]
This is the XSB name, but the manual says incr\_invalidate\_calls/1 and the comment with the code suggests this is misnamed.

deprecated Use incr\_invalidate\_calls/1.

incr\_table\_update
Updated all invalid tables

incr\_propagate\_calls(:Answer) [det]
Activate the monotonic answer propagation similarly to when a new fact is asserted for a monotonic dynamic predicate. The Answer term must match a monotonic dynamic predicate.

A.21 library(intercept): Intercept and signal interface

This library allows for creating an execution context (goal) which defines how calls to send\_signal/1 are handled. This library is typically used to fetch values from the context or process results depending on the context.

For example, assume we parse a (large) file using a grammar (see phrase\_from\_file/3) that has some sort of record structure. What should we do with the recognised records? We can return them in a list, but if the input is large this is a huge overhead if the records are to be asserted or written to a file. Using this interface we can use

```prolog
document -->
   record(Record), !,
   { send\_signal(record(Record)) },
   document.
document --> [].
```
Given the above, we can assert all records into the database using the following query:

```
...,
intercept(phrase_from_file(File, document),
         record(Record),
         assertz(Record)).
```

Or, we can collect all records in a list using `intercept_all/4`:

```
...,
intercept_all(Record,
              phrase_from_file(File, document), record(Record),
              Records).
```

### `intercept(:Goal, ?Ball, :Handler)`

Run `Goal` as `call/1`. If somewhere during the execution of `Goal` `send_signal/1` is called with a `Signal` that unifies with `Ball`, run `Handler` and continue the execution.

This predicate is related to `catch/3`, but rather than aborting the execution of `Goal` and running `Handler` it continues the execution of `Goal`. This construct is also related to delimited continuations (see `reset/3` and `shift/1`). It only covers one (common) use case for delimited continuations, but does so with a simpler interface, at lower overhead and without suffering from poor interaction with the cut.

Note that `Ball` and `Handler` are copied before calling the (copy) of `Handler` to avoid instantiation of `Ball` and/or `Handler` which can make a subsequent signal fail.

See also `intercept/4, reset/3, catch/4, broadcast_request/1`.

Compatibility Ciao

### `intercept(:Goal, ?Ball, :Handler, +Arg)`

Similar to `intercept/3`, but the copy of `Handler` is called as `call(Copy,Arg)`, which allows passing large context arguments or arguments subject to unification or destructive assignment. For example:

```
?- intercept(send_signal(x), X, Y=X).
true.

?- intercept(send_signal(x), X, =(X), Y).
Y = x.
```

### `intercept_all(+Template, :Goal, ?Ball, -List)`

True when `List` contains all instances of `Template` that have been sent using `send_signal/1` where the argument unifies with `Ball`. Note that backtracking in `Goal` resets the `List`. For example, given
enum(I, Max) :- I =< Max, !, send_signal(emit(I)),
    I2 is I+1, enum(I2, Max).
enum(_, _).

Consider the following queries

?- intercept_all(I, enum(1,6), emit(I), List).
List = [1, 2, 3, 4, 5, 6].

?- intercept_all(I, (between(1,3,Max),enum(1,Max)), emit(I), List).
Max = 1, List = [1] ;
Max = 2, List = [1, 2] ;
Max = 3, List = [1, 2, 3].

See also nb_intercept_all/4

nb_intercept_all(+Template, :Goal, ?Ball, -List)
As intercept_all/4, but backtracing inside Goal does not reset List. Consider this pro-
gram and the subsequent queries

enum_b(F, T) :- forall(between(F, T, I), send_signal(emit(I))).

?- intercept_all(I, enum_b(1, 6), emit(I), List).
List = [].

?- nb_intercept_all(I, enum_b(1, 6), emit(I), List).
List = [1, 2, 3, 4, 5, 6].

send_signal(+Signal)
If this predicate is called from a sub-goal of intercept/3, execute the associated Handler
of the intercept/3 environment.

Errors unintercepted_signal(Signal) if there is no matching intercept environment.

send_silent_signal(+Signal)
As send_signal/1, but succeed silently if there is no matching intercept environment.

A.22 library(iostream): Utilities to deal with streams

See also library(archive), library(process), library(zlib), library(http/http_stream)

This library contains utilities that deal with streams, notably originating from non-built-in sources
such as URLs, archives, windows, processes, etc.
The predicate open_any/5 acts as a *broker* between applications that can process data from a stream and libraries that can create streams from diverse sources. Without this predicate, processing data inevitably follows the pattern below. As call_some_open_variation can be anything, this blocks us from writing predicates such as load_xml(From, DOM) that can operate on arbitrary input sources.

```
setup_call_cleanup(
    call_some_open_variation(Spec, In),
    process(In),
    close(In)).
```

Libraries that can open streams can install the hook iostream:open_hook/6 to make their functionality available through open_any/5.

**open_any(+Specification, +Mode, -Stream, -Close, +Options)**

Establish a stream from *Specification* that should be closed using *Close*, which can either be called or passed to close_any/1. **Options** processed:

- **encoding(Enc)**
  
  Set stream to encoding *Enc*.

Without loaded plugins, the open_any/5 processes the following values for *Specification*. If no rule matches, open_any/5 processes *Specification* as file(Specification).

- **Stream**
  
  A plain stream handle. Possible post-processing options such as encoding are applied. *Close* does not close the stream, but resets other side-effects such as the encoding.

- **stream(Stream)**
  
  Same as a plain *Stream*.

- **FileURL**
  
  If *Specification* is of the form =file://...=, the pointed to file is opened using open/4. Requires library(uri) to be installed.

- **file(Path)**
  
  Explicitly open the file *Path*. *Path* can be an Path(File) term as accepted by absolute_file_name/3.

- **string(String)**
  
  Open a Prolog string, atom, list of characters or codes as an input stream.

The typical usage scenario is given in the code below, where <process> processes the input.

```
setup_call_cleanup(
    open_any(Spec, read, In, Close, Options),
    <process>(In),
    Close).
```
Currently, the following libraries extend this predicate:

```
library(http/http_open)
  Adds support for URLs using the http and https schemes.
```

close_any(+Goal)
Execute the Close closure returned by open_any/5. The closure can also be called directly. Using close_any/1 can be considered better style and enhances tractability of the source code.

```
open_hook(+Spec, +Mode, -Stream, -Close, +Options0, -Options) [semidet,multifile]
Open Spec in Mode, producing Stream.
Arguments
  Close is unified to a goal that must be called to undo the side-effects of
  the action, e.g., typically the term close(Stream)
  Options0 are the options passed to open_any/5
  Options are passed to the post processing filters that may be installed by
  open_any/5.
```

A.23  library(listing): List programs and pretty print clauses

To be done
- More settings, support Coding Guidelines for Prolog and make the suggestions there the default.
- Provide persistent user customization

This module implements listing code from the internal representation in a human readable format.

- listing/0 lists a module.
- listing/1 lists a predicate or matching clause
- listing/2 lists a predicate or matching clause with options
- portray_clause/2 pretty-prints a clause-term

Layout can be customized using library(settings). The effective settings can be listed using list_settings/1 as illustrated below. Settings can be changed using set_setting/2.

```
?- list_settings(listing).
========================================================================
Name       Value  (*=modified)        Comment
========================================================================
listing:body_indentation 4                     Indentation used goals in the body
listing:tab_distance   0                     Distance between tab-stops.
...
A.23. LIBRARY(LISTING): LIST PROGRAMS AND PRETTY PRINT CLAUSES

listing
List all predicates defined in the calling module. Imported predicates are not listed. To list the content of the module mymodule, use one of the calls below.

?- mymodule:listing.
?- listing(mymodule:_).

listing(:What) [det]
listing(:What, +Options) [det]
List matching clauses. What is either a plain specification or a list of specifications. Plain specifications are:

- Predicate indicator (Name/Arity or Name//Arity) Lists the indicated predicate. This also outputs relevant declarations, such as multifile/1 or dynamic/1.
- A Head term. In this case, only clauses whose head unify with Head are listed. This is illustrated in the query below that only lists the first clause of append/3.

?- listing(append([], _, _)).
lst:append([], L, L).

- A clause reference as obtained for example from nth_clause/3.

The following options are defined:

variable_names(+How)
One of source (default) or generated. If source, for each clause that is associated to a source location the system tries to restore the original variable names. This may fail if macro expansion is not reversible or the term cannot be read due to different operator declarations. In that case variable names are generated.

source(+Bool)
If true (default false), extract the lines from the source files that produced the clauses, i.e., list the original source text rather than the decompiled clauses. Each set of contiguous clauses is preceded by a comment that indicates the file and line of origin. Clauses that cannot be related to source code are decompiled where the comment indicates the decompiled state. This is notably practical for collecting the state of multifile predicates. For example:

?- listing(file_search_path, [source(true)]).

portray_clause(+Clause) [det]
portray_clause(+Out:stream, +Clause) [det]
portray_clause(+Out:stream, +Clause, +Options) [det]
Portray ‘Clause’ on the current output stream. Layout of the clause is to our best standards. Deals with control structures and calls via meta-call predicates as determined using the predicate property meta_predicate. If Clause contains attributed variables, these are treated as normal variables.
Variable names are by default generated using `numbervars/4` using the option `singletons(true)`. This names the variables A, B, ... and the singletons _. Variables can be named explicitly by binding them to a term `'$VAR'(Name)`, where Name is an atom denoting a valid variable name (see the option `numbervars(true)` from `write_term/2`) as well as by using the `variable_names(Bindings)` option from `write_term/2`.

Options processed in addition to `write_term/2` options:

```
variable_names(+Bindings)
See above and `write_term/2`.
```

```
indent(+Columns)
Left margin used for the clause. Default 0.
```

```
module(+Module)
Module used to determine whether a goal resolves to a meta predicate. Default `user`.
```

### A.24 library(lists): List Manipulation

**Compatibility** Virtually every Prolog system has `library(lists)`, but the set of provided predicates is diverse. There is a fair agreement on the semantics of most of these predicates, although error handling may vary.

This library provides commonly accepted basic predicates for list manipulation in the Prolog community. Some additional list manipulations are built-in. See e.g., `memberchk/2`, `length/2`.

The implementation of this library is copied from many places. These include: “The Craft of Prolog”, the DEC-10 Prolog library (LISTRO.PL) and the YAP lists library. Some predicates are reimplemented based on their specification by Quintus and SICStus.

#### member(?Elem, ?List)
True if `Elem` is a member of `List`. The SWI-Prolog definition differs from the classical one. Our definition avoids unpacking each list element twice and provides determinism on the last element. E.g. this is deterministic:

```
member(X, [One]).
```

**author** Gertjan van Noord

#### append(?List1, ?List2, ?List1AndList2)
`List1AndList2` is the concatenation of `List1` and `List2`

#### append(+ListOfLists, ?List)
Concatenate a list of lists. Is true if `ListOfLists` is a list of lists, and `List` is the concatenation of these lists.

**Arguments**

`ListOfLists` must be a list of possibly partial lists
prefix(?Part, ?Whole)
True iff Part is a leading substring of Whole. This is the same as append(Part, _, Whole).

select(?Elem, ?List1, ?List2)
Is true when List1, with Elem removed, results in List2. This implementation is deterministic if the last element of List1 has been selected.

selectchk(+Elem, +List, -Rest) [semidet]
Semi-deterministic removal of first element in List that unifies with Elem.

select(?X, ?XList, ?Y, ?YList) [nondet]
Select from two lists at the same position. True if XList is unifiable with YList apart a single element at the same position that is unified with X in XList and with Y in YList. A typical use for this predicate is to replace an element, as shown in the example below. All possible substitutions are performed on backtracking.

?- select(b, [a,b,c,b], 2, X).
X = [a, 2, c, b] ;
X = [a, b, c, 2] ;
false.

See also selectchk/4 provides a semidet version.

selectchk(?X, ?XList, ?Y, ?YList) [semidet]
Semi-deterministic version of select/4.

nextto(?X, ?Y, ?List)
True if Y directly follows X in List.

delete(+List1, @Elem, -List2) [det]
Delete matching elements from a list. True when List2 is a list with all elements from List1 except for those that unify with Elem. Matching Elem with elements of List1 is uses \+ Elem \= H, which implies that Elem is not changed.

See also select/3, subtract/3.

deprecated There are too many ways in which one might want to delete elements from a list to justify the name. Think of matching (= vs. ==), delete first/all, be deterministic or not.

nth0(?Index, ?List, ?Elem)
True when Elem is the Index’th element of List. Counting starts at 0.

Errors type_error(integer, Index) if Index is not an integer or unbound.
See also nth1/3.

nth1(?Index, ?List, ?Elem)
Is true when Elem is the Index’th element of List. Counting starts at 1.

See also nth0/3.
nth0(?N, ?List, ?Elem, ?Rest)  [det]
  Select/insert element at index. True when Elem is the N’th (0-based) element of List and Rest is the remainder (as in by select/3) of List. For example:

  ?- nth0(I, [a,b,c], E, R).
  I = 0, E = a, R = [b, c] ;
  I = 1, E = b, R = [a, c] ;
  I = 2, E = c, R = [a, b] ;
  false.

  ?- nth0(1, L, a1, [a,b]).
  L = [a, a1, b].

nth1(?N, ?List, ?Elem, ?Rest)  [det]
  As nth0/4, but counting starts at 1.

last(?List, ?Last)
  Succeeds when Last is the last element of List. This predicate is semidet if List is a list and multi if List is a partial list.

  Compatibility There is no de-facto standard for the argument order of last/2. Be careful when porting code or use append(_, [Last], List) as a portable alternative.

proper_length(@List, -Length)  [semidet]
  True when Length is the number of elements in the proper list List. This is equivalent to

  proper_length(List, Length) :-
    is_list(List),
    length(List, Length).

same_length(?List1, ?List2)
  Is true when List1 and List2 are lists with the same number of elements. The predicate is deterministic if at least one of the arguments is a proper list. It is non-deterministic if both arguments are partial lists.

  See also  length/2

reverse(?List1, ?List2)
  Is true when the elements of List2 are in reverse order compared to List1. This predicate is deterministic if either list is a proper list. If both lists are partial lists backtracking generates increasingly long lists.

permutation(?Xs, ?Ys)  [nondet]
  True when Xs is a permutation of Ys. This can solve for Ys given Xs or Xs given Ys, or even enumerate Xs and Ys together. The predicate permutation/2 is primarily intended to generate permutations. Note that a list of length N has N! permutations, and unbounded permutation generation becomes prohibitively expensive, even for rather short lists (10! = 3,628,800).
If both $Xs$ and $Ys$ are provided and both lists have equal length the order is $|Xs|^2$. Simply testing whether $Xs$ is a permutation of $Ys$ can be achieved in order $\log(|Xs|)$ using $\text{msort/2}$ as illustrated below with the semidet predicate $\text{is_permutation/2}$:

$$\text{is_permutation}(Xs, Ys) :-$$
$$\text{msort}(Xs, Sorted),$$
$$\text{msort}(Ys, Sorted).$$

The example below illustrates that $Xs$ and $Ys$ being proper lists is not a sufficient condition to use the above replacement.

?- permutation([1,2], [X,Y]).
X = 1, Y = 2 ;
X = 2, Y = 1 ;
false.

**Errors**  
type_error(list, Arg) if either argument is not a proper or partial list.

**flatten(+NestedList, -FlatList)**

Is true if $\text{FlatList}$ is a non-nested version of $\text{NestedList}$. Note that empty lists are removed. In standard Prolog, this implies that the atom '[]' is removed too. In SWI7, '[]' is distinct from '[]'.

Ending up needing $\text{flatten/2}$ often indicates, like $\text{append/3}$ for appending two lists, a bad design. Efficient code that generates lists from generated small lists must use difference lists, often possible through grammar rules for optimal readability.

**See also**  
append/2

**clumped(+Items, -Pairs)**

Pairs is a list of Item-Count pairs that represents the run length encoding of Items. For example:

?- clumped([a,a,b,a,a,a,c,c,c], R).
R = [a-2, b-1, a-4, c-3].

**Compatibility**  
SICStus

**max_member(-Max, +List)**

True when $Max$ is the largest member in the standard order of terms. Fails if $List$ is empty.

**See also**

- compare/3
- max.list/2 for the maximum of a list of numbers.

**min_member(-Min, +List)**

True when $Min$ is the smallest member in the standard order of terms. Fails if $List$ is empty.
max_member(Pred, -Max, +List)  \[semidet\]
True when Max is the largest member according to Pred, which must be a 2-argument callable that behaves like \((\leq<)/2\). Fails if List is empty. The following call is equivalent to max_member/2:

\[
\text{?- max_member(\leq<, X, [6,1,8,4]).}
\]
\[
X = 8.
\]
See also max_list/2 for the maximum of a list of numbers.

min_member(Pred, -Min, +List)  \[semidet\]
True when Min is the smallest member according to Pred, which must be a 2-argument callable that behaves like \((\leq<)/2\). Fails if List is empty. The following call is equivalent to max_member/2:

\[
\text{?- min_member(\leq<, X, [6,1,8,4]).}
\]
\[
X = 1.
\]
See also min_list/2 for the minimum of a list of numbers.

sum_list(+List, -Sum)  \[det\]
Sum is the result of adding all numbers in List.

max_list(+List:list(number), -Max:number)  \[semidet\]
True if Max is the largest number in List. Fails if List is empty.
See also max_member/2.

min_list(+List:list(number), -Min:number)  \[semidet\]
True if Min is the smallest number in List. Fails if List is empty.
See also min_member/2.

numlist(+Low, +High, -List)  \[semidet\]
List is a list \([Low, Low+1, \ldots, High]\). Fails if High < Low.

Errors
- type_error(integer, Low)
- type_error(integer, High)

is_set(@Set)  \[semidet\]
True if Set is a proper list without duplicates. Equivalence is based on \(==/2\). The implementation uses sort/2, which implies that the complexity is \(N*\log(N)\) and the predicate may cause a resource-error. There are no other error conditions.
list_to_set(+List, ?Set) \[det\]

True when Set has the same elements as List in the same order. The left-most copy of duplicate elements is retained. List may contain variables. Elements E1 and E2 are considered duplicates iff E1 == E2 holds. The complexity of the implementation is N*\log(N).

Errors List is type-checked.

See also sort/2 can be used to create an ordered set. Many set operations on ordered sets are order N rather than order N**2. The list_to_set/2 predicate is more expensive than sort/2 because it involves, two sorts and a linear scan.

Compatibility Up to version 6.3.11, list_to_set/2 had complexity N**2 and equality was tested using =/2.

intersection(+Set1, +Set2, -Set3) \[det\]

True if Set3 unifies with the intersection of Set1 and Set2. The complexity of this predicate is |Set1| * |Set2|. A set is defined to be an unordered list without duplicates. Elements are considered duplicates if they can be unified.

See also ord_intersection/3.

union(+Set1, +Set2, -Set3) \[det\]

True if Set3 unifies with the union of the lists Set1 and Set2. The complexity of this predicate is |Set1| * |Set2|. A set is defined to be an unordered list without duplicates. Elements are considered duplicates if they can be unified.

See also ord_union/3.

subset(+SubSet, +Set) \[semidet\]

True if all elements of SubSet belong to Set as well. Membership test is based on memberchk/2. The complexity is |SubSet| * |Set|. A set is defined to be an unordered list without duplicates. Elements are considered duplicates if they can be unified.

See also ord_subset/2.

subtract(+Set, +Delete, -Result) \[det\]

Delete all elements in Delete from Set. Deletion is based on unification using memberchk/2. The complexity is |Delete| * |Set|. A set is defined to be an unordered list without duplicates. Elements are considered duplicates if they can be unified.

See also ord_subtract/3.

A.25 library(main): Provide entry point for scripts

See also
- library(prolog_stack) to force backtraces in case of an uncaught exception.
- XPCE users should have a look at library(pce_main), which starts the GUI and processes events until all windows have gone.

This library is intended for supporting PrologScript on Unix using the #! magic sequence for scripts using commandline options. The entry point main/0 calls the user-supplied predicate main/1 passing a list of commandline options. Below is a simple echo implementation in Prolog.
main

Call main/1 using the passed command-line arguments. Before calling main/1 this predicate installs a signal handler for SIGINT (Control-C) that terminates the process with status 1.

When main/0 is called interactively it simply calls main/1 with the arguments. This allows for debugging scripts as follows:

```
$ swipl -l script.pl -- arg ...
?- gspy(suspect/1). % setup debugging
?- main. % run program
```

argv_options(:Argv, -Positional, -Options) [det]

Parse command line arguments. This predicate acts in one of two modes.

- If the calling module defines opt_type/3, full featured parsing with long and short options, type conversion and help is provided.
- If opt_type/3 is not defined, only unguided transformation using long options is supported. See argv_untyped_options/3 for details.

When guided, three predicates are called in the calling module. opt_type/3 must be defined, the others need not. Note that these three predicates may be defined as multifile to allow multiple modules contributing to the provided commandline options. Defining them as discontiguous allows for creating blocks that describe a group of related options.

opt_type(Opt, Name, Type)

Defines Opt to add an option Name(Value), where Value satisfies Type. Opt does not include the leading -. A single character implies a short option, multiple a long option. Long options use _ as word separator, user options may use either _ or -. Type is one of:
A | B
   Disjunctive type.

boolean(Default)

Boolean options are special. They do not take a value except for when using the long
--opt=value notation. This explicit value specification converts true, True,
TRUE, on, On, ON, 1 and the obvious false equivalents to Prolog true or false.
If the option is specified, Default is used. If --no-opt or --noopt is used, the
inverse of Default is used.

integer
   Argument is converted to an integer

float
   Argument is converted to a float. User may specify an integer

nonneg
   As integer. Requires value >= 0.

natural
   As integer. Requires value >= 1.

number
   Any number (integer, float, rational).

between(Low, High)
   If both one of Low and High is a float, convert as float, else convert as integer.
   Then check the range.

atom
   No conversion

oneof(List)
   As atom, but requires the value to be a member of List (enum type).

string
   Convert to a SWI-Prolog string

file
   Convert to a file name in Prolog canonical notation using
   prolog_to_os_filename/2.

file(Access)
   As file, and check access using access_file/2. A value - is not checked for
   access, assuming the application handles this as standard input or output.

term
   Parse option value to a Prolog term.

term(+Options)
   As term, but passes Options to term_string/3. If the option
   variable_names(Bindings) is given the option value is set to the pair
   Term=Bindings.

opt_help(Name, HelpString)
   Help string used by argv_usage/1.

opt_meta(Name, Meta)
   If a typed argument is required this defines the placeholder in the help message. The
default is the uppercase version of the type functor name. This produces the FILE in e.g. 
-f FILE.

By default, -h, -? and --help are bound to help. If opt_type(Opt, help, boolean) is true for some Opt, the default help binding and help message are disabled and the normal user rules apply. In particular, the user should also provide a rule for opt_help(help, String).

argv_options(:Argv, -Positional, -Options, +ParseOptions)  [det]
As argv.options/3 in guided mode, Currently this version allows parsing argument options throwing an exception rather than calling halt/1 by passing an empty list to ParseOptions. ParseOptions:

on_error(+Goal)
If Goal is halt(Code), exit with Code. Other goals are currently not supported.

options_after_arguments(+Boolean)
If false (default true), stop parsing after the first positional argument, returning options that follow this argument as positional arguments. E.g., -x file -y results in positional arguments [file, '-y']

argv_usage(:Level)  [det]
Use print_message/2 to print a usage message at Level. To print the message as plain text in default color, use debug. Other meaningful options are informational or warning. The help page consists of four sections, two of which are optional:

1. The header is created from opt_help(help(header), String). It is optional.
2. The usage is added by default. The part behind Usage: <command> is by default [options] and can be overruled using opt_help(help(usage), String).
3. The actual option descriptions. The options are presented in the order they are defined in opt_type/3. Subsequent options for the same destination (option name) are joined with the first.
4. The footer is created from opt_help(help(footer), String). It is optional.

The help provided by help(header), help(usage) and help(footer) are either a simple string or a list of elements as defined by print_message_lines/3. In the latter case, the construct \Callable can be used to call a DCG rule in the module from which the user calls argv_options/3. For example, we can add a bold title using

\opt_help\(\text{help(header)}, \ Given\{\text{ansi_bold}, {\text{\textasciitilde \textbf{w}}, \{\text{'My title'}\}}\}\).

cli_parse_debug_options(+OptionsIn, -Options)  [det]
Parse certain commandline options for debugging and development purposes. Options processed are below. Note that the option argument is an atom such that these options may be activated as e.g., --debug='http(_)'.

dbge\(\text{g(Topic)}\)
Call debug(Topic). See debug/1 and debug/3.
A.26 library(nb_set): Non-backtrackable set

The library nb_set defines *non-backtrackable sets*, implemented as binary trees. The sets are represented as compound terms and manipulated using nb_setarg/3. Non-backtrackable manipulation of data structures is not supported by a large number of Prolog implementations, but it has several advantages over using the database. It produces less garbage, is thread-safe, reentrant and deals with exceptions without leaking data.

Similar to the assoc library, keys can be any Prolog term, but it is not allowed to instantiate or modify a term.

One of the ways to use this library is to generate unique values on backtracking *without* generating all solutions first, for example to act as a filter between a generator producing many duplicates and an expensive test routine, as outlined below:

```prolog
generate_and_test(Solution) :-
    empty_nb_set(Set),
    generate(Solution),
    add_nb_set(Solution, Set, true),
    test(Solution).
```

**empty_nb_set(?Set)**

True if Set is a non-backtrackable empty set.

**add_nb_set(+Key, !Set)**

Add Key to Set. If Key is already a member of Set, add_nb_set/3 succeeds without modifying Set.

**add_nb_set(+Key, !Set, ?New)**

If Key is not in Set and New is unified to true, Key is added to Set. If Key is in Set, New is unified to false. It can be used for many purposes:

- `add_nb_set(+, +, false)` Test membership
- `add_nb_set(+, +, true)` Succeed only if new member
- `add_nb_set(+, +, Var)` Succeed, binding Var
gen_nb_set(+Set, -Key)
  Generate all members of Set on backtracking in the standard order of terms. To test membership, use add_nb_set/3.

size_nb_set(+Set, -Size)
  Unify Size with the number of elements in Set.

nb_set_to_list(+Set, -List)
  Unify List with a list of all elements in Set in the standard order of terms (i.e., an ordered list).

A.27  library(www_browser): Open a URL in the users browser

This library deals with the highly platform specific task of opening a web page. In addition, it provides a mechanism similar to absolute_file_name/3 that expands compound terms to concrete URLs. For example, the SWI-Prolog home page can be opened using:

?- www_open_url(swipl(.)).

www_open_url(+Url)
  Open URL in running version of the users’ browser or start a new browser. This predicate tries the following steps:

  1. If a prolog flag (see set_prolog_flag/2) browser is set and this is the name of a known executable, use this. The flag may be set to Command-Mode, where mode is one of fg or bg, requesting Command to run in foreground or background mode. Default is bg.
  2. On Windows, use win_shell(open, URL)
  3. Find a generic ‘open’ comment. Candidates are xdg-open, open or gnome-open.
  4. If a environment variable BROWSER is set and this is the name of a known executable, use this.
  5. Try to find a known browser. @tbd Figure out the right tool in step 3 as it is not uncommon that multiple are installed.

known_browser(+FileBaseName, -Compatible) [multifile]
  True if browser FileBaseName has a remote protocol compatible to Compatible.

expand_url_path(+Spec, -URL)
  Expand URL specifications similar to absolute_file_name/3. The predicate url_path/2 plays the role of file_search_path/2.

  Errors  existence_error(url_path, Spec) if the location is not defined.
A.28 library(occurs): Finding and counting sub-terms

See also library(terms) provides similar predicates and is probably more wide-spread than this library.

This is a SWI-Prolog implementation of the corresponding Quintus library, based on the generalised arg/3 predicate of SWI-Prolog.

contains_term(+Sub, +Term) [semidet]
Succeeds if Sub is contained in Term (=, deterministically)

contains_var(+Sub, +Term) [det]
Succeeds if Sub is contained in Term (==, deterministically)

free_of_term(+Sub, +Term)
Succeeds of Sub does not unify to any subterm of Term

free_of_var(+Sub, +Term)
Succeeds of Sub is not equal (==) to any subterm of Term

occurrences_of_term(+SubTerm, +Term, ?Count)
Count the number of SubTerms in Term

occurrences_of_var(+SubTerm, +Term, ?Count)
Count the number of SubTerms in Term

sub_term(-Sub, +Term)
Generates (on backtracking) all subterms of Term.

sub_var(-Sub, +Term)
Generates (on backtracking) all subterms (==) of Term.

sub_term_shared_variables(+Sub, +Term, -Vars) [det]
If Sub is a sub term of Term, Vars is bound to the list of variables in Sub that also appear outside Sub in Term. Note that if Sub appears twice in Term, its variables are all considered shared.

An example use-case is refactoring a large clause body by introducing intermediate predicates. This predicate can be used to find the arguments that must be passed to the new predicate.

A.29 library(option): Option list processing

See also
- library(record)
  - Option processing capabilities may be declared using the directive predicate_options/3.

To be done We should consider putting many options in an assoc or record with appropriate preprocessing to achieve better performance.

The library(option) provides some utilities for processing option lists. Option lists are commonly used as an alternative for many arguments. Examples of built-in predicates are open/4 and write_term/3. Naming the arguments results in more readable code, and the list nature makes it easy to extend the list of options accepted by a predicate. Option lists come in two styles, both of which are handled by this library.
Name(\text{Value}) \hspace{1em} \text{This is the preferred style.}

Name = \text{Value} \hspace{1em} \text{This is often used, but deprecated.}

Processing options inside time-critical code (loops) can cause serious overhead. One possibility is to define a record using \texttt{library(record)} and initialise this using \texttt{make.<record>/2}. In addition to providing good performance, this also provides type-checking and central declaration of defaults.

\begin{verbatim}
:- record atts(width:integer=100, shape:oneof([box,circle])=box).
process(Data, Options) :-
    make_atts(Options, Attributes),
    action(Data, Attributes).
action(Data, Attributes) :-
    atts_shape(Attributes, Shape),
    ...
\end{verbatim}

Options typically have exactly one argument. The library does support options with 0 or more than one argument with the following restrictions:

- The predicate \texttt{option/3} and \texttt{select_option/4}, involving default are meaningless. They perform an \texttt{arg(1, Option, Default)}, causing failure without arguments and filling only the first option-argument otherwise.

- \texttt{meta_options/3} can only qualify options with exactly one argument.

\begin{verbatim}
option(?Option, +OptionList, +Default) \hspace{1em} \textit{[semidet]}
\hspace{1em} \text{Get an Option from OptionList. OptionList can use the Name=Value as well as the Name(\text{Value}) convention.}

\hspace{1em} \text{Arguments}
\hspace{1em} \text{Option} \hspace{1em} \text{Term of the form Name(\text{Value}).}

option(?Option, +OptionList) \hspace{1em} \textit{[semidet]}
\hspace{1em} \text{Get an Option from OptionList. OptionList can use the Name=Value as well as the Name(\text{Value}) convention. Fails silently if the option does not appear in OptionList.}

\hspace{1em} \text{Arguments}
\hspace{1em} \text{Option} \hspace{1em} \text{Term of the form Name(\text{Value}).}

select_option(?Option, +Options, -RestOptions) \hspace{1em} \textit{[semidet]}
\hspace{1em} \text{Get and remove Option from an option list. As option/2, removing the matching option from Options and unifying the remaining options with RestOptions.}

select_option(?Option, +Options, -RestOptions, +Default) \hspace{1em} \textit{[det]}
\hspace{1em} \text{Get and remove Option with default value. As select_option/3, but if Option is not in Options, its value is unified with Default and RestOptions with Options.}
\end{verbatim}
merge_options(+New, +Old, -Merged) [det]
Merge two option lists. Merged is a sorted list of options using the canonical format Name(Value) holding all options from New and Old, after removing conflicting options from Old.

Multi-values options (e.g., proxy(Host, Port)) are allowed, where both option-name and arity define the identity of the option.

meta_options(+IsMeta, :Options0, -Options) [det]
Perform meta-expansion on options that are module-sensitive. Whether an option name is module-sensitive is determined by calling call(IsMeta, Name). Here is an example:

```
meta_options(is_meta, OptionsIn, Options),
...
```
```
is_meta(callback).
```

Meta-options must have exactly one argument. This argument will be qualified.

To be done Should be integrated with declarations from predicate_options/3.

dict_options(?Dict, ?Options) [det]
Convert between an option list and a dictionary. One of the arguments must be instantiated. If the option list is created, it is created in canonical form, i.e., using Option(Value) with the Options sorted in the standard order of terms. Note that the conversion is not always possible due to different constraints and conversion may thus lead to (type) errors.

* Dict keys can be integers. This is not allowed in canonical option lists.
* Options can hold multiple options with the same key. This is not allowed in dicts. This predicate removes all but the first option on the same key.
* Options can have more than one value (name(V1, V2)). This is not allowed in dicts.

Also note that most system predicates and predicates using this library for processing the option argument can both work with classical Prolog options and dicts objects.

A.30 library(optparse): command line parsing

author Marcus Uneson
version 0.20 (2011-04-27)

To be done : validation? e.g, numbers; file path existence; one-out-of-a-set-of-atoms

This module helps in building a command-line interface to an application. In particular, it provides functions that take an option specification and a list of atoms, probably given to the program on the command line, and return a parsed representation (a list of the customary Key(Val) by default; or optionally, a list of Func(Key, Val) terms in the style of current_prolog_flag/2). It can also synthesize a simple help text from the options specification.

The terminology in the following is partly borrowed from python, see <http://docs.python.org/library/optparse.html#terminology>. Very briefly, arguments is what
you provide on the command line and for many prologs show up as a list of atoms Args in
current_prolog_flag(argv, Args). For a typical prolog incantation, they can be divided
into

- **runtime arguments**, which controls the prolog runtime; conventionally, they are ended by ‘–’;
- **options**, which are key-value pairs (with a boolean value possibly implicit) intended to control
your program in one way or another; and
- **positional arguments**, which is what remains after all runtime arguments and options have been
removed (with implicit arguments – true/false for booleans – filled in).

Positional arguments are in particular used for mandatory arguments without which your program
won’t work and for which there are no sensible defaults (e.g., input file names). Options, by contrast,
offer flexibility by letting you change a default setting. Options are optional not only by etymology:
this library has no notion of mandatory or required options (see the python docs for other rationales
than laziness).

The command-line arguments enter your program as a list of atoms, but the programs perhaps
expects booleans, integers, floats or even prolog terms. You tell the parser so by providing an
**options specification**. This is just a list of individual option specifications. One of those, in turn, is a list of
ground prolog terms in the customary Name(Value) format. The following terms are recognized (any
others raise error).

**opt(Key)**

*Key* is what the option later will be accessed by, just like for
current_prolog_flag(Key, Value). This term is mandatory (an error is thrown if
missing).

**shortflags(ListOfFlags)**

*ListOfFlags* denotes any single-dashed, single letter args specifying the current option
(–s , –K, etc). Uppercase letters must be quoted. Usually *ListOfFlags* will be a singleton
list, but sometimes aliased flags may be convenient.

**longflags(ListOfFlags)**

*ListOfFlags* denotes any double-dashed arguments specifying the current option
(–-verbose, –-no-debug, etc). They are basically a more readable alternative to
short flags, except

1. long flags can be specified as **--flag value** or **--flag=value** (but not as
   **--flagvalue**); short flags as **-f val** or **-fval** (but not **-f=val**)

2. boolean long flags can be specified as **--bool-flag** or **--bool-flag=true**
   or **--bool-flag true**; and they can be negated as **--no-boot-flag** or
   **--bool-flag=false** or **--bool-flag false**.

Except that shortflags must be single characters, the distinction between long and short is in
calling convention, not in namespaces. Thus, if you have shortflags ([v]), you can use it
as **-v2** or **-v 2** or **--v=2** or **--v 2** (but not **-v=2** or **--v2**).

Shortflags and longflags both default to [ ]. It can be useful to have flagless options – see
example below.
**meta(Meta)**

Meta is optional and only relevant for the synthesized usage message and is the name (an atom) of the metasyntactic variable (possibly) appearing in it together with type and default value (e.g., `x:integer=3, interest:float=0.11`). It may be useful to have named variables (`x, interest`) in case you wish to mention them again in the help text. If not given the Meta: part is suppressed – see example below.

**type(Type)**

Type is one of `boolean, atom, integer, float, term`. The corresponding argument will be parsed appropriately. This term is optional; if not given, defaults to `term`.

**default(Default)**

Default value. This term is optional; if not given, or if given the special value `'_'`, an uninstantiated variable is created (and any type declaration is ignored).

**help(Help)**

Help is (usually) an atom of text describing the option in the help text. This term is optional (but obviously strongly recommended for all options which have flags).

Long lines are subject to basic word wrapping – split on white space, reindent, rejoin. However, you can get more control by supplying the line breaking yourself: rather than a single line of text, you can provide a list of lines (as atoms). If you do, they will be joined with the appropriate indent but otherwise left untouched (see the option `mode` in the example below).

Absence of mandatory option specs or the presence of more than one for a particular option throws an error, as do unknown or incompatible types.

As a concrete example from a fictive application, suppose we want the following options to be read from the command line (long flag(s), short flag(s), meta:type=default, help)

<table>
<thead>
<tr>
<th>option</th>
<th>description</th>
</tr>
</thead>
<tbody>
<tr>
<td>--mode -m atom=SCAN</td>
<td>data gathering mode, one of SCAN: do this READ: do that MAKE: make numbers WAIT: do nothing</td>
</tr>
<tr>
<td>--rebuild-cache -r boolean=true</td>
<td>rebuild cache in each iteration</td>
</tr>
<tr>
<td>--heisenberg-threshold -t,-h float=0.1</td>
<td>heisenberg threshold</td>
</tr>
<tr>
<td>--depths, --iters -i,-d K:integer=3</td>
<td>stop after K iterations</td>
</tr>
<tr>
<td>--distances</td>
<td>term=[1,2,3,5] initial prolog term</td>
</tr>
<tr>
<td>--output-file -o FILE:atom=_</td>
<td>write output to FILE</td>
</tr>
<tr>
<td>--label -l atom=REPORT</td>
<td>report label</td>
</tr>
<tr>
<td>--verbosity -v V:integer=2</td>
<td>verbosity level, 1 &lt;= V &lt;= 3</td>
</tr>
</tbody>
</table>

We may also have some configuration parameters which we currently think not needs to be controlled from the command line, say `path(’/some/file/path’).`
This interface is described by the following options specification (order between the specifications of a particular option is irrelevant).

```
ExampleOptsSpec =
   [ [opt(mode), type(atom), default('SCAN'),
      shortflags([m]), longflags(['mode'] ),
      help(['data gathering mode, one of'
            ' SCAN: do this'
            ' READ: do that'
            ' MAKE: fabricate some numbers'
            ' WAIT: don't do anything'])]
   , [opt(cache), type(boolean), default(true),
      shortflags([r]), longflags(['rebuild-cache']),
      help('rebuild cache in each iteration')]
   , [opt(threshold), type(float), default(0.1),
      shortflags([t,h]), longflags(['heisenberg-threshold']),
      help('heisenberg threshold')]
   , [opt(depth), meta('K'), type(integer), default(3),
      shortflags([i,d]), longflags([depths, iters]),
      help('stop after K iterations')]
   , [opt(distances), default([1,2,3,5]),
      longflags([distances]),
      help('initial prolog term')]
   , [opt(outfile), meta('FILE'), type(atom),
      shortflags([o]), longflags(['output-file']),
      help('write output to FILE')]
   , [opt(label), type(atom), default('REPORT'),
      shortflags([l]), longflags([label]),
      help('report label')]
   , [opt(verbosity), meta('V'), type(integer), default(2),
      shortflags([v]), longflags([verbosity]),
      help('verbosity level, 1 <= V <= 3')]
   , [opt(path), default('/some/file/path/')]
].
```

The help text above was accessed by opt_help(ExampleOptsSpec, HelpText). The options appear in the same order as in the OptsSpec.

Given ExampleOptsSpec, a command line (somewhat syntactically inconsistent, in order to demonstrate different calling conventions) may look as follows
ExampleArgs = [ '-d5'
, '--heisenberg-threshold', '0.14'
, '--distances=[1,1,2,3,5,8]'
, '--iters', '7'
, '-ooutput.txt'
, '--rebuild-cache', 'true'
, 'input.txt'
, '--verbosity=2'
].

opt_parse(ExampleOptsSpec, ExampleArgs, Opts, PositionalArgs)
would then succeed with

Opts = [ mode('SCAN')
, label('REPORT')
, path('/some/file/path')
, threshold(0.14)
, distances([1,1,2,3,5,8])
, depth(7)
, outfile('output.txt')
, cache(true)
, verbose(2)
],
PositionalArgs = ['input.txt'].

Note that path('/some/file/path') showing up in Opts has a default value (of the implicit type 'term'), but no corresponding flags in OptsSpec. Thus it can’t be set from the command line. The rest of your program doesn’t need to know that, of course. This provides an alternative to the common practice of asserting such hard-coded parameters under a single predicate (for instance setting(path, '/some/file/path')), with the advantage that you may seamlessly upgrade them to command-line options, should you one day find this a good idea. Just add an appropriate flag or two and a line of help text. Similarly, suppressing an option in a cluttered interface amounts to commenting out the flags.

opt_parse/5 allows more control through an additional argument list as shown in the example below.

?- opt_parse(ExampleOptsSpec, ExampleArgs, Opts, PositionalArgs,
[ output_functor(appl_config)
 ]).

Opts = [ appl_config(verbose, 2),
, appl_config(label, 'REPORT')
... ]

This representation may be preferable with the empty-flag configuration parameter style above (perhaps with asserting appl_config/2).
A.30.1 Notes and tips

- In the example we were mostly explicit about the types. Since the default is `term`, which subsumes `integer`, `float`, `atom`, it may be possible to get away cheaper (e.g., by only giving booleans). However, it is recommended practice to always specify types: parsing becomes more reliable and error messages will be easier to interpret.

- Note that `-sbar` is taken to mean `–s bar`, not `–s –b –a –r`, that is, there is no clustering of flags.

- `-s=foo` is disallowed. The rationale is that although some command-line parsers will silently interpret this as `–s =foo`, this is very seldom what you want. To have an option argument start with `’=’` (very un-recommended), say so explicitly.

- The example specifies the option `depth` twice: once as `-d5` and once as `--iters 7`. The default when encountering duplicated flags is to `keeplast` (this behaviour can be controlled, by `ParseOption duplicated_flags`).

- The order of the options returned by the parsing functions is the same as given on the command line, with non-overridden defaults prepended and duplicates removed as in previous item. You should not rely on this, however.

- Unknown flags (not appearing in `OptsSpec`) will throw errors. This is usually a Good Thing. Sometimes, however, you may wish to pass along flags to an external program (say, one called `shell/2`), and it means duplicated effort and a maintenance headache to have to specify all possible flags for the external program explicitly (if it even can be done). On the other hand, simply taking all unknown flags as valid makes error checking much less efficient and identification of positional arguments uncertain. A better solution is to collect all arguments intended for passing along to an indirectly called program as a single argument, probably as an atom (if you don’t need to inspect them first) or as a prolog term (if you do).

\[\text{opt arguments}(\text{+OptsSpec, -Opts, -PositionalArgs})\]  

Extract commandline options according to a specification. Convenience predicate, assuming that command-line arguments can be accessed by `current_prolog_flag/2` (as in swi-prolog). For other access mechanisms and/or more control, get the args and pass them as a list of atoms to `opt_parse/4` or `opt_parse/5` instead.

`Opts` is a list of parsed options in the form `Key(Value)`. Dashed args not in `OptsSpec` are not permitted and will raise error (see tip on how to pass unknown flags in the module description). `PositionalArgs` are the remaining non-dashed args after each flag has taken its argument (filling in `true` or `false` for booleans). There are no restrictions on non-dashed arguments and they may go anywhere (although it is good practice to put them last). Any leading arguments for the runtime (up to and including `’-’`) are discarded.

\[\text{opt parse}(\text{+OptsSpec, +ApplArgs, -Opts, -PositionalArgs})\]  

Equivalent to `opt_parse(OptsSpec, ApplArgs, Opts, PositionalArgs, [])`. 

---

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opt_parse(+OptsSpec, +ApplArgs, -Opts, -PositionalArgs, +ParseOptions) [det]

Parse the arguments Args (as list of atoms) according to OptsSpec. Any runtime arguments (typically terminated by ‘-’) are assumed to be removed already.

Opts is a list of parsed options in the form Key(Value), or (with the option functor(Func) given) in the form Func(Key, Value). Dashed args not in OptsSpec are not permitted and will raise error (see tip on how to pass unknown flags in the module description). PositionalArgs are the remaining non-dashed args after each flag has taken its argument (filling in true or false for booleans). There are no restrictions on non-dashed arguments and they may go anywhere (although it is good practice to put them last). ParseOptions are

output_functor(Func)
Set the functor Func of the returned options Func(Key,Value). Default is the special value ‘OPTION’ (upper-case), which makes the returned options have form Key(Value).

duplicated_flags(Keep)
Controls how to handle options given more than once on the command line. Keep is one of keepfirst, keeplast, keepall with the obvious meaning. Default is keeplast.

allow_empty_flag_spec(Bool)
If true (default), a flag specification is not required (it is allowed that both shortflags and longflags be either [] or absent). Flagless options cannot be manipulated from the command line and will not show up in the generated help. This is useful when you have (also) general configuration parameters in your OptsSpec, especially if you think they one day might need to be controlled externally. See example in the module overview. allow_empty_flag_spec(false) gives the more customary behaviour of raising error on empty flags.

opt_help(+OptsSpec, -Help:atom) [det]
True when Help is a help string synthesized from OptsSpec.

parse_type(+Type, +Codes:list(code), -Result) [semidet,multifile]
Hook to parse option text Codes to an object of type Type.

A.31 library(ordsets): Ordered set manipulation

Ordered sets are lists with unique elements sorted to the standard order of terms (see sort/2). Exploiting ordering, many of the set operations can be expressed in order $N$ rather than $N^2$ when dealing with unordered sets that may contain duplicates. The library(ordsets) is available in a number of Prolog implementations. Our predicates are designed to be compatible with common practice in the Prolog community. The implementation is incomplete and relies partly on library(oset), an older ordered set library distributed with SWI-Prolog. New applications are advised to use library(ordsets).

Some of these predicates match directly to corresponding list operations. It is advised to use the versions from this library to make clear you are operating on ordered sets. An exception is member/2. See ord_memberchk/2.

The ordsets library is based on the standard order of terms. This implies it can handle all Prolog terms, including variables. Note however, that the ordering is not stable if a term inside the set is
further instantiated. Also note that variable ordering changes if variables in the set are unified with each other or a variable in the set is unified with a variable that is ‘older’ than the newest variable in the set. In practice, this implies that it is allowed to use `member(X, OrdSet)` on an ordered set that holds variables only if X is a fresh variable. In other cases one should cease using it as an ordset because the order it relies on may have been changed.

```prolog
is_ordset(@Term) [semidet]
True if Term is an ordered set. All predicates in this library expect ordered sets as input arguments. Failing to fullfil this assumption results in undefined behaviour. Typically, ordered sets are created by predicates from this library, `sort/2` or `setof/3`.

ord_empty(?List) [semidet]
True when List is the empty ordered set. Simply unifies list with the empty list. Not part of Quintus.

ord_seteq(+Set1, +Set2) [semidet]
True if Set1 and Set2 have the same elements. As both are canonical sorted lists, this is the same as `==/2`.

Compatibility sicstus

list_to_ord_set(+List, -OrdSet) [det]
Transform a list into an ordered set. This is the same as sorting the list.

ord_intersect(+Set1, +Set2) [semidet]
True if both ordered sets have a non-empty intersection.

ord_disjoint(+Set1, +Set2) [semidet]
True if Set1 and Set2 have no common elements. This is the negation of `ord_intersect/2`.

ord_intersect(+Set1, +Set2, -Intersection)
Intersection holds the common elements of Set1 and Set2.

    deprecated Use `ord_intersection/3`

ord_intersection(+PowerSet, -Intersection) [semidet]
Intersection of a powerset. True when Intersection is an ordered set holding all elements common to all sets in PowerSet. Fails if PowerSet is an empty list.

Compatibility sicstus

ord_intersection(+Set1, +Set2, -Intersection) [det]
Intersection holds the common elements of Set1 and Set2. Uses `ord_disjoint/2` if Intersection is bound to `[]` on entry.

ord_intersection(+Set1, +Set2, ?Intersection, ?Difference) [det]
Intersection and difference between two ordered sets. Intersection is the intersection between Set1 and Set2, while Difference is defined by `ord_subtract(Set2, Set1, Difference)`.  
```
See also `ord_intersection/3` and `ord_subtract/3`.

### `ord_add_element(+Set1, +Element, ?Set2)`
Insert an element into the set. This is the same as `ord_union(Set1, [Element], Set2)`.

### `ord_del_element(+Set, +Element, -NewSet)`
Delete an element from an ordered set. This is the same as `ord_subtract(Set, [Element], NewSet)`.

### `ord_selectchk(+Item, ?Set1, ?Set2)`
Selectchk/3, specialised for ordered sets. Is true when `select(Item, Set1, Set2)` and `Set1, Set2` are both sorted lists without duplicates. This implementation is only expected to work for `Item` ground and either `Set1` or `Set2` ground. The "chk" suffix is meant to remind you of `memberchk/2`, which also expects its first argument to be ground. `ord_selectchk(X, S, T) => ord_memberchk(X, S) & \+ ord_memberchk(X, T)`.

**author** Richard O’Keefe

### `ord_memberchk(+Element, +OrdSet)`
True if `Element` is a member of `OrdSet`, compared using `==`. Note that `enumerating` elements of an ordered set can be done using `member/2`.

Some Prolog implementations also provide `ord_member/2`, with the same semantics as `ord_memberchk/2`. We believe that having a semidet `ord_member/2` is unacceptably inconsistent with the `*_chk` convention. Portable code should use `ord_memberchk/2` or `member/2`.

**author** Richard O’Keefe

### `ord_subset(+Sub, +Super)`
Is true if all elements of `Sub` are in `Super`.

### `ord_subtract(+InOSet, +NotInOSet, -Diff)`
`Diff` is the set holding all elements of `InOSet` that are not in `NotInOSet`.

### `ord_union(+SetOfSets, -Union)`
True if `Union` is the union of all elements in the superset `SetOfSets`. Each member of `SetOfSets` must be an ordered set, the sets need not be ordered in any way.

**author** Copied from YAP, probably originally by Richard O’Keefe.

### `ord_union(+Set1, +Set2, -Union)`
`Union` is the union of `Set1` and `Set2`.

### `ord_union(+Set1, +Set2, -Union, -New)`
True iff `ord_union(Set1, Set2, Union)` and `ord_subtract(Set2, Set1, New)`.
ord_symdiff(+Set1, +Set2, ?Difference)  \[det\]
Is true when Difference is the symmetric difference of Set1 and Set2. I.e., Difference contains all elements that are not in the intersection of Set1 and Set2. The semantics is the same as the sequence below (but the actual implementation requires only a single scan).

\[
\begin{align*}
&\text{ord_union}(\text{Set1}, \text{Set2}, \text{Union}), \\
&\text{ord_intersection}(\text{Set1}, \text{Set2}, \text{Intersection}), \\
&\text{ord_subtract}(\text{Union}, \text{Intersection}, \text{Difference}).
\end{align*}
\]

For example:

?- ord_symdiff([1,2], [2,3], X).
X = [1,3].

A.32 library(pairs): Operations on key-value lists

author Jan Wielemaker
See also keysort/2, library(assoc)

This module implements common operations on Key-Value lists, also known as Pairs. Pairs have great practical value, especially due to keysort/2 and the library assoc.pl.

This library is based on discussion in the SWI-Prolog mailinglist, including specifications from Quintus and a library proposal by Richard O’Keefe.

pairs_keys_values(?Pairs, ?Keys, ?Values)  \[det\]
True if Keys holds the keys of Pairs and Values the values.
Deterministic if any argument is instantiated to a finite list and the others are either free or finite lists. All three lists are in the same order.

See also pairs_values/2 and pairs_keys/2.

pairs_values(+Pairs, -Values)  \[det\]
Remove the keys from a list of Key-Value pairs. Same as pairs_keys_values(Pairs, _, Values)

pairs_keys(+Pairs, -Keys)  \[det\]
Remove the values from a list of Key-Value pairs. Same as pairs_keys_values(Pairs, Keys, _)

group_pairs_by_key(+Pairs, -Joined:list(Key-Values))  \[det\]
Group values with equivalent (==/2) consecutive keys. For example:

?- group_pairs_by_key([a-2, a-1, b-4, a-3], X).
X = [a-[2,1], b-[4], a-[3]]
A.33. LIBRARY(PERSISTENCY): PROVIDE PERSISTENT DYNAMIC PREDICATES 633

Sorting the list of pairs before grouping can be used to group all values associated with a key. For example, finding all values associated with the largest key:

```prolog
?- sort(1, @>=, [a-1, b-2, c-3, a-4, a-5, c-6], Ps),
   group_pairs_by_key(Ps, [K-Vs|_]).
K = c,
Vs = [3, 6].
```

In this example, sorting by key only (first argument of sort/4 is 1) ensures that the order of the values in the original list of pairs is maintained.

<table>
<thead>
<tr>
<th>Pairs</th>
<th>Key-Value list</th>
</tr>
</thead>
<tbody>
<tr>
<td>Joined</td>
<td>List of Key-Group, where Group is the list of Values associated with equivalent consecutive Keys in the same order as they appear in Pairs.</td>
</tr>
</tbody>
</table>

```prolog
transpose_pairs(+Pairs, -Transposed) [det]
```

Swap Key-Value to Value-Key. The resulting list is sorted using keysort/2 on the new key.

```prolog
map_list_to_pairs(:Function, +List, -Keyed)
```

Create a Key-Value list by mapping each element of List. For example, if we have a list of lists we can create a list of Length-List using

```prolog
map_list_to_pairs(length,ListOfLists, Pairs),
```

A.33 library(persistency): Provide persistent dynamic predicates

To be done
- Provide type safety while loading
- Thread safety must now be provided at the user-level. Can we provide generic thread safety? Basically, this means that we must wrap all exported predicates. That might better be done outside this library.
- Transaction management?
- Should assert,<name> only assert if the database does not contain a variant?
- Since we have prolog.listen/2, we could use direct assert/1 and retract/1 and use the system hooks to deal with the updates.

This module provides simple persistent storage for one or more dynamic predicates. A database is always associated with a module. A module that wishes to maintain a database must declare the terms that can be placed in the database using the directive persistent/1. The persistent/1 expands each declaration into four predicates:

- name(Arg, ...)
- assert_name(Arg, ...)
- retract_name(Arg, ...)
- retractall_name(Arg, ...)
As mentioned, a database can only be accessed from within a single module. This limitation is on purpose, forcing the user to provide a proper API for accessing the shared persistent data.

This module requires the same thread-synchronization as the normal Prolog database. This implies that if each individual assert or retract takes the database from one consistent state to the next, no additional locking is required. If more than one elementary database operation is required to get from one consistent state to the next, both updating and querying the database must be locked using \texttt{with_mutex/2}.

Below is a simple example, where adding a user does not need locking as it is a single \texttt{assert}, while modifying a user requires both a retract and assert and thus needs to be locked.

```prolog
:- module(user_db,
    [ attach_user_db/1,  % +File
      current_user_role/2,  % ?User, ?Role
      add_user/2,  % +User, +Role
      set_user_role/2  % +User, +Role
    ]).
:- use_module(library(persistency)).

:- persistent
    user_role(name:atom, role:oneof([user, administrator])).

attach_user_db(File) :-
    db_attach(File, []).

% current_user_role(+Name, -Role) is semidet.

current_user_role(Name, Role) :-
    with_mutex(user_db, user_role(Name, Role)).

add_user(Name, Role) :-
    assert_user_role(Name, Role).

set_user_role(Name, Role) :-
    user_role(Name, Role), !.

set_user_role(Name, Role) :-
    with_mutex(user_db,
        ( retractall_user_role(Name, _),
          assert_user_role(Name, Role))).

\textbf{persistent +Spec}

Declare dynamic database terms. Declarations appear in a directive and have the following format:

```prolog
:- persistent
    <callable>,
```
Each specification is a callable term, following the conventions of `library(record)`, where each argument is of the form

```
name:type
```

Types are defined by `library(error)`.

**current_persistent_predicate(+Pl)**  
True if `Pl` is a predicate that provides access to the persistent database `DB`.

**db_attach(+File, +Options)**  
Use `File` as persistent database for the calling module. The calling module must defined `persistent/1` to declare the database terms. Defined options:

```
sync(+Sync)
```
One of `close` (close journal after write), `flush` (default, flush journal after write) or `none` (handle as fully buffered stream).

If `File` is already attached this operation may change the `sync` behaviour.

**db_attached(+File)**  
True if the context module attached to the persistent database `File`.

**db_assert(+Term)**  
Assert `Term` into the database and record it for persistency. Note that if the on-disk file has been modified it is first reloaded.

**db_detach**  
Detach persistency from the calling module and delete all persistent clauses from the Prolog database. Note that the file is not affected. After this operation another file may be attached, providing it satisfies the same persistency declaration.

**db_retractall(+Term)**  
Retract all matching facts and do the same in the database. If `Term` is unbound, `persistent/1` from the calling module is used as generator.

**db_retract(+Term)**  
Retract terms from the database one-by-one.

**db_sync(+What)**  
Synchronise database with the associated file. `What` is one of:

```
reload
```
Database is reloaded from file if the file was modified since loaded.
update
As reload, but use incremental loading if possible. This allows for two processes to examine the same database file, where one writes the database and the other periodically calls db_sync(update) to follow the modified data.

gec
Database was re-written, deleting all retractall statements. This is the same as gc(50).

gc(Percentage)
GC DB if the number of deleted terms is greater than the given percentage of the total number of terms.

gc(always)
GC DB without checking the percentage.

close
Database stream was closed

detach
Remove all registered persistency for the calling module

nop
No-operation performed

With unbound What, db_sync/1 reloads the database if it was modified on disk, gc it if it is dirty and close it if it is opened.

db_sync_all(+What)
Sync all registered databases.

A.34 library(pio): Pure I/O

This library provides pure list-based I/O processing for Prolog, where the communication to the actual I/O device is performed transparently through coroutining. This module itself is just an interface to the actual implementation modules.

A.34.1 library(pure_input): Pure Input from files and streams

To be done Provide support for alternative input readers, e.g. reading terms, tokens, etc.

This module is part of pio.pl, dealing with pure input: processing input streams from the outside world using pure predicates, notably grammar rules (DCG). Using pure predicates makes non-deterministic processing of input much simpler.

Pure input uses attributed variables to read input from the external source into a list on demand. The overhead of lazy reading is more than compensated for by using block reads based on read_pending_codes/3.

Ulrich Neumerkel came up with the idea to use coroutining for creating a lazy list. His implementation repositioned the file to deal with re-reading that can be necessary on backtracking. The current implementation uses destructive assignment together with more low-level attribute handling to realise pure input on any (buffered) stream.
phrase_from_file(:Grammar, +File) \[\text{nondet}\]
Process the content of File using the DCG rule Grammar. The space usage of this mechanism depends on the length of the not committed part of Grammar. Committed parts of the temporary list are reclaimed by the garbage collector, while the list is extended on demand due to unification of the attributed tail variable. Below is an example that counts the number of times a string appears in a file. The library 
\text{dcg/basics} provides \text{string}///<1 matching an arbitrary string and \text{remainder}///<1 which matches the remainder of the input without parsing.

```prolog
:- use_module(library(dcg/basics)).

file_contains(File, Pattern) :-
    phrase_from_file(match(Pattern), File).

match(Pattern) -->
    string(_),
    string(Pattern),
    remainder(_).

match_count(File, Pattern, Count) :-
    aggregate_all(count, file_contains(File, Pattern), Count).
```

This can be called as (note that the pattern must be a string (code list)):

```
?- match_count('pure_input.pl', 'file', Count).
```

phrase_from_file(:Grammar, +File, +Options) \[\text{nondet}\]
As phrase_from_file/2, providing additional Options. Options are passed to open/4.

phrase_from_stream(:Grammar, +Stream)
Run Grammar against the character codes on Stream. Stream must be buffered.

syntax_error(+Error) //
Throw the syntax error Error at the current location of the input. This predicate is designed to be called from the handler of phrase_from_file/3.

```prolog
throws error(syntax_error(Error), Location)
```

lazy_list_location(-Location) // \[\text{det}\]
Determine current (error) location in a lazy list. True when Location is an (error) location term that represents the current location in the DCG list.

Arguments

\text{Location} is a term file(Name, Line, LinePos, CharNo) or stream(Stream, Line, LinePos, CharNo) if no file is associated to the stream RestLazyList. Finally, if the Lazy list is fully materialized (ends in []), Location is unified with end_of_file-CharCount.
See also lazy_list.character_count/1 only provides the character count.

lazy_list.character_count(-CharCount) //
True when CharCount is the current character count in the Lazy list. The character count is computed by finding the distance to the next frozen tail of the lazy list. CharCount is one of:

• An integer
• A term end_of_file-Count

See also lazy_list.location/1 provides full details of the location for error reporting.

stream_to_lazy_list(+Stream, -List) [det]
Create a lazy list representing the character codes in Stream. List is a partial list ending in an attributed variable. Unifying this variable reads the next block of data. The block is stored with the attribute value such that there is no need to re-read it.

Compatibility Unlike the previous version of this predicate this version does not require a reposition-able stream. It does require a buffer size of at least the maximum number of bytes of a multi-byte sequence (6).

A.35 library(portray_text): Portray text

SWI-Prolog has the special string data type. However, in Prolog, text may be represented more traditionally as a list of character-codes, i.e. (small) integers (in SWI-Prolog specifically, those are Unicode code points). This results in output like the following (here using the backquote notation which maps text to a list of codes):

?- writeln('hello').
?- atom_codes("hello",X).

Unless you know the Unicode tables by heart, this is pretty unpleasant for debugging. Loading library(portray_text) makes the toplevel and debugger consider certain lists of integers as text and print them as text. This is called ”portraying”. Of course, interpretation is imperfect as there is no way to tell in general whether \[65,66\] should written as ’AB ‘or as \[65,66\]. Therefore it is important that the user be aware of the fact that this conversion is enabled. This is why this library must be loaded explicitly.

To be able to copy the printed representation and paste it back, printed text is enclosed in back quotes if current_prolog_flag/2 for the flag back_quotes is codes (the default), and enclosed in double quotes otherwise. Certain control characters are printed out in backslash-escaped form.

The default heuristic only considers list of codes as text if the codes are all from the set of 7-bit ASCII without most of the control characters. A code is classified as text by text_code/1, which in turn calls is_text_code/1. Define portray_text:is_text_code/1 to succeed on additional codes for more flexibility (by default, that predicate succeeds nowhere). For example:

---

SWI-Prolog 9.1 Reference Manual
?- maplist([C,R]>>(portray_text:text_code(C)->R=y;R=n), 'G\u00e9n\u00e9rateur',Results).
Results = [y,n,y,n,y,y,y,y,y,y].

Now make `is_text_code/1` accept anything:

?- [user].
|: portray_text:is_text_code(_).
|: ^D
% user://3 compiled 0.00 sec, 1 clauses
true.

Then:

?- maplist([C,R]>>(portray_text:text_code(C)->R=y;R=n), 'G\u00e9n\u00e9rateur',Results).
Results = [y,y,y,y,y,y,y,y,y,y].

`portray_text(+OnOff:boolean)` [det]
Switch portraying on or off. If `true`, consider lists of integers as list of Unicode code points and print them as corresponding text inside quotes: `text` or "text". Quoting depends on the value of `current_prolog_flag/2 back_quotes`. Same as

?- set_portray_text(enabled, true).

`set_portray_text(+Key, +Value)` [det]
`set_portray_text(+Key, ?Old, +New)` [det]
Set options for portraying. Defined Keys are:

(enabled)
Enable/disable portray text

(min_length)
Only consider for conversion lists of integers that have a length of at least `Value`. Default is 3.

(ellipsis)
When converting a list that is longer than `Value`, elide the output at the start using ellipsis, leaving only `Value` number of non-elided characters: `...end`

`is_text_code(+Code:nonneg)` [semidet,multifile]
Multifile hook that can be used to extend the set of character codes that is recognised as likely text. By default, `is_text_code/1` fails everywhere and internally, only non-control ASCII characters (32-126) and the the control codes (9,10,13) are accepted.

To be done: we might be able to use the current locale to include the appropriate code page. (Does that really make sense?)
A.36 library(predicate_options): Declare option-processing of predicates

Discussions with Jeff Schultz helped shaping this library

A.36.1 The strength and weakness of predicate options

Many ISO predicates accept options, e.g., `open/4`, `write_term/3`. Options offer an attractive alternative to proliferation into many predicates and using high-arity predicates. Properly defined and used, they also form a mechanism for extending the API of both system and application predicates without breaking portability. I.e., previously fixed behaviour can be replaced by dynamic behaviour controlled by an option where the default is the previously defined fixed behaviour. The alternative to using options is to add an additional argument and maintain the previous definition. While a series of predicates with increasing arity is adequate for a small number of additional parameters, the untyped positional argument handling of Prolog quickly makes this unmanageable.

The ISO standard uses the extensibility offered by options by allowing implementations to extend the set of accepted options. While options form a perfect solution to maintain backward portability in a linear development model, it is not well equipped to deal with concurrent branches because

1. There is no API to find which options are supported in a particular implementation.
2. While the portability problem caused by a missing predicate in Prolog $A$ can easily be solved by implementing this predicate, it is much harder to add processing of an additional option to an already existing predicate.

Different Prolog implementations can be seen as concurrent development branches of the Prolog language. Different sets of supported options pose a serious portability issue. Using an option $O$ that establishes the desired behaviour on system $A$ leads (on most systems) to an error or system $B$. Porting may require several actions:

- Drop $O$ (if the option is not vital, such as the layout options to `write_term/3`)
- Replace $O$ by $O2$ (i.e., a differently named option doing the same)
- Something else (cannot be ported; requires a totally different approach, etc.)

Predicates that process options are particularly a problem when writing a compatibility layer to run programs developed for System $A$ on System $B$ because complete emulation is often hard, may cause a serious slowdown and is often not needed because the application-to-be-ported only uses options that are shared by all target Prolog implementations. Unfortunately, the consequences of a partial emulation cannot be assessed by tools.

A.36.2 Options as arguments or environment?

We distinguish two views on options. One is to see them as additional parameters that require strict existence, type and domain-checking and the other is to consider them ‘locally scoped environment variables’. Most systems adopt the first option. SWI-Prolog adopts the second: it silently ignores options that are not supported but does type and domain checking of option-values. The ‘environment’ view is commonly used in applications to create predicates supporting more options using the skeleton
below. This way of programming requires that pred1 and pred2 do not interpret the same option differently. In cases where this is not true, the options must be distributed by some_pred. We have been using this programming style for many years and in practice it turns out that the need for active distribution of options is rare. I.e., options either have distinct names or multiple predicates implement the same option but this has the desired effect. An example of the latter is the encoding option, which typically needs to be applied consistently.

some_pred(..., Options) :-
    pred1(..., Options),
    pred2(..., Options).

As stated before, options provide a readable alternative to high-arity predicates and offer a robust mechanism to evolve the API, but at the cost of some runtime overhead and weaker consistency checking, both at compiletime and runtime. From our experience, the ‘environment’ approach is productive, but the consequence is that mistyped options are silently ignored. The option infrastructure described in this section tries to remedy these problems.

A.36.3 Improving on the current situation

Whether we see options as arguments or locally scoped environment variables, the most obvious way to improve on the current situation is to provide reflective support for options: discover that an argument is an option-list and find what options are supported. Reflective access to options can be used by the compiler and development environment as well as by the runtime system to warn or throw errors.

Options as types

An obvious approach to deal with options is to define the different possible option values as a type and type the argument that processes the option as list(option_type), as illustrated below. Considering options as types fully covers the case where we consider options as additional parameters.

```prolog
:- type open_option ---> type(stream_type) | alias(atom) | ... .
:- pred open(source_sink, open_mode, stream, list(open_option)).
```

There are three reasons for considering a different approach:

- There is no consensus about types in the Prolog world, neither about what types should look like, nor whether or not they are desirable. It is not likely that this debate will be resolved shortly.
- Considering options as types does not support the ‘environment’ view, which we consider the most productive.
- Even when using types, we need reflective access to what options are provided in order to be able to write compile or runtime conditional code.
Reflective access to options

From the above, we conclude that we require reflective access to find out whether an option is supported and valid for a particular predicate. Possible option values must be described by types. Due to lack of a type system, we use `library(error)` to describe allowed option values. Predicate options are declared using `predicate_options/3`:

\[
\text{predicate_options}(PI, +Arg, +Options) \quad \text{[det]}
\]

Declare that the predicate \( PI \) processes options on \( Arg \). \( Options \) is a list of options processed. Each element is one of:

- Option(ModeAndType) \( PI \) processes Option. The option-value must comply to ModeAndType. Mode is one of + or - and Type is a type as accepted by `must_be/2`.
- pass_to(\( PI, Arg \)) The option-list is passed to the indicated predicate.

Below is an example that processes the option `header(boolean)` and passes all options to `open/4`:

\[
\text{write_xml_file(File, XMLTerm, Options) :-}
\]
\[
\text{open(File, write, Out, Options),}
\]
\[
(\text{option(header(true), Options, true)}\rightarrow \text{write_xml_header(Out)}
\]
This predicate is intended to support conditional compilation using if/1 ... endif/0. The predicate `current_predicate_options/3` can be used to access the full capabilities of a predicate.

`check_predicate_option(:PI, +Arg, +Option)`  
Verify predicate options at runtime. Similar to `current_predicate_option/3`, but intended to support runtime checking.

**Errors**
- `existence_error(option, OptionName)` if the option is not supported by `PI`.  
- `type_error(Type, Value)` if the option is supported but the value does not match the option type. See `must_be/2`.

The predicates below can be used in a development environment to inform the user about supported options. PceEmacs uses this for colouring option names and values.

`current_option_arg(:PI, ?Arg)`  
True when `Arg` of `PI` processes predicate options. Which options are processed can be accessed using `current_predicate_option/3`.

`current_predicate_options(:PI, ?Arg, ?Options)`  
True when `Options` is the current active option declaration for `PI` on `Arg`. See `predicate_options/3` for the argument descriptions. If `PI` is ground and refers to an undefined predicate, the autoloader is used to obtain a definition of the predicate.

The library can execute a complete check of your program using `check_predicate_options/0`:

`check_predicate_options`  
Analyse loaded program for erroneous options. This predicate decompiles the current program and searches for calls to predicates that process options. For each option list, it validates whether the provided options are supported and validates the argument type. This predicate performs partial dataflow analysis to track option-lists inside a clause.

**See also** `derive_predicate_options/0` can be used to derive declarations for predicates that pass options. This predicate should normally be called before `check_predicate_options/0`.

The library offers predicates that may be used to create declarations for your application. These predicates are designed to cooperate with the module system.

`derive_predicate_options`  
Derive new predicate option declarations. This predicate analyses the loaded program to find clauses that process options using one of the predicates from `library(option)` or passes options to other predicates that are known to process options. The process is repeated until no new declarations are retrieved.

**See also** `autoload/0` may be used to complete the loaded program.

`retractall_predicate_options`  
Remove all dynamically (derived) predicate options.
**derived_predicate_options(:PL, ?Arg, ?Options)**  
[non-det]

Derive option arguments using static analysis. True when Options is the current derived active option declaration for PI on Arg.

**derived_predicate_options(+Module)**  
[det]

Derive predicate option declarations for a module. The derived options are printed to the current_output stream.

### A.37 library(prolog_debug): User level debugging tools

This library provides tools to control the Prolog debuggers. Traditionally this code was built-in. Because these tools are only required in (interactive) debugging sessions they have been moved into the library.

**prolog:debug_control_hook(+Action)**  
[multifile]

Allow user-hooks in the Prolog debugger interaction. See the calls below for the provided hooks. We use a single predicate with action argument to avoid an uncontrolled poliferation of hooks.

**spy(:Spec)**  
[det]

**nospy(:Spec)**  
[det]

**nospyall**  
[det]

Set/clear spy-points. A successfully set or cleared spy-point is reported using print_message/2, level informational, with one of the following terms, where Spec is of the form M:Head.

- spy(Spec)
- nospy(Spec)

*See also* spy/1 and nospy/1 call the hook prolog:debug_control_hook/1 to allow for alternative specifications of the thing to debug.*

**debugging**  
[det]

Report current status of the debugger.

**trap(+Formal)**  
[det]

**notrap(+Formal)**  
[det]

Install a trap on error(Formal, Context) exceptions that unify. The tracer is started when a matching exception is raised. This predicate enables debug mode using debug/0 to get more context about the exception. Even with debug mode disabled exceptions are still trapped and thus one may call nodebug/0 to run in normal mode after installing a trap. Exceptions are trapped in any thread. Debug mode is only enabled in the calling thread. To enable debug mode in all threads use tdebug/0.

Calling debugging/0 lists the enabled traps. The predicate notrap/1 removes matching (unifying) traps.

In many cases debugging an exception that is caught is as simple as below (assuming run/0 starts your program).
?- gtrap(_).
?- run.

See also
- gtrap/1 to trap using the graphical debugger.
- Edit exceptions menu in PceEmacs and the graphical debugger that provide a graphical frontend
to trap exceptions.

\texttt{exception\_hook(+ExIn, -ExOut, +Frame, +Catcher)}
\hspace*{1cm} [failure]

Trap exceptions and consider whether or not to start the tracer.

\section*{A.38 library(prolog.jiti): Just In Time Indexing (JITI) utilities}

\textbf{To be done} Use \texttt{print\_message/2} and dynamically figure out the column width.

This module provides utilities to examine just-in-time indexes created by the system and can help
diagnosing space and performance issues.

\texttt{jiti\_list}
\hspace*{1cm} [det]

\texttt{jiti\_list(:Spec)}
\hspace*{1cm} [det]

List the JITI (Just In Time Indexes) of selected predicates. The predicate \texttt{jiti\_list/0} list
all just-in-time indexed predicates. The predicate \texttt{jiti\_list/1} takes one of the patterns
below. All parts except for Name can be variables. The last pattern takes an arbitrary number
of arguments.

- Module:Head
- Module:Name/Arity
- Module:Name

The columns use the following notation:

- The \textit{Indexed} column describes the argument(s) indexed:
  - A plain integer refers to a 1-based argument number
  - A+B is a multi-argument index on the arguments A and B.
  - A/B is a deep-index on sub-argument B of argument A.
- The \textit{Buckets} specifies the number of buckets of the hash table
- The \textit{Speedup} specifies the selectivity of the index
- The \textit{Flags} describes additional properties, currently:
  - $L$ denotes that the index contains multiple compound terms with the same name/arity
    that may be used to create deep indexes. The deep indexes themselves are created as
    just-in-time indexes.
A.39  library(prolog_pack): A package manager for Prolog

See also  Installed packages can be inspected using ?- doc_browser.
To be done  
- Version logic
- Find and resolve conflicts
- Upgrade git packages
- Validate git packages
- Test packages: run tests from directory ‘test’.

The library(prolog_pack) provides the SWI-Prolog package manager. This library lets you inspect installed packages, install packages, remove packages, etc. It is complemented by the built-in attach_packs/0 that makes installed packages available as libraries.

pack_list_installed  
List currently installed packages. Unlike pack_list/1, only locally installed packages are displayed and no connection is made to the internet.

See also  Use pack_list/1 to find packages.

pack_info(+Pack)  
Print more detailed information about Pack.

pack_search(+Query)  pack_list(+Query)  
Query package server and installed packages and display results. Query is matches case-insensitively against the name and title of known and installed packages. For each matching package, a single line is displayed that provides:

- Installation status
  - p: package, not installed
  - i: installed package; up-to-date with public version
  - U: installed package; can be upgraded
  - A: installed package; newer than publically available
  - l: installed package; not on server
- Name@Version
- Name@Version(ServerVersion)
- Title

Hint: ?- pack_list(’’). lists all packages.

The predicates pack_list/1 and pack_search/1 are synonyms. Both contact the package server at http://www.swi-prolog.org to find available packages.

See also  pack_list_installed/0 to list installed packages without contacting the server.

pack_install(+Spec:atom)  
Install a package. Spec is one of
A.39. LIBRARY(PROLOG_PACK): A PACKAGE MANAGER FOR PROLOG

- Archive file name
- HTTP URL of an archive file name. This URL may contain a star (*) for the version. In this case pack_install asks for the directory content and selects the latest version.
- GIT URL (not well supported yet)
- A local directory name given as file:// URL or ‘.’
- A package name. This queries the package repository at http://www.swi-prolog.org

After resolving the type of package, pack_install/2 is used to do the actual installation.

pack_install(+Name, +Options) \[det\]
Install package Name. Processes the options below. Default options as would be used by pack_install/1 are used to complete the provided Options.

url(+URL)
Source for downloading the package

package_directory(+Dir)
Directory into which to install the package.

global(+Boolean)
If true, install in the XDG common application data path, making the pack accessible to everyone. If false, install in the XDG user application data path, making the pack accessible for the current user only. If the option is absent, use the first existing and writable directory. If that doesn’t exist find locations where it can be created and prompt the user to do so.

interactive(+Boolean)
Use default answer without asking the user if there is a default action.

silent(+Boolean)
If true (default false), suppress informational progress messages.

upgrade(+Boolean)
If true (default false), upgrade package if it is already installed.

rebuild(Condition)
Rebuild the foreign components. Condition is one of if_absent (default, do nothing if the directory with foreign resources exists), make (run make) or true (run ‘make distclean’ followed by the default configure and build steps).

test(Boolean)
If true (default), run the pack tests.

git(+Boolean)
If true (default false unless URL ends with =.git=), assume the URL is a GIT repository.

link(+Boolean)
Can be used if the installation source is a local directory and the file system supports symbolic links. In this case the system adds the current directory to the pack registration using a symbolic link and performs the local installation steps.
Non-interactive installation can be established using the option `interactive(false)`. It is advised to install from a particular trusted URL instead of the plain pack name for unattended operation.

```prolog
pack_url_file(+URL, -File) [det]
```

True if `File` is a unique id for the referenced pack and version. Normally, that is simply the base name, but GitHub archives destroy this picture. Needed by the pack manager.

```prolog
ssl_verify(+SSL, +ProblemCert, +AllCerts, +FirstCert, +Error)
```

Currently we accept all certificates. We organise our own security using SHA1 signatures, so we do not care about the source of the data.

```prolog
pack_rebuild(+Pack) [det]
```

Rebuilt possible foreign components of `Pack`.

```prolog
pack_rebuild [det]
```

Rebuild foreign components of all packages.

```prolog
pack_upgrade(+Pack) [semidet]
```

Try to upgrade the package `Pack`.

To be done Update dependencies when updating a pack from git?

```prolog
pack_remove(+Name) [det]
```

Remove the indicated package.

```prolog
pack_property(?Pack, ?Property) [nondet]
```

True when `Property` is a property of an installed `Pack`. This interface is intended for programs that wish to interact with the package manager. Defined properties are:

- **directory**(`Directory`)  
  Directory into which the package is installed
- **version**(`Version`)  
  Installed version
- **title**(`Title`)  
  Full title of the package
- **author**(`Author`)  
  Registered author
- **download**(`URL`)  
  Official download `URL`
- **readme**(`File`)  
  Package README file (if present)
- **todo**(`File`)  
  Package TODO file (if present)

```prolog
atom_version(?Atom, ?Version)
```

Translate between atomic version representation and term representation. The term representation is a list of version components as integers and can be compared using `@>`
pack_attach(+Dir, +Options)  
Attach a single package in Dir. The Dir is expected to contain the file pack.pl and a prolog directory. Options processed:

duplicate(+Action)  
What to do if the same package is already installed in a different directory. Action is one of

  warning  
  Warn and ignore the package

  keep  
  Silently ignore the package

  replace  
  Unregister the existing and insert the new package

search(+Where)  
Determines the order of searching package library directories. Default is last, alternative is first.

See also  attach_packs/2 to attach multiple packs from a directory.

A.40  library(prolog_xref): Prolog cross-referencer data collection

See also  Where this library analyses source text, library(prolog_codewalk) may be used to analyse loaded code. The library(check) exploits library(prolog_codewalk) to report on e.g., undefined predicates.

bug  meta_predicate/1 declarations take the module into consideration. Predicates that are both available as meta-predicate and normal (in different modules) are handled as meta-predicate in all places.

This library collects information on defined and used objects in Prolog source files. Typically these are predicates, but we expect the library to deal with other types of objects in the future. The library is a building block for tools doing dependency tracking in applications. Dependency tracking is useful to reveal the structure of an unknown program or detect missing components at compile time, but also for program transformation or minimising a program saved state by only saving the reachable objects.

The library is exploited by two graphical tools in the SWI-Prolog environment: the XPCE frontend started by gxref/0, and library(prolog_colour), which exploits this library for its syntax highlighting.

For all predicates described below, Source is the source that is processed. This is normally a filename in any notation acceptable to the file loading predicates (see load_files/2). Input handling is done by the library(prolog_source), which may be hooked to process any source that can be translated into a Prolog stream holding Prolog source text. Callable is a callable term (see callable/1). Callables do not carry a module qualifier unless the referred predicate is not in the module defined by Source.

prolog:called_by(+Goal, +Module, +Context, -Called)  
[semidet,multifile]  
True when Called is a list of callable terms called from Goal, handled by the predicate Module:Goal and executed in the context of the module Context. Elements of Called may be qualified. If not, they are called in the context of the module Context.
If this succeeds, the cross-referencer assumes Goal may call any of the goals inListOfCalled. If this call fails, default meta-goal analysis is used to determine additional called goals.

Deprecated. New code should use prolog:called_by/4.

Define meta-predicates. See the examples in this file for details.

True if Goal is a hook that is called spontaneously (e.g., from foreign code).

Generate the cross-reference data for Source if not already done and the source is not modified. Checking for modifications is only done for files. Options processed:

If true (default false), emit warning messages.

Define the initial context module to work in.

Determines which calls are registered. Which is one of all, non_iso or non_built_in.

How to handle comments. If store, comments are stored into the database as if the file was compiled. If collect, comments are entered to the xref database and made available through xref_mode/2 and xref_comment/4. If ignore, comments are simply ignored. Default is to collect comments.

Process the content of included files (default is true).

Reset the database for the given source.

Check what sources have been analysed.

Cross-reference executed at Time.

True when By is called from Called in Source. Note that xref_called/3 and
xref_called/4 use distinct/2 to return only distinct Called-By pairs. The xref_called/5 version may return duplicate Called-By if Called is called from multiple clauses in By, but at most one call per clause.

Arguments

By is a head term or one of the reserved terms '.directive'(Line) or 'public'(Line), indicating the call is from an (often initialization/1) directive or there is a public/1 directive that claims the predicate is called from in some untractable way.

Cond is the (accumulated) condition as defined by :- if(Cond) under which the calling code is compiled.

Line is the start line of the calling clause.

xref_defined(?Source, +Goal, ?How) [nondet]
Test if Goal is accessible in Source. If this is the case, How specifies the reason why the predicate is accessible. Note that this predicate does not deal with built-in or global predicates, just locally defined and imported ones. How is one of the terms below. Location is one of Line (an integer) or File:Line if the definition comes from an included (using :- include(File)) directive.

- dynamic(Location)
- thread_local(Location)
- multifile(Location)
- public(Location)
- local(Location)
- foreign(Location)
- constraint(Location)
- imported(From)

xref_definition_line(+How, -Line)
If the 3th argument of xref_defined contains line info, return this in Line.

xref_exported(?Source, ?Head) [nondet]
True when Source exports Head.

xref_module(?Source, ?Module) [nondet]
True if Module is defined in Source.

xref_uses_file(?Source, ?Spec, ?Path) [nondet]
True when Source tries to load a file using Spec.

Arguments

Spec is a specification for absolute_file_name/3
Path is either an absolute file name of the target file or the atom <not_found>.

xref_op(?Source, Op) [nondet]
Give the operators active inside the module. This is intended to setup the environment for incremental parsing of a term from the source-file.
APPENDIX A. THE SWI-PROLOG LIBRARY

Arguments

\[ Op \quad \text{Term of the form } \text{op}(\text{Priority, Type, Name}) \]

\text{xref\_prolog\_flag(?Source, ?Flag, ?Value, ?Line) [nondet]}

True when \( \text{Flag} \) is set to \( \text{Value} \) at \( \text{Line} \) in \( \text{Source} \). This is intended to support incremental parsing of a term from the source-file.

\text{xref\_comment(?Source, ?Title, ?Comment) [nondet]}

Is true when \( \text{Source} \) has a section comment with \( \text{Title} \) and \( \text{Comment} \).

\text{xref\_comment(?Source, ?Head, ?Summary, ?Comment) [nondet]}

Is true when \( \text{Head in Source} \) has the given PlDoc comment.

\text{xref\_mode(?Source, ?Mode, ?Det) [nondet]}

Is true when \( \text{Source} \) provides a predicate with \( \text{Mode} \) and determinism.

\text{xref\_option(?Source, ?Option) [nondet]}

True when \( \text{Source} \) was processed using \( \text{Option} \). Options are defined with \text{xref\_source/2}.

\text{xref\_meta(+Source, +Head, -Called) [semidet]}

True when \( \text{Head} \) calls \( \text{Called} \) in \( \text{Source} \).

\[ \text{Called} \quad \text{is a list of called terms, terms of the form Term+Extra or terms of the form } //\text{(Term)}. \]

\text{xref\_meta(+Head, -Called) [semidet]}

\text{xref\_meta\_src(+Head, -Called, +Src) [semidet]}

True when \( \text{Called} \) is a list of terms called from \( \text{Head} \). Each element in \( \text{Called} \) can be of the form \( \text{Term+Int} \), which means that \( \text{Term} \) must be extended with \( \text{Int} \) additional arguments. The variant \text{xref\_meta/3} first queries the local context.

\text{deprecated} \quad \text{New code should use xref\_meta/3.}

\text{To be done}

- Split predefined in several categories. E.g., the ISO predicates cannot be redefined.
- Rely on the meta\_predicate property for many predicates.

\text{xref\_hook(?Callable) [semidet]}

Definition of known hooks. Hooks that can be called in any module are unqualified. Other hooks are qualified with the module where they are called.

\text{xref\_public\_list(+Spec, +Source, +Options) [semidet]}

Find meta-information about \( \text{File} \). This predicate reads all terms upto the first term that is not a directive. It uses the module and meta\_predicate directives to assemble the information in \( \text{Options} \). \( \text{Options} \) processed:

\text{path(-Path) [semidet]}

\( \text{Path} \) is the full path name of the referenced file.

\text{module(-Module) [semidet]}

\( \text{Module} \) is the module defines in \( \text{Spec} \).
A.41. LIBRARY(QUASI_QUOTATIONS): DEFINE QUASI QUOTATION SYNTAX

exports(-Exports)
Exports is a list of predicate indicators and operators collected from the module/2 term and reexport declarations.

public – Public
Public declarations of the file.

meta(-Meta)
Meta is a list of heads as they appear in meta_predicate/1 declarations.

silent(+Boolean)
Do not print any messages or raise exceptions on errors.

The information collected by this predicate is cached. The cached data is considered valid as long as the modification time of the file does not change.

Arguments
Source is the file from which Spec is referenced.

xref_public_list(+File, -Path, -Export, +Src) [semidet]
xref_public_list(+File, -Path, -Module, -Export, -Meta, +Src) [semidet]
xref_public_list(+File, -Path, -Module, -Export, -Public, -Meta, +Src) [semidet]

Find meta-information about File. This predicate reads all terms upto the first term that is not a directive. It uses the module and meta_predicate directives to assemble the information described below.

These predicates fail if File is not a module-file.

Arguments
Path is the canonical path to File
Module is the module defined in Path
Export is a list of predicate indicators.
Meta is a list of heads as they appear in meta_predicate/1 declarations.
Src is the place from which File is referenced.

deprecated New code should use xref_public_list/3, which unifies all variations using an option list.

xref_source_file(+Spec, -File, +Src) [semidet]
xref_source_file(+Spec, -File, +Src, +Options) [semidet]

Find named source file from Spec, relative to Src.

A.41 library(quasi_quotations): Define Quasi Quotation syntax

author Jan Wielemaker. Introduction of Quasi Quotation was suggested by Michael Hendricks.
See also Why it’s nice to be quoted: quasiquoting for haskell

Inspired by Haskell, SWI-Prolog support quasi quotation. Quasi quotation allows for embedding (long) strings using the syntax of an external language (e.g., HTML, SQL) in Prolog text and syntax-aware embedding of Prolog variables in this syntax. At the same time, quasi quotation provides an alternative to represent long strings and atoms in Prolog.
The basic form of a quasi quotation is defined below. Here, Syntax is an arbitrary Prolog term that must parse into a callable (atom or compound) term and Quotation is an arbitrary sequence of characters, not including the sequence `||`. If this sequence needs to be embedded, it must be escaped according to the rules of the target language or the ‘quoter’ must provide an escaping mechanism.

```
||Syntax||Quotation||
```

While reading a Prolog term, and if the Prolog flag quasi_quotes is set to true (which is the case if this library is loaded), the parser collects quasi quotations. After reading the final full stop, the parser makes the call below. Here, SyntaxName is the functor name of Syntax above and SyntaxArgs is a list holding the arguments, i.e., Syntax =.. [SyntaxName|SyntaxArgs]. Splitting the syntax into its name and arguments is done to make the quasi quotation parser a predicate with a consistent arity 4, regardless of the number of additional arguments.

```
call(+SyntaxName, +Content, +SyntaxArgs, +VariableNames, -Result)
```

The arguments are defined as

- **SyntaxName** is the principal functor of the quasi quotation syntax. This must be declared using quasi_quotation_syntax/1 and there must be a predicate SyntaxName/4.

- **Content** is an opaque term that carries the content of the quasi quoted material and position information about the source code. It is passed to with_quasi_quote_input/3.

- **SyntaxArgs** carries the additional arguments of the Syntax. These are commonly used to make the parameter passing between the clause and the quasi quotation explicit. For example:

  ```
  ...,
  ||html(Name, Address)||
  <tr><td>Name</td><td>Address</td></tr>
  ||
  ```

- **VariableNames** is the complete variable dictionary of the clause as it is made available throug read_term/3 with the option variable_names. It is a list of terms Name = Var.

- **Result** is a variable that must be unified to resulting term. Typically, this term is structured Prolog tree that carries a (partial) representation of the abstract syntax tree with embedded variables that pass the Prolog parameters. This term is normally either passed to a predicate that serializes the abstract syntax tree, or a predicate that processes the result in Prolog. For example, HTML is commonly embedded for writing HTML documents (see library(http/html_write)). Examples of languages that may be embedded for processing in Prolog are SPARQL, RuleML or regular expressions.

The file library(http/html_quasiquotations) provides the, suprisingly simple, quasi quotation parser for HTML.
with_quasi_quotation_input(+Content, -Stream, :Goal)  
Process the quasi-quoted Content using Stream parsed by Goal. Stream is a temporary stream with the following properties:

- Its initial position represents the position of the start of the quoted material.
- It is a text stream, using utf8 encoding.
- It allows for repositioning
- It will be closed after Goal completes.

Arguments

Goal is executed as once(Goal). Goal must succeed. Failure or exceptions from Goal are interpreted as syntax errors.

See also phrase_from_quasi_quotation/2 can be used to process a quotation using a grammar.

phrase_from_quasi_quotation(:Grammar, +Content)  
Process the quasi quotation using the DCG Grammar. Failure of the grammar is interpreted as a syntax error.

See also with_quasi_quotation_input/3 for processing quotations from stream.

quasi_quotation_syntax(:SyntaxName)  
Declare the predicate SyntaxName/4 to implement the the quasi quote syntax SyntaxName. Normally used as a directive.

quasi_quotation_syntax_error(+Error)  
Report syntax_error(Error) using the current location in the quasi quoted input parser.

  throws error(syntax_error(Error), Position)

A.42 library(random): Random numbers

author R.A. O’Keefe, V.S. Costa, L. Damas, Jan Wielemaker

See also Built-in function random/1: A is random(10)

This library is derived from the DEC10 library random. Later, the core random generator was moved to C. The current version uses the SWI-Prolog arithmetic functions to realise this library. These functions are based on the GMP library.

random(-R:float)  
Binds R to a new random float in the open interval (0.0,1.0).

See also
- setrand/1, getrand/1 may be used to fetch/set the state.
- In SWI-Prolog, random/1 is implemented by the function random_float/0.
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random_between(+L:int, +U:int, -R:int)  [semidet]
Binds R to a random integer in [L,U] (i.e., including both L and U). Fails silently if U<L.

random(+L:int, +U:int, -R:int)  [det]
random(+L:float, +U:float, -R:float)  [det]
Generate a random integer or float in a range. If L and U are both integers, R is a random
integer in the half open interval [L,U). If L and U are both floats, R is a float in the open interval
(L,U).

deprecated Please use random/1 for generating a random float and random_between/3 for gen-
erating a random integer. Note that random_between/3 includes the upper bound, while this
predicate excludes it.

setrand(+State)  [det]
getrand(-State)  [det]
Query/set the state of the random generator. This is intended for restarting the generator
at a known state only. The predicate setrand/1 accepts an opaque term returned by
getrand/1. This term may be asserted, written and read. The application may not make
other assumptions about this term.

For compatibility reasons with older versions of this library, setrand/1 also accepts a term
rand(A,B,C), where A, B and C are integers in the range 1..30,000. This argument is used
to seed the random generator. Deprecated.

Errors existence_error(random_state, _) is raised if the underlying infrastructure can-
not fetch the random state. This is currently the case if SWI-Prolog is not compiled with the
GMP library.
See also set_random/1 and random_property/1 provide the SWI-Prolog native implementa-
tion.

maybe  [semidet]
Succeed/fail with equal probability (variant of maybe/1).

maybe(+P)  [semidet]
Succeed with probability P, fail with probability 1-P

maybe(+K, +N)  [semidet]
Succeed with probability K/N (variant of maybe/1)

Does X=A,Y=B or X=B,Y=A with equal probability.

random_member(-X, +List:list)  [semidet]
X is a random member of List. Equivalent to random_between(1, |List|), followed by nth1/3.
Fails of List is the empty list.

Compatibility Quintus and SICStus libraries.

random_select(-X, +List, -Rest)  [semidet]
random_select(+X, -List, +Rest)  [det]
Randomly select or insert an element. Either List or Rest must be a list. Fails if List is the
empty list.
random_subseq(+List, -Subseq, -Complement)  [det]
random_subseq(-List, +Subseq, +Complement)  [semidet]

Selects a random subsequence Subseq of List, with Complement containing all elements of List that were not selected. Each element of List is included with equal probability in either Subseq or Complement.

random_subseq/3 may also be called with Subseq and Complement bound and List unbound, which will recreate List by randomly interleaving Subseq and Complement. This mode may fail randomly, matching SICStus behavior. The failure probability corresponds to the probability of the "forward" mode selecting a Subseq/Complement combination with different lengths.

Compatibility  SICStus 4

randset(+K:int, +N:int, -S:list(int))  [det]

S is a sorted list of K unique random integers in the range 1..N. The implementation uses different techniques depending on the ratio K/N. For small K/N it generates a set of K random numbers, removes the duplicates and adds more numbers until |S| is K. For a large K/N it enumerates 1..N and decides randomly to include the number or not. For example:

?- randset(5, 5, S).
S = [1, 2, 3, 4, 5].  (always)
?- randset(5, 20, S).
S = [2, 7, 10, 19, 20].

See also  randseq/3.

randseq(+K:int, +N:int, -List:list(int))  [det]

S is a list of K unique random integers in the range 1..N. The order is random. Defined as

\[
\text{randseq}(K, N, \text{List}) :-
\text{randset}(K, N, \text{Set}),
\text{random_permutation}(\text{Set}, \text{List}).
\]

See also  randset/3.

random_permutation(+List, -Permutation)  [det]
random_permutation(-List, +Permutation)  [det]

Permutation is a random permutation of List. This is intended to process the elements of List in random order. The predicate is symmetric.

Errors  instantiation_error, type_error(list, _).

random_numlist(+P, +L, +U, -List)  [det]

Unify List with an ascending list of integers between L and U (inclusive). Each integer in the range L..U is included with probability P.

Compatibility  SICStus 4
library(rbtrees): Red black trees

author  Vitor Santos Costa, Jan Wielemaker, Samer Abdallah, Peter Ludemann.

See also
- library(pairs), library(assoc)

Red-Black trees are balanced search binary trees. They are named because nodes can be classified
as either red or black. The code we include is based on "Introduction to Algorithms", second edition,
by Cormen, Leiserson, Rivest and Stein. The library includes routines to insert, lookup and delete
elements in the tree.

A Red black tree is represented as a term $t(Nil, Tree)$, where Nil is the
Nil-node, a node shared for each nil-node in the tree. Any node has the form
colour(Left, Key, Value, Right), where colour is one of red or black.

Warning: instantiation of keys

Red-Black trees depend on the Prolog standard order of terms to organize the keys as a (balanced)
binary tree. This implies that any term may be used as a key. The tree may produce wrong results,
such as not being able to find a key, if the ordering of keys changes after the key has been inserted
into the tree. The user is responsible to ensure that variables used as keys or appearing in a term used
as key that may affect ordering are not unified, with the exception of unification against new fresh
variables. For this reason, ground terms are safe keys. When using non-ground terms, either make
sure the variables appear in places that do not affect the standard order relative to other keys in the
tree or make sure to not unify against these variables as long as the tree is being used.

rb_new(-Tree) [det]
Create a new Red-Black tree Tree.

deprecated Use rb_empty/1.

rb_empty(?Tree) [semidet]
Succeeds if Tree is an empty Red-Black tree.

rb_lookup(+Key, -Value, +Tree) [semidet]
True when Value is associated with Key in the Red-Black tree Tree. The given Key may include
variables, in which case the RB tree is searched for a key with equivalent variables (using
(==)/2). Time complexity is $O(\log N)$ in the number of elements in the tree.

See also  rb_in/3 for backtracking over keys.

rb_min(+Tree, -Key, -Value) [semidet]
Key is the minimum key in Tree, and is associated with Val.

rb_max(+Tree, -Key, -Value) [semidet]
Key is the maximal key in Tree, and is associated with Val.

rb_next(+Tree, +Key, -Next, -Value) [semidet]
Next is the next element after Key in Tree, and is associated with Val. Fails if Key isn’t in Tree
or if Key is the maximum key.
**rb_previous(+Tree, +Key, -Previous, -Value)**

*Previous* is the previous element after *Key* in *Tree*, and is associated with *Val*. Fails if *Key* isn’t in *Tree* or if *Key* is the minimum key.

**rb_update(+Tree, +Key, ?NewVal, -NewTree)**

*Tree NewTree* is tree *Tree*, but with value for *Key* associated with *NewVal*. Fails if *Key* is not in *Tree* (using (==)/2). This predicate may fail or give unexpected results if *Key* is not sufficiently instantiated.

See also *rb_in/3* for backtracking over keys.

**rb_update(+Tree, +Key, -OldVal, ?NewVal, -NewTree)**

Same as *rb_update(Tree, Key, NewVal, NewTree)* but also unifies *OldVal* with the value associated with *Key* in *Tree*.

**rb_apply(+Tree, +Key, :G, -NewTree)**

If the value associated with key *Key* is Val0 in *Tree*, and if call(G,Val0,ValF) holds, then *NewTree* differs from *Tree* only in that *Key* is associated with value ValF in tree *NewTree*. Fails if it cannot find *Key* in *Tree*, or if call(G,Val0,ValF) is not satisfiable.

**rb_in(?Key, ?Value, +Tree)**

True when *Key*-Value is a key-value pair in red-black tree *Tree*. Same as below, but does not materialize the pairs.

```
rb_visit(Tree, Pairs), member(Key-Value, Pairs)
```

Leaves a choicepoint even if *Key* is instantiated; to avoid a choicepoint, use *rb_lookup/3*.

**rb_insert(+Tree, +Key, ?Value, -NewTree)**

Add an element with key *Key* and *Value* to the tree *Tree* creating a new red-black tree *NewTree*. If *Key* is a key in *Tree*, the associated value is replaced by *Value*. See also *rb_insert_new/4*. Does *not* validate that *Key* is sufficiently instantiated to ensure the tree remains valid if a key is further instantiated.

**rb_insert_new(+Tree, +Key, ?Value, -NewTree)**

Add a new element with key *Key* and *Value* to the tree *Tree* creating a new red-black tree *NewTree*. Fails if *Key* is a key in *Tree*. Does *not* validate that *Key* is sufficiently instantiated to ensure the tree remains valid if a key is further instantiated.

**rb_delete(+Tree, +Key, -NewTree)**

Delete element with key *Key* from the tree *Tree*, returning the value Val associated with the key and a new tree *NewTree*. Fails if *Key* is not in *Tree* (using (==)/2).

See also *rb_in/3* for backtracking over keys.

**rb_delete(+Tree, +Key, -Val, -NewTree)**

Same as *rb_delete(Tree, Key, NewTree)*, but also unifies *Val* with the value associated with *Key* in *Tree*.
rb_del_min(+Tree, -Key, -Val, -NewTree)
Delete the least element from the tree Tree, returning the key Key, the value Val associated with
the key and a new tree NewTree. Fails if Tree is empty.

rb_del_max(+Tree, -Key, -Val, -NewTree)
Delete the largest element from the tree Tree, returning the key Key, the value Val associated
with the key and a new tree NewTree. Fails if Tree is empty.

rb_visit(+Tree, -Pairs) [det]
Pairs is an infix visit of tree Tree, where each element of Pairs is of the form Key-Value.

rb_map(+T, :Goal) [semidet]
True if call(Goal, Value) is true for all nodes in T.

rb_map(+Tree, ,G, -NewTree) [semidet]
For all nodes Key in the tree Tree, if the value associated with key Key is Val0 in tree Tree, and
if call(G,Val0,ValF) holds, then the value associated with Key in NewTree is ValF. Fails if call(G,Val0,ValF) is not satisfiable for all Val0. If G is non-deterministic, rb_map/3 will backtrack over all possible values from call(G,Val0,ValF). You should not depend on the order of tree traversal (currently: key order).

rb_fold(:Goal, +Tree, +State0, -State)
Fold the given predicate over all the key-value pairs in Tree, starting with initial state State0
and returning the final state State. Pred is called as

call(Pred, Key-Value, State1, State2)

Determinism depends on Goal.

rb_clone(+TreeIn, -TreeOut, -Pairs) [det]
‘Clone’ the red-back tree TreeIn into a new tree TreeOut with the same keys as the original but
with all values set to unbound values. Pairs is a list containing all new nodes as pairs K-V.

rb_partial_map(+Tree, +Keys, :G, -NewTree)
For all nodes Key in Keys, if the value associated with key Key is Val0 in tree Tree, and if
call(G,Val0,ValF) holds, then the value associated with Key in NewTree is ValF, otherwise it is the value associated with the key in Tree. Fails if Key isn’t in Tree or if call(G,Val0,ValF) is not satisfiable for all Val0 in Keys. Assumes keys are sorted and not repeated (fails if this is not true).

rb_keys(+Tree, -Keys) [det]
Keys is unified with an ordered list of all keys in the Red-Black tree Tree.

list_to_rbtree(+List, -Tree) [det]
Tree is the red-black tree corresponding to the mapping in List, which should be a list of
Key-Value pairs. List should not contain more than one entry for each distinct key, but this is
not validated by list_to_rbtree/2.
ord_list_to_rbtree(+List, -Tree)  [det]

Tree is the red-black tree corresponding to the mapping in list List, which should be a list of Key-Value pairs. List should not contain more than one entry for each distinct key, but this is not validated by ord_list_to_rbtree/2. List is assumed to be sorted according to the standard order of terms.

rb_size(+Tree, -Size)  [det]

Size is the number of elements in Tree.

is_rbtree(@Term)  [semidet]

True if Term is a valid Red-Black tree. Processes the entire tree, checking the coloring of the nodes, the balance and the ordering of keys. Does not validate that keys are sufficiently instantiated to ensure the tree remains valid if a key is further instantiated.

A.44 library(readutil): Read utilities

See also
- library(pure_input) allows for processing files with DCGs.
- library(lazy_lists) for creating lazy lists from input.

This library provides some commonly used reading predicates. As these predicates have proven to be time-critical in some applications we moved them to C. For compatibility as well as to reduce system dependency, we link the foreign code at runtime and fallback to the Prolog implementation if the shared object cannot be found.

read_line_to_codes(+Stream, -Line:codes)  [det]

Read the next line of input from Stream. Unify content of the lines as a list of character codes with Line after the line has been read. A line is ended by a newline character or end-of-file. Unlike read_line_to_codes/3, this predicate removes a trailing newline character.

read_line_to_codes(+Stream, -Line, ?Tail)  [det]

Difference-list version to read an input line to a list of character codes. Reading stops at the newline or end-of-file character, but unlike read_line_to_codes/2, the newline is retained in the output. This predicate is especially useful for reading a block of lines up to some delimiter. The following example reads an HTTP header ended by a blank line:

```
read_header_data(Stream, Header) :-
    read_line_to_codes(Stream, Header, Tail),
    read_header_data(Header, Stream, Tail).
```

```
read_header_data(\r\n", _, _) :- !.
read_header_data(\n", _, _) :- !.
read_header_data("", _, _) :- !.
read_header_data(_, Stream, Tail) :-
    read_line_to_codes(Stream, Tail, NewTail),
    read_header_data(Tail, Stream, NewTail).
```
read_line_to_string(+Stream, -String) [det]
Read the next line from Stream into String. String does not contain the line terminator. String is unified with the atom end_of_file if the end of the file is reached.

See also read_string/5 can be used to read lines with separated records without creating intermediate strings.

read_stream_to_codes(+Stream, -Codes) [det]
read_stream_to_codes(+Stream, -Codes, ?Tail) [det]
Read input from Stream to a list of character codes. The version read_stream_to_codes/3 creates a difference-list.

read_file_to_codes(+Spec, -Codes, +Options) [det]
Read the file Spec into a list of Codes. Options is split into options for absolute_file_name/3 and open/4. In addition, the following option is provided:

tail(?Tail)
Read the data into a difference list Codes\Tail.

See also phrase_from_file/3 and read_file_to_string/3.

read_file_to_string(+Spec, -String, +Options) [det]
Read the file Spec into a the string String. Options is split into options for absolute_file_name/3 and open/4.

See also phrase_from_file/3 and read_file_to_codes/3.

read_file_to_terms(+Spec, -Terms, +Options) [det]
Read the file Spec into a list of terms. Options is split over absolute_file_name/3, open/4 and read_term/3. In addition, the following option is processed:

tail(?Tail)
If present, Terms\Tail forms a difference list.

Note that the output options of read_term/3, such as variable_names or subterm_positions will cause read_file_to_terms/3 to fail if Spec contains multiple terms because the values for the different terms will not unify.

A.45 library(record): Access named fields in a term

The library record provides named access to fields in a record represented as a compound term such as point(X, Y). The Prolog world knows various approaches to solve this problem, unfortunately with no consensus. The approach taken by this library is proposed by Richard O’Keefe on the SWI-Prolog mailinglist.

The approach automates a technique commonly described in Prolog text-books, where access and modification predicates are defined for the record type. Such predicates are subject to normal import/export as well as analysis by cross-referencers. Given the simple nature of the access predicates, an optimizing compiler can easily inline them for optimal performance.

A record is defined using the directive record/1. We introduce the library with a short example:
The principal functor and arity of the term used defines the name and arity of the compound used as records. Each argument is described using a term of the format below.

\[
\langle \text{name}\rangle[:\langle \text{type}\rangle]=\langle \text{default}\rangle
\]

In this definition, \(\langle \text{name}\rangle\) is an atom defining the name of the argument, \(\langle \text{type}\rangle\) is an optional type specification as defined by \text{must be}/2 from library \text{error}, and \(\langle \text{default}\rangle\) is the default initial value. The \(\langle \text{type}\rangle\) defaults to \text{any}. If no default value is specified the default is an unbound variable.

A record declaration creates a set of predicates through term-expansion. We describe these predicates below. In this description, \(\langle \text{constructor}\rangle\) refers to the name of the record (‘point’ in the example above) and \(\langle \text{name}\rangle\) to the name of an argument (field).

- \text{default}\(\langle \text{constructor}\rangle\)(-Record)
  Create a new record where all fields have their default values. This is the same as \text{make}\(\langle \text{constructor}\rangle\)([]\text{. Record})\).

- \text{make}\(\langle \text{constructor}\rangle\)(+Fields, -Record)
  Create a new record where specified fields have the specified values and remaining fields have their default value. Each field is specified as a term \(\langle \text{name}\rangle(\langle \text{value}\rangle)\). See example in the introduction.

- \text{make}\(\langle \text{constructor}\rangle\)(+Fields, -Record, -RestFields)
  Same as \text{make}\(\langle \text{constructor}\rangle\)/2, but named fields that do not appear in \text{Record} are returned in \text{RestFields}. This predicate is motivated by option-list processing. See library \text{option}.

- \(\langle \text{constructor}\rangle\).\(\langle \text{name}\rangle\)(Record, Value)
  Unify \text{Value} with argument in \text{Record} named \(\langle \text{name}\rangle\)\.

- \(\langle \text{constructor}\rangle\).\text{data}(\text{Name}, +\text{Record}, \text{?Value})
  True when \text{Value} is the value for the field named \text{Name} in \text{Record}. This predicate does not perform type-checking.

- \text{set}\(\langle \text{name}\rangle\).\(\langle \text{constructor}\rangle\)(+Value, +\text{OldRecord}, -\text{NewRecord})
  Replace the value for \(\langle \text{name}\rangle\) in \text{OldRecord} by \text{Value} and unify the result with \text{NewRecord}.

- \text{set}\(\langle \text{name}\rangle\).\(\langle \text{constructor}\rangle\)(+Value, !\text{Record})
  Destructively replace the argument \(\langle \text{name}\rangle\) in \text{Record} by \text{Value} based on \text{setarg}/3. Use with care.

\(\text{Note this is not called ‘get’ as it performs unification and can perfectly well instantiate the argument.}\)
• \texttt{nb\_set\_\langle name\rangle\_of\_\langle constructor\rangle(+Value, !Record)}
  As above, but using non-backtrackable assignment based on \texttt{nb\_set\_arg/3}. Use with \texttt{extreme} care.

• \texttt{set\_\langle constructor\rangle\_\langle fields\rangle(+Fields, +Record0, -Record)}
  Set multiple fields using the same syntax as \texttt{make\_\langle constructor\rangle/2}, but starting with \texttt{Record0} rather than the default record.

• \texttt{set\_\langle constructor\rangle\_\langle fields\rangle(+Fields, +Record0, -Record, -RestFields)}
  Similar to \texttt{set\_\langle constructor\rangle\_\langle fields\rangle/4}, but fields not defined by \texttt{\langle constructor\rangle} are returned in \texttt{RestFields}.

• \texttt{set\_\langle constructor\rangle\_\langle field\rangle(+Field, +Record0, -Record)}
  Set a single field specified as a term \texttt{\langle name\rangle(\langle value\rangle)}.

\begin{verbatim}
record(+Spec)
  The construct :- record Spec, ... is used to define access to named fields in a compound. It is subject to term-expansion (see \texttt{expand\_term/2}) and cannot be called as a predicate. See section \textbf{A.45} for details.
\end{verbatim}

\section*{A.46 library(registry): Manipulating the Windows registry}

The \texttt{registry} is only available on the MS-Windows version of SWI-Prolog. It loads the foreign extension \texttt{plregtry.dll}, providing the predicates described below. This library only makes the most common operations on the registry available through the Prolog user. The underlying DLL provides a more complete coverage of the Windows registry API. Please consult the sources in \texttt{pl/src/win32/foreign/plregtry.c} for further details.

In all these predicates, \texttt{Path} refers to a ‘\texttt{/}’ separated path into the registry. This is \texttt{not} an atom containing ‘\texttt{/}’-characters as used for filenames, but a term using the functor \texttt{//2}. Windows defines the following roots for the registry: \texttt{classes\_root}, \texttt{current\_user}, \texttt{local\_machine} and \texttt{users}.

\begin{verbatim}
registry\_get\_key(+Path, -Value)
  Get the principal (default) value associated to this key. Fails silently if the key does not exist.

registry\_get\_key(+Path, +Name, -Value)
  Get a named value associated to this key.

registry\_set\_key(+Path, +Value)
  Set the principal (default) value of this key. Creates (a path to) the key if it does not already exist.

registry\_set\_key(+Path, +Name, +Value)
  Associate a named value to this key. Creates (a path to) the key if it does not already exist.

registry\_delete\_key(+Path)
  Delete the indicated key.

shell\_register\_file\_type(+Ext, +Type, +Name, +OpenAction)
  Register a file-type. \texttt{Ext} is the extension to associate. \texttt{Type} is the type name, often something
\end{verbatim}
like prolog.type. Name is the name visible in the Windows file-type browser. Finally, OpenAction defines the action to execute when a file with this extension is opened in the Windows explorer.

**shell_register_dde(+Type, +Action, +Service, +Topic, +Command, +IfNotRunning)**

Associate DDE actions to a type. Type is the same type as used for the 2nd argument of shell_register_file_type/4, Action is the action to perform, Service and Topic specify the DDE topic to address, and Command is the command to execute on this topic. Finally, IfNotRunning defines the command to execute if the required DDE server is not present.

**shell_register_prolog(+Ext)**

Default registration of SWI-Prolog, which is invoked as part of the initialisation process on Windows systems. As the source also includes the above predicates, it is given as an example:

```prolog
shell_register_prolog(Ext) :-
    current_prolog_flag(argv, [Me|_]),
    atomic_list_concat([""', Me, "" "$1""]', OpenCommand),
    shell_register_file_type(
        Ext, 'prolog.type', 'Prolog Source', OpenCommand),
    shell_register_dde(
        'prolog.type', consult,
        prolog, control, 'consult(''%1'')', Me),
    shell_register_dde(
        'prolog.type', edit,
        prolog, control, 'edit(''%1'')', Me).
```

**A.47 library(settings): Setting management**

**author** Jan Wielemaker

**See also** library(config) distributed with XPCE provides an alternative aimed at graphical applications.

This library allows management of configuration settings for Prolog applications. Applications define settings in one or multiple files using the directive setting/4 as illustrated below:

```prolog
:- use_module(library(settings)).

:- setting(version, atom, '1.0', 'Current version').
:- setting(timeout, number, 20, 'Timeout in seconds').
```

The directive is subject to term_expansion/2, which guarantees proper synchronisation of the database if source-files are reloaded. This implies it is not possible to call setting/4 as a predicate.

Settings are local to a module. This implies they are defined in a two-level namespace. Managing settings per module greatly simplifies assembling large applications from multiple modules that
configuration through settings. This settings management library ensures proper access, loading and saving of settings.

**setting(:Name, +Type, +Default, +Comment)**  
[det]  
Define a setting. Name denotes the name of the setting, Type its type. Default is the value before it is modified. Default can refer to environment variables and can use arithmetic expressions as defined by eval_default/4.

If a second declaration for a setting is encountered, it is ignored if Type and Default are the same. Otherwise a permission_error is raised.

**Arguments**

- **Name**: Name of the setting (an atom)
- **Type**: Type for setting. One of any or a type defined by must_be/2.
- **Default**: Default value for the setting.
- **Comment**: Atom containing a (short) descriptive note.

**setting(:Name, ?Value)**  
[nondet]  
True when Name is a currently defined setting with Value. Note that setting(Name, Value) only enumerates the settings of the current module. All settings can be enumerated using setting(Module:Name, Value). This predicate is det if Name is ground.

**Errors**  
existence_error(setting, Name)

eval_default(+Name:atom, -Value:number)  
[det]  
eval_default(+Name:atom, +Default:number, -Value:number)  
[det]  
Evaluate environment variables on behalf of arithmetic expressions.

**set_setting(:Name, +Value)**  
[det]  
Change a setting. Performs existence and type-checking for the setting. If the effective value of the setting is changed it broadcasts the event below.

```
settings(changed(Module:Name, Old, New))
```

Note that modified settings are not automatically persistent. The application should call save_settings/0 to persist the changes.

**Errors**

- existence_error(setting, Name)
- type_error(Type, Value)

**restore_setting(:Name)**  
[det]  
Restore the value of setting Name to its default. Broadcast a change like set_setting/2 if the current value is not the default.

**set_setting_default(:Name, +Default)**  
[det]  
Change the default for a setting. The effect is the same as set_setting/2, but the new value is considered the default when saving and restoring a setting. It is intended to change application defaults in a particular context.
**A.47. LIBRARY(SETTINGS): SETTING MANAGEMENT**

`load_settings(File)`  
Load local settings from `File`. Succeeds if `File` does not exist, setting the default save-file to `File`. **Options** are:

- `undefined`  
  Define how to handle settings that are not defined. When `error`, an error is printed and the setting is ignored. When `load`, the setting is loaded anyway, waiting for a definition.

If possibly changed settings need to be persistent, the application must call `save_settings/0` as part of its shutdown. In simple cases calling `at_halt(save_settings)` is sufficient.

`save_settings`  
Save modified settings to `File`. Fails silently if the settings file cannot be written. The `save_settings/0` only attempts to save the settings file if some setting was modified using `set_setting/2`.

**Errors** `context_error(settings, no_default_file)` for `save_settings/0` if no default location is known.

`current_setting(?Setting)`  
True if `Setting` is a currently defined setting.

`setting_property(+Setting, +Property)`  
Query currently defined settings. `Property` is one of

- `comment(-Atom)`  
  Comment

- `type(-Type)`  
  Type of the setting.

- `default(-Default)`  
  Default value. If this is an expression, it is evaluated.

- `source(-File:-Line)`  
  Location where the setting is defined.

`list_settings`  
List settings to `current_output`. The second form only lists settings on the matching module.

**To be done** Compute the required column widths

`convert_setting_text(+Type, +Text, -Value)`  
Converts from textual form to Prolog `Value`. Used to convert values obtained from the environment. Public to provide support in user-interfaces to this library.

**Errors** `type_error(Type, Value)`
A.48 library(statistics): Get information about resource usage

This library provides predicates to obtain information about resource usage by your program. The predicates of this library are for human use at the toplevel: information is printed. All predicates obtain their information using public low-level primitives. These primitives can be use to obtain selective statistics during execution.

\[\text{statistics} \quad \text{[det]}\]
Print information about resource usage using \text{print_message}/2.

\[\text{statistics}(-\text{Stats:dict}) \quad \text{[det]}\]
\text{Stats} is a dict representing the same information as \text{statistics}/0. This convinence function is primarily intended to pass statistical information to e.g., a web client. Time critical code that wishes to collect statistics typically only need a small subset and should use \text{statistics}/2 to obtain exactly the data they need.

\[\text{thread_statistics}(-\text{Thread}, -\text{Stats:dict}) \quad \text{[nondet]}\]
Obtain statistical information about a single thread. Fails silently of the \text{Thread} is no longer alive.

\text{Stats} is a dict containing status, time and stack-size information about \text{Thread}.

\[\text{time}(\text{Goal}) \quad \text{[nondet]}\]
Execute \text{Goal}, reporting statistics to the user. If \text{Goal} succeeds non-deterministically, retrying reports the statistics for providing the next answer.

Statistics are retrieved using \text{thread_statistics}/3 on the calling thread. Note that not all systems support thread-specific CPU time. Notable, this is lacking on MacOS X.

\[\text{call_time}(\text{Goal}, -\text{Time:dict})\]
\[\text{call_time}(\text{Goal}, -\text{Time:dict}, -\text{Result})\]
Call \text{Goal} as call/1, unifying \text{Time} with a dict that provides information on the resource usage. Currently \text{Time} contains the keys below. Future versions may provide additional keys.

- \text{wall:Seconds}
- \text{cpu:Seconds}
- \text{inferences:Count}

\text{Result} is one of true or false depending on whether or not the goal succeeded.
A.48. LIBRARY(STATISTICS): GET INFORMATION ABOUT RESOURCE USAGE

profile(:Goal)
profile(:Goal, +Options)

Run Goal under the execution profiler. Defined options are:

  time(Which)
  Profile cpu or wall time. The default is CPU time.

  top(N)
  When generating a textual report, show the top N predicates.

    cumulative(Bool)
    If true (default false), show cumulative output in a textual report.

show_profile(+Options)
Display last collected profiling data. Options are

  top(N)
  When generating a textual report, show the top N predicates.

    cumulative(Bool)
    If true (default false), show cumulative output in a textual report.

profile_data(-Data) [det]
Gather all relevant data from profiler. This predicate may be called while profiling is active in which case it is suspended while collecting the data. Data is a dict providing the following fields:

  summary : Dict
  Overall statistics providing
  • samples:Count: Times the statistical profiler was called
  • ticks:Count Virtual ticks during profiling
  • accounting:Count Tick spent on accounting
  • time:Seconds Total time sampled
  • nodes:Count Nodes in the call graph.

  nodes
  List of nodes. Each node provides:
  • predicate:PredicateIndicator
  • ticks_self:Count
  • ticks_siblings:Count
  • call:Count
  • redo:Count
  • exit:Count
  • callers:list_of(Relative)
  • callees:list_of(Relative)

  Relative is a term of the shape below that represents a caller or callee. Future versions are likely to use a dict instead.
node(PredicateIndicator, CycleID, Ticks, TicksSiblings, Calls, Redos, Exits)

profile_procedure_data(?Pred, -Data:dict) [nondet]
Collect data for Pred. If Pred is unbound data for each predicate that has profile data available is returned. Data is described in profile_data/1 as an element of the nodes key.

A.49 library(strings): String utilities

See also
- format/3 can format to a string as well. The library(lynx/format) provides primitive to wrap long strings.
- The core system provides many additional string processing predicates.

To be done There are probably many other high level string predicates that belong in this library. For example, predicates similar to the functions in https://docs.python.org/3/library/textwrap.html

This module provides string handling utilities, currently notably for dealing with multi-line strings and interpolation. The library provides a couple of primitives as well definitions for the string quasi quotation syntax. The latter allows for constructing both single line and multi-line long strings based on template interpolation. Below is a simple example using the quasi quotation syntax.

test(To) :-
  write({|string(To)||
    | Dear {To},
    |
    | I’m happy to announce a string interpolation quasi quoter. |
  }.

Warning
The general purpose string interpolation implemented by this library should not be used to create strings for a formal language such as HTML, JavaScript, SQL, etc. because the result will be subject to injection attacks, providing a serious security risk. The core idea of quasi quotation is to know about the target language and interpolate Prolog data into the template while respecting the syntax of the target language, notably to escape certain characters where needed. See also library(http/html_write) and library(http/js_write) which define quasi quotation rules for HTML and JavaScript.

string(+Content, +Args, +Binding, -DOM)
Implements the quasi quotation syntax string. If the first character of the content is a newline (i.e., there is a newline immediately after the || token) this first uses dedent_lines/3 to the remove common white space prefix from the lines. This is called with the option chars("\s\t"), i.e., also removing | characters and tab(8).

If the quasi quotation syntax carries arguments (e.g., string(To)), the string is compiled into a function that produces the result of interpolating the arguments into the template. See user functions on dict objects. If there are no arguments, the result is simply the final string.
interpolate_string(:In, -Out, +Map, +Options)

Establish a string from a template by replacing patterns. Supported patterns are:

\{Name\}
   If Map contains Name=Value, insert Value using write/1. If Name does not appear in Map, raise an existence error. Name must satisfy the rules for a Prolog variable.

\{Name,Default\}
   As above, but if Name does not appear in Map, use Value

\{@(Goal)\}
   Insert the output (to current_output) of Goal here. For safety reasons only accepted if Options contains goals(true)

string_lines(?String, ?Lines)  [det]

True when String represents Lines. This follows the normal text convention that a line is defined as a possible empty string followed by a newline character ("\n"). E.g.

?- string_lines("a\nb\n", L).
   L = ["a", "b"].

?- string_lines(S, ["a", "b"]).
   S = "a\nb\n".

This predicate is a true relation if both arguments are in canonical form, i.e. all text is represented as strings and the first argument ends with a newline. The implementation tolerates non-canonical input: other types than strings are accepted and String does not need to end with a newline.

See also split_string/4. Using split_string(String, "\n", ",", Lines) on a string that ends in a newline adds an additional empty string compared to string_lines/2.

dedent_lines(+In, -Out, +Options)

Remove shared indentation for all lines in a string. Lines are separated by "\n" – conversion to and from external forms (such as "\r\n") are typically done by the I/O predicates. A final "\n" is preserved.

Options:

tab(N)
   Assume tabs at columns of with N. When omitted, tabs are taken literally and only exact matches are removed.

chars(CodesOrString)
   Characters to remove. This can notably be used to remove additional characters such as * or \'. Default is " \	".
indent_lines(+Prefix, +In, -Out)  \[det\]
Add Prefix to the beginning of lines in In. Lines are separated by "\n" – conversion to and from external forms (such as "\r\n") are typically done by the I/O predicates. Lines that consist entirely of whitespace are left as-is.

indent_lines(:Filter, +Prefix, +In, -Out)  \[det\]
Similar to indent_lines/3, but only adds Prefix to lines for which call(Filter, Line) succeeds.

A.50 library(simplex): Solve linear programming problems

author Markus Triska

A.50.1 Introduction

A linear programming problem or simply linear program (LP) consists of:

• a set of linear constraints
• a set of variables
• a linear objective function.

The goal is to assign values to the variables so as to maximize (or minimize) the value of the objective function while satisfying all constraints.

Many optimization problems can be modeled in this way. As one basic example, consider a knapsack with fixed capacity C, and a number of items with sizes \(s(i)\) and values \(v(i)\). The goal is to put as many items as possible in the knapsack (not exceeding its capacity) while maximizing the sum of their values.

As another example, suppose you are given a set of coins with certain values, and you are to find the minimum number of coins such that their values sum up to a fixed amount. Instances of these problems are solved below.

Solving an LP or integer linear program (ILP) with this library typically comprises 4 stages:

1. an initial state is generated with \texttt{gen_state/1}
2. all relevant constraints are added with \texttt{constraint/3}
3. \texttt{maximize/3} or \texttt{minimize/3} are used to obtain a solved state that represents an optimum solution
4. \texttt{variable_value/3} and \texttt{objective/2} are used on the solved state to obtain variable values and the objective function at the optimum.

The most frequently used predicates are thus:

\texttt{gen_state(-State)}
Generates an initial state corresponding to an empty linear program.
A.50. LIBRARY(SIMPLEX): SOLVE LINEAR PROGRAMMING PROBLEMS

constraint(+Constraint, +S0, -S)

Adds a linear or integrality constraint to the linear program corresponding to state S0. A linear constraint is of the form \( \text{Left } \text{Op } C \), where \( \text{Left} \) is a list of \( \text{Coefficient*Variable} \) terms (variables in the context of linear programs can be atoms or compound terms) and \( C \) is a non-negative numeric constant. The list represents the sum of its elements. \( \text{Op} \) can be \( =, =< \) or \( >= \). The coefficient 1 can be omitted. An integrality constraint is of the form \( \text{integral} \{ \text{Variable} \} \) and constrains Variable to an integral value.

maximize(+Objective, +S0, -S)

Maximizes the objective function, stated as a list of \( \text{Coefficient*Variable} \) terms that represents the sum of its elements, with respect to the linear program corresponding to state S0. \( \text{arg}\{S\} \) is unified with an internal representation of the solved instance.

minimize(+Objective, +S0, -S)

Analogous to maximize/3.

variable_value(+State, +Variable, -Value)

Value is unified with the value obtained for \( \text{Variable} \). \( \text{State} \) must correspond to a solved instance.

objective(+State, -Objective)

Unifies Objective with the result of the objective function at the obtained extremum. \( \text{State} \) must correspond to a solved instance.

All numeric quantities are converted to rationals via \text{rationalize/1}, and rational arithmetic is used throughout solving linear programs. In the current implementation, all variables are implicitly constrained to be non-negative. This may change in future versions, and non-negativity constraints should therefore be stated explicitly.

A.50.2 Delayed column generation

Delayed column generation means that more constraint columns are added to an existing LP. The following predicates are frequently used when this method is applied:

constraint(+Name, +Constraint, +S0, -S)

Like constraint/3, and attaches the name \( \text{Name} \) (an atom or compound term) to the new constraint.

shadow_price(+State, +Name, -Value)

Unifies Value with the shadow price corresponding to the linear constraint whose name is \( \text{Name} \). \( \text{State} \) must correspond to a solved instance.

constraint_add(+Name, +Left, +S0, -S)

\( \text{Left} \) is a list of \( \text{Coefficient*Variable} \) terms. The terms are added to the left-hand side of the constraint named \( \text{Name} \). \( S \) is unified with the resulting state.

An example application of delayed column generation to solve a bin packing task is available from: metalevel.at/various/colgen/
A.50.3 Solving LPs with special structure

The following predicates allow you to solve specific kinds of LPs more efficiently:

**transportation(+Supplies, +Demands, +Costs, -Transport)**

Solves a transportation problem. *Supplies* and *Demands* must be lists of non-negative integers. Their respective sums must be equal. *Costs* is a list of lists representing the cost matrix, where an entry $(i,j)$ denotes the integer cost of transporting one unit from $i$ to $j$. A transportation plan having minimum cost is computed and unified with *Transport* in the form of a list of lists that represents the transportation matrix, where element $(i,j)$ denotes how many units to ship from $i$ to $j$.

**assignment(+Cost, -Assignment)**

Solves a linear assignment problem. *Cost* is a list of lists representing the quadratic cost matrix, where element $(i,j)$ denotes the integer cost of assigning entity $i$ to entity $j$. An assignment with minimal cost is computed and unified with *Assignment* as a list of lists, representing an adjacency matrix.

A.50.4 Examples

We include a few examples for solving LPs with this library.

**Example 1**

This is the "radiation therapy" example, taken from *Introduction to Operations Research* by Hillier and Lieberman.

**Prolog DCG notation** is used to implicitly thread the state through posting the constraints:

```prolog
:- use_module(library(simplex)).

radiation(S) :-
    gen_state(S0),
    post_constraints(S0, S1),
    minimize([0.4*x1, 0.5*x2], S1, S).

post_constraints -->
    constraint([0.3*x1, 0.1*x2] =< 2.7),
    constraint([0.5*x1, 0.5*x2] = 6),
    constraint([0.6*x1, 0.4*x2] >= 6),
    constraint([x1] >= 0),
    constraint([x2] >= 0).
```

An example query:

```prolog
?- radiation(S), variable_value(S, x1, Val1),
   variable_value(S, x2, Val2).
Val1 = 15 rdiv 2,
Val2 = 9 rdiv 2.
```
Example 2

Here is an instance of the knapsack problem described above, where \( C = 8 \), and we have two types of items: One item with value 7 and size 6, and 2 items each having size 4 and value 4. We introduce two variables, \( x(1) \) and \( x(2) \) that denote how many items to take of each type.

```prolog
:- use_module(library(simplex)).

knapsack(S) :-
    knapsack_constraints(S0),
    maximize([7*x(1), 4*x(2)], S0, S).

knapsack_constraints(S) :-
    gen_state(S0),
    constraint([6*x(1), 4*x(2)] <= 8, S0, S1),
    constraint([x(1)] <= 1, S1, S2),
    constraint([x(2)] <= 2, S2, S).
```

An example query yields:

```prolog
?- knapsack(S), variable_value(S, x(1), X1),
    variable_value(S, x(2), X2).
X1 = 1
X2 = 1 + 1/2.
```

That is, we are to take the one item of the first type, and half of one of the items of the other type to maximize the total value of items in the knapsack.

If items can not be split, integrality constraints have to be imposed:

```prolog
knapsack_integral(S) :-
    knapsack_constraints(S0),
    constraint(integral(x(1)), S0, S1),
    constraint(integral(x(2)), S1, S2),
    maximize([7*x(1), 4*x(2)], S2, S).
```

Now the result is different:

```prolog
?- knapsack_integral(S), variable_value(S, x(1), X1),
   variable_value(S, x(2), X2).
X1 = 0
X2 = 2
```

That is, we are to take only the two items of the second type. Notice in particular that always choosing the remaining item with best performance (ratio of value to size) that still fits in the knapsack does not necessarily yield an optimal solution in the presence of integrality constraints.
Example 3

We are given:

- 3 coins each worth 1 unit
- 20 coins each worth 5 units and
- 10 coins each worth 20 units.

The task is to find a minimal number of these coins that amount to 111 units in total. We introduce variables $c(1)$, $c(5)$ and $c(20)$ denoting how many coins to take of the respective type:

```prolog
:- use_module(library(simplex)).

coins(S) :-
    gen_state(S0),
    coins(S0, S).

coins -->
    constraint([c(1), 5*c(5), 20*c(20)] = 111),
    constraint([c(1)] =< 3),
    constraint([c(5)] =< 20),
    constraint([c(20)] =< 10),
    constraint([c(1)] >= 0),
    constraint([c(5)] >= 0),
    constraint([c(20)] >= 0),
    constraint(integral(c(1))),
    constraint(integral(c(5))),
    constraint(integral(c(20))),
    minimize([c(1), c(5), c(20)]).
```

An example query:

```prolog
?- coins(S), variable_value(S, c(1), C1),
   variable_value(S, c(5), C5),
   variable_value(S, c(20), C20).
```

C1 = 1,
C5 = 2,
C20 = 5.

A.51 library(solution_sequences): Modify solution sequences

See also
- all solution predicates findall/3, bagof/3 and setof/3.
- library(aggregate)
The meta predicates of this library modify the sequence of solutions of a goal. The modifications and the predicate names are based on the classical database operations DISTINCT, LIMIT, OFFSET, ORDER BY and GROUP BY.

These predicates were introduced in the context of the SWISH Prolog browser-based shell, which can represent the solutions to a predicate as a table. Notably wrapping a goal in `distinct/1` avoids duplicates in the result table and using `order_by/2` produces a nicely ordered table.

However, the predicates from this library can also be used to stay longer within the clean paradigm where non-deterministic predicates are composed from simpler non-deterministic predicates by means of conjunction and disjunction. While evaluating a conjunction, we might want to eliminate duplicates of the first part of the conjunction. Below we give both the classical solution for solving variations of \((a(X), b(X))\) and the ones using this library side-by-side.

### Avoid duplicates of earlier steps

```prolog
setof(X, a(X), Xs), distinct(a(X)),
member(X, Xs), b(X).
```

Note that the `distinct/1` based solution returns the first result of `distinct(a(X))` immediately after `a/1` produces a result, while the `setof/3` based solution will first compute all results of `a/1`.

### Only try \((a(X), b(X))\) only for the top 10

```prolog
setof(X, a(X), Xs), limit(10, order_by([desc(X)], a(X))),
reverse(Xs, Desc),
first_max_n(10, Desc, Limit),
member(X, Limit),
b(X).
```

Here we see power of composing primitives from this library and staying within the paradigm of pure non-deterministic relational predicates.

---

**distinct(:Goal)**

**distinct(?Witness, :Goal)**

True if `Goal` is true and no previous solution of `Goal` bound `Witness` to the same value. As previous answers need to be copied, equivalence testing is based on term variance (=@=/2).

The variant `distinct/1` is equivalent to `distinct(Goal,Goal)`.

If the answers are ground terms, the predicate behaves as the code below, but answers are returned as soon as they become available rather than first computing the complete answer set.

```prolog
distinct(Goal) :-
    findall(Goal, Goal, List),
    list_to_set(List, Set),
    member(Goal, Set).
```

**reduced(:Goal)**

**reduced(?Witness, :Goal, +Options)**
Similar to distinct/1, but does not guarantee unique results in return for using a limited amount of memory. Both distinct/1 and reduced/1 create a table that block duplicate results. For distinct/1, this table may get arbitrary large. In contrast, reduced/1 discards the table and starts a new one of the table size exceeds a specified limit. This filter is useful for reducing the number of answers when processing large or infinite long tail distributions. Options:

size_limit(+Integer)
   Max number of elements kept in the table. Default is 10,000.

limit(+Count, :Goal)
   Limit the number of solutions. True if Goal is true, returning at most Count solutions. Solutions are returned as soon as they become available.

   Arguments
   Count is either infinite, making this predicate equivalent to call/1 or an integer. If Count < 1 this predicate fails immediately.

offset(+Count, :Goal)
   Ignore the first Count solutions. True if Goal is true and produces more than Count solutions. This predicate computes and ignores the first Count solutions.

call_nth(:Goal, ?Nth)
   True when Goal succeeded for the Nth time. If Nth is bound on entry, the predicate succeeds deterministically if there are at least Nth solutions for Goal.

order_by(+Spec, :Goal)
   Order solutions according to Spec. Spec is a list of terms, where each element is one of. The ordering of solutions of Goal that only differ in variables that are not shared with Spec is not changed.

   Arguments
   asc(Term)
      Order solution according to ascending Term

   desc(Term)
      Order solution according to descending Term

   This predicate is based on findall/3 and (thus) variables in answers are copied.

group_by(+By, +Template, :Goal, -Bag)
   [nondet]
   Group bindings of Template that have the same value for By. This predicate is almost the same as bagof/3, but instead of specifying the existential variables we specify the free variables. It is provided for consistency and complete coverage of the common database vocabulary.

A.52 library(tables): XSB interface to tables

This module provides an XSB compatible library to access tables as created by tabling (see table/1). The aim of this library is first of all compatibility with XSB. This library contains some old and internal XSB predicates that are marked deprecated.
t not(:Goal)
   Tabled negation.
   
   deprecated This is a synonym to tnot/1.

tfindall(+Template, :Goal, -Answers)
   This predicate emerged in XSB in an attempt to provide a safer alternative to findall/3.
   This doesn’t really work in XSB and the SWI-Prolog emulation is a simple call to findall/3.
   Note that Goal may not be a variant of an incomplete table.
   
   deprecated Use findall/3

set_pil_on
set_pil_off
   Dummy predicates for XSB compatibility.
   
   deprecated These predicates have no effect.

get_call(:CallTerm, -Trie, -Return)  [semidet]
   True when Trie is an answer trie for a variant of CallTerm. Return is a term ret/N with N variables that share with variables in CallTerm. The Trie contains zero or more instances of the Return term. See also get_calls/3.

get_calls(:CallTerm, -Trie, -Return)  [nondet]
   True when Tria is an answer trie for a variant that unifies with CallTerm and Skeleton is the answer skeleton. See get_call/3 for details.

get_returns(+ATrie, -Return)  [nondet]
   True when Return is an answer template for the AnswerTrie.

   Arguments
   return is a term ret(...). See get_calls/3.

get_returns(+AnswerTrie, -Return, -NodeID)  [nondet]
   True when Return is an answer template for the AnswerTrie and the answer is represented by the trie node NodeID.

   Arguments
   Return is a term ret(...). See get_calls/3.

get_returns_and_tws(+AnswerTrie, -Return, -TruthValue)  [nondet]
   Identical to get_returns/2, but also obtains the truth value of a given answer, setting TruthValue to t if the answer is unconditional and to u if it is conditional. If a conditional answer has multiple delay lists, this predicate will succeed only once, so that using this predicate may be more efficient than get_residuel/2 (although less informative)

get_returns_and_dls(+AnswerTrie, -Return, :DelayLists)  [nondet]
   True when Return appears in AnswerTrie with the given DelayLists. DelayLists is a list of lists, where the inner lists expresses a conjunctive condition and and outer list a disjunction.
get_residual(:CallTerm, -DelayList)  
True if CallTerm appears in a table and has DelayList. SWI-Prolog’s representation for a delay is a body term, more specifically a disjunction of conjunctions. The XSB representation is non-deterministic and uses a list to represent the conjunction.

The delay condition is a disjunction of conjunctions and is represented as such in the native SWI-Prolog interface as a nested term of ;/2 and ,/2, using true if the answer is unconditional. This XSB predicate returns the associated conjunctions non-deterministically as a list.

See also call_residual_program/2 from library(wfs).

get_returns_for_call(:CallTerm, -AnswerTerm)  
True if AnswerTerm appears in the tables for the variant CallTerm.

abolish_table_pred(:CallTermOrPI)
Invalidates all tabled subgoals for the predicate denoted by the predicate or term indicator Pred.

To be done If Pred has a subgoal that contains a conditional answer, the default behavior will be to transitively abolish any tabled predicates with subgoals having answers that depend on any conditional answers of S.

abolish_table_call(+Head)  
[det]
abolish_table_call(+Head, +Options)  
[det]
Same as abolish_table_subgoals/1. See also abolish_table_pred/1.

deprecated Use abolish_table_subgoals/[1,2].

abolish_table_subgoals(:Head, +Options)
Behaves as abolish_table_subgoals/1, but allows the default table_gc_action to be over-ridden with a flag, which can be either abolish_tables_transitively or abolish_tables_singly.

Compatibility Options is compatible with XSB, but does not follow the ISO option handling conventions.

A.53 library(terms): Term manipulation

Compatibility YAP, SICStus, Quintus. Not all versions of this library define exactly the same set of predicates, but defined predicates are compatible.

Compatibility library for term manipulation predicates. Most predicates in this library are provided as SWI-Prolog built-ins.

term_size(@Term, -Size)  
[det]
True if Size is the size in cells occupied by Term on the global (term) stack. A cell is 4 bytes on 32-bit machines and 8 bytes on 64-bit machines. The calculation does take sharing into account. For example:
?- A = a(1,2,3), term_size(A,S).
S = 4.
?- A = a(1,2,3), term_size(a(A,A),S).
S = 7.
?- term_size(a(a(1,2,3), a(1,2,3)), S).
S = 11.

Note that small objects such as atoms and small integers have a size 0. Space is allocated for floats, large integers, strings and compound terms.

variant(@Term1, @Term2) [semidet]
Same as SWI-Prolog Term1 =@= Term2.

subsumes_chk(@Generic, @Specific)
True if Generic can be made equivalent to Specific without changing Specific.

deprecated Replace by subsumes_term/2.

subsumes(+Generic, @Specific)
True if Generic is unified to Specific without changing Specific.

deprecated It turns out that calls to this predicate almost always should have used subsumes_term/2. Also the name is misleading. In case this is really needed, one is advised to follow subsumes_term/2 with an explicit unification.

term_subsumer(+Special1, +Special2, -General) [det]
General is the most specific term that is a generalisation of Special1 and Special2. The implementation can handle cyclic terms.

author Inspired by LOGIC.PRO by Stephen Muggleton
Compatibility SICStus

term_factorized(+Term, -Skeleton, -Substitution)
Is true when Skeleton is Term where all subterms that appear multiple times are replaced by a variable and Substitution is a list of Var=Value that provides the subterm at the location Var. I.e., After unifying all substitutions in Substitutions, Term =\= Skeleton. Term may be cyclic. For example:

?- X = a(X), term_factorized(b(X,X), Y, S).
Y = b(_G255, _G255),
S = [\_G255=a(_G255)].

mapargs(:Goal, ?Term1, ?Term2)
Term1 and Term2 have the same functor (name/arity) and for each matching pair of arguments call(Goal, A1, A2) is true.
mapsubterms(:Goal, +Term1, -Term2)  [det]
mapsubterms_var(:Goal, +Term1, -Term2)  [det]

Recursively map sub terms of Term1 into subterms of Term2 for every pair for which call(Goal, ST1, ST2) succeeds. Procedurally, the mapping for each (sub) term pair T1/T2 is defined as:

- If T1 is a variable
  - mapsubterms/3 unifies T2 with T1.
  - mapsubterms_var/3 treats variables as other terms.
- If call(Goal, T1, T2) succeeds we are done. Note that the mapping does not continue in T2. If this is desired, Goal must call mapsubterms/3 explicitly as part of its conversion.
- If T1 is a dict, map all values, i.e., the tag and keys are left untouched.
- If T1 is a list, map all elements, i.e., the list structure is left untouched.
- If T1 is a compound, use same_functoar/3 to instantiate T2 and recurse over the term arguments left to right.
- Otherwise T2 is unified with T1.

Both predicates are implemented using foldsubterms/5.

foldsubterms(:Goal3, +Term1, +State0, -State)  [semidet]
foldsubterms(:Goal4, +Term1, ?Term2, +State0, -State)  [semidet]
foldsubterms(:Goal5, +Term1, +State0, -State)  [semidet]

The predicate foldsubterms/5 calls call(Goal4, SubTerm1, SubTerm2, StateIn, StateOut) for each subterm, including variables, in Term1. If this call fails, StateIn and StateOut are the same. This predicate may be used to map subterms in a term while collecting state about the mapped subterms. The foldsubterms/4 variant does not map the term.

same_functoar(?Term1, ?Term2)  [semidet]
same_functoar(?Term1, ?Term2, -Arity)  [semidet]
same_functoar(?Term1, ?Term2, ?Name, ?Arity)  [semidet]

True when Term1 and Term2 are terms that have the same functor (Name/Arity). The arguments must be sufficiently instantiated, which means either Term1 or Term2 must be bound or both Name and Arity must be bound.

If Arity is 0, Term1 and Term2 are unified with Name for compatibility.

A.54 library(thread): High level thread primitives

author Jan Wielemaker

This module defines simple to use predicates for running goals concurrently. Where the core multi-threaded API is targeted at communicating long-living threads, the predicates here are defined to run goals concurrently without having to deal with thread creation and maintenance explicitly.

Note that these predicates run goals concurrently and therefore these goals need to be thread-safe. As the predicates in this module also abort branches of the computation that are no longer needed, predicates that have side-effect must act properly. In a nutshell, this has the following consequences:
- Nice clean Prolog code without side-effects (but with cut) works fine.

- Side-effects are bad news. If you really need assert to store intermediate results, use the `thread_local/1` declaration. This also guarantees cleanup of left-over clauses if the thread is cancelled. For other side-effects, make sure to use `call_cleanup/2` to undo them should the thread be cancelled.

- Global variables are ok as they are thread-local and destroyed on thread cancellation. Note however that global variables in the calling thread are not available in the threads that are created. You have to pass the value as an argument and initialise the variable in the new thread.

- Thread-cancellation uses `thread_signal/2`. Using this code with long-blocking foreign predicates may result in long delays, even if another thread asks for cancellation.

```
concurrent(+N, :Goals, +Options)  [semidet]
```

Run `Goals` in parallel using `N` threads. This call blocks until all work has been done. The `Goals` must be independent. They should not communicate using shared variables or any form of global data. All `Goals` must be thread-safe.

Execution succeeds if all goals have succeeded. If one goal fails or throws an exception, other workers are abandoned as soon as possible and the entire computation fails or re-throws the exception. Note that if multiple goals fail or raise an error it is not defined which error or failure is reported.

On successful completion, variable bindings are returned. Note however that threads have independent stacks and therefore the goal is copied to the worker thread and the result is copied back to the caller of `concurrent/3`.

Choosing the right number of threads is not always obvious. Here are some scenarios:

- If the goals are CPU intensive and normally all succeeding, typically the number of CPUs is the optimal number of threads. Less does not use all CPUs, more wastes time in context switches and also uses more memory.

- If the tasks are I/O bound the number of threads is typically higher than the number of CPUs.

- If one or more of the goals may fail or produce an error, using a higher number of threads may find this earlier.

<table>
<thead>
<tr>
<th>Arguments</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>N</code></td>
<td>Number of worker-threads to create. Using 1, no threads are created. If <code>N</code> is larger than the number of <code>Goals</code> we create exactly as many threads as there are <code>Goals</code>.</td>
</tr>
<tr>
<td><code>Goals</code></td>
<td>List of callable terms.</td>
</tr>
<tr>
<td><code>Options</code></td>
<td>Passed to <code>thread_create/3</code> for creating the workers. Only options changing the stack-sizes can be used. In particular, do not pass the detached or alias options.</td>
</tr>
</tbody>
</table>

**See also** In many cases, `concurrent_maplist/2` and friends is easier to program and is tractable to program analysis.
**APPENDIX A. THE SWI-PROLOG LIBRARY**

**concurrent_forall**:(*Generate*, *Action*)  
[semidet]

**concurrent_forall**:(*Generate*, *Action*, +Options)  
[semidet]

True when *Action* is true for all solutions of *Generate*. This has the same semantics as *forall/2*, but the *Action* goals are executed in multiple threads. Notable a failing *Action* or a *Action* throwing an exception signals the calling thread which in turn aborts all workers and fails or re-throws the generated error. *Options*:

**threads**:(+Count)

Number of threads to use. The default is determined by the Prolog flag `cpu_count`.

**To be done**  Ideally we would grow the set of workers dynamically, similar to dynamic scheduling of HTTP worker threads. This would avoid creating threads that are never used if *Generate* is too slow or does not provide enough answers and would further raise the number of threads if *Action* is I/O bound rather than CPU bound.

**concurrent_and**:(*Generator*, *Test*)

**concurrent_and**:(*Generator*, *Test*, +Options)

Concurrent version of *(Generator, Test)*. This predicate creates a thread providing solutions for *Generator* that are handed to a pool of threads that run *Test* for the different instantiations provided by *Generator* concurrently. The predicate is logically equivalent to a simple conjunction except for two aspects: (1) terms are copied from *Generator* to the test *Test* threads while answers are copied back to the calling thread and (2) answers may be produced out of order.

If the evaluation of some *Test* raises an exception, *concurrent_and/2,3* is terminated with this exception. If the caller commits after a given answer or raises an exception while *concurrent_and/2,3* is active with pending choice points, all involved resources are re-claimed.

*Options*:

**threads**:(+Count)

Create a worker pool holding *Count* threads. The default is the Prolog flag `cpu_count`.

This predicate was proposed by Jan Burse as `balance((Generator, Test))`.

**concurrent_maplist**:(*Goal*, +List)  
[semidet]

**concurrent_maplist**:(*Goal*, +List1, +List2)  
[semidet]

**concurrent_maplist**:(*Goal*, +List1, +List2, +List3)  
[semidet]

Concurrent version of `maplist/2`. This predicate uses `concurrent/3`, using multiple worker threads. The number of threads is the minimum of the list length and the number of cores available. The number of cores is determined using the prolog flag `cpu_count`. If this flag is absent or 1 or *List* has less than two elements, this predicate calls the corresponding `maplist/N` version using a wrapper based on `once/1`. Note that all goals are executed as if wrapped in `once/1` and therefore these predicates are `semidet`.

Note that the the overhead of this predicate is considerable and therefore *Goal* must be fairly expensive before one reaches a speedup.

**first_solution**:(-X, :Goals, +Options)  
[semidet]

Try alternative solvers concurrently, returning the first answer. In a typical scenario, solving
any of the goals in Goals is satisfactory for the application to continue. As soon as one of the tried alternatives is successful, all the others are killed and first_solution/3 succeeds.

For example, if it is unclear whether it is better to search a graph breadth-first or depth-first we can use:

```prolog
search_graph(Graph, Path) :-
    first_solution(Path, [ breadth_first(Graph, Path),
                          depth_first(Graph, Path) ], [], []). 
```

Options include thread stack-sizes passed to thread_create, as well as the options on_fail and on_error that specify what to do if a solver fails or triggers an error. By default execution of all solvers is terminated and the result is returned. Sometimes one may wish to continue. One such scenario is if one of the solvers may run out of resources or one of the solvers is known to be incomplete.

**on_fail(Act)**
If stop (default), terminate all threads and stop with the failure. If continue, keep waiting.

**on_error(Act)**
As above, re-throwing the error if an error appears.

**bug** first_solution/3 cannot deal with non-determinism. There is no obvious way to fit non-determinism into it. If multiple solutions are needed wrap the solvers in findall/3.

**call_in_thread(+Thread, .Goal)**
Run Goal as an interrupt in the context of Thread. This is based on thread_signal/2. If waiting times out, we inject a stop(Reason) exception into Goal. Interrupts can be nested, i.e., it is allowed to run a call_in_thread/2 while the target thread is processing such an interrupt.

This predicate is primarily intended for debugging and inspection tasks.

### A.55 library(thread_pool): Resource bounded thread management

**See also** http_handler/3 and http_spawn/2.

The module library(thread_pool) manages threads in pools. A pool defines properties of its member threads and the maximum number of threads that can coexist in the pool. The call thread_create_in_pool/4 allocates a thread in the pool, just like thread_create/3. If the pool is fully allocated it can be asked to wait or raise an error.

The library has been designed to deal with server applications that receive a variety of requests, such as HTTP servers. Simply starting a thread for each request is a bit too simple minded for such servers:

- Creating many CPU intensive threads often leads to a slow-down rather than a speedup.
• Creating many memory intensive threads may exhaust resources

• Tasks that require little CPU and memory but take long waiting for external resources can run many threads.

Using this library, one can define a pool for each set of tasks with comparable characteristics and create threads in this pool. Unlike the worker-pool model, threads are not started immediately. Depending on the design, both approaches can be attractive.

The library is implemented by means of a manager thread with the fixed thread id __thread_pool_manager. All state is maintained in this manager thread, which receives and processes requests to create and destroy pools, create threads in a pool and handle messages from terminated threads. Thread pools are not saved in a saved state and must therefore be recreated using the initialization/1 directive or otherwise during startup of the application.

thread_pool_create(+Pool, +Size, +Options) [det]
Create a pool of threads. A pool of threads is a declaration for creating threads with shared properties (stack sizes) and a limited number of threads. Threads are created using thread_create_in_pool/4. If all threads in the pool are in use, the behaviour depends on the wait option of thread_create_in_pool/4 and the backlog option described below. Options are passed to thread_create/3, except for

backlog(+MaxBackLog)
Maximum number of requests that can be suspended. Default is infinite. Otherwise it must be a non-negative integer. Using backlog(0) will never delay thread creation for this pool.

The pooling mechanism does not interact with the detached state of a thread. Threads can be created both detached and normal and must be joined using thread_join/2 if they are not detached.

thread_pool_destroy(+Name) [det]
Destroy the thread pool named Name.

Errors existence_error(thread_pool, Name).

current_thread_pool(?Name) [nondet]
True if Name refers to a defined thread pool.

thread_pool_property(?Name, ?Property) [nondet]
True if Property is a property of thread pool Name. Defined properties are:

options(Options)
Thread creation options for this pool

free(Size)
Number of free slots on this pool

size(Size)
Total number of slots on this pool
members(ListOfIDs)
    ListOfIDs is the list or threads running in this pool

running(Running)
    Number of running threads in this pool

backlog(Size)
    Number of delayed thread creations on this pool

thread_create_in_pool(+Pool, :Goal, -Id, +Options) [det]
    Create a thread in Pool. Options overrule default thread creation options associated to the pool.

    In addition, the following option is defined:

    wait(+Boolean)
        If true (default) and the pool is full, wait until a member of the pool completes. If false, throw a resource_error.

    Errors
        - resource_error(threads_in_pool(Pool)) is raised if wait is false or the backlog limit has been reached.
        - existence_error(thread_pool, Pool) if Pool does not exist.

workerExited(+PoolName, +WorkerId, :AtExit)
    It is possible that ’thread_pool_manager’ no longer exists while closing down the process because the manager was killed before the worker.

    To be done Find a way to discover that we are terminating Prolog.

create_pool(+PoolName) [semidet,multifile]
    Hook to create a thread pool lazily. The hook is called if thread_create_in_pool/4 discovers that the thread pool does not exist. If the hook succeeds, thread_create_in_pool/4 retries creating the thread. For example, we can use the following declaration to create threads in the pool media, which holds a maximum of 20 threads.

    :- multifile thread_pool:create_pool/1.

    thread_pool:create_pool(media) :-
        thread_pool_create(media, 20, []).

A.56 library(ugraphs): Graph manipulation library

    author
        - R.A.O’Keefe
        - Vitor Santos Costa
        - Jan Wielemaker

    license BSD-2 or Artistic 2.0

    The S-representation of a graph is a list of (vertex-neighbours) pairs, where the pairs are in standard order (as produced by keysort) and the neighbours of each vertex are also in standard order (as produced by sort). This form is convenient for many calculations.
A new UGraph from raw data can be created using `vertices_edges_to_ugraph/3`. Adapted to support some of the functionality of the SICStus ugraphs library by Vitor Santos Costa. Ported from YAP 5.0.1 to SWI-Prolog by Jan Wielemaker.

```prolog
vertices(+Graph, -Vertices)
    Unify Vertices with all vertices appearing in Graph. Example:

    ?- vertices([1-[3,5],2-[4],3-[],4-[5],5-[]], L).
    L = [1, 2, 3, 4, 5]
```

```prolog
vertices_edges_to_ugraph(+Vertices, +Edges, -UGraph)
    Create a UGraph from Vertices and edges. Given a graph with a set of Vertices and a set of Edges, Graph must unify with the corresponding S-representation. Note that the vertices without edges will appear in Vertices but not in Edges. Moreover, it is sufficient for a vertice to appear in Edges.

    ?- vertices_edges_to_ugraph([], [1-3,2-4,4-5,1-5], L).
    L = [1-[3,5], 2-[4], 3-[], 4-[5], 5-[]]
```

In this case all vertices are defined implicitly. The next example shows three unconnected vertices:

```prolog
? - vertices_edges_to_ugraph([6,7,8], [1-3,2-4,4-5,1-5], L).
L = [1-[3,5], 2-[4], 3-[], 4-[5], 5-[], 6-[], 7-[], 8-[]]
```

```prolog
add_vertices(+Graph, +Vertices, -NewGraph)
    Unify NewGraph with a new graph obtained by adding the list of Vertices to Graph. Example:

    ?- add_vertices([1-[3,5],2-[]], [0,1,2,9], NG).
    NG = [0-[], 1-[3,5], 2-[], 9-[]]
```

```prolog
del_vertices(+Graph, +Vertices, -NewGraph)
    Unify NewGraph with a new graph obtained by deleting the list of Vertices and all the edges that start from or go to a vertex in Vertices to the Graph. Example:

    ?- del_vertices([1-[3,5],2-[4],3-[],4-[5],5-[],6-[],7-[2,6],8-[]], [2,1], NL).
    NL = [3-[], 4-[5], 5-[], 6-[], 7-[6], 8-[]]
```

Compatibility Upto 5.6.48 the argument order was (+Vertices, +Graph, -NewGraph). Both YAP and SWI-Prolog have changed the argument order for compatibility with recent SICStus as well as consistency with `del_edges/3`. 
add_edges(+Graph, +Edges, -NewGraph)
Unify NewGraph with a new graph obtained by adding the list of Edges to Graph. Example:

?- add_edges([1-[3,5],2-[4],3-[1],4-[5],
              5-[],6-[],7-[],8-[]),
           [1-6,2-3,3-2,5-7,3-2,4-5],
           NL).
NL = [1-[3,5,6], 2-[3,4], 3-[2], 4-[5],
      5-[7], 6-[], 7-[], 8-[]]

ugraph_union(+Graph1, +Graph2, -NewGraph)
NewGraph is the union of Graph1 and Graph2. Example:

?- ugraph_union([1-[2],2-[3]], [2-[4],3-[1,2,4]], L).
L = [1-[2], 2-[3,4], 3-[1,2,4]]

del_edges(+Graph, +Edges, -NewGraph)
Unify NewGraph with a new graph obtained by removing the list of Edges from Graph. Notice that no vertices are deleted. Example:

?- del_edges([1-[3,5],2-[4],3-[1],4-[5],5-[],6-[],7-[],8-[]),
             [1-6,2-3,3-2,5-7,3-2,4-5,1-3],
             NL).
NL = [1-[5], 2-[4], 3-[1,4], 4-[1], 5-[1,6], 7-[1,8-[]]

del_edges(+Graph, +Edges, -NewGraph)
Unify NewGraph with a new graph obtained by removing the list of Edges from Graph. Notice that no vertices are deleted. Example:

?- del_edges([1-[3,5],2-[4],3-[1],4-[5],5-[],6-[],7-[],8-[]),
             [1-6,2-3,3-2,5-7,3-2,4-5,1-3],
             NL).
NL = [1-[5], 2-[4], 3-[1,4], 4-[1], 5-[1,6], 7-[1,8-[]]

edges(+Graph, -Edges)
Unify Edges with all edges appearing in Graph. Example:

?- edges([1-[3,5],2-[4],3-[1],4-[5],5-[1],], L).
L = [1-3, 1-5, 2-4, 4-5]

transitive_closure(+Graph, -Closure)
Generate the graph Closure as the transitive closure of Graph. Example:

?- transitive_closure([1-[2,3],2-[4,5],4-[]], L).
L = [1-[2,3,4,5,6], 2-[4,5,6], 4-[6]]

transpose_ugraph(Expr, NewGraph)
Unify NewGraph with a new graph obtained from Graph by replacing all edges of the form V1-V2 by edges of the form V2-V1. The cost is O(|V|*log(|V|)). Notice that an undirected graph is its own transpose. Example:

?- transpose([1-[3,5],2-[4],3-[1],4-[5],
              5-[1,6]-[],7-[1,8-[[],
             NL).
NL = [1-[], 2-[1,3-[]], 4-[2], 5-[], 6-[], 7-[1,8-[]]

SWI-Prolog 9.1 Reference Manual
Compatibility This predicate used to be known as transpose/2. Following SICStus 4, we reserve transpose/2 for matrix transposition and renamed ugraph transposition to transpose_ugraph/2.

**compose**(+LeftGraph, +RightGraph, -NewGraph)
Compose NewGraph by connecting the drains of LeftGraph to the sources of RightGraph. Example:

```prolog
?- compose([1-[2],2-[3]],[2-[4],3-[1,2,4]],L).
L = [1-[4], 2-[1,2,4], 3-[1]]
```

**top_sort**(+Graph, -Sorted) [semidet]
**top_sort**(+Graph, -Sorted, ?Tail) [semidet]
Sorted is a topological sorted list of nodes in Graph. A topological sort is possible if the graph is connected and acyclic. In the example we show how topological sorting works for a linear graph:

```prolog
?- top_sort([1-[2], 2-[3], 3-[1]], L).
L = [1, 2, 3]
```

The predicate top_sort/3 is a difference list version of top_sort/2.

**neighbors**(+Vertex, +Graph, -Neighbours) [det]
**neighbours**(+Vertex, +Graph, -Neighbours) [det]
Neighbours is a sorted list of the neighbours of Vertex in Graph. Example:

```prolog
?- neighbours(4,[1-[3,5],2-[4],3-[1],
  4-[1,2,7,5],5-[1],6-[1],7-[1],8-[1]], NL).
NL = [1,2,7,5]
```

**connect_ugraph**(+UGraphIn, -Start, -UGraphOut) [det]
Adds Start as an additional vertex that is connected to all vertices in UGraphIn. This can be used to create an topological sort for a not connected graph. Start is before any vertex in UGraphIn in the standard order of terms. No vertex in UGraphIn can be a variable.

Can be used to order a not-connected graph as follows:

```prolog
top_sort_unconnected(Graph, Vertices) :-
  (   top_sort(Graph, Vertices)
  -> true
  ;   connect_ugraph(Graph, Start, Connected),
  top_sort(Connected, Ordered0),
  Ordered0 = [Start|Vertices]
  ).
```

**complement**(+UGraphIn, -UGraphOut)
UGraphOut is a ugraph with an edge between all vertices that are not connected in UGraphIn and all edges from UGraphIn removed. Example:
A.57  library(url): Analysing and constructing URL

author
- Jan Wielemaker
- Lukas Faulstich

deprecated  New code should use library(uri), provided by the clib package.

This library deals with the analysis and construction of a URL, Universal Resource Locator. URL is the basis for communicating locations of resources (data) on the web. A URL consists of a protocol identifier (e.g. HTTP, FTP, and a protocol-specific syntax further defining the location. URLs are standardized in RFC-1738.

The implementation in this library covers only a small portion of the defined protocols. Though the initial implementation followed RFC-1738 strictly, the current is more relaxed to deal with frequent violations of the standard encountered in practical use.

global_url(+URL, +Base, -Global)  \[det\]
Translate a possibly relative URL into an absolute one.

Errors  syntax_error(illegal_url) if URL is not legal.

is_absolute_url(+URL)
True if URL is an absolute URL. That is, a URL that starts with a protocol identifier.

http_location(?Parts, ?Location)
Construct or analyze an HTTP location. This is similar to parse_url/2, but only deals with the location part of an HTTP URL. That is, the path, search and fragment specifiers. In the HTTP protocol, the first line of a message is

<Action> <Location> HTTP/<version>
APPENDIX A. THE SWI-PROLOG LIBRARY

Arguments

Location Atom or list of character codes.

parse_url(?URL, ?Attributes) [det]
Construct or analyse a URL. URL is an atom holding a URL or a variable. Attributes is a list of components. Each component is of the format Name(Value). Defined components are:

protocol(Protocol)
The used protocol. This is, after the optional `url:`, an identifier separated from the remainder of the URL using `:`. parse_url/2 assumes the http protocol if no protocol is specified and the URL can be parsed as a valid HTTP url. In addition to the RFC-1738 specified protocols, the file protocol is supported as well.

host(Host)
Host-name or IP-address on which the resource is located. Supported by all network-based protocols.

port(Port)
Integer port-number to access on the \( \text{arg}\{\text{Host}\} \). This only appears if the port is explicitly specified in the URL. Implicit default ports (e.g., 80 for HTTP) do not appear in the part-list.

path(Path)
(File-) path addressed by the URL. This is supported for the ftp, http and file protocols. If no path appears, the library generates the path `/`.

search(ListOfNameValue)
Search-specification of HTTP URL. This is the part after the `?`, normally used to transfer data from HTML forms that use the HTTP GET method. In the URL it consists of a www-form-encoded list of Name=Value pairs. This is mapped to a list of Prolog Name=Value terms with decoded names and values.

fragment(Fragment)
Fragment specification of HTTP URL. This is the part after the `#` character.

The example below illustrates all of this for an HTTP URL.

```
P = [ protocol(http),
    host('www.xyz.org'),
    fragment(x),
    search([ msg = 'Hello World! ']),
    path('/hello') ]
```

By instantiating the parts-list this predicate can be used to create a URL.
parse_url(+URL, +BaseUrl, -Attributes) [det]
Similar to parse_url/2 for relative URLs. If URL is relative, it is resolved using the absolute URL BaseURL.

www_form_encode(+Value, -XWWWFormEncoded) [det]
www_form_encode(-Value, +XWWWFormEncoded) [det]
En/decode to/from application/x-www-form-encoded. Encoding encodes all characters except RFC 3986 unreserved (ASCII alnum (see code_type/2)), and one of "_~" using percent encoding. Newline is mapped to %OD%OA. When decoding, newlines appear as a single newline (10) character.

Note that a space is encoded as %20 instead of +. Decoding decodes both to a space.

deprecated Use uri_encoded/3 for new code.

set_url_encoding(?Old, +New) [semidet]
Query and set the encoding for URLs. The default is utf8. The only other defined value is iso_latin_1.

To be done Having a global flag is highly inconvenient, but a work-around for old sites using ISO Latin 1 encoding.

url_iri(+Encoded, -Decoded) [det]
url_iri(-Encoded, +Decoded) [det]
Convert between a URL, encoding in US-ASCII and an IRI. An IRI is a fully expanded Unicode string. Unicode strings are first encoded into UTF-8, after which %-encoding takes place.

parse_url_search(?Spec, ?Fields:list(Name=Value)) [det]
Construct or analyze an HTTP search specification. This deals with form data using the MIME-type application/x-www-form-urlencoded as used in HTTP GET requests.

file_name_to_url(+File, -URL) [det]
file_name_to_url(-File, +URL) [semidet]
Translate between a filename and a file: // URL.

To be done Current implementation does not deal with paths that need special encoding.

A.58 library(varnumbers): Utilities for numbered terms

See also numbervars/4, =@=/2 (variant/2).

Compatibility This library was introduced by Quintus and available in many related implementations, although not with exactly the same set of predicates.

This library provides the inverse functionality of the built-in numbervars/3. Note that this library suffers from the known issues that '$VAR'(X) is a normal Prolog term and, -unlike the built-in numbervars-, the inverse predicates do not process cyclic terms. The following predicate is true for any acyclic term that contains no '$VAR'(X), integer(X) terms and no constraint variables:
always_true(X) :-
    copy_term(X, X2),
    numbervars(X),
    varnumbers(X, Copy),
    Copy =@@= X2.

numbervars(+Term)                  [det]
    Number variables in Term using $VAR(N). Equivalent to numbervars(Term, 0, _).

    See also numbervars/3,numbervars/4

varnumbers(+Term, -Copy)           [det]
    Inverse of numbervars/1. Equivalent to varnumbers(Term, 0, Copy).

varnumbers(+Term, +Start, -Copy)   [det]
    Inverse of numbervars/3. True when Copy is a copy of Term with all variables numbered
    >= Start consistently replaced by fresh variables. Variables in Term are shared with Copy
    rather than replaced by fresh variables.

    Errors domain_error(acyclic_term, Term) if Term is cyclic.
    Compatibility Quintus, SICStus. Not in YAP version of this library

max_var_number(+Term, +Start, -Max) [det]
    True when Max is the max of Start and the highest numbered $VAR(N) term.

    author Vitor Santos Costa
    Compatibility YAP

varnumbers_names(+Term, -Copy, -VariableNames) [det]
    If Term is a term with numbered and named variables using the reserved term '$VAR'(X),
    Copy is a copy of Term where each '$VAR'(X) is consistently replaced by a fresh variable and
    Bindings is a list X = Var, relating the X terms with the variable it is mapped to.

    See also numbervars/3,varnumbers/3,read_term/3 using the variable_names option.

A.59 library(yall): Lambda expressions

    author Paulo Moura and Jan Wielemaker
    To be done Extend optimization support

Prolog realizes high-order programming with meta-calling. The core predicate of this is call/1,
which simply calls its argument. This can be used to define higher-order predicates such as
ignore/1 or forall/2. The call/N construct calls a closure with N-1 additional arguments.
This is used to define higher-order predicates such as the maplist/2-5 family or foldl/4-7.
The closure concept used here is somewhat different from the closure concept from functional programming. The latter is a function that is always evaluated in the context that existed at function creation time. Here, a closure is a term of arity $0 =< L =< K$. The term’s functor is the name of a predicate of arity $K$ and the term’s $L$ arguments (where $L$ could be 0) correspond to $L$ leftmost arguments of said predicate, bound to parameter values. For example, a closure involving $\text{atom_concat}/3$ might be the term $\text{atom_concat}$(prefix). In order of increasing $L$, one would have increasingly more complete closures that could be passed to $\text{call}/3$, all giving the same result:

\[
\begin{align*}
call(\text{atom_concat}, \text{prefix}, \text{suffix}, R) . \\
call(\text{atom_concat}(\text{prefix}), \text{suffix}, R) . \\
call(\text{atom_concat}(\text{prefix}, \text{suffix}), R) . \\
call(\text{atom_concat}(\text{prefix}, \text{suffix}, R)).
\end{align*}
\]

The problem with higher order predicates based on $\text{call}/N$ is that the additional arguments are always added to the end of the closure’s argument list. This often requires defining trivial helper predicates to get the argument order right. For example, if you want to add a common postfix to a list of atoms you need to apply $\text{atom_concat}(\text{In}, \text{Postfix}, \text{Out})$, but $\text{maplist}(\text{atom_concat}(\text{Postfix}), \text{ListIn}, \text{ListOut})$ calls $\text{atom_concat}(\text{Postfix}, \text{In}, \text{Out})$. This is where library(yall) comes in, where the module name, \textit{yall}, stands for Yet Another Lambda Library.

The library allows us to write a lambda expression that wraps around the (possibly complex) goal to call:

\[
\text{?- maplist}([\text{In}, \text{Out}] >> \text{atom_concat}(\text{In},‘\_p’, \text{Out}), [\text{a}, \text{b}], \text{ListOut}).
\]

\[
\text{ListOut} = [\text{a}_p, \text{b}_p].
\]

A bracy list {...} specifies which variables are shared between the wrapped goal and the surrounding context. This allows us to write the code below. Without the {Postfix} a fresh variable would be passed to $\text{atom_concat}/3$.

\[
\text{add_postfix}(\text{Postfix}, \text{ListIn}, \text{ListOut}) :-
\text{maplist}({\text{Postfix}}/[\text{In}, \text{Out}] >> \text{atom_concat}(\text{In}, \text{Postfix}, \text{Out}),
\text{ListIn}, \text{ListOut}).
\]

This introduces the second application area of lambda expressions: the ability to confine variables to the called goal’s context. This features shines when combined with $\text{bagof}/3$ or $\text{setof}/3$ where one normally has to list those variables whose bindings one is not interested in using the Var^Goal construct (marking Var as existentially quantified and confining it to the called goal’s context). Lambda expressions allow you to do the converse: specify the variables which one is interested in. These variables are common to the context of the called goal and the surrounding context.

Lambda expressions use the syntax below

\[
{\ldots}/[\ldots] >> \text{Goal}.
\]

The {...} optional part is used for lambda-free variables (the ones shared between contexts). The order of variables doesn’t matter, hence the {...} set notation.
The [...] optional part lists lambda parameters. Here, order of variables matters, hence the list notation.

As / and >>= are standard infix operators, no new operators are added by this library. An advantage of this syntax is that we can simply unify a lambda expression with \{Free\} >>= \[Parameters\] >>= \Lambda to access each of its components. Spaces in the lambda expression are not a problem although the goal may need to be written between "()"s. Goals that are qualified by a module prefix also need to be wrapped inside parentheses.

Combined with library(apply_macros), library(yall) allows writing one-liners for many list operations that have the same performance as hand-written code.

This module implements Logtalk’s lambda expressions syntax.

The development of this module was sponsored by Kyndi, Inc.

+Parameters >>= +\Lambda

>>(+Parameters, +\Lambda, ?A1)
>>(+Parameters, +\Lambda, ?A1, ?A2)
>>(+Parameters, +\Lambda, ?A1, ?A2, ?A3)

Calls a copy of \Lambda. This is similar to \texttt{call(\Lambda, A1, ...)}), but arguments are reordered according to the list \texttt{Parameters}:

- The first \texttt{length(Parameters)} arguments from \texttt{A1, ...} are unified with (a copy of) \texttt{Parameters}, which may share them with variables in \texttt{Lambda}.
- Possible excess arguments are passed by position.

\texttt{Parameters} is either a plain list of parameters or a term \texttt{\{Free\}/List}. \texttt{Free} represents variables that are shared between the context and the \texttt{Lambda} term. This is needed for compiling \texttt{Lambda} expressions.

+F / :\Lambda

/\(+F, :\Lambda, \text{ ?A1}\)
/\(+F, :\Lambda, \text{ ?A1, ?A2}\)
/\(+F, :\Lambda, \text{ ?A1, ?A2, ?A3}\)

Shorthand for \texttt{Free/[]} >>= \texttt{\Lambda}. This is the same as applying \texttt{call/N} on \texttt{\Lambda}, except that only variables appearing in \texttt{Free} are bound by the call. For example

\begin{verbatim}
    p(1,a).
p(2,b).
\end{verbatim}
This can in particularly be combined with bagof/3 and setof/3 to select particular variables to be concerned rather than using existential quantification (^/2) to exclude variables. For example, the two calls below are equivalent.

```
setof(X, Y^p(X,Y), Xs)
setof(X, {X}/p(X,_), Xs)
```

is_lambda(@Term)  \[semidet]\n
True if Term is a valid Lambda expression.

lambda_calls(+LambdaExpression, -Goal)  \[det]\n
lambda_calls(+LambdaExpression, +ExtraArgs, -Goal)  \[det]\n
Goal is the goal called if call/N is applied to LambdaExpression, where ExtraArgs are the additional arguments to call/N. ExtraArgs can be an integer or a list of concrete arguments. This predicate is used for cross-referencing and code highlighting.
Hackers corner

This appendix describes a number of predicates which enable the Prolog user to inspect the Prolog environment and manipulate (or even redefine) the debugger. They can be used as entry points for experiments with debugging tools for Prolog. The predicates described here should be handled with some care as it is easy to corrupt the consistency of the Prolog system by misusing them.

B.1 Examining the Environment Stack

prolog_current_frame(-Frame)  [det]
Unify Frame with an integer providing a reference to the parent of the current local stack frame. A pointer to the current local frame cannot be provided as the predicate succeeds deterministically and therefore its frame is destroyed immediately after succeeding.

prolog_current_choice(-Choice)  [semidet]
Unify Choice with an integer provided a reference to the last choice point. Fails if the current environment has no choice points. See also prolog_choice_attribute/3.

prolog_frame_attribute(+Frame, +Key, :Value)
Obtain information about the local stack frame Frame. Frame is a frame reference as obtained through prolog_current_frame/1, prolog_trace_interception/4 or this predicate. The key values are described below.

alternative
Value is unified with an integer reference to the local stack frame in which execution is resumed if the goal associated with Frame fails. Fails if the frame has no alternative frame.

has_alternatives
Value is unified with true if Frame still is a candidate for backtracking; false otherwise.

goal
Value is unified with the goal associated with Frame. If the definition module of the active predicate is not the calling context, the goal is represented as ⟨module⟩: ⟨goal⟩. Do not instantiate variables in this goal unless you know what you are doing! Note that the returned term may contain references to the frame and should be discarded before the frame terminates.¹

¹The returned term is actually an illegal Prolog term that may hold references from the global to the local stack to preserve the variable names.
B.1. EXAMINING THE ENVIRONMENT STACK

**parent_goal**

**parent_goal(-Parent)**

If Value is instantiated to a callable term, find a frame executing the predicate described by Value and unify the arguments of Value to the goal arguments associated with the frame. This is intended to check the current execution context. The user must ensure the checked parent goal is not removed from the stack due to last-call optimisation and be aware of the slow operation on deeply nested calls.

The variant `parent_goal(-Parent)` unifies the frame reference of the parent of the found frame with `Parent`. That allows for finding frames higher up in the stack running the same goal.

**predicate_indicator**

Similar to `goal`, but only returning the `[⟨module⟩]:⟨name⟩/(⟨arity⟩)` term describing the term, not the actual arguments. It avoids creating an illegal term as `goal` and is used by the library `prolog_stack`.

**clause**

Value is unified with a reference to the currently running clause. Fails if the current goal is associated with a foreign (C) defined predicate. See also `nth_clause/3` and `clause_property/2`.

**level**

Value is unified with the recursion level of Frame. The top level frame is at level ‘0’.

**parent**

Value is unified with an integer reference to the parent local stack frame of Frame. Fails if Frame is the top frame.

**context_module**

Value is unified with the name of the context module of the environment.

**top**

Value is unified with true if Frame is the top Prolog goal from a recursive call back from the foreign language; false otherwise.

**hidden**

Value is unified with true if the frame is hidden from the user, either because a parent has the hide-childs attribute (all system predicates), or the system has no trace-me attribute.

**skipped**

Value is true if this frame was skipped in the debugger.

**pc**

Value is unified with the program pointer saved on behalf of the parent goal if the parent goal is not owned by a foreign predicate or belongs to a compound meta-call (e.g., call((a,b))).

**argument(N)**

Value is unified with the N-th slot of the frame. Argument 1 is the first argument of the goal. Arguments above the arity refer to local variables. Fails silently if N is out of range.

**prolog_choice_attribute(+ChoicePoint, +Key, -Value)**

Extract attributes of a choice point. ChoicePoint is a reference to a choice point as
passed to prolog_trace_interception/4 on the 3rd argument or obtained using prolog_current_choice/1. Key specifies the requested information:

parent
Requests a reference to the first older choice point.
frame
Requests a reference to the frame to which the choice point refers.
type
Requests the type. Defined values are clause (the goal has alternative clauses), foreign (non-deterministic foreign predicate), jump (clause internal choice point), top (first dummy choice point), catch (catch/3 to allow for undo), debug (help the debugger), or none (has been deleted).

pc
Requests the program counter to which the choice point refers. Only applicable for in-clause choice points.

clause
Request the clause that will be tried if this choice point is activated. Only applicable for choice points of type clause.

This predicate is used for the graphical debugger to show the choice point stack.

deterministic(-Boolean)
Unifies its argument with true if no choice point exists that is more recent than the entry of the clause in which it appears. There are few realistic situations for using this predicate. It is used by the prolog/0 top level to check whether Prolog should prompt the user for alternatives. Similar results can be achieved in a more portable fashion using call_cleanup/2.

B.2 Ancestral cuts

prolog_cut_to(+Choice)
Prunes all choice points created since Choice. Can be used together with prolog_current_choice/1 to implement ancestral cuts. This predicate is in the hackers corner because it should not be used in normal Prolog code. It may be used to create new high level control structures, particularly for compatibility purposes.

Note that in the current implementation, the pruned choice points and environment frames are not reclaimed. As a consequence, where predicates that are deterministic due to clause indexing, normal cuts or (if->then;else) and and tail recursive run in bounded local stack space, predicates using prolog_cut_to/1 will run out of stack.

B.3 Intercepting the Tracer

prolog_trace_interception(+Port, +Frame, +Choice, -Action)
Dynamic predicate, normally not defined. This predicate is called from the SWI-Prolog debugger just before it would show a port. If this predicate succeeds, the debugger assumes that the
trace action has been taken care of and continues execution as described by Action. Otherwise the normal Prolog debugger actions are performed.

Port denotes the reason to activate the tracer (‘port’ in the 4/5-port, but with some additions):

- **call**
  Normal entry through the call port of the 4-port debugger.

- **redo**(PC)
  Normal entry through the redo port of the 4-port debugger. The redo port signals resuming a predicate to generate alternative solutions. If PC is 0 (zero), clause indexing has found another clause that will be tried next. Otherwise, PC is the program counter in the current clause where execution continues. This implies we are dealing with an in-clause choice point left by, e.g., ;/2. Note that non-determinism in foreign predicates are also handled using an in-clause choice point.

- **unify**
  The unify port represents the neck instruction, signalling the end of the head-matching process. This port is normally invisible. See leash/1 and visible/1.

- **exit**
  The exit port signals the goal is proved. It is possible for the goal to have alternatives. See prolog_frame_attribute/3 to examine the goal stack.

- **fail**
  The fail port signals final failure of the goal.

- **exception**(Except)
  An exception is raised and still pending. This port is activated on each parent frame of the frame generating the exception until the exception is caught or the user restarts normal computation using retry. Except is the pending exception term.

- **cut_call**(PC)
  A cut is encountered at PC. This port is used by the graphical debugger to visualise the effect of the cut.

- **cut_exit**(PC)
  A cut has been executed. See cut_call(PC) for more information.

Frame is a reference to the current local stack frame, which can be examined using prolog_frame_attribute/3. Choice is a reference to the last choice point and can be examined using prolog_choice_attribute/3. Action must be unified with a term that specifies how execution must continue. The following actions are defined:

- **abort**
  Abort execution. See abort/0.

- **continue**
  Continue (i.e., creep in the command line debugger).

- **fail**
  Make the current goal fail.

- **ignore**
  Step over the current goal without executing it.
nodebug
Continue execution in normal nodebugging mode. See nodebug/0.

retry
Retry the current frame.

retry(Frame)
Retry the given frame. This must be a parent of the current frame.

skip
Skip over the current goal (i.e., skip in the command line debugger).

up
Skip to the parent goal (i.e., up in the command line debugger).

Together with the predicates described in section 4.39 and the other predicates of this chapter, this predicate enables the Prolog user to define a complete new debugger in Prolog. Besides this, it enables the Prolog programmer to monitor the execution of a program. The example below records all goals trapped by the tracer in the database.

```prolog
prolog_trace_interception(Port, Frame, _PC, continue) :-
    prolog_frame_attribute(Frame, goal, Goal),
    prolog_frame_attribute(Frame, level, Level),
    recordz(trace, trace(Port, Level, Goal)).
```

To trace the execution of ‘go’ this way the following query should be given:

```prolog
?- trace, go, notrace.
```

prolog_skip_frame(-Frame)
Indicate Frame as a skipped frame and set the ‘skip level’ (see prolog_skip_level/2 to the recursion depth of Frame. The effect of the skipped flag is that a redo on a child of this frame is handled differently. First, a redo trace is called for the child, where the skip level is set to redo_in_skip. Next, the skip level is set to skip level of the skipped frame.

prolog_skip_level(-Old, +New)
Unify Old with the old value of ‘skip level’ and then set this level according to New. New is an integer, the atom very_deep (meaning don’t skip) or the atom skip_in_redo (see prolog_skip_frame/1). The ‘skip level’ is a setting of each Prolog thread that disables the debugger on all recursion levels deeper than the level of the variable. See also prolog_skip_frame/1.

B.4 Simulating a debugger interrupt

prolog_interrupt
Calls the functionality that allows for debugging after receiving (normally) SIGINT. This may be used in IDE environments to start debugging a toplevel thread by injecting this into the target thread using thread_signal/2.
B.5 Breakpoint and watchpoint handling

SWI-Prolog support breakpoints. Breakpoints can be manipulated with the library prolog_breakpoints. Setting a breakpoint replaces a virtual machine instruction with the D_BREAK instruction. If the virtual machine executes a D_BREAK, it performs a callback to decide on the action to perform. This section describes this callback, called prolog:break_hook/7.

prolog:break_hook(+Clause, +PC, +FR, +BFR, +Expression, +Debug, -Action) [hook,semidet]

Experimental This hook is called if the virtual machine executes a D_BREAK, set using set_breakpoint/4. Clause and PC identify the breakpoint. FR and BFR provide the environment frame and current choicepoint. Debug is true if the system was in debug mode when the breakpoint was reached, otherwise Debug is false. Expression identifies the action that is interrupted, and is one of the following:

- **call(Goal)**
  The instruction will call Goal. This is generated for nearly all instructions. Note that Goal is semantically equivalent to the compiled body term, but might differ syntactically. This is notably the case when arithmetic expressions are compiled in optimized mode (see optimise). In particular, the arguments of arithmetic expressions have already been evaluated. Thus, $A$ is $3*B$, where $B$ equals 3 results in a term call(A is 9) if the clause was compiled with optimization enabled.

- **!**
  The instruction will call the cut. Because the semantics of metacalling the cut differs from executing the cut in its original context we do not wrap the cut in call/1.

- **:-**
  The breakpoint is on the neck instruction, i.e., after performing the head unifications.

- **exit**
  The breakpoint is on the exit instruction, i.e., at the end of the clause. Note that the exit instruction may not be reached due to last-call optimisation.

- **unify_exit**
  The breakpoint is on the completion of an in-lined unification while the system is not in debug mode. If the system is in debug mode, inlined unification is returned as call(Var=Term).

If prolog:break_hook/7 succeeds, it must unify Action with a value that describes how execution must continue. Possible values for Action are:

- **continue**
  Just continue as if no breakpoint was present.

- **debug**
  Continue in debug mode. See debug/0.

- **trace**
  Continue in trace mode. See trace/0.

2This hack will disappear if we find a good solution for applying D_BREAK to inlined unification. Only option might be to place the break on both the unification start and end instructions.
call(Goal)

Execute Goal instead of the goal that would be executed. Goal is executed as call/1, preserving (non-)determinism and exceptions.

If this hook throws an exception, the exception is propagated normally. If this hook is not defined or fails, the default action is executed. This implies that, if the thread is in debug mode, the tracer will be enabled (trace) and otherwise the breakpoint is ignored (continue).

This hook allows for injecting various debugging scenarios into the executable without recompiling. The hook can access variables of the calling context using the frame inspection predicates. Here are some examples.

- Create conditional breakpoints by imposing conditions before deciding the return trace.
- Watch variables at a specific point in the execution. Note that binding of these variables can be monitored using attributed variables, see section 8.1.
- Dynamically add assertions on variables using assertion/1.
- Wrap the Goal into a meta-call that traces progress of the Goal.

### B.6 Adding context to errors: prolog_exception_hook

The hook prolog_exception_hook/4 has been introduced in SWI-Prolog 5.6.5 to provide dedicated exception handling facilities for application frameworks, for example non-interactive server applications that wish to provide extensive context for exceptions for offline debugging.

**prolog_exception_hook(+ExceptionIn, -ExceptionOut, +Frame, +CatcherFrame)**

This hook predicate, if defined in the module user, is between raising an exception and handling it. It is intended to allow a program adding additional context to an exception to simplify diagnosing the problem. ExceptionIn is the exception term as raised by throw/1 or one of the built-in predicates. The output argument ExceptionOut describes the exception that is actually raised. Frame is the innermost frame. See prolog_frame_attribute/3 and the library prolog_stack for getting information from this. CatcherFrame is a reference to the frame calling the matching catch/3, none if the exception is not caught or ‘C’ if the exception is caught in C calling Prolog using the flag PL_Q_CATCH_EXCEPTION.

The hook is run in ‘nodebug’ mode. If it succeeds, ExceptionOut is considered the current exception. If it fails, ExceptionIn is used for further processing. The hook is never called recursively. The hook is not allowed to modify ExceptionOut in such a way that it no longer unifies with the catching frame.

Typically, prolog_exception_hook/4 is used to fill the second argument of error(Formal, Context) exceptions. Formal is defined by the ISO standard, while SWI-Prolog defines Context as a term context(Location, Message). Location is bound to a term \( \langle \text{name} \rangle/\langle \text{arity} \rangle \) by the kernel. This hook can be used to add more information on the calling context, such as a full stack trace.

Applications that use exceptions as part of normal processing must do a quick test of the environment before starting expensive gathering information on the state of the program.

The hook can call trace/0 to enter trace mode immediately. For example, imagine an application performing an unwanted division by zero while all other errors are expected and handled.
We can force the debugger using the hook definition below. Run the program in debug mode (see debug/0) to preserve as much as possible of the error context.

```
user:prolog_exception_hook(
    error(evaluation_error(zero_divisor), _),
    _, _, _) :-
    trace, fail.
```

### B.7 Hooks using the exception predicate

This section describes the predicate `exception/3`, which can be defined by the user in the module `user` as a multifile predicate. Unlike the name suggests, this is actually a hook predicate that has no relation to Prolog exceptions as defined by the ISO predicates `catch/3` and `throw/1`.

The predicate `exception/3` is called by the kernel on a couple of events, allowing the user to ‘fix’ errors just-in-time. The mechanism allows for lazy creation of objects such as predicates.

#### `exception(+Exception, +Context, -Action)`

Dynamic predicate, normally not defined. Called by the Prolog system on run-time exceptions that can be repaired ‘just-in-time’. The values for `Exception` are described below. See also `catch/3` and `throw/1`.

If this hook predicate succeeds it must instantiate the `Action` argument to the atom `fail` to make the operation fail silently, `retry` to tell Prolog to retry the operation or `error` to make the system generate an exception. The action `retry` only makes sense if this hook modified the environment such that the operation can now succeed without error.

- **undefined_predicate**
  
  `Context` is instantiated to a predicate indicator (`[module]:⟨name⟩⟨arity⟩`). If the predicate fails, Prolog will generate an `existence_error` exception. The hook is intended to implement alternatives to the built-in autoloader, such as autoloading code from a database. Do *not* use this hook to suppress existence errors on predicates. See also `unknown` and section 2.14.

- **undefined_global_variable**
  
  `Context` is instantiated to the name of the missing global variable. The hook must call `nb_setval/2` or `b_setval/2` before returning with the action `retry`. See also `nb_current/2`.

### B.8 Prolog events

Version 8.1.9 introduces a uniform mechanism to listen to events that happen in the Prolog engine. It replaces and generalises `prolog_event_hook/1`, a hook that was introduced to support the graphical debugger. The current implementation deals with debug, thread and dynamic database events. We expect this mechanism to deal with more hooks in the future.
**prolog_listen**(+Channel, :Closure)
**prolog_listen**(+Channel, :Closure, +Options)

Call Closure if an event that matches Channel happens inside Prolog. Possible choice points are pruned as by once/1. Possible failure is ignored, but exceptions are propagated into the environment. Multiple closures can be associated with the same channel. Execution of the list of closures may be terminated by an exception. Options:

**as**(+Location)
*Location* is one of *first* (default) or *last* and determines whether the new handler is expected as first or last.

**name**(+Atom)
Give the handler a name. A new registration using the same name replaces the existing handler rather than adding a new handler. Names are local to the Channel, i.e., different channels can use the same name.

Defined channels are described below. The Channel argument is the name of the term listed below. The arguments are added as additional arguments to the given Closure.

**abort**
Called by abort/0.

**erase**(DbRef)
Called on an erased recorded database reference or clause. Note that a retracted clauses is not immediately removed. Clauses are reclaimed by garbage_collect_clauses/0, which is normally executed automatically in the gc thread. This specific channel is used by clause_info/5 to reclaim source layout of reclaimed clauses. User applications should typically use the PredicateIndicator channel.

**break**(Action, ClauseRef, PCOffset)
Traps events related to Prolog break points. See library prolog_breakpoints

**frame_fi**nished**(FrameRef)
Indicates that a stack frame that has been examined using prolog_current_frame/1, prolog_frame_attribute/3 and friends has been deleted. Used by the source level debugger to avoid that the stack view references non-existing frames.

**thread_exit**(Thread)
Globally registered channel that is called by any thread just before the thread is terminated.

**thread_start**(Thread)
Globally registered channel that is called by any thread after the thread initialization and before running the thread’s goal.

**this_thread_exit**
Thread local version of the thread_exit channel that is also used by the at_exit(Closure) option of thread_create/3.

**PredicateIndicator**(Action, Context)
Track changes to a predicate. This notably allows tracking modifications to dynamic predicates. The channel also allows tracking changes to monotonic tables (section 7.8). Both monotonic and incremental tabling use this to track changes to incremental and monotonic dynamic predicates. Below is an example illustrating events from changing a dynamic predicate.
B.9 Hooks for integrating libraries

Some libraries realise an entirely new programming paradigm on top of Prolog. An example is XPCE which adds an object system to Prolog as well as an extensive set of graphical primitives. SWI-Prolog provides several hooks to improve the integration of such libraries. See also section A.23 for editing hooks and section 4.11 for hooking into the message system.
prolog_list_goal(:Goal)
Hook, normally not defined. This hook is called by the ‘L’ command of the tracer in the module user to list the currently called predicate. This hook may be defined to list only relevant clauses of the indicated Goal and/or show the actual source code in an editor. See also portray/1 and multifile/1.

prolog:debug_control_hook(:Action)
Hook for the debugger control predicates that allows the creator of more high-level programming languages to use the common front-end predicates to control the debugger. For example, XPCE uses these hooks to allow for spying methods rather than predicates. Action is one of:

spy(Spec)
Hook in spy/1. If the hook succeeds spy/1 takes no further action.

nospy(Spec)
Hook in nospy/1. If the hook succeeds nospy/1 takes no further action. If spy/1 is hooked, it is advised to place a complementary hook for nospy/1.

nospyall
Hook in nospyall/0. Should remove all spy points. This hook is called in a failure-driven loop.

debugging
Hook in debugging/0. It can be used in two ways. It can report the status of the additional debug points controlled by the above hooks and fail to let the system report the others, or it succeeds, overruling the entire behaviour of debugging/0.

prolog:help_hook(+Action)
Hook into help/0 and help/1. If the hook succeeds, the built-in actions are not executed. For example, ?- help(picture). is caught by the XPCE help hook to give help on the class picture. Defined actions are:

help
User entered plain help/0 to give default help. The default performs help(help/1), giving help on help.

help(What)
Hook in help/1 on the topic What.

apropos(What)
Hook in apropos/1 on the topic What.

B.10 Hooks for loading files

All loading of source files is achieved by load_files/2. The hook prolog_load_file/2 can be used to load Prolog code from non-files or even load entirely different information, such as foreign files.

prolog_load_file(+Spec, +Options)
Load a single object. If this call succeeds, load_files/2 assumes the action has been taken
B.10. HOOKS FOR LOADING FILES

This hook is only called if Options does not contain the stream(Input) option. The hook must be defined in the module user.

This can be used to load from unusual places as well as dealing with Prolog code that is not represented as a Prolog source text (for example some binary representation). For example, library http/http_load loads Prolog directly from an HTTP server. See also prolog:open_source_hook/3, which merely allows for changing how a physical file is opened.

prolog:open_source_hook(+Path, -Stream, +Options)
This hook is called by the compiler to overrule the default open/3 call open(Path, read, Stream). Options provide the options as provided to load_files/2. If the hook succeeds compilation continues by loading from the returned (input) stream. This hook is particularly suited to support running the code to a preprocessor. See also prolog_load_file/2.

prolog:comment_hook(+Comments, +Pos, +Term)
This hook allows for processing comments encountered by the compiler. If this hook is defined, the compiler calls read_term/2 with the option comments(Comments). If the list of comments returned by read_term/2 is not empty it calls this comment hook with the following arguments.

- Comments is the non-empty list of comments. Each comment is a pair Position-String, where String is a string object (see section 5.2) that contains the comment including delimiters. Consecutive line comments are returned as a single comment.
- Pos is a stream-position term that describes the starting position of Term
- Term is the term read.

This hook is exploited by the documentation system. See stream_position_data/3. See also read_term/3.
Compatibility with other Prolog dialects

This chapter explains issues for writing portable Prolog programs. It was started after discussion with Vitor Santos Costa, the leading developer of YAP Prolog. YAP and SWI-Prolog have expressed the ambition to enhance the portability beyond the trivial Prolog examples, including complex libraries involving foreign code.

Although it is our aim to enhance compatibility, we are still faced with many incompatibilities between the dialects. As a first step both YAP and SWI will provide some instruments that help developing portable code. A first release of these tools appeared in SWI-Prolog 5.6.43. Some of the facilities are implemented in the base system, others in the library dialect.pl.

- The Prolog flag `dialect` is an unambiguous and fast way to find out which Prolog dialect executes your program. It has the value `swi` for SWI-Prolog and `yap` on YAP.
- The Prolog flag `version_data` is bound to a term `swi(Major, Minor, Patch, Extra)`.
- Conditional compilation using `:- if(Condition) ...:- endif` is supported. See section 4.3.1.
- The predicate `expects_dialect/1` allows for specifying for which Prolog system the code was written.
- The predicates `exists_source/1` and `source_exports/2` can be used to query the library content. The `require/1` directive can be used to get access to predicates without knowing their location.
- The module predicates `use_module/1`, `use_module/2` have been extended with a notion for ‘import-except’ and ‘import-as’. This is particularly useful together with `reexport/1` and `reexport/2` to compose modules from other modules and mapping names.
- Foreign code can expect `__SWI_PROLOG__` when compiled for SWI-Prolog and `__YAP_PROLOG__` when compiled on YAP.

`:- expects_dialect(+Dialect)`

This directive states that the code following the directive is written for the given Prolog `Dialect`. See also `dialect`. The declaration holds until the end of the file in which it appears. The current dialect is available using `prolog_load_context/2`.

The exact behaviour of this predicate is still subject to discussion. Of course, if `Dialect` matches the running dialect the directive has no effect. Otherwise we check for the existence of `library(dialect/Dialect)` and load it if the file is found. Currently, this file has this functionality:

1http://yap.sourceforge.net/
C.1 Some considerations for writing portable code

The traditional way to write portable code is to define custom predicates for all potentially non-portable code and define these separately for all Prolog dialects one wishes to support. Here are some considerations.

- Probably the best reason for this is that it allows to define minimal semantics required by the application for the portability predicates. Such functionality can often be mapped efficiently to the target dialect. Contrary, if code was written for dialect $X$, the defined semantics are those of dialect $X$. Emulating all extreme cases and full error handling compatibility may be tedious and result in a much slower implementation than needed. Take for example `call_cleanup/2`. The SICStus definition is fundamentally different from the SWI definition, but 99% of the applications just want to make calls like below to guarantee `StreamIn` is closed, even if `process/1` misbehaves.

  ```prolog
  call_cleanup(process(StreamIn), close(In))
  ```

- As a drawback, the code becomes full of `my_call_cleanup`, etc. and every potential portability conflict needs to be abstracted. It is hard for people who have to maintain such code later to grasp the exact semantics of the `my_*` predicates and applications that combine multiple libraries using this compatibility approach are likely to encounter conflicts between the portability layers. A good start is not to use `my_*`, but a prefix derived from the library or application name or names that explain the intended semantics more precisely.

- Another problem is that most code is initially not written with portability in mind. Instead, ports are requested by users or arise from the desire to switch Prolog dialect. Typically, we want to achieve compatibility with the new Prolog dialect with minimal changes, often keeping compatibility with the original dialect(s). This problem is well known from the C/Unix world and we advise anyone to study the philosophy of GNU autoconf, from which we will illustrate some highlights below.

  The GNU autoconf suite, known to most people as `configure`, was an answer to the frustrating life of Unix/C programmers when Unix dialects were about as abundant and poorly standardised as Prolog dialects today. Writing a portable C program can only be achieved using `cpp`, the C preprocessor. The C preprocessor performs two tasks: macro expansion and conditional compilation.
realises macro expansion through `term_expansion/2` and `goal_expansion/2`. Conditional compilation is achieved using `:- if(Condition)` as explained in section 4.3.1. The situation appears similar.

The important lesson learned from GNU autoconf is that the last resort for conditional compilation to achieve portability is to switch on the platform or dialect. Instead, GNU autoconf allows you to write tests for specific properties of the platform. Most of these are whether or not some function or file is available. Then there are some standard tests for difficult-to-write-portable situations and finally there is a framework that allows you to write arbitrary C programs and check whether they can be compiled and/or whether they show the intended behaviour. Using a separate `configure` program is needed in C, as you cannot perform C compilation step or run C programs from the C preprocessor. In most Prolog environments we do not need this distinction as the compiler is integrated into the runtime environment and Prolog has excellent reflexion capabilities.

We must learn from the distinction to test for features instead of platform (dialect), as this makes the platform-specific code robust for future changes of the dialect. Suppose we need `compare/3` as defined in this manual. The `compare/3` predicate is not part of the ISO standard, but many systems support it and it is not unlikely it will become ISO standard or the intended dialect will start supporting it. GNU autoconf strongly advises to test for the availability:

```
:- if(+current_predicate(_, compare(_,_,_))).
compare(<, Term1, Term2) :-
    Term1 @< Term2, !.
compare(>, Term1, Term2) :-
    Term1 @> Term2, !.
compare(=, Term1, Term2) :-
    Term1 == Term2.
:- endif.
```

This code is much more robust against changes to the intended dialect and, possibly at least as important, will provide compatibility with dialects you didn’t even consider porting to right now.

In a more challenging case, the target Prolog has `compare/3`, but the semantics are different. What to do? One option is to write a `my_compare/3` and change all occurrences in the code. Alternatively you can rename calls using `goal_expansion/2` like below. This construct will not only deal with Prolog dialects lacking `compare/3` as well as those that only implement it for numeric comparison or have changed the argument order. Of course, writing rock-solid code would require a complete test-suite, but this example will probably cover all Prolog dialects that allow for conditional compilation, have core ISO facilities and provide `goal_expansion/2`, the things we claim a Prolog dialect should have to start writing portable code for it.

```
:- if(+catch(compare(<,a,b), _, fail)).
compare_standard_order(<, Term1, Term2) :-
    Term1 @< Term2, !.
compare_standard_order(>, Term1, Term2) :-
    Term1 @> Term2, !.
compare_standard_order(=, Term1, Term2) :-
    Term1 == Term2.
goal_expansion(compare(Order, Term1, Term2),
```

---

Swi-Prolog 9.1 Reference Manual
C.2. NOTES ON SPECIFIC DIALECTS

The level of maturity of the various dialect emulation implementations varies enormously. All of them have been developed to realise portability for one or more, often large, programs. This section provides some notes on emulating a particular dialect.

C.2.1 Notes on specific dialects

XSB Prolog compatibility emerged from a project to integrate XSB’s advanced tabling support in SWI-Prolog (see section 7). This project has been made possible by Kyndi.\textsuperscript{2} The XSB dialect implementation has been created to share as much as possible of the XSB test suite as well as some larger programs to evaluate both tabling implementations. The dialect emulation was extended to support Pharos.\textsuperscript{3}

Emulating XSB is relatively complicated due to the large distance from the Quintus descendant Prolog systems. Notably XSB’s name based module system is hard to map on SWI-Prolog’s predicate based module system. As a result, only non-modular projects or projects with basic usage of modules are supported. For the development of new projects that require modules more advanced module support we suggest using Logtalk.

Loading XSB source files

SWI-Prolog’s emulation of XSB depends on the XSB preferred file name extension \texttt{.P}. This extension is used by \texttt{dialect/xsb/source} to initiate a two phase loading process based on \texttt{term_expansion/2} of the virtual \texttt{term begin_of_file}.

1. In the first phase the file is read with XSB compatible operator declarations and all directives (:- Term) are extracted. The directives are used to determine that the file defines a module (iff the file contains an \texttt{export/1} directive) and construct a SWI-Prolog compatible module declaration. As XSB has a two phase compiler where SWI has a single phase compiler, this is also used to move some directives to the start of the file.

2. The second phase loads the file as normal.

To load a project in both XSB and SWI-Prolog it is advised to make sure all source files use the \texttt{.P} file name extension. Next, write a SWI-Prolog loader in a \texttt{.pl} file that contains e.g.,

\begin{verbatim}
:- use_module(library(dialect/xsb/source)).
:- [main_file].
\end{verbatim}

\textsuperscript{2}This project was initiated by Benjamin Grosof and carried out in cooperation with Theresa Swift, David S. Warren and Fabrizio Riguzzi.

\textsuperscript{3}Pharos was used to evaluate \textit{incremental tabling} (section 7.7), a project with Edward Schwatz and Cory Cohen from CMU.
It is also possible to put the able `use_module/1` directive in your personal initialization file (see section 2.2), after which XSB files can be loaded as normal SWI-Prolog files using

```
% swipl file.P
```

XSB code may depend on the `gpp` preprocessor. We do not provide `gpp`. It is however possible to send XSB source files through `gpp` by loading `library/dialect/xsb/gpp`. This require `gpp` to be accessible through the environment variable `PATH` or the `file_search_path/2` alias `path`. We refer to the `gpp` library for details.

### C.2.2 The XSB import directive

The XSB import directive takes the form as below.

```
:- import p/1, q/2, ... from <lib>.
```

This import directive is resolved as follows:

- If the referenced library is found as a local file, it is loaded and the requested predicates are imported.
- Otherwise, the referenced library is searched for in the `dialect/xsb` directory of the SWI-Prolog library. If found, the predicates are imported from this library.
- The referenced predicates are searched for in SWI-Prolog built-in predicates and the SWI-Prolog library. If found, they are made available if necessary.
Glossary of Terms

anonymous [variable]
   The variable _ is called the anonymous variable. Multiple occurrences of _ in a single term are not shared.

arguments
   Arguments are terms that appear in a compound term. A1 and a2 are the first and second argument of the term myterm(A1, a2).

arity
   Argument count (= number of arguments) of a compound term.

assert
   Add a clause to a predicate. Clauses can be added at either end of the clause-list of a predicate. See asserta/1 and assertz/1.

atom
   Textual constant. Used as name for compound terms, to represent constants or text.

backtracking
   Search process used by Prolog. If a predicate offers multiple clauses to solve a goal, they are tried one-by-one until one succeeds. If a subsequent part of the proof is not satisfied with the resulting variable binding, it may ask for an alternative solution (= binding of the variables), causing Prolog to reject the previously chosen clause and try the next one.

binding [of a variable]
   Current value of the variable. See also backtracking and query.

built-in [predicate]
   Predicate that is part of the Prolog system. Built-in predicates cannot be redefined by the user, unless this is overruled using redefine_system Predicate/1.

body
   Part of a clause behind the neck operator (; −).

choice point
   A choice point represents a choice in the search for a solution. Choice points are created if multiple clauses match a query or using disjunction (; / 2). On backtracking, the execution state of the most recent choice point is restored and search continues with the next alternative (i.e., next clause or second branch of ; / 2).
clause
‘Sentence’ of a Prolog program. A clause consists of a head and body separated by the neck operator (:-) or it is a fact. For example:

\[
\text{parent}(X) :- \\
\text{father}(X, _).
\]

Expressed as “X is a parent if X is a father of someone”. See also variable and predicate.

compile
Process where a Prolog program is translated to a sequence of instructions. See also interpreted. SWI-Prolog always compiles your program before executing it.

compound [term]
Also called structure. It consists of a name followed by \(N\) arguments, each of which are terms. \(N\) is called the arity of the term.

context module
If a term is referring to a predicate in a module, the context module is used to find the target module. The context module of a goal is the module in which the predicate is defined, unless this predicate is module transparent, in which case the context module is inherited from the parent goal. See also module transparent/1 and meta-predicate.

dcg
Abbreviation for Definite Clause Grammar.

det [determinism]
Short for deterministic.

determinism
How many solutions a goal can provide. Values are ‘nondet’ (zero to infinite), ‘multi’ (one to infinite), ‘det’ (exactly one) and ‘semidet’ (zero or one).

deterministic
A predicate is deterministic if it succeeds exactly one time without leaving a choice point.

dynamic [predicate]
A dynamic predicate is a predicate to which clauses may be asserted and from which clauses may be retracted while the program is running. See also update view.

exported [predicate]
A predicate is said to be exported from a module if it appears in the public list. This implies that the predicate can be imported into another module to make it visible there. See also use_module/[1,2].

fact
Clause without a body. This is called a fact because, interpreted as logic, there is no condition to be satisfied. The example below states john is a person.

\[
\text{person}(\text{john}).
\]
fail
A goal is said to have failed if it could not be proven.

float
Computer’s crippled representation of a real number. Represented as ‘IEEE double’.

foreign
Computer code expressed in languages other than Prolog. SWI-Prolog can only cooperate
directly with the C and C++ computer languages.

functor
Combination of name and arity of a compound term. The term `foo(a, b, c)` is said to be a term
belonging to the functor `foo/3`. `foo/0` is used to refer to the atom `foo`.

goal
Question stated to the Prolog engine. A goal is either an atom or a compound term. A goal
either succeeds, in which case the variables in the compound terms have a binding, or it fails if
Prolog fails to prove it.

hashing
Indexing technique used for quick lookup.

head
Part of a clause before the neck operator (:-). This is an atom or compound term.

imported [predicate]
A predicate is said to be imported into a module if it is defined in another module and made
available in this module. See also chapter 6.

indexing
Indexing is a technique used to quickly select candidate clauses of a predicate for a specific
goal. In most Prolog systems, indexing is done (only) on the first argument of the head. If this
argument is instantiated to an atom, integer, float or compound term with functor, hashing is
used to quickly select all clauses where the first argument may unify with the first argument of
the goal. SWI-Prolog supports just-in-time and multi-argument indexing. See section 2.18.

integer
Whole number. On all implementations of SWI-Prolog integers are at least 64-bit signed
values. When linked to the GNU GMP library, integer arithmetic is unbounded. See also
current_prolog_flag/2, flags bounded, max_integer and min_integer.

interpreted
As opposed to compiled, interpreted means the Prolog system attempts to prove a goal by
directly reading the clauses rather than executing instructions from an (abstract) instruction set
that is not or only indirectly related to Prolog.

instantiation [of an argument]
To what extend a term is bound to a value. Typical levels are ‘unbound’ (a variable), ‘ground’
term without variables) or ‘partially bound’ (term with embedded variables).
meta-predicate
A predicate that reasons about other predicates, either by calling them, (re)defining them or querying properties.

mode [declaration]
Declaration of an argument instantiation pattern for a predicate, often accompanied with a determinism.

module
Collection of predicates. Each module defines a name-space for predicates. built-in predicates are accessible from all modules. Predicates can be published (exported) and imported to make their definition available to other modules.

module transparent [predicate]
A predicate that does not change the context module. Sometimes also called a meta-predicate.

multi [determinism]
A predicate is said to have determinism multi if it generates at least one answer.

multifile [predicate]
Predicate for which the definition is distributed over multiple source files. See multifile/1.

neck
Operator (:~) separating head from body in a clause.

non-det
Short for non deterministic.

non deterministic
A non deterministic predicate is a predicate that mail fail or succeed any number of times.

operator
Symbol (atom) that may be placed before its operand (prefix), after its operand (postfix) or between its two operands (infix).
In Prolog, the expression a+b is exactly the same as the canonical term +(a, b).

operand
Argument of an operator.

precedence
The priority of an operator. Operator precedence is used to interpret a+b*c as +(a, *(b, c)).

predicate
Collection of clauses with the same functor (name/arity). If a goal is proved, the system looks for a predicate with the same functor, then uses indexing to select candidate clauses and then tries these clauses one-by-one. See also backtracking.

predicate indicator
Term of the form Name/Arity (traditional) or Name//Arity (ISO DCG proposal), where Name is an atom and Arity a non-negative integer. It acts as an indicator (or reference) to a predicate or DCG rule.
priority
   In the context of operators a synonym for precedence.

program
   Collection of predicates.

property
   Attribute of an object. SWI-Prolog defines various *property predicates to query the status of predicates, clauses, etc.

prove
   Process where Prolog attempts to prove a query using the available predicates.

public list
   List of predicates exported from a module.

query
   See goal.

retract
   Remove a clause from a predicate. See also dynamic, update view and assert.

semidet
   Shorthand for

semi deterministic
   A predicate that is semi deterministic either fails or succeeds exactly once without a choice point. See also deterministic.

shared
   Two variables are called shared after they are unified. This implies if either of them is bound, the other is bound to the same value:

   
   |- A = B, A = a.
   |     A = B, B = a.

singleton [variable]
   Variable appearing only one time in a clause. SWI-Prolog normally warns for this to avoid you making spelling mistakes. If a variable appears on purpose only once in a clause, write it as _ (see anonymous). Rules for naming a variable and avoiding a warning are given in section 2.16.1.

solution
   Bindings resulting from a successfully proven goal.

structure
   Synonym for compound term.
string
Used for the following representations of text: a packed array (see section 5.2, SWI-Prolog specific), a list of character codes or a list of one-character atoms.

succeed
A goal is said to have succeeded if it has been proven.

term
Value in Prolog. A term is either a variable, atom, integer, float or compound term. In addition, SWI-Prolog also defines the type string.

transparent
See module transparent.

unify
Prolog process to make two terms equal by assigning variables in one term to values at the corresponding location of the other term. For example:

```
?- foo(a, B) = foo(A, b).
A = a,
B = b.
```

Unlike assignment (which does not exist in Prolog), unification is not directed.

update view
How Prolog behaves when a dynamic predicate is changed while it is running. There are two models. In most older Prolog systems the change becomes immediately visible to the goal, in modern systems including SWI-Prolog, the running goal is not affected. Only new goals ‘see’ the new definition.

variable
A Prolog variable is a value that ‘is not yet bound’. After binding a variable, it cannot be modified. Backtracking to a point in the execution before the variable was bound will turn it back into a variable:

```
?- A = b, A = c.
false.

?- (A = b; true; A = c).
A = b ;
true ;
A = c .
```

See also unify.
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This, unfortunately, does not mean you can any version of SWI-Prolog under the above license. The SWI-Prolog core may be linked to libraries that are more restrictive and in addition your code may have loaded extension packages that have more restrictive conditions. In particular, the core is by default linked to libgmp, distributed under the Lesser GNU Public license.

The above implies you need to configure and recompile the system without these components. For this we provide options to the configure script:

```
./configure --without-gpl
./configure --without-lgpl
```
The GNU MP Bignum Library provides unbounded integers, rational numbers and some cryptographi- 
cal functionality. As libgmp is provided under the Lesser GNU Public license it may legally be 
combined with proprietary software as long as libgmp is dynamically linked (default) and the end user 
can replace the libgmp shared object and use your application with their (possibly modified) version 
of libgmp. In practice this leads to problems if the application is not accessible (e.g., embedded in 
closed hardware) or you want to avoid customers to peek around in the process memory as they can 
easily do so by adding a backdoor to the modified LGPL component. Note that such a protection is 
in general not possible anyway if the customer has unrestricted access to the machine on which the 
application runs.

E.1 Contributing to the SWI-Prolog project

To reach maximal coherence we will, as a rule of thumb, only accept new code that has the Simplified 
BSD license and existing code with a permissive license such as MIT, Apache, BSD-3, etc. In excep- 
tional cases we may accept code with GPL or LGPL conditions. Such code must be tagged using a 
license/1 directive (Prolog) or a call to PL-license() for foreign code and, if they are part of 
the core, the code must be excluded using the --without-gpl or --without-lgpl option.

E.2 Software support to keep track of license conditions

Given the above, it is possible that SWI-Prolog packages and extensions rely on the GPL, LGPL or 
other licenses. The predicates below allow for registering license requirements for Prolog files and 
foreign modules. The predicate license/0 reports which components from the currently config-
ured system are distributed under non-permissive open source licenses and therefore may need to be 
replaced to suit your requirements.

license

Evaluate the license conditions of all loaded components. If the system contains one or more 
components that are licenced under GPL-like restrictions the system indicates this program 
may only be distributed under the GPL license as well as which components prohibit the use of 
other license conditions. Likewise for for LGPL components.

license(+LicenseId, +Component)

Register the fact that Component is distributed under a license identified by LicenseId. Known 
license identifiers can be listed using known_licenses/0. A new license can be registered 
as a known language using a declaration like below. The second argument defines the category 
if the license, which is one of gpl, lgpl, permissive or proprietary.

:- multifile license:license/3.

license:license(mylicense, permissive, 
    [ comment('My personal license'), 
      url('http://www.mine.org/license.html') 
    ]).

:- license(mylicense).
E.3. LICENSE CONDITIONS INHERITED FROM USED CODE

license(+LicenseId)
   Intended as a directive in Prolog source files. It takes the current filename and calls license/2.

void PL_license(const char *LicenseId, const char *Component)
   Intended for the install() procedure of foreign libraries. This call can be made before PL_initialise().

known licenses
   List all licenses known to the system. This does not imply the system contains code covered by the listed licenses. See license/2.

E.3 License conditions inherited from used code

E.3.1 Cryptographic routines

Cryptographic routines are used in variant_sha1/2 and crypt. These routines are provided under the following conditions:

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Summary

F.1 Predicates

The predicate summary is used by the Prolog predicate \texttt{apropos/1} to suggest predicates from a keyword.

\begin{verbatim}
@@/2 Call using calling context
!0 Cut (discard choicepoints)
$0 Discard choicepoints and demand deterministic success
$/1 Verify goal succeeds deterministically
,1 Conjunction of goals
\rightarrow/2 If-then-else
\leftarrow/2 Soft-cut
./2 Consult. Also functional notation
:</2 Select keys from a dict
:=/2 WASM: Call JavaScript
;/2 Disjunction of two goals
<2 Arithmetic smaller
=/2 True when arguments are unified
=../2 “Univ.” Term to list conversion
=:=/2 Arithmetic equality
=</2 Arithmetic smaller or equal
==/2 Test for strict equality
=@=/2 Test for structural equality (variant)
=\=/2 Arithmetic not equal
>/2 Arithmetic larger
>=/2 Arithmetic larger or equal
>:</2 Partial dict unification
?=/2 Test of terms can be compared now
@</2 Standard order smaller
@=</2 Standard order smaller or equal
@/>/2 Standard order larger
@>=/2 Standard order larger or equal
\+/1 Negation by failure. Same as \texttt{not/1}
\=2 True if arguments cannot be unified
\==/2 True if arguments are not strictly equal
\@=/2 Not structural identical
\^/2 Existential quantification (\texttt{bagof/3, setof/3})
1/2 Disjunction in DCGs. Same as ;/2
\end{verbatim}
abolish/1 Remove predicate definition from the database
abolish/2 Remove predicate definition from the database
abolish_all_tables/0 Abolish computed tables
abolish_module_tables/1 Abolish all tables in a module
abolish_monotonic_tables/0 Abolish all monotonic tables
abolish_nonincremental_tables/0 Abolish non-automatic tables
abolish_nonincremental_tables/1 Abolish non-automatic tables
abolish_private_tables/0 Abolish tables of this thread
abolish_shared_tables/0 Abolish tables shared between threads
abolish_table_subgoals/1 Abolish tables for a goal
abort/0 Abort execution, return to top level
absolute_file_name/2 Get absolute path name
absolute_file_name/3 Get absolute path name with options
answer_count_restraint/0 Undefined answer due to max_answers
access_file/2 Check access permissions of a file
acyclic_term/1 Test term for cycles
add_import_module/3 Add module to the auto-import list
add_nb_set/2 Add term to a non-backtrackable set
add_nb_set/3 Add term to a non-backtrackable set
append/1 Append to a file
apply/2 Call goal with additional arguments
apropos/1 online_help Search manual
arg/3 Access argument of a term
assoc_to_list/2 Convert association tree to list
assert/1 Add a clause to the database
assert/2 Add a clause to the database, give reference
asserta/1 Add a clause to the database (first)
asserta/2 Add a clause to the database (first)
assertion/1 Make assertions about your program
assertz/1 Add a clause to the database (last)
assertz/2 Add a clause to the database (last)
attach_console/0 Attach I/O console to thread
attach_packs/0 Attach add-ons
attach_packs/1 Attach add-ons from directory
attach_packs/2 Attach add-ons from directory
attribute_goals/3 Project attributes to goals
attr_unify_hook/2 Attributed variable unification hook
attr_portray_hook/2 Attributed variable print hook
attvar/1 Type test for attributed variable
at_end_of_stream/0 Test for end of file on input
at_end_of_stream/1 Test for end of file on stream
at_halt/1 Register goal to run at halt/1
atom/1 Type check for an atom
atom_chars/2 Convert between atom and list of characters
atom_codes/2 Convert between atom and list of characters codes
APPENDIX F. SUMMARY

atom_concat/3 Contenate two atoms
atom_length/2 Determine length of an atom
atom_number/2 Convert between atom and number
atom_prefix/2 Test for start of atom
atom_string/2 Conversion between atom and string
atom_to_term/3 Convert between atom and term
atomic/1 Type check for primitive
atomic_concat/3 Concatenate two atomic values to an atom
atomic_list_concat/2 Append a list of atomics
atomic_list_concat/3 Append a list of atomics with separator
atomics_to_string/2 Concatenate list of inputs to a string
atomics_to_string/3 Concatenate list of inputs to a string
autoload/1 Declare a file for autoloading
autoload/2 Declare a file for autoloading specific predicates
autoload_all/0 Autoload all predicates now
autoload_path/1 Add directories for autoloading
await/2 WASM: Wait for a Promise
b_getval/2 Fetch backtrackable global variable
b_set_dict/3 Destructive assignment on a dict
b_setval/2 Assign backtrackable global variable
bagof/3 Find all solutions to a goal
between/3 Integer range checking/generating
blob/2 Type check for a blob
bounded_number/3 Number between bounds
break/0 Start interactive top level
break_hook/6 (hook) Debugger hook
byte_count/2 Byte-position in a stream
call/1 Call a goal
call/[2..] Call with additional arguments
call_cleanup/3 Guard a goal with a cleanup-handler
call_cleanup/2 Guard a goal with a cleanup-handler
call_dcg/3 As phrase/3 without type checking
call_delays/2 Get the condition associated with an answer
call_residue_vars/2 Find residual attributed variables
call_residual_program/2 Get residual program associated with an answer
call_shared_object_function/2 UNIX: Call C-function in shared (.so) file
call_with_depth_limit/3 Prove goal with bounded depth
call_with_inference_limit/3 Prove goal in limited inferences
callable/1 Test for atom or compound term
cancel_halt/1 Cancel halt/0 from an at_halt/1 hook
catch/3 Call goal, watching for exceptions
char_code/2 Convert between character and character code
char_conversion/2 Provide mapping of input characters
char_type/2 Classify characters
character_count/2 Get character index on a stream
chdir/1 Compatibility: change working directory
chr_constraint/1 CHR Constraint declaration
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<th>Description</th>
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<td>Start CHR tracer</td>
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<td>CHR Type declaration</td>
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<td>Get clauses of a predicate</td>
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<td>Name and arguments of a compound term</td>
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<td>current_arithmetic_function/1</td>
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<tr>
<td>current_key/1</td>
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current_locale/1  Get the current locale
current_module/1  Examine existing modules
current_op/3  Examine current operator declarations
current_output/1  Get the current output stream
current_predicate/1  Examine existing predicates (ISO)
current_predicate/2  Examine existing predicates
current_signal/3  Current software signal mapping
current_stream/3  Examine open streams
current_table/2  Find answer table for a variant
current_transaction/1  Detect encapsulating transactions
current_trie/1  Enumerate known tries
cyclic_term/1  Test term for cycles
day_of_the_week/2  Determine ordinal-day from date
date_time_stamp/2  Convert date structure to time-stamp
date_time_value/3  Extract info from a date structure
dcg_translate_rule/2  Source translation of DCG rules
dcg_translate_rule/4  Source translation of DCG rules
dde_current_connection/2  Win32: Examine open DDE connections
dde_current_service/2  Win32: Examine DDE services provided
dde_execute/2  Win32: Execute command on DDE server
dde_register_service/2  Win32: Become a DDE server
dde_request/3  Win32: Make a DDE request
dde_poke/3  Win32: POKE operation on DDE server
dde_unregister_service/1  Win32: Terminate a DDE service
debug/0  Show debugger status
debug/1  Test where we are debugging topic
debug/3  Query module inheritance
debug_control_hook/1  (hook) Extend spy/1, etc.
debugging/0  Test where we are debugging topic
debugging/1  Query module inheritance
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del_attributes/1  Delete Key-Value pair from a dict
del_dict/4  Get the residual program for an answer
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delete_file/1  Remove module from import list
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dif/2  Get entries of a directory/folder
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divmod/4  Convert atom to lower-case
downcase_atom/2  Create a copy of a term
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<th>Description</th>
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<td>Indicate predicate definition may change</td>
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<td>edit/1</td>
<td>Edit a file, predicate, module (extensible)</td>
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<td>elif/1</td>
<td>Part of conditional compilation (directive)</td>
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<tr>
<td>else/0</td>
<td>Part of conditional compilation (directive)</td>
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<td>Check existence of file</td>
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<td>Check existence of a Prolog source</td>
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<td>expand_term/4</td>
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F.1. PREDICATES

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Obtain execution statistics
Obtain profile results on a predicate
Obtain/change status of the profiler
Run interactive top level
Query/set unblock signal
Examine the choice point stack
Reference to most recent choice point
Reference to goal’s environment stack
Realise global cuts
Locate targets for edit/1
Locate targets for edit/1
Call editor for edit/1
Specify editor activation
Load edit/1 extensions
Rewrite exceptions
Define meaning of file extension
Obtain information on a goal environment
Program access to the development environment
Allow debugging a thread
(hook) Intercept tracer ‘L’ command
Listen to Prolog events
Listen to Prolog events
Context information for directives
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Indicate deepest recursion to trace
Perform ‘skip’ on a frame
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Convert between Prolog and OS filenames
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Stop listening to Prolog events
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Change the prompt used by read/1
Make a log of the user interaction
Append log of the user interaction to file
On what file is user interaction logged
Declaration that a predicate may be called
Write a character
Write a character on a stream
Add Key-Value to association tree
Put attribute on a variable
Set/replace all attributes on a variable
Write a byte
Write a byte on a stream
Write a character
Write a character on a stream
Write a character-code
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</tr>
<tr>
<td>require/1</td>
<td>This file requires these predicates</td>
</tr>
<tr>
<td>reset/3</td>
<td>Wrapper for delimited continuations</td>
</tr>
<tr>
<td>reset_gensym/1</td>
<td>Reset a gensym key</td>
</tr>
<tr>
<td>reset_gensym/0</td>
<td>Reset all gensym keys</td>
</tr>
<tr>
<td>reset_profiler/0</td>
<td>Clear statistics obtained by the profiler</td>
</tr>
<tr>
<td>resource/2</td>
<td>Declare a program resource</td>
</tr>
<tr>
<td>resource/3</td>
<td>Declare a program resource</td>
</tr>
<tr>
<td>retract/1</td>
<td>Remove clause from the database</td>
</tr>
<tr>
<td>retractall/1</td>
<td>Remove unifying clauses from the database</td>
</tr>
</tbody>
</table>
same_file/2  
Succeeds if arguments refer to same file

same_term/2  
Test terms to be at the same address

se/1  
Change the current input stream

seeng/1  
Query the current input stream

seek/4  
Modify the current position in a stream

seen/0  
Close the current input stream

select_dict/2  
Select matching attributes from a dict

select_dict/3  
Select matching attributes from a dict

set_end_of_stream/1  
Set physical end of an open file

set_flag/2  
Set value of a flag

set_input/1  
Set current input stream from a stream

set_locale/1  
Set the default local

set_malloc/1  
Set memory allocator property

set_module/1  
Set properties of a module

set_output/1  
Set current output stream from a stream

set_prolog_IO/3  
Prepare streams for interactive session

set_prolog_flag/2  
Define a system feature

set_prolog_gc_thread/1  
Control the gc thread

set_prolog_stack/2  
Control stack characteristics

set_random/1  
Control random number generation

set_stream/2  
Set stream attribute

set_stream_position/2  
Seek stream to position

set_system_IO/3  
Rebind stdin/stderr/stdout

setup_call_cleanup/3  
Undo side-effects safely

setup_call_catcher_cleanup/4  
Undo side-effects safely

destrg/3  
Destructive assignment on term

setenv/2  
Set shell environment variable

setlocale/3  
Set/query C-library regional information

setupof/3  
Find all unique solutions to a goal

shell/1  
Execute OS command

shell/2  
Execute OS command

shift/1  
Shift control to the closest reset/3

shift_for_copy/1  
Shift control to the closest reset/3

show_profile/1  
Show results of the profiler

sig_atomic/1  
Run goal without handling signals

sig_block/1  
Block matching thread signals

sig_pending/1  
Query pending signals

sig_remove/2  
Remove pending signals

sig_unblock/1  
Unblock matching thread signals

size_abstract_term/3  
Abstract a term (tabling support)

size_file/2  
Get size of a file in characters

size_nb_set/2  
Determine size of non-backtrackable set

skip/1  
Skip to character in current input

skip/2  
Skip to character on stream

sleep/1  
Suspend execution for specified time

snapshot/1  
Run goal in isolation

sort/2  
Sort elements in a list
sort/4  Sort elements in a list
source_exports/2  Check whether source exports a predicate
source_file/1  Examine currently loaded source files
source_file/2  Obtain source file of predicate
source_file_property/2  Information about loaded files
source_location/2  Location of last read term
split_string/4  Break a string into substrings
spy/1  Force tracer on specified predicate
stamp_date_time/3  Convert time-stamp to date structure
statistics/2  Obtain collected statistics
stream_pair/3  Create/examine a bi-directional stream
stream_position_data/3  Access fields from stream position
stream_property/2  Get stream properties
string/1  Type check for string
string_bytes/3  Translates between text and bytes in encoding
string_concat/3  \texttt{atom_concat/3} for strings
string_length/2  Determine length of a string
string_chars/2  Conversion between string and list of characters
string_codes/2  Conversion between string and list of character codes
string_code/3  Get or find a character code in a string
string_lower/2  Case conversion to lower case
string_upper/2  Case conversion to upper case
string_predicate/1  \texttt{(hook)} Predicate contains strings
strip_module/3  Extract context module and term
style_check/1  Change level of warnings
sub_atom/5  Take a substring from an atom
sub_atom_icasechk/3  Case insensitive substring match
sub_string/5  Take a substring from a string
subsumes_term/2  One-sided unification test
succ/2  Logical integer successor relation
swritef/2  Formatted write on a string
swritef/3  Formatted write on a string
tab/1  Output number of spaces
tab/2  Output number of spaces on a stream
table/1  Declare predicate to be tabled
tabled_call/1  Helper for \texttt{not_exists/1}
tdebug/0  Switch all threads into debug mode
tdebug/1  Switch a thread into debug mode
tell/1  Change current output stream
telling/1  Query current output stream
term_expansion/2  \texttt{(hook)} Convert term before compilation
term_expansion/4  \texttt{(hook)} Convert term before compilation
term_singletons/2  Find singleton variables in a term
term_string/2  Read/write a term from/to a string
term_string/3  Read/write a term from/to a string
term_subsumer/3  Most specific generalization of two terms
term_to_atom/2  Convert between term and atom
### F.1. PREDICATES

- **thread_affinity/3**: Query and control the *affinity* mask
- **thread_alias/1**: Set the alias name of a thread
- **thread_at_exit/1**: Register goal to be called at exit
- **thread_create/2**: Create a new Prolog task
- **thread_create/3**: Create a new Prolog task
- **thread_detach/1**: Make thread cleanup after completion
- **thread_exit/1**: Terminate Prolog task with value
- **thread_get_message/1**: Wait for message
- **thread_get_message/2**: Wait for message in a queue
- **thread_get_message/3**: Wait for message in a queue
- **thread_idle/2**: Reduce footprint while waiting
- **thread_initialization/1**: Run action at start of thread
- **thread_join/1**: Wait for Prolog task-completion
- **thread_join/2**: Wait for Prolog task-completion
- **thread_local/1**: Declare thread-specific clauses for a predicate
- **thread_message_hook/3**: Thread local
- **thread_peek_message/1**: Test for message
- **thread_peek_message/2**: Test for message in a queue
- **thread_property/2**: Examine Prolog threads
- **thread_self/1**: Get identifier of current thread
- **thread_send_message/2**: Send message to another thread
- **thread_send_message/3**: Send message to another thread
- **thread_setconcurrency/2**: Number of active threads
- **thread_signal/2**: Execute goal in another thread
- **thread_statistics/3**: Get statistics of another thread
- **thread_update/2**: Update a module and signal waiters
- **thread_wait/2**: Wait for a goal to become true
- **threads/0**: List running threads
- **throw/1**: Raise an exception (see *catch/3*)
- **time/1**: Determine time needed to execute goal
- **time_file/2**: Get last modification time of file
- **tmp_file/2**: Create a temporary filename
- **tmp_file_stream/3**: Create a temporary file and open it
- **tnodebug/0**: Switch off debug mode in all threads
- **tnodebug/1**: Switch off debug mode in a thread
- **tnot/1**: Tabled negation
- **told/0**: Close current output
- **tprofile/1**: Profile a thread for some period
- **trace/0**: Start the tracer
- **trace/1**: Set trace point on predicate
- **trace/2**: Set/Clear trace point on ports
- **tracing/0**: Query status of the tracer
- **transaction/1**: Run goal in a transaction
- **transaction/2**: Run goal in a transaction
- **transaction/3**: Run goal in a transaction
- **transaction_updates/1**: Updates to be committed in a transaction
- **trie_delete/3**: Remove term from trie
<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>trie_destroy/1</td>
<td>Destroy a trie</td>
</tr>
<tr>
<td>trie_gen/3</td>
<td>Get all terms from a trie</td>
</tr>
<tr>
<td>trie_gen_compiled/2</td>
<td>Get all terms from a trie</td>
</tr>
<tr>
<td>trie_gen_compiled/3</td>
<td>Get all terms from a trie</td>
</tr>
<tr>
<td>trie_insert/2</td>
<td>Insert term into a trie</td>
</tr>
<tr>
<td>trie_insert/3</td>
<td>Insert term into a trie</td>
</tr>
<tr>
<td>trie_insert/4</td>
<td>Insert term into a trie</td>
</tr>
<tr>
<td>trie_lookup/3</td>
<td>Lookup a term in a trie</td>
</tr>
<tr>
<td>trie_new/1</td>
<td>Create a trie</td>
</tr>
<tr>
<td>trie_property/2</td>
<td>Examine a trie’s properties</td>
</tr>
<tr>
<td>trie_update/3</td>
<td>Update associated value in trie</td>
</tr>
<tr>
<td>trie_term/2</td>
<td>Get term from a trie by handle</td>
</tr>
<tr>
<td>trim_heap/0</td>
<td>Release unused malloc() resources</td>
</tr>
<tr>
<td>trim_stacks/0</td>
<td>Release unused stack resources</td>
</tr>
<tr>
<td>tripwire/2</td>
<td>(hook) Handle a tabling tripwire event</td>
</tr>
<tr>
<td>true/0</td>
<td>Succeed</td>
</tr>
<tr>
<td>tsy/1</td>
<td>Set spy point and enable debugging in all threads</td>
</tr>
<tr>
<td>tsy/2</td>
<td>Set spy point and enable debugging in a thread</td>
</tr>
<tr>
<td>tty_get_capability/3</td>
<td>Get terminal parameter</td>
</tr>
<tr>
<td>tty_goto/2</td>
<td>Goto position on screen</td>
</tr>
<tr>
<td>tty_put/2</td>
<td>Write control string to terminal</td>
</tr>
<tr>
<td>tty_size/2</td>
<td>Get row/column size of the terminal</td>
</tr>
<tr>
<td>ttyflush/0</td>
<td>Flush output on terminal</td>
</tr>
<tr>
<td>undefined/0</td>
<td>Well Founded Semantics: true nor false</td>
</tr>
<tr>
<td>undo/1</td>
<td>Schedule goal for backtracking</td>
</tr>
<tr>
<td>unify_with_occurs_check/2</td>
<td>Logically sound unification</td>
</tr>
<tr>
<td>unifiable/3</td>
<td>Determining binding required for unification</td>
</tr>
<tr>
<td>unknown/2</td>
<td>Trap undefined predicates</td>
</tr>
<tr>
<td>unload_file/1</td>
<td>Unload a source file</td>
</tr>
<tr>
<td>unload_foreign_library/1</td>
<td>Detach shared library (.so file)</td>
</tr>
<tr>
<td>unload_foreign_library/2</td>
<td>Detach shared library (.so file)</td>
</tr>
<tr>
<td>unsetenv/1</td>
<td>Delete shell environment variable</td>
</tr>
<tr>
<td>untable/1</td>
<td>Remove tabling instrumentation</td>
</tr>
<tr>
<td>upcase_atom/2</td>
<td>Convert atom to upper-case</td>
</tr>
<tr>
<td>use_foreign_library/1</td>
<td>Load DLL/shared object (directive)</td>
</tr>
<tr>
<td>use_foreign_library/2</td>
<td>Load DLL/shared object (directive)</td>
</tr>
<tr>
<td>use_module/1</td>
<td>Import a module</td>
</tr>
<tr>
<td>use_module/2</td>
<td>Import predicates from a module</td>
</tr>
<tr>
<td>valid_string_goal/1</td>
<td>(hook) Goal handles strings</td>
</tr>
<tr>
<td>var/1</td>
<td>Type check for unbound variable</td>
</tr>
<tr>
<td>var_number/2</td>
<td>Check that var is numbered by numbervars</td>
</tr>
<tr>
<td>var_property/2</td>
<td>Variable properties during macro expansion</td>
</tr>
<tr>
<td>variant_sha1/2</td>
<td>Term-hash for term-variants</td>
</tr>
<tr>
<td>variant_hash/2</td>
<td>Term-hash for term-variants</td>
</tr>
<tr>
<td>version/0</td>
<td>Print system banner message</td>
</tr>
<tr>
<td>version/1</td>
<td>Add messages to the system banner</td>
</tr>
<tr>
<td>visible/1</td>
<td>Ports that are visible in the tracer</td>
</tr>
</tbody>
</table>
volatile/1  Predicates that are not saved
wait_for_input/3  Wait for input with optional timeout
when/2  Execute goal when condition becomes true
wildcard_match/2  POSIX style glob pattern matching
wildcard_match/3  POSIX style glob pattern matching
win_add_dll_directory/1  Add directory to DLL search path
win_add_dll_directory/2  Add directory to DLL search path
win_remove_dll_directory/1  Remove directory from DLL search path
win_exec/2  Win32: spawn Windows task
win_has_menu/0  Win32: true if console menu is available
win_folder/2  Win32: get special folder by CSIDL
win_insert_menu/2  swipl-win.exe: add menu
win_insert_menu_item/4  swipl-win.exe: add item to menu
win_process_modules/1  Win32 get .exe and .dll files of the process
win_shell/2  Win32: open document through Shell
win_shell/3  Win32: open document through Shell
win_registry_get_value/3  Win32: get registry value
win_get_user_preferred_ui_languages/2  Win32: get language preferences
win_window_color/2  Win32: change colors of console window
window_title/2  Win32: change title of window
with_mutex/2  Run goal while holding mutex
with_output_to/2  Write to strings and more
with_quasi_quotation_input/3  Parse quasi quotation from stream
with_tty_raw/1  Run goal with terminal in raw mode
working_directory/2  Query/change CWD
write/1  Write term
write/2  Write term to stream
writeln/1  Write term, followed by a newline
writeln/2  Write term, followed by a newline to a stream
write_canonical/1  Write a term with quotes, ignore operators
write_canonical/2  Write a term with quotes, ignore operators on a stream
write_length/3  Determine #characters to output a term
write_term/2  Write term with options
write_term/3  Write term with options to stream
writef/1  Formatted write
writef/2  Formatted write on stream
writeq/1  Write term, insert quotes
writeq/2  Write term, insert quotes on stream
F.2 Library predicates

F.2.1 library(aggregate)

aggregate/3 Aggregate bindings in Goal according to Template.
aggregate/4 Aggregate bindings in Goal according to Template.
aggregate_all/3 Aggregate bindings in Goal according to Template.
aggregate_all/4 Aggregate bindings in Goal according to Template.
foreach/2 True when the conjunction of _instances_ of Goal created from solutions for Generator is true.
free_variables/4 Find free variables in bagof/setof template.

F.2.2 library(ansi_term)

ansi_format/3 Format text with ANSI attributes.
ansi_get_color/2 Obtain the RGB color for an ANSI color parameter.
ansi_hyperlink/2 Create a hyperlink for a terminal emulator.
ansi_hyperlink/3 Create a hyperlink for a terminal emulator.
console_color/2 Hook that allows for mapping abstract terms to concrete ANSI attributes.
hyperlink/2 Multifile hook that may be used to redefine ansi_hyperlink/2,3.

F.2.3 library(apply)

convlist/3 Similar to maplist/3, but elements for which call(Goal, ElemIn, _) fails are omitted from ListOut.
exclude/3 Filter elements for which Goal fails.
foldl/4 Fold an ensemble of _m_ (0 <= _m_ <= 4) lists of length _n_ head-to-tail ("fold-left"), using columns of _m_ elements.
foldl/5 Fold an ensemble of _m_ (0 <= _m_ <= 4) lists of length _n_ head-to-tail ("fold-left"), using columns of _m_ elements.
foldl/6 Fold an ensemble of _m_ (0 <= _m_ <= 4) lists of length _n_ head-to-tail ("fold-left"), using columns of _m_ elements.
foldl/7 Fold an ensemble of _m_ (0 <= _m_ <= 4) lists of length _n_ head-to-tail ("fold-left"), using columns of _m_ elements.
include/3 Filter elements for which Goal succeeds.
maplist/2 True if Goal is successfully applied on all matching elements of the list.
maplist/3 True if Goal is successfully applied on all matching elements of the list.
maplist/4 True if Goal is successfully applied on all matching elements of the list.
maplist/5 True if Goal is successfully applied on all matching elements of the list.
person/4 Filter elements of List according to Pred.
person/5 Filter List according to Pred in three sets.
scanl/4 Scan an ensemble of _m_ (0 <= _m_ <= 4) lists of length _n_ head-to-tail ("scan-left"), using columns of _m_ elements.
scanl/5 Scan an ensemble of _m_ (0 <= _m_ <= 4) lists of length _n_ head-to-tail ("scan-left"), using columns of _m_ elements.
scanl/6 Scan an ensemble of _m_ (0 <= _m_ <= 4) lists of length _n_ head-to-tail ("scan-left"), using columns of _m_ elements.
scanl/7 Scan an ensemble of _m_ (0 <= _m_ <= 4) lists of length _n_ head-to-tail ("scan-left"), using columns of _m_ elements.

F.2.4 library(assoc)

assoc_to_list/2 Translate assoc into a pairs list
assoc_to_keys/2 Translate assoc into a key list
### F.2. LIBRARY PREDICATES

<table>
<thead>
<tr>
<th>Predicate</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>assoc_to_values/2</td>
<td>Translate assoc into a value list</td>
</tr>
<tr>
<td>empty_assoc/1</td>
<td>Test/create an empty assoc</td>
</tr>
<tr>
<td>gen_assoc/3</td>
<td>Non-deterministic enumeration of assoc</td>
</tr>
<tr>
<td>get_assoc/3</td>
<td>Get associated value</td>
</tr>
<tr>
<td>get_assoc/5</td>
<td>Get and replace associated value</td>
</tr>
<tr>
<td>list_to_assoc/2</td>
<td>Translate pair list to assoc</td>
</tr>
<tr>
<td>map_assoc/2</td>
<td>Test assoc values</td>
</tr>
<tr>
<td>map_assoc/3</td>
<td>Map assoc values</td>
</tr>
<tr>
<td>max_assoc/3</td>
<td>Max key-value of an assoc</td>
</tr>
<tr>
<td>min_assoc/3</td>
<td>Min key-value of an assoc</td>
</tr>
<tr>
<td>ord_list_to_assoc/2</td>
<td>Translate ordered list into an assoc</td>
</tr>
<tr>
<td>put_assoc/4</td>
<td>Add association to an assoc</td>
</tr>
</tbody>
</table>

#### F.2.5 library(broadcast)

<table>
<thead>
<tr>
<th>Predicate</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>broadcast/1</td>
<td>Send event notification</td>
</tr>
<tr>
<td>broadcast_request/1</td>
<td>Request all agents</td>
</tr>
<tr>
<td>listen/2</td>
<td>Listen to event notifications</td>
</tr>
<tr>
<td>listen/3</td>
<td>Listen to event notifications</td>
</tr>
<tr>
<td>unlisten/1</td>
<td>Stop listening to event notifications</td>
</tr>
<tr>
<td>unlisten/2</td>
<td>Stop listening to event notifications</td>
</tr>
<tr>
<td>unlisten/3</td>
<td>Stop listening to event notifications</td>
</tr>
<tr>
<td>listening/3</td>
<td>Who is listening to event notifications?</td>
</tr>
</tbody>
</table>

#### F.2.6 library(charsio)

<table>
<thead>
<tr>
<th>Predicate</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>atom_to_chars/2</td>
<td>Convert Atom into a list of character codes.</td>
</tr>
<tr>
<td>atom_to_chars/3</td>
<td>Convert Atom into a difference list of character codes.</td>
</tr>
<tr>
<td>format_to_chars/3</td>
<td>Use format/2 to write to a list of character codes.</td>
</tr>
<tr>
<td>format_to_chars/4</td>
<td>Use format/2 to write to a difference list of character codes.</td>
</tr>
<tr>
<td>number_to_chars/2</td>
<td>Convert Atom into a list of character codes.</td>
</tr>
<tr>
<td>number_to_chars/3</td>
<td>Convert Number into a difference list of character codes.</td>
</tr>
<tr>
<td>open_chars_stream/2</td>
<td>Open Codes as an input stream.</td>
</tr>
<tr>
<td>read_from_chars/2</td>
<td>Read Codes into Term</td>
</tr>
<tr>
<td>read_term_from_chars/3</td>
<td>Read Codes into Term</td>
</tr>
<tr>
<td>with_output_to_chars/2</td>
<td>Run Goal as with once/1.</td>
</tr>
<tr>
<td>with_output_to_chars/3</td>
<td>Run Goal as with once/1.</td>
</tr>
<tr>
<td>with_output_to_chars/4</td>
<td>Same as with_output_to_chars/3 using an explicit stream.</td>
</tr>
<tr>
<td>write_to_chars/2</td>
<td>Write a term to a code list</td>
</tr>
<tr>
<td>write_to_chars/3</td>
<td>Write a term to a code list</td>
</tr>
</tbody>
</table>

#### F.2.7 library(check)

<table>
<thead>
<tr>
<th>Predicate</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>check/0</td>
<td>Run all consistency checks defined by checker/2.</td>
</tr>
<tr>
<td>checker/2</td>
<td>Register code validation routines.</td>
</tr>
</tbody>
</table>
APPENDIX F. SUMMARY

list_autoload/0 Report predicates that may be auto-loaded.
list_cross_module_calls/0 List calls from one module to another using Module:Goal where the callee is not defined exported, public or multifile, i.e., where the callee should be considered private.
list_format_errors/0 List argument errors for format/2,3.
list_format_errors/1 List argument errors for format/2,3.
list_rationals/0 List rational numbers that appear in clauses.
list_rationals/1 List rational numbers that appear in clauses.
list_redefined/0 Lists predicates that are defined in the global module =user= as well as in a normal module; that is, predicates for which the local definition overrules the global default definition.
list_strings/0 List strings that appear in clauses.
list_strings/1 List strings that appear in clauses.
list_trivial_fails/0 List goals that trivially fail because there is no matching clause.
list_trivial_fails/1 List goals that trivially fail because there is no matching clause.
list Undefined/0 Report undefined predicates.
list Undefined/1 Report undefined predicates.
list voiddeclarations/0 List predicates that have declared attributes, but no clauses.
string_predicate/1 Multifile hook to disable list_strings/0 on the given predicate.
trivial_fail_goal/1 Multifile hook that tells list_trivial_fails/0 to accept Goal as valid.
valid_string_goal/1 Multifile hook that qualifies Goal as valid for list_strings/0.

F.2.8 library(clpb)

labeling/1 Enumerate concrete solutions.
random_labeling/2 Select a single random solution.
sat/1 True iff Expr is a satisfiable Boolean expression.
sat_count/2 Count the number of admissible assignments.
taut/2 Tautology check.
weighted_maximum/3 Enumerate weighted optima over admissible assignments.

F.2.9 library(clpfd)

#\/
2 P and Q hold.
#<\2 The arithmetic expression X is less than Y.
#<\=\2 Q implies P.
#<\=\>
2 P and Q are equivalent.
#=\2 The arithmetic expression X equals Y.
#<\=
2 The arithmetic expression X is less than or equal to Y.
#==\2 P implies Q.
#\>
2 Same as Y #< X.
#\=<
2 Same as Y #=< X.
#\1 Q does_not_hold.
#\/
2 Either P holds or Q holds, but not both.
#\/\2 P or Q holds.
#\=
2 The arithmetic expressions X and Y evaluate to distinct integers.
all_different/1 Like all_distinct/1, but with weaker propagation.
all_distinct/1 True iff Vars are pairwise distinct.
avtomaton/3 Describes a list of finite domain variables with a finite automaton.
automaton/8  Describes a list of finite domain variables with a finite automaton.
chain/2   Zs form a chain with respect to Relation.
circuit/1 True iff the list Vs of finite domain variables induces a Hamiltonian circuit.
cumulative/1 Equivalent to cumulative(Tasks, [limit(1)]).
cumulative/2 Schedule with a limited resource.
disjoint2/1 True iff Rectangles are not overlapping.
element/3  The N-th element of the list of finite domain variables Vs is V.
empty_fdset/1 Set is the empty FD set.
empty_interval/2 Min..Max is an empty interval.
fd_degree/2 Degree is the number of constraints currently attached to Var.
fd_dom/2    Dom is the current domain (see in/2) of Var.
fd_inf/2    Inf is the infimum of the current domain of Var.
fd_set/2    Set is the FD set representation of the current domain of Var.
fd_size/2   Reflect the current size of a domain.
fd_sup/2    Sup is the supremum of the current domain of Var.
fd_var/1    True iff Var is a CLP(FD) variable.
fdset_add_element/3 Set2 is the same FD set as Set1, but with the integer Elt added.
fdset_complement/2 The FD set Complement is the complement of the FD set Set.
fdset_del_element/3 Set2 is the same FD set as Set1, but with the integer Elt removed.
fdset_disjoint/2 The FD sets Set1 and Set2 have no elements in common.
fdset_eq/2    True if the FD sets Set1 and Set2 are equal, i.
fdset_intersection/2 The FD sets Set1 and Set2 have at least one element in common.
fdset_interval/3 Intersection is an FD set (possibly empty) of all elements that the FD sets Set1 and Set2 have in common.
fdset_max/2    Max is the upper bound (supremum) of the non-empty FD set Set.
fdset_member/2 The integer Elt is a member of the FD set Set.
fdset_min/2    Min is the lower bound (infimum) of the non-empty FD set Set.
fdset_parts/4  Set is a non-empty FD set representing the domain Min..Max \ / Rest, where Min..Max is a non-empty interval and Rest is another FD set (possibly empty).
fdset_singleton/2 Set is the FD set containing the single integer Elt.
fdset_size/2   Size is the number of elements of the FD set Set, or the atom *sup* if Set is infinite.
fdset_subset/2 The FD set Set1 is a (non-strict) subset of Set2, i.
fdset_subtract/3 The FD set Difference is Set1 with all elements of Set2 removed, i.
fdset_to_list/2 List is a list containing all elements of the finite FD set Set, in ascending order.
fdset_to_range/2 Domain is a domain equivalent to the FD set Set.
fdset_union/2    The FD set Union is the n-ary union of all FD sets in the list Sets.
fset_union/3    The FD set Union is the union of FD sets Set1 and Set2.
global_cardinality/2 Global Cardinality constraint.
global_cardinality/3 Global Cardinality constraint.
in/2     Var is an element of Domain.
in_set/2 Var is an element of the FD set Set.
indomain/1 Bind Var to all feasible values of its domain on backtracking.
ins/2    The variables in the list Vars are elements of Domain.
is_fdset/1 Set is currently bound to a valid FD set.
label/1  Equivalent to labeling([], Vars).
labeling/2 Assign a value to each variable in Vars.
lex_chain/1 Lists are lexicographically non-decreasing.
list_to_fdset/2 Set is an FD set containing all elements of List, which must be a list of integers.
range_to_fdset/2  Set is an FD set equivalent to the domain Domain.
scalar_product/4  True iff the scalar product of Cs and Vs is in relation Rel to Expr.
serialized/2  Describes a set of non-overlapping tasks.
sum/3  The sum of elements of the list Vars is in relation Rel to Expr.
transpose/2  Transpose a list of lists of the same length.
tuples_in/2  True iff all Tuples are elements of Relation.
zcompare/3  Analogous to compare/3, with finite domain variables A and B.

F.2.10  library(clpqr)

entailed/1  Check if constraint is entailed
inf/2  Find the infimum of an expression
sup/2  Find the supremum of an expression
minimize/1  Minimizes an expression
maximize/1  Maximizes an expression
bb_inf/3  Infimum of expression for mixed-integer problems
bb_inf/4  Infimum of expression for mixed-integer problems
bb_inf/5  Infimum of expression for mixed-integer problems
dump/3  Dump constraints on variables

F.2.11  library(csv)

csv_options/2  Compiled is the compiled representation of the CSV processing options as they may be passed into csv\//2, etc.
csv_read_file/2  Read a CSV file into a list of rows.
csv_read_file/3  Read a CSV file into a list of rows.
csv_read_file_row/3  True when Row is a row in File.
csv_read_row/3  Read the next CSV record from Stream and unify the result with Row.
csv_read_stream/3  Read CSV data from Stream.
csv_write_file/2  Write a list of Prolog terms to a CSV file.
csv_write_file/3  Write a list of Prolog terms to a CSV file.
csv_write_stream/3  Write the rows in Data to Stream.
csv\//1  Prolog DCG to ‘read/write’ CSV data.
csv\//2  Prolog DCG to ‘read/write’ CSV data.

F.2.12  library(dcg basics)

alpha_to_lower//1  Read a letter (class =alpha=) and return it as a lowercase letter.
atom/1  Generate codes of Atom.
blank//0  Take next =space= character from input.
blanks//0  Skip zero or more white-space characters.
blanks_to_nl//0  Take a sequence of blank // /0 codes if blanks are followed by a newline or end of the input.
digit/1  Number processing.
digits/1  Number processing.
eol/0  Matches end-of-line.
cos/0  Matches end-of-input.
F.2. LIBRARY PREDICATES

float//1 Process a floating point number.
integer//1 Number processing.
nonblank//1 Code is the next non-blank (=graph=) character.
nonblanks//1 Take all =graph= characters.
number//1 Generate extract a number.
prolog_var_name//1 Matches a Prolog variable name.
remainder//1 Unify List with the remainder of the input.
string//1 Take as few as possible tokens from the input, taking one more each time on backtracking.
string_without//2 Take as many codes from the input until the next character code appears in the list EndCodes.
white//0 Take next =white= character from input.
whites//0 Skip white space inside a line.
xdigit//1 True if the next code is a hexadecimal digit with Weight.
xdigits//1 List of weights of a sequence of hexadecimal codes.
xinteger//1 Generate or extract an integer from a sequence of hexadecimal digits.

F.2.13 library(dcghighorder)

foreach//2 Generate a list from the solutions of Generator.
foreach//3 Generate a list from the solutions of Generator.
optional//2 Perform an optional match, executing Default if Match is not matched.
sequence//2 Match or generate a sequence of Element.
sequence//3 Match or generate a sequence of Element where each pair of elements is separated by Sep.
sequence//5 Match or generate a sequence of Element enclosed by Start end End, where each pair of elements is separated by Sep.

F.2.14 library(debug)

assertion/1 Acts similar to C assert() macro.
assertion_failed/2 This hook is called if the Goal of assertion/1 fails.
debug/1 Add/remove a topic from being printed.
debug/3 Format a message if debug topic is enabled.
debug_message_context/1 Specify additional context for debug messages.
debug_print_hook/3 Hook called by debug/3.
debugging/1 Examine debug topics.
debugging/2 Examine debug topics.
list_debug_topics/0 List currently known debug topics and their setting.
nodebug/1 Add/remove a topic from being printed.

F.2.15 library(dicts)

dict_fill/4 Implementation for the dicts_to_same_keys/3 'OnEmpty' closure that fills new cells with a copy

dict_keys/2 True when Keys is an ordered set of the keys appearing in Dict.
dict_size/2 True when KeyCount is the number of keys in Dict.

dicts_join/3 Join dicts in Dicts that have the same value for Key, provided they do not have conflicting values.
dicts_join/4 Join two lists of dicts (Dicts1 and Dicts2) on Key.
dicts_same_keys/2 True if List is a list of dicts that all have the same keys and Keys is an ordered set of these keys.
dicts_same_tag/2 True when List is a list of dicts that all have the tag Tag.
dicts_slice/3 DictsOut is a list of Dicts only containing values for Keys.
dicts_to_compounds/4 True when Dicts and Compounds are lists of the same length and each element of Compounds is a compound term whose arguments represent the values associated with the corresponding keys in Keys.
dicts_to_same_keys/3 DictsOut is a copy of DictsIn, where each dict contains all keys appearing in all dicts of DictsIn.

F.2.16 library(error)
current_encoding/1 True if Name is the name of a supported encoding.
current_type/3 True when Type is a currently defined type and Var satisfies Type of the body term Body succeeds.
domain_error/2 The argument is of the proper type, but has a value that is outside the supported values.
existence_error/2 Culprit is of the correct type and correct domain, but there is no existing (external) resource of the type of Culprit.
existence_error/3 Culprit is of the correct type and correct domain, but there is no existing (external) resource of the type of Culprit in the provided set.
has_type/2 True if Term satisfies Type.
instatiation_error/1 An argument is under-instantiated.
is_of_type/2 True if Term satisfies Type.
must_be/2 True if Term satisfies the type constraints for Type.
permission_error/3 It is not allowed to perform Operation on (whatever is represented by) Culprit that is of the given PermissionType.
representation_error/1 A representation error indicates a limitation of the implementation.
resource_error/1 A goal cannot be completed due to lack of resources.
syntax_error/1 A text has invalid syntax.
type_error/2 Tell the user that Culprit is not of the expected ValidType.
uninstantiation_error/1 An argument is over-instantiated.

F.2.17 library(fastrw)
fast_read/1 The next term is read from current standard input and is unified with Term.
fast_write/1 Output Term in a way that fast_read/1 and fast_read/2 will be able to read it back.
fast_write_to_string/3 Perform a fast-write to the difference-slist String\Tail.

F.2.18 library(explain)
explain/1 Give an explanation on Term.
explain/2 True when Explanation is an explanation of Term.

F.2.19 library(help)
apropos/1 Print objects from the manual whose name or summary match with Query.
help/0 Show help for What.
help/1 Show help for What.
show_html_hook/1 Hook called to display the extracted HTML document.

F.2.20 library(gensym)
F.2. LIBRARY PREDICATES

F.2.21 library(heaps)

- add_to_heap/4: Adds Key with priority Priority to Heap0, constructing a new heap in Heap.
- delete_from_heap/4: Deletes Key from Heap0, leaving its priority in Priority and the resulting data structure in Heap.
- empty_heap/1: True if Heap is an empty heap.
- get_from_heap/4: Retrieves the minimum-priority pair Priority-Key from Heap0.
- heap_size/2: Determines the number of elements in Heap.
- heap_to_list/2: Constructs a list List of Priority-Element terms, ordered by (ascending) priority.
- is_heap/1: Returns true if X is a heap.
- list_to_heap/2: If List is a list of Priority-Element terms, constructs a heap out of List.
- merge_heaps/3: Merge the two heaps Heap0 and Heap1 in Heap.
- min_of_heap/3: Unifies Key with the minimum-priority element of Heap and Priority with its priority value.
- min_of_heap/5: Gets the two minimum-priority elements from Heap.
- singleton_heap/3: True if Heap is a heap with the single element Priority-Key.

F.2.22 library(increval)

- incr_directly_depends/2: True if Goal1 depends on Goal2 in the IDG.
- incr_invalid_subgoals/1: List is a sorted list (set) of the incremental subgoals that are currently invalid.
- incr_invalidate_call/1: This is the XSB name, but the manual says incr_invalidate_calls/1 and the comment with the code suggests this is misnamed.
- incr_invalidate_calls/1: Invalidate all tables for subgoals of Goal as well as tables that are affected by these.
- incr_is_invalid/1: True when Subgoal’s table is marked as invalid.
- incr_propagate_calls/1: Activate the monotonic answer propagation similarly to when a new fact is asserted for a monotonic dynamic predicate.
- incr_table_update/0: Updated all invalid tables.
- incr_trans_depends/2: True for each pair in the transitive closure of incr_directly_depends(G1, G2).
- is_incremental_subgoal/1: This predicate non-deterministically unifies Subgoal with incrementally tabled subgoals that

F.2.23 library(intercept)

- intercept/3: Run Goal as call/1.
- intercept/4: Similar to intercept/3, but the copy of Handler is called as call(Copy,Arg), which allows passing large context.
- intercept_all/4: True when List contains all instances of Template that have been sent using send_signal/1 where the argument unifies with Ball.
- nb_intercept_all/4: As intercept_all/4, but backtracing inside Goal does not reset List.
- send_signal/1: If this predicate is called from a sub-goal of intercept/3, execute the associated _Handler_ of the intercept environment.
- send_silent_signal/1: As send_signal/1, but succeed silently if there is no matching intercept environment.

F.2.24 library(iostream)

- close_any/1: Execute the ‘Close’ closure returned by open_any/5.
- open_any/5: Establish a stream from Specification that should be closed using Close, which can either be called or passed as an argument.
open_hook/6  Open Spec in Mode, producing Stream.

F.2.25 library(listing)

listing/0  Lists all predicates defined in the calling module.
listing/1  List matching clauses.
listing/2  List matching clauses.
portray_clause/1  Portray ‘Clause’ on the current output stream.
portray_clause/2  Portray ‘Clause’ on the current output stream.
portray_clause/3  Portray ‘Clause’ on the current output stream.

F.2.26 library(lists)

append/2  Concatenate a list of lists.
append/3  List1 AndList2 is the concatenation of List1 and List2.
clumped/2  Pairs is a list of ‘Item-Count’ pairs that represents the _run length encoding_ of Items.
delete/3  Delete matching elements from a list.
flatten/2  Is true if Flatten is a non-nested version of NestedList.
intersection/3  True if Set3 unifies with the intersection of Set1 and Set2.
is_set/1  True if Set is a proper list without duplicates.
last/2  Succeeds when Last is the last element of List.
list_to_set/2  True when Set has the same elements as List in the same order.
max_list/2  True if Max is the largest number in List.
max_member/2  True when Max is the largest member in the standard order of terms.
max_member/3  True when Max is the largest member according to Pred, which must be a 2-argument callable that behaves like (\(\leq\))/2.
member/2  True if Elem is a member of List.
min_list/2  True if Min is the smallest number in List.
min_member/2  True when Min is the smallest member in the standard order of terms.
min_member/3  True when Min is the smallest member according to Pred, which must be a 2-argument callable that behaves like (\(\leq\))/2.
nextto/3  True if Y directly follows X in List.
nth0/3  True when Elem is the Index’th element of List.
nth0/4  Select/insert element at index.
nth1/3  Is true when Elem is the Index’th element of List.
nth1/4  As nth0/4, but counting starts at 1.
umlist/3  List is a list [Low, Low+1, ... High].
permutation/2  True when Xs is a permutation of Ys.
prefix/2  True iff Part is a leading substring of Whole.
proper_length/2  True when Length is the number of elements in the proper list List.
reverse/2  Is true when the elements of List2 are in reverse order compared to List1.
same_length/2  Is true when List1 and List2 are lists with the same number of elements.
select/3  Is true when List1, with Elem removed, results in List2.
select/4  Select from two lists at the same position.
selectchk/3  Semi-deterministic removal of first element in List that unifies with Elem.
selectchk/4  Semi-deterministic version of select/4.
subset/2  True if all elements of SubSet belong to Set as well.
F.2. LIBRARY PREDICATES

subtract/3 Delete all elements in Delete from Set.
sum_list/2 Sum is the result of adding all numbers in List.
union/3 True if Set3 unifies with the union of the lists Set1 and Set2.

F.2.27 library(main)

argv_options/3 Parse command line arguments.
argv_options/4 As argv_options/3 in _guided_ mode; Currently this version allows parsing arguments that are module-sensitive.
argv_usage/1 Use print_message/2 to print a usage message at Level.
cli_enable_development_system/0 Re-enable the development environment.
cli_parse_debug_options/2 Parse certain command line options for debugging and development purposes.
main/0 Call main/1 using the passed command-line arguments.

F.2.28 library(occurs)

contains_term/2 Succeeds if Sub is contained in Term (=, deterministically).
contains_var/2 Succeeds if Sub is contained in Term (==, deterministically).
free_of_term/2 Succeeds if Sub does not unify to any subterm of Term.
free_of_var/2 Succeeds if Sub is not equal (==) to any subterm of Term.
occurrences_of_term/3 Count the number of SubTerms in Term.
occurrences_of_var/3 Count the number of SubTerms in Term.
sub_term/2 Generates (on backtracking) all subterms of Term.
sub_term_shared_variables/3 If Sub is a sub term of Term, Vars is bound to the list of variables in Sub that also appear outside Sub in Term.
sub_var/2 Generates (on backtracking) all subterms (==) of Term.

F.2.29 library(option)

dict_options/2 Convert between an option list and a dictionary.
merge_options/3 Merge two option lists.
meta_options/3 Perform meta-expansion on options that are module-sensitive.
option/2 Get an Option from OptionList.
option/3 Get an Option from OptionList.
select_option/3 Get and remove Option from an option list.
select_option/4 Get and remove Option with default value.

F.2.30 library(optparse)

opt_arguments/3 Extract commandline options according to a specification.
opt_help/2 True when Help is a help string synthesized from OptsSpec.
opt_parse/4 Equivalent to opt_parse(OptsSpec, ApplArgs, Opts, PositionalArgs, [])
opt_parse/5 Parse the arguments Args (as list of atoms) according to OptsSpec.
parse_type/3 Hook to parse option text Codes to an object of type Type.
APPENDIX F. SUMMARY

F.2.31 library(ordsets)

is_ordset/1 True if Term is an ordered set.
list_to_ord_set/2 Transform a list into an ordered set.
ord_add_element/3 Insert an element into the set.
ord_del_element/3 Delete an element from an ordered set.
ord_disjoint/2 True if Set1 and Set2 have no common elements.
ord_empty/1 True when List is the empty ordered set.
ord_intersect/2 True if both ordered sets have a non-empty intersection.
ord_intersect/3 Intersection holds the common elements of Set1 and Set2.
ord_intersection/2 Intersection of a powerset.
ord_intersection/3 Intersection holds the common elements of Set1 and Set2.
ord_intersection/4 Intersection and difference between two ordered sets.
ord_memberchk/2 True if Element is a member of OrdSet, compared using ==.
ord_selectchk/3 Selectchk/3, specialised for ordered sets.
ord_seteq/2 True if Set1 and Set2 have the same elements.
ord_subset/2 Is true if all elements of Sub are in Super.
ord_subtract/3 Diff is the set holding all elements of InOSet that are not in NotInOSet.
ord_symdiff/3 Is true when Difference is the symmetric difference of Set1 and Set2.
ord_union/2 True if Union is the union of all elements in the superset SetOfSets.
ord_union/3 Union is the union of Set1 and Set2.
ord_union/4 True iff ord_union(Set1, Set2, Union) and ord_subtract(Set2, Set1, New).

F.2.32 library(persistency)

current_persistent_predicate/1 True if PI is a predicate that provides access to the persistent database DB.
db_assert/1 Assert Term into the database and record it for persistency.
db_attach/2 Use File as persistent database for the calling module.
db_attached/1 True if the context module attached to the persistent database File.
db_detach/0 Detach persistency from the calling module and delete all persistent clauses from the Prolog database.
db_retract/1 Retract terms from the database one-by-one.
db_retractall/1 Retract all matching facts and do the same in the database.
db_sync/1 Synchronise database with the associated file.
db_sync_all/1 Sync all registered databases.
persistent/1 Declare dynamic database terms.

F.2.33 library(portraytext)

is_text_code/1 Multifile hook that can be used to extend the set of character codes that is recognised as likely text.
portray_text/1 Switch portraying on or off.
set_portray_text/2 Set options for portraying.
set_portray_text/3 Set options for portraying.

F.2.34 library(predicate_options)
F.2. LIBRARY PREDICATES

assert_predicate_options/4  As predicate_options(:PI, +Arg, +Options).
check_predicate_option/3   Verify predicate options at runtime.
check_predicate_options/0  Analyse loaded program for erroneous options.
current_option_arg/2      True when Arg of PI processes predicate options.
current_predicate_option/3 True when Arg of PI processes Option.
current_predicate_options/3 True when Options is the current active option declaration for PI on Arg.
derive_predicate_options/0 Derive new predicate option declarations.
derive_predicate_options/1 Derive predicate option declarations for a module.
derive_predicate_options/3 Derive option arguments using static analysis.
predicate_options/3       Declare that the predicate PI processes options on Arg.
retractall_predicate_options/0 Remove all dynamically (derived) predicate options.

F.2.35 library(prologdebug)

debugging/0       Report current status of the debugger.
exception_hook/4  Trap exceptions and consider whether or not to start the tracer.
nospy/1           Set/clear spy-points.
nospyall/0        Set/clear spy-points.
notrap/1          Install a trap on error(\text{Formal, Context}) exceptions that unify.
spy/1             Set/clear spy-points.
trap/1            Install a trap on error(\text{Formal, Context}) exceptions that unify.

F.2.36 library(prologjiti)

jiti_list/0  List the JITI (Just In Time Indexes) of selected predicates.
jiti_list/1  List the JITI (Just In Time Indexes) of selected predicates.

F.2.37 library(prologpack)

atom_version/2  Translate between atomic version representation and term representation.
pack_attach/2   Attach a single package in Dir.
pack_info/1     Print more detailed information about Pack.
pack_install/1  Install a package.
pack_install/2  Install package Name.
pack_list/1     Query package server and installed packages and display results.
pack_list_installed/0  List currently installed packages.
pack_property/2 True when Property is a property of an installed Pack.
pack_rebuild/0  Rebuild foreign components of all packages.
pack_rebuild/1  Rebuilt possible foreign components of Pack.
pack_remove/1   Remove the indicated package.
pack_search/1    Query package server and installed packages and display results.
pack_upgrade/1   Try to upgrade the package Pack.
pack_url_file/2  True if File is a unique id for the referenced pack and version.
ssl_verify/5     Currently we accept all certificates.
F.2.38  library(prologxref)

prolog:called_by/2 (hook) Extend cross-referencer
xref_built_in/1 Examine defined built-ins
xref_called/3 Examine called predicates
xref_clean/1 Remove analysis of source
xref_current_source/1 Examine cross-referenced sources
xref_defined/3 Examine defined predicates
xref_exported/2 Examine exported predicates
xref_module/2 Module defined by source
xref_source/1 Cross-reference analysis of source

F.2.39  library(pairs)

group_pairs_by_key/2 Group values with equivalent (==/2) consecutive keys.
map_list_to_pairs/3 Create a Key-Value list by mapping each element of List.
pairs_keys/2 Remove the values from a list of Key-Value pairs.
pairs_keys_values/3 True if Keys holds the keys of Pairs and Values the values.
pairs_values/2 Remove the keys from a list of Key-Value pairs.
transpose_pairs/2 Swap Key-Value to Value-Key.

F.2.40  library(pio)

library(pure_input)

phrase_from_file/2 Process the content of File using the DCG rule Grammar.
phrase_from_file/3 As phrase_from_file/2, providing additional Options.
phrase_from_stream/2 Run Grammer against the character codes on Stream.
stream_to_lazy_list/2 Create a lazy list representing the character codes in Stream.
lazy_list_character_count//1 True when CharCount is the current character count in the Lazy list.
lazy_list_location//1 Determine current (error) location in a lazy list.
syntax_error//1 Throw the syntax error Error at the current location of the input.

F.2.41  library(random)

getrnd/1 Query/set the state of the random generator.
maybe/0 Succeed/fail with equal probability (variant of maybe/1).
maybe/1 Succeed with probability P, fail with probability 1-P.
maybe/2 Succeed with probability K/N (variant of maybe/1).
random/1 Binds R to a new random float in the open interval (0.0,1.0).
random/3 Generate a random integer or float in a range.
random_between/3 Binds R to a random integer in [L,U] (i.e., including both L and U).
random_member/2 X is a random member of List.
random_numlist/4 Unify List with an ascending list of integers between L and U (inclusive).
random_perm2/4 Does X=A,Y=B or X=B,Y=A with equal probability.
F.2. LIBRARY PREDICATES

random_permutation/2  Permutation is a random permutation of List.
random_select/3       Randomly select or insert an element.
random_subseq/3       Selects a random subsequence Subseq of List, with Complement containing all elements of List.
randseq/3             S is a list of K unique random integers in the range 1..N.
randset/3             S is a sorted list of K unique random integers in the range 1..N.
setrand/1             Query/set the state of the random generator.

F.2.42 library(rbtrees)

is_rbtree/1          True if Term is a valid Red-Black tree.
list_to_rbtree/2     Tree is the red-black tree corresponding to the mapping in List, which should be a list of Key-Value pairs.
ord_list_to_rbtree/2 Tree is the red-black tree corresponding to the mapping in list List, which should be a list of Key-Value pairs.
r_b_apply/4          If the value associated with key Key is Val0 in Tree, and if call(G,Val0,ValF) holds, then NewTree is...
r_b_clone/3          ‘Clone’ the red-back tree TreeIn into a new tree TreeOut with the same keys as the original but with...
r_b_del_max/4        Delete the largest element from the tree Tree, returning the key Key, the value Val associated with the key and...
r_b_del_min/4        Delete the least element from the tree Tree, returning the key Key, the value Val associated with the key and...
r_b_delete/3          Delete element with key Key from the tree Tree, returning the value Val associated with the key and...
r_b_delete/4          Same as rb_delete(Tree, Key, NewTree), but also unifies Val with the value associated with Key in T.
r_b_empty/1           Succeeds if Tree is an empty Red-Black tree.
r_b_fold/4            Fold the given predicate over all the key-value pairs in Tree, starting with initial state State0 and returning the final state State.
r_b_in/3              True when Key-Value is a key-value pair in red-black tree Tree.
r_b_insert/4          Add an element with key Key and Value to the tree Tree creating a new red-black tree NewTree.
r_b_insert_new/4      Add a new element with key Key and Value to the tree Tree creating a new red-black tree NewTree.
r_b_keys/2            Keys is unified with an ordered list of all keys in the Red-Black tree Tree.
r_b_lookup/3          True when Value is associated with Key in the Red-Black tree Tree.
r_b_map/2             True if call(Goal, Value) is true for all nodes in T.
r_b_map/3             For all nodes Key in the tree Tree, if the value associated with key Key is Val0 in tree Tree, and if call(G,Val...
r_b_max/3             Key is the maximal key in Tree, and is associated with Val.
r_b_min/3             Key is the minimum key in Tree, and is associated with Val.
r_b_new/1             Create a new Red-Black tree Tree.
r_b_next/4            Next is the next element after Key in Tree, and is associated with Val.
r_b_partial_map/4     For all nodes Key in Keys, if the value associated with key Key is Val0 in tree Tree, and if call(G,Val...
r_b_previous/4        Previous is the previous element after Key in Tree, and is associated with Val.
r_b_size/2            Size is the number of elements in Tree.
r_b_update/4          Tree NewTree is tree Tree, but with value for Key associated with NewVal.
r_b_update/5          Same as = [ rb_update(Tree, Key, NewVal, NewTree) ] = but also unifies OldVal with the value associated with Key in T.
r_b_visit/2           Pairs is an infix visit of tree Tree, where each element of Pairs is of the form Key-Value.

F.2.43 library(readutil)

read_file_to_codes/3  Read the file Spec into a list of Codes.
read_file_to_string/3 Read the file Spec into a the string String.
read_file_to_terms/3  Read the file Spec into a list of terms.
read_line_to_codes/2  Read the next line of input from Stream.
read_line_to_codes/3  Difference-list version to read an input line to a list of character codes.
read_line_to_string/2  Read the next line from Stream into String.
read_stream_to_codes/2 Read input from Stream to a list of character codes.
read_stream_to_codes/3 Read input from Stream to a list of character codes.

F.2.44 library(record)

record/1  Define named fields in a term

F.2.45 library(registry)

This library is only available on Windows systems.

registry_get_key/2  Get principal value of key
registry_get_key/3  Get associated value of key
registry_set_key/2  Set principal value of key
registry_set_key/3  Set associated value of key
registry_delete_key/1 Remove a key
shell_register_file_type/4 Register a file-type
shell_register_dde/6 Register DDE action
shell_register_prolog/1 Register Prolog

F.2.46 library(settings)

convert_setting_text/3 Converts from textual form to Prolog Value.
current_setting/1 True if Setting is a currently defined setting.
env/2  Evaluate environment variables on behalf of arithmetic expressions.
env/3  Evaluate environment variables on behalf of arithmetic expressions.
list_settings/0 List settings to =current_output=.
list_settings/1 List settings to =current_output=.
load_settings/1 Load local settings from File.
load_settings/2 Load local settings from File.
restore_setting/1 Restore the value of setting Name to its default.
save_settings/0 Save modified settings to File.
save_settings/1 Save modified settings to File.
set_setting/2 Change a setting.
set_setting_default/2 Change the default for a setting.
setting/2 True when Name is a currently defined setting with Value.
setting/4 Define a setting.
setting_property/2 Query currently defined settings.

F.2.47 library(simplex)

assignment/2  Solve assignment problem
constraint/3  Add linear constraint to state
constraint/4  Add named linear constraint to state
F.2. LIBRARY PREDICATES

constraint_add/4 Extend a named constraint
gen_state/1 Create empty linear program
maximize/3 Maximize objective function in to linear constraints
minimize/3 Minimize objective function in to linear constraints
objective/2 Fetch value of objective function
shadow_price/3 Fetch shadow price in solved state
transportation/4 Solve transportation problem
variable_value/3 Fetch value of variable in solved state

F.2.48 library(statistics)

call_time/2 Call Goal as call/1, unifying Time with a dict that provides information on the resource usage.
call_time/3 Call Goal as call/1, unifying Time with a dict that provides information on the resource usage.
profile/1 Run Goal under the execution profiler.
profile/2 Run Goal under the execution profiler.
profile_data/1 Gather all relevant data from profiler.
profile_data/2 Collect data for Pred.
profile/1 Display last collected profiling data.
statistics/0 Print information about resource usage using print_message/2.
statistics/1 Stats is a dict representing the same information as statistics/0.
thread_statistics/2 Obtain statistical information about a single thread.
time/1 Execute Goal, reporting statistics to the user.

F.2.49 library(terms)

foldsubterms/4 The predicate foldsubterms/5 calls call(Goal4, SubTerm1, SubTerm2, StateIn, StateOut) for each subterm, including variables, in Term1.
foldsubterms/5 The predicate foldsubterms/5 calls call(Goal4, SubTerm1, SubTerm2, StateIn, StateOut) for each subterm, including variables, in Term1.
mapargs/3 Term1 and Term2 have the same functor (name/arity) and for each matching pair of arguments call(Goal, A1, A2) is true.
mapsubterms/3 Recursively map sub terms of Term1 into subterms of Term2 for every pair for which call(Goal, ST1, ST2) succeeds.
mapsubterms_var/3 Recursively map sub terms of Term1 into subterms of Term2 for every pair for which call(Goal, ST1, ST2) succeeds.
same_functor/2 True when Term1 and Term2 are terms that have the same functor (Name/Arity).
same_functor/3 True when Term1 and Term2 are terms that have the same functor (Name/Arity).
same_functor/4 True when Term1 and Term2 are terms that have the same functor (Name/Arity).
subsumes/2 True if Generic is unified to Specific without changing Specific.
subsumeschk/2 True if Generic can be made equivalent to Specific without changing Specific.
term_factorized/3 Is true when Skeleton is Term where all subterms that appear multiple times are replaced by a variable.
term_size/2 True if Size is the size in _cells_ occupied by Term on the global (term) stack.
term_subsumer/3 General is the most specific term that is a generalisation of Special1 and Special2.
variant/2 Same as SWI-Prolog = | Term1 =[@= Term2 | =.

F.2.50 library(ugraphs)

add_edges/3 Unify NewGraph with a new graph obtained by adding the list of Edges to Graph.
add_vertices/3 Unify NewGraph with a new graph obtained by adding the list of Vertices to Graph.
complement/2 UGraphOut is a ugraph with an edge between all vertices that are _not_ connected in UGraph.
compose/3  Compose NewGraph by connecting the \_drains\_ of LeftGraph to the \_sources\_ of RightGraph.

connect_ugraph/3 Adds Start as an additional vertex that is connected to all vertices in UGraphIn.

del_edges/3  Unify NewGraph with a new graph obtained by removing the list of Edges from Graph.

del_vertices/3 Unify NewGraph with a new graph obtained by deleting the list of Vertices and all the edges.

edges/2  Neighbours is a sorted list of the neighbours of Vertex in Graph.

neighbors/3  Neighbours is a sorted list of the neighbours of Vertex in Graph.

reachable/3 True when Vertices is an ordered set of vertices reachable in UGraph, including Vertex.

top_sort/2 Sorted is a topological sorted list of nodes in Graph.

top_sort/3 Sorted is a topological sorted list of nodes in Graph.

transitive_closure/2 Generate the graph Closure as the transitive closure of Graph.

transpose_ugraph/2 Unify NewGraph with a new graph obtained from Graph by replacing all edges of the form V1-V2 by edges of the form V2-V1.

ugraph_union/3 NewGraph is the union of Graph1 and Graph2.

vertices/2 Unify Vertices with all vertices appearing in Graph.

vertices_edges_to_ugraph/3 Create unweighted graph

vertices/2 Find vertices in graph

edges/2 Find edges in graph

add_vertices/3 Add vertices to graph

del_vertices/3 Delete vertices from graph

add_edges/3 Add edges to graph

del_edges/3 Delete edges from graph

transpose_ugraph/2 Invert the direction of all edges

neighbors/3 Find neighbors of vertex

neighbours/3 Find neighbors of vertex

complement/2 Inverse presence of edges

compose/3

top_sort/2 Sort graph topologically

top_sort/3 Sort graph topologically

transitive_closure/2 Create transitive closure of graph

reachable/3 Find all reachable vertices

ugraph_union/3 Union of two graphs

\section*{F.2.51 library(url)}

file_name_to_url/2 Translate between a filename and a file://URL.

global_url/3 Translate a possibly relative URL into an absolute one.

http_location/2 Construct or analyze an HTTP location.

is_absolute_url/1 True if URL is an absolute URL.

parse_url/2 Construct or analyse a URL.

parse_url/3 Similar to parse_url/2 for relative URLs.

parse_url_search/2 Construct or analyze an HTTP search specification.

set_url_encoding/2 Query and set the encoding for URLs.

url_iri/2 Convert between a URL, encoding in US-ASCII and an IRI.
F.2. LIBRARY PREDICATES

www_form_encode/2  En/decode to/from application/x-www-form-encoded.

F.2.52 library(www_browser)

expand_url_path/2  Expand URL specifications similar to absolute_file_name/3.
known_browser/2    True if browser FileBaseName has a remote protocol compatible to Compatible.
www_open_url/1     Open URL in running version of the users' browser or start a new browser.

F.2.53 library(solution_sequences)

call_nth/2          True when Goal succeeded for the Nth time.
distinct/1          True if Goal is true and no previous solution of Goal bound Witness to the same value.
distinct/2          True if Goal is true and no previous solution of Goal bound Witness to the same value.
group_by/4          Group bindings of Template that have the same value for By.
limit/2             Limit the number of solutions.
offset/2            Ignore the first Count solutions.
order_by/2          Order solutions according to Spec.
reduced/1           Similar to distinct/1, but does not guarantee unique results in return for using a limited amount of memory.
reduced/3           Similar to distinct/1, but does not guarantee unique results in return for using a limited amount of memory.

F.2.54 library(thread)

call_in_thread/2    Run Goal as an interrupt in the context of Thread.
concurrent/3        Run Goals in parallel using N threads.
concurrent_and/2    Concurrent version of '(Generator,Test)'.
concurrent_and/3    Concurrent version of '(Generator,Test)'.
concurrent forall/2 True when Action is true for all solutions of Generate.
concurrent forall/3 True when Action is true for all solutions of Generate.
concurrent_maplist/2 Concurrent version of maplist/2.
concurrent_maplist/3 Concurrent version of maplist/2.
concurrent_maplist/4 Concurrent version of maplist/2.
first_solution/3    Try alternative solvers concurrently, returning the first answer.

F.2.55 library(thread_pool)

create_pool/1       Hook to create a thread pool lazily.
current_thread_pool/1 True if Name refers to a defined thread pool.
thread_create_in_pool/4 Create a thread in Pool.
thread_pool_create/3 Create a pool of threads.
thread_pool_destroy/1 Destroy the thread pool named Name.
thread_pool_property/2 True if Property is a property of thread pool Name.
worker_exitted/3    It is possible that '_thread_pool_manager' no longer exists while closing down the process bec
F.2.56 library(varnumbers)

- max_var_number/3: True when Max is the max of Start and the highest numbered $VAR(N)$ term.
- numbervars/1: Number variables in Term using $VAR(N)$.
- varnumbers/2: Inverse of numbervars/1.
- varnumbers/3: Inverse of numbervars/3.
- varnumbers_names/3: If Term is a term with numbered and named variables using the reserved term '$VAR'(X), Copy is a term with the same structure as Term but instead of the 'X' terms, they are replaced by a fresh variable and Bindings is a list 'X = Var', relating the 'X' terms with the variable it is mapped to.

F.2.57 library(yall)

- /2: Shorthand for ‘Free/[]>>Lambda’.
- /3: Shorthand for ‘Free/[]>>Lambda’.
- /4: Shorthand for ‘Free/[]>>Lambda’.
- /5: Shorthand for ‘Free/[]>>Lambda’.
- /6: Shorthand for ‘Free/[]>>Lambda’.
- /7: Shorthand for ‘Free/[]>>Lambda’.
- /8: Shorthand for ‘Free/[]>>Lambda’.
- /9: Shorthand for ‘Free/[]>>Lambda’.

- >>=/2: Calls a copy of Lambda.
- >>=/3: Calls a copy of Lambda.
- >>=/4: Calls a copy of Lambda.
- >>=/5: Calls a copy of Lambda.
- >>=/6: Calls a copy of Lambda.
- >>=/7: Calls a copy of Lambda.
- >>=/8: Calls a copy of Lambda.
- >>=/9: Calls a copy of Lambda.

- is_lambda/1: True if Term is a valid Lambda expression.
- lambda_calls/2: Goal is the goal called if call/N is applied to LambdaExpression, where ExtraArgs are the additional arguments to LambdaExpression.
- lambda_calls/3: Goal is the goal called if call/N is applied to LambdaExpression, where ExtraArgs are the additional arguments to LambdaExpression.
F.3 Arithmetic Functions

* / 2 Multiplication
* * / 2 Power function
+ / 1 Unary plus (No-op)
+ / 2 Addition
− / 1 Unary minus
− / 2 Subtraction
/ / 2 Division
/ / / 2 Integer division
/ / \ 2 Bitwise and
< < / 2 Bitwise left shift
>> / 2 Bitwise right shift
. / 1 List of one character: character code
\ / 1 Bitwise negation
\ / / 2 Bitwise or
\ ^ / 2 Power function
abs / 1 Absolute value
acos / 1 Inverse (arc) cosine
acosh / 1 Inverse hyperbolic cosine
asin / 1 Inverse (arc) sine
asinh / 1 Inverse (arc) sine
atan / 1 Inverse hyperbolic sine
atan / 2 Rectangular to polar conversion
atanh / 1 Inverse hyperbolic tangent
atan2 / 2 Rectangular to polar conversion
ceil / 1 Smallest integer larger than arg
ceiling / 1 Smallest integer larger than arg
cos / 1 Cosine
cosh / 1 Hyperbolic cosine
copysign / 2 Apply sign of N2 to N1
cputime / 0 Get CPU time
denominator / 1 Denominator of a rational number (N/D)
div / 2 Integer division
e / 0 Mathematical constant
erf / 1 Gauss error function
erfc / 1 Complementary error function
epsilon / 0 Floating point precision
eval / 1 Evaluate term as expression
exp / 1 Exponent (base e)
float / 1 Explicitly convert to float
float_fractional_part / 1 Fractional part of a float
float_integer_part / 1 Integer part of a float
floor / 1 Largest integer below argument
gcd / 2 Greatest common divisor
getbit / 2 Get bit at index from large integer
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>inf/0</td>
<td>Positive infinity</td>
</tr>
<tr>
<td>integer/1</td>
<td>Round to nearest integer</td>
</tr>
<tr>
<td>lgamma/1</td>
<td>Log of gamma function</td>
</tr>
<tr>
<td>log/1</td>
<td>Natural logarithm</td>
</tr>
<tr>
<td>log10/1</td>
<td>10 base logarithm</td>
</tr>
<tr>
<td>lcm/2</td>
<td>Least Common Multiple</td>
</tr>
<tr>
<td>lsb/1</td>
<td>Least significant bit</td>
</tr>
<tr>
<td>max/2</td>
<td>Maximum of two numbers</td>
</tr>
<tr>
<td>min/2</td>
<td>Minimum of two numbers</td>
</tr>
<tr>
<td>msb/1</td>
<td>Most significant bit</td>
</tr>
<tr>
<td>mod/2</td>
<td>Remainder of division</td>
</tr>
<tr>
<td>nan/0</td>
<td>Not a Number (NaN)</td>
</tr>
<tr>
<td>nexttoward/2</td>
<td>Next float in some direction</td>
</tr>
<tr>
<td>numerator/1</td>
<td>Numerator of a rational number (N/D)</td>
</tr>
<tr>
<td>powm/3</td>
<td>Integer exponent and modulo</td>
</tr>
<tr>
<td>random/1</td>
<td>Generate random number</td>
</tr>
<tr>
<td>random_float/0</td>
<td>Generate random number</td>
</tr>
<tr>
<td>rational/1</td>
<td>Convert to rational number</td>
</tr>
<tr>
<td>rationalize/1</td>
<td>Convert to rational number</td>
</tr>
<tr>
<td>rdiv/2</td>
<td>Ration number division</td>
</tr>
<tr>
<td>rem/2</td>
<td>Remainder of division</td>
</tr>
<tr>
<td>round/1</td>
<td>Round to nearest integer</td>
</tr>
<tr>
<td>roundtoward/2</td>
<td>Float arithmetic with specified rounding</td>
</tr>
<tr>
<td>truncate/1</td>
<td>Truncate float to integer</td>
</tr>
<tr>
<td>pi/0</td>
<td>Mathematical constant</td>
</tr>
<tr>
<td>popcount/1</td>
<td>Count 1s in a bitvector</td>
</tr>
<tr>
<td>sign/1</td>
<td>Extract sign of value</td>
</tr>
<tr>
<td>sin/1</td>
<td>Sine</td>
</tr>
<tr>
<td>sinh/1</td>
<td>Hyperbolic sine</td>
</tr>
<tr>
<td>sqrt/1</td>
<td>Square root</td>
</tr>
<tr>
<td>tan/1</td>
<td>Tangent</td>
</tr>
<tr>
<td>tanh/1</td>
<td>Hyperbolic tangent</td>
</tr>
<tr>
<td>xor/2</td>
<td>Bitwise exclusive or</td>
</tr>
</tbody>
</table>
F.4 Operators

\$ 1 fx Bind top-level variable
\^ 200 fxy Existential qualification
\^ 200 fxy Arithmetic function
\text{mod} 300 ffx Arithmetic function
\* 400 ffx Arithmetic function
/ 400 ffx Arithmetic function
\text{/} 400 ffx Arithmetic function
<< 400 ffx Arithmetic function
>> 400 ffx Arithmetic function
\text{xor} 400 ffx Arithmetic function
+ 500 fx Arithmetic function
- 500 ffx Arithmetic function
? 500 fx XPCE: obtainer
\text{\textbackslash} 500 fx Arithmetic function
+ 500 ffx Arithmetic function
- 500 ffx Arithmetic function
/\ 500 ffx Arithmetic function
\text{/} 500 ffx Arithmetic function
: 600 ffx module:term separator
< 700 ffx Predicate
= 700 ffx Predicate
=.. 700 ffx Predicate
=:= 700 ffx Predicate
< 700 ffx Predicate
>= 700 ffx Predicate
=@= 700 ffx Predicate
=@= 700 \text{fxy} Predicate
>=\ 700 ffx Predicate
> 700 ffx Predicate
@< 700 ffx Predicate
@=< 700 ffx Predicate
@> 700 ffx Predicate
@>= 700 ffx Predicate
\text{as} 700 ffx Predicate
\text{is} 700 ffx Predicate
\text{\textbackslash=} 700 ffx Predicate
\text{\textbackslash=} 700 ffx Predicate
@=\ 700 ffx Predicate
\text{not} 900 fy Predicate
\text{\textbackslash+} 900 fy Predicate
, 1000 fxy Predicate
\text{->} 1050 fxy Predicate
\text{\textast{}->} 1050 fxy Predicate
; 1100 fxy Predicate
<table>
<thead>
<tr>
<th></th>
<th>1105</th>
<th>$xfy$</th>
<th>DCG disjunction</th>
</tr>
</thead>
<tbody>
<tr>
<td>discontiguous</td>
<td>1150</td>
<td>$fx$</td>
<td>Directive</td>
</tr>
<tr>
<td>dynamic</td>
<td>1150</td>
<td>$fx$</td>
<td>Directive</td>
</tr>
<tr>
<td>module_transparent</td>
<td>1150</td>
<td>$fx$</td>
<td>Directive</td>
</tr>
<tr>
<td>meta_predicate</td>
<td>1150</td>
<td>$fx$</td>
<td>Head</td>
</tr>
<tr>
<td>multifile</td>
<td>1150</td>
<td>$fx$</td>
<td>Directive</td>
</tr>
<tr>
<td>thread_local</td>
<td>1150</td>
<td>$fx$</td>
<td>Directive</td>
</tr>
<tr>
<td>volatile</td>
<td>1150</td>
<td>$fx$</td>
<td>Directive</td>
</tr>
<tr>
<td>initialization</td>
<td>1150</td>
<td>$fx$</td>
<td>Directive</td>
</tr>
<tr>
<td>$: -$</td>
<td>1200</td>
<td>$fx$</td>
<td>Introduces a directive</td>
</tr>
<tr>
<td>$?- $</td>
<td>1200</td>
<td>$fx$</td>
<td>Introduces a directive</td>
</tr>
<tr>
<td>$--&gt; $</td>
<td>1200</td>
<td>$xfx$</td>
<td>DCGGrammar: rewrite</td>
</tr>
<tr>
<td>$:- $</td>
<td>1200</td>
<td>$xfx$</td>
<td>head $:$ body, separator</td>
</tr>
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