SWI-Prolog 3.2
Reference Manual

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SWI-Prolog is a Prolog implementation based on a subset of the WAM (Warren Abstract Machine [Warren, 1983]). SWI-Prolog has been designed and implemented such that it can easily be modified for experiments with logic programming and the relation between logic programming and other programming paradigms (such as the object oriented XPCE environment [Anjewierden & Wielemaker, 1989]). SWI-Prolog has a rich set of built-in predicates and reasonable performance, which makes it possible to develop substantial applications in it. The current version offers a module system, garbage collection and an interface to the C language.

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

SWI-Prolog has been designed and implemented to get a Prolog implementation which can be used for experiments with logic programming and the relation to other programming paradigms. The intention was to build a Prolog environment which offers enough power and flexibility to write substantial applications, but is straightforward enough to be modified for experiments with debugging, optimisation or the introduction of non-standard data types. Performance optimisation is limited due to the main objectives: portability (SWI-Prolog is entirely written in C and Prolog) and modifiability.

SWI-Prolog is based on a very restricted form of the WAM (Warren Abstract Machine) described in [Bowen & Byrd, 1983] 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 WAM interpreter 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 when in debug mode. The price we have to pay is some performance degradation (taking out the debugger from the WAM 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 & Byrd, 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 (\(/2\), \(/\), \(\rightarrow/2\), if-then \((-\rightarrow/2\)) and not \((\\neq/1\)).

This manual does not describe the full syntax and semantics of Prolog, nor how one should write a program in Prolog. These subjects have been described extensively in the literature. See [Bratko, 1986], [Sterling & Shapiro, 1986], and [Clocksin & Melish, 1987]. For more advanced Prolog material see [OKeefe, 1990]. Syntax and standard operator declarations confirm to the ‘Edinburgh standard’. Most built in predicates are compatible with those described in [Clocksin & Melish, 1987]. SWI-Prolog also offers a number of primitive predicates compatible with Quintus Prolog\(^1\) [Qui, 1997] and BIM\_Prolog\(^2\) [BIM, 1989].

ISO compliant predicates are based on “Prolog: The Standard”, [Deransart et al., 1996].

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\(^1\)Quintus is a trademark of Quintus Computer Systems Inc., USA

\(^2\)BIM is a trademark of BIM sa/nv., Belgium
1.2 Status

This manual describes version 3.2 of SWI-Prolog. SWI-Prolog has been used now for several years. The application range includes Prolog course material, meta-interpreters, simulation of parallel Prolog, learning systems, natural language processing and two large workbenches for knowledge engineering. Although we experienced rather obvious and critical bugs can remain unnoticed for a remarkable long period, we can assume the basic Prolog system is fairly stable. Bugs can be expected in infrequently used builtin predicates.

Some bugs are known to the author. They are described as footnotes in this manual.

1.3 Should you be Using SWI-Prolog?

There are a number of reasons why you better choose a commercial Prolog system, or another academic product:

- **SWI-Prolog is not supported**
  Although I usually fix bugs shortly after a bug report arrives, I cannot promise anything. Now that the sources are provided, you can always dig into them yourself.

- **Memory requirements and performance are your first concerns**
  A number of commercial compilers are more keen on memory and performance than SWI-Prolog. I do not wish to sacrifice some of the nice features of the system, nor its portability to compete on raw performance.

- **You need features not offered by SWI-Prolog**
  In this case you may wish to give me suggestions for extensions. If you have great plans, please contact me (you might have to implement them yourself however).

On the other hand, SWI-Prolog offers some nice facilities:

- **Nice environment**
  This includes ‘Do What I Mean’, automatic completion of atom names, history mechanism and a tracer that operates on single key-strokes. Interfaces to standard Unix editors are provided, as well as a facility to maintain programs (see `make/0`).

- **Very fast compiler**
  Even very large applications can be loaded in seconds on most machines. If this is not enough, there is a Quick Load Format that is slightly more compact and loading is almost always I/O bound.

- **Transparent compiled code**
  SWI-Prolog compiled code can be treated just as interpreted code: you can list it, trace it, assert to or retract from it, etc. This implies you do not have to decide beforehand whether a module should be loaded for debugging or not. Also, performance is much better than the performance of most interpreters.

- **Profiling**
  SWI-Prolog offers tools for performance analysis, which can be very useful to optimise programs. Unless you are very familiar with Prolog and Prolog performance considerations this might be more helpful than a better compiler without these facilities.
• **Flexibility**

SWI-Prolog allows for easy and flexible integration with C, both Prolog calling C functions as C calling Prolog predicates. SWI-Prolog is provided in source form, which implies SWI-Prolog can be linked in with another package. Command line options and predicates to obtain information from the system and feedback into the system are provided.

• **Integration with XPCE**

SWI-Prolog offers a tight integration to the Object Oriented Package for User Interface Development, called XPCE [Anjewierden & Wielemaker, 1989]. XPCE allows you to implement graphical user interfaces that are source-code compatible over Unix/X11 and Win32 (Windows 95 and NT).

### 1.4 The XPCE GUI system for Prolog

The XPCE GUI system for dynamically typed languages has been with SWI-Prolog for a long time. It is developed by Anjo Anjewierden and Jan Wielemaker from the department of SWI, University of Amsterdam. It aims at a high-productive development environment for graphical applications based on Prolog.

Object oriented technology has proven to be a suitable model for implementing GUIs, which typically deal with things Prolog is not very good at: event-driven control and global state. With XPCE, we designed a system that has similar characteristics that make Prolog such a powerful tool: dynamic typing, meta-programming and dynamic modification of the running system.

XPCE is an object-system written in the C-language. It provides for the implementation of methods in multiple languages. New XPCE classes may be defined from Prolog using a simple, natural syntax. The body of the method is executed by Prolog itself, providing a natural interface between the two systems. Below is a very simple class definition.

```prolog
:- pce_begin_class(prolog_lister, frame, "List Prolog predicates").

initialise(Self) :-
  "As the C++ constructor":
  send(Self, send_super, initialise, 'Prolog Lister'),
  send(Self, append, new(D, dialog)),
  send(D, append,
      text_item(predicate, message(Self, list, @arg1))),
  send(new(view), below, D).

list(Self, From:name) :-
  "List predicates from specification":
  ( term_to_atom(Term, From)
    -> get(Self, member, view, V),
      pce_open(V, write, Fd),
      set_output(Fd),
      listing(Term),
      close(Fd)
    ; send(Self, report, error, 'Syntax error'))
```

---

SWI-Prolog 3.2 Reference Manual
1.5 Version 1.5 Release Notes

There are not many changes between version 1.4 and 1.5. The C-sources have been cleaned and comments have been updated. The stack memory management based on using the MMU has been changed to run on a number of System-V Unix systems offering shared memory. Handling dates has been changed. All functions handling dates now return a floating point number, expressing the time in seconds since January 1, 1970. A predicate `convert_time/8` is available to get the year, month, etc. The predicate `time/6` has been deleted. `get_time/1` and `convert_time/8` together do the same.

From version 1.5, the system is distributed in source form, rather than in object form as used with previous releases. This allows users to port SWI-Prolog to new machines, extend and improve the system. If you want your changes to be incorporated in the next release, please indicate all changes using a C-preprocessor flag and send complete source files back to me. Difference listings are of no use, as I generally won’t have exactly the same version around.

1.6 Version 1.6 Release Notes

Version 1.6 is completely compatible with version 1.5. Some new features have been added, the system has been ported to various new platforms and there is a provisional interface to GNU Emacs. This interface will be improved and documented later.

The WAM virtual-machine interpreter has been modified to use GCC-2’s support for threaded code.

From version 1.6, the sources are now versioned using the CVS version control system.

1.7 Version 1.7 Release Notes

Version 1.7 integrates the GNU-readline library, offering powerful history and command-line editing both using Emacs and vi key-bindings.
1.8 Version 1.8 Release Notes

Version 1.8 offers a stack-shifter to provide dynamically expanding stacks on machines that do not offer operating-system support for implementing dynamic stacks.

1.9 Version 1.9 Release Notes

Version 1.9 offers better portability including an MS-Windows 3.1 version. Changes to the Prolog system include:

- **Redefinition of system predicates**
  Redefinition of system predicates was allowed silently in older versions. Version 1.9 only allows it if the new definition is headed by a `:- redefine_systemredicate/1` directive.

- **‘Answer’ reuse**
  The toplevel maintains a table of bindings returned by toplevel goals and allows for reuse of these bindings by prefixing the variables with the $ sign. See section 2.8.

- **Better source code administration**
  Allows for proper updating of multifile predicates and finding the sources of individual clauses.

1.10 Version 2.0 Release Notes

Version 2.0 is first of all a freeze of all the features added to the various 1.9.x releases. Version 2.0.6 for PC has moved from the WATCOM C 32-bit windows extender to Windows NT and runs under Windows 3.1 using the Win32s NT emulator.

New features offered:

- **32-bit Virtual Machine**
  Removes various limits and improves performance.

- **Inline foreign functions**
  ‘Simple’ foreign predicates no longer build a Prolog stack-frame, but are directly called from the VM. Notably provides a speedup for the test predicates such as `var/1`, etc.

- **Various compatibility improvements**

- **Stream based I/O library**
  All SWI-Prolog’s I/O is now handled by the stream-package defined in the foreign include file `SWI-Stream.h`. Physical I/O of Prolog streams may be redefined through the foreign language interface, facilitating much simpler integration in window environments.

Version 2.0.6 offers a few incompatibilities:

- **retractall/1**
  In previous releases, the definition of `retractall/1` was:
retractall(Term) :-
    retract(Term),
    fail.
retractall(_).

As from version 2.0.6, retractall/1 is implemented as a deterministic foreign predicate compatible with Quintus Prolog. It behaves as:

retractall(Head) :-
    retract(Head),
    fail.
retractall(Head) :-
    retract((Head :- _)),
    fail.
retractall(_).

I.e. the definition behaves the same when handling predicates consisting of facts. Clauses with a non-true body will be retracted if their head matches.

- **Foreign interface types**
  All foreign interface types now have names ending in `_t` to lessen the chance for conflicts. `term`, `atomic`, `functor` and `module` have `#define`'s for backward compatibility.

- **PL_register_foreign()**
  The attributes is now a bitwise or of the attribute flags rather than a 0 terminated list. This has no consequences for predicates that have no attributes (99% of them), while predicates with just one attribute will generate a compiler warning, but work properly otherwise. Predicates with more than one attributes must be changed.

- **PL_dispatch_events**
  This pointer is replaced by `PL_dispatch_hook()`. A function was necessary for the Win32 .DLL interface.

### 1.11 Version 2.1 Release Notes

In addition to several bug fixes, the 2.1 versions provide some new features:

- **setarg/3**
  A new predicate `setarg/3` for extra-logical (destructive) assignment to arguments of terms is provided.

- **Modified keysort/2**
  `keysort/2` is now stable with regard to multiple values on the same key. Makes this predicate compatible with SICStus and Quintus.

- **Modified grammar rule expansion**
  DCG translation of free variables now calls `phrase/3`, which has been changed slightly to deal with ‘un-parsing’. Modification is probably not complete, but it fixes some problems encountered by Michael Böhlen.
1.12 Version 2.5 Release Notes

Version 2.5 is an intermediate release on the path from 2.1 to 3.0. All changes are to the foreign-language interface, both to user- and system-predicates implemented in the C-language. The aim is twofold. First of all to make garbage-collection and stack-expansion (stack-shifts) possible while foreign code is active without the C-programmer having to worry about locking and unlocking C-variables pointing to Prolog terms. The new approach is closely compatible to the Quintus and SIC-Stus Prolog foreign interface using the `+term` argument specification (see their respective manuals). This allows for writing foreign interfaces that are easily portable over these three Prolog platforms.

According to the current plan, ISO compliant exception handling and hooks for source-code debugging will be added before the system will be called 3.0.

Apart from various bug fixes listed in the Changelog file, these are the main changes since 2.1.0:

- **ISO compatibility**
  Many ISO compatibility features have been added: `open/4`, arithmetic functions, syntax, etc.

- **Win32**
  Many fixes for the Win32 (NT, '95 and win32s) platforms. Notably many problems related to pathnames and a problem in the garbage collector.

- **Performance**
  Many changes to the clause indexing system: added hash-tables, lazy computation of the index information, etc.

- **Portable saved-states**
  The predicate `qsave_program/[1,2]` allows for the creating of machine independent saved-states that load very quickly.

1.13 Version 2.6 Release Notes

Version 2.6 provides a stable implementation of the features added in the 2.5.x releases, but at the same time implements a number of new features that may have impact on the system stability.

- **32-bit integer and double float arithmetic**
  The biggest change is the support for full 32-bit signed integers and raw machine-format double precision floats. The internal data representation as well as the arithmetic instruction set and interface to the arithmetic functions has been changed for this.

- **Embedding for Win32 applications**
  The Win32 version has been reorganised. The Prolog kernel is now implemented as Win32 DLL that may be embedded in C-applications. Two front ends are provided, one for window-based operation and one to run as a Win32 console application.
• Creating stand-alone executables
  Version 2.6.0 can create stand-alone executables by attaching the saved-state to the emulator.
  See qsave_program/2.

1.14 Version 2.7 Release Notes

Version 2.7 reorganises the entire data-representation of the Prolog data itself. The aim is to remove
most of the assumption on the machine’s memory layout to improve portability in general and enable
embedding on systems where the memory layout may depend on invocation or on how the executable
is linked. The latter is notably a problem on the Win32 platforms. Porting to 64-bit architectures
should be feasible now.

Furthermore, 2.7 lifts the limits on arity of predicates and number of variables in a clause consider-
ably and allow for further expansion at minimal cost.

1.15 Version 2.8 Release Notes

With version 2.8, we declare the data-representation changes of 2.7.x stable. Version 2.8 exploits the
changes of 2.7 to support 64-bit processors like the DEC Alpha. As of version 2.8.5, the representation
of recorded terms has changed, and terms on the heap are now represented in a compiled format. SWI-
Prolog no longer limits the use of malloc() or uses assumptions on the addresses returned by this
function.

1.16 Version 2.9 Release Notes

Version 2.9 is the next step towards version 3.0, improving ISO compliance and introducing ISO com-
pliant exception handling. New are catch/3, throw/1, abolish/1, write_term/[2,3],
write_canonical/[1,2] and the C-functions PL_exception() and PL_throw(). The
predicates display/[1,2] and displayq/[1,2] have been moved to library(backcomp),
so old code referring to them will autoload them.

The interface to PL_open_query() has changed. The debug argument is replaced by a bitwise or’d flags argument. The values FALSE and TRUE have their familiar meaning, making old code using these constants compatible. Non-zero values other than TRUE (1) will be interpreted different.

1.17 Version 3.0 Release Notes

Complete redesign of the saved-state mechanism, providing the possibility of ‘program resources’.
See resource/3, open_resource/3, and qsave_program/[1,2].

1.18 Version 3.1 Release Notes

Improvements on exception-handling. Allows relating software interrupts (signals) to exceptions,
handling signals in Prolog and C (see on_signal/3 and PL_signal()). Prolog stack overflows
now raise the resource_error exception and thus can be handled in Prolog using catch/3.
1.19 Version 3.2 Release Notes

Many small patches and improvements. Support for XPCE 5.0 (improved exception-handling from foreign code, recorded-database interface from C). Moved compiler to MSVC 5.0 on Windows, repackaged sources and projects to make building on Windows from the sources feasible for normal users. Support for non-blocking Input streams. Better and portable support for mmap()-based stacks on Unix. Raised maximum stack size to 128 MB, etc.

As of 3.2.9, first steps in supporting multi-threaded applications (Unix, developers only).

1.20 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 writef/2. Also some of the C-code originates from C-Prolog: finding the path of the currently running executable and the code underlying absolute_file_name/2. Ideas on programming style and techniques originate from C-Prolog and Richard O’Keefe’s thief editor. An important source of inspiration are the programming techniques introduced by Anjo Anjewierden in PCE version 1 and 2.

I also would like to thank those who had the fade 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 Peerdeman, 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!
2.1 Getting started quickly

2.1.1 Starting SWI-Prolog

Starting SWI-Prolog on Unix

By default, SWI-Prolog is installed as ‘pl’, though some administrators call it ‘swipl’ or ‘swi-prolog’. The commandline 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:

```
% pl
/staff/jan/.plrc compiled, 0.00 sec, 1,016 bytes.
Welcome to SWI-Prolog (Version 3.2.9)
Copyright (c) 1993-1998 University of Amsterdam. All rights reserved.

For help, use ?- help(Topic). or ?- apropos(Word).
```

?-

After starting Prolog, one normally loads a program into it using consult/1, which—for historical reasons—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].
likes compiled, 0.00 sec, 596 bytes.

Yes
?- 
```

After this point, Unix and Windows users are united again.

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 pl containing the executables, libraries, etc. of the system. No files are installed outside this directory.
2.2. THE USER’S INITIALISATION FILE

- A program `plwin.exe`, providing a window for interaction with Prolog. The program `plcon.exe` is a version of SWI-Prolog that runs in a DOS-box.

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

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

2.1.2 Executing a query

After loading a program, one can ask Prolog queries about the program. The query below asks Prolog to prove whether ‘john’ likes someone and who is liked by ‘john’. The system responds with \( X = \langle \text{value} \rangle \) if it can prove the goal for a certain \( X \). The user can type the semi-colon (;) if (s)he wants another solution, or `RETURN` if (s)he is satisfied, after which Prolog will say `Yes`. If Prolog answers `No`, it indicates it cannot find any more answers to the query. Finally, Prolog can answer using an error message to indicate the query or program contains an error.

```prolog
?- likes(john, X).

X = mary
```

2.2 The user’s initialisation file

After the necessary system initialisation the system consults (see `consult/1`) the user’s startup file. The base-name of this file follows conventions of the operating system. On MS-Windows, it is the file `pl.ini` and on Unix systems `plrc`. The file is searched using the `file_search_path/2` clauses for `user_profile`. The table below shows the default value for this search-path.

<table>
<thead>
<tr>
<th>Unix</th>
<th>Windows</th>
</tr>
</thead>
<tbody>
<tr>
<td>local</td>
<td>.</td>
</tr>
<tr>
<td>home</td>
<td>~</td>
</tr>
<tr>
<td></td>
<td>%HOMEPATH% or %HOMEDRIVE%%HOMEPATH%</td>
</tr>
<tr>
<td>global</td>
<td>SWI-Home directory or %WINDIR% or %SYSTEMROOT%</td>
</tr>
</tbody>
</table>

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.

2.3 Initialisation goals

After loading the startup file SWI-Prolog executes a user initialisation goal. The default goal is a system predicate that prints the banner message. The default can be modified with the ‘-g goal’ option. Next the toplevel goal is started. Default is the interactive Prolog loop (see `prolog/0`). The user can overwrite this default with the ‘-t toplevel’ option.
2.4 Command Line Options

The full set of command line options is given below:

- **-help**
  When given as the only option, it summarises the most important options.

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

- **-arch**
  When given as the only option, it prints the architecture identifier (see feature(arch, Arch)) and exits.

- **-Lsize[km]**
  Give local stack limit (2 Mbytes default). Note that there is no space between the size option and its argument. By default, the argument is interpreted in Kbytes. Postfixing the argument with m causes the argument to be interpreted in Mbytes. The following example specifies 32 Mbytes local stack.

  ```
  % pl -L32m
  ```

  A maximum is useful to stop buggy programs from claiming all memory resources. -L0 sets the limit to the highest possible value.

- **-Gsize[km]**
  Give global stack limit (4 Mbytes default). See -L for more details.

- **-Tsize[km]**
  Give trail stack limit (4 Mbytes default). This limit is relatively high because trail-stack overflows are not often caused program bugs. See -L for more details.

- **-Asize[km]**
  Give argument stack limit (1 Mbytes default). The argument stack limits the maximum nesting of terms that can be compiled and executed. SWI-Prolog does ‘last-argument optimisation’ to avoid many deeply nested structure using this stack. Enlarging this limit is only necessary in extreme cases. See -L for more details.

- **-Hsize[km]**
  Give malloc() heap limit. The default is to raise the limit as high as possible. This option only applies to machines using the mmap() function for allocating the Prolog stacks. See -L for more details.

- **-c file . . .**
  Compile files into an ‘intermediate code file’. See section 2.10.

- **-o output**
  Used in combination with -c or -b to determine output file for compilation.

- **-O**
  Optimised compilation. See feature/2.
-f file
Use file as startup file instead of the default. ‘-f none’ stops SWI-Prolog from searching for a startup file. See section 2.2.

-F script
Selects a startup-script from the SWI-Prolog home directory. The script-file is named (script).rc. 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.

-g goal
Goal is executed just before entering the top level. Default is a predicate which prints the welcome message. The welcome message can thus be suppressed by giving -g true. goal can be a complex term. In this case quotes are normally needed to protect it from being expanded by the Unix shell.

-t goal
Use goal as interactive toplevel instead of the default goal prolog/0. goal can be a complex term. If the toplevel goal succeeds SWI-Prolog exits with status 0. If it fails the exit status is 1. This flag also determines the goal started by break/0 and abort/0. If you want to stop the user from entering interactive mode start the application with ‘-g goal’ and give ‘halt’ as toplevel.

-tty
Switches tty control (using ioctl(2)) on (+tty) or off (-tty). Normally tty control is switched on. This default depends on the installation. You may wish to switch tty control off if Prolog is used from an editor such as Emacs. If switched off get_single_char/1 and the tracer will wait for a return.

-x bootfile
Boot from bootfile instead of the system’s default boot file. A bootfile 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, path1 ... is a : separated list of values for the alias. 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.

--
Stops scanning for more arguments, so you can pass arguments for your application after this one.

The following options are for system maintenance. They are given for reference only.
-b initfile ... -c file ...
   Boot compilation. initfile ... are compiled by the C-written bootstrap compiler, file ... by the
   normal Prolog compiler. System maintenance only.

-d level
   Set debug level to level. Only has effect if the system is compiled with the -DO_DEBUG flag.
   System maintenance only.

2.5 GNU Emacs Interface

A provisional interface to emacs has been included since version 1.6 of SWI-Prolog. The interface
is based on the freely distributed interface delivered with Quintus Prolog. When running Prolog as
an inferior process under GNU-Emacs, there is support for finding predicate definitions, completing
atoms, finding the locations of compilation-warnings and many more. For details, see the files pl/
lisp/README and pl/lisp/swi-prolog.el.

2.6 Online Help

Online help provides a fast lookup and browsing facility to this manual. The online manual can show
predicate definitions as well as entire sections of the manual.

The online help is displayed from the file library('MANUAL'). The file library(helpidx) pro-
vides an index into this file. library('MANUAL') is created from the \LaTeX sources with a modified
version of dvitty, using overstrike for printing bold text and underlining for rendering italic text.
XPCE is shipped with library(swi.help), presenting the information from the online help in a hy-
pertex window. The feature write_help_with_overstrike controls whether or not help/1
writes its output using overstrike to realise bold and underlined output or not. If this feature is not set
it is initialised by the help library to true if the TERM variable equals xterm and false otherwise.
If this default does not satisfy you, add the following line to your personal startup file (see section 2.2):

:- set_feature(write_help_with_overstrike, true).

help
   Equivalent to help(help/1).

help(+What)
   Show specified part of the manual. What is one of:

   ⟨Name⟩⟨Arity⟩    Give help on specified predicate
   ⟨Name⟩        Give help on named predicate with any arity or C interface
                  function with that name
   ⟨Section⟩    Display specified section. Section numbers are dash-
                 separated numbers: 2–3 refers to section 2.3 of the man-
                 ual. Section numbers are obtained using apropos/1.

Examples:
2.7 QUERY SUBSTITUTIONS

?- help(assert).    Give help on predicate assert
?- help(3-4).       Display section 3.4 of the manual
?- help('PL_retry'). Give help on interface function PL_retry()

apropos(+Pattern)
    Display all predicates, functions and sections that have Pattern in their name or summary description. Lowercase letters in Pattern also match a corresponding uppercase letter. Example:

?- apropos(file).    Display predicates, functions and sections that have ‘file’ (or ‘File’, etc.) in their summary description.

explain(+ToExplain)
    Give an explanation on the given ‘object’. 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 will try to explain the predicate as well as possible references to it.

explain(+ToExplain, -Explanation)
    Unify Explanation with an explanation for ToExplain. Backtracking yields further explanations.

2.7 Query Substitutions

SWI-Prolog offers a query substitution mechanism similar to that of Unix csh (csh(1)), called ‘history’. The availability of this feature is controlled by set_feature/2, using the history feature. By default, history is available if the feature readline is false. To enable this feature, remembering the last 50 commands, put the following into your startup file (see section 2.2:

:- set_feature(history, 50).

The history system allows the user to compose new queries from those typed before and remembered by the system. It also allows to correct queries and syntax errors. SWI-Prolog does not offer the Unix csh capabilities to include arguments. This is omitted as it is unclear how the first, second, etc. argument should be defined.¹

The available history commands are shown in table 2.1. Figure 2.1 gives some examples.

2.7.1 Limitations of the History System

When in top level SWI-Prolog reads the user’s queries using read_history/6 rather than read/1. This predicate first reads the current input stream up to a full stop. While doing so it maps all contiguous blank space onto a single space and deletes /* ... */ and % ... <cr> comments. Parts between double quotes (") or single quotes (‘’) are left unaltered. Note that a Prolog full stop consists of a ‘non-symbol’ character, followed by a period (.), followed by a blank character. ‘Symbol’ characters are: #$&*+-./:<=>?@ˆ ‘˜. A single quote immediately preceded by a digit (0-9) is considered part of the ⟨digit⟩⟨digit⟩... (e.g. 2’101; binary number 101) sequence.

After this initial parsing the result is first checked for the special ^⟨old⟩^⟨new⟩ construction. If this fails the string is checked for all occurrences of the !, followed by a !, ?, a digit, a letter or an

¹One could choose words, defining words as a sequence of alpha-numeric characters and the word separators as anything else, but one could also choose Prolog arguments
Welcome to SWI-Prolog (Version \plversion)
Copyright (c) 1993-1996 University of Amsterdam. All rights reserved.

For help, use ?- help(Topic). or ?- apropos(Word).

1 ?- append("Hello ", "World", L).


Yes
2 ?- !!, writef('L = %s\n', [L]).
append("Hello ", "World", L), writef('L = %s\n', [L]).
L = Hello World


Yes
3 ?- sublist(integer, [3, f, 3.4], L).

L = [3]

Yes
4 ?- ^integer^number.
sublist(number, [3, f, 3.4], L).

L = [3, 3.400000]

Yes
5 ?- h.
   1  append("Hello ", "World", L).
   2  append("Hello ", "World", L), writef('L = %s\n', [L]).
   3  sublist(integer, [3, f, 3.4], L).
   4  sublist(number, [3, f, 3.4], L).

5 ?- !2^World^Universe.
append("Hello ", "Universe", L), writef('L = %s\n', [L]).
L = Hello Universe


Yes
6 ?- halt.

Figure 2.1: Some examples of the history facility
2.8. REUSE OF TOLEVEL BINDINGS

<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>!?str.</td>
<td>Repeat last query holding ⟨str⟩</td>
</tr>
<tr>
<td>&quot;old^new.</td>
<td>Substitute ⟨old⟩ into ⟨new⟩ in last query</td>
</tr>
<tr>
<td>!nr^old^new.</td>
<td>Substitute in query numbered ⟨nr⟩</td>
</tr>
<tr>
<td>!str^old^new.</td>
<td>Substitute in query starting with ⟨str⟩</td>
</tr>
<tr>
<td>!?str^old^new.</td>
<td>Substitute in query holding ⟨str⟩</td>
</tr>
<tr>
<td>h.</td>
<td>Show history list</td>
</tr>
<tr>
<td>!h.</td>
<td>Show this list</td>
</tr>
</tbody>
</table>

Table 2.1: History commands

1 ?- maplist(plus(1), "hello", X).

X = [105, 102, 109, 109, 112]

Yes

2 ?- format('\~s\~n', [\$X]).

ifmmp

Yes

Figure 2.2: Reusing toplevel bindings

underscore. These special sequences are analysed and the appropriate substitution from the history list is made.

From the above it follows that it is hard or impossible to correct quotation with single or double quotes, comment delimiters and spacing.

2.8 Reuse of toplevel bindings

Bindings resulting from the successful execution of a toplevel goal are asserted in a database. These values may be reused in further toplevel queries as $Var. Only the latest binding is available. Example:

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

6 ?- X = statistics.

X = statistics

Yes

7 ?- $X.

28.00 seconds cpu time for 183,128 inferences
4,016 atoms, 1,904 functors, 2,042 predicates, 52 modules
55,915 byte codes; 11,239 external references
1 ?- visible(+all), leash(-exit).

Yes

2 ?- trace, min([3, 2], X).
   Call: ( 3) min([3, 2], G235) ? creep
   Unify: ( 3) min([3, 2], G235)
   Call: ( 4) min([2], G244) ? creep
   Unify: ( 4) min([2], 2)
   Exit: ( 4) min([2], 2)
   Call: ( 4) min(3, 2, G235) ? creep
   Unify: ( 4) min(3, 2, G235)
   Call: ( 5) 3 < 2 ? creep
   Fail: ( 5) 3 < 2 ? creep
   Redo: ( 4) min(3, 2, G235) ? creep
   Exit: ( 4) min(3, 2, 2)
   Exit: ( 3) min([3, 2], 2)

Yes

[trace] 3 ?-

Figure 2.3: Example trace

<table>
<thead>
<tr>
<th></th>
<th>Limit</th>
<th>Allocated</th>
<th>In use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heap</td>
<td></td>
<td></td>
<td>624,820 Bytes</td>
</tr>
<tr>
<td>Local stack</td>
<td>2,048,000</td>
<td>8,192</td>
<td>404 Bytes</td>
</tr>
<tr>
<td>Global stack</td>
<td>4,096,000</td>
<td>16,384</td>
<td>968 Bytes</td>
</tr>
<tr>
<td>Trail stack</td>
<td>4,096,000</td>
<td>8,192</td>
<td>432 Bytes</td>
</tr>
</tbody>
</table>

Yes

2.9 Overview of the Debugger

SWI-Prolog has a 6-port tracer, extending the standard 4-port tracer [Clocksin & Melish, 1987] with two additional ports. The optional unify port allows the user to inspect the result after unification of the head. The exception port shows exceptions raised by throw/1 or one of the built-in predicates. See section 3.8.

The standard ports are called call, exit, redo, fail and unify. The tracer is started by the trace/0 command, when a spy point is reached and the system is in debugging mode (see spy/1 and debug/0) or when an exception is raised.

The interactive toplevel goal trace/0 means “trace the next query”. The tracer shows the port, displaying the port name, the current depth of the recursion and the goal. The goal is printed using the Prolog predicate write_term/2. The style can be modified to include the ignore_ops and/or portray options using the w, p or d command.
On leashed ports (set with the predicate leash/1, default are call, exit, redo and fail) the user is prompted for an action. All actions are single character commands which are executed without waiting for a return, unless the command line option -tty is active. Tracer options:

+ (Spy)
   Set a spy point (see spy/1) on the current predicate.

- (No spy)
   Remove the spy point (see nospy/1) from the current predicate.

/ (Find)
   Search for a port. 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:

```
/f
/fe solve
/c solve(a, _)
/a member(_, _)
```

. (Repeat find)
   Repeat the last find command (see ‘/’).

A (Alternatives)
   Show all goals that have alternatives.

C (Context)
   Toggle ‘Show Context’. If on the context module of the goal is displayed between square brackets (see section 4). Default is off.

L (Listing)
   List the current predicate with listing/1.

a (Abort)
   Abort Prolog execution (see abort/0).

b (Break)
   Enter a Prolog break environment (see break/0).

c (Creep)
   Continue execution, stop at next port. (Also return, space).

d (Display)
   Write goals using ignore_ops option.
(Exit)
Terminate Prolog (see `halt/0`).

(Fail)
Force failure of the current goal.

(Goals)
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.

(Help)
Show available options (also ‘?’).

(Ignore)
Ignore the current goal, pretending it succeeded.

(Leap)
Continue execution, stop at next spy point.

(No debug)
Continue execution in ‘no debug’ mode.

(Print)
Write goals using the `portray` option (default).

(Retry)
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.

(Skip)
Continue execution, stop at the next port of this goal (thus skipping all calls to children of this goal).

(Up)
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.

(Write)
Write goals without using the `portray` option.

The ideal 4 port model 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 (`debug/0`) choice points are only destroyed when removed by the cut. In debug mode, tail recursion optimisation is switched off.\(^2\)

\(^2\)This implies the system can run out of local stack in debug mode, while no problems arise when running in non-debug mode.
2.10 Compilation

2.10.1 During program development

During program development, programs are normally loaded using consult/1, or the list abbreviation. 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:

```prolog
% pl
<banner>
1 ?- [load].
<compilation messages>
Yes
2 ?- go.
<program interaction>
```

When using Windows, the user may open load.pl from the Windows explorer, which will cause plwin.exe to be started in the directory holding load.pl. Prolog loads load.pl before entering the toplevel.

2.10.2 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).

Creating a shell-script

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=pl

exec $PL -f none -g "load_files(['$base/load'],[silent(true)])" -t go -- $*

go :
    unix(argv(Arguments)),
    append(_SystemArgs, [--|Args], Arguments), !,
    go(Args).
```
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 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 using the linker `plld(1)`. 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 6.

**Compilation using the -c commandline 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:

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

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`.

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

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

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

This performs exactly the same as executing

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

See also `unix/1`. 

---

SWI-Prolog 3.2 Reference Manual
2.11 Environment Control

The current system defines 2 different mechanisms to query and/or set properties of the environment: `flag/3` and `feature/2` as well as a number of special purpose predicates of which `unknown/2`, `fileerrors/2` are examples. The ISO standard defines `prolog_flag`. It is likely that all these global features will be merged into a single in the future.

`feature(?Key, -Value)`

The predicate `feature/2` defines an interface to installation features: options compiled in, version, home, etc. With both arguments unbound, it will generate all defined features. With the `Key` instantiated it unify the value of the feature. Features come in three types: boolean features, features with an atom value and features with an integer value. A boolean feature is true iff the feature is present and the `Value` is the atom `true`. Currently defined keys:

`arch (atom)`

Identifier for the hardware and operating system SWI-Prolog is running on. Used to determine the startup file as well as to select foreign files for the right architecture. See also `load_foreign/5`.

`version (integer)`

The version identifier is an integer with value:

\[ 10000 \times \text{Major} + 100 \times \text{Minor} + \text{Patch} \]

Note that in releases upto 2.7.10 this feature yielded an atom holding the three numbers separated by dots. The current representation is much easier for implementing version-conditional statements.

`home (atom)`

SWI-Prolog’s notion of the home-directory. SWI-Prolog uses it’s home directory to find its startup file as well as to select foreign files for the right architecture. See also `load_foreign/5`.

`pipe (bool)`

If true, tell(pipe(command)), etc. are supported.

`load_foreign (bool)`

If true, `load_foreign/[2, 5]` are implemented.

`open_shared_object (bool)`

If true, `open_shared_object/2` and friends are implemented, providing access to shared libraries (.so files). This requires the C-library functions dlopen() and friends as well as the configuration option `--with-dlopen`.

`dynamic_stacks (bool)`

If true, the system uses some form of ‘sparse-memory management’ to realise the stacks. If false, `malloc()/realloc()` are used for the stacks. In earlier days this had consequences for foreign code. As of version 2.5, this is no longer the case.

Systems using ‘sparse-memory management’ are a bit faster as there is no stack-shifter, and checking the stack-boundary is often realised by the hardware using a ‘guard-page’. Also, memory is actually returned to the system after a garbage collection or call to `trim_stacks/0` (called by `prolog/0` after finishing a user-query).
c_libs (atom)
Libraries passed to the C-linker when SWI-Prolog was linked. May be used to determine the libraries needed to create statically linked extensions for SWI-Prolog. See section 5.7.

c_staticlibs (atom)
On some machines, the SWI-Prolog executable is dynamically linked, but requires some libraries to be statically linked. Obsolete.

c_cc (atom)
Name of the C-compiler used to compile SWI-Prolog. Normally either gcc or cc. See section 5.7.

c_ldflags (atom)
Special linker flags passed to link SWI-Prolog. See section 5.7.

save (bool)
If true, save/[1,2] is implemented. Saving using save/0 is obsolete. See qsave_program/[1,2].

save_program (bool)
If true, save_program/[1,2] is implemented. Saving using save_program/0 is obsolete. See qsave_program/[1,2].

readline (bool)
If true, SWI-Prolog is linked with the readline library. This is done by default if you have this library installed on your system. It is also true for the Win32 plwin.exe version of SWI-Prolog, which realises a subset of the readline functionality.

saved_program (bool)
If true, Prolog is started from a state saved with qsave_program/[1,2].

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

max_integer (integer)
Maximum integer value. Most arithmetic operations will automatically convert to floats if integer values above this are returned.

min_integer (integer)
Minimum integer value.

max_tagged_integer (integer)
Maximum integer value represented as a ‘tagged’ value. Tagged integers require 4-bytes storage and are used for indexing. Larger integers are represented as ‘indirect data’ and require 16-bytes on the stacks (though a copy requires only 4 additional bytes).

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

float_format (atom)
C printf() format specification used by write/1 and friends to determine how floating point numbers are printed. The default is %g. May be changed. The specified value is passed to printf() without further checking. For example, if you want more digits printed, %.12g will print all floats using 12 digits instead of the default 6. See also format/[1,2], write/1, print/1 and portray/1.
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.

character_escapes (bool)
If true (default), read/1 interprets \ escape sequences in quoted atoms and strings. May be changed.

allow_variable_name_as_functor (bool)
If true (default is false), Functor(arg) is read as if it was 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 none-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.

history (integer)
If integer > 0, support Unix csh(1) like history as described in section 2.7. Otherwise, only support reusing commands through the commandline editor. The default is to set this feature to 0 if a commandline editor is provided (see feature readline) and 15 otherwise.

gc (bool)
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.

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

- is/2 and evaluation under flag/3 do not automatically convert floats to integers if the float represents an integer.
- In the standard order of terms (see section 3.5.1), all floats are before all integers.

optimise (bool)
If true, compile in optimised mode. The initial value is true if Prolog was started with the -O commandline option.
Currently optimise 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).

autoload (bool)
If true (default) autoloading of library functions is enabled. See section 2.12.

verbose_autoload (bool)
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.
trace gc (bool)
If true (false is the default), garbage collections and stack-shifts will be reported on the terminal. May be changed.

max arity (unbounded)
ISO feature describing there is no maximum arity to compound terms.

integer rounding function (down, toward, zero)
ISO feature describing rounding by /\ and rem arithmetic functions. Value depends on the C-compiler used.

bounded (true)
ISO feature describing integer representation is bound by min integer and min integer.

tty control (bool)
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. See also the +/-tty command-line option.

debug on error (bool)
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 file errors/2 and the feature report error. May be changed. Default is true, except for the runtime version.

report error (bool)
If true, print error messages, otherwise suppress them. May be changed. See also the debug on error feature. Default is true, except for the runtime version.

file name variables (bool)
If true (default false), expand $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 should be used to expand environment variables and wildcard patterns. This feature is intended for backward compatibility with older versions of SWI-Prolog.

unix (bool)
If 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.

windows (bool)
If true, the operating system is an implementation of Microsoft Windows (3.1, 95, NT, etc.).

set feature(+Key, +Value)
Define a new feature or change its value. Key is an atom, Value is an atom or number.

2.12 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. If this fails the auto loader is activated. On first activation an index to all library files in all library directories is loaded in core (see library directory/1). If the undefined predicate can be located in the one of the libraries that library file is automatically loaded
and the call to the (previously undefined) predicate is resumed. By default this mechanism loads the file silently. The feature/2 verbose.autoload is provided to get verbose loading. The feature autoload can be used to enable/disable the entire auto load system.

The auto-loader only works if the unknown flag (see unknown/2) is set to trace (default). A more appropriate interaction with this flag will be considered.

Autoloading only handles (library) source files that use the module mechanism described in chapter 4. The files are loaded with use.module/2 and only the trapped undefined predicate will be imported to 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:

```
index(Name, Arity, Module, File).
```

The predicate make/0 scans the autoload libraries and updates the index if it exists, is writable and out-of-date. It is advised to create an empty file called INDEX.pl in a library directory meant for auto loading before doing anything else. This index file can then be updated by running the prolog make_library_index/1 ('%' is the Unix prompt):

```
% mkdir ~/lib/prolog
% cd !$
% pl -g true -t 'make_library_index(.)
```

If there are more than one library files 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.

2. Otherwise library files are considered in the order they appear in the library.directory/1 predicate and within the directory alphabetically.

```
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.

### 2.13 Garbage Collection

SWI-Prolog version 1.4 was the first release to support garbage collection. Together with last-call optimisation this guarantees forward chaining programs do not waste infinite amounts of memory.

### 2.14 Syntax Notes

SWI-Prolog uses standard ‘Edinburgh’ syntax. A description of this syntax can be found in the Prolog books referenced in the introduction. Below are some non-standard or non-common constructs that are accepted by SWI-Prolog:
This construct is not accepted by all Prolog systems that claim to have Edinburgh compatible syntax. It describes the ASCII value of $\texttt{\textless char\textgreater}$. To test whether $\texttt{C}$ is a lower case character one can use $\texttt{between(0'a, 0'z, C)}$.

The $\texttt{/* ...*/}$ comment statement can be nested. This is useful if some code with $\texttt{/* ...*/}$ comment statements in it should be commented out.

### 2.14.1 ISO Syntax Support

SWI-Prolog offers ISO compatible extensions to the Edinburgh syntax.

**Character Escape Syntax**

Within quoted atoms (using single quotes: $\texttt{\textsinglequote{atom}}$) special characters are represented using escape-sequences. An escape sequence is lead in by the backslash ($\texttt{\textbackslash}$) character. The list of escape sequences is compatible with the ISO standard, but contains one extension and the interpretation of numerically specified characters is slightly more flexible to improve compatibility.

- $\texttt{\textbackslash a}$
  - Alert character. Normally the ASCII character 7 (beep).
- $\texttt{\textbackslash b}$
  - Backspace character.
- $\texttt{\textbackslash c}$
  - No output. All input characters upto but not including the first non-layout character are skipped. This allows for the specification of pretty-looking long lines. For compatibility with Quintus Prolog. Not supported by ISO. Example:

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

- $\texttt{\textbackslash \text{\textbackslash}}$
  - No output. Skips input till the next non-layout character or to the end of the next line. Same intention as $\texttt{\textbackslash c}$ but ISO compatible.
- $\texttt{\textbackslash f}$
  - Form-feed character.
- $\texttt{\textbackslash n}$
  - Next-line character.
- $\texttt{\textbackslash r}$
  - Carriage-return only (i.e. go back to the start of the line).
- $\texttt{\textbackslash t}$
  - Horizontal tab-character.
2.15. SYSTEM LIMITS

\v
Vertical tab-character (ASCII 11).

\x{23}
Hexadecimal specification of a character. 23 is just an example. The ‘x’ may be followed by a maximum of 2 hexadecimal digits. The closing \ is optional. The code \xa\3 emits the character 10 (hexadecimal ‘a’) followed by ‘3’. The code \x201 emits 32 (hexadecimal ‘20’) followed by ‘1’. According to ISO, the closing \ is obligatory and the number of digits is unlimited. The SWI-Prolog definition allows for ISO compatible specification, but is compatible with other implementations.

\40
Octal character specification. The rules and remarks for hexadecimal specifications apply to octal specifications too, but the maximum allowed number of octal digits is 3.

\{character\}
Any character immediately preceded by a \ and not covered by the above escape sequences is copied verbatim. Thus, ‘\’ is an atom consisting of a single \ and ‘\’ and ‘’’ both describe the atom with a single ‘’.

Character escaping is only available if the feature(character_escapes, true) is active (default). See feature/2. Character escapes conflict with writef/2 in two ways: \40 is interpreted as decimal 40 by writef/2, but character escapes handling by read has already interpreted as 32 (40 octal). Also, \l is translated to a single ‘l’. It is advised to use the more widely supported format/[2,3] predicate instead. If you insist using writef, 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.

2.15 System Limits

2.15.1 Limits on Memory Areas

SWI-Prolog has a number of memory areas which are only enlarged to a certain limit. The default sizes for these areas should suffice for most applications, but big applications may require larger ones. They are modified by command line options. The table below shows these areas. The first column gives the option name to modify the size of the area. The option character is immediately followed by a number and optionally by a k or m. With k or no unit indicator, the value is interpreted in Kbytes (1024 bytes), with m, the value is interpreted in Mbytes (1024 \times 1024 bytes).

The local-, global- and trail-stack are limited to 128 Mbytes on 32 bit processors, or more in general to 2^{bits-per-long} bytes.
<table>
<thead>
<tr>
<th>Option</th>
<th>Default</th>
<th>Area name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>-L</td>
<td>2M</td>
<td>local stack</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 (tail recursion optimisation).</td>
</tr>
<tr>
<td>-G</td>
<td>4M</td>
<td>global stack</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>-T</td>
<td>4M</td>
<td>trail stack</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.</td>
</tr>
<tr>
<td>-A</td>
<td>1M</td>
<td>argument stack</td>
<td>The argument stack is used to store one of the intermediate code interpreter’s registers. The amount of space needed on this stack is determined entirely by the depth in which terms are nested in the clauses that constitute the program. Overflow is most likely when using long strings in a clause.</td>
</tr>
</tbody>
</table>

Table 2.2: Memory areas
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. As of SWI-Prolog 2.8.5, no limits are imposed on the addresses returned by malloc() and friends.

On some machines, the runtime stacks described above are allocated using ‘sparse allocation’. Virtual space upto the limit is claimed at startup and committed and released while the area grows and shrinks. On Win32 platform this is realised using VirtualAlloc() and friends. On Unix systems this is realised using mmap().

2.15.2 Other Limits

Clauses Currently the following limitations apply to clauses. The arity may not be more than 1024 and the number of variables should be less than 65536.

Atoms and Strings SWI-Prolog has no limits on the sizes of atoms and strings. read/1 and its derivatives however normally limit the number of newlines in an atom or string to 5 to improve error detection and recovery. This can be switched off with style_check/1.

Address space 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.

Integers Integers are 32-bit to the user, but integers upto the value of the max_tagged_integer feature are represented more efficiently.

Floats Floating point numbers are represented as native double precision floats, 64 bit IEEE on most machines.

2.15.3 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 (see style_check/1).

The compiler uses the special functor $VAR$/1 while analysing the clause to compile. Using this functor in a program causes unpredictable behaviour of the compiler and resulting program.
3.1 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 ‘+’, ‘-’ or ‘?’ sign. ‘+’ indicates the argument is input to the predicate, ‘-’ denotes output and ‘?’ denotes ‘either input or output’.

1 Constructs like ‘op/3’ refer to the predicate ‘op’ with arity ‘3’.

3.2 Consulting Prolog Source files

SWI-Prolog source files normally have a suffix ‘.pl’. Specifying the suffix is optional. All predicates that handle source files first check whether a file with suffix ‘.pl’ exists. If not the plain file name is checked for existence. Library files are specified by embedding the file name using the functor library/1. Thus ‘foo’ refers to ‘foo.pl’ or ‘foo’ in the current directory. ‘library(foo)’ refers to ‘foo.pl’ or ‘foo’ in one of the library directories specified by the dynamic predicate library_directory/1. The user may specify other ‘aliases’ than library using the predicate file_search_path/2. This is strongly encouraged for managing complex applications. See also absolute_file_name/2,3.

SWI-Prolog recognises grammar rules as defined in [Clocksin & Melish, 1987]. The user may define additional compilation of the source file by defining the dynamic predicate term_expansion/2. Transformations by this predicate overrule the systems grammar rule transformations. 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.

Directives may be placed anywhere in a source file, invoking any predicate. They are executed when encountered. If the directive fails, a warning is printed. Directives are specified by :-/1 or ?-/1. There is no difference between the two.

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.

load_files(+Files, +Options)

The predicate load_files/2 is the parent of all the other loading predicates. It currently supports a subset of the options of Quintus load_files/2. Files is either specifies a single, or a list of source-files. The specification for a source-file is handled absolute_file_name/2.

See this predicate for the supported expansions. Options is a list of options using the format

OptionName(OptionValue)

These marks do not suggest instantiation (e.g. var(+Var)).

It does work for consult, but makes it impossible to compile programs into a stand alone executable (see section 2.10).
The following options are currently supported:

**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.

**must_be_module(Bool)**
If `true`, raise an error if the file is not a module file. Used by `use_module/[1,2]`.

**imports(ListOrAll)**
If `all` and the file is a module file, import all public predicates. Otherwise import only the named predicates. Each predicate is referred to as `<name>/<arity>`. This option has no effect if the file is not a module file.

**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.

**consult(+File)**
Read `File` as a Prolog source file. `File` may be a list of files, in which case all members are consulted in turn. `File` may start with the `csh(1)` special sequences `~`, `<user>` and `$<var>`. `File` may also be `library(Name)`, in which case the libraries are searched for a file with the specified name. See also `library_directory/1` and `file_search_path/2`. `consult/1` may be abbreviated by just typing a number of file names in a list. Examples:

```prolog
?- consult(load). % consult load or load.pl
?- [library(quintus)]. % load Quintus compatibility library
```

Equivalent to `load_files(File, [])`.

**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 the semantics, we hope to get as closely 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(File, [if(changed)])`.

**require(+ListOfNameAndArity)**
Declare that this file/module requires the specified predicates to be defined “with their commonly accepted definition”. This predicate originates from the Prolog portability layer for XPCE. It is intended to provide a portable mechanism for specifying that this module requires the specified predicates.

The implementation normally first verifies whether the predicate is already defined. If not, it will search the libraries and load the required library.

SWI-Prolog, having autoloading, does **not** load the library. Instead it creates a procedure header for the predicate if this does not exist. This will flag the predicate as ‘undefined’. See also `check/0` and `autoload/0`. 

---

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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 \texttt{pl -c} ... and files loaded using consult or one of its derivatives. \texttt{make/0} is normally invoked by the \texttt{edit/[0,1]} and \texttt{ed/[0,1]} predicates. \texttt{make/0} can be combined with the compiler to speed up the development of large packages. In this case compile the package using

\begin{verbatim}
    sun% pl -g make -o my_program -c file ...
\end{verbatim}

If ’my_program’ is started it will first reconsult all source files that have changed since the compilation.

\texttt{library_directory(\textit{Atom})}
Dynamic predicate used to specify library directories. Default \texttt{./lib, ~/lib/prolog} and the system’s library (in this order) are defined. The user may add library directories using \texttt{assert/1, asserta/1} or remove system defaults using \texttt{retract/1}.

\texttt{file_search_path(+\textit{Alias}, ?\textit{Path})}
Dynamic predicate used to specify ’path-aliases’. This feature is best described using an example. Given the definition

\begin{verbatim}
    file_search_path(demo, ’~/demo’).
\end{verbatim}

the file specification \texttt{demo(myfile)} will be expanded to \texttt{~/demo/myfile}. The second argument of \texttt{file_search_path/2} may be another alias.

Below is the initial definition of the file search path. This path implies \texttt{swi(\textit{Path})} refers to a file in the SWI-Prolog home directory. The alias \texttt{foreign(\textit{Path})} is intended for storing shared libraries (.so or .DLL files). See also \texttt{load_foreign_library/[1,2]}.

\begin{verbatim}
user:file_search_path(library, X) :-
    library_directory(X).
user:file_search_path(swi, Home) :-
    feature(home, Home).
user:file_search_path(foreign, swi(ArchLib)) :-
    feature(arch, Arch),
    concat(’lib/’, Arch, ArchLib).
user:file_search_path(foreign, swi(lib)).
\end{verbatim}

The \texttt{file_search_path/2} expansion is used by all loading predicates as well as by \texttt{absolute_file_name/[2,3]}.

\texttt{expand_file_search_path(+\textit{Spec}, -\textit{Path})}
Unifies \textit{Path} will all possible expansions of the file name specification \textit{Spec}. See also \texttt{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, 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) :-
   feature(associate, Ext), Ext \== pl.
user:prolog_file_type(qlf, qlf).
user:prolog_file_type(so, executable) :-
   feature(open_shared_object, true).
user:prolog_file_type(dlI, executable) :-
   feature(dll, true).

Users may wish to change the extension used for Prolog source files to avoid conflicts (for example with perl) as well as to be compatible with some specific implementation. The preferred alternative extension is .pro.

source_file(?File)
Succeeds if File was loaded using consult/1 or ensure_loaded/1. File refers to the full path name of the file (see expand_file_name/2). The predicate source_file/1 backtracks over all loaded source files.

source_file(?Pred, ?File)
Is true if the predicate specified by Pred was loaded from file File, where File is an absolute path name (see expand_file_name/2). Can be used with any instantiation pattern, but the database only maintains the source file for each predicate. Predicates declared multifile (see multifile/1) cannot be found this way.

prolog_load_context(?Key, ?Value)
Determine loading context. The following keys are defined:

<table>
<thead>
<tr>
<th>Key</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>module</td>
<td>Module into which file is loaded</td>
</tr>
<tr>
<td>file</td>
<td>File loaded</td>
</tr>
<tr>
<td>stream</td>
<td>Stream identifier (see current_input/1)</td>
</tr>
<tr>
<td>directory</td>
<td>Directory in which File lives.</td>
</tr>
<tr>
<td>term_position</td>
<td>Position of last term read. Term of the form '$stream_position'(0, (Line), 0, 0, 0)</td>
</tr>
</tbody>
</table>

Quintus compatibility predicate. See also source_location/2.

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.
**term**_**expansion**(+Term1, -Term2)

Dynamic predicate, normally not defined. When defined by the user all terms read during consulting that 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 a the form `?- 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 4 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 user:term_expansion/2. 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.

**expand_term**(+Term1, -Term2)

This predicate is normally called by the compiler to perform preprocessing. First it calls term_expansion/2. If this predicate fails it performs a grammar-rule translation. If this fails it returns the first argument.

**goal**_**expansion**(+Goal1, -Goal2)

Like term_expansion/2, goal_expansion/2 provides for macro-expansion of Prolog source-code. Between term_expand/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 on the user module.

Only goals appearing in the body of clauses when reading a source-file are expanded using mechanism, and only if they appear literally in the clause, or as an argument to the meta-predicates not/1, call/1 or forall/2. A real predicate definition is required to deal with dynamically constructed calls.

**expand_goal**(+Goal1, -Goal2)

This predicate is normally called by the compiler to perform preprocessing. First it calls goal_expansion/2. If this fails it returns the first argument.

**at**_**initialization**(+Goal)

Register Goal to be ran when the system initialises. Initialisation takes place after reloading a .qlf (formerly .wic) file as well as after reloading a saved-state. The hooks are run in the order they were registered. A warning message is issued if Goal fails, but execution continues. See also at_halt/1.

**at**_**halt**(+Goal)

Register Goal to be ran when the system halts. The hooks are run in the order they were registered. Success or failure executing a hook is ignored. These hooks may not call halt/[0,1].
initialization(+Goal)

Call Goal and register it using at_initialization/1. Directives that do other things that creating clauses, records, flags or setting predicate attributes should normally be written using this tag to ensure the initialisation is executed when a saved system starts. See also \texttt{qsaveweb/1}. \hfill 43

compiling

Succeeds if the system is compiling source files with the \texttt{-c} option into an intermediate code file. Can be used to perform code optimisations in \texttt{expand_term/2} under this condition.

preprocessor(-Old, +New)

Read the input file via a Unix process that acts as preprocessor. A preprocessor is specified as an atom. The first occurrence of the string '\%f' is replaced by the name of the file to be loaded. The resulting atom is called as a Unix command and the standard output of this command is loaded. To use the Unix C preprocessor one should define:

\begin{verbatim}
?- preprocessor(Old, '/lib/cpp -C -P %f'), consult(...).
\end{verbatim}

\texttt{Old = none}

3.2.1 Quick Load Files

The features described in this section should be regarded alpha.

As of version 2.0.0, SWI-Prolog supports compilation of individual or multiple Prolog source files into ‘Quick Load Files’. A ‘Quick Load Files’ (.qlf file) stores the contents of the file in a precompiled format very similar to compiled files created using the \texttt{-b} and \texttt{-c} flags (see section 2.10).

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 \texttt{qcompile/1}. They may be loaded explicitly using \texttt{qload/1} or implicitly using \texttt{consult/1} or one of the other file-loading predicates described in section 3.2. If \texttt{consult} is given the explicit .pl file, it will load the Prolog source. When given the .qlf file, it will call \texttt{qload/1} to load the file. When no extension is specified, it will load the .qlf file when present and the fileextpl file otherwise.

\texttt{qcompile(+File)}

Takes a single file specification like \texttt{consult/1} (i.e. accepts constructs like \texttt{library(LibFile)}) and creates a Quick Load File from \texttt{File}. The file-extension of this file is .qlf. The base name of the Quick Load File is the same as the input file.

If the file contains ‘:- consult(+File)’ or ‘:- [+File]’ 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 \texttt{term expansion/2}, the same rules as described in section 2.10 apply.

Source references (\texttt{source_file/2}) in the Quick Load File refer to the Prolog source file from which the compiled code originates.
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qload(+File)
  Loads the ‘Quick Load File’. It has the same semantics as consult/1 for a normal sourcefile.
  Equivalent to consult(File) iff File refers to a ‘Quick Load File’.

3.3 Listing and 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 extended or redefined by adding clauses to various multi-file (see multifile/1) predicates defined in the module prolog.edit.

The built-in edit specifications for edit/1 (see prolog.edit:locate/3) are described below.

<table>
<thead>
<tr>
<th>Fully specified objects</th>
</tr>
</thead>
<tbody>
<tr>
<td>⟨Module⟩⟨Name⟩⟨Arity⟩</td>
</tr>
<tr>
<td>module(⟨Module⟩)</td>
</tr>
<tr>
<td>file(⟨Path⟩)</td>
</tr>
<tr>
<td>source_file(⟨Path⟩)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ambiguous specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>⟨Name⟩⟨Arity⟩</td>
</tr>
<tr>
<td>⟨Name⟩</td>
</tr>
</tbody>
</table>

edit(+Specification)
  First exploits prolog.edit:locate/3 to translate Specification into a list of Locations. If there is more than one ‘hit’, the user is allows to select from the found locations. Finally, prolog.edit:edit_source/1 is used to invoke the user’s preferred editor.

prolog.edit:locate(+Spec, -FullSpec, -Location)
  Where Spec is the specification provided through edit/1. This multi-file predicate is used to enumerate locations at with 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 base-name 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 locate/3 for the format of a location term. This multi-file predicate is normally not defined. If it succeeds, edit/1 assumes the editor is started.

If it fails, edit/1 will invoke an external editor. The editor to be invoked is determined from the environment variable EDITOR, which may be set from the operating system or from the Prolog initialisation file using setenv/2. If no editor is defined, vi is the default in Unix systems, and notepad on Windows.

The predicate prolog.edit:edit_command/2 defines how the editor will be invoked.
3.4. VERIFY TYPE OF A TERM

\texttt{prolog\_edit:edit\_command(+Editor, -Command)}

Determines how \textit{Editor} is to be invoked using \texttt{shell/1}. \textit{Editor} is the determined editor (see \texttt{edit\_source/1}), without the full path specification, and without possible (exe) extension. \textit{Command} is an atom describing the command. The pattern \%f is replaced by the full file-name of the location, and \%d by the line number. If the editor can deal with starting at a specified line, two clauses should be provided, one holding only the \%f pattern, and one holding both patterns.

The default contains definitions for \texttt{vi, emacs, emacsclient, vim} and \texttt{notepad} (latter without line-number version).

Please contribute your specifications to jan@swi.psy.uva.nl.

\texttt{prolog\_edit:load}

Normally not-defined 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{library(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}

\texttt{listing(+Pred)}

List specified predicates (when an atom is given all predicates with this name will be listed). The listing is produced on the basis of the internal representation, thus loosing user’s layout and variable name information. See also \texttt{portray\_clause/1}.

\texttt{listing}

List all predicates of the database using \texttt{listing/1}.

\texttt{portray\_clause(+Clause)}

Pretty print a clause as good as we can. A clause should be specified as a term ‘\texttt{(Head)} :- \texttt{(Body)}’ (put brackets around it to avoid operator precedence problems). Facts are represented as ‘\texttt{(Head)} :- true’.

3.4  Verify Type of a Term

\texttt{var(+Term)}

Succeeds if \textit{Term} currently is a free variable.

\texttt{nonvar(+Term)}

Succeeds if \textit{Term} currently is not a free variable.

\texttt{integer(+Term)}

Succeeds if \textit{Term} is bound to an integer.

\texttt{float(+Term)}

Succeeds if \textit{Term} is bound to a floating point number.
number(+Term)
    Succeeds if Term is bound to an integer or a floating point number.

atom(+Term)
    Succeeds if Term is bound to an atom.

string(+Term)
    Succeeds if Term is bound to a string.

atomic(+Term)
    Succeeds if Term is bound to an atom, string, integer or floating point number.

compound(+Term)
    Succeeds if Term is bound to a compound term. See also functor/3 and =../2.

ground(+Term)
    Succeeds if Term holds no free variables.

3.5 Comparison and Unification of Terms

3.5.1 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 < Atoms < Strings\(^3\) < Numbers < Terms
2. Old Variable < New Variable\(^4\)
3. Atoms are compared alphabetically.
4. Strings are compared alphabetically.
5. Numbers are compared by value. Integers and floats are treated identically.
6. Compound terms are first checked on their arity, then on their functor-name (alphabetically) and finally recursively on their arguments, leftmost argument first.

If the feature (see feature/2) iso is defined, all floating point numbers precede all integers.

+Term1 == +Term2
    Succeeds if Term1 is equivalent to Term2. A variable is only identical to a sharing variable.

+Term1 \== +Term2
    Equivalent to \+Term1 == Term2.

+Term1 = +Term2
    Unify Term1 with Term2. Succeeds if the unification succeeds.

---

\(^3\)Strings might be considered atoms in future versions. See also section 3.21
\(^4\)In fact the variables are compared on their (dereferenced) addresses. Variables living on the global stack are always < than variables on the local stack. Programs should not rely on the order in which variables are sorted.
3.6 Control Predicates

The predicates of this section implement control structures. Normally these constructs are translated into virtual machine instructions by the compiler. It is still necessary to implement these constructs as true predicates to support meta-calls, as demonstrated in the example below. The predicate finds all currently defined atoms of 1 character long. Note that the cut has no effect when called via one of these predicates (see !/0).

one_character_atoms(As) :-
    findall(A, (current_atom(A), atom_length(A, 1)), As).

fail

Always fail. The predicate fail/0 is translated into a single virtual machine instruction.
true
Always succeed. The predicate \texttt{true/0} is translated into a single virtual machine instruction.

repeat
Always succeed, provide an infinite number of choice points.

\texttt{!}
Cut. Discard choice points of parent frame and frames created after the parent frame. Note that the control structures \texttt{;/2}, \texttt{\mid;/2}, \texttt{->/2} and \texttt{\+)/1} are normally handled by the compiler and do not create a frame, which implies the cut operates through these predicates. Some examples are given below. Note the difference between \texttt{t3/1} and \texttt{t4/1}. Also note the effect of \texttt{call/1} in \texttt{t5/0}. As the argument of \texttt{call/1} is evaluated by predicates rather than the compiler the cut has no effect.

\begin{verbatim}
t1 :- (a, !, fail ; b). % cuts a/0 and t1/0
t2 :- (a -> b, ! ; c). % cuts b/0 and t2/0
t3(G) :- a, G, fail. % if ‘G =!’ cuts a/0 and t1/1
t4(G) :- a, call(G), fail. % if ‘G =!’ cut has no effect
t5 :- call((a, !, fail ; b)). % Cut has no effect
t6 :- +(a, !, fail ; b). % cuts a/0 and t6/0
\end{verbatim}

\texttt{+Goal1} , \texttt{+Goal2}
Conjunction. Succeeds if both ‘Goal1’ and ‘Goal2’ can be proved. It is defined as (this definition does not lead to a loop as the second comma is handled by the compiler):

\begin{verbatim}
Goal1, Goal2 :- Goal1, Goal2.
\end{verbatim}

\texttt{+Goal1} ; \texttt{+Goal2}
The ‘or’ predicate is defined as:

\begin{verbatim}
Goal1 ; _Goal2 :- Goal1.
_Goal1 ; Goal2 :- Goal2.
\end{verbatim}

\texttt{+Goal1} \mid \texttt{+Goal2}
Equivalent to \texttt{;/2}. Retained for compatibility only. New code should use \texttt{;/2}. Still nice though for grammar rules.

\texttt{+Condition \rightarrow +Action}
If-then and If-Then-Else. The \texttt{->/2} construct commits to the choices made at its left-hand side, destroying choice-points created inside the clause (by \texttt{;/2}), or by goals called by this clause. Unlike \texttt{!/0}, the choicepoint of the predicate as a whole (due to multiple clauses) is not destroyed. The combination \texttt{;/2} and \texttt{->/2} is defines as:

\begin{verbatim}
If -> Then; _Else :- If, !, Then.
If -> _Then; Else :- !, Else.
If -> Then :- If, !, Then.
\end{verbatim}
Note that the operator precedence relation between ; and \( \rightarrow \) ensure \( \text{If} \ \rightarrow \ \text{Then} \ \ ; \ \text{Else} \) is actually a term of the form \( (\rightarrow (\text{If}, \ \text{Then}), \ \text{Else}) \). The first two clauses belong to the definition of \( ;/2 \), while only the last defines \( \rightarrow /2 \).

\(+\text{Condition} \ \rightarrow\ \rightarrow +\text{Action} ; +\text{Else}\)

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 \( (\text{Condition}, \ \text{Action}) \). 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 \( \text{Condition} \) and \( \text{Action} \), otherwise execute \( \text{Else} \).

\(\backslash+ +\text{Goal}\)

Succeeds if ‘Goal’ cannot be proven (mnemonic: + refers to \textit{provable} and the backslash (\( \backslash \)) is normally used to indicate negation).

### 3.7 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}(+\texttt{Goal})

Invoke \texttt{Goal} as a goal. Note that clauses may have variables as subclauses, which is identical to \texttt{call}/1, except when the argument is bound to the cut. See \texttt{!/0}.

\texttt{call}(+\texttt{Goal}, +\texttt{ExtraArg1}, \ldots)

Append \texttt{ExtraArg1}, \texttt{ExtraArg2}, \ldots to the argument list of \texttt{Goal} and call the result. For example, \texttt{call(plus(1), 2, X)} will call \texttt{plus/3}, binding \texttt{X} to 3.

The \texttt{call/[2..]} construct is handled by the compiler, which implies that redefinition as a predicate has no effect. The predicates \texttt{call/[2–6]} are defined as true predicates, so they can be handled by interpreted code.

\texttt{apply}(+\texttt{Term}, +\texttt{List})

Append the members of \texttt{List} to the arguments of \texttt{Term} and call the resulting term. For example: \texttt{apply(plus(1), [2, X])} will call \texttt{plus(1, 2, X)}. \texttt{apply/2} is incorporated in the virtual machine of SWI-Prolog. This implies that the overhead can be compared to the overhead of \texttt{call/1}. New code should use \texttt{call/[2..]} if the length of \texttt{List} is fixed, which is more widely supported and faster because there is no need to build and examine the argument list.

\texttt{not}(+\texttt{Goal})

Succeeds when \texttt{Goal} cannot be proven. Retained for compatibility only. New code should use \texttt{\!/1}.

\texttt{once}(+\texttt{Goal})

Defined as:

\[\text{once(} \text{Goal} \text{)} : - \]
\[\text{Goal}, !.\]
once/1 can in many cases be replaced with ->/2. The only difference is how the cut behaves (see !/0). The following two clauses are identical:

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:

```prolog
ignore(Goal) :-
    Goal, !.
ignore(_).
```

**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 differ from the depth computed based on a theoretical model. For example, true/0 is translated into an inlined virtual machine instruction. Also, repeat/0 is not implemented as below, but as a non-deterministic foreign predicate.

```prolog
repeat.
repeat :-
    repeat.
```

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.
It was implemented after discussion with Steve Moyle smoyle@ermine.ox.ac.uk.

### 3.8 ISO compliant Exception handling

SWI-Prolog defines the predicates catch/3 and throw/1 for ISO compliant raising and catching of exceptions. In the current implementation (2.9.0), only part of the built-in predicates generate exceptions. In general, exceptions are implemented for I/O and arithmetic.

**catch(:Goal, +Catcher, :-Recover)**
Behaves as call/1 if no exception is raised when executing **Goal**. If a 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 choicepoints generated by **Goal** are cut, and **Recover** is called as in call/1.

The overhead of calling a goal through catch/3 is very comparable to call/1. Recovery from an exception has a similar overhead.
3.8. ISO COMPLIANT EXCEPTION HANDLING

throw(+Exception)
Raise an exception. The system will look for the innermost catch/3 ancestor for which
Exception unifies with the Catcher argument of the catch/3 call. See catch/3 for details.

If there is no catch/3 willing to catch the error in the current Prolog context, the toplevel
(prolog/0) catches the error and prints a warning message. If an exception was raised in a
callback from C (see chapter 5), PLnext_solution() will fail and the exception context
can be retrieved using PL_exception().

3.8.1 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 feature (see feature/2) 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
toplevel 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 toplevel is running, the error will be printed, and the system will enter trace
mode.

If the system is in a non-interactive callback 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 feature debug_on_error:

- feature(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.

- feature(debug_on_error, true)
If the exception is not caught by Prolog in the current context, it will trap the tracer to help
analysing 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.

3.8.2 The exception term

Builtin predicates generates exceptions using a term error(Formal, Context). The first argument
is the ‘formal’ description of the error, specifying the class and generic defined context information.
When applicable, the ISO error-term definition is used. The second part describes some additional
context to help the programmer while debugging. In its most generic form this is a term of the form
context(Name/Arity, Message), where Name/Arity describes the built-in predicate that raised
the error, and Message provides an additional description of the error. Any part of this structure may be a
variable if no information was present.
3.8.3 Printing a message from an exception

The predicate `print_message/2` may be used to print an exception term in a human readable format:

`print_message(+Kind, +Term)`

This predicate is modelled after the Quintus predicate with the same name, though its current implementation is incomplete. It is used only for printing messages from exceptions from built-in predicates. `Kind` is one of informational, warning, consterror, help or silent. Currently only error is defined. `Term` is an error(2) term described in section 3.8.2. A human-readable message is printed to the stream `user_error`.

This predicate first obtains the ‘human translation’ of `Term` and then calls `message_hook/3`. If this fails the message is printed to the stream `user_error`.

The `print_message/2` predicate and its rules are in the file `<plhome>/boot/messages.pl`, which may be inspected for more information on the error messages and related error terms.

`message_hook(+Term, +Kind, +Message)`

Hook predicate that may be define in the module user to intercept messages from `print_message/2`. `Term` and `Kind` are the same as passed to `print_message/2`. `Message` is a string containing the human readable translation of the message. If this predicate succeeds, `print_message/2` considers the message printed.

This predicate should be defined dynamic and multifile to allow other modules defining clauses for it too.

3.9 Handling signals

As of version 3.1.0, SWI-Prolog is capable to handle software interrupts (signals) in Prolog as well as in foreign (C) code (see section 5.6.11).

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 asynchronous inter-process 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 functionalty to raise a signal in another thread for achieving asynchronous inter-process (or inter-thread) communication (Unix kill() function).

`on_signal(+Signal, -Old, :New)`

Determines the reaction on `Signal`. `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 `<Module>:<Name>` refers to the `<Name>/1 in the module `<Module>`.

Two predicate-names have special meaning. `throw` implies Prolog will map the signal onto a Prolog exception as described in section 3.8. `default` resets the handler to the settings active before SWI-Prolog manipulated the handler.
After receiving a signal mapped to `throw`, the exception raised has the structure

```
error(signal(SigName, SigNum), Context)
```

One possible usage of this is, for example, to limit the time spent on proving a goal. This requires a little C-code for setting the alarm timer (see chapter 5):

```c
#include <SWI-Prolog.h>
#include <unistd.h>

foreign_t
pl_alarm(term_t time)
{
  double t;

  if ( PL_get_float(time, &t) )
  {
    alarm((long)(t+0.5));

    PL_succeed;
  }

  PL_fail;
}

install_t
install()
{
  PL_register_foreign("alarm", 1, pl_alarm, 0);
}
```

Next, we can define the following Prolog code:

```prolog
:- load_foreign_library(alarm).

:- on_signal(alrm, throw).

:- module_transparent
  call_with_time_limit/2.

call_with_time_limit(Goal, MaxTime) :-
  alarm(MaxTime),
  catch(Goal, signal(alrm, _), fail), !,
  alarm(0).

call_with_time_limit(_, _) :-
  alarm(0),
  fail.
```
The signal names are defined by the C-Posix standards as symbols of the form `SIG.<SIGNAME>`. The Prolog name for a signal is the lowercase version of `<SIGNAME>`. The predicate `current_signal/3` may be used to map between names and signals.

Initially, some signals are mapped to `throw`, while all other signals are `default`. The following signals throw an exception: `ill`, `fpe`, `segv`, `pipe`, `alrm`, `bus`, `xcpu`, `xfsz` and `vtalrm`.

```
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`).

### 3.9.1 Notes on signal handling

Before deciding to deal with signals in your application, please consider the following:

- **Portibility**
  - 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.

- **Safety**
  - Signal handling is not completely safe in the current implementation, especially if `throw` is used in combination with external foreign code. The system will use the C `longjmp()` construct to direct control to the innermost `PL_next_solution()`, thus forcing an external procedure to be abandoned at an arbitrary moment. Most likely not all SWI-Prologs own foreign code is (yet) safe too.

- **Garbage Collection**
  - The garbage collector will block all signals that are handled by Prolog. While handling a signal, the garbage-collector is disabled.

- **Time of delivery**
  - Normally delivery is immediate (or as defined by the operating system used). Signals are blocked when the garbage collector is active, and internally delayed if they occur within a ‘critical section’. The critical sections are generally very short.

### 3.10 Advanced control-structures: blocks

The predicates of this section form a tightly related set for realising premature successful or failing exits from a block. These predicates are first of all useful for error-recovery. They were primarily implemented for compatibility reasons.

```
block(+Label, +Goal, -ExitValue)
```

Execute Goal in a block. Label is the name of the block. Label is normally an atom, but the system imposes no type constraints and may even be a variable. ExitValue is normally unified to the second argument of an `exit/2` call invoked by Goal.

```
exit(+Label, +Value)
```

Calling `exit/2` makes the innermost `block` which `Label` unifies exit. The block’s `ExitValue` is unified with `Value`. If this unification fails the block fails.
fail(+Label)

Calling fail/1 makes the innermost block which Label unifies fail immediately. Implemented as

\[
\text{fail(Label)} : - !\text{(Label)}, \text{fail}.
\]

!(+Label)

Cut all choice-points created since the entry of the innermost block which Label unifies.

The example below illustrate these constructs to immediately report a syntax-error from a ‘deep-down’ procedure to the outside world without passing it as an argument ‘all-over-the-place’.

\[
\text{parse(RuleSet, InputList, Rest)} : - \text{block(syntaxerror, phrase(RuleSet, InputList, Rest), Error),}
\]

\[
\begin{align*}
& \quad (\text{var(Error)} \rightarrow \text{true}) \\
& \quad \text{format('Syntax-error: ˜w˜n', Error), fail)}.
\end{align*}
\]

\[
\text{integer(N)} \rightarrow \\
\quad \text{digit(D1), !, digits(Ds), }
\quad \{ \text{name(N, [D1|Ds])} \}.
\]

\[
\begin{align*}
\text{digits([D|R])} & \rightarrow \text{digit(D), digits(R).} \\
\text{digits(_)} & \rightarrow \text{letter(_), !, \{ exit(syntaxerror, 'Illegal number') \}.} \\
\text{digits([])} & \rightarrow \[].
\end{align*}
\]

\[
\begin{align*}
\text{digit(D, [D|R], R)} & : - \text{between(0’0, 0’9, D).} \\
\text{letter(D, [D|R], R)} & : - \text{between(0’a, 0’z, D).}
\end{align*}
\]

3.11 Grammar rule interface (phrase)

The predicates below may be called to activate a grammar-rule set:

\[
\text{phrase(+RuleSet, +InputList)}
\]

Equivalent to \text{phrase}(\text{RuleSet, InputList, []}). 

\[
\text{phrase(+RuleSet, +InputList, -Rest)}
\]

Activate the rule-set with given name. ‘InputList’ is the list of tokens to parse, ‘Rest’ is unified with the remaining tokens if the sentence is parsed correctly.
3.12 Database

SWI-Prolog offers three different database mechanisms. The first one is the common assert/retract mechanism for manipulating the clause database. As facts and clauses asserted using assert/1 or one of its derivatives become part of the program these predicates compile the term given to them. retract/1 and retractall/1 have to unify a term and therefore have to decompile the program. For these reasons the assert/retract mechanism is expensive. On the other hand, once compiled, queries to the database are faster than querying the recorded database discussed below. See also dynamic/1.

The second way of storing arbitrary terms in the database is using the “recorded database”. In this database terms are associated with a key. A key can be an atom, integer or term. In the last case only the functor and arity determine the key. Each key has a chain of terms associated with it. New terms can be added either at the head or at the tail of this chain. This mechanism is considerably faster than the assert/retract mechanism as terms are not compiled, but just copied into the heap.

The third mechanism is a special purpose one. It associates an integer or atom with a key, which is an atom, integer or term. Each key can only have one atom or integer associated with it. It again is considerably faster than the mechanisms described above, but can only be used to store simple status information like counters, etc.

**abolish(PredicateIndicator)**
Removes all clauses of a predicate with functor `Functor` and arity `Arity` from the database. Unlike version 1.2, 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. For ‘cleanup’ of the dynamic database, one should use `retractall/1` rather than `abolish/2`.

**abolish(+Name, +Arity)**
Same as `abolish(Name/Arity)`. The predicate `abolish/2` conforms to the Edinburgh standard, while `abolish/1` is ISO compliant.

**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 context is discouraged.

**retract(+Term)**
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.

**retractall(+Head)**
All facts or clauses in the database for which the head unifies with `Head` are removed.5

**assert(+Term)**
Assert a fact or clause in the database. `Term` is asserted as the last fact or clause of the corresponding predicate.

5Note that the definition has changed since version 2.0.6. See release notes.
3.12. DATABASE

asserta(+Term)
   Equivalent to assert/1, but Term is asserted as first clause or fact of the predicate.

assertz(+Term)
   Equivalent to assert/1.

assert(+Term, -Reference)
   Equivalent to assert/1, but Reference is unified with a unique reference to the asserted clause. This key can later be used with clause/3 or erase/1.

asserta(+Term, -Reference)
   Equivalent to assert/2, but Term is asserted as first clause or fact of the predicate.

assertz(+Term, -Reference)
   Equivalent to assert/2.

recorda(+Key, +Term, -Reference)
   Assert Term in the recorded database under key Key. Key is an integer, atom or term. Reference is unified with a unique reference to the record (see erase/1).

recorda(+Key, +Term)
   Equivalent to recorda(Key, Value, _).

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, Value, _).

recorded(+Key, -Value, -Reference)
   Unify Value with the first term recorded under Key which does unify. Reference is unified with the memory location of the record.

recorded(+Key, -Value)
   Equivalent to recorded(Key, Value, _).

erase(+Reference)
   Erase a record or clause from the database. Reference is an integer returned by recorda/3 or recorded/3, clause/3, assert/2, asserta/2 or assertz/2. Other integers might conflict with the internal consistency of the system. Erase can only be called once on a record or clause. A second call also might conflict with the internal consistency of the system.\(^6\)

flag(+Key, -Old, +New)
   Key is an atom, integer or term. Unify Old with the old value associated with Key. If the key is used for the first time Old is unified with the integer 0. Then store the value of New, which should be an integer, float, atom or arithmetic expression, under Key. flag/3 is a very fast mechanism for storing simple facts in the database. Example:

\(^6\)BUG: The system should have a special type for pointers, thus avoiding the Prolog user having to worry about consistency matters. Currently some simple heuristics are used to determine whether a reference is valid.
:- module_transparent succeeds_n_times/2.

succeeds_n_times(Goal, Times) :-
    flag(succeeds_n_times, Old, 0),
    Goal,
    flag(succeeds_n_times, N, N+1),
    fail ; flag(succeeds_n_times, Times, Old).

3.12.1 Indexing databases

By default, SWI-Prolog, as most other implementations, indexes predicates on their first argument.
SWI-Prolog allows indexing on other and multiple arguments using the declaration index/1.

For advanced database indexing, it defines hash_term/2:

hash_term(+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 succeeds
    immediately, leaving HashKey an unbound variable.

    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 as-
    sumed constant over different invocations of SWI-Prolog.

3.13 Declaring Properties of Predicates

This section describes directives which manipulate attributes of predicate definitions. The functors
dynamic/1, multifile/1 and discontiguous/1 are operators of priority 1150 (see op/3),
which implies the list of predicates they involve can just be a comma separated list:

:- dynamic
    foo/0,
    baz/2.

On SWI-Prolog all these directives are just predicates. This implies they can also be called by a pro-
gram. Do not rely on this feature if you want to maintain portability to other Prolog implementations.

dynamic +Functor+/Arity, ...
    Informs the interpreter that the definition of the predicate(s) may change during execution (us-
ing assert/1 and/or retract/1). Currently dynamic/1 only stops the interpreter from
complaining about undefined predicates (see unknown/2). Future releases might prohibit
assert/1 and retract/1 for not-dynamic declared procedures.

multifile +Functor+/Arity, ...
    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 +Functor/+Arity, ...
Informs the system that the clauses of the specified predicate(s) might not be together in the source file. See also style_check/1.

index(+Head)
Index the clauses of the predicate with the same name and arity as Head on the specified arguments. Head is a term of which all arguments are either ‘1’ (denoting ‘index this argument’) or ‘0’ (denoting ‘do not index this argument’). Indexing has no implications for the semantics of a predicate, only on its performance. If indexing is enabled on a predicate a special purpose algorithm is used to select candidate clauses based on the actual arguments of the goal. This algorithm checks whether indexed arguments might unify in the clause head. Only atoms, integers and functors (e.g. name and arity of a term) are considered. Indexing is very useful for predicates with many clauses representing facts.

Due to the representation technique used at most 4 arguments can be indexed. All indexed arguments should be in the first 32 arguments of the predicate. If more than 4 arguments are specified for indexing only the first 4 will be accepted. Arguments above 32 are ignored for indexing.

By default all predicates with $\langle\text{arity}\rangle \geq 1$ are indexed on their first argument. It is possible to redefine indexing on predicates that already have clauses attached to them. This will initiate a scan through the predicates clause list to update the index summary information stored with each clause.

If—for example—one wants to represents sub-types using a fact list ‘sub_type(Sub, Super)’ that should be used both to determine sub- and super types one should declare sub_type/2 as follows:

```prolog
:- index(sub_type(1, 1)).
sub_type(horse, animal).
...
```

### 3.14 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.

current_functor(?Name, ?Arity)
Successively unifies Name with the name and Arity with the arity of functors known to the system.

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(\?Name, \?Head)
Successively unifies \Name with the name of predicates currently defined and \Head with the most general term built from \Name and the arity of the predicate. This predicate succeeds for all predicates defined in the specified module, imported to it, or in one of the modules from which the predicate will be imported if it is called.

predicate_property(\?Head, \?Property)
Succeeds if \Head refers to a predicate that has property \Property. Can be used to test whether a predicate has a certain property, obtain all properties known for \Head, find all predicates having property or even obtaining all information available about the current program. \Property is one of:

interpreted
Is 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.

built_in
Is 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.

foreign
Is true if the predicate is defined in the C language.

dynamic
Is true if the predicate is declared dynamic using the \texttt{dynamic/1} declaration.

multifile
Is true if the predicate is declared multifile using the \texttt{multifile/1} declaration.

undefined
Is true if a procedure definition block for the predicate exists, but there are no clauses in it and it is not declared dynamic. 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 or the predicate had a definition in the past. See the library package \texttt{check} for example usage.

transparent
Is true if the predicate is declared transparent using the \texttt{module_transparent/1} declaration.

exported
Is 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 \texttt{Module}.

indexed(Head)
Predicate is indexed (see \texttt{index/1}) according to \Head. \Head is a term whose name and arity are identical to the predicate. The arguments are unified with ‘1’ for indexed arguments, ‘0’ otherwise.

file(FileName)
Unify \FileName with the name of the sourcefile in which the predicate is defined. See also \texttt{source_file/2}. 

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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.

number_of_clauses(ClauseCount)
    Unify ClauseCount to the number of clauses associated with the predicate. Fails for foreign predicates.

dwim_predicate(+Term, -Dwim)
    ‘Do What I Mean’ (‘dwim’) support predicate. Term is a term, which 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 style_check(+dollar) is active. Backtracking provides all alternative matches.

clause(?Head, ?Body)
    Succeeds when 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. Normally clause/2 is used to find clause definitions for a predicate, but it can also be used to find clause heads for some body template.

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.

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 indices and the references of all clauses of the predicate. The following example finds the 2nd clause of member/2:

    ?- nth_clause(member(_,_), 2, Ref), clause(Head, Body, Ref).

    Ref = 160088
    Head = system : member(G575, [G578|G579])
    Body = member(G575, G579)

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. Property is one of the following:

    file(FileName)
    Unify FileName with the name of the sourcefile in which the clause is defined. Fails if the clause is not associated to a file.
line_count(LineNumber)
    Unify LineNumber with the line number of the clause. Fails if the clause is not associated to a file.

fact
    True if the clause has no body.

erased
    True if the clause has been erased, but not yet reclaimed because it is referenced.

3.15 Input and Output

SWI-Prolog provides two different packages for input and output. One confirms to the Edinburgh standard. This package has a notion of ‘current-input’ and ‘current-output’. The reading and writing predicates implicitly refer to these streams. In the second package, streams are opened explicitly and the resulting handle is used as an argument to the reading and writing predicate to specify the source or destination. Both packages are fully integrated; the user may switch freely between them.

3.15.1 Input and Output Using Implicit Source and Destination

The package for implicit input and output destination is upwards compatible to DEC-10 and C-Prolog. The reading and writing predicates refer resp. the current input- and output stream. 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 streams current value can be obtained using telling/1 for output- and seeing/1 for input streams. The table below shows the valid stream specifications. The reserved names user_input, user_output and user_error are for neat integration with the explicit streams.

<table>
<thead>
<tr>
<th>Source/destination</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>user input</td>
<td>Input from the terminal</td>
</tr>
<tr>
<td>user output</td>
<td>Output to the terminal</td>
</tr>
<tr>
<td>user_error</td>
<td>Unix error stream (output only)</td>
</tr>
<tr>
<td>(Atom)</td>
<td>Name of a Unix file</td>
</tr>
<tr>
<td>pipe((Atom))</td>
<td>Name of a Unix command</td>
</tr>
</tbody>
</table>

Source and destination are either a file, one of the reserved words above, or a term ‘pipe(Command)’. In the predicate descriptions below we will call the source/destination argument ‘SrcDest’. Below are some examples of source/destination specifications.

?- see(data).           % Start reading from file ‘data’.
?- tell(stderr).        % Start writing on the error stream.
?- 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.

getwd(Wd) :-
    seeing(Old), see(pipe(pwd)),
    collect_wd(String),

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3.15. INPUT AND OUTPUT

seen, see(Old),
atom_chars(Wd, String).

collect_wd([C|R]) :-
  get0(C), C \== -1, !,
  collect_wd(R).
collect_wd([]).

\textbf{see(+SrcDest)}

Make \textit{SrcDest} the current input stream. If \textit{SrcDest} was already opened for reading with \texttt{see/1} and has not been closed since, reading will be resumed. Otherwise \textit{SrcDest} will be opened and the file pointer is positioned at the start of the file.

\textbf{tell(+SrcDest)}

Make \textit{SrcDest} the current output stream. If \textit{SrcDest} was already opened for writing with \texttt{tell/1} or \texttt{append/1} and has not been closed since, writing will be resumed. Otherwise the file is created or—when existing—truncated. See also \texttt{append/1}.

\textbf{append(+File)}

Similar to \texttt{tell/1}, but positions the file pointer at the end of \textit{File} rather than truncating an existing file. The pipe construct is not accepted by this predicate.

\textbf{seeing(?SrcDest)}

Unify the name of the current input stream with \textit{SrcDest}.

\textbf{telling(?SrcDest)}

Unify the name of the current output stream with \textit{SrcDest}.

\textbf{seen}

Close the current input stream. The new input stream becomes \texttt{user}.

\textbf{told}

Close the current output stream. The new output stream becomes \texttt{user}.

3.15.2 Explicit Input and Output Streams

The predicates below are part of the Quintus compatible stream-based I/O package. In this package streams are explicitly created using the predicate \texttt{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.

\textbf{open(+SrcDest, +Mode, -Stream, +Options)}

ISO compliant predicate to open a stream. \textit{SrcDes} is either an atom, specifying a Unix file, or a term \texttt{`pipe(Command)'}, just like \texttt{see/1} and \texttt{tell/1}. \textit{Mode} is one of \texttt{read}, \texttt{write}, \texttt{append} or \texttt{update}. \texttt{Mode append} opens the file for writing, positioning the file-pointer at the end. \texttt{Mode update} opens the file for writing, positioning the file-pointer at the beginning of the file without truncating the file. See also \texttt{stream_position/3}. \textit{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. The \textit{Options} list can contain the following options:
type(\texttt{Type})
Using \texttt{type text} (default), Prolog will write a text-file in an operating-system compatible way. Using \texttt{type binary} the bytes will be read or written without any translation. Note there is no difference between the two on Unix systems.

\texttt{alias(Atom)}
Gives the stream a name. The following two calls are identical, but only the latter is allowed in ISO Prolog.

\begin{verbatim}
?- open(foo, read, in, []).
?- open(foo, read, S, [alias(in)]).
\end{verbatim}

eof\_action\texttt{(Action)}
Defines what happens if the end of the input stream is reached. Action \texttt{eof\_code} makes \texttt{get0/1} and friends return -1 and \texttt{read/1} and friends return the atom \texttt{end\_of\_file}. Repetitive reading keeps yielding the same result. Action \texttt{error} is like \texttt{eof\_code}, but repetitive reading will raise an error. With action \texttt{reset}, Prolog will examine the file again and return more data if the file has grown.

\texttt{buffer(Buffering)}
Defines output buffering. The atom \texttt{fullf} (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/0} and \texttt{flush\_output/1}. This option is not an ISO option.

close\_on\_abort\texttt{(Bool)}
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, it will be flushed however. Useful for logfiles and if the stream is associated to a process (using the \texttt{pipe/1} construct).

The option \texttt{reposition} is not supported in SWI-Prolog. All streams connected to a file may be repositioned.

\texttt{open(+SrcDest, +Mode, ?Stream)}
Equivalent to \texttt{open/4} with an empty option-list.

\texttt{open\_null\_stream(?Stream)}
Open a stream that produces no output. All counting functions are enabled on such a stream. An attempt to read from a null-stream will immediately signal end-of-file. Similar to Unix \texttt{/dev/null}. \texttt{Stream} can be an atom, giving the null-stream an alias name.

\texttt{close(+Stream)}
Close the specified stream. If \texttt{Stream} is not open an error message is displayed. If the closed stream is the current input or output stream the terminal is made the current input or output.

\texttt{current\_stream(?File, ?Mode, ?Stream)}
Is true if a stream with file specification \texttt{File}, mode \texttt{Mode} and stream identifier \texttt{Stream} is open. The reserved streams \texttt{user} and \texttt{user\_error} are not generated by this predicate. If a stream has been opened with mode \texttt{append} this predicate will generate mode \texttt{write}.
stream_position(+Stream, -Old, +New)
    Unify the position parameters of Stream with Old and set them to New. A position is represented
    by the following term:

    `$stream_position` (CharNo, LineNo, LinePos).

    It is only possible to change the position parameters if the stream is connected to a disk file. If
    the position is changed, the CharNo field determines the new position in the file. The LineNo
    and LinePos are copied in the stream administration. See also seek/4.

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.

    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 repostioned, a reposition error is raised. The predicate seek/4 is
    compatible to Quintus Prolog, though the error conditions and signalling is ISO compliant. See
    also stream_position/3.

3.15.3 Switching Between Implicit and Explicit I/O

    The predicates below can be used for switching between the implicit- and the explicit stream based
    I/O predicates.

set_input(+Stream)
    Set the current input stream to become Stream. Thus, open(file, read, Stream), set_input(Stream)
    is equivalent to see(file).

set_output(+Stream)
    Set the current output stream to become Stream.

current_input(-Stream)
    Get the current input stream. Useful to get access to the status predicates associated with
    streams.

current_output(-Stream)
    Get the current output stream.

dup_stream(+From, +To)
    Duplicate the underlying data from stream From to streamTo, so actions performed on either
    stream have the same effect. The primary goal of this predicate is to facilitate redirection of the
    user interaction to allow for ‘interactor’ windows. For example, the following code will redirect
    output to user_output and user_error to an XPCE text window:

    ..., pce_open(Window, append, Fd), dup_stream(user_output, Fd), dup_stream(user_error, Fd), ...

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The old status of a stream can be stored by duplicating to a null-stream as obtained using\nopen null stream/1.
This predicate is SWI-Prolog specific.

3.16 Status of Input and Output Streams

wait_for_input(+ListOfStreams, -ReadyList, +TimeOut)
Wait for input on one of the streams in ListOfStreams and return a list of streams on which input\nis available in ReadyList. wait_for_input/3 waits for at most TimeOut seconds. Timeout\nmay be specified as a floating point number to specify fractions of a second. If Timeout equals\n0, wait_for_input/3 waits indefinitely. This predicate can be used to implement timeout\nwhile reading and to handle input from multiple sources. The following example will wait for\ninput from the user and an explicitly opened second terminal. On return, Inputs may hold user\nor P4 or both.

?- open(’/dev/ttyp4’, read, P4),\n   wait_for_input([user, P4], Inputs, 0).

character count(+Stream, -Count)
Unify Count with the current character index. For input streams this is the number of characters\nread since the open, for output streams this is the number of characters written. Counting starts\nat 0.

line count(+Stream, -Count)
Unify Count with the number of lines read or written. Counting starts at 1.

line position(+Stream, -Count)
Unify Count with the position on the current line. Note that this assumes the position is 0 after\nthe open. Tabs are assumed to be defined on each 8-th character and backspaces are assumed to\nreduce the count by one, provided it is positive.

fileerrors(-Old, +New)
Define error behaviour on errors when opening a file for reading or writing. Valid values are the\natoms on (default) and off. First Old is unified with the current value. Then the new value is\nset to New.

3.17 Primitive Character Input and Output

nl
Write a newline character to the current output stream. On Unix systems \nl/0 is equivalent to\nput (10).

nl(+Stream)
Write a newline to Stream.

\(^7\)Note that Edinburgh Prolog defines fileerrors/0 and nofileerrors/0. As this does not allow you to switch\nback to the old mode I think this definition is better.
### 3.17. PRIMITIVE CHARACTER INPUT AND OUTPUT

<table>
<thead>
<tr>
<th>Predicate</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>put(+Char)</strong></td>
<td>Write ☑️ to the current output stream. ☑️ is either an integer-expression evaluating to an ASCII value (0 ≤ ☑️ ≤ 255) or an atom of one character.</td>
</tr>
<tr>
<td><strong>put(+Stream, +Char)</strong></td>
<td>Write ☑️ to Stream.</td>
</tr>
<tr>
<td><strong>tab(+Amount)</strong></td>
<td>Writes Amount spaces on the current output stream. Amount should be an expression that evaluates to a positive integer (see section 3.23).</td>
</tr>
<tr>
<td><strong>tab(+Stream, +Amount)</strong></td>
<td>Writes Amount spaces to Stream.</td>
</tr>
<tr>
<td><strong>flush</strong></td>
<td>Flush pending output on current output stream. flush/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.</td>
</tr>
<tr>
<td><strong>flush_output(+Stream)</strong></td>
<td>Flush output on the specified stream. The stream must be open for writing.</td>
</tr>
<tr>
<td><strong>ttyflush</strong></td>
<td>Flush pending output on stream user. See also flush/0.</td>
</tr>
<tr>
<td><strong>get0(-Char)</strong></td>
<td>Read the current input stream and unify the next character with ☑️. ☑️ is unified with -1 on end of file.</td>
</tr>
<tr>
<td><strong>get0(+Stream, -Char)</strong></td>
<td>Read the next character from Stream.</td>
</tr>
<tr>
<td><strong>get(-Char)</strong></td>
<td>Read the current input stream and unify the next non-blank character with ☑️. ☑️ is unified with -1 on end of file.</td>
</tr>
<tr>
<td><strong>get(+Stream, -Char)</strong></td>
<td>Read the next non-blank character from Stream.</td>
</tr>
<tr>
<td><strong>peek_byte(-Char)</strong></td>
<td>Reads the next input character like get0/1, but does not remove it from the input stream. This predicate is ISO compliant.</td>
</tr>
<tr>
<td><strong>peek_byte(+Stream, -Char)</strong></td>
<td>Reads the next input character like get0/2, but does not remove it from the stream. This predicate is ISO compliant.</td>
</tr>
<tr>
<td><strong>skip(+Char)</strong></td>
<td>Read the input until ☑️ or the end of the file is encountered. A subsequent call to get0/1 will read the first character after ☑️.</td>
</tr>
</tbody>
</table>
skip(+Stream, +Char)
Skip input (as skip/1) on Stream.

get_single_char(-Char)
Get a single character from input stream ‘user’ (regardless of the current input stream). Unlike get0/1 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 –tty option this predicate reads an entire line of input and returns the first non-blank character on this line, or the ASCII code of the newline (10) if the entire line consisted of blank characters.

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.

3.18 Term Reading and Writing

This section describes the basic term reading and writing predicates. The predicates term_to_atom/2 and atom_to_term/3 provide means for translating atoms and strings to terms. The predicates format/[1,2] and writef/2 provide formatted output.

There are two ways to manipulate the output format. The predicate print/[1,2] may be programmed using portray/1. The format of floating point numbers may be manipulated using the feature (see feature/2) float_format.

Reading is sensitive to the feature character_escapes, which controls the interpretation of the \ character in quoted atoms and strings.

write_term(+Term, +Options)
The predicate write_term/2 is the generic form of all Prolog term-write predicates. Valid options are:

quoted(true or false)
If true, atoms and functors that needs quotes will be quoted. The default is false.

ignore.ops(true or false)
If true, the generic term-representation ((functor)(args) ...) will be used for all terms, Otherwise (default), operators, list-notation and {}/1 will be written using their special syntax.

numbervars(true or false)
If true, terms of the format $VAR(N), where ⟨N⟩ is a positive integer, will be written as a variable name. The default is false.

portray(true or false)
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.
write_term(+Stream, +Term, +Options)
    As write_term/2, but output is sent to Stream rather than the current output.

write_canonical(+Term)
    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 and quoted.

write_canonical(+Stream, +Term)
    Write Term in canonical form on Stream.

write(+Term)
    Write Term to the current output, using brackets and operators where appropriate. See feature/2 for controlling floating point output format.

write(+Stream, +Term)
    Write Term to Stream.

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.

print(+Term)
    Prints Term on the current output stream similar to write/1, but for each (sub)term of Term first the dynamic predicate portray/1 is called. If this predicate succeeds print assumes the (sub)term has been written. This allows for user defined term writing.

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 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 a syntax error read/1 displays an error message, attempts to skip the erroneous term and fails. On reaching end-of-file Term is unified with the atom end_of_file.

read(+Stream, -Term)
    Read Term from Stream.
**read_clause(-Term)**

Equivalent to `read/1`, but warns the user for variables only occurring once in a term (singleton variables) which do not start with an underscore if `style_check(singleton)` is active (default). Used to read Prolog source files (see `consult/1`). New code should use `read_term/2` with the option `singletons(warning)`.

**read_clause(+Stream, -Term)**

Read a clause from `Stream`. See `read_clause/1`.

**read_variables(-Term, -Bindings)**

Similar to `read/1`, but `Bindings` is unified with a list of `Name = Var` tuples, thus providing access to the actual variable names. New code should use `read_term/2` using the option `variables(X)`.

**read_variables(+Stream, -Term, -Bindings)**

Read, returning term and bindings from `Stream`. See `read_variables/2`.

**read_term(-Term, +Options)**

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 to Quintus Prolog. The argument order is according to the ISO standard. Options:

- `syntax_errors(atom or variable)`
  Define the behaviour for when a syntax error occurs. The possible values are:
  - `fail`
  - `quiet`
  - `Variable`
  - `variable_names(Vars)`
  - `singleton(Vars)`
  - `term_position(Pos)`
  - `subterm_positions(TermPos)`

  These options are used to control the behaviour of syntax errors, variable names, singletons, term positions, and subterm positions.

  **Syntax Errors**
  - `fail`
  - `quiet`
  - `Variable`

  **Variable Names**
  - `variable_names(Vars)`

  **Singletons**
  - `singleton(Vars)`

  **Term Position**
  - `term_position(Pos)`

  **Subterm Positions**
  - `subterm_positions(TermPos)`

  These options provide additional control over the reading process, allowing for more flexible and customizable input handling.
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 \{ \ldots \}, 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 \( \mid (TailTerm) \), 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.

**read_term** (+Stream, -Term, +Options)
Read term with options from Stream. See **read_term/2**.

**read_history** (+Show, +Help, +Special, +Prompt, -Term, -Bindings)
Similar to **read_variables/2**, but allows for history substitutions. read_history/6 is used by the top level to read the user’s actions. Show is the command the user should type to show the saved events. Help is the command to get an overview of the capabilities. Special is a list of commands that are not saved in the history. Prompt is the first prompt given. Continuation prompts for more lines are determined by prompt/2. A \%w in the prompt is substituted by the event number. See section 2.7 for available substitutions.

SWI-Prolog calls read_history/6 as follows:

```prolog
read_history(h, ’!h’, [trace], ’%w ?- ’, Goal, Bindings)
```

**prompt** (-Old, +New)
Set prompt associated with read/1 and its derivatives. Old is first unified with the current prompt. On success the prompt will be set to New if this is an atom. Otherwise an error message is displayed. A prompt is printed if one of the read predicates is called and the cursor is at the left margin. It is also printed whenever a newline is given and the term has not been terminated. Prompts are only printed when the current input stream is user.

**prompt1** (+Prompt)
Sets the prompt for the next line to be read. Continuation lines will be read using the prompt defined by prompt/2.

### 3.19 Analysing and Constructing Terms

**functor** (?Term, ?Functor, ?Arity)
Succeeds if Term is a term with functor Functor and arity Arity. If Term is a variable it is unified
with a new term holding only variables. functor/3 silently fails on instantiation faults\textsuperscript{8} If 
Term is an atom or number, Functor will be unified with Term and arity will be unified with the integer 0 (zero).

arg(?Arg, ?Term, ?Value)
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.\textsuperscript{9} The predicate arg/3 fails silently if Arg = 0 or Arg > arity and raises the exception domain_error(not_less_then_zero, Arg) if Arg < 0.

setarg(+Arg, +Term, +Value)
Extra-logical predicate. Assigns the Arg-th argument of the compound term Term with the given Value. The assignment is undone if backtracking brings the state back into a position before the setarg/3 call.

This predicate may be used for destructive assignment to terms, using them as extra-logical storage bin.

?Term =.. ?List
List is a list which head is the functor of Term and the remaining arguments are the arguments of the term. Each of the arguments may be a variable, but not both. This predicate is called ‘Univ’. Examples:

?- foo(hello, X) =.. List.
List = [foo, hello, X]

?- Term =.. [baz, foo(1)]
Term = baz(foo(1))

numbervars(+Term, +Functor, +Start, -End)
Unify the free variables of Term with a term constructed from the atom Functor with one argument. The argument is the number of the variable. Counting starts at Start. End is unified with the number that should be given to the next variable. Example:

?- numbervars(foo(A, B, A), this_is_a_variable, 0, End).
A = this_is_a_variable(0)
B = this_is_a_variable(1)
End = 2

In Edinburgh Prolog the second argument is missing. It is fixed to be $VAR.$

\textsuperscript{8}In version 1.2 instantiation faults led to error messages. The new version can be used to do type testing without the need to catch illegal instantiations first.

\textsuperscript{9}The instantiation pattern (-, +, ?) is an extension to ‘standard’ Prolog.
3.20. ANALYSING AND CONSTRUCTING ATOMS

free_variables(+Term, -List)
    Unify List with a list of variables, each sharing with a unique variable of Term. For example:

    ?- free_variables(a(X, b(Y, X), Z), L).
    L = [G367, G366, G371]
    X = G367
    Y = G366
    Z = G371

copy_term(+In, -Out)
    Make a copy of term In and unify the result with Out. Ground parts of In are shared by Out. Provided In and Out have no sharing variables before this call they will have no sharing variables afterwards. copy_term/2 is semantically equivalent to:

    copy_term(In, Out) :-
        recorda(copy_key, In, Ref),
        recorded(copy_key, Out, Ref),
        erase(Ref).

3.20 Analysing and Constructing Atoms

These predicates convert between Prolog constants and lists of ASCII values. The predicates atom_chars/2, number_chars/2 and name/2 behave the same when converting from a constant to a list of ASCII values. When converting the other way around, atom_chars/2 will generate an atom, number_chars will generate a number or fail and name/2 will return a number if possible and an atom otherwise.

atom_chars(?Atom, ?String)
    Convert between an atom and a list of ASCII values. If Atom is instantiated, if will be translated into a list of ASCII values and the result is unified with String. If Atom is unbound and String is a list of ASCII values, it will Atom will be unified with an atom constructed from this list.

atom_char(?Atom, ?ASCII)
    Convert between character and ASCII value for a single character.

number_chars(?Number, ?String)
    Similar to atom_chars/2, but converts between a number and its representation as a list of ASCII values. Fails silently if Number is unbound and String does not describe a number.

name(?AtomOrInt, ?String)
    String is a list of ASCII values describing Atom. Each of the arguments may be a variable, but not both. When String is bound to an ASCII value list describing an integer and Atom is a variable Atom will be unified with the integer value described by String (e.g. 'name(N, "300"), 400 is N + 100' succeeds).
\textbf{int\_to\_atom(+Int, +Base, -Atom)}

Convert \textit{Int} to an ASCII representation using base \textit{Base} and unify the result with \textit{Atom}. If \textit{Base} \neq 10 the base will be prepended to \textit{Atom}. \textit{Base} = 0 will try to interpret \textit{Int} as an ASCII value and return 0\textasciitilde(c). Otherwise $2 \leq \textit{Base} \leq 36$. Some examples are given below.

\begin{align*}
\text{int\_to\_atom}(45, 2, A) & \quad \Rightarrow \quad A = 2\text{'}101101 \\
\text{int\_to\_atom}(97, 0, A) & \quad \Rightarrow \quad A = 0\text{'}A \\
\text{int\_to\_atom}(56, 10, A) & \quad \Rightarrow \quad A = 56
\end{align*}

\textbf{int\_to\_atom(+Int, -Atom)}

Equivalent to \texttt{int\_to\_atom(Int, 10, Atom)}.

\textbf{term\_to\_atom(?Term, ?Atom)}

Succeeds if \textit{Atom} describes a term that unifies with \textit{Term}. When \textit{Atom} is instantiated \textit{Atom} is converted and then unified with \textit{Term}. Otherwise \textit{Term} is “written” on \textit{Atom} using write/1.

\textbf{atom\_to\_term(+Atom, -Term, -Bindings)}

Use \textit{Atom} as input to read\_variables/2 and return the read term in \textit{Term} and the variable bindings in \textit{Bindings}. \textit{Bindings} is a list of \texttt{Name = Var} couples, thus providing access to the actual variable names. See also read\_variables/2.

\textbf{concat(?Atom1, ?Atom2, ?Atom3)}

\textit{Atom3} forms the concatenation of \textit{Atom1} and \textit{Atom2}. At least two of the arguments must be instantiated to atoms, integers or floating point numbers.

\textbf{concat\_atom(+List, -Atom)}

\textit{List} is a list of atoms, integers or floating point numbers. Succeeds if \textit{Atom} can be unified with the concatenated elements of \textit{List}. If \textit{List} has exactly 2 elements it is equivalent to \texttt{concat/3}, allowing for variables in the list.

\textbf{concat\_atom(+List, +Separator, -Atom)}

Creates an atom just like \texttt{concat\_atom/2}, but inserts \texttt{Separator} between each pair of atoms. For example:

\begin{verbatim}
?- concat\_atom([gnu, gnat], ', ', A).
A = 'gnu, gnat'
\end{verbatim}

\textbf{atom\_length(+Atom, -Length)}

Succeeds if \textit{Atom} is an atom of \textit{Length} characters long. This predicate also works for integers and floats, expressing the number of characters output when given to write/1.

\textbf{atom\_prefix(+Atom, +Prefix)}

Succeeds if \textit{Atom} starts with the characters from \textit{Prefix}. Its behaviour is equivalent to \texttt{?- concate\_atom\_atom(Prefix, _, Atom)}, but avoids the construction of an atom for the ‘remainder’.
3.21 Representing Text in Strings

SWI-Prolog supports the data type string. Strings are a time and space efficient mechanism to handle text in Prolog. Atoms are under some circumstances not suitable because garbage collection on them is next to impossible (Although it is possible: BIM_prolog does it). Representing text as a list of ASCII values is, from the logical point of view, the cleanest solution. It however has two drawbacks: 1) they cannot be distinguished from a list of (small) integers; and 2) they consume (in SWI-Prolog) 12 bytes for each character stored.

Within strings each character only requires 1 byte storage. Strings live on the global stack and their storage is thus reclaimed on backtracking. Garbage collection can easily deal with strings.

The ISO standard proposes " ... " is transformed into a string object by read/1 and derivatives. This poses problems as in the old convention " ... " is transformed into a list of ASCII characters. For this reason the style check option 'string' is available (see style_check/1).

The set of predicates associated with strings is incomplete and tentative. Names and definitions might change in the future to confirm to the emerging standard.

**string_to_atom(?String, ?Atom)**
Logical conversion between a string and an atom. At least one of the two arguments must be instantiated. Atom can also be an integer or floating point number.

**string_to_list(?String, ?List)**
Logical conversion between a string and a list of ASCII characters. At least one of the two arguments must be instantiated.

**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 atoms, integers and floats as its first argument.

**string_concat(?String1, ?String2, ?String3)**
Similar to 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.

**substring(+String, +Start, +Length, -Sub)**
Create a substring of String that starts at character Start (1 base) and has Length characters. Unify this substring with Sub.\(^\text{10}\)

3.22 Operators

**op(+Precedence, +Type, +Name)**
Declare Name to be an operator of type Type with precedence Precedence. Name can also be a list of names, in which case all elements of the list are declared to be identical operators. Precedence is an integer between 0 and 1200. Precedence 0 removes the declaration. Type is\(^\text{10}\)

\(^{10}\)Future versions probably will provide a more logical variant of this predicate.
one of: xf, yf, xfx, xfy, yfx, yfy, 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 brackets (...) has precedence 0.

The predefined operators are shown in table 3.1. Note that all operators can be redefined by the user.

\[
\text{current.op}(\text{?Precedence, ?Type, ?Name})
\]

Succeeds when Name is currently defined as an operator of type Type with precedence Prece- dence. See also \text{op}/3.

### 3.23 Arithmetic

Arithmetic can be divided into some special purpose integer predicates and a series of general pre- dicates for floating point and integer arithmetic as appropriate. The integer predicates are as “logical” as possible. Their usage is recommended whenever applicable, resulting in faster and more “logical” programs.

The general arithmetic predicates are optionally compiled now (see \text{set.feature}/2 and the \text{–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.

The general arithmetic predicates all handle \textit{expressions}. An expression is either a simple number or a \textit{function}. The arguments of a function are expressions. The functions are described in section 3.24.
between(+Low, +High, ?Value)

Low and High are integers, High ≥ Low. If Value is an integer, Low ≤ Value ≤ High. When Value is a variable it is successively bound to all integers between Low and High.

succ(?Int1, ?Int2)
Succeeds if Int2 = Int1 + 1. At least one of the arguments must be instantiated to an integer.

plus(?Int1, ?Int2, ?Int3)
Succeeds if Int3 = Int1 + Int2. At least two of the three arguments must be instantiated to integers.

+Expr1 > +Expr2
Succeeds when expression Expr1 evaluates to a larger number than Expr2.

+Expr1 < +Expr2
Succeeds when expression Expr1 evaluates to a smaller number than Expr2.

+Expr1 =< +Expr2
Succeeds when expression Expr1 evaluates to a smaller or equal number to Expr2.

+Expr1 >= +Expr2
Succeeds when expression Expr1 evaluates to a larger or equal number to Expr2.

+Expr1 =\= +Expr2
Succeeds when expression Expr1 evaluates to a number non-equal to Expr2.

+Expr1 =:= +Expr2
Succeeds when expression Expr1 evaluates to a number equal to Expr2.

-Number is +Expr
Succeeds when Number has successfully been unified with the number Expr evaluates to. If Expr evaluates to a float that can be represented using an integer (i.e. the value is integer and within the range that can be described by Prolog’s integer representation), Expr is unified with the integer value.

Note that normally, is/2 will be used with unbound left operand. If equality is to be tested, =:=/2 should be used. For example:

?- 1.0 is sin(pi/2).  \(\text{Fails!}\)  sin(pi/2) evaluates to 1.0, but is/2 will represent this as the integer 1, after which unify will fail.

?- 1.0 is float(sin(pi/2)).  \(\text{Succeeds}\)  as the float/1 function forces the result to be float.

?- 1.0 =:= sin(pi/2).  \(\text{Succeeds as expected}\).

3.24 Arithmetic Functions

Arithmetic functions are terms which are evaluated by the arithmetic predicates described above. SWI-Prolog tries to hide the difference between integer arithmetic and floating point arithmetic from the Prolog user. Arithmetic is done as integer arithmetic as long as possible and converted to floating
point arithmetic whenever one of the arguments or the combination of them requires it. If a function returns a floating point value which is whole it is automatically transformed into an integer. There are three types of arguments to functions:

\[ \begin{align*}
Expr & \quad \text{Arbitrary expression, returning either a floating point value or an integer.} \\
IntExpr & \quad \text{Arbitrary expression that should evaluate into an integer.} \\
Int & \quad \text{An integer.}
\end{align*} \]

In case integer addition, subtraction and multiplication would lead to an integer overflow the operands are automatically converted to floating point numbers. The floating point functions (\texttt{sin/1}, \texttt{exp/1}, etc.) form a direct interface to the corresponding C library functions used to compile SWI-Prolog. Please refer to the C library documentation for details on precision, error handling, etc.

\[ \begin{align*}
\text{- } +Expr & \quad \text{Result} = -Expr \\
+Expr1 * +Expr2 & \quad \text{Result} = Expr1 + Expr2 \\
+Expr1 - +Expr2 & \quad \text{Result} = Expr1 - Expr2 \\
+Expr1 * +Expr2 & \quad \text{Result} = Expr1 \times Expr2 \\
+Expr1 / +Expr2 & \quad \text{Result} = \frac{Expr1}{Expr2} \\
+IntExpr1 \text{ mod } +IntExpr2 & \quad \text{Modulo: Result} = IntExpr1 - (IntExpr1 // IntExpr2) \times IntExpr2 \quad \text{The function } \texttt{mod/2} \text{ is implemented using the C } \% \text{ operator. Its behaviour with negative values is illustrated in the table below.} \\
2 & = 17 \mod 5 \\
-2 & = -17 \mod 5 \\
-2 & = -17 \mod 5 \\
+IntExpr1 \text{ rem } +IntExpr2 & \quad \text{Remainder of division: Result} = \text{float\_fractional\_part(IntExpr1//IntExpr2)} \\
+IntExpr1 // +IntExpr2 & \quad \text{Integer division: Result} = \text{truncate(Expr1/Expr2)} \\
\text{abs}(+Expr) & \quad \text{Evaluate Expr and return the absolute value of it.} \\
\text{sign}(+Expr) & \quad \text{Evaluate to -1 if } Expr < 0, 1 \text{ if } Expr > 0 \text{ and 0 if } Expr = 0.
\end{align*} \]
max(+Expr1, +Expr2)
   Evaluates to the largest of both Expr1 and Expr2.

min(+Expr1, +Expr2)
   Evaluates to the smallest of both Expr1 and Expr2.

.(+Int, [])
   A list of one element evaluates to the element. This implies "a" evaluates to the ASCII
   value of the letter ‘a’ (97). This option is available for compatibility only. It will not work
   if ‘style_check(+string)’ is active as "a" will then be transformed into a string object.
   The recommended way to specify the ASCII value of the letter ‘a’ is 0'a.

random(+Int)
   Evaluates to a random integer $i$ for which $0 \leq i < Int$. The seed of this random generator is
determined by the system clock when SWI-Prolog was started.

round(+Expr)
   Evaluates Expr and rounds the result to the nearest integer.

integer(+Expr)
   Same as round/1 (backward compatibility).

float(+Expr)
   Translate the result to a floating point number. Normally, Prolog will use integers whenever
   possible. When used around the 2nd argument of is/2, the result will be returned as a floating
   point number. In other contexts, the operation has no effect.

float_fractional_part(+Expr)
   Fractional part of a floating-point number. Negative if Expr is negative, 0 if Expr is integer.

float_integer_part(+Expr)
   Integer part of floating-point number. Negative if Expr is negative, Expr if Expr is integer.

truncate(+Expr)
   Truncate Expr to an integer. Same as float_integer_part/1.

floor(+Expr)
   Evaluates Expr and returns the largest integer smaller or equal to the result of the evaluation.

ceiling(+Expr)
   Evaluates Expr and returns the smallest integer larger or equal to the result of the evaluation.

ceil(+Expr)
   Same as ceiling/1 (backward compatibility).

+IntExpr >> +IntExpr
   Bitwise shift IntExpr1 by IntExpr2 bits to the right.

+IntExpr << +IntExpr
   Bitwise shift IntExpr1 by IntExpr2 bits to the left.

+IntExpr \ / +IntExpr
   Bitwise ‘or’ IntExpr1 and IntExpr2.
+IntExpr /\ +IntExpr
    Bitwise ‘and’ IntExpr1 and IntExpr2.

+IntExpr xor +IntExpr
    Bitwise ‘exclusive or’ IntExpr1 and IntExpr2.

\ +IntExpr
    Bitwise negation.

sqrt(+Expr)
    Result = \sqrt{Expr}

sin(+Expr)
    Result = \sin(Expr). Expr is the angle in radians.

cos(+Expr)
    Result = \cos(Expr). Expr is the angle in radians.

tan(+Expr)
    Result = \tan(Expr). Expr is the angle in radians.

asin(+Expr)
    Result = \arcsin(Expr). Result is the angle in radians.

acos(+Expr)
    Result = \arccos(Expr). Result is the angle in radians.

atan(+Expr)
    Result = \arctan(Expr). Result is the angle in radians.

atan(+YExpr, +XExpr)
    Result = \arctan \frac{YExpr}{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.

log(+Expr)
    Result = \ln(Expr)

log10(+Expr)
    Result = \log_{10}(Expr)

e^x
    Result = e^x

+Expr1 ** +Expr2
    Result = +Expr1^+Expr2

+Expr1 ^ +Expr2
    Same as **/2. (backward compatibility).

\pi
    Evaluates to the mathematical constant \pi (3.141593).
### 3.25 Adding Arithmetic Functions

Prolog predicates can be given the role of arithmetic function. The last argument is used to return the result, the arguments before the last are the inputs. Arithmetic functions are added using the predicate `arithmetic_function/1`, which takes the head as its argument. Arithmetic functions are module sensitive, that is they are only visible from the module in which the function is defined and declared. Global arithmetic functions should be defined and registered from module `user`. Global definitions can be overruled locally in modules. The built-in functions described above can be redefined as well.

**arithmetic_function(+Head)**

Register a Prolog predicate as an arithmetic function (see `is/2`, `=/2`, etc.). The Prolog predicate should have one more argument than specified by `Head`, which it either a term `Name/Arity`, an atom or a complex term. This last argument is an unbound variable at call time and should be instantiated to an integer or floating point number. The other arguments are the parameters. This predicate is module sensitive and will declare the arithmetic function only for the context module, unless declared from module `user`. Example:

```
1 ?- [user].
    :- arithmetic_function(mean/2).

mean(A, B, C) :-
    C is (A+B)/2.

user compiled, 0.07 sec, 440 bytes.

Yes
2 ?- A is mean(4, 5).

A = 4.500000
```

**current_arithmetic_function(?Head)**

Successively unifies all arithmetic functions that are visible from the context module with `Head`.

### 3.26 List Manipulation

**is_list(+Term)**

Succeeds if `Term` is bound to the empty list `([], )` or a term with functor `.` and arity 2.
proper_list(+Term)
   Equivalent to is_list/1, but also requires the tail of the list to be a list (recursively). Examples:

   is_list([x|A]) % true
   proper_list([x|A]) % false

append(?List1, ?List2, ?List3)
   Succeeds when List3 unifies with the concatenation of List1 and List2. The predicate can be
   used with any instantiation pattern (even three variables).

member(?Elem, +List)
   Succeeds when Elem can be unified with one of the members of List. The predicate can be used
   with any instantiation pattern.

memberchk(?Elem, +List)
   Equivalent to member/2, but leaves no choice point.

delete(+List1, ?Elem, ?List2)
   Delete all members of List1 that simultaneously unify with Elem and unify the result with List2.

select(?List1, ?Elem, ?List2)
   Select an element of List1 that unifies with Elem. List2 is unified with the list remaining from
   List1 after deleting the selected element. Normally used with the instantiation pattern +List1,
   -Elem, -List2, but can also be used to insert an element in a list using -List1, +Elem, +List2.

nth0(?Index, ?List, ?Elem)
   Succeeds when the Index-th element of List unifies with Elem. Counting starts at 0.

nth1(?Index, ?List, ?Elem)
   Succeeds when the Index-th element of List unifies with Elem. Counting starts at 1.

last(?Elem, ?List)
   Succeeds if Elem unifies with the last element of List. If List is a proper list last/2 is deter-
   ministic. If List has an unbound tail, backtracking will cause List to grow.

reverse(+List1, -List2)
   Reverse the order of the elements in List1 and unify the result with the elements of List2.

flatten(+List1, -List2)
   Transform List1, possibly holding lists as elements into a ‘flat’ list by replacing each list with
   its elements (recursively). Unify the resulting flat list with List2. Example:

   ?- flatten([a, [b, [c, d], e]], X).
   X = [a, b, c, d, e]

length(?List, ?Int)
   Succeeds if Int represents the number of elements of list List. Can be used to create a list holding
   only variables.
merge(+List1, +List2, -List3)

List1 and List2 are lists, sorted to the standard order of terms (see section 3.5). List3 will be unified with an ordered list holding both the elements of List1 and List2. Duplicates are not removed.

### 3.27 Set Manipulation

is_set(+Set)

Succeeds if Set is a proper list (see proper_list/1) without duplicates.

list_to_set(+List, -Set)

Unifies Set with a list holding the same elements as List in the same order. If list contains duplicates, only the first is retained. See also sort/2. Example:

?- list_to_set([a, b, a], X)

X = [a, b]

intersection(+Set1, +Set2, -Set3)

Succeeds if Set3 unifies with the intersection of Set1 and Set2. Set1 and Set2 are lists without duplicates. They need not be ordered.

subtract(+Set, +Delete, -Result)

Delete all elements of set ‘Delete’ from ‘Set’ and unify the resulting set with ‘Result’.

union(+Set1, +Set2, -Set3)

Succeeds if Set3 unifies with the union of Set1 and Set2. Set1 and Set2 are lists without duplicates. They need not be ordered.

subset(+Subset, +Set)

Succeeds if all elements of Subset are elements of Set as well.

merge_set(+Set1, +Set2, -Set3)

Set1 and Set2 are lists without duplicates, sorted to the standard order of terms. Set3 is unified with an ordered list without duplicates holding the union of the elements of Set1 and Set2.

### 3.28 Sorting Lists

sort(+List, -Sorted)

Succeeds if Sorted can be unified with a list holding the elements of List, sorted to the standard order of terms (see section 3.5). Duplicates are removed. Implemented by translating the input list into a temporary array, calling the C-library function qsort(3) using PL_compare() for comparing the elements, after which the result is translated into the result list.

msort(+List, -Sorted)

Equivalent to sort/2, but does not remove duplicates.
keysort(+List, -Sorted)
List is a list of Key-Value pairs (e.g. terms of the functor ‘-’ with arity 2). keysort/2 sorts List like msort/2, but only compares the keys. Can be used to sort terms not on standard order, but on any criterion that can be expressed on a multi-dimensional scale. Sorting on more than one criterion can be done using terms as keys, putting the first criterion as argument 1, the second as argument 2, etc. The order of multiple elements that have the same Key is not changed.

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 <, const> or =. If built-in predicate compare/3 is used, the result is the same as sort/2. See also keysort/2.11

3.29 Finding all Solutions to a Goal

findall(+Var, +Goal, -Bag)
Creates a list of the instantiations Var gets successively on backtracking over Goal and unifies 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 bound with the existence operator (ˆ), except that bagof/3 fails when goal has no solutions.

bagof(+Var, +Goal, -Bag)
Unify Bag with the alternatives of Var, if Goal has free variables besides the one sharing with Var bagof will backtrack over the alternatives of these free variables, unifying Bag with the corresponding alternatives of Var. The construct +Var~Goal tells bagof 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).
foo(a, b, d).
foo(b, c, e).
foo(b, c, f).
foo(c, c, g).

Yes
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] ;

No

11Please note that the semantics have changed between 3.1.1 and 3.1.2
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] ;

No
5  ?-

setof(+Var, +Goal, -Set)
Equivalent to bagof/3, but sorts the result using sort/2 to get a sorted list of alternatives without duplicates.

3.30  Invoking Predicates on all Members of a List

All the predicates in this section call a predicate on all members of a list or until the predicate called fails. The predicate is called via call/2[..], which implies common arguments can be put in front of the arguments obtained from the list(s). For example:

?- maplist(plus(1), [0, 1, 2], X).
X = [1, 2, 3]

we will phrase this as “Predicate is applied on…”

checklist(+Pred, +List)
Pred is applied successively on each element of List until the end of the list or Pred fails. In the latter case the checklist/2 fails.

maplist(+Pred, ?List1, ?List2)
Apply Pred on all successive pairs of elements from List1 and List2. Fails if Pred can not be applied to a pair. See the example above.

sublist(+Pred, +List1, ?List2)
Unify List2 with a list of all elements of List1 to which Pred applies.

3.31  Forall

forall(+Cond, +Action)
For all alternative bindings of Cond Action can be proven. The example verifies that all arithmetic statements in the list L are correct. It does not say which is wrong if one proves wrong.

?- forall(member(Result = Formula, [2 = 1 + 1, 4 = 2 * 2]),
   Result =:= Formula).
3.32 Formatted Write

The current version of SWI-Prolog provides two formatted write predicates. The first is `writef/[1,2]`, which is compatible with Edinburgh C-Prolog. The second is `format/[1,2]`, which is compatible with Quintus Prolog. We hope the Prolog community will once define a standard formatted write predicate. If you want performance use `format/[1,2]` as this predicate is defined in C. Otherwise compatibility reasons might tell you which predicate to use.

3.32.1 Writef

`write/ln(+Term)`

Equivalent to `write(Term), nl.`

`writef(+Atom)`

Equivalent to `writef(Atom, []).`

`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` then 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 neline character (see also <code>nl/[0,1]</code>)</td>
</tr>
<tr>
<td>\l</td>
<td>Output a line separator (same as \n)</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 (\langle nnn \rangle) is an integer (1-3 digits) the character with ASCII code (\langle nnn \rangle) is output (NB: (\langle nnn \rangle) is read as decimal)</td>
</tr>
</tbody>
</table>

Note that \l, \nnn and \ are interpreted differently when character-escapes are in effect. See section 2.14.1.

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.
3.32. 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 an ASCII value) |
| %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. |
| %Nl | Write the next item Left justified 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)
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)
Equivalent to swritef(String , Format, []).

3.32.2 Format

format(+Format)
Defined as ‘format(Format) :- format(Format, []).’

format(+Format, +Arguments)
Format is an atom, list of ASCII values, or a Prolog string. Arguments provides the arguments required by the format specification. If only one argument is required and this is not a list of ASCII values the argument need not be put in a list. Otherwise the arguments are put in a list.

Special sequences start with the tilde (~), followed by an optional numeric argument, 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 ASCII value of the character (only useful for ~t) or a asterisk (*), in when the numeric argument is taken from the next argument of the argument list, which should be a positive integer. Actions are:
~ Output the tilde itself.
a Output the next argument, which should be an atom. This option is equivalent to w.
Compatibility reasons only.
c Output the next argument as an ASCII value. This argument should be an integer in the
range \([0, \ldots, 255]\) (including 0 and 255).
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).
d Same as d, but makes large values easier to read by inserting a comma every three digits
left to the dot or right.
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 \(\% .(\text{precision})e\).
E Equivalent to e, but outputs a capital E to indicate the exponent.
f Floating point in non-exponential notation. See C library function printf().
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.
k Give the next argument to displayq/1 (canonical write).
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 the numeric argument notation. Thus \(\sim_{16r}\) prints its argument
hexadecimal. The argument should be in the range \([2, \ldots, 36]\). Lower case letters are
used for digits above 9.
R Same as r, but uses upper case letters for digits above 9.
s Output a string of ASCII characters or a string (see string/1 and section 3.21) from
the next argument.
t All remaining space between 2 tabs tops is distributed equally over \(\sim t\) statements between
the tabs tops. This space is padded with spaces by default. If an argument is supplied this
is taken to be the ASCII value of the character used for padding. This can be used to do
left or right alignment, centering, distributing, etc. See also \(\sim \mid\) and \(\sim +\) to set tab stops. A
tabs top is assumed at the start of each line.
| Set a tabs top on the current position. If an argument is supplied set a tabs top on the
position of that argument. This will cause all \(\sim t\)’s to be distributed between the previous
and this tabs top.
+ Set a tabs top relative to the current position. Further the same as \(\sim \mid\).
w Give the next argument to write/1.
3.32. FORMATTED WRITE

Example:

```
simple_statistics :-
    <obtain statistics>  % left to the user
    format(\Statistics\n),
    format(\Runtime: \2f\34|\n\, [RunT, Inf]),
    ....
```

Will output

```
Statistics

```

```
format(+Stream, +Format, +Arguments)
As format/2, but write the output on the given Stream.
```

```
sformat(-String, +Format, +Arguments)
Equivalent to format/2, but “writes” the result on String instead of the current output stream.
Example:

?- sformat(S, "\w\t15|\w", [Hello, World]).
S = "Hello     World"
```

```
sformat(-String, +Format)
Equivalent to ‘sformat(String, Format, []).’
```

3.32.3 Programming Format

```
format_predicate(+Char, +Head)
If a sequence ~c (tilde, followed by some character) is found, the format derivatives will 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 an ASCII value, 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 redefines ~n to produce Arg times return followed by linefeed (so a (Grr.) DOS machine is happy with the output).

:- format_predicate(n, dos_newline(_Arg)).

dos_newline(Arg) :-
    between(1, Ar, _), put(13), put(10), fail ; true.
```
current_format_predicate(?Code, ?:Head)
  Enumerates all user-defined format predicates. Code is the character code of the format character. Head is unified with a term with the same name and arity as the predicate. If the predicate does not reside in module user, Head is qualified with the definition module of the predicate.

3.33 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 consoles 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 result 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).

set_tty(-OldStream, +NewStream)
  Set the output stream, used by tty_put/2 and tty_goto/2 to a specific stream. Default is user_output.

3.34 Operating System Interaction

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 Win32 systems, 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.

shell(+Command)
  Equivalent to 'shell(Command, 0)'.

shell
  Start an interactive Unix shell. Default is /bin/sh, the environment variable SHELL overrides this default. Not available for Win32 platforms.
3.34. OPERATING SYSTEM INTERACTION

**win_exec(+Command, +Show)**

Win32 systems only. Spawns a Windows task without waiting for its completion. *Show* is either iconic or normal and dictates the initial status of the window. The iconic option is notably handy to start (DDE) servers.

**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 environment variable. *Name* and *Value* should 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`.

**unsetenv(+Name)**

Remove environment variable from the environment.

**unix(+Command)**

This predicate comes from the Quintus compatibility library and provides a partial implementation thereof. It provides access to some operating system features and unlike the name suggests, is not operating system specific. Currently it is the only way to fetch the Prolog command-line arguments. Defined *Command*s are below.

**system(+Command)**

Equivalent to calling `shell/1`. Use for compatibility only.

**shell(+Command)**

Equivalent to calling `shell/1`. Use for compatibility only.

**shell**

Equivalent to calling `shell/0`. Use for compatibility only.

**cd**

Equivalent to calling `chdir/1` as `chdir(`). Use for compatibility only.

**cd(+Directory)**

Equivalent to calling `chdir/1`. Use for compatibility only.

**argv(-Argv)**

Unify *Argv* with the list of commandline arguments provides to this Prolog run. Please note that Prolog system-arguments and application arguments are separated by --. Integer arguments are passed as Prolog integers, float arguments and Prolog floating point numbers and all other arguments as Prolog atoms.

A stand-alone program could use the following skeleton to handle command-line arguments. See also section 2.10.2.

```prolog
main :-
    unix(argv(Argv)),
    append(_PrologArgs, [--|AppArgs], Argv), !,
    main(AppArgs).
```
get_time(-Time)
Return the number of seconds that elapsed since the epoch of Unix, 1 January 1970, 0 hours. Time is a floating point number. Its granularity is system dependent. On SUN, this is 1/60 of a second.

convert_time(+Time, -Year, -Month, -Day, -Hour, -Minute, -Second, -MilliSeconds)
Convert a time stamp, provided by get_time/1, time_file/2, etc. Year is unified with the year, Month with the month number (January is 1), Day with the day of the month (starting with 1), Hour with the hour of the day (0–23), Minute with the minute (0–59). Second with the second (0–59) and MilliSecond with the milliseconds (0–999). Note that the latter might not be accurate or might always be 0, depending on the timing capabilities of the system. See also convert_time/2.

convert_time(+Time, -String)
Convert a time-stamp as obtained though get_time/1 into a textual representation using the C-library function ctime(). The value is returned as a SWI-Prolog string object (see section 3.21). See also convert_time/8.

### 3.35 File System Interaction

access_file(+File, +Mode)
Succeeds if File exists and can be accessed by this prolog process under mode Mode. Mode is one of the atoms read, write, append, exist, none or execute. File may also be the name of a directory. Fails silently otherwise. access_file(File, none) simply succeeds without testing anything.

If ‘Mode’ is write or append, this predicate also succeeds if the file does not exist and the user has write-access to the directory of the specified location.

exists_file(+File)
Succeeds when File exists. This does not imply the user has read and/or write permission for the file.

file_directory_name(+File, -Directory)
Extracts the directory-part of File. The resulting Directory name ends with the directory separator character /. If File is an atom that does not contain any directory separator characters, the empty atom ‘’ is returned. See also file_base_name/2.

file_base_name(+File, -BaseName)
Extracts the filename part from a path specification. If File does not contain any directory separators, File is returned.

same_file(+File1, +File2)
Succeeds 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).

exists_directory(+Directory)
Succeeds if Directory exists. This does not imply the user has read, search and or write permission for the directory.
delete_file(+File)
   Unlink File from the Unix file system.

rename_file(+File1, +File2)
   Rename File1 into File2. Currently files cannot be moved across devices.

size_file(+File, -Size)
   Unify Size with the size of File in characters.

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.

absolute_file_name(+File, -Absolute)
   Expand Unix file specification into an absolute path. User home directory expansion (~ and
   <user>) and variable expansion is done. The absolute path is canonised: references to . and
   .. are deleted. SWI-Prolog uses absolute file names to register source files independent of the
   current working directory. See also absolute_file_name/3.

absolute_file_name(+Spec, +Options, -Absolute)
   Converts the given file specification into an absolute path. Option is a list of options to guide
   the conversion:

   extensions(ListOfExtensions)
      List of file-extensions to try. Default is ''. 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 of the list is tried. Extensions may be specified both as ..ext or plain ext.

   access(Mode)
      Imposes the condition access_file(File, Mode). Mode is on of read, write, append, exist or none. See also access_file/2.

   file_type(Type)
      Defines extensions. Current mapping: txt implies ['', prolog implies ['','.pl', ''], executable implies ['','.so', ''], qlf implies ['','.qlf', ''] and directory implies [''].

   file_errors(fail/error)
      If error (default), throw and existence_error exception if the file cannot be found.
      If fail, stay silent.footnoteSilent operation was the default upto version 3.2.6.

   solutions(first/all)
      If first (default), the predicates leaves no choice-point. Otherwise a choice-point will
      be left and backtracking may yield more solutions.

is_absolute_file_name(+File)
   True if File specifies and absolute path name. On Unix systems, this implies the path starts
   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 be done case-insensitive too. Extension may be specified with or without a leading dot (.). If an Extension is generated, it will not have a leading dot.

expand_file_name(+WildCard, -List)
Unify List with a sorted list of files or directories matching WildCard. The normal Unix wildcard constructs ‘?’, ‘*’, ‘[...]’ and ‘{...}’ are recognised. The interpretation of ‘{...}’ is interpreted 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.

Before expanding wildchards, the construct $\text{var}$ is expanded to the value of the environment variable var and a possible leading ~ character is expanded to the user’s home directory.\footnote{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.}

prolog_to_os_filename(?PrologPath, ?OsPath)
Converts between the internal Prolog pathname conventions and the operating-system pathname conventions. The internal conventions are Unix and this predicates is equivalent to =/2 (unify) on Unix systems. On DOS systems it will change the directory-separator, limit the filename length map dots, except for the last one, onto underscores.

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)
Create a name for a temporary file. Base is an identifier for the category of file. The TmpName is guaranteed to be unique. If the system halts, it will automatically remove all created temporary files.

chdir(+Path)
Change working directory to Path.\footnote{BUG: Some of the file-I/O predicates use local filenames. Using chdir/1 while file-bound streams are open causes wrong results on telling/1, seeing/1 and current_stream/3}

3.36 Multi-threading (PRE-ALPHA: developers only!)
The features described in this section are only enabled on Unix systems providing POSIX threads and if the system is configured using the --enable-mt option. SWI-Prolog multithreading support is very incomplete and for developers ONLY. This section however does provide an overview of the forthcoming functionality.
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.

- **Multi-threaded 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 (A Pentium-II/450 can create and join approx. 10,000 threads per second on Linux 2.2).

- **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.

- **Natural integration with foreign code**
  Each Prolog thread runs in a C-thread, 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.

Below is the tentative and incomplete API for dealing with multiple Prolog threads. Forthcoming: mutexes, semaphores, thread-suspend and cancel, foreign-language interface and debugger interface.

```
thread_create(:Goal, -Id, +Options)
Create a new Prolog thread (and underlying C-thread) and start it by executing Goal. If the thread is created successfully, the thread-identifier of the created thread is unified to Id. Options is a list of options. Currently defined options are:

local(K-Bytes)
Set the limit to which the local stack of this thread may grow. If omitted, the limit of the calling thread is used. See also the -L commandline option.

global(K-Bytes)
Set the limit to which the global stack of this thread may grow. If omitted, the limit of the calling thread is used. See also the -G commandline option.

trail(K-Bytes)
Set the limit to which the trail stack of this thread may grow. If omitted, the limit of the calling thread is used. See also the -T commandline option.

argument(K-Bytes)
Set the limit to which the argument stack of this thread may grow. If omitted, the limit of the calling thread is used. See also the -A commandline option.

The Goal argument is copied to the new Prolog engine. This implies further instantiation of this term in either thread does not have consequences for the other thread: Prolog thread do not share data from their stacks.
```
current_thread(?Id, ?Status)
Enumerates identifiers and status of all currently known threads. Calling current_thread/2 does not influence any thread. See also thread_join/2. Status is one of:

running
The thread is running. This is the initial status of a thread. Please note that threats waiting for something are considered running too.

false
The Goal of the thread has been completed and failed.

ture
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.

exception(Term)
The Goal of the thread has been terminated due to an uncaught exception (see throw/1 and catch/3).

thread_join(+Id, -Status)
Wait for the termination of thread with given Id. Then unify the result-status (see thread_exit/1) of the thread with Status. After this call, Id becomes invalid and all resources associated with the thread are reclaimed. See also current_thread/2.

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.

thread_exit(+Term)
Terminates the thread immediately, leaving exited(Term) as result-state. The Prolog stacks and C-thread are reclaimed.

3.37 User Toplevel Manipulation
break
Recursively start a new Prolog top level. This Prolog top level has its own stacks, but shares the heap with all break environments and the top level. 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 the -t toplevel command line option is given this goal is started instead of entering the default interactive top level (prolog/0).

abort
Abort the Prolog execution and start a new top level. If the -t toplevel command line options is given this goal is started instead of entering the default interactive top level. Break
environments are aborted as well. All open files except for the terminal related files are closed. 
The input- and output stream again refers to user.\textsuperscript{14}

\textbf{halt}

Terminate Prolog execution. Open files are closed and if the command line option \texttt{-tty} is not active the terminal status (see Unix \texttt{stty(1)}) is restored. Hooks may be registered both in Prolog and in foreign code. Prolog hooks are registered using \texttt{at_halt/1}. \texttt{halt/0} is equivalent to \texttt{halt(0)}.

\textbf{halt(+Status)}

Terminate Prolog execution with given status. Status is an integer. See also \texttt{halt/0}.

\textbf{prolog}

This goal starts the default interactive top level. Queries are read from the stream \texttt{user_input}. See also the \textit{history} feature (\texttt{feature/2}). The \texttt{prolog/0} predicate is terminated (succeeds) by typing the end-of-file character (Unix: control-D).

The following two hooks allow for expanding queries and handling the result of a query. These hooks are used by the toplevel variable expansion mechanism described in section 2.8.

\textbf{expand_query(+Query, -Expanded, +Bindings, -ExpandedBindings)}

Hook in module \texttt{user}, normally not defined. \textit{Query} and \textit{Bindings} represents the query read from the user and the names of the free variables as obtained using \texttt{read_term/3}. If this predicate succeeds, it should bind \textit{Expanded} and \textit{ExpandedBindings} to the query and bindings to be executed by the toplevel. This predicate is used by the toplevel (\texttt{prolog/0}). See also \texttt{expand_answer/2} and \texttt{term_expansion/2}.

\textbf{expand_answer(+Bindings, -ExpandedBindings)}

Hook in module \texttt{user}, normally not defined. Expand the result of a successfully executed toplevel query. \textit{Bindings} is the query \(\langle \text{Name} \rangle = \langle \text{Value} \rangle\) binding list from the query. \textit{ExpandedBindings} must be unified with the bindings the toplevel should print.

\section*{3.38 Creating a Protocol of the User Interaction}

SWI-Prolog offers the possibility to log the interaction with the user on a file.\textsuperscript{15} All Prolog interaction, including warnings and tracer output, are written on the protocol file.

\textbf{protocol(+File)}

Start protocolling on file \textit{File}. If there is already a protocol file open then close it first. If \textit{File} exists it is truncated.

\textbf{protocola(+File)}

Equivalent to \texttt{protocol/1}, but does not truncate the \textit{File} if it exists.

\textbf{noprotocol}

Stop making a protocol of the user interaction. Pending output is flushed on the file.

\textsuperscript{14}BUG: Erased clauses which could not actually be removed from the database, because they are active in the interpreter, will never be garbage collected after an abort.

\textsuperscript{15}A similar facility was added to Edinburgh C-Prolog by Wouter Jansweijer.
protocolling(-File)
Succeeds if a protocol was started with protocol/1 or protocola/1 and unifies File with the current protocol output file.

3.39 Debugging and Tracing Programs

trace
Start the tracer. trace/0 itself cannot be seen in the tracer. Note that the Prolog toplevel treats trace/0 special; it means ‘trace the next goal’.

tracing
Succeeds when the tracer is currently switched on. tracing/0 itself can not 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 portnames (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.

The predicate trace/2 activates debug mode (see debug/0). Each time a port (of the 4-port model) is passed that has a trace-point set the goal is printed as with trace/0. 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.

The predicate debugging/0 shows all currently defined trace-points.

notrace(+Goal)
Call Goal, but suspend the debugger while Goal is executing. The current implementation cuts the choicepoints of Goal after successful completion. See once/1. Later implementations may have the same semantics as call/1.

debug
Start debugger (stop at spy points).

nodebug
Stop debugger (do not trace, nor stop at spy points).
3.39. DEBUGGING AND TRACING PROGRAMS

debugging
Print debug status and spy points on current output stream.

spy(+Pred)
Put a spy point on all predicates meeting the predicate specification Pred. See section 3.3.

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 port specification. Default is full.

unknown(-Old, +New)
Unify Old with the current value of the unknown system flag. On success New will be used to specify the new value. New should be instantiated to either fail or trace and determines the interpreters action when an undefined predicate which is not declared dynamic is encountered (see dynamic/1). fail implies the predicate just fails silently. trace implies the tracer is started. Default is trace. The unknown flag is local to each module and unknown/2 is module transparent. Using it as a directive in a module file will only change the unknown flag for that module. Using the :/2 construct the behaviour on trapping an undefined predicate can be changed for any module. Note that if the unknown flag for a module equals fail the system will not call exception/3 and will not try to resolve the predicate via the dynamic library system. The system will still try to import the predicate from the public module.

style_check(+Spec)
Set style checking options. Spec is either +option, -option, ?option or a list of such options. +option sets a style checking option, -option clears it and ?option succeeds or fails according to the current setting. consult/1 and derivatives resets the style checking options to their value before loading the file. If—for example—a file containing long atoms should be loaded the user can start the file with:

:- style_check(-atom).

Currently available options are:
<table>
<thead>
<tr>
<th>Name</th>
<th>Default</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>singleton</td>
<td>on</td>
<td>read_clause/1 (used by consult/1) warns on variables only appearing once in a term (clause) which have a name not starting with an underscore.</td>
</tr>
<tr>
<td>atom</td>
<td>on</td>
<td>read/1 and derivatives will produce an error message on quoted atoms or strings longer than 5 lines.</td>
</tr>
<tr>
<td>dollar</td>
<td>off</td>
<td>Accept dollar as a lower case character, thus avoiding the need for quoting atoms with dollar signs. System maintenance use only.</td>
</tr>
<tr>
<td>discontiguous</td>
<td>on</td>
<td>Warn if the clauses for a predicate are not together in the same source file.</td>
</tr>
<tr>
<td>string</td>
<td>off</td>
<td>Read and derivatives transform &quot;...&quot; into a prolog string instead of a list of ASCII characters.</td>
</tr>
</tbody>
</table>

### 3.40 Obtaining Runtime Statistics

**statistics(+Key, -Value)**

Unify system statistics determined by Key with Value. The possible keys are given in the table 3.2.

**statistics**

Display a table of system statistics on the current output stream.
3.41. FINDING PERFORMANCE BOTTLENECKS

3.41 Finding Performance Bottlenecks

SWI-Prolog offers a statistical program profiler similar to Unix prof(1) for C and some other languages. A profiler is used as an aid to find performance pigs in programs. It provides information on the time spent in the various Prolog predicates.

The profiler is based on the assumption that if we monitor the functions on the execution stack on time intervals not correlated to the program’s execution the number of times we find a procedure on the environment stack is a measure of the time spent in this procedure. It is implemented by calling a procedure each time slice Prolog is active. This procedure scans the local stack and either just counts the procedure on top of this stack (plain profiling) or all procedures on the stack (cumulative profiling). To get accurate results each procedure one is interested in should have a reasonable number of counts. Typically a minute runtime will suffice to get a rough overview of the most expensive procedures.

profile(+Goal, +Style, +Number)
Execute Goal just like time(1) (i.e. leaving no choice points), but print used time, number of logical inferences and the average number of lips (logical inferences per second). Note that SWI-Prolog counts the actual executed number of inferences rather than the number of passes through the call- and redo ports of the theoretical 4-port model.

show_profile(+Number)
Show the collected results of the profiler. Stops the profiler first to avoid interference from show_profile/1. It shows the top Number predicates according the percentage CPU-time used.16

profiler(-Old, +New)
Query or change the status of the profiler. The status is one of off, plain or cumulative. plain implies the time used by children of a predicate is not added to the time of the predicate. For status cumulative the time of children is added (except for recursive calls). Cumulative profiling implies the stack is scanned up to the top on each time slice to find all active predicates. This implies the overhead grows with the number of active frames on the stack. Cumulative profiling starts debugging mode to disable tail recursion optimisation, which would otherwise remove the necessary parent environments. Switching status from plain to cumulative resets the profiler. Switching to and from status off does not reset the collected statistics, thus allowing to suspend profiling for certain parts of the program.

reset_profiler
Switches the profiler to off and clears all collected statistics.

16show_profile/1 is defined in Prolog and takes a considerable amount of memory.
profile_count(+Head, -Calls, -Promilage)

Obtain profile statistics of the predicate specified by Head. Head is an atom for predicates with arity 0 or a term with the same name and arity as the predicate required (see current_predicate/2). Calls is unified with the number of ‘calls’ and ‘redos’ while the profiler was active. Promilage is unified with the relative number of counts the predicate was active (cumulative) or on top of the stack (plain). Promilage is an integer between 0 and 1000.

3.42 Memory Management

Note: limit_stack/2 and trim_stacks/0 have no effect on machines that do not offer dynamic stack expansion. On these machines these predicates simply succeed to improve portability.

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.

limit_stack(+Key, +Kbytes)

Limit one of the stack areas to the specified value. Key is one of local, global or trail. The limit is an integer, expressing the desired stack limit in K bytes. If the desired limit is smaller than the currently used value, the limit is set to the nearest legal value above the currently used value. If the desired value is larger than the maximum, the maximum is taken. Finally, if the desired value is either 0 or the atom unlimited the limit is set to its maximum. The maximum and initial limit is determined by the command line options -L, -G and -T.

trim_stacks

Release stack memory resources that are not in use at this moment, returning them to the operating system. Trim stack is a relatively cheap call. 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 should be written as follows:

```prolog
loop :-
    generator,
    trim_stacks,
    potentially_expensive_operation,
    stop_condition, !.
```

The prolog top level loop is written this way, reclaiming memory resources after every user query.

stack_parameter(+Stack, +Key, -Old, +New)

Query/set a parameter for the runtime stacks. Stack is one of local, global, trail or argument. The table below describes the Key/Value pairs. Old is first unified with the current value.
This predicate is currently only available on versions that use the stack-shifter to enlarge the runtime stacks when necessary. It’s definition is subject to change.

### 3.43 Windows DDE interface

The predicates in this section deal with MS-Windows ‘Dynamic Data Exchange’ or DDE protocol. A Windows DDE conversation is a form of interprocess communication based on sending reserved window-events between the communicating processes.

See also section 5.4 for loading Windows DLL’s into SWI-Prolog.

#### 3.43.1 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:

1 ?- open_dde_conversation(progman, progman, C).
   C = 0
2 ?- dde_request(0, groups, X)
   --> Unifies X with description of groups
3 ?- dde_execute(0, '[CreateGroup("DDE Demo")]').
   Yes
4 ?- close_dde_conversation(0).
   Yes

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.

**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.

**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.

---

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. If unsuccessful, *Value* will be unified with a term of form `error(R)` , identifying the problem. This call uses SWI-Prolog string objects to return the value rather than atoms to reduce the load on the atom-space. See section 3.21 for a discussion on this data type.

**dde_execute(+Handle, +Command)**

Request the DDE server to execute the given command-string. Succeeds if the command could be executed and fails with 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.

### 3.43.2 DDE server mode

The (autoload) 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 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*.

The example below registers the Prolog `feature/2` predicate to be accessible from other applications. The request may be given from the same Prolog as well as from another application.

```prolog
?- dde_register_service(prolog(feature, F, V),
                        feature(F, V)).
```

```prolog
?- open_dde_conversation(prolog, feature, Handle),
   dde_request(Handle, home, Home),
   close_dde_conversation(Handle).
```

```
Home = '/usr/local/lib/pl-2.0.6/'
```

Handling DDE execute requests is very similar. In this case the template is of the form:

```
+Service(+Topic, +Item)
```

Passing a *Value* argument is not needed as execute requests either succeed or fail. If *Goal* fails, a `notprocessed` is passed back to the caller of the DDE request.
3.44. MISCELLANEOUS

**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.

### 3.44. Miscellaneous

**dwim_match(+Atom1, +Atom2)**

Succeeds if *Atom1* matches *Atom2* in ‘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 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)**

Succeeds if *String* matches the wildcard pattern *Pattern*. *Pattern* is very similar the 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. *char1*-*char2* indicates a range.
- {...} Matches any of the patterns of the comma separated list between the braces.

Example:

?- wildcard_match(’[a-z]*.{pro,pl}[%¬]’, ’a_hello.pl%’).

Yes.

**gensym(+Base, -Unique)**

Generate a unique atom from base *Base* and unify it with *Unique*. *Base* should be an atom. The first call will return *base*1, the next *base*2, etc. Note that this is no warrant that the atom is unique in the system.\(^{18}\)

\(^{18}\)BUG: I plan to supply a real *gensym/2* which does give this warrant for future versions.
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.
4.1 Why Using Modules?

In traditional Prolog systems the predicate space was flat. This approach is not very suitable for the development of large applications, certainly not if these applications are developed by more than one programmer. In many cases, the definition of a Prolog predicate requires sub-predicates that are intended only to complete the definition of the main predicate. With a flat and global predicate space these support predicates will be visible from the entire program.

For this reason, it is desirable that each source module has its own predicate space. A module consists of a declaration for its name, its public predicates and the predicates themselves. This approach allows the programmer to use short (local) names for support predicates without worrying about name conflicts with the support predicates of other modules. The module declaration also makes explicit which predicates are meant for public usage and which for private purposes. Finally, using the module information, cross reference programs can indicate possible problems much better.

4.2 Name-based versus Predicate-based Modules

Two approaches to realize a module system are commonly used in Prolog and other languages. The first one is the name based module system. In these systems, each atom read is tagged (normally prefixed) with the module name, with the exception of those atoms that are defined public. In the second approach, each module actually implements its own predicate space.

A critical problem with using modules in Prolog is introduced by the meta-predicates that transform between Prolog data and Prolog predicates. Consider the case where we write:

```prolog
:- module(extend, [add_extension/3]).

add_extension(Extension, Plain, Extended) :-
    maplist(extend_atom(Extension), Plain, Extended).

extend_atom(Extension, Plain, Extended) :-
    concat(Plain, Extension, Extended).
```

In this case we would like maplist to call extend_atom/3 in the module extend. A name based module system will do this correctly. It will tag the atom extend_atom with the module and maplist will use this to construct the tagged term extend_atom/3. A name based module however, will not only tag the atoms that will eventually be used to refer to a predicate, but all atoms that are not declared public. So, with a name based module system also data is local to the module. This introduces another serious problem:
:- module(action, [action/3]).

action(Object, sleep, Arg) :- ....
action(Object, awake, Arg) :- ....

:- module(process, [awake_process/2]).

awake_process(Process, Arg) :-
    action(Process, awake, Arg).

This code uses a simple object-oriented implementation technique were atoms are used as method selectors. Using a name based module system, this code will not work, unless we declare the selectors public atoms in all modules that use them. Predicate based module systems do not require particular precautions for handling this case.

It appears we have to choose either to have local data, or to have trouble with meta-predicates. Probably it is best to choose for the predicate based approach as novice users will not often write generic meta-predicates that have to be used across multiple modules, but are likely to write programs that pass data around across modules. Experienced Prolog programmers should be able to deal with the complexities of meta-predicates in a predicate based module system.

### 4.3 Defining a Module

Modules normally are 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.

:- module(reverse, [reverse/2]).

reverse(List1, List2) :-
    rev(List1, [], List2).

rev([], List, List).

rev([Head|List1], List2, List3) :-
    rev(List1, [Head|List2], List3).

### 4.4 Importing Predicates into a Module

As explained before, in the predicate based approach adapted by SWI-Prolog, each module has it’s own predicate space. In SWI-Prolog, a module initially is completely empty. Predicates can be added to a module by loading a module file as demonstrated in the previous section, using assert or by importing them from another module.

Two mechanisms for importing predicates explicitly from another module exist. The use_module/[1,2] predicates load a module file and import (part of the) public predicates of the file. The import/1 predicate imports any predicate from any module.
use_module(+File)

Load the file(s) specified with File just like ensure_loaded/1. The files should all be module files. All exported predicates from the loaded files are imported into the context module. The difference between this predicate and ensure_loaded/1 becomes apparent if the file is already loaded into another module. In this case ensure_loaded/1 does nothing; use_module will import all public predicates of the module into the current context module.

use_module(+File, +ImportList)

Load the file specified with File (only one file is accepted). File should be a module file. ImportList is a list of name/arity pairs specifying the predicates that should be imported from the loaded module. If a predicate is specified that is not exported from the loaded module a warning will be printed. The predicate will nevertheless be imported to simplify debugging.

import(+Head)

Import predicate Head into the current context module. Head should specify the source module using the (module):(term) construct. Note that predicates are normally imported using one of the directives use_module/[1,2]. import/1 is meant for handling imports into dynamically created modules.

It would be rather inconvenient to have to import each predicate referred to by the module, including the system predicates. For this reason each module is assigned a default module. All predicates in the default module are available without extra declarations. Their definition however can be overruled in the local module. This schedule is implemented by the exception handling mechanism of SWI-Prolog: if an undefined predicate exception is raised for a predicate in some module, the exception handler first tries to import the predicate from the module’s default module. On success, normal execution is resumed.

4.4.1 Reserved Modules

SWI-Prolog contains two special modules. The first one is the module system. This module contains all built-in predicates described in this manual. Module system has no default module assigned to it. The second special module is the module user. This module forms the initial working space of the user. Initially it is empty. The default module of module user is system, making all built-in predicate definitions available as defaults. Built-in predicates thus can be overruled by defining them in module user before they are used.

All other modules default to module user. This implies they can use all predicates imported into user without explicitly importing them.

4.5 Using the Module System

The current structure of the module system has been designed with some specific organisations for large programs in mind. Many large programs define a basic library layer on top of which the actual program itself is defined. The module user, acting as the default module for all other modules of the program can be used to distribute these definitions over all program module without introducing the need to import this common layer each time explicitly. It can also be used to redefine built-in predicates if this is required to maintain compatibility to some other Prolog implementation. Typically, the loadfile of a large application looks like this:
:- use_module(compatibility). % load XYZ prolog compatibility

:- use_module(
    [ error, % errors and warnings
      , goodies, % general goodies (library extensions)
      , debug, % application specific debugging
      , virtual_machine, % virtual machine of application
      , ... % more generic stuff
    ]).

:- ensure_loaded(
    [ ... % the application itself
    ]).

The ‘use_module’ declarations will import the public predicates from the generic modules into the user module. The ‘ensure_loaded’ directive loads the modules that constitute the actual application. It is assumed these modules import predicates from each other using use_module/[1,2] as far as necessary.

In combination with the object-oriented schema described below it is possible to define a neat modular architecture. The generic code defines general utilities and the message passing predicates (invoke/3 in the example below). The application modules define classes that communicate using the message passing predicates.

### 4.5.1 Object Oriented Programming

Another typical way to use the module system is for defining classes within an object oriented paradigm. The class structure and the methods of a class can be defined in a module and the explicit module-boundary overruling describes in section 4.6.2 can be used by the message passing code to invoke the behaviour. An outline of this mechanism is given below.

% Define class point

:- module(point, []). % class point, no exports

% name type, default access
% value

variable(x, integer, 0, both).
variable(y, integer, 0, both).

% method name predicate name arguments

behaviour(mirror, mirror, []).

mirror(P) :-
    fetch(P, x, X),
4.6 Meta-Predicates in Modules

As indicated in the introduction, the problem with a predicate based module system lies in the difficulty to find the correct predicate from a Prolog term. The predicate ‘solution(Solution)’ can exist in more than one module, but ‘assert(solution(4))’ in some module is supposed to refer to the correct version of solution/1.

Various approaches are possible to solve this problem. One is to add an extra argument to all predicates (e.g. ‘assert(Module, Term)’). Another is to tag the term somehow to indicate which module is desired (e.g. ‘assert(Module:Term)’). Both approaches are not very attractive as they make the user responsible for choosing the correct module, inviting unclear programming by asserting in other modules. The predicate assert/1 is supposed to assert in the module it is called from and should do so without being told explicitly. For this reason, the notion context module has been introduced.

4.6.1 Definition and Context Module

Each predicate of the program is assigned a module, called it’s 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 from a Prolog term. By default, this module is the definition module of the predicate running the goal. For meta-predicates however, this is the context module of the goal that invoked them. We call this module transparent in SWI-Prolog. In the ‘using maplist’ example above, the predicate maplist/3 is declared module transparent. This implies the context module remains extend, the context module of add_extension/3. This way maplist/3 can decide to call extend_atom in module extend rather than in it’s own definition module.

All built-in predicates that refer to predicates via a Prolog term are declared module transparent. Below is the code defining maplist.
:- module(maplist, maplist/3).

:- module_transparent maplist/3.

% maplist(+Goal, +List1, ?List2)
% True if Goal can successfully be applied to all successive pairs
% of elements of List1 and List2.

maplist(_, [], []).  
maplist(Goal, [Elem1|Tail1], [Elem2|Tail2]) :-
    apply(Goal, [Elem1, Elem2]),
    maplist(Goal, Tail1, Tail2).

4.6.2 Overruling Module Boundaries

The mechanism above is sufficient to create an acceptable module system. 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 in some module. The first is useful to invoke goals in some module from the user’s toplevel or to implement a object-oriented system (see above). The latter is useful to create and modify dynamic modules (see section 4.7).

For this purpose, the reserved term :/2 has been introduced. All built-in predicates that transform a term into a predicate reference will check whether this term is of the form ‘<Module>:<Term>’. If so, the predicate is searched for in Module instead of the goal’s context module. The : operator may be nested, in which case the inner-most module is used.

The special calling construct <Module>:Goal pretends Goal is called from Module instead of the context module. Examples:

?- assert(world:done). % asserts done/0 into module world
?- world:assert(done). % the same
?- world:done. % calls done/0 in module world

4.7 Dynamic Modules

So far, we discussed modules that were created by loading a module-file. These modules have been introduced on 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. Example:

?- assert(world_a:consistent),
   world_a:unknown(_), fail).
These calls create a module called ‘world_a’ and make the call ‘world_a:consistent’ succeed. Unde-
defined predicates will not start the tracer or autoloader for this module (see unknown/2).

Import and export from dynamically created world is arranged via the predicates import/1 and
export/1:

?- world_b:export(solve(_,_)). % exports solve/2 from world_b
?- world_c:import(world_b:solve(_,_)). % and import it to world_c

4.8 Module Handling Predicates

This section gives the predicate definitions for the remaining built-in predicates that handle modules.

:- 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 Module and exporting the predicates of PublicList. PublicList is a list of
name/arity pairs.

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.

meta_predicate +Heads
This predicate is defined in library(quintus) and provides a partial emulation of the Quintus
predicate. See section 4.9.1 for details.

current_module(-Module)
Generates all currently known modules.

current_module(?Module, ?File)
Is true if File is the file from which Module was loaded. File is the internal canonical filename.
See also source_file/[1,2].

context_module(-Module)
Unify Module with the context module of the current goal. context_module/1 itself is
transparent.

export(+Head)
Add a predicate 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.

export_list(+Module, ?Exports)
Unifies Exports with a list of terms. Each term has the name and arity of a pub-
lic predicate of Module. The order of the terms in Exports is not defined. See also
predicate_property/2.
\texttt{default_module(+Module, -Default)}

Succesively unifies \texttt{Default} with the module names from which a call in \texttt{Module} attempts to use the definition. For the module \texttt{user}, this will generate \texttt{user} and \texttt{system}. For any other module, this will generate the module itself, followed by \texttt{user} and \texttt{system}.

\texttt{module(+Module)}

The call \texttt{module(Module)} may be used to switch the default working module for the interactive toplevel (see \texttt{prolog/0}). This may be used to when debugging a module. The example below lists the clauses of file\_of\_label/2 in the module \texttt{tex}.

\begin{verbatim}
1 ?- module(tex).
Yes
tex: 2 ?- listing(file\_of\_label/2).
...
\end{verbatim}

\section{Compatibility of the Module System}

The principles behind the module system of SWI-Prolog differ in a number of aspects from the Quintus Prolog module system.

- The SWI-Prolog module system allows the user to redefine system predicates.

- All predicates that are available in the \texttt{system} and \texttt{user} modules are visible in all other modules as well.

- Quintus has the \textquote{meta\_predicate/1\} declaration were SWI-Prolog has the \texttt{module\_transparent/1} declaration.

The \texttt{meta\_predicate/1} declaration causes the compiler to tag arguments that pass module sensitive information with the module using the \texttt{:/2} operator. This approach has some disadvantages:

- Changing a \texttt{meta\_predicate} declaration implies all predicates \texttt{calling} the predicate need to be reloaded. This can cause serious consistency problems.

- It does not help for dynamically defined predicates calling module sensitive predicates.

- It slows down the compiler (at least in the SWI-Prolog architecture).

- At least within the SWI-Prolog architecture the run-time overhead is larger than the overhead introduced by the transparent mechanism.

Unfortunately the transparent predicate approach also has some disadvantages. If a predicate \texttt{A} passes module sensitive information to a predicate \texttt{B}, passing the same information to a module sensitive system predicate both \texttt{A} and \texttt{B} should be declared transparent. Using the Quintus approach only \texttt{A} needs to be treated special (i.e. declared with \texttt{meta\_predicate/1})\textsuperscript{1}. A second problem arises if the body of a transparent predicate uses module sensitive predicates for which it wants to refer to its own module. Suppose we want to define \texttt{findall/3} using \texttt{assert/1} and \texttt{retract/1}\textsuperscript{2}. The example in figure 4.1 gives the solution.

\textsuperscript{1}Although this would make it impossible to call \texttt{B} directly.

\textsuperscript{2}The system version uses \texttt{recordz/2} and \texttt{recorded/3}.
:- module(findall, [findall/3]).

:- dynamic
    solution/1.

:- module_transparent
    findall/3,
    store/2.

findall(Var, Goal, Bag) :-
    assert(findall:solution('mark')),
    store(Var, Goal),
    collect(Bag).

store(Var, Goal) :-
    Goal, % refers to context module of % caller of findall/3
    assert(findall:solution(Var)),
    fail.
store(_, _).

collect(Bag) :-
    ..., 

Figure 4.1: findall/3 using modules
4.9.1 Emulating `meta_predicate/1`

The Quintus `meta_predicate/1` directive can in many cases be replaced by the transparent declaration. Below is the definition of `meta_predicate/1` as available from library(`quintus`).

```prolog
:- op(1150, fx, (meta_predicate)).

meta_predicate((Head, More)) :- !,
    meta_predicate1(Head),
    meta_predicate(More).
meta_predicate(Head) :-
    meta_predicate1(Head).

meta_predicate1(Head) :-
    Head =.. [Name|Arguments],
    member(Arg, Arguments),
    module_expansion_argument(Arg), !,
    functor(Head, Name, Arity),
    module_transparent(Name/Arity).
meta_predicate1(_). % just a mode declaration

module_expansion_argument( :).  
module_expansion_argument(N) :- integer(N).
```

The discussion above about the problems with the transparent mechanism show the two cases in which this simple transformation does not work.
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 an 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.

5.1 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 (?- feature(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.)

5.2 Linking Foreign Modules

Foreign modules may be linked to Prolog in three ways. Using static linking, the extensions, a small description file and the basic SWI-Prolog object file 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 the running Prolog process.¹.

5.2.1 What linking is provided?

The static linking schema can be used on all versions of SWI-Prolog. The feature/2 predicate may be used to find out what other linking methods are provided for this version.

- feature(open_shared_object, true)
  
  If this succeeds the system provides the open_shared_object/2 and related predicates that allow for handling Unix shared object files based on the Unix library functions dlopen(2) and friends. See section 5.4.

- feature(dll, true)
  
  If this succeeds the system provides an interface for loading .DLL files by means of open_dll/2 and friends. See section 5.4.

If either the feature open_shared_object or dll is true, the library library(shlib) provides a common interface for loading foreign files from Prolog.

5.2.2 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.

Loading shared objects or DLL files 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.

5.3 Dynamic Linking of shared libraries

The interface defined in this section allows the user to load shared libraries (.so files on most Unix systems). This interface is portable to all machines providing the function dlopen(2) or an equivalent, normally from the library -ldl. These functions provide the basic interface layer. It is advised to use the predicates from section 5.4 in your application.

open_shared_object(+File, -Handle)

File is the name of a .so file (see your C programmers documentation on how to create a .so file). This file is attached to the current process and Handle is unified with a handle to the shared object. Equivalent to open_shared_object(File, [global], Handle). See also load_foreign_library/[1,2].

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 gets quickly smaller and this interface is difficult to port and slow, it is no longer described in this manual. The best alternatively would be to use the dld package on machines do not have shared libraries.
5.4. USING THE LIBRARY SHLIB FOR .DLL AND .SO FILES

open_shared_object(+File, +Options, -Handle)
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.

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().

5.4 Using the library shlib for .DLL and .so files

This section discusses the functionality of the (autoload) library shlib.pl, providing an interface to shared libraries. Currently it supports MS-Windows DLL (.DLL) libraries and Unix .so (shared object) files.

load_foreign_library(+Lib)
Equivalent to load_foreign_library(Lib, install).

load_foreign_library(+Lib, +Entry)
Search for the given foreign library and link it to the current SWI-Prolog instance. The library may be specified with or without the extension. First, absolute_file_name/3 is used to locate the file. If this succeeds, the full path is passed to the low-level function to open the library. Otherwise, the plain library name is passed, exploiting the operating-system defined search mechanism for the shared library. The file_search_path/2 alias mechanism defines the alias foreign, which refers to the directories 〈plhome〉/lib/〈arch〉 and 〈plhome〉/lib, in this order.

If the library can be loaded, the function called Entry will be called without arguments. The return value of the function is ignored.

The Entry function will normally call PL_register_foreign() to declare functions in the library as foreign predicates.

unload_foreign_library(+Lib)
If the foreign library defines the function uninstall(), this function will be called without arguments and its return value is ignored. Next, abolish/2 is used to remove all known foreign predicates defined in the library. Finally the library itself is detached from the process.

current_foreign_library(-Lib, -Predicates)
Query the currently loaded foreign libraries and their predicates. Predicates is a list with elements of the form Module:Head, indicating the predicates installed with PL_register_foreign() when the entry-point of the library was called.

Figure 5.1 connects a Windows message-box using a foreign function. This example was tested using Windows NT and Microsoft Visual C++ 2.0.
static foreign_t
pl_say_hello(term_t to) {
    char *a;

    if (PL_get_atom_chars(to, &a)) {
        MessageBox(NULL, a, "DLL test", MB_OK | MB_TASKMODAL);

        PL_succeed;
    }

    PL_fail;
}

install_t
install() {
    PL_register_forign("say_hello", 1, pl_say_hello, 0);
}

Figure 5.1: MessageBox() example in Windows NT

5.4.1 Static Linking

Below is an outline of the files structure required for statically linking SWI-Prolog with foreign ex-
tensions. \ldots/pl refers to the SWI-Prolog home directory (see feature/2). 〈arch〉 refers to
the architecture identifier that may be obtained using feature/2.

    .../pl/runtime/〈arch〉/libpl.a    SWI-Library
    \ldots/pl/include/SWI-Prolog.h   Include file
    \ldots/pl/include/SWI-Stream.h   Stream I/O include file
    \ldots/pl/include/SWI-Exports    Export declarations (AIX only)
    \ldots/pl/include/stub.c        Extension stub

The definition of the foreign predicates is the same as for dynamic linking. Unlike with dynamic
linking however, there is no initialisation function. Instead, the file \ldots/pl/include/stub.
c may be copied to your project and modified to define the foreign extensions. Below is stub.c,
modified to link the lowercase example described later in this chapter:

    /* Copyright (c) 1991 Jan Wielemaker. All rights reserved.
     jan@swi.psy.uva.nl

     Purpose: Skeleton for extensions
    */

    #include <stdio.h>
#include <SWI-Prolog.h>

extern foreign_t pl_lowercase(term, term);

PL_extension predicates[] =
{
  /* { "name", arity, function, PL_FA_<flags> }, */
  { "lowercase", 2, pl_lowercase, 0 },
  { NULL, 0, NULL, 0 } /* terminating line */
};

int
main(int argc, char **argv)
{
  PL_register_extensions(predicates);

  if ( !PL_initialise(argc, argv) )
    PL_halt(1);

  PL_install_readline(); /* delete if not required */

  PL_halt(PL_toplevel() ? 0 : 1);
}

Now, a new executable may be created by compiling this file and linking it to libpl.a from the runtime directory and the libraries required by both the extensions and the SWI-Prolog kernel. This may be done by hand, or using the plld utility described in secrlld.

5.4.2 Dynamic Linking based on load_foreign/[2,5]

The predicates below are considered obsolete. They are briefly described here for compatibility purposes. New code should use the predicates from the library(shlib).

load_foreign(+File, +Entry)
Load a foreign file or list of files specified by File. The files are searched for similar to consult/1. Except that the ‘.o’ extension is used rather than ‘.pl’. 

Entry defines the entry point of the resulting executable. The entry point will be called by Prolog to install the foreign predicates.

load_foreign(+File, +Entry, +Options, +Libraries, +Size)
The first two arguments are identical to those of load_foreign/2. Options is (a list of) additional option to be given to the loader. The options are inserted just before the files. Libraries is (a list of) libraries to be passed to the loader. They are inserted just after the files. If Size is specified Prolog first assumes that the resulting executable will fit in Size bytes and do the loading in one pass.
foreign_file(?File)

Is true if File is the absolute path name of a file loaded as foreign file.

5.5 Interface Data types

5.5.1 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 unsigned long, 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(). 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()/PL_discard_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 the 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.

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 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 refs with the same characteristics as PL_new_term_ref(). See PL_open_query().

- **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 5.3.
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_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 manage-
ment for allocation the Prolog stacks. The returned reference describes a variable.
}
```

```c
void 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. 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
void 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.
}
```

```c
void PL_reset_term_refs(term_t after) {
    // Destroy all term references that have been created after after, including after itself. Any refer-
ence 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 information necessary to perform its memory management without special precautions from the C-programmer.

**5.5.2 Other foreign interface types**

atom_t  An atom in Prologs internal representation. Atoms are pointers to an opaque structure. They are a unique representation for represented text, which implies that atom A represents the same text as atom B if-and-only-if A and B are the same pointer.
Atoms are the central representation for textual constants in Prolog. The transformation of a character string to an atom implies a hash-table lookup. If the same atom is needed often, it is advised to store its reference in a global variable to avoid repeated lookup.

`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()`/`PL_close_query()` to handle backtracking from C.

`fid_t` Frame Identifier. Used by `PL_open_foreign_frame()`/`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 `secrefshlib`.

### 5.6 The Foreign Include File

#### 5.6.1 Argument Passing and Control

If Prolog encounters a foreign predicate at runtime it will call a function specified in the predicate definition of the foreign predicate. The arguments $1, \ldots, \langle \text{arity} \rangle$ 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:

```c
void PL_succeed()
{
    Succeed deterministically. PL_succeed is defined as return TRUE.
}
```

```c
void 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:

- **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_CUTTED)**
  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.

```c
void PL_retry(long)

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()` will return the handle passed via `PL_retry()`. This handle is a 30 bits signed value (two bits are used for status indication).

void PL_retry_address(void *)

As `PL_retry()`, but ensures an address as returned by `malloc()` is correctly recovered by `PL_foreign_context_address()`.

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_CUTTED` case and should be aware that the other arguments are not valid in this case.

long PL_foreign_context(control_t)

Extracts the context from the context argument. In 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` as `PL_CUTTED`).

void * PL_foreign_context_address(control_t)

Extracts an address as passed in by `PL_retry_address()`.
typedef struct /* define a context structure */
{ ...
} context;

foreign_t
my_function(term_t a0, term_t a1, foreign_t handle)
{ struct context * ctxt;

    switch( PL_foreign_control(handle) )
    { case PL_FIRST_CALL:
        ctxt = malloc(sizeof(struct context));
        ...
        PL_retry_address(ctxt);
        case PL_REDO:
        ctxt = PL_foreign_context_address(handle);
        ...
        PL_retry_address(ctxt);
        case PL_CUTTED:
        free(ctxt);
        PL_succeed;
        }
    }

Figure 5.2: Skeleton for non-deterministic foreign functions

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_CUTTED will follow.

The code of figure 5.2 shows a skeleton for a non-deterministic foreign predicate definition.

5.6.2 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 for the entire session.

const char * PL_atom_chars(atom_t atom)
Return a C-string for the text represented by the given atom. The returned text will not be changed by Prolog. It is not allowed to modify the contents, not even ‘temporary’ as the string may reside in read-only memory.

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.
atom_t PL functor_name(functor_t)
    Return an atom representing the name of the given functor.

int PL functor_arity(functor_t)
    Return the arity of the given functor.

5.6.3 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

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_ge_t*() also validate the type and thus the two sections below are equivalent.

\[
\text{if ( PL_is_atom(t) )}
\begin{align*}
\{ & \text{char *s;} \\
& \text{PL_get_atom_chars(t, &s);} \\
& \text{...;}
\}
\end{align*}
\]

or

\[
\text{char *s;} \\
\text{if ( PL_get_atom_chars(t, &s) )}
\begin{align*}
\{ & \text{...;}
\}
\end{align*}
\]

| PL_VARIABLE | An unbound variable. The value of term as such is a unique identifier for the variable. |
| PL_ATOM     | A Prolog atom. |
| PL_STRING   | A Prolog string. |
| PL_INTEGER  | A Prolog integer. |
| PL_FLOAT    | A Prolog floating point number. |
| PL_TERM     | A compound term. Note that a list is a compound term ./2. |

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 \texttt{PL\_term\_type()} is faster and more readable than using an if-then-else using the functions below. All these functions return either \texttt{TRUE} or \texttt{FALSE}.

\begin{verbatim}
int PL_is_variable(term_t)
    Returns non-zero if \texttt{term} is a variable.

int PL_is_atom(term_t)
    Returns non-zero if \texttt{term} is an atom.

int PL_is_string(term_t)
    Returns non-zero if \texttt{term} is a string.

int PL_is_integer(term_t)
    Returns non-zero if \texttt{term} is an integer.

int PL_is_float(term_t)
    Returns non-zero if \texttt{term} is a float.

int PL_is_compound(term_t)
    Returns non-zero if \texttt{term} is a compound term.

int PL_is_functor(term_t, functor_t)
    Returns non-zero if \texttt{term} is compound and its functor is \texttt{functor}. This test is equivalent to \texttt{PL\_get\_functor()}, followed by testing the functor, but easier to write and faster.

int PL_is_list(term_t)
    Returns non-zero if \texttt{term} is a compound term with functor \texttt{/2} or the atom \texttt{[]}.

int PL_is_atomic(term_t)
    Returns non-zero if \texttt{term} is atomic (not variable or compound).

int PL_is_number(term_t)
    Returns non-zero if \texttt{term} is an integer or float.
\end{verbatim}

\textbf{Reading data from a term}

The functions \texttt{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.

\begin{verbatim}
int PL_get_atom(term_t +t, atom_t *a)
    If \texttt{t} is an atom, store the unique atom identifier over \texttt{a}. See also \texttt{PL\_atom\_chars()} and \texttt{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.

int PL_get_atom_chars(term_t +t, char **s)
    If \texttt{t} is an atom, store a pointer to a 0-terminated C-string in \texttt{s}. It is explicitly \texttt{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.
\end{verbatim}
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#### PL_get_string(term_t t, char **s, int *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 save operations are to pass it immediately to a C-function that doesn’t involve Prolog.

#### 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 converted and the second how the argument is stored. Below is a specification of these constants. \texttt{BUF\_RING} implies, if the data is not static (as from an atom), the data is copied to the next buffer from a ring of four (4) buffers. This is a convenient way of converting multiple arguments passed to a foreign predicate to C-strings. If \texttt{BUF\_MALLOC} is used, the data must be freed using \texttt{free()} when not needed any longer.

<table>
<thead>
<tr>
<th>CVT_AMD</th>
<th>Convert if term is an atom</th>
</tr>
</thead>
<tbody>
<tr>
<td>CVT_STRING</td>
<td>Convert if term is a string</td>
</tr>
<tr>
<td>CVT_LIST</td>
<td>Convert if term is a list of integers between 1 and 255</td>
</tr>
<tr>
<td>CVT_INTEGER</td>
<td>Convert if term is an integer (using %d)</td>
</tr>
<tr>
<td>CVT_FLOAT</td>
<td>Convert if term is a float (using %f)</td>
</tr>
<tr>
<td>CVT_NUMBER</td>
<td>Convert if term is an integer or float</td>
</tr>
<tr>
<td>CVT_ATOMIC</td>
<td>Convert if term is atomic</td>
</tr>
<tr>
<td>CVT_VARIABLE</td>
<td>Convert variable to print-name</td>
</tr>
<tr>
<td>CVT_ALL</td>
<td>Convert if term is any of the above, except for variables</td>
</tr>
<tr>
<td>BUF_DISCARDABLE</td>
<td>Data must copied immediately</td>
</tr>
<tr>
<td>BUF_RING</td>
<td>Data is stored in a ring of buffers</td>
</tr>
<tr>
<td>BUF_MALLOC</td>
<td>Data is copied to a new buffer returned by malloc(3)</td>
</tr>
</tbody>
</table>

#### PL_get_list_chars(term_t l, char **s, unsigned flags)

Same as \texttt{PL_get_chars} \( l, s, CVT\_LIST—flags \), provided flags contains no of the CVT_* flags.

#### PL_get_integer(term_t t, int *i)

If \( t \) is a Prolog integer, assign its value over \( i \). On 32-bit machines, this is the same as \texttt{PL_get_long()}, but avoids a warning from the compiler. See also \texttt{PL_get_long()}.

#### PL_get_long(term_t t, long *i)

If \( t \) is a Prolog integer, assign its value over \( i \). Note that Prolog integers have limited value-range. If \( t \) is a floating point number that can be represented as a long, this function succeeds as well.

#### PL_get_pointer(term_t t, void **ptr)

In the current system, pointers are represented by Prolog integers, but need some manipulation to make sure they do not get truncated due to the limited Prolog integer range. \texttt{PL_put_pointer()}/\texttt{PL_get_pointer()} guarantees pointers in the range of malloc() are handled without truncating.

#### PL_get_float(term_t t, double *f)

If \( t \) is a float or integer, its value is assigned over \( f \).
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, int *arity)
If t is compound or an atom, the functor-name will be assigned over name and the arity over arity. See also PL_get_functor() and PL_is_functor().

int PL_get_module(term_t *t, module_t *module)
If t is an atom, the system will lookup or create the corresponding module and assign an opaque pointer to it over module.

int PL_get_arg(int index, term_t *t, term_t -a)
If t is compound and index is between 1 and arity (including), assign a with a term-reference to the argument.

int _PL_get_arg(int index, term_t *t, term_t -a)
Same as PL_get_arg(), but no checking is performed, nor whether t is actually a term, nor whether index is a valid argument-index.

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(); /* variable for the elements */
  term_t list = PL_copy_term_ref(l); /* copy as we need to write */

  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 [] */
}
```

int PL_get_list(term_t *l, term_t -h, term_t -t)
If l is a list and not [] 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 [] 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 [] assign a term-reference to the tail to t.

int PL_get_nil(term_t +l)
    Succeeds if represents the atom [].

An example: defining write/1 in C

Figure 5.3 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.

5.6.4 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.

void PL_put_variable(term_t -t)
    Put a fresh variable in the term. The new variable lives on the global stack. Note that the initial variable lives on the local stack and is lost after a write to the term-references. After using this function, the variable will continue to live.

void 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().

void PL_put_atom_chars(term_t -t, const char *chars)
    Put an atom in the term-reference constructed from the 0-terminated string. The string itself will never be references by Prolog after this function.

void 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().

void PL_put_string_nchars(term_t -t, unsigned int 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 5.6.17.

void PL_put_list_chars(term_t -t, const char *chars)
    Put a list of ASCII values in the term-reference.

void PL_put_integer(term_t -t, long i)
    Put a Prolog integer in the term reference.

void 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.
```c
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(" ");
                break;
            default:
                PL_fail;
                /* should not happen */
            } break;
    }

    PL_succeed;
}
```

Figure 5.3: A Foreign definition of display/1
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void **PL_put_float(term_t -t, double f)
Put a floating-point value in the term-reference.

void **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().

void **PL_put_list(term_t -l)
Same as **PL_put_functor(l, **PL_new_functor(**PL_new_atom(".")", 2)).

void **PL_put_nil(term_t -l)
Same as **PL_put_atom_chars("[]").

void **PL_put_term(term_t -t1, term_t +t2)
Make t1 point to the same term as t2.

void **PL_cons_functor(term_t -h, functor_t f, . . .)
Create a term, whose arguments are filled from 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:

```
   term_t a1 = **PL_new_term_ref();
   term_t a2 = **PL_new_term_ref();
   term_t t = **PL_new_term_ref();
   **PL_put_atom_chars(a1, "gnu");
   **PL_put_integer(a2, 50);
   **PL_cons_functor(t, **PL_new_functor(**PL_new_atom("animal")", 2),
                      a1, a2);
```

After this sequence, the term-references a1 and a2 may be used for other purposes.

void **PL_cons_functor_v(term_t -h, functor_t f, term_t a0)
Creates 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.

void **PL_cons_list(term_t -l, term_t +h, term_t +t)
Create a list (cons-) cell in l from the head and tail. 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.

```
void
put_list(term_t l, int n, char **words)
{ term_t a = **PL_new_term_ref();

   **PL_put_nil(l);
   while ( --n >= 0 )
       { **PL_put_atom_chars(a, words[n]);
```
Note that $l$ can be redefined within a `PL_cons_list` call as shown here because operationally its old value is consumed before its new value is set.

### 5.6.5 Unifying data

The functions of this section unify terms with other terms or translated C-data structures. Except for `PL_unify()`, the functions of this section are specific to SWI-Prolog. They have been introduced to make translation of old code easier, but also because they provide for a faster mechanism for returning data to Prolog that requires less term-references. 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, buf);
    }
    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;
}
```

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- `int PL_unify(term_t ?t1, term_t ?t2)`
  Unify two Prolog terms and return non-zero on success.

- `int PL_unify_atom(term_t ?t, atom_t a)`
  Unify $t$ with the atom $a$ and return non-zero on success.
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```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().

void PL_unify_string_nchars(term_t t, unsigned int len, const char *chars)
    Unify t with a Prolog string object created from the string created from the len/chars pair. The data will be copied. This interface can deal with 0-bytes in the string. See also section 5.6.17.

int PL_unify_integer(term_t t, long n)
    Unify t with a Prolog integer from n.

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 fails. Not that this function does not create a term if the argument is already instantiated.

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 to h and a reference to the tail of the list in 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.

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) )
    ...
```
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 is 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.

The type identifiers are:

PL_VARIABLE none
    No op. Used in arguments of PL_FUNCTOR.

PL_ATOM atom t
    Unify the argument with an atom, as in PL_unify_atom().

PL_INTEGER long
    Unify the argument with an integer, as in PL_unify_integer().

PL_FLOAT 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_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 the return value of a PL_new_term_ref() call to get access to a variable.

PL_CHARS const char *
    Unify the argument with an atom, constructed from the C char *, as in PL_unify_atom_chars().

PL_FUNCTOR functor t, ...
    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.

PL_LIST int length, ...
    Create a list of the indicated length. The following arguments contain the elements of the list.
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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();
}
```

5.6.6 Calling Prolog from C

The Prolog engine can be called from C. There are to interfaces for this. For the first, a term is created that could be used as an argument to call/1 and next 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 defined or not, redefined, etc., a Prolog predicate has a handle that is not destroyed, nor moved. This handle is known by the type `predicate_t`.

```c
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. This function always succeeds, creating a handle for an undefined predicate if no handle was available.

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, int *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 \texttt{PL\_predicate()}. If the predicate was imported into the module given to \texttt{PL\_predicate()}, this function will return the module where the predicate was defined.

**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 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 \texttt{PL\_next\_solution()}. Be sure to call \texttt{PL\_cut\_query()} or \texttt{PL\_close\_query()} on any query you opened before opening the next or returning control back to Prolog.

\texttt{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. This function always succeeds, regardless whether the predicate is defined or not. \texttt{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 \texttt{module\_transparent} predicates. See \texttt{context\_module/1} and \texttt{module\_transparent/1}. The \texttt{p} argument specifies the predicate, and should be the result of a call to \texttt{PL\_pred()} or \texttt{PL\_predicate()}. Note that it is allowed to store this handle as global data and reuse it for future queries. The term-reference \texttt{\_t0} is the first of a vector of term-references as returned by \texttt{PL\_new\_term\_refs(n)}.

The \texttt{flags} arguments provides some additional options concerning debugging and exception handling. It is a bitwise or of the following values:

\begin{itemize}
  \item \texttt{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.\footnote{Do not pass the integer 0 for normal operation, as this is interpreted as \texttt{PL\_Q\_NODEBUG} for backward compatibility reasons.}
  \item \texttt{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 \texttt{print/1} calling \texttt{portray/1} from foreign code.
  \item \texttt{PL\_Q\_CATCH\_EXCEPTION}  
    If an exception is raised while executing the goal, do not report it, but make it available for \texttt{PL\_exception()}.  
  \item \texttt{PL\_Q\_PASS\_EXCEPTION}  
    As \texttt{PL\_Q\_CATCH\_EXCEPTION}, but do not invalidate the exception-term while calling \texttt{PL\_close\_query()}. This option is experimental.
\end{itemize}

The example below opens a query to the predicate \texttt{is\_a/2} to find the ancestor of for some name.
char *
ancestor(const char *me)
{
    term_t a0 = PL_new_termRefs(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.

void PL_cut_query(qid)
Discards the query, but does not delete any of the data created by the query. It just invalidate
qid, allowing for a new call to PL_open_query() in this context.

void PL_close_query(qid)
As PL_cut_query(), but all data and bindings created by the query are destroyed.

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(), generat-
ing 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, module_t)
Call term just like the Prolog predicate once/1. Term is called in the specified module, or in
the context module if module_t = NULL. Returns TRUE if the call succeeds, FALSE otherwise.
Figure 5.4 shows an example to obtain the number of defined atoms. All checks are omitted to
improve readability.

5.6.7 Discarding Data

The Prolog data created and term-references needed to setup the call and/or analyse the result can in
most cases be discarded right after the call. PL_close_query() allows for destructing the data,
while leaving the term-references. The calls below may be used to destroy term-references and data.
See figure 5.4 for an example.

fid_t PL_open_foreign_frame()
Created 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.
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 5.4: Calling Prolog

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.

    It is obligatory to call either of the two closing functions to discard a foreign frame. Foreign frames may be nested.

5.6.8 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.

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 inner most module is returned via module *. If raw is not a module construct arg will simply be put in plain. If module * is NULL it will be set to the context module. Otherwise it will be left untouched. The following example shows how to obtain the plain term and module if the default module is the user module:
5.6. THE FOREIGN INCLUDE FILE

{ 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)
  Return the name of module as an atom.

module_t PL_new_module(atom_t name)
  Find an existing or create a new module with name specified by the atom name.

5.6.9 Prolog exceptions in foreign code

This section discusses PL_exception(), PL_throw() and PL_raise_exception(), the interface functions to detect and generate Prolog exceptions from C-code. PL_throw() and PL_raise_exception() from the C-interface to raise an exception from foreign code. PL_throw() exploits the C-function longjmp() to return immediately to the innermost PL_next_solution(). PL_raise_exception() 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.

Calling these functions outside the context of a function implementing a foreign predicate results in undefined behaviour.

PL_exception() may be used after a call to PL_next_solution() fails, and returns a term reference to an exception term if an exception was raised, and 0 otherwise.

If a C-function, implementing a predicate calls Prolog and detects an exception using PL_exception(), it can handle this exception, or return with the exception. Some caution is required though. It is not allowed to call PL_close_query() or PL_discard_foreign_frame() afterwards, as this will invalidate the exception term. Below is the code that calls a Prolog defined arithmetic function (see arithmetic_function/1).

If PL_next_solution() succeeds, the result is analysed and translated to a number, after which the query is closed and all Prolog data created after PL_open_foreign_frame() is destroyed. On the other hand, if PL_next_solution() fails and if an exception was raised, just pass it. Otherwise generate an exception (PL_error() is an internal call for building the standard error terms and calling PL_raise_exception()). After this, the Prolog environment should be discarded using PL_cut_query() and PL_close_foreign_frame() to avoid invalidating the exception term.

static int prologFunction(ArithFunction f, term_t av, Number r)
{ int arity = f->proc->definition->functor->arity;
  fid_t fid = PL_open_foreign_frame();
  qid_t qid;
  int rval;

  qid = PL_open_query(NULL, PL_Q_NORMAL, f->proc, av);
if (PL_next_solution(qid))
{
  rval = valueExpression(a+arity-1, r);
  PL_close_query(qid);
  PL_discard_foreign_frame(fid);
}
else
{
  term_t except;

  if ( (except = PL_exception(qid)) )
  {
    rval = PL_throw(except);  /* pass exception */
  }
  else
  {
    char *name = stringAtom(f->proc->definition->functor->name);
    /* generate exception */
    rval = PL_error(name, arity-1, NULL, ERR_FAILED, f->proc);
  }

  PL_cut_query(qid);         /* donot destroy data */
  PL_close_foreign_frame(fid);         /* same */
}

return rval;

int PL_raise_exception(term_t exception)
Generate an exception (as throw/1) and return FALSE. Below is an example returning an exception from foreign predicate:

foreign_t
pl_hello(term_t to)
{
  char *s;

  if (PL_get_atom_chars(to, &s))
  {
    Sprintf("Hello \\
    "s"
    \\
    n", s);

    PL_succeed;
  }
  else
  {
    term_t except = PL_new_term_ref();

    PL_unify_term(except,
      PL_FUNCTOR, PL_new_functor(PL_new_atom("type_error"), 2),
      PL_CHARS, "atom",
      PL_TERM, to);

    return PL_raise_exception(except);
  }
}
int PL_throw(term_t exception)
    Similar to PL_raise_exception(), but returns using the C longjmp() function to the innermost PL_next_solution().

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 0 if the Prolog goal simply failed.3

5.6.10 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.

Recorded database

The interface functions below provide for efficient management of Prolog terms in the Prolog database. They provide an alternative to calling asserta/1 or recorda/3 or friends.

record_t PL_record(term_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.

void 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. 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 resources.

5.6.11 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 3.9. 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.

Some versions of SWI-Prolog, notably running on popular Unix platforms, handle SIG_SEGV for guarding the Prolog stacks. If the application whishes to handle this signal too, it should use PL_signal() to install its handler after initialisating Prolog. SWI-Prolog will pass SIG_SEGV to the user code if it detected the signal is not related to a Prolog stack overflow.

Any handler that wishes to call one of the Prolog interface functions should call PL_signal() for its installation.

3This interface differs in two ways from Quintus. The calling predicates simp,y signal failure if an exception was raised, and a term referenced is returned, rather passed and filled with the error term. Exceptions can only be handled using the PL_next_solution() interface, as a handle to the query is required.
void (*)() \texttt{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.

5.6.12 Errors and warnings

\texttt{PL\_warning()} prints a standard Prolog warning message to the standard error (user\_error) stream. Please note that new code should consider using \texttt{PL\_raise\_exception()} to raise a Prolog exception. See also section 3.8.

\texttt{int PL\_warning(format, a1, \ldots)}
Print an error message starting with ‘[WARNING: ’, followed by the output from \texttt{format}, followed by a ’]’ and a newline. Then start the tracer. \texttt{format} and the arguments are the same as for \texttt{printf(2)}. Always returns FALSE.

5.6.13 Environment Control from Foreign Code

\texttt{int PL\_action(int, \ldots)}
Perform some action on the Prolog system. \texttt{int} describes the action, Remaining arguments depend on the requested action. The actions are listed in table 5.1.

5.6.14 Querying Prolog

\texttt{C\_type PL\_query(int)}
Obtain status information on the Prolog system. The actual argument type depends on the information required. \texttt{int} describes what information is wanted. The options are given in table 5.2.

5.6.15 Registering Foreign Predicates

\texttt{int PL\_register\_foreign(name, arity, function, flags)}
Register a C-function to implement a Prolog predicate. After this call returns successfully a predicate with name \texttt{name} (a char *) and arity \texttt{arity} (a C int) is created. When called in Prolog, Prolog will call \texttt{function}. \texttt{flags} forms bitwise or’ed list of options for the installation. These are:

<table>
<thead>
<tr>
<th>\texttt{PL_FA_NOTRACE}</th>
<th>Predicate cannot be seen in the tracer</th>
</tr>
</thead>
<tbody>
<tr>
<td>\texttt{PL_FA_TRANSPARENT}</td>
<td>Predicate is module transparent</td>
</tr>
<tr>
<td>\texttt{PL_FA_NONDETERMINISTIC}</td>
<td>Predicate is non-deterministic. See also \texttt{PL_retry()}</td>
</tr>
</tbody>
</table>

\texttt{void PL\_register\_extensions(PL\_extension *e)}
Register foreign predicates from a table of structures. The type \texttt{PL\_extension} is defined as:

```c
typedef struct _PL_extension
{ char *predicate_name; /* Name of the predicate */
  short arity; /* Arity of the predicate */

```

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<table>
<thead>
<tr>
<th>PL_ACTION_TRACE</th>
<th>Start Prolog tracer (trace/0). Requires no arguments.</th>
</tr>
</thead>
<tbody>
<tr>
<td>PL_ACTION_DEBUG</td>
<td>Switch on Prolog debug mode (debug/0). Requires no arguments.</td>
</tr>
<tr>
<td>PL_ACTION_BACKTRACE</td>
<td>Print backtrace on current output stream. The argument (an int) is the number of frames printed.</td>
</tr>
<tr>
<td>PL_ACTION_HALT</td>
<td>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.</td>
</tr>
<tr>
<td>PL_ACTION_ABORT</td>
<td>Generate a Prolog abort (abort/0). This call does not return. Requires no arguments.</td>
</tr>
<tr>
<td>PL_ACTION_BREAK</td>
<td>Create a standard Prolog break environment (break/0).</td>
</tr>
<tr>
<td></td>
<td>Returns after the user types the end-of-file character. Requires no arguments.</td>
</tr>
<tr>
<td>PL_ACTION_GUIAPP</td>
<td>Win32: Used to indicate 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 simply prints the error and exits otherwise.</td>
</tr>
<tr>
<td>PL_ACTION_WRITE</td>
<td>Write the argument, a char * to the current output stream.</td>
</tr>
<tr>
<td>PL_ACTION_FLUSH</td>
<td>Flush the current output stream. Requires no arguments.</td>
</tr>
</tbody>
</table>

Table 5.1: PL_action() options

<table>
<thead>
<tr>
<th>PL_QUERY_ARGC</th>
<th>Return an integer holding the number of arguments given to Prolog from Unix.</th>
</tr>
</thead>
<tbody>
<tr>
<td>PL_QUERY_ARGV</td>
<td>Return a char ** holding the argument vector given to Prolog from Unix.</td>
</tr>
<tr>
<td>PL_QUERY_SYMBOLFILE</td>
<td>Return a char * holding the current symbol file of the running process.</td>
</tr>
<tr>
<td>PL_MAX_INTEGER</td>
<td>Return a long, representing the maximal integer value represented by a Prolog integer.</td>
</tr>
<tr>
<td>PL_MIN_INTEGER</td>
<td>Return a long, representing the minimal integer value.</td>
</tr>
<tr>
<td>PL_QUERY_VERSION</td>
<td>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, 2.07.17 means 2.07.17.</td>
</tr>
</tbody>
</table>

Table 5.2: PL_query() options
pl_function_t function;  /* Implementing functions */
short flags;  /* Or of PL_FA_... */
} PL_extension;

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(predicates);
    if ( !PL_initialise(argc, argv) )
        PL_halt(1);
    ...
}

The function PL_register_extensions() is the only PL_* function that may be called
before PL_initialise(). The functions are registered after registration of the SWI-Prolog
builtin foreign predicates and before loading the initial saved state. This implies that
initialization/1 directives can refer to them.

5.6.16 Foreign Code Hooks

For various specific applications some hooks re 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 sup-
possed to dispatch events when SWI-Prolog is connected to a window environment. It can re-
turn 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:

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 toplevel is reinvoked. The type
PL_abort_hook_t is defined as:

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.

5.6.17 Storing foreign data

This section provides some hints for handling foreign data in Prolog. With foreign data, we refer to data that is used by foreign language predicates and needs to be passed around in Prolog. Excluding combinations, there are three principal options for storing such data

- **Natural Prolog data**
  E.i. using the representation one would choose if there was no foreign interface required.

- **Opaque packed Prolog data**
  Data can also be represented in a foreign structure and stored on the Prolog stacks using PL_put_string_nchars() and retrieved using PL_get_string_chars(). It is generally good practice to wrap the string in a compound term with arity 1, so Prolog can identify the type. portray/1 rules may be used to streamline printing such terms during development.

- **Natural foreign data, passing a pointer**
  An alternative is to pass a pointer to the foreign data. Again, this functor may be 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 of which Prolog never examines the contents of the data itself. If the data is opaque to Prolog, the chosen representation does not depend on simple analysis by Prolog, and the selection will be driven solely by simplicity of the interface and performance (both in time and space).

- **How big is the data**
  Is efficient encoding required? For examine, a boolean array may be expressed as a compound term, holding integers each of which contains a number of bits, or as a list of true and false.

- **What is the nature of the data**
  For examples in C, constants are often expressed using ‘enum’ or #define’d integer values. If prolog needs to handle this data, atoms are a more logical choice. Whether or not this mapping is used depends on whether Prolog needs to interpret the data, how important debugging is and how important performance is.

- **What is the lifetime of the data**
  We can distinguish three cases.

  1. The lifetime is dictated by the accessibility of the data on the Prolog stacks. Their is no way by which the foreign code when the data becomes ‘garbage’, and the data thus needs to be represented on the Prolog stacks using Prolog data-types. (2),
  2. The data lives on the ‘heap’ and is explicitly allocated and deallocated. In this case, representing the data using native foreign representation and passing a pointer to it is a sensible choice.
3. The data lives as during the lifetime of a foreign 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 5.6.1.

Examples for storing foreign data

In this section, we will 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. In the second example, we look at handling a 'netmask'. Finally, we discuss the outline of the DDE interface.

**Integer sets** with not-to-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 bitvectors. This can be done in Prolog, using a compound term holding integer arguments. Especially if the integers are kept below the maximum tagged integer value (see feature/2), this representation is fairly space-efficient (wasting 1 word for the functor and and 7 bits per integer for the tags). Arithmetic can all be performed in Prolog too.

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, lower-bound of the vector is 0, and the upperbound 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);
```

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`return PL_unify_string_nchars(a, len, (const char *)data);`

`PL_fail;`

```c
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 unify_bitvector(u, l, s3);
        }
        return PL_warning("Not enough memory");
    }

    return PL_fail;
}
```

`install_t
install()
{
    PL_register_foreign("bitvector_union", 3, pl_bitvector_union, 0);

    FUNCTOR_bitvector1 = PL_new_functor(PL_new_atom("bitvector"), 1);
}

**Netmask's** are used with TCP/IP configuration. Suppose we have an application dealing with reasoning about a network configuration. Such an application requires communicating netmask struc-
tures from the operating system, reasoning about them and possibly communicate them to the user. A netmask consists of 4 bitmasks between 0 and 255. C-application normally see them as an 4-byte wide unsigned integer. SWI-Prolog cannot do that, as integers are always signed.

We could use the string approach outlined above, but this makes it hard to handle these terms in Prolog. A better choice is a compound term netmask/4, holding the 4 submasks as integer arguments.

As the implementation is trivial, we will omit this here.

The DDE interface (see section 3.43) 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 contains 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 using 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, not to verify 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.

5.6.18 Embedding SWI-Prolog in a C-program

As of version 2.1.0, SWI-Prolog may be embedded in a C-program. To reach at a compiled C-program with SWI-Prolog as an embedded application is very similar to creating a statically linked SWI-Prolog executable as described in section 5.4.1.

The file ./include/stub.c defines SWI-Prologs default main program:

```c
int main(int argc, char **argv)
{
  if ( !PL_initialise(argc, argv) )
    PL_halt(1);

  PL_install_readline();        /* delete if you don’t want read-
                                line */

  PL_halt(PL_toplevel() ? 0 : 1);
}
```

This may be replaced with your own main C-program. The interface function PL_initialise() must be called before any of the other SWI-Prolog foreign language functions described in this chapter. PL_initialise() interprets all the command-line arguments, except for the -t toplevel flag that is interpreted by PL_toplevel().

```c
int PL_initialise(int argc, char **argv, char **environ)
{
  Initialises the SWI-Prolog heap and stacks, restores the boot QLF file, loads the system and
```
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personal initialisation files, runs the at_initialization/1 hooks and finally runs the
-g goal hook.

PL_initialise() returns 1 if all initialisation succeeded and 0 otherwise. Various fatal
errors may cause PL_initialise to call PL_halt(1), preventing it from returning at all.

void PL_install_readline()
Installs the GNU-readline line-editor. Embedded applications that do not use the Prolog toplevel
should normally delete this line, shrinking the Prolog kernel significantly.

int PL_toplevel()
Runs the goal of the -t toplevel switch (default prolog/0) and returns 1 if successful,
0 otherwise.

void PL_halt(int status)
Cleanup the Prolog environment and calls exit() with the status argument.

5.7 Linking embedded applications using plld

The utility program plld (Win32: plld.exe) may be used to link a combination of C-files and Prolog
files into a stand-alone executable. plld automates most of what is described in the previous sections.

In the normal usage, a copy is made of the default embedding template \ldots/pl/include/
stub.c. The main() routine is modified to suit your application. PL_initialise() must
be passed the program-name (argv[0]) (Win32: the executing program can be obtained using
GetModuleFileName()). The other elements of the command-line may be modified. Next, plld
is typically invoked as:

plld -o output stubfile.c [other-c-or-o-files] [plfiles]

plld 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.

-help
Print brief synopsis.

-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.

-ld linker
Linker used to link the raw executable. Default is to use the C-compiler (Win32: link.exe).

-cc C-compiler
Compiler for .c files found on the commandline. Default is the compiler used to build SWI-
Prolog (see feature/2) (Win32: cl.exe).
-c++ C++ compiler
Compiler for C++ sources (extensions .cpp, .cxx, .cc or .C) files found on the command-line. Default is c++ or g++ if the C-compiler is gcc (Win32: cl.exe).

-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 plld. In the latter case the state is created separately and appended to the kernel using cat (kernel) (state) > (out) (Win32: copy /b (kernel)+(state) (out))

-pl-options, ...
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 passed -F xpce as additional flags to Prolog.

-ld-options, ...
Passes options to the linker, similar to -pl-options.

-cc-options, ...
Passes options to the C/C++ compiler, similar to -pl-options.

-v
Select verbose operation, showing the various programs and their options.

-o outfile
Reserved to specify the final output file.

-library
Specifies a library for the C-compiler. By default, -lpl (Win32: libpl.lib) and the libraries needed by the Prolog kernel are given.

-library-directory
Specifies a library directory for the C-compiler. By default the directory containing the Prolog C-library for the current architecture is passed.

-g | -Iinclude-directory | -Ddefinition
These options are passed to the C-compiler. By default, the include directory containing SWI-Prolog.h is passed. plld adds two additional * -Ddef flags:

-D__SWI_PROLOG__
Indicates the code is to be connected to SWI-Prolog.

-D__SWI_EMBEDDED__
Indicates the creation of an embedded program.

*.o | *.c | *.C | *.cxx | *.cpp
Passed as input files to the C-compiler

*.pl | *.qlf
Passed as input files to the Prolog compiler to create the saved-state.
5.8. 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 lower case letters. Figure 5.6 shows the C-source file, figure 5.7 illustrates compiling and loading of foreign code.
```c
#include <stdio.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 5.5: C source for the calc application
/* Include file depends on local installation */
#include <SWI-Prolog.h>
#include <stdlib.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);

    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_fori
Fig 5.6: Lowercase source file

% gcc -I/usr/local/lib/pl-\plversion/include -fpic -c lowercase.c
% gcc -shared -o lowercase.so lowercase.o
% pl
Welcome to SWI-Prolog (Version \plversion)
Copyright (c) 1993-1996 University of Amsterdam. All rights reserved.

For help, use ?- help(Topic). or ?- apropos(Word).

1 ?- load_foreign_library(lowercase).
Yes
2 ?- lowercase('Hello World!', L).
L = 'hello world!'
Yes

Figure 5.7: Compiling the C-source and loading the object file
5.9. NOTES ON USING FOREIGN CODE

5.9 Notes on Using Foreign Code

5.9.1 Memory Allocation

SWI-Prolog’s memory allocation is based on the `malloc(3)` library routines. Foreign applications can safely use `malloc(3)`, `realloc(3)` and `free(3)`. Memory allocation using `brk(2)` or `sbrk(2)` is not allowed as these calls conflict with `malloc(3)`.

5.9.2 Debugging Foreign Code

Statically linked foreign code or embedded systems can be debugged normally. Most modern environments provide debugging tools for dynamically loaded shared objects or dynamic load libraries. The following example traces the code of lowercase using `gdb(1)` in a Unix environment.

```
% gcc -I/usr/local/lib/pl-2.2.0/include -fpic -c -g lowercase.c
% gcc -shared -o lowercase.so lowercase.o
% gdb pl
(gdb) r
Welcome to SWI-Prolog (Version \plversion)
Copyright (c) 1993-1996 University of Amsterdam. All rights reserved.

For help, use ?- help(Topic). or ?- apropos(Word).

?- load_foreign_library(lowercase).
<type Control-C>
(gdb) shared % loads symbols for shared objects
(gdb) break pl_lowercase
(gdb) continue
?- lowercase('HELLO', X).
```

5.9.3 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 to 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.

```
#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.

5.9.4 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 uses ⟨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:

#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_term_refs(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.
This chapter describes the features of SWI-Prolog for delivering applications that can run without the development version of the system installed.

A SWI-Prolog runtime executable is a file consisting of two parts. The first part is the emulator, which is machine dependent. The second part is the resource archive, which contains the compiled program in a machine-independent format, startup options and possibly user-defined resources, see resource/3 and open_resource/3.

These two parts can be connected in various different ways. The most common way for distributed runtime applications is to concatenate the two parts. This can be achieved using external commands (Unix: cat, Windows: copy), or using the stand_alone option to qsave_program/2. The second option is to attach a startup script in front of the resource that starts the emulator with the proper options. This is the default under Unix. Finally, an emulator can be told to use a specified resource file using the -x commandline switch.

qsave_program(+File, +ListOfOptions)

Saves the current state of the program to the file File. The result is a resource archive containing a saved-state that expresses all Prolog data from the running program and all user-defined resources. Depending on the stand_alone option, the resource is headed by the emulator, a Unix shell-script or nothing.

ListOfOptions is a list of ⟨Key⟩ = ⟨Value⟩ or ⟨Key⟩(⟨Value⟩) pairs. The available keys are described in table 6.1.

Before writing the data to file, qsave_program/2 will run autoload/0 to all required autoloading the system can discover. See autoload/0.

Provided the application does not require any of the Prolog libraries to be loaded at runtime, the only file from the SWI-Prolog development environment required is the emulator itself. The emulator may be built in two flavours. The default is the development emulator. The runtime emulator is similar, but lacks the tracer.

If the option stand_alone(on) is present, the emulator is the first part of the state. If the emulator is started it will test whether a boot-file (state) is attached to the emulator itself and load this state. Provided the application has all libraries loaded, the resulting executable is completely independent of the runtime environment or location where it was build.

See also section 2.10.2.

qsave_program(+File)

Equivalent to qsave_program(File, []).
### Table 6.1: \langle Key \rangle = \langle Value \rangle pairs for qsave_program/2

This predicate is used by qsave_program/[1,2] to ensure the saved state will not depend on one of the libraries. The predicate autoload/0 will find all **direct** references to predicates. It does not find predicates referenced via meta-predicates. The predicate log/2 is defined in the library(quintus) to provide a quintus compatible means to compute the natural logarithm of a number. The following program will behave correctly if its state is executed in an environment where the library(quintus) is not available:

```prolog
logtable(From, To) :-
  From > To, !.
logtable(From, To) :-
  log(From, Value),
  format('d\t8\tt2f\tn', [From, Value]),
  F is From + 1,
  logtable(F, To).
```

However, the following implementation refers to log/2 through the meta-predicate maplist/3. Autoload will not be able to find the reference. This problem may be fixed either by loading the module library(quintus) explicitly or use require/1 to tell the system that the predicate log/2 is required by this module.

```prolog
logtable(From, To) :-
  findall(X, between(From, To, X), Xlist),
```

---

<table>
<thead>
<tr>
<th>Key</th>
<th>Option</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>local</td>
<td>-L</td>
<td>K-bytes</td>
<td>Size (Limit) of local stack</td>
</tr>
<tr>
<td>global</td>
<td>-G</td>
<td>K-bytes</td>
<td>Size (Limit) of global stack</td>
</tr>
<tr>
<td>trail</td>
<td>-T</td>
<td>K-bytes</td>
<td>Size (Limit) of trail stack</td>
</tr>
<tr>
<td>argument</td>
<td>-A</td>
<td>K-bytes</td>
<td>Size (Limit) of argument stack</td>
</tr>
<tr>
<td>goal</td>
<td>-g</td>
<td>atom</td>
<td>Initialisation goal</td>
</tr>
<tr>
<td>toplevel</td>
<td>-t</td>
<td>atom</td>
<td>Prolog toplevel goal</td>
</tr>
<tr>
<td>init_file</td>
<td>-f</td>
<td>atom</td>
<td>Personal initialisation file</td>
</tr>
<tr>
<td>class</td>
<td></td>
<td>atom</td>
<td>If runtime, only read resources from the state (default). If kernel, lock all predicates as system predicates If development, change the predicates in their current state and keep reading resources from their source (if present). See also resource/3.</td>
</tr>
<tr>
<td>autoload</td>
<td></td>
<td>bool</td>
<td>If true, run autoload/0 first</td>
</tr>
<tr>
<td>map</td>
<td></td>
<td>file</td>
<td>File to write info on dump</td>
</tr>
<tr>
<td>op</td>
<td></td>
<td>save/standard</td>
<td>Save operator declarations?</td>
</tr>
<tr>
<td>stand_alone</td>
<td></td>
<td>bool</td>
<td>Include the emulator in the state</td>
</tr>
<tr>
<td>emulator</td>
<td></td>
<td>file</td>
<td>Emulator attached to the (stand-alone) executable. Default is the running emulator.</td>
</tr>
</tbody>
</table>
6.1 Limitations of qsave_program

There are three areas that require special attention when using 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 6.2 for details.

- If the program uses directives (:- goal. lines) that perform other actions then setting predicate attributes (dynamic, volatile, etc.) or loading files (consult, etc.), the directive may need to be prefixed with initialization/1.

- Database references as returned by clause/3, recorded/3, etc. are not preserved and may thus not be part of the database when saved.

6.2 Runtimes and Foreign Code

Some applications may need to use the foreign language interface. Object code is by definition machine-dependent and thus cannot be part of the saved program file.

To complicate the matter even further there are various ways of loading foreign code:

- Using the library(shlib) predicates
  This is the preferred way of dealing with foreign code. It loads quickly and ensures an acceptable level of independence between the versions of the emulator and the foreign code loaded. It works on Unix machines supporting shared libraries and library functions to load them. Most modern Unices, as well as Win32 (Windows 95/NT) satisfy this constraint.

- Static linking
  This mechanism works on all machines, but generally requires the same C-compiler and linker to be used for the external code as is used to build SWI-Prolog itself.

To make a runtime executable that can run on multiple platforms one must make runtime checks to find the correct way of linking. Suppose we have a source-file myextension defining the installation function install().

If this file is compiled into a shared library, load_foreign_library/1 will load this library and call the installation function to initialise the foreign code. If it is loaded as a static extension, define install() as the predicate install/0:
static foreign_t
pl_install()
{ install();
    PL_succeed;
}

PL_extension PL_extensions [] =
{
    /* "name", arity, function, PL_FA_<flags> */,*/
    { "install", 0, pl_install, 0 },
    { NULL, 0, NULL, 0 } /* terminating line */
};

Now, use the following Prolog code to load the foreign library:

load_foreign_extensions :-
    current_predicate(install, install), !, % static loaded
    install.
load_foreign_extensions :- % shared library
    load_foreign_library(foreign(myextension)).

:- initialization load_foreign_extensions.

The path alias foreign is defined by file_search_path/2. By default it searches the directories
/home/lib/arch and /home/lib. The application can specify additional rules for file_search_path/2.

6.3 Using program resources

A resource is very 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).

A resource has a name and a class. The source data of the resource is a file. Resources are declared
by declaring the predicate resource/3. They are accessed using the predicate open_resource/3.

Before going into details, let us start with an example. Short texts can easily be expressed in
Prolog sourcecode, but long texts are cumbersome. Assume our application defines a command ‘help’
that prints a helptext to the screen. We put the content of the helptext into a file called help.txt.
The following code implements our help command such that help.txt is incorporated into the runtime
executable.

resource(help, text, ’help.txt’).

help :-
    open_resource(help, text, In),

copy_stream(In, user_output),
close(In).

copy_stream(In, Out) :-
get0(In, C),
copy_stream(C, In, Out).

copy_stream(-1, _, _) :- !.
copy_stream(C, In, Out) :-
put(Out, C),
get0(In, C2),
copy_stream(C2, In, Out).

The predicate `help/0` opens the resource as a Prolog stream. If we are executing this from the development environment, this will actually return a stream to the `gelp.txt` itself. When executed from the saved-state, the stream will actually be a stream opened on the program resource file, taking care of the offset and length of the resource.

### 6.3.1 Predicates Definitions

**resource(+Name, +Class, +FileSpec)**

This predicate is defined as a dynamic predicate in the module `user`. Clauses for it may be defined in any module, including the user module. `Name` is the name of the resource (an atom). `Name` is the name of the resource (an atom).

A resource name may contain all characters, except for $ and :, which are reserved for internal usage by the resource library. `Class` describes what kind of object we are dealing with. In the current implementation, it is just an atom. `FileSpec` is a file specification that may exploit `file_search_path/2` (see `absolute_file_name/2`).

Normally, resources are defined as unit clauses (facts), but the definition of this predicate can also imply rules. For proper generation of the saved state generation, it must be possible to enumerate the available resources by calling this predicate with all its arguments unbound.

Dynamic rules can be useful to turn all files in a certain directory into resources, without specifying a resources for each file. For example, assume the `file_search_path/2` icons refers to the resource directory containing (XPM) icons. The following definition makes all these images available as resources:

resource(Name, image, icons(XpmName)) :-
atom(Name), !,
file_name_extension(Name, xpm, XpmName).

resource(Name, image, XpmFile) :-
var(Name),
absolute_file_name/icons(.), [type(directory)], Dir)
concat(Dir, '/*.xpm', Pattern),
expand_file_name(Pattern, XpmFiles),
member(XpmFile, XpmFiles).
open_resource(+Name, ?Class, -Stream)

Opens the resource specified by Name and Class. If the latter is a variable, it will be unified to the class of the first resource found that has the specified Name. If successful, Stream becomes a handle to a binary input stream, providing access to the content of the resource.

The predicate open_resource/3 first checks resource/3. When successful it will open the returned resource source-file. Otherwise it will look in the programs 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 affect the running environment, while the runtime system quickly accesses the system resources.

6.3.2 The plrc program

The utility program plrc can be used to examine and manipulate the contents of a SWI-Prolog resource file. The options are inspired by the Unix ar program. The basic command is:

% plrc option resource-file member ...

The options are described below.

l

List contents of the archive.

x

Extract named (or all) members of the archive into the current directory.

a

Add files to the archive. If the archive already contains a member with the same name, the contents is replaced. Anywhere in the sequence of members, the options --class=class and --encoding=encoding may appear. They affect the class and encoding of subsequent files. The initial class is data and encoding none.

d

Delete named members from the archive.

This command is also described in the pl(1) Unix manual page.

6.4 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 -palias command-line argument is the preferred way to locate runtime files. The first step is to define an alias for the toplevel directory of your application. We will call this directory gnatdir in our examples.

A good place for storing data associated with SWI-Prolog runtime systems is below the emulator’s home-directory. swi is a predefined alias for this directory. The following is a useful default definition for the search path.

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6.5. THE RUNTIME ENVIRONMENT

```
user:file_search_path(gnatdir, swi(gnat)).
```

The application should locate all files using `absolute_file_name`. Suppose `gnatdir` contains a file `config.pl` to define local configuration. Then use the code below to load this file:

```
configure_gnat :-
   ( absolute_file_name(gnatdir('config.pl'), ConfigFile)
     -> consult(ConfigFile)
   ; format(user_error, 'gnat: Cannot locate config.pl
     , halt(1)
   ).
```

### 6.4.1 Passing a path to the application

Suppose the system administrator has installed the SWI-Prolog runtime environment in `/usr/local/lib/rt-pl-3.2.0`. A user wants to install `gnat`, but `gnat` will look for its configuration in `/usr/local/lib/rt-pl-3.2.0/gnat` where the user cannot write.

The user decides to install the `gnat` runtime files in `/users/bob/lib/gnat`. For one-time usage, the user may decide to start `gnat` using the command:

```
% gnat -p gnatdir=/users/bob/lib/gnat
```

### 6.5 The Runtime Environment

#### 6.5.1 The Runtime Emulator

The sources may be used to build two versions of the emulator. By default, the `development emulator` is built. This emulator contains all features for interactive development of Prolog applications. If the system is configured using `--enable-runtime`, `make(1)` will create a `runtime version` of the emulator. This emulator is equivalent to the development version, except for the following features:

- **No input editing**
  The GNU library `-lreadline` that provides EMACS compatible editing of input lines will not be linked to the system.

- **No tracer**
  The tracer and all its options are removed, making the system a little faster too.

- **No profiler**
  `profile/3` and friends are not supported. This saves some space and provides better performance.

- **No interrupt**
  Keyboard interrupt (Control-C normally) is not rebound and will normally terminate the application.

---

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• **feature(runtime, true) succeeds**
  This may be used to verify your application is running in the runtime environment rather than the development environment.

• **clause/[2,3] do not work on static predicates**
  This feature inhibits listing your program. It is only a very limited protection however.

The following fragment is an example for building the runtime environment in \`$HOME/lib/rt-pl-3.2.0`. If possible, the shared-library interface should be configured to ensure it can serve a large number of applications.

% cd pl-3.2.0
% mkdir runtime
% cd runtime
% ../src/configure --enable-runtime --prefix=$HOME
% make
% make rt-install

The runtime directory contains the components listed below. This directory may be tar’ed and shipped with your application.

<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>README.RT</td>
<td>Info on the runtime environment</td>
</tr>
<tr>
<td>bin/{arch}/pl</td>
<td>The emulator itself</td>
</tr>
<tr>
<td>man/pl.1</td>
<td>Manual page for pl</td>
</tr>
<tr>
<td>swipl</td>
<td>pointer to the home directory (.)</td>
</tr>
<tr>
<td>lib/</td>
<td>directory for shared libraries</td>
</tr>
<tr>
<td>lib/{arch}/</td>
<td>machine-specific shared libraries</td>
</tr>
</tbody>
</table>
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.

### A.1 Examining the Environment Stack

**prolog_current_frame(-Frame)**

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_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 `user` the goal is represented as `<module>:(goal)`. Do not instantiate variables in this goal unless you know what you are doing!

- **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.

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.

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.

A.2 Intercepting the Tracer

prolog_trace_interception(+Port, +Frame, +PC, -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 the trace action has been taken care of and continues execution as described by Action. Otherwise the normal Prolog debugger actions are performed.

  Port is one of call, redo, exit, fail or unify. Frame is an integer reference to the current local stack frame. PC is the current value of the program-counter, relative to the start of the current clause, or 0 if it is invalid, for example because the current frame runs a foreign predicate, or no clause has been selected yet. Action should be unified with one of the atoms continue (just continue execution), retry (retry the current goal) or fail (force the current goal to fail). Leaving it a variable is identical to continue.

  Together with the predicates described in section 3.39 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 monitor the execution of a program. The example below records all goals trapped by the tracer in the database.

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:

?- trace, go, notrace.

prolog_skip_level(-Old, +New)
Unify Old with the old value of ‘skip level’ and than set this level according to New. New is an integer, or the special atom very_deep (meaning don’t skip). The ‘skip level’ is a global variable of the Prolog system that disables the debugger on all recursion levels deeper than the level of the variable. Used to implement the trace options ‘skip’ (sets skip level to the level of the frame) and ‘up’ (sets skip level to the level of the parent frame (i.e. the level of this frame minus 1).

user:prolog_list_goal(:Goal)
Hook, normally not defined. This hook is called by the ‘L’ command of the tracer 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.

A.3 Exception Handling

A start has been made to make exception handling available to the Prolog user. On exceptions a dynamic and multifile defined predicate exception/3 is called. If this user defined predicate succeeds Prolog assumes the exception has been taken care of. Otherwise the system default exception handler is called.

exception(+Exception, +Context, -Action)
Dynamic predicate, normally not defined. Called by the Prolog system on run-time exceptions. Currently exception/3 is only used for trapping undefined predicates. Future versions might handle signal handling, floating exceptions and other runtime errors via this mechanism. The values for Exception are described below.

undefined_predicate
If Exception is undefined_predicate Context is instantiated to a term Name/Arity. Name refers to the name and Arity to the arity of the undefined predicate. If the definition module of the predicate is not user, Context will be of the form ⟨Module⟩: ⟨Name⟩/⟨Arity⟩. If the predicate fails Prolog will print the default error warning and start the tracer. If the predicate succeeds it should instantiate the last argument either to the atom fail to tell Prolog to fail the predicate or the atom retry to tell Prolog to retry the predicate. This only makes sense if the exception handler has defined the predicate. Otherwise it will lead to a loop.

warning
If prolog wants to give a warning while reading a file, it will first raise the exception warning. The context argument is a term of the form warning(⟨Path⟩, ⟨LineNo⟩, ⟨Message⟩), where Path is the absolute filename of the file prolog is reading; LineNo is an estimate of the line number where the error occurred and Message is a Prolog string indicating the message. The Action argument is ignored. The error is supposed to be presented to the user if the exception handler succeeds. Otherwise the standard Prolog warning message is printed.

This exception is used by the library(emacs_interface), that integrates error handling with GNU Emacs.
A.4 Readline Interaction

The following predicates are available if feature(readline, true) succeeds. They allow for direct interaction with the GNU readline library. See also readline(3)

\texttt{rl_read_init_file(+File)}

Read a readline initialisation file. Readline by default reads ~/.inputrc. This predicate may be used to read alternative readline initialisation files.

\texttt{rl_add_history(+Line)}

Add a line to the Control-P/Control-N history system of the readline library.
## B.1 Predicates

The predicate summary is used by the Prolog predicate `apropos/1` to suggest predicates from a keyword.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>(!) /0</td>
<td>Cut (discard choicepoints)</td>
</tr>
<tr>
<td>(!) /1</td>
<td>Cut block. See <code>block/3</code></td>
</tr>
<tr>
<td>(,) /2</td>
<td>Conjunction of goals</td>
</tr>
<tr>
<td>(\leftarrow) /2</td>
<td>If-then-else</td>
</tr>
<tr>
<td>(\leftarrow) /2</td>
<td>Soft-cut</td>
</tr>
<tr>
<td>. /2</td>
<td>Consult. Also list constructor</td>
</tr>
<tr>
<td>; /2</td>
<td>Disjunction of goals. Same as (</td>
</tr>
<tr>
<td>(&lt;) /2</td>
<td>Arithmetic smaller</td>
</tr>
<tr>
<td>= /2</td>
<td>Unification</td>
</tr>
<tr>
<td>(=_) /2</td>
<td>“Univ.” Term to list conversion</td>
</tr>
<tr>
<td>(=__) /2</td>
<td>Arithmetic equal</td>
</tr>
<tr>
<td>(=__) /2</td>
<td>Arithmetic smaller or equal</td>
</tr>
<tr>
<td>(=_) /2</td>
<td>Identical</td>
</tr>
<tr>
<td>(=@) /2</td>
<td>Structural identical</td>
</tr>
<tr>
<td>(=__) /2</td>
<td>Arithmetic not equal</td>
</tr>
<tr>
<td>(&gt;) /2</td>
<td>Arithmetic larger</td>
</tr>
<tr>
<td>(\geq) /2</td>
<td>Arithmetic larger or equal</td>
</tr>
<tr>
<td>(_\leq) /2</td>
<td>Standard order smaller</td>
</tr>
<tr>
<td>(_\leq) /2</td>
<td>Standard order smaller or equal</td>
</tr>
<tr>
<td>(_\geq) /2</td>
<td>Standard order larger</td>
</tr>
<tr>
<td>(_\geq) /2</td>
<td>Standard order larger or equal</td>
</tr>
<tr>
<td>(+) /1</td>
<td>Negation by failure. Same as <code>not/1</code></td>
</tr>
<tr>
<td>(__) /2</td>
<td>Not unifiable</td>
</tr>
<tr>
<td>(___) /2</td>
<td>Not identical</td>
</tr>
<tr>
<td>(___) /2</td>
<td>Not structural identical</td>
</tr>
<tr>
<td>(^) /2</td>
<td>Existential quantification (<code>bagof/3</code>, <code>setof/3</code>)</td>
</tr>
<tr>
<td>(__) /2</td>
<td>Disjunction of goals. Same as <code>; /2</code></td>
</tr>
<tr>
<td>abolish/1</td>
<td>Remove predicate definition from the database</td>
</tr>
<tr>
<td>abolish/2</td>
<td>Remove predicate definition from the database</td>
</tr>
<tr>
<td>abort/0</td>
<td>Abort execution, return to top level</td>
</tr>
<tr>
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<td>Get absolute path name</td>
</tr>
<tr>
<td>absolute_file_name/3</td>
<td>Get absolute path name with options</td>
</tr>
<tr>
<td>access_file/2</td>
<td>Check access permissions of a file</td>
</tr>
<tr>
<td>Function</td>
<td>Description</td>
</tr>
<tr>
<td>-----------------------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
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</tr>
<tr>
<td><code>append/3</code></td>
<td>Concatenate lists</td>
</tr>
<tr>
<td><code>apply/2</code></td>
<td>Call goal with additional arguments</td>
</tr>
<tr>
<td><code>apropos/1</code></td>
<td><code>library(online_help)</code> Show related predicates and manual sections</td>
</tr>
<tr>
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<td>Access argument of a term</td>
</tr>
<tr>
<td><code>arithmetic_function/1</code></td>
<td>Register an evaluable function</td>
</tr>
<tr>
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<td>Add a clause to the database</td>
</tr>
<tr>
<td><code>assert/2</code></td>
<td>Add a clause to the database, give reference</td>
</tr>
<tr>
<td><code>asserta/1</code></td>
<td>Add a clause to the database (first)</td>
</tr>
<tr>
<td><code>asserta/2</code></td>
<td>Add a clause to the database (first)</td>
</tr>
<tr>
<td><code>assertz/1</code></td>
<td>Add a clause to the database (last)</td>
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<tr>
<td><code>assertz/2</code></td>
<td>Add a clause to the database (last)</td>
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<tr>
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</tr>
<tr>
<td><code>at_end_of_stream/1</code></td>
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</tr>
<tr>
<td><code>athalt/1</code></td>
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<tr>
<td><code>at_initialization/1</code></td>
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<tr>
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<tr>
<td><code>atom_char/2</code></td>
<td>Convert between atom and ASCII value</td>
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<tr>
<td><code>atom_chars/2</code></td>
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<tr>
<td><code>atom_prefix/2</code></td>
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<tr>
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<td>Convert between atom and term</td>
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<tr>
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</tr>
<tr>
<td><code>autoload/0</code></td>
<td>Autoload all predicates now</td>
</tr>
<tr>
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<tr>
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<tr>
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<td>Get clauses of a predicate</td>
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<tr>
<td><code>clause/3</code></td>
<td>Get clauses of a predicate</td>
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<td><code>close_dde_conversation/1</code></td>
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<tr>
<td><code>close_dll/1</code></td>
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</tr>
<tr>
<td><code>close_shared_object/1</code></td>
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</tr>
<tr>
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<tr>
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<td>------------------------------------------------------------------</td>
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<td><code>concat_atom/2</code></td>
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<td><code>concat_atom/3</code></td>
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<tr>
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</tr>
<tr>
<td><code>current_atom/1</code></td>
<td>Examine existing atoms</td>
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<td><code>current_flag/1</code></td>
<td>Examine existing flags</td>
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<tr>
<td><code>current_foreign_library/2</code></td>
<td><code>library(shelib)</code> Examine loaded shared libraries (.so files)</td>
</tr>
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<td><code>current_format_predicate/2</code></td>
<td>Enumerate user-defined format codes</td>
</tr>
<tr>
<td><code>current_functor/2</code></td>
<td>Examine existing name/arity pairs</td>
</tr>
<tr>
<td><code>current_input/1</code></td>
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<td><code>current_key/1</code></td>
<td>Examine existing database keys</td>
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<tr>
<td><code>current_module/1</code></td>
<td>Examine existing modules</td>
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<td><code>current_module/2</code></td>
<td>Examine existing modules</td>
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<td>Examine current operator declarations</td>
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<tr>
<td><code>current_output/1</code></td>
<td>Get the current output stream</td>
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<td><code>current_predicate/2</code></td>
<td>Examine existing predicates</td>
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<tr>
<td><code>current_signal/3</code></td>
<td>Current software signal mapping</td>
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<tr>
<td><code>current_stream/3</code></td>
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<td><code>current_thread/2</code></td>
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<td><code>dde_current_connection/2</code></td>
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<td><code>dde_current_service/2</code></td>
<td>Win32: Examine DDE services provided</td>
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<tr>
<td><code>dde_execute/2</code></td>
<td>Win32: Execute command on DDE server</td>
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<tr>
<td><code>dde_register_service/2</code></td>
<td>Win32: Become a DDE server</td>
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<tr>
<td><code>dde_request/3</code></td>
<td>Win32: Make a DDE request</td>
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<tr>
<td><code>dde_poke/3</code></td>
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</tr>
<tr>
<td><code>debug/0</code></td>
<td>Test for debugging mode</td>
</tr>
<tr>
<td><code>debugging/0</code></td>
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<td>Get the default modules of a module</td>
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<td><code>delete/3</code></td>
<td>Delete all matching members from a list</td>
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<td><code>delete_file/1</code></td>
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<td><code>discontiguous/1</code></td>
<td>Indicate distributed definition of a predicate</td>
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<tr>
<td><code>dup_stream/2</code></td>
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<tr>
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<tr>
<td><code>dwim_match/3</code></td>
<td>Atoms match in “Do What I Mean” sense</td>
</tr>
<tr>
<td><code>dwim_predicate/2</code></td>
<td>Find predicate in “Do What I Mean” sense</td>
</tr>
<tr>
<td><code>dynamic/1</code></td>
<td>Indicate predicate definition may change</td>
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<td>Edit a file</td>
</tr>
<tr>
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<td>Consult a file if that has not yet been done</td>
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<tr>
<td><code>erase/1</code></td>
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</tr>
<tr>
<td><code>exception/3</code></td>
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</tr>
<tr>
<td><code>exists_directory/1</code></td>
<td>Check existence of directory</td>
</tr>
</tbody>
</table>
exists_file/1       Check existence of file
exit/2            Exit from named block. See block/3
expand_answer/2   Expand answer of query
expand_file_name/2 Wildcard expansion of file names
expand_file_search_path/2 Wildcard expansion of file paths
expand_goal/2     Compiler: expand goal in clause-body
expand_query/4    Compiler: expanded entered query
expand_term/2     Compiler: expand read term into clause(s)
explain/1         library(explain) Explain argument
explain/2         library(explain) 2nd argument is explanation of first
export/1          Export a predicate from a module
export_list/2     List of public predicates of a module
fail/0            Always false
fail/1            Immediately fail named block. See block/3
feature/2         Get system configuration parameters
file_base_name/2  Get file part of path
file_directory_name/2 Get directory part of path
file_name_extension/3 Add, remove or test file extensions
file_search_path/2 Define path-aliases for locating files
fileerrors/2      Do/Don’t warn on file errors
findall/3         Find all solutions to a goal
flag/3            Simple global variable system
flatten/2         Transform nested list into flat list
float/1           Type check for a floating point number
flush/0           Output pending characters on current stream
flush_output/1    Output pending characters on specified stream
forall/2          Prove goal for all solutions of another goal
foreign_file/1    Examine loaded foreign files
format/1          Formatted output
format/2          Formatted output with arguments
format/3          Formatted output on a stream
format_predicate/2 Program format/[1,2]
free_variables/2  Find unbound variables in a term
functor/3         Get name and arity of a term or construct a term
garbage_collect/0 Invoke the garbage collector
gensym/2          Generate unique atoms from a base
get/1             Read first non-blank character
get/2             Read first non-blank character from a stream
get0/1            Read next character
get0/2            Read next character from a stream
get_single_char/1 Read next character from the terminal
get_time/1        Get current time
getenv/2          Get shell environment variable
goal_expansion/2  Hook for macro-expanding goals
ground/1          Verify term holds no unbound variables
halt/0            Exit from Prolog
halt/1            Exit from Prolog with status
B.1. PREDICATES

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help/1
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module/1
module/2
module_transparent/1
msort/2
multifile/1
name/2

Hash-value of ground term
Give help on help
Give help on predicates and show parts of manual
Call the argument, but always succeed
Import a predicate from a module
Change clause indexing
Initialization directive
Convert from integer to atom
Convert from integer to atom (non-decimal)
Type check for integer
Set intersection
Evaluate arithmetic expression
True if arg defines an absolute path
Type check for a list
Type check for a set
Sort, using a key
Last element of a list
Change ports visited by the tracer
Length of a list
(hook) Directories holding Prolog libraries
Limit stack expansion
Line number on stream
Character position in line on stream
Remove duplicates
List program in current module
List predicate
Load source files with options
Load foreign (C) module
Load foreign (C) module
library(\(\text{shlib}\)) Load shared library (.so file)
library(\(\text{shlib}\)) Load shared library (.so file)
Reconsult all changed source files
Win32: Create file containing non-FAT filenames
Create autoload file INDEX.pl
Transform all elements of a list
Element is member of a list
Deterministic member/2
Merge two sorted lists
Merge two sorted sets
Intercept print_message/2
Quintus compatibility
Query/set current type-in module
Declare a module
Indicate module based meta predicate
Sort, do not remove duplicates
Indicate distributed definition of predicate
Convert between atom and list of ASCII characters
### APPENDIX B. SUMMARY

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<th>Description</th>
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<td>Generate a newline</td>
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<tr>
<td>nl/1</td>
<td>Generate a newline on a stream</td>
</tr>
<tr>
<td>nodebug/0</td>
<td>Disable debugging</td>
</tr>
<tr>
<td>nonvar/1</td>
<td>Type check for bound term</td>
</tr>
<tr>
<td>noprotocol/0</td>
<td>Disable logging of user interaction</td>
</tr>
<tr>
<td>nospy/1</td>
<td>Remove spy point</td>
</tr>
<tr>
<td>nospyall/0</td>
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</tr>
<tr>
<td>not/1</td>
<td>Negation by failure (argument not provable). Same as +/1</td>
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<tr>
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</tr>
<tr>
<td>notrace/1</td>
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<tr>
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<tr>
<td>nth1/3</td>
<td>N-th element of a list (1-based)</td>
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<td>number/1</td>
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<td>open_null_stream/1</td>
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<td>open_resource/3</td>
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<td>UNIX: Open shared library (.so file)</td>
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<tr>
<td>peek_byte/1</td>
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<td>Query/change environment parameters</td>
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<td>plus/3</td>
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<td>portray/1, portray_clause/1</td>
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<td>−/2</td>
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<td>Division</td>
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<td>///2</td>
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<td>\v/2</td>
<td>Bitwise and</td>
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<tr>
<td>&gt;&gt;=/2</td>
<td>Bitwise right shift</td>
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<td>\1</td>
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<tr>
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<td>^/2</td>
<td>Power function</td>
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<td>Inverse (arc) sine</td>
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</tr>
<tr>
<td>ceiling/1</td>
<td>Smallest integer larger than arg</td>
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<td>Cosine</td>
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<td>Mathematical constant</td>
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<td>Fractional part of a float</td>
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<tr>
<td>float_integer_part/1</td>
<td>Integer part of a float</td>
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<tr>
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<tr>
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<td>Natural logarithm</td>
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<tr>
<td>log10/1</td>
<td>10 base logarithm</td>
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<td>Maximum of two numbers</td>
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<tr>
<td>min/2</td>
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<tr>
<td>mod/2</td>
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<td>rem/2</td>
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<td>pi/0</td>
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<td>tan/1</td>
<td>Tangent</td>
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<tr>
<td>~</td>
<td>200</td>
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<td>mod</td>
<td>300</td>
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<td>\</td>
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<td>Introduces a directive</td>
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<tr>
<td>?= 1200</td>
<td>Introduces a directive</td>
<td></td>
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<td>= = &gt; 1200</td>
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