Introduction

This technical recommendation (TR) is an optional part of the International Standard for Prolog, ISO/IEC 13211. Prolog systems wishing to implement multi-threading supporting predicates should do so in compliance with this TR.

Multi-thread predicates are based on the semantics of POSIX threads. They have been implemented in some Prolog systems. As such, they are deemed a worthy extension to the ISO/IEC 13211 Prolog standard.

This TR was designed to follow the predicate naming conventions found on other Prolog standard documents. In addition, the specified set of built-in predicates allow for extension by Prolog vendors in a controlled way aimed to prevent future sources of incompatibilities.

This draft may contain in several places informative text, type-set in italics. Such informative text is used for editorial comments deemed useful during the development of this draft and may not be included in the final version.

Previous editors and draft documents

- Paulo Nunes (April 12, 2006 — July 31, 2006).

Draft document comments

- None.

Contributors

- Jan Wielemaker (Netherlands)
- Manuel Carro (Spain)
- Paulo Moura (Portugal)
1 Scope

This TR is designed to promote the portability of multi-threaded Prolog applications. As such, this TR specifies:

a) A set of built-in predicates for thread management, monitoring, and communication.

b) A set of built-in predicates for thread synchronization using mutexes.

c) A set of built-in predicates for message queue management, monitoring, and communication.

This TR specifies both mandatory and optional built-in predicates. All the optional built-in predicates are related to statistical information that, although sometimes useful, imply a runtime overhead that a conforming implementation may prefer to avoid.

2 Language concepts and semantics

2.1 Types

2.1.1 Kibibyte

A kibibyte is 1024 bytes. The unit kibibyte (KiB) is specified by the IEC 60027-2 standard.

2.1.2 Thread and message queue aliases

The predicates specified in this TR allow the definition of thread aliases and message queue aliases, which share the same namespace.

NOTE — Each thread is associated with its own message queue, accessed using the thread identifier. Thus, in order to avoid ambiguities, the alias of a new thread may not be in use as a queue alias. Likewise, the alias of a new queue may not be in use as a thread alias.
2.1.3 Thread status

The thread status shall include:

- **exception(Exception)** — The thread goal has been terminated due to an uncaught exception, represented by the term `Exception`.
- **exited(ExitTerm)** — The thread goal has been terminated using the built-in predicate `thread_exit/1` (3.2.7) with `ExitTerm` as its argument.
- **false** — The thread goal has been completed and failed.
- **running** — The thread is running. This is the initial status of a thread (note that threads suspended or waiting are also considered as running).
- **true** — The thread goal has been completed and succeeded.

2.2 Thread-creation options

Thread-creation options may be used with the `thread_create/3` (3.2.1) built-in predicate in order to bypass default creation options.

2.2.1 Mandatory options

The supported thread-creation options shall include:

- **alias(Alias)** — Specifies that the atom `Alias` is to be an alias for the thread.
- **detached(Bool)** — When `Bool` is `false`, the thread can be waited for using the built-in predicate `thread_join/2` (3.2.5). When `Bool` is `true`, it is expected that the system will reclaim all associated resources automatically after the thread finishes.

2.2.2 Optional data area options

The thread-creation data area options supported may include:

- **local(KiB)** — Sets the size limit to the local stack of the thread. When omitted, a default size value is used.
- **global(KiB)** — Sets the size limit to the global stack of the thread. When omitted, a default size value is used.
- **trail(KiB)** — Sets the size limit to the trail stack of the thread. When omitted, a default size value is used.
- **stack(KiB)** — Sets the size limit to the system stack of the thread. When omitted, a default size value is used.

NOTE — The default size values are implementation defined (3.2.2).
2.2.3 Optional scheduling options

The thread-creation scheduling options supported may include:

- **scheduling_scope(Value)** — The possible values of scheduling scope Value shall include:
  - *system* — Kernel threads.
  - *process* — User Threads.

- **policy(Value)** — The possible values of policy Value shall include:
  - *round_robin* — Round Robin.
  - *fifo* — First in first out.
  - *other* — Other.

- **priority(Value)** — Value is an integer value between 0 (minimum priority) and 31 (maximum priority). Priority is settable at thread creation time or dynamically.

  NOTE — The interval $[0, 31]$ is a virtual priority range that must be mapped to real priority values, which are implementation and operating-system dependent. This virtual range follows the POSIX 1b recommendation and the current practice on Microsoft Windows operating-systems.

- **yield(Value)** — The possible values of yield Value shall include:
  - *round_robin* — Round Robin.
  - *fifo* — First in first out.
  - *other* — Other.

  NOTE — *round_robin* and *fifo* only yields to a thread of the same priority.

- **scheduling_inheritance(Value)** — The possible values of scheduling inheritance Value shall include:
  - *inherit* — Inherits scheduling attributes from the parent thread.
  - *explicit* — Uses thread specific scheduling attributes.

2.3 Thread-creation options list

A thread-creation options list is a list of thread-creation options which may be used with the built-in predicate `thread_create/3` in order to bypass default creation options.
2.4 Thread properties

Thread properties include the thread creation options specified in section 2.2, plus the following one:

\texttt{status(Status)} — \texttt{Status} is the state of the thread (2.1.3).

2.5 Mutex-creation options

Mutex-creation options may be used with the built-in predicate \texttt{mutex_create/2 (3.4.1)} in order to bypass default creation options. The supported mutex-creation options shall include:

\texttt{alias(Alias)} — Specifies that the atom \texttt{Alias} is to be an alias for the mutex.

2.6 Mutex-creation options list

A mutex-creation options list is a list of mutex-creation options (2.5) which may be used with the built-in predicate \texttt{mutex_create/2 (3.4.1)} in order to bypass default creation options.

2.7 Mutex properties

Mutex properties include the mutex creation options specified in section 2.5, plus the following optional one:

\texttt{status(Status)} — the status of the mutex is \texttt{Status}.

The possible mutex status are:

\texttt{locked(ThreadOrAlias, Count)} — \texttt{ThreadOrAlias} is the identifier of, or an alias to, the holding thread, and \texttt{Count} is the recursive count of the mutex.

\texttt{unlocked} — the mutex is unlocked.

NOTE — Implementations shall return thread aliases, when defined, instead of thread identifiers.

2.8 Queue-creation options

Queue-creation options may be used with the \texttt{message_queue_create/2} built-in predicate (3.5.1) in order to bypass default creation options.

\texttt{alias(Alias)} — Specifies that the atom \texttt{Alias} is to be an alias for the queue.

\texttt{max_size(MaxSize)} — Sets the size limit to the queue. When omitted, the maximum value of items in a message queue is expected to be resource bound.
2.9 Queue-creation options list

A queue-creation options list is a list of queue-creation options (2.8) that may be used with the built-in predicate `message_queue_create/2` (section 3.5.1) in order to bypass default creation options.

2.10 Queue properties

Queue properties include the queue creation options specified in section 2.8 plus the following one:

`size(Size)` — Size is the number of elements on the message queue.

NOTE — Due to concurrent access, the value of this property may be outdated before it is returned (3.5.3). Nevertheless, this property may be used for debugging purposes.

2.11 Database

The Prolog database is shared with all threads.

2.11.1 Dynamic predicates

It is possible to use dynamic predicates for thread communication. Compliant implementations shall ensure that access to a dynamic predicate is properly synchronized in order to guarantee both the logical update semantics of single-threaded Prolog when two threads call the same dynamic predicate and the consistency of the dynamic predicate when two threads assert or retract clauses for the same dynamic predicate.

2.12 Executing a threaded Prolog goal

Executing a Prolog goal in a thread works by first making a copy of the goal term and then executing the copy in the thread Prolog engine. This implies that further instantiation of the goal term in one thread does not have consequences for the other thread; i.e. any variable bindings are lost when a goal is proved using another thread.

2.13 Flags

The following flags are added to those of section 7.11 of ISO/IEC 13211-1.

2.13.1 Flag: `max_threads`

Possible values: `undefined`, `positive integer value`
Default value: implementation defined
Changeable: No
2.13.2 Flag: hardware_threads

Possible values: undefined, positive integer value
Default value: implementation defined
Changeable: Yes

Description: If the default value of this flag is undefined, the maximum number of hardware supported simultaneous threads is not defined.

If the default value of this flag is a positive integer value, the maximum number of hardware supported simultaneous threads is given by this value. The flag value can be modified by the programmer in order to simulate running an application in hardware with a greater or a lower number of supported simultaneous threads.

2.14 Errors

The following errors are defined in addition to those defined in section 7.12 of ISO/IEC 13211-1.

2.14.1 Error classification

The following types are added to the classification of 7 12.2 of ISO/IEC 13211-1.

a) The list of valid domains is extended by the addition of mutex or alias, mutex_option, thread or alias, thread_option, thread_property, queue or alias, queue_option, and queue_property (see 7 12.2 c of ISO/IEC 13211-1).

b) The list of object types is extended by the addition of mutex, queue, and thread (see 7 12.2 d of ISO/IEC 13211-1).

c) The list of operations is extended by the addition of detach, join, unlock, cancel, and destroy; the list of permission types is extended by mutex, queue, thread, and thread_option (see 7 12.2 e of ISO/IEC 13211-1).

d) The list of valid flags is extended by the addition of max_threads (see 7 12.2 f of ISO/IEC 13211-1).
2.15 Main Prolog thread

When starting a multi-threading enabled Prolog process, there shall be a main thread, referenced by the alias `main`. This thread shall be automatically created and cannot be canceled during the lifetime of the Prolog process.

2.16 Signaling threads

This TR specifies a predicate, `thread_signal/1`, to make a thread execute some goal as an interrupt [3.2.8]. Conforming implementations shall ensure that these interrupts are only checked at safe points in their virtual machines. These safe points shall include thread sleep, thread suspended waiting for a message (from a queue), and stream read operations. Signaling should always be handled with care as the receiving thread may hold a mutex.

Signaling may be used to start debugging a thread or to cancel no-longer-needed threads with `throw/1`, where the receiving thread should be designed carefully to handle exceptions at any point.

2.17 Thread message queues

Each thread owns a private message queue that can be accessed using the thread identifier or the thread alias. For a non-detached thread, its private message queue is only destroyed when thread is joined. For a detached thread, its private message queue is destroyed when the thread exits.

3 Built-in predicates

3.1 The format of built-in predicate definitions

These subclauses define the format of the definitions of built-in predicates.

3.1.1 Description

The description of the built-in predicate assumes that no error condition is satisfied, and is in two parts: (1) the logical condition for the built-in predicate to be true, and (2) a procedural description of what happens when a goal is executed and whether the goal succeeds or fails.

Most built-in predicates are not re-executable; the description mentions the exceptional cases explicitly.

3.1.2 Templates and modes

3.1.2.1 Type of an argument
This TR defines the following additional argument types, augmenting those found on the ISO/IEC 13211 Prolog standard:

- `mutex` — a term identifying a mutex (shall be regarded as an opaque type)
- `mutex_or_alias` — a mutex or an atom acting as a mutex alias
- `mutex_property` — a mutex property (2.7)
- `queue` — a term identifying a queue (shall be regarded as an opaque type)
- `queue_option` — a queue option (2.8)
- `queue_options` — a list of queue options (2.8)
- `queue_or_alias` — a queue or an atom acting as a queue alias
- `queue_property` — a message queue property (2.10)
- `thread` — a term identifying a thread (shall be regarded as an opaque type)
- `thread_option` — a thread option (2.2)
- `thread_options` — a list of thread options (2.3)
- `thread_or_alias` — a thread or an atom acting as a thread alias
- `thread_property` — a thread property (2.4)
- `thread_status` — a thread status (2.1.3)

NOTE — The types `queue` and `queue_or_alias` also include, respectively, the types `thread` and `thread_or_alias` given that each thread is associated with a queue identified by the thread identifier or the thread alias.

### 3.2 Thread management

These built-in predicates enable threads to be created, detached, joined, and destroyed. They include predicates for setting and querying default thread creation options.

The examples provided for these built-in predicates assume the environment created from the following Prolog text:

```prolog
:- initialization(management).

thread_goal :-
    thread_get_message(M),
    write(M).

signal_goal :-
```
3 BUILT-IN PREDICATES

write('Hello, from signal goal!').

hello :-
    write('Hello!').
dog.

management :-
    thread_create(thread_goal, _,
        [detached(true), alias(thread_detached)]),
    thread_create(hello, _,
        [alias(thread_hello), local(512)]),
    thread_create(thread_goal, _, [alias(thread)]).

3.2.1 thread_create/3, thread_create/2, thread_create/1

3.2.1.1 Description

\text{thread} \text{create}(\text{Goal}, \text{Thread}, \text{Options}) \text{ creates a new thread and starts it by executing } \text{Goal}. \text{ If the thread is created successfully, the thread identifier of the created thread is unified to } \text{Thread}. \text{ Options} \text{ is a list of thread options } [2,3]. \text{ The } \text{Goal} \text{ 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.}

3.2.1.2 Template and modes

\text{thread} \text{create}(\text{@callable}] \text{term}, \text{-thread}, \text{@thread} \text{options})

3.2.1.3 Errors

a) \text{Goal} \text{ is a variable}
   \begin{itemize}
   \item \text{instantiation} \text{error}
   \end{itemize}

b) \text{Goal} \text{ is neither a variable nor a callable term}
   \begin{itemize}
   \item \text{type} \text{error(} \text{callable}, \text{Goal} \text{)}
   \end{itemize}

c) \text{Thread} \text{ is not a variable}
   \begin{itemize}
   \item \text{type} \text{error(} \text{variable}, \text{Thread} \text{)}
   \end{itemize}

d) \text{Options} \text{ is a partial list or a list with an element } \text{E} \text{ which is a variable}
   \begin{itemize}
   \item \text{instantiation} \text{error}
   \end{itemize}

e) \text{Options} \text{ is neither a partial list nor a list}
   \begin{itemize}
   \item \text{type} \text{error(} \text{list}, \text{Options} \text{)}
   \end{itemize}

f) An element of \text{E} \text{ of the } \text{Options} \text{ list is not a valid thread option}
   \begin{itemize}
   \item \text{domain} \text{error(} \text{thread} \text{option}, \text{E} \text{)}
   \end{itemize}

3 BUILT-IN PREDICATES

- The maximum number of threads has been reached
  \[ \text{resource} \text{error} (\text{threads}) \]

- There is no memory available for creating the thread data areas
  \[ \text{resource} \text{error} (\text{memory}) \]

- An element \(E\) of the \textit{Options} list is \textit{alias}(A) and \(A\) is already associated with an existing thread or queue
  \[ \text{permission} \text{error} (\text{create, thread, alias}(A)) \]

**NOTE** — When the maximum number of threads is known by the Prolog compiler, its value shall be available using the Prolog flag \texttt{max_threads} \[2.13.1\].

### 3.2.1.4 Bootstrapped built-in predicates

The built-in predicates \texttt{thread_create/2} and \texttt{thread_create/1} provide similar functionality to the built-in predicate \texttt{thread_create/3}.

\[
\text{Goal } \text{thread} \text{create} \text{Goal, Thread) creates a new thread using default options } [3.2.2] \text{. Goal thread_create(Goal) creates a new detached thread using default options } [3.2.2] .
\]

\[
\text{thread} \text{create}(\text{Goal, Thread) :-}
\]
\[
\text{thread} \text{create}(\text{Goal, Thread, []}).
\]

\[
\text{thread} \text{create}(\text{Goal) :-}
\]
\[
\text{thread} \text{create}(\text{Goal, _, [detached(true)]}).
\]

### 3.2.1.5 Examples

These examples assume the environment has been created from the Prolog text defined at the beginning of section 3.2.

\[
\text{thread} \text{create}(\text{hello, Thread, []}).
\]
Succeeds.

\[ \text{It creates a thread, unifies Thread with a thread-term for the thread.} \]

\[
\text{thread} \text{create}(\text{hello, Thread}).
\]
Succeeds.

\[ \text{It creates a thread using default thread-creation options, unifies Thread with a thread-term for the thread.} \]

\[
\text{thread} \text{create}(\text{thread} \text{goal, Thread, [alias(thread11)])}.\]
Succeeds.

\[ \text{It creates a thread, unifies Thread} \]
with a thread-term for the thread, and
associates the alias ‘thread11’ with the thread.]

thread_create(Goal, Thread, []).  
  instantiation_error.

thread_create(4, Thread, []).  
  type_error(callable, 4).

thread_create(hello, thread, []).  
  type_error(variable, thread).

thread_create(hello, Thread, Options).  
  instantiation_error.

thread_create(hello, Thread, [alias(thread_x), X]).  
  instantiation_error.

thread_create(thread_goal, Thread, options).  
  type_error(list, options).

thread_create(thread_goal, Thread, [name(paul)]).  
  domain_error(thread_option, name(paul)).

thread_create(thread_goal, Thread, [alias(thread)]).  
  permission_error(create, thread, alias(thread)).  
  [Assuming that there already exists a thread
   named ‘thread’.]

3.2.2 thread_default/1

3.2.2.1 Description

thread_default(Default) gets the default options used when a new thread is
created. The allowed values for Default are listed in section 2.2. Depending
on the implementation, some default options may be read-only and thus not
modifiable. The order in which thread options are found by thread_default/1
is implementation dependent.

NOTE — There is no default value for the option alias/1.

Procedurally, thread_default(Default) is executed as follows:

a) Create a Set_D of all terms (D) such that D is a default option for thread
creation,

b) If Set_D is empty, the goal fails,
3.2.2.2 Template and modes

thread_default(?thread_option)

3.2.2.3 Errors

a) Default is neither a variable nor a thread option
   — domain_error(thread_option, Default)

3.2.2.4 Examples

    thread_default(detached(Boolean)).
    Succeeds, unifying Boolean with the
current detached default value.

    thread_default(cpu(X)).
    domain_error(thread_option, cpu(X)).

3.2.3 thread_set_default/1

3.2.3.1 Description

thread_set_default(Default) sets a default option for thread creation. The
items allowed in Default are listed in section 2.2. Some implementations may
not support changing the value of some thread options.

NOTE — It is not possible to set a default value for the option alias/1.
3.2.3.3 Errors

a) Default is a variable
   — instantiation_error

b) Default is neither a variable nor a thread option
   — domain_error(thread_option, Default)

c) The thread option is read-only or does not support a default value
   — permission_error(modify, thread_option, Default)

3.2.3.4 Examples

thread_set_default(detached(true)).
   Succeeds.

thread_set_default(Default).
   instantiation_error.

thread_set_default(cpu(100)).
   domain_error(thread_option, cpu(100)).

thread_set_default(detached(yes)).
   domain_error(thread_option, detached(yes)).

3.2.4 thread_self/1

3.2.4.1 Description

thread_self(ThreadOrAlias) is true when ThreadOrAlias is the identifier or an alias of the calling thread.

3.2.4.2 Template and modes

thread_self(+thread_or_alias)
thread_self(-thread)

3.2.4.3 Errors

a) ThreadOrAlias is neither a variable nor a thread-term or alias
   — domain_error(thread_or_alias, ThreadOrAlias)

3.2.4.4 Examples

The goal thread_self(Thread) succeeds, unifying Thread with miguel.
3 BUILT-IN PREDICATES

:- initialization(main(paulo, miguel)).

child(Parent) :-
    thread_self(Thread),
    write('I\'am '),
    write(Thread),
    write( ' child of ' ),
    write(Parent),
    write( '.' ).

main(Parent, Child):-
    thread_create(child(Parent), T,
                  [alias(Child), detached(false)]).

% % Second example
% %
child(Parent) :-
    thread_self(thread_s),
    ...,
    domain_error(thread_or_alias, thread_s).

3.2.5 thread_join/2

3.2.5.1 Description

thread_join(ThreadOrAlias, Status) waits for the termination of thread with given ThreadOrAlias, unifying the result-status of the thread with Status. After this call, the ThreadOrAlias identifier or alias becomes invalid.

NOTES

1 After this call it is expected that all resources associated with the thread be reclaimed.
2 Threads with the property detached(true) cannot be joined.

3.2.5.2 Template and modes

thread_join(+thread_or_alias, -thread_status)

3.2.5.3 Errors

a) ThreadOrAlias is a variable
   — instantiation_error

b) ThreadOrAlias is neither a variable nor a thread-term or alias
   — domain_error(thread_or_alias, ThreadOrAlias)
c) ThreadOrAlias is not associated with a current thread
   — existence_error(thread, ThreadOrAlias)

d) ThreadOrAlias does not correspond to a joinable thread
   — permission_error(join, thread, ThreadOrAlias)

e) Status is not a variable
   — type_error(variable, Status)

3.2.5.4 Examples

These examples assume the environment has been created from the Prolog text defined at the beginning of section 3.2.

```prolog
thread_join(thread, Status).
Succeeds, unifying Status with true.
[After the thread receives a message.]

thread_join(Thread, Status).
instantiation_error.

thread_join(dog, Status).
domain_error(thread_or_alias, dog).

thread_join(thread5, Status).
estinction_error(thread, thread5).

thread_join(thread_detached, true).
permission_error(join, thread, thread_detached).

thread_join(thread, status).
type_error(variable, status).
```

```prolog
:- initialization(main_join).

thread_goal :-
    thread_self(T),
    write('I\'m am '),
    write(T), nl.

main_join :-
    write('I\'m main.'), nl,
    thread_create(thread_goal, T, [alias(t1)]),
    thread_join(t1, Status),
    write(Status).
```

The predicate `thread_join(t1, Status)` in the previous example succeeds, unifying Status with true.
3.2.6 thread_detach/1

3.2.6.1 Description

thread_detach(ThreadOrAlias) switches a thread into detached-state at run-time. ThreadOrAlias is the identifier of, or an alias to, the thread to be placed in a detached state.

Threads that are created as detached are expected to leave no traces if they terminate. Threads nobody is waiting for may be created normally and detach themselves just before completion. This way they leave no traces on normal completion and their reason for failure can be inspected. This guarantees that the resources consumed by the thread will be freed immediately when the thread terminates. However, this prevents other threads from synchronizing on the termination of ThreadOrAlias using thread_join/2 (3.2.5). If, when thread_detach/1 is called, the thread has already terminated, all remaining threads resources will be freed.

3.2.6.2 Template and modes

thread_detach(+thread_or_alias)

3.2.6.3 Errors

a) ThreadOrAlias is a variable
   — instantiation_error

b) ThreadOrAlias is neither a variable nor a thread-term nor an alias
   — domain_error(thread_or_alias, ThreadOrAlias)

c) ThreadOrAlias is not associated with a current thread
   — existence_error(thread, ThreadOrAlias)

d) ThreadOrAlias is not joinable
   — permission_error(detach, thread, ThreadOrAlias)

3.2.6.4 Examples

    thread_detach(thread).  % Succeeds.

    thread_detach(Thread).  % instantiation_error.
                      
    thread_detach(dog).    % domain_error(thread_or_alias, dog).
                          
    thread_detach(thread5).
existence_error(thread, thread5).

thread_detach(thread_detached).
permission_error(detach, thread, thread_detached).
[Assumes that the thread has the thread-creation option detached(true).]

3.2.7 thread_exit/1

3.2.7.1 Description

thread_exit(Term) terminates the thread immediately, leaving exited(Term) as result-state for thread_join/2 \[3.2.5\]. If the thread has the thread-creation option detached(true) it terminates, but its exit status cannot be retrieved using thread_join/2 making the value of Term irrelevant.

3.2.7.2 Template and modes

thread_exit(@nonvar)

3.2.7.3 Errors

a) Term is a variable
   — instantiation_error.

b) the calling thread is the main Prolog process thread
   — permission_error(cancel, thread, main)

3.2.7.4 Examples

:- initialization(main).

goal :-
   repeat,
   thread_get_message(M),
   ( M == 'exit' ->
      thread_exit(write('Exit'))
   ;   write(M), nl, fail
   ).

main :-
   thread_create(goal, _, [alias(t)]).

thread_join(t, Term).
Succeeds, unifying Term with exited(write('Exit')).
[Immediately after the execution:
   thread_send_message(t, exit).]
3.2.8 thread_signal/2

3.2.8.1 Description

thread_signal(ThreadOrAlias, Goal) makes thread ThreadOrAlias execute Goal at the first opportunity. The predicate thread_signal/2 places Goal into the signaled thread’s signal queue and returns immediately. Goal can be any valid Prolog goal, including throw/1 to make the receiving thread generate an exception.

3.2.8.2 Template and modes

thread_signal(+thread_or_alias, @callable_term)

3.2.8.3 Errors

a) ThreadOrAlias is a variable
--- instantiation_error

b) ThreadOrAlias is neither a variable nor a thread-term or alias
--- domain_error(thread_or_alias, ThreadOrAlias)

c) ThreadOrAlias is not associated with a current thread
--- existence_error(thread, ThreadOrAlias)

d) Goal is a variable
--- instantiation_error

e) Goal is neither a variable nor a callable term
--- type_error(callable, Goal)

3.2.8.4 Examples

    thread_signal(thread_detached, signal_goal).
    % Succeeds.

    thread_signal(Thread, signal_goal).
    % instantiation_error.

    thread_signal(dog, signal_goal).
    % domain_error(thread_or_alias, dog).

    thread_signal(thread5, signal_goal).
    % existence_error(thread, thread2).

    thread_signal(thread, Goal).
    % instantiation_error.
thread_signal(thread, 4).
type_error(callable, 4).

In the following example, the predicate `main` creates two threads with alias `thread_1` and `thread_2`. Then `thread_2` sends a signal to `thread_1` with goal `write('from thread2')`.

```prolog
:- initialization(main).

thread_1 :-
    thread_self(T),
    write('Thread '),
    write(T), nl,
    write('Send work to thread_2: '), nl
    thread_signal(t2, write('from thread_1')).

thread_2 :-
    thread_self(T),
    write('Thread '),
    write(T), nl,
    write('Receives from thread_1: '),
    write(M), nl.

main :-
    thread_create(thread_1, _, [alias(t1)]),
    thread_create(thread_2, _, [alias(t2)]).
```

3.2.9 thread_cancel/1

3.2.9.1 Description

`thread_cancel(ThreadOrAlias)` cancels a thread. Any mutexes held by the thread shall be automatically released. The main Prolog thread (2.15) cannot be cancelled. Other than this, any thread can cancel any other thread.

NOTE — It is expected that all the resources consumed by a thread will be released upon thread cancellation.

3.2.9.2 Template and modes

`thread_cancel(+thread_or_alias)`

3.2.9.3 Errors

a) `ThreadOrAlias` is a variable
   — instantiation_error
b) ThreadOrAlias is neither a variable nor a thread-term or alias
   — domain_error(thread_or_alias, ThreadOrAlias)

c) ThreadOrAlias is not associated with a current thread
   — existence_error(thread, ThreadOrAlias)

d) ThreadOrAlias is the main Prolog process thread
   — permission_error(cancel, thread, main)

3.2.9.4 Examples
   thread_cancel(thread).
   Succeeds.

   thread_cancel(main).
   permission_error(cancel, thread, main).

3.2.10 thread_yield/0

3.2.10.1 Description

thread_yield forces the calling thread to relinquish use of its processor and to
wait in the run queue before it is scheduled again. If the run queue is empty
when the thread_yield/0 predicate is called, the calling thread is immediately
rescheduled.

3.2.10.2 Template and modes

thread_yield

3.2.10.3 Errors

None.

3.2.10.4 Examples

   thread_yield.
   Succeeds.

3.2.11 thread_sleep/1

3.2.11.1 Description

thread_sleep(Seconds) suspends the current threads execution until Seconds
seconds elapsed. When the number of seconds is zero or a negative value, the
call succeeds and returns immediately.

NOTE — The thread shall not be awakened before this time but, depending on
the implementation of the thread scheduler, it might be awakened later.
3.2.11.2 Template and modes

thread_sleep(+number)

3.2.11.3 Errors

a) Seconds is a variable
   → instantiation_error

b) Seconds is neither a variable nor a number
   → type_error(number, Seconds)

3.2.11.4 Examples

thread_sleep(Seconds).
   instantiation_error.

thread_sleep(dog).
   type_error(number, dog).

thread_sleep(1.5).
   Succeeds.

thread_sleep(-10).
   Succeeds.

%
% The thread simply count from 1 to N,
% incremented one time per second.
%
:- initialization(counter(10)).

counter(N) :-
   thread_create(do_counter(N), _, [detached(true)]).

do_counter(0) :- !.
do_counter(N) :-
   M is N - 1,
   thread_sleep(1),
   write(M), nl,
   do_counter(M).

3.3 Monitoring threads

The predicates described in this section are provided for diagnosing and monitoring threads. Most multi-threaded applications should not need the predicates from this section because almost any usage of these predicates is unsafe. For
example checking the existence of a thread before signaling it is of no use as it may vanish between the two calls. Catching exceptions using `catch/3` is the only safe way to deal with thread-existence errors.

### 3.3.1 thread_property/2, thread_property/1

#### 3.3.1.1 Description

`thread_property(ThreadOrAlias, Property)` enumerates thread properties.

Procedurally, `thread_property(ThreadOrAlias, Property)` is executed as follows:

a) Create a $Set_{TP}$ of all terms $(T, P)$ such that $T$ is a current thread which has property $P$,

b) If $Set_{TP}$ is empty, the goal fails,

c) Else, chooses a member $(TT, PP)$ of $Set_{TP}$ and removes it from the set,

d) Unifies $TT$ with $ThreadOrAlias$, and $PP$ with $Property$,

e) If unification succeeds, the goal succeeds,

f) Else proceeds to 3.3.1.1 b.

`thread_property(ThreadOrAlias, Property)` is re-executable. On backtracking, continue at 3.3.1.1 b.

#### 3.3.1.2 Template and modes

`thread_property(?thread_or_alias, ?thread_property)`

#### 3.3.1.3 Errors

a) $ThreadOrAlias$ is neither a variable nor a thread-term or alias  
   — `domain_error(thread_or_alias, ThreadOrAlias)`

b) $ThreadOrAlias$ is not associated with a current thread  
   — `existence_error(thread, ThreadOrAlias)`

c) $Property$ is neither a variable nor a thread property  
   — `domain_error(thread_property, Property)`
3.3.1.4 Bootstrapped built-in predicate

The built-in predicate `thread_property/1` provides similar functionality to the built-in predicate `thread_property/2`.

Goal `thread_property(Property)` allows access to the properties of the calling thread.

```
thread_property(Property) :-
    thread_self(Thread),
    thread_property(Thread, Property).
```

3.3.1.5 Examples

These examples assume the environment has been created from the Prolog text defined at the beginning of section 3.2.

```
thread_property(thread, alias(thread)).
    Succeeds.

thread_property(thread, alias(N)).
    Succeeds, unifying N with thread.

thread_property(thread, status(Status)).
    Succeeds, unifying Status with running.

thread_property(thread, P).
    Succeeds, unifying P with a property of the thread.
    On re-execution, succeeds, in turn with each property of the thread.

thread_property(T, P).
    Succeeds, unifying T with the thread and P with a property of the thread.
    On re-execution, succeeds, in turn with each property of the thread and in turn with thread.

thread_property(thread_detached, detached(false)).
    Fails.

thread_property(dog, P).
    domain_error(thread_or_alias, dog).

thread_property(thread_detached, man(paul)).
    domain_error(thread_property, man(paul)).
```
3.3.2 thread_statistics/3, thread_statistics/2

3.3.2.1 Description

\texttt{thread_statistics(ThreadOrAlias, Key, Value)} obtains statistical information on thread \texttt{ThreadOrAlias}. The possible values of \texttt{Key} are implementation defined. The order in which the keys are found is implementation dependent. The implementation of this predicate is optional for Prolog compilers compliant with this TR due to the implied computation overhead in keeping statistical information.

Procedurally, \texttt{thread_statistics(ThreadOrAlias, Key, Value)} is executed as follows:

a) Create a \texttt{SetTKV} of all terms \((T, K, V)\) such that \(T\) is a current thread with statistics \(K\) which has the value \(V\),

b) If \texttt{SetTKP} is empty, the goal fails,

c) Else, chooses a member \((TT, KK, VV)\) of \texttt{SetTKV} and removes it from the set,

d) Unifies \(TT\) with \texttt{ThreadOrAlias}, \(KK\) with \texttt{Key}, and \(VV\) with \texttt{Value},

e) If unification succeeds, the goal succeeds,

f) Else proceeds to 3.3.2.1 b.

\texttt{thread_statistics(ThreadOrAlias, Key, Value)} is re-executable. On backtracking, continue at 3.3.2.1 b.

3.3.2.2 Template and modes

\texttt{thread_statistics(?thread_or_alias, ?key, ?value)}

3.3.2.3 Errors

a) \texttt{MutexOrAlias} is neither a variable nor a mutex-term or alias
   — \texttt{domain_error(mutex_or_alias, MutexOrAlias)}

b) \texttt{Key} is neither a variable nor an atom
   — \texttt{type_error(atom, Key)}

c) \texttt{Value} is neither a variable nor an atom
   — \texttt{type_error(variable, Value)}
3.3.2.4 Bootstrapped built-in predicate

The built-in predicate thread_statistics/2 provides similar functionality to the built-in predicate thread_statistics/3.

Goal thread_statistics(Key, Value) allows access to the statistics information of the calling thread.

\[
\text{thread_statistics(Key, Value) :- thread_self(Thread), thread_statistics(Thread, Key, Value).}
\]

3.3.2.5 Examples

These examples assume the environment has been created from the Prolog text defined at the beginning of section 3.2.

\[
\text{thread_statistics(thread, cputime, Time). Succeeds, unifying Time with the CPU time. [Assumes that the cputime key are defined.]}\]

\[
\text{thread_statistics(thread, disktime, Time). Fails. [Assumes that the disktime key are not defined.]}\]

\[
\text{thread_statistics(dog, cputime, Time). domain_error(thread_or_alias, dog).}\]

\[
\text{thread_statistics(thread, 1, Time). type_error(atom, Key).}\]

3.4 Thread synchronization

These built-in predicates enable thread synchronization using a mutex, which is an abbreviation for mutual exclusion. Mutex built-in predicates provide for creating, destroying, locking, and unlocking mutexes. In addition, predicates for getting runtime mutex usage statistics are also specified.

All internal Prolog operations are thread-safe. This implies two Prolog threads can operate on the same dynamic predicate without corrupting the consistency of the predicate. A mutex is a MUTual EXclusive device, which implies at most one thread can hold a mutex.

Mutexes are used to realize related updates to the Prolog database. With related, we refer to the situation where a transaction implies two or more changes to the Prolog database. For example, we have a predicate address/2, representing the address of a person and we want to change the address by retracting the
old and asserting the new address. Between these two operations the database
is invalid: this person has either no address or two addresses, depending on the
assert/retract order.

The examples provided for these built-in predicate assume the environment
created from the following Prolog text:

```prolog
:- initialization(init).

init :-
    mutex_create(_, [alias(mutex1)]),
    mutex_create(_, [alias(mutex2)]),
    mutex_create(_, [alias(mutex3)]),
    mutex_create(_, [alias(mutex21)]),
    mutex_create(_, [alias(mutex22)]),
    mutex_create(_, [alias(mutex33)]),
    mutex_lock(mutex22),
    mutex_create(_, [alias(bank)]),
    mutex_create(_, [alias(addressbook)]).

cat.
dog.

:- dynamic(balance/2).

balance(paul, 1000).

bank_transaction(Id, Deposit) :-
    balance(Id, V),
    T is V + Deposit,
    retractall(balance(Id, _)),
    asserta(balance(Id, T)).

:- dynamic(address/2).

address(paul, guarda).

change_address(Id, Address) :-
    mutex_lock(addressbook),
    retractall(address(Id, _)),
    asserta(address(Id, Address)),
    mutex_unlock(addressbook).
```

3.4.1 mutex_create/2, mutex_create/1
3.4.1.1 Description
mutex_create(Mutex, Options) creates a new mutex using the given list of options. The variable Mutex is unified with the mutex identifier.

### 3.4.1.2 Template and modes

mutex_create(-mutex, @mutex_options)

### 3.4.1.3 Errors

a) Mutex is not a variable
   — type_error(variable, Mutex)

b) Options is a partial list or a list with an element Option which is a variable
   — instantiation_error

c) Options is neither a partial list nor a list
   — type_error(list, Options)

d) An element of Option of the Options list is not a valid mutex option
   — domain_error(mutex_option, Option)

e) An element Option of the Options list is alias(Alias) and Alias is not an atom
   — type_error(atom, Alias)

f) An element Option of the Options list is alias(Alias) and Alias is already associated with an existing mutex
   — permission_error(create, mutex, Alias)

### 3.4.1.4 Bootstrapped built-in predicate

The built-in predicate mutex_create/1 provides similar functionality to the built-in predicate mutex_create/2.

Goal mutex_create(Mutex) creates a new mutex with alias Mutex when the argument is instantiated to an atom; otherwise Mutex must be a variable which will be instantiated to a new mutex identifier. I.e the predicate behaves as defined by the following clause:

```
mutex_create(Mutex) :-
 (    atom(Mutex) ->
     mutex_create(_, [alias(Mutex)])
 ;    mutex_create(Mutex, [])
 ).
```
3.4.1.5 Examples

mutex_create(Mutex, []).  
Succeeds.  
[It creates a mutex using the default mutex-creation options, unifying Mutex with the new mutex identifier.]

mutex_create(Mutex).  
Succeeds.  
[It creates a mutex using the default mutex-creation options, unifying Mutex with the new mutex identifier.]

mutex_create(Mutex, [alias(mutex_1)]).  
Succeeds.  
[It creates a mutex, unifying Mutex with a mutex-term for the mutex, and associating the alias ‘mutex_1’ with the mutex.]

mutex_create(mutex, []).  
type_error(variable, mutex).

mutex_create(mutex, [alias(mutex_x), X]).  
instantiation_error.

mutex_create(Mutex, options).  
type_error(list, options).

mutex_create(Mutex, [alias(mutex_1), size(512)]).  
domain_error(mutex_option, size(512))

mutex_create(Mutex, [alias(mutex1)]).  
permission_error(create, mutex, mutex1).  
[The mutex named mutex1, has been created previously]

3.4.2 mutex_destroy/1

3.4.2.1 Description

mutex_destroy(MutexOrAlias) destroys a mutex. After this call, the mutex identifier or alias, MutexOrAlias, becomes invalid.

3.4.2.2 Template and modes

mutex_destroy(+mutex_or_alias)

3.4.2.3 Errors
3 BUILT-IN PREDICATES

a) MutexOrAlias is a variable
   — instantiation_error

b) MutexOrAlias is neither a variable nor a mutex-term or alias
   — domain_error(mutex_or_alias, MutexOrAlias)

c) MutexOrAlias is not associated with a current mutex
   — existence_error(mutex, MutexOrAlias)

d) MutexOrAlias the mutex is locked
   — permission_error(destroy, mutex, MutexOrAlias)

3.4.2.4 Examples

These examples assume the environment has been created from the Prolog text defined at the beginning of section

mutex_destroy(mutex1).
   Succeeds.

mutex_destroy(Mutex).
   instantiation_error.

mutex_destroy(cat).
   domain_error(mutex_or_alias, cat).

mutex_destroy(mutex112).
   existence_error(mutex, mutex112).

mutex_lock(mutex1), mutex_destroy(mutex1).
   permission_error(destroy, mutex, mutex1).

3.4.3 with_mutex/2

3.4.3.1 Description

with_mutex(MutexOrAlias, Goal) executes Goal while holding MutexOrAlias. The call blocks if the mutex is not available until it is released. If Goal leaves choice-points, these are destroyed. The mutex is unlocked regardless of whether Goal succeeds, fails, or raises an exception. An exception thrown by Goal is re-thrown after the mutex has been successfully unlocked.

NOTE — The predicate with_mutex/2 allows the execution of a Goal as an atomic transaction, without the need for explicit synchronization by the programmer.
3.4.3.2 Template and modes

\texttt{with_mutex(+mutex_or_alias, +callable_term)}

3.4.3.3 Errors

a) \texttt{MutexOrAlias} is a variable
   \hspace{1em} \texttt{instantiation_error}

b) \texttt{MutexOrAlias} is neither a variable nor a mutex-term or alias
   \hspace{1em} \texttt{domain_error(mutex_or_alias, MutexOrAlias)}

c) \texttt{MutexOrAlias} is not associated with a current mutex
   \hspace{1em} \texttt{existence_error(mutex, MutexOrAlias)}

d) \texttt{Goal} is a variable
   \hspace{1em} \texttt{instantiation_error}

e) \texttt{Goal} is neither a variable nor a callable term
   \hspace{1em} \texttt{type_error(callable, Goal)}

3.4.3.4 Examples

These examples assume the environment has been created from the Prolog text defined at the beginning of section 3.4.

\begin{verbatim}
with_mutex(bank, bank_transaction(paul, 200)).
  Succeeds, noting the list of clauses to be retracted
  = [ balance(paul, 1000) ], and the list of clauses
  to be asserted = [ balance(paul, 1200)].

with_mutex(M, bank_transaction(paul, 200)).
  instantiation_error.

with_mutex(dog, bank_transaction(paul, 200)).
  domain_error(mutex_or_alias, dog).

with_mutex(mutex_bank, bank_transaction(paul, 200)).
  existence_error(mutex, mutex_bank).

with_mutex(bank, Goal).
  instantiation_error.

with_mutex(bank, (bear := 4)).
  type_error(callable, 4).
\end{verbatim}
3.4.4 mutex/lock\(^1\)

3.4.4.1 Description

`mutex_lock(MutexOrAlias)` locks a mutex. Prolog mutexes shall act as recursive mutexes, enabling them to be locked multiple times by the same thread. Only after unlocking it as many times as it is locked, the mutex shall become available for locking by other threads. If another thread has locked the mutex, the calling thread is suspended until the mutex is unlocked.

NOTE — Locking and unlocking mutexes should be paired carefully in order to avoid deadlocks. In particular, the programmer shall ensure that mutexes are properly unlocked even if the protected code fails or raises an exception. For most common cases, the built-in predicate `with_mutex/2` \(^{[3.4.3]}\) provides a safer way for using mutexes.

3.4.4.2 Template and modes

`mutex_lock(+mutex_or_alias)`

3.4.4.3 Errors

a) `MutexOrAlias` is a variable
   — instantiation_error

b) `MutexOrAlias` is neither a variable nor a mutex-term or alias
   — domain_error(mutex_or_alias, MutexOrAlias)

c) `MutexOrAlias` is not associated with a current mutex
   — existence_error(mutex, MutexOrAlias)

3.4.4.4 Examples

These examples assume the environment has been created from the Prolog text defined at the beginning of section \(^{3.4}\)

```
mutex_lock(mutex1).
Succeeds.

mutex_lock(mutex1), mutex_lock(mutex1).
Succeeds.
[A mutex may be locked several times by the same thread.]

mutex_lock(M).
instantiation_error.

mutex_lock(dog).
```
domain_error(mutex_or_alias, dog).

mutex_lock(mutex4).
    existence_error(mutex, mutex4).

change_address(paul, alfarazes).
    Succeeds, noting the list of clauses to be retracted = [ address(paul, guarda) ], and the list of clauses to be asserted = [ address(paul, alfarazes).]

3.4.5 mutex trylock/1

3.4.5.1 Description

mutex_trylock(MutexOrAlias) as mutex_lock/1 [3.4.4], but if the mutex is held by another thread, this predicate fails immediately.

3.4.5.2 Template and modes

mutex_trylock(+mutex_or_alias)

3.4.5.3 Errors

a) MutexOrAlias is a variable — instantiation_error

b) MutexOrAlias is neither a variable nor a mutex-term or alias — domain_error(mutex_or_alias, MutexOrAlias)

c) MutexOrAlias is not associated with a current mutex — existence_error(mutex, MutexOrAlias)

3.4.5.4 Examples

These examples assume the environment has been created from the Prolog text defined at the beginning of section 3.4.

mutex_trylock(mutex1).
    Succeeds.

mutex_trylock(mutex22).
    Fails.
    [The mutex named mutex22 has been locked.]

mutex_trylock(M).
    instantiation_error.
mutex_trylock(dog).
  domain_error(mutex_or_alias, dog).

mutex_trylock(mutex4).
  existence_error(mutex, mutex4).

3.4.6 mutex_unlock/1

3.4.6.1 Description

mutex_unlock(MutexOrAlias) unlocks a mutex. This predicate must be called by the thread holding the mutex.

3.4.6.2 Template and modes

mutex_unlock(+mutex_or_alias)

3.4.6.3 Errors

a) MutexOrAlias is a variable
  — instantiation_error

b) MutexOrAlias is neither a variable nor a mutex-term or alias
  — domain_error(mutex_or_alias, MutexOrAlias)

c) MutexOrAlias is not associated with a current mutex
  — existence_error(mutex_or_alias, MutexOrAlias)

d) the calling thread do not hold the mutex MutexOrAlias
  — permission_error(unlock, mutex, MutexOrAlias)

3.4.6.4 Examples

These examples assume the environment has been created from the Prolog text defined at the beginning of section 3.4.

mutex_lock(mutex22).
  Succeeds.

mutex_unlock(dog).
  domain_error(mutex_or_alias, dog).

mutex_unlock(mutex4).
  existence_error(mutex, mutex4).

mutex_unlock(mutex3).
  permission_error(unlock, mutex, mutex3).
  [Mutex was not locked previously.]
3.4.7 mutex_unlock_all/0

3.4.7.1 Description

mutex_unlock_all unlocks all mutexes held by the current thread.

3.4.7.2 Template and modes

mutex_unlock_all

3.4.7.3 Errors

None.

3.4.7.4 Examples

These examples assume the environment has been created from the Prolog text defined at the beginning of section 3.4.

mutex_unlock_all.
Succeeds.

3.4.8 mutex_property/2

3.4.8.1 Description

mutex_property(MutexOrAlias, Property) enumerates the properties of all current mutexes.

Procedurally, mutex_property(MutexOrAlias, Property) is executed as follows:

a) Create a SetMP of all terms (M, P) such that M is a current mutex which has property P,
b) If SetMP is empty, the goal fails,
c) Else, chooses a member (MM, PP) of SetMP and removes it from the set,
d) Unifies MM with MutexOrAlias, and PP with Property,
e) If unification succeeds, the goal succeeds,
f) Else proceeds to 3.4.8.1 b.

mutex_property(MutexOrAlias, Property) is re-executable. On backtracking, continue at 3.4.8.1 b.
3.4.8.2 Template and modes

mutex_property(?mutex_or_alias, ?mutex_property)

3.4.8.3 Errors

a) MutexOrAlias is neither a variable nor a mutex-term or alias
   — domain_error(mutex_or_alias, MutexOrAlias)

b) MutexOrAlias is not associated with a current mutex
   — existence_error(mutex, MutexOrAlias)

c) Property is neither a variable nor a mutex property
   — domain_error(mutex_property, Property)

3.4.8.4 Examples

These examples assume the environment has been created from the Prolog text
defined at the beginning of section 3.4.

mutex_property(mutex21, alias(mutex21)).
Succeeds.

mutex_property(mutex21, alias(A)).
Succeeds, unifying A with mutex21.

mutex_property(mutex21, status(locked(main, C))).
Succeeds, unifying C with 1.

mutex_property(mutex22, status(locked(main, C))).
Succeeds, unifying C with 2.

mutex_property(Mutex, Property).
Succeeds, unifying Mutex with a mutex-term of an existing mutex
and Property with a property of the mutex.
On re-execution, succeeds, in turn with each property of the mutex.

mutex_property(Mutex, status(locked(Thread, 1))).
Succeeds, unifying Mutex with a mutex-term of an existing
mutex and Thread with the thread that holding the mutex, and has
locked one time.
On re-execution, succeeds, in turn with each mutex.

mutex_property(mutex22, status(locked(main, 1))).
Fails.
mutex_property(dog, status(locked(main, 1))).
domain_error(mutex_or_alias, dog).

mutex_property(mutex4, status(locked(main, 1))).
domain_error(mutex, mutex4).

mutex_property(mutex4, status(locked(dog, 1))).
domain_error(thread_or_alias, dog})

mutex_property(mutex22, status(locked(main, -2))).
domain_error(not_less_than_zero, -2).

3.4.9 mutex_statistics/3

3.4.9.1 Description

mutex_statistics(MutexOrAlias, Key, Value) obtains statistical information of the MutexOrAlias for the calling thread. The possible values of Key are implementation defined. The implementation of this predicate is optional for Prolog compilers compliant with this TR due to the implied computation overhead in keeping statistical information.

NOTE — Two suggested key values are acquisitions (the number of times the thread acquired the mutex) and collisions (the number of times a thread failed to acquire the mutex).

Procedurally, mutex_statistics(MutexOrAlias, Key, Value) is executed as follows:

a) Create a $Set_{MKV}$ of all terms (M, K, V) such that M is a current mutex with statistics K which has the value V,
b) If $Set_{MKP}$ is empty, the goal fails,
c) Else, chooses a member (MM, KK, VV) of $Set_{MKV}$ and removes it from the set,
d) Unifies MM with MutexOrAlias, KK with Key, and VV with Value,
e) If unification succeeds, the goal succeeds,
f) Else proceeds to 3.4.9.1 b.

mutex_statistics(MutexOrAlias, Key, Value) is re-executable. On backtracking, continue at 3.4.9.1 b.

3.4.9.2 Template and modes

mutex_statistics(?mutex_or_alias, ?key, ?value)
3.4.9.3 Errors

a) MutexOrAlias is neither a variable nor a mutex-term or alias
   — domain_error(mutex_or_alias, MutexOrAlias)

b) Key is neither a variable nor an atom
   — type_error(atom, Key)

c) Value is neither a variable nor an atom
   — type_error(variable, Value)

3.4.9.4 Examples

3.5 Message queues

Prolog threads may exchange data using dynamic predicates. However, these provide no suitable means to wait for data or a condition as they can only be checked in an expensive polling loop. Message queues provide a means for threads to wait for data or conditions without consuming computation time. Explicit message queues are commonly used when implementing worker-pool models, where multiple threads wait on a single queue and pick up the first goal to execute.

The built-in predicates presented in this section enables message queue management, monitoring, and communication.

NOTE — Each thread has a message queue attached to it that is identified by the thread.

The examples provided for these built-in predicate assume the pool created from the following Prolog text:

```prolog
:- initialization(main).

main :-
    thread_create(thread_goal, _, [alias(t1)]),
    message_queue_create(_, [alias(q1)]),
    message_queue_create(_, [alias(q2), max_size(20)]).

noqueue.

thread_goal :-
    repeat,
    thread_get_message(q2, M),
    write(M), nl,
    fail.
```
3.5.1 message\_queue\_create/2, message\_queue\_create/1

3.5.1.1 Description

message\_queue\_create(\textit{Queue}, \textit{Options}) creates a new queue using the given list of options. The variable \textit{Queue} is unified with the queue identifier.

3.5.1.2 Template and modes

message\_queue\_create(-queue, @\textit{queue} options)

3.5.1.3 Errors

a) \textit{Queue} is not a variable
   — type\_error(variable, \textit{Queue})

b) \textit{Options} is a partial list or a list with an element \textit{E} which is a variable
   — instantiation\_error

c) \textit{Options} is neither a partial list nor a list
   — type\_error(list, \textit{Options})

d) An element of \textit{E} of the \textit{Options} list is not a valid queue option
   — domain\_error(queue\_option, \textit{E})

e) An element \textit{E} of the \textit{Options} list is alias(\textit{A}) and \textit{A} is already associated with an existing thread or queue
   — permission\_error(create, queue, alias(\textit{A}))

3.5.1.4 Bootstrapped built-in predicate

The built-in predicate message\_queue\_create/1 provides similar functionality to the built-in predicate message\_queue\_create/2.

Goal message\_queue\_create(\textit{Queue}) creates a new queue using default options.

message\_queue\_create(\textit{Queue}) :-
message\_queue\_create(\textit{Queue}, []).

3.5.1.5 Examples

message\_queue\_create(\textit{Queue}, []).
Succeeds.
   [It creates a queue, unifying \textit{Queue} with a queue-term for the queue.]

message\_queue\_create(\textit{Queue}).
Succeeds.
[It creates a queue using de default queue-creation options, unifying Queue with a queue-term for the queue.]

message_queue_create(Queue, [alias(q3)]).
Succeeds.
[It creates a queue, unifies Queue with a queue-term for the queue, and associates the alias ‘q3’ with the queue.]

message_queue_create(Queue, [alias(q3), max_size(20)]).
Succeeds.
[It creates a queue with maximum size 20, unifies Queue with a queue-term for the new queue, and associates the alias ‘q3’ with the queue.]

message_queue_create(queue).
type_error(variable, queue).

message_queue_create(Queue, [alias(q3), X]).
instantiation_error.

message_queue_create(Queue, options).
type_error(list, options).

message_queue_create(Queue, [alias(q2), name(q2)]).
domain_error(queue_option, name(q2)).

message_queue_create(Q, [alias(q1)]).
permission_error(create, queue, alias(q1)).
[Assume that already exists one queue named ‘q1’.]  

3.5.2 message_queue_destroy/1

3.5.2.1 Description

message_queue_destroy(QueueOrAlias) destroys a message queue created with message_queue_create/1-2 built-in predicates (3.5.1). It is not allowed to destroy the queue of a thread. Neither is it allowed to destroy a queue other threads are waiting for or may try to wait for later.

3.5.2.2 Template and modes

message_queue_destroy(+queue_or_alias)
3.5.2.3 Errors

a) QueueOrAlias is a variable
   — instantiation_error

b) QueueOrAlias is neither a variable nor a queue-term or alias
   — domain_error(queue_or_alias, QueueOrAlias)

c) QueueOrAlias is the identifier of an existing thread
   — permission_error(destroy, thread_queue, QueueOrAlias)

d) QueueOrAlias there are threads waiting for, or for anonymous message queues
   — permission_error(destroy, queue, QueueOrAlias)

e) QueueOrAlias is not associated with a current queue
   — existence_error(queue, QueueOrAlias)

3.5.2.4 Examples

These examples assume the environment has been created from the Prolog text defined at the beginning of 3.5.

```
message_queue_destroy(queue1).
  Succeeds.

message_queue_destroy(Queue).
  instantiation_error.

message_queue_destroy(noqueue).
  domain_error(queue_or_alias, noqueue).

message_queue_destroy(t1).
  permission_error(destroy, thread_queue, t1).
  [It is not allowed to destroy the queue of a thread]

message_queue_destroy(q2).
  permission_error(destroy, queue, q2).
  [The thread named t1 is waiting for a message]

message_queue_destroy(q3).
  existence_error(queue, q3).
```

3.5.3 message_queue_property/2

3.5.3.1 Description
message_queue_property(QueueOrAlias, Property) enumerates message queue properties.

Procedurally, message_queue_property(QueueOrAlias, Property) is executed as follows:

a) Creates a Set\(_{QP}\) of all terms (Q, P) such that T is a current message queue which has property P,

b) If Set\(_{QP}\) is empty, the goal fails,

c) Else, chooses a member (QQ, PP) of Set\(_{QP}\) and removes it from the set,

d) Unifies QQ with QueueOrAlias, and PP with Property,

e) If unification succeeds, the goal succeeds,

f) Else proceeds to [3.5.3.1] b.

message_queue_property(QueueOrAlias, Property) is re-executable. On backtracking, continue at [3.5.3.1] b.

### 3.5.3.2 Template and modes

message_queue_property(?queue_or_alias, ?queue_property)

### 3.5.3.3 Errors

a) QueueOrAlias is neither a variable nor a queue-term or alias — domain_error(queue_or_alias, QueueOrAlias)

b) QueueOrAlias is not associated with a current message queue — existence_error(queue, QueueOrAlias)

c) Property is neither a variable nor a message queue property — domain_error(queue_property, Property)

### 3.5.3.4 Examples

message_queue_property(q1, size(Size)).
   Succeeds, unifying Size with 0.

message_queue_property(q2, size(Size)).
   Succeeds, unifying Size with 0.

message_queue_property(q2, size(4)).
   Fails.

message_queue_property(noqueue, Size).
domain_error(queue_or_alias, noqueue).
message_queue_property(q3, Property).
existence_error(queue, q3).
message_queue_property(q2, size(size)).
type_error(integer, size).

3.6 Thread and message queue communication

These built-in predicates enable thread and message queue communication, and queue monitoring.

Prolog threads can exchange data using dynamic predicates, database records, and other globally shared data. These provide no suitable means to wait for data or a condition as they can only be checked in an expensive polling loop. Message queues provide a means for threads to wait for data or conditions without using the CPU. Each thread has a message queue attached to it that can be referenced using the thread identifier or alias (if defined).

The examples provided for these built-in predicate assume the environment created from the following Prolog text:

```prolog
:- initialization(main).

thread_goal :-
    repeat,
    thread_get_message(M),
    write(M), nl,
    fail.

main :-
    message_queue_create(_, [alias(queue1)]),
    message_queue_create(_, [alias(queue2), max_size(2)]),
    thread_create(thread_goal, _, [alias(thread1)]),
    thread_send_message(queue2, father(antonio)),
    thread_send_message(queue2, mother(maria)).
```

3.6.1 thread_send_message/2, thread_send_message/1

3.6.1.1 Description

`thread_send_message(QueueOrAlias, Term)` places `Term` in a message queue. Any term may be placed in a message queue. The term is copied to the receiving queue; thus, any variable-bindings are lost. This call returns immediately.
3.6.1.2 Template and modes

\texttt{thread_send_message(+queue\_or\_alias, \_term)}

3.6.1.3 Errors

a) \texttt{QueueOrAlias} is a variable
   \quad \rightarrow \textit{instantiation\_error}

b) \texttt{QueueOrAlias} is neither a variable nor a queue-term or alias
   \quad \rightarrow \textit{domain\_error(queue\_or\_alias, QueueOrAlias)}

c) \texttt{QueueOrAlias} is not associated with a current queue
   \quad \rightarrow \textit{existence\_error(queue, QueueOrAlias)}

3.6.1.4 Bootstrapped built-in predicate

The built-in predicate \texttt{thread\_send\_message/1} provides similar functionality to the built-in predicate \texttt{thread\_send\_message/2}.

Goal \texttt{thread\_send\_message(Term)} sends a message to the message queue of the calling thread.

\begin{verbatim}
thread_send_message(Term) :-
    thread_self(Thread),
    thread_send_message(Thread, Term).
\end{verbatim}

3.6.1.5 Examples

These examples assume the environment has been created from the Prolog text defined at the beginning of 3.6.

\begin{verbatim}
thread_send_message(queue1, father(antonio)).
  Succeeds.

thread_send_message(thread1, father(antonio)).
  Succeeds.

thread_send_message(queue2, father(paul)).
  Succeeds.

thread_send_message(Queue, mother(maria)).
  instantiation\_error.

thread_send_message(noqueue, mother(maria)).
  domain\_error(queue\_or\_alias, noqueue).
\end{verbatim}
3.6.2 thread_get_message/2, thread_get_message/1

3.6.2.1 Description

thread_get_message(QueueOrAlias, Term) gets a Term from a message queue. The predicate walks the message queue and if necessary blocks execution until a term that unifies to Term arrives in the queue. After a term from the queue has been unified to Term, the term is deleted from the queue and this predicate returns. Note that non-unifying messages remain in the queue.

3.6.2.2 Template and modes

thread_get_message(+queue_or_alias, ?term)

3.6.2.3 Errors

a) QueueOrAlias is a variable
   — instantiation_error

b) QueueOrAlias is neither a variable nor a queue-term or alias
   — domain_error(queue_or_alias, QueueOrAlias)

c) QueueOrAlias is not associated with a current queue
   — existence_error(queue, QueueOrAlias)

3.6.2.4 Bootstrapped built-in predicate

The built-in predicate thread_get_message/1 provides similar functionality to the built-in predicate thread_get_message/2.

Goal thread_get_message(Term) gets a message from the message queue of the calling thread.

thread_get_message(Term) :-
    thread_self(Thread),
    thread_get_message(Thread, Term).

3.6.2.5 Examples

These examples assume the environment has been created from the Prolog text defined at the beginning of 3.6.

thread_get_message(queue2, father(antonio)).
  Succeeds.
thread_get_message(queue2, father(Father)).
   Succeeds, unifying Father with antonio.

thread_get_message(queue2, Message).
   Succeeds, unifying Message with father(antonio).

thread_get_message(Queue, mother(maria)).
   instantiation_error.

thread_get_message(noqueue, mother(maria)).
   domain_error(queue_or_alias, noqueue).

thread_get_message(queue3, mother(maria)).
   existence_error(queue, queue3).

After the following has been executed, thread_1 has the term b(gnu) in its queue
and continues execution using A is gnat.

<thread_1>
   thread_get_message(a(A)),

<thread_2>
   thread_send_message(Thread_1, b(gnu)),
   thread_send_message(Thread_1, a(gnat)),

3.6.3 thread_peek_message/2, thread_peek_message/1

3.6.3.1 Description

thread_peek_message(QueueOrAlias, Term) walks a message queue and com-
pares the queued terms with Term until one unifies or the end of the queue has
been reached. In the first case the call succeeds (possibly instantiating Term).
If no term from the queue unifies this call fails.

3.6.3.2 Template and modes

thread_peek_message(+queue_or_alias, ?term)

3.6.3.3 Errors

   a) QueueOrAlias is a variable
      — instantiation_error

   b) QueueOrAlias is neither a variable nor a queue-term or alias
      — domain_error(queue_or_alias, QueueOrAlias)
c) QueueOrAlias is not associated with a current queue
   — existence_error(queue, QueueOrAlias)

3.6.3.4 Bootstrapped built-in predicate

The built-in predicate `thread_peek_message/1` provides similar functionality to the built-in predicate `thread_peek_message/2`.

Goal `thread_peek_message(Term)` searches the calling thread queue for a message match.

```
thread_peek_message(Term) :-
    thread_self(Thread),
    thread_peek_message(Thread, Term).
```

3.6.3.5 Examples

These examples assume the environment has been created from the Prolog text defined at the beginning of 3.6.

```
thread_peek_message(queue2, father(antonio)).
   Succeeds.

thread_peek_message(queue2, mother(maria)).
   Succeeds.

thread_peek_message(queue2, father(Father)).
   Succeeds, unifying Father with antonio.

thread_peek_message(queue2, Message).
   Succeeds, unifying Message with father(antonio).

thread_peek_message(queue2, father(anne)).
   Fails.

thread_peek_message(queue, mother(maria)).
   instantiation_error.

thread_peek_message(noqueue, mother(maria)).
   domain_error(queue_or_alias, noqueue).

thread_peek_message(queue3, mother(maria)).
   existence_error(queue, queue3).
```