Erlang Run-Time System Application (ERTS)

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Erlang Run-Time System Application (ERTS) 9.2
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1 ERTS User's Guide

1.1 Introduction

1.1.1 Scope

The Erlang Runtime System Application, ERTS, contains functionality necessary to run the Erlang system.

Note:

By default, `ERTS` is only guaranteed to be compatible with other Erlang/OTP components from the same release as `ERTS` itself.

For information on how to communicate with Erlang/OTP components from earlier releases, see the documentation of system flag `+R` in `erl(1)`.

1.1.2 Prerequisites

It is assumed that the reader is familiar with the Erlang programming language.

1.2 Communication in Erlang

Communication in Erlang is conceptually performed using asynchronous signaling. All different executing entities, such as processes and ports, communicate through asynchronous signals. The most commonly used signal is a message. Other common signals are exit, link, unlink, monitor, and demonitor signals.

1.2.1 Passing of Signals

The amount of time that passes between a signal is sent and the arrival of the signal at the destination is unspecified but positive. If the receiver has terminated, the signal does not arrive, but it can trigger another signal. For example, a link signal sent to a non-existing process triggers an exit signal, which is sent back to where the link signal originated from. When communicating over the distribution, signals can be lost if the distribution channel goes down.

The only signal ordering guarantee given is the following: if an entity sends multiple signals to the same destination entity, the order is preserved; that is, if `A` sends a signal `S1` to `B`, and later sends signal `S2` to `B`, `S1` is guaranteed not to arrive after `S2`.

1.2.2 Synchronous Communication

Some communication is synchronous. If broken down into pieces, a synchronous communication operation consists of two asynchronous signals; one request signal and one reply signal. An example of such a synchronous communication is a call to `erlang:process_info/2` when the first argument is not `self()`. The caller sends an asynchronous signal requesting information, and then waits for the reply signal containing the requested information. When the request signal reaches its destination, the destination process replies with the requested information.

1.2.3 Implementation

The implementation of different asynchronous signals in the virtual machine can vary over time, but the behavior always respects this concept of asynchronous signals being passed between entities as described above.

By inspecting the implementation, you might notice that some specific signal gives a stricter guarantee than described above. It is of vital importance that such knowledge about the implementation is **not** used by Erlang code, as the implementation can change at any time without prior notice.

Examples of major implementation changes:

- As from ERTS 5.5.2 exit signals to processes are truly asynchronously delivered.
- As from ERTS 5.10 all signals from processes to ports are truly asynchronously delivered.

1.3 Time and Time Correction in Erlang

1.3.1 New Extended Time Functionality

Note:

As from Erlang/OTP 18 (ERTS 7.0) the time functionality has been extended. This includes a *new API* for time and *time warp modes* that change the system behavior when system time changes.

The *default time warp mode* has the same behavior as before, and the old API still works. Thus, you are not required to change anything unless you want to. However, **you are strongly encouraged to use the new API** instead of the old API based on `erlang:now/0`. `erlang:now/0` is deprecated, as it is and will be a scalability bottleneck.

By using the new API, you automatically get scalability and performance improvements. This also enables you to use the *multi-time warp mode* that improves accuracy and precision of time measurements.

1.3.2 Terminology

To make it easier to understand this section, some terms are defined. This is a mix of our own terminology (Erlang/OS system time, Erlang/OS monotonic time, time warp) and globally accepted terminology.

Monotonically Increasing

In a monotonically increasing sequence of values, all values that have a predecessor are either larger than or equal to its predecessor.

Strictly Monotonically Increasing

In a strictly monotonically increasing sequence of values, all values that have a predecessor are larger than its predecessor.

UT1

Universal Time. UT1 is based on the rotation of the earth and conceptually means solar time at 0° longitude.

UTC

Coordinated Universal Time. UTC almost aligns with *UT1*. However, UTC uses the SI definition of a second, which has not exactly the same length as the second used by UT1. This means that UTC slowly drifts from UT1. To keep UTC relatively in sync with UT1, leap seconds are inserted, and potentially also deleted. That is, an UTC day can be 86400, 86401, or 86399 seconds long.

POSIX Time

Time since **Epoch**. Epoch is defined to be 00:00:00 *UTC*, 1970-01-01. **A day in POSIX time** is defined to be exactly 86400 seconds long. Strangely enough, Epoch is defined to be a time in UTC, and UTC has another definition of how long a day is. Quoting the Open Group **"POSIX time is therefore not necessarily UTC, despite its appearance"**. The effect of this is that when an UTC leap second is inserted, POSIX time either stops for a second, or repeats the

last second. If an UTC leap second would be deleted (which has not happened yet), POSIX time would make a one second leap forward.

Time Resolution

The shortest time interval that can be distinguished when reading time values.

Time Precision

The shortest time interval that can be distinguished repeatedly and reliably when reading time values. Precision is limited by the *resolution*, but resolution and precision can differ significantly.

Time Accuracy

The correctness of time values.

Time Warp

A time warp is a leap forwards or backwards in time. That is, the difference of time values taken before and after the time warp does not correspond to the actual elapsed time.

OS System Time

The operating systems view of *POSIX time*. To retrieve it, call `os:system_time()`. This may or may not be an accurate view of POSIX time. This time may typically be adjusted both backwards and forwards without limitation. That is, *time warps* may be observed.

To get information about the Erlang runtime system's source of OS system time, call `erlang:system_info(os_system_time_source)`.

OS Monotonic Time

A monotonically increasing time provided by the OS. This time does not leap and has a relatively steady frequency although not completely correct. However, it is not uncommon that OS monotonic time stops if the system is suspended. This time typically increases since some unspecified point in time that is not connected to *OS system time*. This type of time is not necessarily provided by all OSs.

To get information about the Erlang runtime system's source of OS monotonic time, call `erlang:system_info(os_monotonic_time_source)`.

Erlang System Time

The Erlang runtime systems view of *POSIX time*. To retrieve it, call `erlang:system_time()`.

This time may or may not be an accurate view of POSIX time, and may or may not align with *OS system time*. The runtime system works towards aligning the two system times. Depending on the *time warp mode* used, this can be achieved by letting Erlang system time perform a *time warp*.

Erlang Monotonic Time

A monotonically increasing time provided by the Erlang runtime system. Erlang monotonic time increases since some unspecified point in time. To retrieve it, call `erlang:monotonic_time()`.

The *accuracy* and *precision* of Erlang monotonic time heavily depends on the following:

- Accuracy and precision of *OS monotonic time*
- Accuracy and precision of *OS system time*
- *time warp mode* used

On a system without OS monotonic time, Erlang monotonic time guarantees monotonicity, but cannot give other guarantees. The frequency adjustments made to Erlang monotonic time depend on the time warp mode used.

Internally in the runtime system, Erlang monotonic time is the "time engine" that is used for more or less everything that has anything to do with time. All timers, regardless of it is a `receive ... after` timer, BIF timer, or a timer in the *`timer(3)`* module, are triggered relative Erlang monotonic time. Even *Erlang system time* is based on Erlang monotonic time. By adding current Erlang monotonic time with current time offset, you get current Erlang system time.

To retrieve the current time offset, call *`erlang:time_offset/0`*.

1.3.3 Introduction

Time is vital to an Erlang program and, more importantly, **correct** time is vital to an Erlang program. As Erlang is a language with soft real-time properties and we can express time in our programs, the Virtual Machine and the language must be careful about what is considered a correct time and in how time functions behave.

When Erlang was designed, it was assumed that the wall clock time in the system showed a monotonic time moving forward at exactly the same pace as the definition of time. This more or less meant that an atomic clock (or better time source) was expected to be attached to your hardware and that the hardware was then expected to be locked away from any human tinkering forever. While this can be a compelling thought, it is simply never the case.

A "normal" modern computer cannot keep time, not on itself and not unless you have a chip-level atomic clock wired to it. Time, as perceived by your computer, must normally be corrected. Hence the Network Time Protocol (NTP) protocol, together with the `ntpd` process, does its best to keep your computer time in sync with the correct time. Between NTP corrections, usually a less potent time-keeper than an atomic clock is used.

However, NTP is not fail-safe. The NTP server can be unavailable, `ntp.conf` can be wrongly configured, or your computer can sometimes be disconnected from Internet. Furthermore, you can have a user (or even system administrator) who thinks the correct way to handle Daylight Saving Time is to adjust the clock one hour two times a year (which is the incorrect way to do it). To complicate things further, this user fetched your software from Internet and has not considered what the correct time is as perceived by a computer. The user does not care about keeping the wall clock in sync with the correct time. The user expects your program to have unlimited knowledge about the time.

Most programmers also expect time to be reliable, at least until they realize that the wall clock time on their workstation is off by a minute. Then they set it to the correct time, but most probably not in a smooth way.

The number of problems that arise when you always expect the wall clock time on the system to be correct can be immense. Erlang therefore introduced the "corrected estimate of time", or the "time correction", many years ago. The time correction relies on the fact that most operating systems have some kind of monotonic clock, either a real-time extension or some built-in "tick counter" that is independent of the wall clock settings. This counter can have microsecond resolution or much less, but it has a drift that cannot be ignored.

1.3.4 Time Correction

If time correction is enabled, the Erlang runtime system makes use of both *OS system time* and *OS monotonic time*, to adjust the frequency of the Erlang monotonic clock. Time correction ensures that *Erlang monotonic time* does not warp and that the frequency is relatively accurate. The type of frequency adjustments depends on the time warp mode used. Section *Time Warp Modes* provides more details.

By default time correction is enabled if support for it exists on the specific platform. Support for it includes both OS monotonic time, provided by the OS, and an implementation in the Erlang runtime system using OS monotonic time. To check if your system has support for OS monotonic time, call *`erlang:system_info(os_monotonic_time_source)`*. To check if time correction is enabled on your system, call *`erlang:system_info(time_correction)`*.

To enable or disable time correction, pass command-line argument *`+c [true|false]`* to *`erl(1)`*.

If time correction is disabled, Erlang monotonic time can warp forwards or stop, or even freeze for extended periods of time. There are then no guarantees that the frequency of the Erlang monotonic clock is accurate or stable.

You typically never want to disable time correction. Previously a performance penalty was associated with time correction, but nowadays it is usually the other way around. If time correction is disabled, you probably get bad scalability, bad performance, and bad time measurements.

1.3.5 Time Warp Safe Code

Time warp safe code can handle a *time warp* of *Erlang system time*.

`erlang:now/0` behaves bad when Erlang system time warps. When Erlang system time does a time warp backwards, the values returned from `erlang:now/0` freeze (if you disregard the microsecond increments made because of the actual call) until OS system time reaches the point of the last value returned by `erlang:now/0`. This freeze can continue for a long time. It can take years, decades, and even longer until the freeze stops.

All uses of `erlang:now/0` are not necessarily time warp unsafe. If you do not use it to get time, it is time warp safe. However, **all uses of `erlang:now/0` are suboptimal** from a performance and scalability perspective. So you really want to replace the use of it with other functionality. For examples of how to replace the use of `erlang:now/0`, see section *How to Work with the New API*.

1.3.6 Time Warp Modes

Current *Erlang system time* is determined by adding the current *Erlang monotonic time* with current *time offset*. The time offset is managed differently depending on which time warp mode you use.

To set the time warp mode, pass command-line argument *`+C [no_time_warp|single_time_warp|multi_time_warp]`* to *`erl(1)`*.

No Time Warp Mode

The time offset is determined at runtime system start and does not change later. This is the default behavior, but not because it is the best mode (which it is not). It is default **only** because this is how the runtime system behaved until ERTS 7.0. Ensure that your Erlang code that can execute during a time warp is *time warp safe* before enabling other modes.

As the time offset is not allowed to change, time correction must adjust the frequency of the Erlang monotonic clock to align Erlang system time with OS system time smoothly. A significant downside of this approach is that we on purpose will use a faulty frequency on the Erlang monotonic clock if adjustments are needed. This error can be as large as 1%. This error will show up in all time measurements in the runtime system.

If time correction is not enabled, Erlang monotonic time freezes when OS system time leaps backwards. The freeze of monotonic time continues until OS system time catches up. The freeze can continue for a long time. When OS system time leaps forwards, Erlang monotonic time also leaps forward.

Single Time Warp Mode

This mode is more or less a backward compatibility mode as from its introduction.

On an embedded system it is not uncommon that the system has no power supply, not even a battery, when it is shut off. The system clock on such a system is typically way off when the system boots. If *no time warp mode* is used, and the Erlang runtime system is started before OS system time has been corrected, Erlang system time can be wrong for a long time, centuries or even longer.

If you need to use Erlang code that is not *time warp safe*, and you need to start the Erlang runtime system before OS system time has been corrected, you may want to use the single time warp mode.

> **Note:**
>
> There are limitations to when you can execute time warp unsafe code using this mode. If it is possible to use time warp safe code only, it is **much** better to use the *multi-time warp mode* instead.

Using the single time warp mode, the time offset is handled in two phases:

Preliminary Phase

This phase starts when the runtime system starts. A preliminary time offset based on current OS system time is determined. This offset is from now on to be fixed during the whole preliminary phase.

If time correction is enabled, adjustments to the Erlang monotonic clock are made to keep its frequency as correct as possible. However, **no** adjustments are made trying to align Erlang system time and OS system time. That is, during the preliminary phase Erlang system time and OS system time can diverge from each other, and no attempt is made to prevent this.

If time correction is disabled, changes in OS system time affects the monotonic clock the same way as when the *no time warp mode* is used.

Final Phase

This phase begins when the user finalizes the time offset by calling `erlang:system_flag(time_offset, finalize)`. The finalization can only be performed once.

During finalization, the time offset is adjusted and fixed so that current Erlang system time aligns with the current OS system time. As the time offset can change during the finalization, Erlang system time can do a time warp at this point. The time offset is from now on fixed until the runtime system terminates. If time correction has been enabled, the time correction from now on also makes adjustments to align Erlang system time with OS system time. When the system is in the final phase, it behaves exactly as in *no time warp mode*.

In order for this to work properly, the user must ensure that the following two requirements are satisfied:

Forward Time Warp

The time warp made when finalizing the time offset can only be done forwards without encountering problems. This implies that the user must ensure that OS system time is set to a time earlier or equal to actual POSIX time before starting the Erlang runtime system.

If you are not sure that OS system time is correct, set it to a time that is guaranteed to be earlier than actual POSIX time before starting the Erlang runtime system, just to be safe.

Finalize Correct OS System Time

OS system time must be correct when the user finalizes the time offset.

If these requirements are not fulfilled, the system may behave very bad.

Assuming that these requirements are fulfilled, time correction is enabled, and OS system time is adjusted using a time adjustment protocol such as NTP, only small adjustments of Erlang monotonic time are needed to keep system times aligned after finalization. As long as the system is not suspended, the largest adjustments needed are for inserted (or deleted) leap seconds.

Warning:

To use this mode, ensure that all Erlang code that will execute in both phases is *time warp safe*.

Code executing only in the final phase does not have to be able to cope with the time warp.

Multi-Time Warp Mode

Multi-time warp mode in combination with time correction is the preferred configuration. This as the Erlang runtime system have better performance, scale better, and behave better on almost all platforms. Also, the accuracy and precision of time measurements are better. Only Erlang runtime systems executing on ancient platforms benefit from another configuration.

The time offset can change at any time without limitations. That is, Erlang system time can perform time warps both forwards and backwards at **any** time. As we align Erlang system time with OS system time by changing the time offset, we can enable a time correction that tries to adjust the frequency of the Erlang monotonic clock to be as correct as possible. This makes time measurements using Erlang monotonic time more accurate and precise.

If time correction is disabled, Erlang monotonic time leaps forward if OS system time leaps forward. If OS system time leaps backwards, Erlang monotonic time stops briefly, but it does not freeze for extended periods of time. This as the time offset is changed to align Erlang system time with OS system time.

Warning:

To use this mode, ensure that all Erlang code that will execute on the runtime system is *time warp safe*.

1.3.7 New Time API

The old time API is based on *`erlang:now/0`*. `erlang:now/0` was intended to be used for many unrelated things. This tied these unrelated operations together and caused issues with performance, scalability, accuracy, and precision for operations that did not need to have such issues. To improve this, the new API spreads different functionality over multiple functions.

To be backward compatible, `erlang:now/0` remains "as is", but **you are strongly discouraged from using it**. Many use cases of `erlang:now/0` prevents you from using the new *multi-time warp mode*, which is an important part of this new time functionality improvement.

Some of the new BIFs on some systems, perhaps surprisingly, return negative integer values on a newly started runtime system. This is not a bug, but a memory use optimization.

The new API consists of the following new BIFs:

- *`erlang:convert_time_unit/3`*
- *`erlang:monotonic_time/0`*
- *`erlang:monotonic_time/1`*
- *`erlang:system_time/0`*
- *`erlang:system_time/1`*
- *`erlang:time_offset/0`*
- *`erlang:time_offset/1`*
- *`erlang:timestamp/0`*
- *`erlang:unique_integer/0`*
- *`erlang:unique_integer/1`*
- *`os:system_time/0`*
- *`os:system_time/1`*

The new API also consists of extensions of the following existing BIFs:

- *`erlang:monitor(time_offset, clock_service)`*
- *`erlang:system_flag(time_offset, finalize)`*
- *`erlang:system_info(os_monotonic_time_source)`*
- *`erlang:system_info(os_system_time_source)`*
- *`erlang:system_info(time_offset)`*
- *`erlang:system_info(time_warp_mode)`*
- *`erlang:system_info(time_correction)`*
- *`erlang:system_info(start_time)`*

- *`erlang:system_info(end_time)`*

New Erlang Monotonic Time

Erlang monotonic time as such is new as from ERTS 7.0. It is introduced to detach time measurements, such as elapsed time from calendar time. In many use cases there is a need to measure elapsed time or specify a time relative to another point in time without the need to know the involved times in UTC or any other globally defined time scale. By introducing a time scale with a local definition of where it starts, time that do not concern calendar time can be managed on that time scale. Erlang monotonic time uses such a time scale with a locally defined start.

The introduction of Erlang monotonic time allows us to adjust the two Erlang times (Erlang monotonic time and Erlang system time) separately. By doing this, the accuracy of elapsed time does not have to suffer just because the system time happened to be wrong at some point in time. Separate adjustments of the two times are only performed in the time warp modes, and only fully separated in the *multi-time warp mode*. All other modes than the multi-time warp mode are for backward compatibility reasons. When using these modes, the accuracy of Erlang monotonic time suffer, as the adjustments of Erlang monotonic time in these modes are more or less tied to Erlang system time.

The adjustment of system time could have been made smother than using a time warp approach, but we think that would be a bad choice. As we can express and measure time that is not connected to calendar time by the use of Erlang monotonic time, it is better to expose the change in Erlang system time immediately. This as the Erlang applications executing on the system can react on the change in system time as soon as possible. This is also more or less exactly how most operating systems handle this (OS monotonic time and OS system time). By adjusting system time smoothly, we would just hide the fact that system time changed and make it harder for the Erlang applications to react to the change in a sensible way.

To be able to react to a change in Erlang system time, you must be able to detect that it happened. The change in Erlang system time occurs when the current time offset is changed. We have therefore introduced the possibility to monitor the time offset using *`erlang:monitor(time_offset, clock_service)`*. A process monitoring the time offset is sent a message on the following format when the time offset is changed:

```
{'CHANGE', MonitorReference, time_offset, clock_service, NewTimeOffset}
```

Unique Values

Besides reporting time, `erlang:now/0` also produces unique and strictly monotonically increasing values. To detach this functionality from time measurements, we have introduced *`erlang:unique_integer()`*.

How to Work with the New API

Previously `erlang:now/0` was the only option for doing many things. This section deals with some things that `erlang:now/0` can be used for, and how you use the new API.

Retrieve Erlang System Time

Don't:

Use `erlang:now/0` to retrieve the current Erlang system time.

Do:

Use *`erlang:system_time/1`* to retrieve the current Erlang system time on the *time unit* of your choice.

If you want the same format as returned by `erlang:now/0`, use *`erlang:timestamp/0`*.

Measure Elapsed Time

Don't:

Take time stamps with `erlang:now/0` and calculate the difference in time with *`timer:now_diff/2`*.

Do:

Take time stamps with *`erlang:monotonic_time/0`* and calculate the time difference using ordinary subtraction. The result is in `native` *time unit*. If you want to convert the result to another time unit, you can use *`erlang:convert_time_unit/3`*.

An easier way to do this is to use *`erlang:monotonic_time/1`* with the desired time unit. However, you can then lose accuracy and precision.

Determine Order of Events

Don't:

Determine the order of events by saving a time stamp with `erlang:now/0` when the event occurs.

Do:

Determine the order of events by saving the integer returned by *`erlang:unique_integer([monotonic])`* when the event occurs. These integers are strictly monotonically ordered on current runtime system instance corresponding to creation time.

Determine Order of Events with Time of the Event

Don't:

Determine the order of events by saving a time stamp with `erlang:now/0` when the event occurs.

Do:

Determine the order of events by saving a tuple containing *monotonic time* and a *strictly monotonically increasing integer* as follows:

```
Time = erlang:monotonic_time(),
UMI = erlang:unique_integer([monotonic]),
EventTag = {Time, UMI}
```

These tuples are strictly monotonically ordered on the current runtime system instance according to creation time. It is important that the monotonic time is in the first element (the most significant element when comparing two-tuples). Using the monotonic time in the tuples, you can calculate time between events.

If you are interested in Erlang system time at the time when the event occurred, you can also save the time offset before or after saving the events using `erlang:time_offset/0`. Erlang monotonic time added with the time offset corresponds to Erlang system time.

If you are executing in a mode where time offset can change, and you want to get the actual Erlang system time when the event occurred, you can save the time offset as a third element in the tuple (the least significant element when comparing three-tuples).

Create a Unique Name

Don't:

Use the values returned from `erlang:now/0` to create a name unique on the current runtime system instance.

Do:

Use the value returned from `erlang:unique_integer/0` to create a name unique on the current runtime system instance. If you only want positive integers, you can use `erlang:unique_integer([positive])`.

Seed Random Number Generation with a Unique Value

Don't:

Seed random number generation using `erlang:now()`.

Do:

Seed random number generation using a combination of `erlang:monotonic_time()`, `erlang:time_offset()`, `erlang:unique_integer()`, and other functionality.

To sum up this section: **Do not use `erlang:now/0`.**

1.3.8 Support of Both New and Old OTP Releases

It can be required that your code must run on a variety of OTP installations of different OTP releases. If so, you cannot use the new API out of the box, as it will not be available on releases before OTP 18. The solution is **not** to avoid using the new API, as your code would then not benefit from the scalability and accuracy improvements made. Instead, use the new API when available, and fall back on `erlang:now/0` when the new API is unavailable.

Fortunately most of the new API can easily be implemented using existing primitives, except for:

- *`erlang:system_info(start_time)`*
- *`erlang:system_info(end_time)`*
- *`erlang:system_info(os_monotonic_time_source)`*
- *`erlang:system_info(os_system_time_source)`*)

By wrapping the API with functions that fall back on `erlang:now/0` when the new API is unavailable, and using these wrappers instead of using the API directly, the problem is solved. These wrappers can, for example, be implemented as in **$ERL_TOP/erts/example/time_compat.erl**.

1.4 Match Specifications in Erlang

A "match specification" (`match_spec`) is an Erlang term describing a small "program" that tries to match something. It can be used to either control tracing with *erlang:trace_pattern/3* or to search for objects in an ETS table with for example *ets:select/2*. The match specification in many ways works like a small function in Erlang, but is interpreted/compiled by the Erlang runtime system to something much more efficient than calling an Erlang function. The match specification is also very limited compared to the expressiveness of real Erlang functions.

The most notable difference between a match specification and an Erlang fun is the syntax. Match specifications are Erlang terms, not Erlang code. Also, a match specification has a strange concept of exceptions:

- An exception (such as `badarg`) in the `MatchCondition` part, which resembles an Erlang guard, generates immediate failure.
- An exception in the `MatchBody` part, which resembles the body of an Erlang function, is implicitly caught and results in the single atom `'EXIT'`.

1.4.1 Grammar

A match specification used in tracing can be described in the following **informal** grammar:

- MatchExpression ::= [MatchFunction, ...]
- MatchFunction ::= { MatchHead, MatchConditions, MatchBody }
- MatchHead ::= MatchVariable | `'_'` | [MatchHeadPart, ...]
- MatchHeadPart ::= term() | MatchVariable | `'_'`
- MatchVariable ::= '$<number>'
- MatchConditions ::= [MatchCondition, ...] | `[]`
- MatchCondition ::= { GuardFunction } | { GuardFunction, ConditionExpression, ... }
- BoolFunction ::= `is_atom` | `is_float` | `is_integer` | `is_list` | `is_number` | `is_pid` | `is_port` | `is_reference` | `is_tuple` | `is_map` | `is_binary` | `is_function` | `is_record` | `is_seq_trace` | `'and'` | `'or'` | `'not'` | `'xor'` | `'andalso'` | `'orelse'`
- ConditionExpression ::= ExprMatchVariable | { GuardFunction } | { GuardFunction, ConditionExpression, ... } | TermConstruct
- ExprMatchVariable ::= MatchVariable (bound in the MatchHead) | `'$_'` | `'$$'`
- TermConstruct = {{}} | {{ ConditionExpression, ... }} | `[]` | [ConditionExpression, ...] | `#{}` | #{term() => ConditionExpression, ...} | NonCompositeTerm | Constant
- NonCompositeTerm ::= term() (not list or tuple or map)
- Constant ::= {`const`, term()}
- GuardFunction ::= BoolFunction | `abs` | `element` | `hd` | `length` | `node` | `round` | `size` | `tl` | `trunc` | `'+'` | `'-'` | `'*'` | `'div'` | `'rem'` | `'band'` | `'bor'` | `'bxor'` | `'bnot'` | `'bsl'` | `'bsr'` | `'>'` | `'>='` | `'<'` | `'=<'` | `'=:='` | `'=='` | `'=/='` | `'/='` | `self` | `get_tcw`
- MatchBody ::= [ActionTerm]
- ActionTerm ::= ConditionExpression | ActionCall

- ActionCall ::= {ActionFunction} | {ActionFunction, ActionTerm, ...}
- ActionFunction ::= `set_seq_token` | `get_seq_token` | `message` | `return_trace` | `exception_trace` | `process_dump` | `enable_trace` | `disable_trace` | `trace` | `display` | `caller` | `set_tcw` | `silent`

A match specification used in *`ets(3)`* can be described in the following **informal** grammar:

- MatchExpression ::= [MatchFunction, ...]
- MatchFunction ::= { MatchHead, MatchConditions, MatchBody }
- MatchHead ::= MatchVariable | `'_'` | { MatchHeadPart, ... }
- MatchHeadPart ::= term() | MatchVariable | `'_'`
- MatchVariable ::= '$<number>'
- MatchConditions ::= [MatchCondition, ...] | `[]`
- MatchCondition ::= { GuardFunction } | { GuardFunction, ConditionExpression, ... }
- BoolFunction ::= `is_atom` | `is_float` | `is_integer` | `is_list` | `is_number` | `is_pid` | `is_port` | `is_reference` | `is_tuple` | `is_map` | `is_binary` | `is_function` | `is_record` | `is_seq_trace` | `'and'` | `'or'` | `'not'` | `'xor'` | `'andalso'` | `'orelse'`
- ConditionExpression ::= ExprMatchVariable | { GuardFunction } | { GuardFunction, ConditionExpression, ... } | TermConstruct
- ExprMatchVariable ::= MatchVariable (bound in the MatchHead) | `'$_'` | `'$$'`
- TermConstruct = {{}} | {{ ConditionExpression, ... }} | `[]` | [ConditionExpression, ...] | #{} | #{term() => ConditionExpression, ...} | NonCompositeTerm | Constant
- NonCompositeTerm ::= term() (not list or tuple or map)
- Constant ::= {`const`, term()}
- GuardFunction ::= BoolFunction | `abs` | `element` | `hd` | `length` | `node` | `round` | `size` | `tl` | `trunc` | `'+'` | `'-'` | `'*'` | `'div'` | `'rem'` | `'band'` | `'bor'` | `'bxor'` | `'bnot'` | `'bsl'` | `'bsr'` | `'>'` | `'>='` | `'<'` | `'=<'` | `'=:='` | `'=='` | `'=/='` | `'/='` | `self` | `get_tcw`
- MatchBody ::= [ConditionExpression, ...]

1.4.2 Function Descriptions

Functions Allowed in All Types of Match Specifications

The functions allowed in `match_spec` work as follows:

`is_atom`, `is_float`, `is_integer`, `is_list`, `is_number`, `is_pid`, `is_port`, `is_reference`, `is_tuple`, `is_map`, `is_binary`, `is_function`

Same as the corresponding guard tests in Erlang, return `true` or `false`.

`is_record`

Takes an additional parameter, which **must** be the result of `record_info(size, <record_type>)`, like in `{is_record, '$1', rectype, record_info(size, rectype)}`.

`'not'`

Negates its single argument (anything other than `false` gives `false`).

`'and'`

Returns `true` if all its arguments (variable length argument list) evaluate to `true`, otherwise `false`. Evaluation order is undefined.

`'or'`

Returns `true` if any of its arguments evaluates to `true`. Variable length argument list. Evaluation order is undefined.

`'andalso'`

Works as `'and'`, but quits evaluating its arguments when one argument evaluates to something else than `true`. Arguments are evaluated left to right.

`'orelse'`

Works as `'or'`, but quits evaluating as soon as one of its arguments evaluates to `true`. Arguments are evaluated left to right.

`'xor'`

Only two arguments, of which one must be `true` and the other `false` to return `true`; otherwise `'xor'` returns false.

`abs`, `element`, `hd`, `length`, `node`, `round`, `size`, `tl`, `trunc`, `'+'`, `'-'`, `'*'`, `'div'`, `'rem'`, `'band'`, `'bor'`, `'bxor'`, `'bnot'`, `'bsl'`, `'bsr'`, `'>'`, `'>='`, `'<'`, `'=<'`, `'=:='`, `'=='`, `'=/='`, `'/='`, `self`

Same as the corresponding Erlang BIFs (or operators). In case of bad arguments, the result depends on the context. In the `MatchConditions` part of the expression, the test fails immediately (like in an Erlang guard). In the `MatchBody` part, exceptions are implicitly caught and the call results in the atom `'EXIT'`.

Functions Allowed Only for Tracing

The functions allowed only for tracing work as follows:

`is_seq_trace`

Returns `true` if a sequential trace token is set for the current process, otherwise `false`.

`set_seq_token`

Works as `seq_trace:set_token/2`, but returns `true` on success, and `'EXIT'` on error or bad argument. Only allowed in the `MatchBody` part and only allowed when tracing.

`get_seq_token`

Same as `seq_trace:get_token/0` and only allowed in the `MatchBody` part when tracing.

`message`

Sets an additional message appended to the trace message sent. One can only set one additional message in the body. Later calls replace the appended message.

As a special case, `{message, false}` disables sending of trace messages ('call' and 'return_to') for this function call, just like if the match specification had not matched. This can be useful if only the side effects of the `MatchBody` part are desired.

Another special case is `{message, true}`, which sets the default behavior, as if the function had no match specification; trace message is sent with no extra information (if no other calls to `message` are placed before `{message, true}`, it is in fact a "noop").

Takes one argument: the message. Returns `true` and can only be used in the `MatchBody` part and when tracing.

`return_trace`

Causes a `return_from` trace message to be sent upon return from the current function. Takes no arguments, returns `true` and can only be used in the `MatchBody` part when tracing. If the process trace flag `silent` is active, the `return_from` trace message is inhibited.

Warning: If the traced function is tail-recursive, this match specification function destroys that property. Hence, if a match specification executing this function is used on a perpetual server process, it can only be active for a limited period of time, or the emulator will eventually use all memory in the host machine and crash. If this match specification function is inhibited using process trace flag `silent`, tail-recursiveness still remains.

`exception_trace`

Works as `return_trace` plus; if the traced function exits because of an exception, an `exception_from` trace message is generated, regardless of the exception is caught or not.

`process_dump`

Returns some textual information about the current process as a binary. Takes no arguments and is only allowed in the `MatchBody` part when tracing.

`enable_trace`

With one parameter this function turns on tracing like the Erlang call `erlang:trace(self(), true, [P2])`, where `P2` is the parameter to `enable_trace`.

With two parameters, the first parameter is to be either a process identifier or the registered name of a process. In this case tracing is turned on for the designated process in the same way as in the Erlang call `erlang:trace(P1, true, [P2])`, where `P1` is the first and `P2` is the second argument. The process `P1` gets its trace messages sent to the same tracer as the process executing the statement uses. `P1` **cannot** be one of the atoms `all`, `new` or `existing` (unless they are registered names). `P2` **cannot** be `cpu_timestamp` or `tracer`.

Returns `true` and can only be used in the `MatchBody` part when tracing.

`disable_trace`

With one parameter this function disables tracing like the Erlang call `erlang:trace(self(), false, [P2])`, where `P2` is the parameter to `disable_trace`.

With two parameters this function works as the Erlang call `erlang:trace(P1, false, [P2])`, where `P1` can be either a process identifier or a registered name and is specified as the first argument to the match specification function. `P2` **cannot** be `cpu_timestamp` or `tracer`.

Returns `true` and can only be used in the `MatchBody` part when tracing.

`trace`

With two parameters this function takes a list of trace flags to disable as first parameter and a list of trace flags to enable as second parameter. Logically, the disable list is applied first, but effectively all changes are applied atomically. The trace flags are the same as for `erlang:trace/3`, not including `cpu_timestamp`, but including `tracer`.

If a tracer is specified in both lists, the tracer in the enable list takes precedence. If no tracer is specified, the same tracer as the process executing the match specification is used.

When using a *tracer module*, the module must be loaded before the match specification is executed. If it is not loaded, the match fails.

With three parameters to this function, the first is either a process identifier or the registered name of a process to set trace flags on, the second is the disable list, and the third is the enable list.

Returns `true` if any trace property was changed for the trace target process, otherwise `false`. Can only be used in the `MatchBody` part when tracing.

`caller`

Returns the calling function as a tuple `{Module, Function, Arity}` or the atom `undefined` if the calling function cannot be determined. Can only be used in the `MatchBody` part when tracing.

Notice that if a "technically built in function" (that is, a function not written in Erlang) is traced, the `caller` function sometimes returns the atom `undefined`. The calling Erlang function is not available during such calls.

`display`

For debugging purposes only. Displays the single argument as an Erlang term on `stdout`, which is seldom what is wanted. Returns `true` and can only be used in the `MatchBody` part when tracing.

`get_tcw`

Takes no argument and returns the value of the node's trace control word. The same is done by `erlang:system_info(trace_control_word)`.

The trace control word is a 32-bit unsigned integer intended for generic trace control. The trace control word can be tested and set both from within trace match specifications and with BIFs. This call is only allowed when tracing.

`set_tcw`

Takes one unsigned integer argument, sets the value of the node's trace control word to the value of the argument, and returns the previous value. The same is done by `erlang:system_flag(trace_control_word, Value)`. It is only allowed to use `set_tcw` in the `MatchBody` part when tracing.

`silent`

Takes one argument. If the argument is `true`, the call trace message mode for the current process is set to silent for this call and all later calls, that is, call trace messages are inhibited even if `{message, true}` is called in the `MatchBody` part for a traced function.

This mode can also be activated with flag `silent` to `erlang:trace/3`.

If the argument is `false`, the call trace message mode for the current process is set to normal (non-silent) for this call and all later calls.

If the argument is not `true` or `false`, the call trace message mode is unaffected.

Note:

All "function calls" must be tuples, even if they take no arguments. The value of `self` is the atom() `self`, but the value of `{self}` is the pid() of the current process.

1.4.3 Match target

Each execution of a match specification is done against a match target term. The format and content of the target term depends on the context in which the match is done. The match target for ETS is always a full table tuple. The match target for call trace is always a list of all function arguments. The match target for event trace depends on the event type, see table below.

Context	Type	Match target	Description
ETS		{Key, Value1, Value2, ...}	A table object
Trace	call	[Arg1, Arg2, ...]	Function arguments
Trace	send	[Receiver, Message]	Receiving process/port and message term

Trace	'receive'	[Node, Sender, Message]	Sending node, process/port and message term

Table 4.1: Match target depending on context

1.4.4 Variables and Literals

Variables take the form `'$<number>'`, where `<number>` is an integer between 0 and 100,000,000 (1e+8). The behavior if the number is outside these limits is **undefined**. In the `MatchHead` part, the special variable `'_'` matches anything, and never gets bound (like _ in Erlang).

- In the `MatchCondition/MatchBody` parts, no unbound variables are allowed, so `'_'` is interpreted as itself (an atom). Variables can only be bound in the `MatchHead` part.
- In the `MatchBody` and `MatchCondition` parts, only variables bound previously can be used.
- As a special case, the following apply in the `MatchCondition/MatchBody` parts:
  - The variable `'$_'` expands to the whole *match target* term.
  - The variable `'$$'` expands to a list of the values of all bound variables in order (that is, `['$1','$2', ...]`).

In the `MatchHead` part, all literals (except the variables above) are interpreted "as is".

In the `MatchCondition/MatchBody` parts, the interpretation is in some ways different. Literals in these parts can either be written "as is", which works for all literals except tuples, or by using the special form `{const, T}`, where `T` is any Erlang term.

For tuple literals in the match specification, double tuple parentheses can also be used, that is, construct them as a tuple of arity one containing a single tuple, which is the one to be constructed. The "double tuple parenthesis" syntax is useful to construct tuples from already bound variables, like in `{{'$1', [a,b,'$2']}}`. Examples:

Expression	**Variable Bindings**	**Result**
{{'$1','$2'}}	'$1' = a, '$2' = b	{a,b}
{const, {'$1', '$2'}}	Irrelevant	{'$1', '$2'}
a	Irrelevant	a
'$1'	'$1' = []	[]
['$1']	'$1' = []	[[]]
[{{a}}]	Irrelevant	[{a}]
42	Irrelevant	42
"hello"	Irrelevant	"hello"
$1	Irrelevant	49 (the ASCII value for character '1')

Table 4.2: Literals in MatchCondition/MatchBody Parts of a Match Specification

1.4.5 Execution of the Match

The execution of the match expression, when the runtime system decides whether a trace message is to be sent, is as follows:

For each tuple in the `MatchExpression` list and while no match has succeeded:

- Match the `MatchHead` part against the match target term, binding the `'$<number>'` variables (much like in `ets:match/2`). If the `MatchHead` part cannot match the arguments, the match fails.
- Evaluate each `MatchCondition` (where only `'$<number>'` variables previously bound in the `MatchHead` part can occur) and expect it to return the atom `true`. When a condition does not evaluate to `true`, the match fails. If any BIF call generates an exception, the match also fails.
- Two cases can occur:
  - If the match specification is executing when tracing:

    Evaluate each `ActionTerm` in the same way as the `MatchConditions`, but ignore the return values. Regardless of what happens in this part, the match has succeeded.
  - If the match specification is executed when selecting objects from an ETS table:

    Evaluate the expressions in order and return the value of the last expression (typically there is only one expression in this context).

1.4.6 Differences between Match Specifications in ETS and Tracing

ETS match specifications produce a return value. Usually the `MatchBody` contains one single `ConditionExpression` that defines the return value without any side effects. Calls with side effects are not allowed in the ETS context.

When tracing there is no return value to produce, the match specification either matches or does not. The effect when the expression matches is a trace message rather than a returned term. The `ActionTerm`s are executed as in an imperative language, that is, for their side effects. Functions with side effects are also allowed when tracing.

1.4.7 Tracing Examples

Match an argument list of three, where the first and third arguments are equal:

```
[{['$1', '_', '$1'],
  [],
  []}]
```

Match an argument list of three, where the second argument is a number > 3:

```
[{['_', '$1', '_'],
  [{ '>', '$1', 3}],
  []}]
```

Match an argument list of three, where the third argument is either a tuple containing argument one and two, **or** a list beginning with argument one and two (that is, `[a,b,[a,b,c]]` or `[a,b,{a,b}]`):

```
[{['$1', '$2', '$3'],
  [{'orelse',
      {'=:=', '$3', {{'$1','$2'}}},
      {'and',
        {'=:=', '$1', {hd, '$3'}},
        {'=:=', '$2', {hd, {tl, '$3'}}}}}],
  []}]
```

The above problem can also be solved as follows:

```
[{['$1', '$2', {'$1', '$2}], [], []},
 {['$1', '$2', ['$1', '$2' | '_']], [], []}]
```

Match two arguments, where the first is a tuple beginning with a list that in turn begins with the second argument times two (that is, `[{[4,x],y},2]` or `[{[8], y, z},4]`):

```
[{['$1', '$2'],[{'=:=', {'*', 2, '$2'}, {hd, {element, 1, '$1'}}}],
  []}]
```

Match three arguments. When all three are equal and are numbers, append the process dump to the trace message, otherwise let the trace message be "as is", but set the sequential trace token label to 4711:

```
[{['$1', '$1', '$1'],
  [{is_number, '$1'}],
  [{message, {process_dump}}]},
 {'_', [], [{set_seq_token, label, 4711}]}]
```

As can be noted above, the parameter list can be matched against a single `MatchVariable` or an `'_'`. To replace the whole parameter list with a single variable is a special case. In all other cases the `MatchHead` must be a **proper** list.

Generate a trace message only if the trace control word is set to 1:

```
[{'_',
  [{'==',{get_tcw},{const, 1}}],
  []}]
```

Generate a trace message only if there is a `seq_trace` token:

```
[{'_',
  [{'==',{is_seq_trace},{const, 1}}],
  []}]
```

Remove the `'silent'` trace flag when the first argument is `'verbose'`, and add it when it is `'silent'`:

```
[{'$1',
  [{'==',{hd, '$1'},verbose}],
  [{trace, [silent],[]}]},
 {'$1',
  [{'==',{hd, '$1'},silent}],
  [{trace, [],[silent]}]}]
```

Add a `return_trace` message if the function is of arity 3:

```
[{'$1',
  [{'==',{length, '$1'},3}],
  [{return_trace}]},
 {'_',[],[]}]
```

Generate a trace message only if the function is of arity 3 and the first argument is `'trace'`:

```
[{['trace','$2','$3'],
  [],
  []},
 {'_',[],[]}]
```

1.4.8 ETS Examples

Match all objects in an ETS table, where the first element is the atom `'strider'` and the tuple arity is 3, and return the whole object:

```
[{{strider,'_','_'},
  [],
  ['$_']}]
```

Match all objects in an ETS table with arity > 1 and the first element is 'gandalf', and return element 2:

```
[{'$1',
  [{'==', gandalf, {element, 1, '$1'}},{'>=',{size, '$1'},2}],
  [{element,2,'$1'}]}]
```

In this example, if the first element had been the key, it is much more efficient to match that key in the `MatchHead` part than in the `MatchConditions` part. The search space of the tables is restricted with regards to the `MatchHead` so that only objects with the matching key are searched.

Match tuples of three elements, where the second element is either `'merry'` or `'pippin'`, and return the whole objects:

```
[{{'_',merry,'_'},
  [],
  ['$_']},
 {{'_',pippin,'_'},
  [],
  ['$_']}]
```

Function *`ets:test_ms/2>`* can be useful for testing complicated ETS matches.

1.5 How to Interpret the Erlang Crash Dumps

This section describes the `erl_crash.dump` file generated upon abnormal exit of the Erlang runtime system.

Note:

The Erlang crash dump had a major facelift in Erlang/OTP R9C. The information in this section is therefore not directly applicable for older dumps. However, if you use *`crashdump_viewer(3)`* on older dumps, the crash dumps are translated into a format similar to this.

The system writes the crash dump in the current directory of the emulator or in the file pointed out by the environment variable (whatever that means on the current operating system) `ERL_CRASH_DUMP`. For a crash dump to be written, a writable file system must be mounted.

Crash dumps are written mainly for one of two reasons: either the built-in function `erlang:halt/1` is called explicitly with a string argument from running Erlang code, or the runtime system has detected an error that cannot be handled. The most usual reason that the system cannot handle the error is that the cause is external limitations, such as running out of memory. A crash dump caused by an internal error can be caused by the system reaching limits in the emulator itself (like the number of atoms in the system, or too many simultaneous ETS tables). Usually the emulator or the operating system can be reconfigured to avoid the crash, which is why interpreting the crash dump correctly is important.

On systems that support OS signals, it is also possible to stop the runtime system and generate a crash dump by sending the `SIGUSR1` signal.

The Erlang crash dump is a readable text file, but it can be difficult to read. Using the Crashdump Viewer tool in the `Observer` application simplifies the task. This is a wx-widget-based tool for browsing Erlang crash dumps.

1.5.1 General Information

The first part of the crash dump shows the following:

- The creation time for the dump
- A slogan indicating the reason for the dump
- The system version of the node from which the dump originates
- The compile time of the emulator running the originating node
- The number of atoms in the atom table
- The runtime system thread that caused the crash dump

Reasons for Crash Dumps (Slogan)

The reason for the dump is shown in the beginning of the file as:

```
Slogan: <reason>
```

If the system is halted by the BIF `erlang:halt/1`, the slogan is the string parameter passed to the BIF, otherwise it is a description generated by the emulator or the (Erlang) kernel. Normally the message is enough to understand the problem, but some messages are described here. Notice that the suggested reasons for the crash are **only suggestions**. The exact reasons for the errors can vary depending on the local applications and the underlying operating system.

<A>: Cannot allocate <N> bytes of memory (of type "<T>")

The system has run out of memory. <A> is the allocator that failed to allocate memory, <N> is the number of bytes that <A> tried to allocate, and <T> is the memory block type that the memory was needed for. The most common case is that a process stores huge amounts of data. In this case <T> is most often `heap`, `old_heap`, `heap_frag`, or `binary`. For more information on allocators, see *`erts_alloc(3)`*.

<A>: Cannot reallocate <N> bytes of memory (of type "<T>")

Same as above except that memory was reallocated instead of allocated when the system ran out of memory.

Unexpected op code <N>

Error in compiled code, `beam` file damaged, or error in the compiler.

Module <Name> undefined | Function <Name> undefined | No function <Name>:<Name>/1 | No function <Name>:start/2

The Kernel/STDLIB applications are damaged or the start script is damaged.

Driver_select called with too large file descriptor `N`

The number of file descriptors for sockets exceeds 1024 (Unix only). The limit on file descriptors in some Unix flavors can be set to over 1024, but only 1024 sockets/pipes can be used simultaneously by Erlang (because of limitations in the Unix `select` call). The number of open regular files is not affected by this.

Received SIGUSR1

Sending the `SIGUSR1` signal to an Erlang machine (Unix only) forces a crash dump. This slogan reflects that the Erlang machine crash-dumped because of receiving that signal.

Kernel pid terminated (<Who>) (<Exit reason>)

The kernel supervisor has detected a failure, usually that the `application_controller` has shut down (`Who` = `application_controller`, `Why` = `shutdown`). The application controller can have shut down for many reasons, the most usual is that the node name of the distributed Erlang node is already in use. A complete supervisor tree "crash" (that is, the top supervisors have exited) gives about the same result. This message comes from the Erlang code and not from the virtual machine itself. It is always because of some failure in an application, either within OTP or a "user-written" one. Looking at the error log for your application is probably the first step to take.

Init terminating in do_boot ()

The primitive Erlang boot sequence was terminated, most probably because the boot script has errors or cannot be read. This is usually a configuration error; the system can have been started with a faulty `-boot` parameter or with a boot script from the wrong OTP version.

Could not start kernel pid (<Who>) ()

One of the kernel processes could not start. This is probably because of faulty arguments (like errors in a `-config` argument) or faulty configuration files. Check that all files are in their correct location and that the configuration files (if any) are not damaged. Usually messages are also written to the controlling terminal and/or the error log explaining what is wrong.

Other errors than these can occur, as the `erlang:halt/1` BIF can generate any message. If the message is not generated by the BIF and does not occur in the list above, it can be because of an error in the emulator. There can however be unusual messages, not mentioned here, which are still connected to an application failure. There is much more information available, so a thorough reading of the crash dump can reveal the crash reason. The size of processes, the number of ETS tables, and the Erlang data on each process stack can be useful to find the problem.

Number of Atoms

The number of atoms in the system at the time of the crash is shown as **Atoms: <number>**. Some ten thousands atoms is perfectly normal, but more can indicate that the BIF `erlang:list_to_atom/1` is used to generate many **different** atoms dynamically, which is never a good idea.

1.5.2 Scheduler Information

Under the tag **=scheduler** is shown information about the current state and statistics of the schedulers in the runtime system. On operating systems that allow suspension of other threads, the data within this section reflects what the runtime system looks like when a crash occurs.

The following fields can exist for a process:

=scheduler:id

Heading. States the scheduler identifier.

Scheduler Sleep Info Flags

If empty, the scheduler was doing some work. If not empty, the scheduler is either in some state of sleep, or suspended. This entry is only present in an SMP-enabled emulator.

Scheduler Sleep Info Aux Work

If not empty, a scheduler internal auxiliary work is scheduled to be done.

Current Port

The port identifier of the port that is currently executed by the scheduler.

Current Process

The process identifier of the process that is currently executed by the scheduler. If there is such a process, this entry is followed by the **State**, **Internal State**, **Program Counter**, and **CP** of that same process. The entries are described in section *Process Information*.

Notice that this is a snapshot of what the entries are exactly when the crash dump is starting to be generated. Therefore they are most likely different (and more telling) than the entries for the same processes found in the **=proc** section. If there is no currently running process, only the **Current Process** entry is shown.

Current Process Limited Stack Trace

This entry is shown only if there is a current process. It is similar to ***=proc_stack***, except that only the function frames are shown (that is, the stack variables are omitted). Also, only the top and bottom part of the stack are

shown. If the stack is small (< 512 slots), the entire stack is shown. Otherwise the entry **skipping ## slots** is shown, where ## is replaced by the number of slots that has been skipped.

Run Queue

Shows statistics about how many processes and ports of different priorities are scheduled on this scheduler.

**** crashed ****

This entry is normally not shown. It signifies that getting the rest of the information about this scheduler failed for some reason.

1.5.3 Memory Information

Under the tag **=memory** is shown information similar to what can be obtainted on a living node with `erlang:memory()`.

1.5.4 Internal Table Information

Under the tags **=hash_table:<table_name>** and **=index_table:<table_name>** is shown internal tables. These are mostly of interest for runtime system developers.

1.5.5 Allocated Areas

Under the tag **=allocated_areas** is shown information similar to what can be obtained on a living node with `erlang:system_info(allocated_areas)`.

1.5.6 Allocator

Under the tag **=allocator:<A>** is shown various information about allocator <A>. The information is similar to what can be obtained on a living node with `erlang:system_info({allocator, <A>})`. For more information, see also `erts_alloc(3)`.

1.5.7 Process Information

The Erlang crashdump contains a listing of each living Erlang process in the system. The following fields can exist for a process:

=proc:<pid>

Heading. States the process identifier.

State

The state of the process. This can be one of the following:

Scheduled
: The process was scheduled to run but is currently not running ("in the run queue").

Waiting
: The process was waiting for something (in `receive`).

Running
: The process was currently running. If the BIF `erlang:halt/1` was called, this was the process calling it.

Exiting
: The process was on its way to exit.

Garbing
: This is bad luck, the process was garbage collecting when the crash dump was written. The rest of the information for this process is limited.

Suspended

The process is suspended, either by the BIF `erlang:suspend_process/1` or because it tries to write to a busy port.

Registered name

The registered name of the process, if any.

Spawned as

The entry point of the process, that is, what function was referenced in the `spawn` or `spawn_link` call that started the process.

Last scheduled in for | Current call

The current function of the process. These fields do not always exist.

Spawned by

The parent of the process, that is, the process that executed `spawn` or `spawn_link`.

Started

The date and time when the process was started.

Message queue length

The number of messages in the process' message queue.

Number of heap fragments

The number of allocated heap fragments.

Heap fragment data

Size of fragmented heap data. This is data either created by messages sent to the process or by the Erlang BIFs. This amount depends on so many things that this field is utterly uninteresting.

Link list

Process IDs of processes linked to this one. Can also contain ports. If process monitoring is used, this field also tells in which direction the monitoring is in effect. That is, a link "to" a process tells you that the "current" process was monitoring the other, and a link "from" a process tells you that the other process was monitoring the current one.

Reductions

The number of reductions consumed by the process.

Stack+heap

The size of the stack and heap (they share memory segment).

OldHeap

The size of the "old heap". The Erlang virtual machine uses generational garbage collection with two generations. There is one heap for new data items and one for the data that has survived two garbage collections. The assumption (which is almost always correct) is that data surviving two garbage collections can be "tenured" to a heap more seldom garbage collected, as they will live for a long period. This is a usual technique in virtual machines. The sum of the heaps and stack together constitute most of the allocated memory of the process.

Heap unused, OldHeap unused

The amount of unused memory on each heap. This information is usually useless.

Memory

The total memory used by this process. This includes call stack, heap, and internal structures. Same as *`erlang:process_info(Pid,memory)`*.

Program counter

The current instruction pointer. This is only of interest for runtime system developers. The function into which the program counter points is the current function of the process.

CP

The continuation pointer, that is, the return address for the current call. Usually useless for other than runtime system developers. This can be followed by the function into which the CP points, which is the function calling the current function.

Arity

The number of live argument registers. The argument registers if any are live will follow. These can contain the arguments of the function if they are not yet moved to the stack.

Internal State

A more detailed internal representation of the state of this process.

See also section *Process Data*.

1.5.8 Port Information

This section lists the open ports, their owners, any linked processes, and the name of their driver or external process.

1.5.9 ETS Tables

This section contains information about all the ETS tables in the system. The following fields are of interest for each table:

=ets:<owner>

Heading. States the table owner (a process identifier).

Table

The identifier for the table. If the table is a `named_table`, this is the name.

Name

The table name, regardless of if it is a `named_table` or not.

Hash table, Buckets

If the table is a hash table, that is, if it is not an `ordered_set`.

Hash table, Chain Length

If the table is a hash table. Contains statistics about the table, such as the maximum, minimum, and average chain length. Having a maximum much larger than the average, and a standard deviation much larger than the expected standard deviation is a sign that the hashing of the terms behaves badly for some reason.

Ordered set (AVL tree), Elements

If the table is an `ordered_set`. (The number of elements is the same as the number of objects in the table.)

Fixed

If the table is fixed using *`ets:safe_fixtable/2`* or some internal mechanism.

Objects

The number of objects in the table.

Words

The number of words (usually 4 bytes/word) allocated to data in the table.

Type

The table type, that is, `set`, `bag`, `dublicate_bag`, or `ordered_set`.

Compressed

If the table was compressed.

Protection

The protection of the table.

Write Concurrency

If `write_concurrency` was enabled for the table.

Read Concurrency

If `read_concurrency` was enabled for the table.

1.5.10 Timers

This section contains information about all the timers started with the BIFs `erlang:start_timer/3` and `erlang:send_after/3`. The following fields exist for each timer:

=timer:<owner>

Heading. States the timer owner (a process identifier), that is, the process to receive the message when the timer expires.

Message

The message to be sent.

Time left

Number of milliseconds left until the message would have been sent.

1.5.11 Distribution Information

If the Erlang node was alive, that is, set up for communicating with other nodes, this section lists the connections that were active. The following fields can exist:

=node:<node_name>

The node name.

no_distribution

If the node was not distributed.

=visible_node:<channel>

Heading for a visible node, that is, an alive node with a connection to the node that crashed. States the channel number for the node.

=hidden_node:<channel>

Heading for a hidden node. A hidden node is the same as a visible node, except that it is started with the `"-hidden"` flag. States the channel number for the node.

=not_connected:<channel>

Heading for a node that was connected to the crashed node earlier. References (that is, process or port identifiers) to the not connected node existed at the time of the crash. States the channel number for the node.

Name

The name of the remote node.

Controller

The port controlling communication with the remote node.

Creation

An integer (1-3) that together with the node name identifies a specific instance of the node.

Remote monitoring: <local_proc> <remote_proc>

The local process was monitoring the remote process at the time of the crash.

Remotely monitored by: <local_proc> <remote_proc>

The remote process was monitoring the local process at the time of the crash.

Remote link: <local_proc> <remote_proc>

A link existed between the local process and the remote process at the time of the crash.

1.5.12 Loaded Module Information

This section contains information about all loaded modules.

First, the memory use by the loaded code is summarized:

Current code

Code that is the current latest version of the modules.

Old code

Code where there exists a newer version in the system, but the old version is not yet purged.

The memory use is in bytes.

Then, all loaded modules are listed. The following fields exist:

=mod:<module_name>

Heading. States the module name.

Current size

Memory use for the loaded code, in bytes.

Old size

Memory use for the old code, if any.

Current attributes

Module attributes for the current code. This field is decoded when looked at by the Crashdump Viewer tool.

Old attributes

Module attributes for the old code, if any. This field is decoded when looked at by the Crashdump Viewer tool.

Current compilation info

Compilation information (options) for the current code. This field is decoded when looked at by the Crashdump Viewer tool.

Old compilation info

Compilation information (options) for the old code, if any. This field is decoded when looked at by the Crashdump Viewer tool.

1.5.13 Fun Information

This section lists all funs. The following fields exist for each fun:

=fun

Heading.

Module

The name of the module where the fun was defined.

Uniq, Index

Identifiers.

Address

The address of the fun's code.

Native_address

The address of the fun's code when HiPE is enabled.

Refc

The number of references to the fun.

1.5.14 Process Data

For each process there is at least one **=proc_stack** and one **=proc_heap** tag, followed by the raw memory information for the stack and heap of the process.

For each process there is also a **=proc_messages** tag if the process message queue is non-empty, and a **=proc_dictionary** tag if the process dictionary (the `put/2` and `get/1` thing) is non-empty.

The raw memory information can be decoded by the Crashdump Viewer tool. You can then see the stack dump, the message queue (if any), and the dictionary (if any).

The stack dump is a dump of the Erlang process stack. Most of the live data (that is, variables currently in use) are placed on the stack; thus this can be interesting. One has to "guess" what is what, but as the information is symbolic, thorough reading of this information can be useful. As an example, we can find the state variable of the Erlang primitive loader online `(5)` and `(6)` in the following example:

```
(1)  3cac44   Return addr 0x13BF58 (<terminate process normally>)
(2)  y(0)     ["/view/siri_r10_dev/clearcase/otp/erts/lib/kernel/ebin",
(3)            "/view/siri_r10_dev/clearcase/otp/erts/lib/stdlib/ebin"]
(4)  y(1)     <0.1.0>
(5)  y(2)     {state,[],none,#Fun<erl_prim_loader.6.7085890>,undefined,#Fun<erl_prim_loader.7.9000327>,
(6)            #Fun<erl_prim_loader.8.116480692>,#Port<0.2>,infinity,#Fun<erl_prim_loader.9.10708760>}
(7)  y(3)     infinity
```

When interpreting the data for a process, it is helpful to know that anonymous function objects (funs) are given the following:

- A name constructed from the name of the function in which they are created
- A number (starting with 0) indicating the number of that fun within that function

1.5.15 Atoms

This section presents all the atoms in the system. This is only of interest if one suspects that dynamic generation of atoms can be a problem, otherwise this section can be ignored.

Notice that the last created atom is shown first.

1.5.16 Disclaimer

The format of the crash dump evolves between OTP releases. Some information described here may not apply to your version. A description like this will never be complete; it is meant as an explanation of the crash dump in general and as a help when trying to find application errors, not as a complete specification.

1.6 How to Implement an Alternative Carrier for the Erlang Distribution

This section describes how to implement an alternative carrier protocol for the Erlang distribution. The distribution is normally carried by TCP/IP. Here is explained a method for replacing TCP/IP with another protocol.

The section is a step-by-step explanation of the `uds_dist` example application (in the Kernel application `examples` directory). The `uds_dist` application implements distribution over Unix domain sockets and is written for the Sun Solaris 2 operating environment. The mechanisms are however general and apply to any operating system Erlang runs on. The reason the C code is not made portable, is simply readability.

Note:

This section was written a long time ago. Most of it is still valid, but some things have changed since then. Most notably is the driver interface. Some updates have been made to the documentation of the driver presented here, but more can be done and is planned for the future. The reader is encouraged to read the *`erl_driver`* and *`driver_entry`* documentation also.

1.6.1 Introduction

To implement a new carrier for the Erlang distribution, the main steps are as follows.

Writing an Erlang Driver

First, the protocol must be available to the Erlang machine, which involves writing an Erlang driver. A port program cannot be used, an Erlang driver is required. Erlang drivers can be:

- Statically linked to the emulator, which can be an alternative when using the open source distribution of Erlang, or
- Dynamically loaded into the Erlang machines address space, which is the only alternative if a precompiled version of Erlang is to be used

Writing an Erlang driver is not easy. The driver is written as some callback functions called by the Erlang emulator when data is sent to the driver, or the driver has any data available on a file descriptor. As the driver callback routines execute in the main thread of the Erlang machine, the callback functions can perform no blocking activity whatsoever. The callbacks are only to set up file descriptors for waiting and/or read/write available data. All I/O must be non-blocking. Driver callbacks are however executed in sequence, why a global state can safely be updated within the routines.

Writing an Erlang Interface for the Driver

When the driver is implemented, one would preferably write an Erlang interface for the driver to be able to test the functionality of the driver separately. This interface can then be used by the distribution module, which will cover the details of the protocol from the `net_kernel`.

The easiest path is to mimic the `inet` and `inet_tcp` interfaces, but not much functionality in those modules needs to be implemented. In the example application, only a few of the usual interfaces are implemented, and they are much simplified.

Writing a Distribution Module

When the protocol is available to Erlang through a driver and an Erlang interface module, a distribution module can be written. The distribution module is a module with well-defined callbacks, much like a `gen_server` (there is no compiler support for checking the callbacks, though). This module implements:

- The details of finding other nodes (that is, talking to `epmd` or something similar)
- Creating a listen port (or similar)
- Connecting to other nodes
- Performing the handshakes/cookie verification

There is however a utility module, `dist_util`, which does most of the hard work of handling handshakes, cookies, timers, and ticking. Using `dist_util` makes implementing a distribution module much easier and that is done in the example application.

Creating Boot Scripts

The last step is to create boot scripts to make the protocol implementation available at boot time. The implementation can be debugged by starting the distribution when all the system is running, but in a real system the distribution is to start very early, why a boot script and some command-line parameters are necessary.

This step also implies that the Erlang code in the interface and distribution modules is written in such a way that it can be run in the startup phase. In particular, there can be no calls to the `application` module or to any modules not loaded at boot time. That is, only `Kernel`, `STDLIB`, and the application itself can be used.

1.6.2 The Driver

Although Erlang drivers in general can be beyond the scope of this section, a brief introduction seems to be in place.

Drivers in General

An Erlang driver is a native code module written in C (or assembler), which serves as an interface for some special operating system service. This is a general mechanism that is used throughout the Erlang emulator for all kinds of I/O. An Erlang driver can be dynamically linked (or loaded) to the Erlang emulator at runtime by using the `erl_ddll` Erlang module. Some of the drivers in OTP are however statically linked to the runtime system, but that is more an optimization than a necessity.

The driver data types and the functions available to the driver writer are defined in header file `erl_driver.h` seated in Erlang's include directory. See the *erl_driver* documentation for details of which functions are available.

When writing a driver to make a communications protocol available to Erlang, one should know just about everything worth knowing about that particular protocol. All operation must be non-blocking and all possible situations are to be accounted for in the driver. A non-stable driver will affect and/or crash the whole Erlang runtime system.

The emulator calls the driver in the following situations:

- When the driver is loaded. This callback must have a special name and inform the emulator of what callbacks are to be used by returning a pointer to a `ErlDrvEntry` struct, which is to be properly filled in (see below).

- When a port to the driver is opened (by a `open_port` call from Erlang). This routine is to set up internal data structures and return an opaque data entity of the type `ErlDrvData`, which is a data type large enough to hold a pointer. The pointer returned by this function is the first argument to all other callbacks concerning this particular port. It is usually called the port handle. The emulator only stores the handle and does never try to interpret it, why it can be virtually anything (anything not larger than a pointer that is) and can point to anything if it is a pointer. Usually this pointer refers to a structure holding information about the particular port, as it does in the example.
- When an Erlang process sends data to the port. The data arrives as a buffer of bytes, the interpretation is not defined, but is up to the implementor. This callback returns nothing to the caller, answers are sent to the caller as messages (using a routine called `driver_output` available to all drivers). There is also a way to talk in a synchronous way to drivers, described below. There can be an additional callback function for handling data that is fragmented (sent in a deep io-list). That interface gets the data in a form suitable for Unix `writev` rather than in a single buffer. There is no need for a distribution driver to implement such a callback, so we will not.
- When a file descriptor is signaled for input. This callback is called when the emulator detects input on a file descriptor that the driver has marked for monitoring by using the interface `driver_select`. The mechanism of driver select makes it possible to read non-blocking from file descriptors by calling `driver_select` when reading is needed, and then do the reading in this callback (when reading is possible). The typical scenario is that `driver_select` is called when an Erlang process orders a read operation, and that this routine sends the answer when data is available on the file descriptor.
- When a file descriptor is signaled for output. This callback is called in a similar way as the previous, but when writing to a file descriptor is possible. The usual scenario is that Erlang orders writing on a file descriptor and that the driver calls `driver_select`. When the descriptor is ready for output, this callback is called and the driver can try to send the output. Queuing can be involved in such operations, and there are convenient queue routines available to the driver writer to use.
- When a port is closed, either by an Erlang process or by the driver calling one of the `driver_failure_XXX` routines. This routine is to clean up everything connected to one particular port. When other callbacks call a `driver_failure_XXX` routine, this routine is immediately called. The callback routine issuing the error can make no more use of the data structures for the port, as this routine surely has freed all associated data and closed all file descriptors. If the queue utility available to driver writer is used, this routine is however **not** called until the queue is empty.
- When an Erlang process calls *`erlang:port_control/3`*, which is a synchronous interface to drivers. The control interface is used to set driver options, change states of ports, and so on. This interface is used a lot in the example.
- When a timer expires. The driver can set timers with the function `driver_set_timer`. When such timers expire, a specific callback function is called. No timers are used in the example.
- When the whole driver is unloaded. Every resource allocated by the driver is to be freed.

The Data Structures of the Distribution Driver

The driver used for Erlang distribution is to implement a reliable, order maintaining, variable length packet-oriented protocol. All error correction, resending and such need to be implemented in the driver or by the underlying communications protocol. If the protocol is stream-oriented (as is the case with both TCP/IP and our streamed Unix domain sockets), some mechanism for packaging is needed. We will use the simple method of having a header of four bytes containing the length of the package in a big-endian 32-bit integer. As Unix domain sockets only can be used between processes on the same machine, we do not need to code the integer in some special endianess, but we will do it anyway because in most situation you need to do it. Unix domain sockets are reliable and order maintaining, so we do not need to implement resends and such in the driver.

We start writing the example Unix domain sockets driver by declaring prototypes and filling in a static `ErlDrvEntry` structure:

```
( 1) #include <stdio.h>
( 2) #include <stdlib.h>
( 3) #include <string.h>
( 4) #include <unistd.h>
( 5) #include <errno.h>
( 6) #include <sys/types.h>
( 7) #include <sys/stat.h>
( 8) #include <sys/socket.h>
( 9) #include <sys/un.h>
(10) #include <fcntl.h>

(11) #define HAVE_UIO_H
(12) #include "erl_driver.h"

(13) /*
(14) ** Interface routines
(15) */
(16) static ErlDrvData uds_start(ErlDrvPort port, char *buff);
(17) static void uds_stop(ErlDrvData handle);
(18) static void uds_command(ErlDrvData handle, char *buff, int bufflen);
(19) static void uds_input(ErlDrvData handle, ErlDrvEvent event);
(20) static void uds_output(ErlDrvData handle, ErlDrvEvent event);
(21) static void uds_finish(void);
(22) static int uds_control(ErlDrvData handle, unsigned int command,
(23)                        char* buf, int count, char** res, int res_size);

(24) /* The driver entry */
(25) static ErlDrvEntry uds_driver_entry = {
(26)     NULL,                            /* init, N/A */
(27)     uds_start,                       /* start, called when port is opened */
(28)     uds_stop,                        /* stop, called when port is closed */
(29)     uds_command,                     /* output, called when erlang has sent */
(30)     uds_input,                       /* ready_input, called when input
(31)                                         descriptor ready */
(32)     uds_output,                      /* ready_output, called when output
(33)                                         descriptor ready */
(34)     "uds_drv",                       /* char *driver_name, the argument
(35)                                         to open_port */
(36)     uds_finish,                      /* finish, called when unloaded */
(37)     NULL,                            /* void * that is not used (BC) */
(38)     uds_control,                     /* control, port_control callback */
(39)     NULL,                            /* timeout, called on timeouts */
(40)     NULL,                            /* outputv, vector output interface */
(41)     NULL,                            /* ready_async callback */
(42)     NULL,                            /* flush callback */
(43)     NULL,                            /* call callback */
(44)     NULL,                            /* event callback */
(45)     ERL_DRV_EXTENDED_MARKER,         /* Extended driver interface marker */
(46)     ERL_DRV_EXTENDED_MAJOR_VERSION,  /* Major version number */
(47)     ERL_DRV_EXTENDED_MINOR_VERSION,  /* Minor version number */
(48)     ERL_DRV_FLAG_SOFT_BUSY,          /* Driver flags. Soft busy flag is
(49)                                         required for distribution drivers */
(50)     NULL,                            /* Reserved for internal use */
(51)     NULL,                            /* process_exit callback */
(52)     NULL                             /* stop_select callback */
(53) };
```

On line 1-10 the OS headers needed for the driver are included. As this driver is written for Solaris, we know that the header `uio.h` exists. So the preprocessor variable `HAVE_UIO_H` can be defined before `erl_driver.h` is included on line 12. The definition of `HAVE_UIO_H` will make the I/O vectors used in Erlang's driver queues to correspond to the operating systems ditto, which is very convenient.

On line 16-23 the different callback functions are declared ("forward declarations").

The driver structure is similar for statically linked-in drivers and dynamically loaded. However, some of the fields are to be left empty (that is, initialized to NULL) in the different types of drivers. The first field (the `init` function pointer) is always left blank in a dynamically loaded driver, see line 26. `NULL` on line 37 is always to be there, the field is no longer used and is retained for backward compatibility. No timers are used in this driver, why no callback for timers is needed. The `outputv` field (line 40) can be used to implement an interface similar to Unix `writev` for output. The Erlang runtime system could previously not use `outputv` for the distribution, but it can as from ERTS 5.7.2. As this driver was written before ERTS 5.7.2 it does not use the `outputv` callback. Using the `outputv` callback is preferred, as it reduces copying of data. (We will however use scatter/gather I/O internally in the driver.)

As from ERTS 5.5.3 the driver interface was extended with version control and the possibility to pass capability information. Capability flags are present on line 48. As from ERTS 5.7.4 flag *`ERL_DRV_FLAG_SOFT_BUSY`* is required for drivers that are to be used by the distribution. The soft busy flag implies that the driver can handle calls to the `output` and `outputv` callbacks although it has marked itself as busy. This has always been a requirement on drivers used by the distribution, but no capability information has been available about this previously. For more information. see *`erl_driver:set_busy_port()`*).

This driver was written before the runtime system had SMP support. The driver will still function in the runtime system with SMP support, but performance will suffer from lock contention on the driver lock used for the driver. This can be alleviated by reviewing and perhaps rewriting the code so that each instance of the driver safely can execute in parallel. When instances safely can execute in parallel, it is safe to enable instance-specific locking on the driver. This is done by passing *`ERL_DRV_FLAG_USE_PORT_LOCKING`* as a driver flag. This is left as an exercise for the reader.

Thus, the defined callbacks are as follows:

`uds_start`

Must initiate data for a port. We do not create any sockets here, only initialize data structures.

`uds_stop`

Called when a port is closed.

`uds_command`

Handles messages from Erlang. The messages can either be plain data to be sent or more subtle instructions to the driver. This function is here mostly for data pumping.

`uds_input`

Called when there is something to read from a socket.

`uds_output`

Called when it is possible to write to a socket.

`uds_finish`

Called when the driver is unloaded. A distribution driver will never be unloaded, but we include this for completeness. To be able to clean up after oneself is always a good thing.

`uds_control`

The *`erlang:port_control/3`* callback, which is used a lot in this implementation.

The ports implemented by this driver operate in two major modes, named `command` and `data`. In `command` mode, only passive reading and writing (like `gen_tcp:recv`/`gen_tcp:send`) can be done. The port is in this mode during the distribution handshake. When the connection is up, the port is switched to `data` mode and all data is immediately read and passed further to the Erlang emulator. In `data` mode, no data arriving to `uds_command` is interpreted, only packaged and sent out on the socket. The `uds_control` callback does the switching between those two modes.

While `net_kernel` informs different subsystems that the connection is coming up, the port is to accept data to send. However, the port should not receive any data, to avoid that data arrives from another node before every kernel subsystem is prepared to handle it. A third mode, named `intermediate`, is used for this intermediate stage.

An enum is defined for the different types of ports:

```
( 1) typedef enum {
( 2)     portTypeUnknown,      /* An uninitialized port */
( 3)     portTypeListener,     /* A listening port/socket */
( 4)     portTypeAcceptor,     /* An intermediate stage when accepting
( 5)                              on a listen port */
( 6)     portTypeConnector,    /* An intermediate stage when connecting */
( 7)     portTypeCommand,      /* A connected open port in command mode */
( 8)     portTypeIntermediate, /* A connected open port in special
( 9)                              half active mode */
(10)     portTypeData          /* A connected open port in data mode */
(11) } PortType;
```

The different types are as follows:

`portTypeUnknown`

The type a port has when it is opened, but not bound to any file descriptor.

`portTypeListener`

A port that is connected to a listen socket. This port does not do much, no data pumping is done on this socket, but read data is available when one is trying to do an accept on the port.

`portTypeAcceptor`

This port is to represent the result of an accept operation. It is created when one wants to accept from a listen socket, and it is converted to a `portTypeCommand` when the accept succeeds.

`portTypeConnector`

Very similar to `portTypeAcceptor`, an intermediate stage between the request for a connect operation and that the socket is connected to an accepting ditto in the other end. When the sockets are connected, the port switches type to `portTypeCommand`.

`portTypeCommand`

A connected socket (or accepted socket) in `command` mode mentioned earlier.

`portTypeIntermediate`

The intermediate stage for a connected socket. There is to be no processing of input for this socket.

`portTypeData`

The mode where data is pumped through the port and the `uds_command` routine regards every call as a call where sending is wanted. In this mode, all input available is read and sent to Erlang when it arrives on the socket, much like in the active mode of a `gen_tcp` socket.

We study the state that is needed for the ports. Notice that not all fields are used for all types of ports. Some space could be saved by using unions, but that would clutter the code with multiple indirections, so here is used one struct for all types of ports, for readability:

```
( 1) typedef unsigned char Byte;
( 2) typedef unsigned int Word;

( 3) typedef struct uds_data {
( 4)     int fd;                   /* File descriptor */
( 5)     ErlDrvPort port;          /* The port identifier */
( 6)     int lockfd;               /* The file descriptor for a lock file in
( 7)                                  case of listen sockets */
( 8)     Byte creation;            /* The creation serial derived from the
( 9)                                  lock file */
(10)     PortType type;            /* Type of port */
(11)     char *name;               /* Short name of socket for unlink */
(12)     Word sent;                /* Bytes sent */
(13)     Word received;            /* Bytes received */
(14)     struct uds_data *partner; /* The partner in an accept/listen pair */
(15)     struct uds_data *next;    /* Next structure in list */
(16)     /* The input buffer and its data */
(17)     int buffer_size;          /* The allocated size of the input buffer */
(18)     int buffer_pos;           /* Current position in input buffer */
(19)     int header_pos;           /* Where the current header is in the
(20)                                  input buffer */
(21)     Byte *buffer;             /* The actual input buffer */
(22) } UdsData;
```

This structure is used for all types of ports although some fields are useless for some types. The least memory consuming solution would be to arrange this structure as a union of structures. However, the multiple indirections in the code to access a field in such a structure would clutter the code too much for an example.

The fields in the structure are as follows:

`fd`

The file descriptor of the socket associated with the port.

`port`

The port identifier for the port that this structure corresponds to. It is needed for most `driver_XXX` calls from the driver back to the emulator.

`lockfd`

If the socket is a listen socket, we use a separate (regular) file for two purposes:

- We want a locking mechanism that gives no race conditions, to be sure if another Erlang node uses the listen socket name we require or if the file is only left there from a previous (crashed) session.
- We store the `creation` serial number in the file. The `creation` is a number that is to change between different instances of different Erlang emulators with the same name, so that process identifiers from one emulator do not become valid when sent to a new emulator with the same distribution name. The creation can be from 0 through 3 (two bits) and is stored in every process identifier sent to another node.

  In a system with TCP-based distribution, this data is kept in the **Erlang port mapper daemon** (`epmd`), which is contacted when a distributed node starts. The lock file and a convention for the UDS listen socket's name remove the need for `epmd` when using this distribution module. UDS is always restricted to one host, why avoiding a port mapper is easy.

`creation`

The creation number for a listen socket, which is calculated as (the value found in the lock-file + 1) rem 4. This creation value is also written back into the lock file, so that the next invocation of the emulator finds our value in the file.

`type`

The current type/state of the port, which can be one of the values declared above.

`name`

The name of the socket file (the path prefix removed), which allows for deletion (`unlink`) when the socket is closed.

`sent`

How many bytes that have been sent over the socket. This can wrap, but that is no problem for the distribution, as the Erlang distribution is only interested in if this value has changed. (The Erlang `net_kernel` `ticker` uses this value by calling the driver to fetch it, which is done through the *`erlang:port_control/3`* routine.)

`received`

How many bytes that are read (received) from the socket, used in similar ways as `sent`.

`partner`

A pointer to another port structure, which is either the listen port from which this port is accepting a connection or conversely. The "partner relation" is always bidirectional.

`next`

Pointer to next structure in a linked list of all port structures. This list is used when accepting connections and when the driver is unloaded.

`buffer_size`, `buffer_pos`, `header_pos`, `buffer`

Data for input buffering. For details about the input buffering, see the source code in directory `kernel/examples`. That certainly goes beyond the scope of this section.

Selected Parts of the Distribution Driver Implementation

The implemenation of the distribution driver is not completely covered here, details about buffering and other things unrelated to driver writing are not explained. Likewise are some peculiarities of the UDS protocol not explained in detail. The chosen protocol is not important.

Prototypes for the driver callback routines can be found in the `erl_driver.h` header file.

The driver initialization routine is (usually) declared with a macro to make the driver easier to port between different operating systems (and flavors of systems). This is the only routine that must have a well-defined name. All other callbacks are reached through the driver structure. The macro to use is named `DRIVER_INIT` and takes the driver name as parameter:

```
(1) /* Beginning of linked list of ports */
(2) static UdsData *first_data;

(3) DRIVER_INIT(uds_drv)
(4) {
(5)     first_data = NULL;
(6)     return &uds_driver_entry;
(7) }
```

The routine initializes the single global data structure and returns a pointer to the driver entry. The routine is called when `erl_ddll:load_driver` is called from Erlang.

The `uds_start` routine is called when a port is opened from Erlang. In this case, we only allocate a structure and initialize it. Creating the actual socket is left to the `uds_command` routine.

```
( 1) static ErlDrvData uds_start(ErlDrvPort port, char *buff)
( 2) {
( 3)     UdsData *ud;
( 4)
( 5)     ud = ALLOC(sizeof(UdsData));
( 6)     ud->fd = -1;
( 7)     ud->lockfd = -1;
( 8)     ud->creation = 0;
( 9)     ud->port = port;
(10)     ud->type = portTypeUnknown;
(11)     ud->name = NULL;
(12)     ud->buffer_size = 0;
(13)     ud->buffer_pos = 0;
(14)     ud->header_pos = 0;
(15)     ud->buffer = NULL;
(16)     ud->sent = 0;
(17)     ud->received = 0;
(18)     ud->partner = NULL;
(19)     ud->next = first_data;
(20)     first_data = ud;
(21)
(22)     return((ErlDrvData) ud);
(23) }
```

Every data item is initialized, so that no problems arise when a newly created port is closed (without there being any corresponding socket). This routine is called when `open_port({spawn, "uds_drv"},[])` is called from Erlang.

The `uds_command` routine is the routine called when an Erlang process sends data to the port. This routine handles all asynchronous commands when the port is in `command` mode and the sending of all data when the port is in `data` mode:

```
( 1) static void uds_command(ErlDrvData handle, char *buff, int bufflen)
( 2) {
( 3)     UdsData *ud = (UdsData *) handle;

( 4)     if (ud->type == portTypeData || ud->type == portTypeIntermediate) {
( 5)         DEBUGF(("Passive do_send %d",bufflen));
( 6)         do_send(ud, buff + 1, bufflen - 1); /* XXX */
( 7)         return;
( 8)     }
( 9)     if (bufflen == 0) {
(10)         return;
(11)     }
(12)     switch (*buff) {
(13)     case 'L':
(14)         if (ud->type != portTypeUnknown) {
(15)             driver_failure_posix(ud->port, ENOTSUP);
(16)             return;
(17)         }
(18)         uds_command_listen(ud,buff,bufflen);
(19)         return;
(20)     case 'A':
(21)         if (ud->type != portTypeUnknown) {
(22)             driver_failure_posix(ud->port, ENOTSUP);
(23)             return;
(24)         }
(25)         uds_command_accept(ud,buff,bufflen);
(26)         return;
(27)     case 'C':
(28)         if (ud->type != portTypeUnknown) {
(29)             driver_failure_posix(ud->port, ENOTSUP);
(30)             return;
(31)         }
(32)         uds_command_connect(ud,buff,bufflen);
(33)         return;
(34)     case 'S':
(35)         if (ud->type != portTypeCommand) {
(36)             driver_failure_posix(ud->port, ENOTSUP);
(37)             return;
(38)         }
(39)         do_send(ud, buff + 1, bufflen - 1);
(40)         return;
(41)     case 'R':
(42)         if (ud->type != portTypeCommand) {
(43)             driver_failure_posix(ud->port, ENOTSUP);
(44)             return;
(45)         }
(46)         do_recv(ud);
(47)         return;
(48)     default:
(49)         return;
(50)     }
(51) }
```

The command routine takes three parameters; the handle returned for the port by `uds_start`, which is a pointer to the internal port structure, the data buffer, and the length of the data buffer. The buffer is the data sent from Erlang (a list of bytes) converted to an C array (of bytes).

If Erlang sends, for example, the list `[$a,$b,$c]` to the port, the `bufflen` variable is `3` and the `buff` variable contains `{'a','b','c'}` (no `NULL` termination). Usually the first byte is used as an opcode, which is the case in this driver too (at least when the port is in `command` mode). The opcodes are defined as follows:

`'L'<socket name>`

Creates and listens on socket with the specified name.

`'A'<listen number as 32-bit big-endian>`

Accepts from the listen socket identified by the specified identification number. The identification number is retrieved with the `uds_control` routine.

`'C'<socket name>`

Connects to the socket named <socket name>.

`'S'<data>`

Sends the data <data> on the connected/accepted socket (in `command` mode). The sending is acknowledged when the data has left this process.

`'R'`

Receives one packet of data.

"One packet of data" in command `'R'` can be explained as follows. This driver always sends data packaged with a 4 byte header containing a big-endian 32-bit integer that represents the length of the data in the packet. There is no need for different packet sizes or some kind of streamed mode, as this driver is for the distribution only. Why is the header word coded explicitly in big-endian when a UDS socket is local to the host? It is good practice when writing a distribution driver, as distribution in practice usually crosses the host boundaries.

On line 4-8 is handled the case where the port is in `data` mode or `intermediate` mode and the remaining routine handles the different commands. The routine uses the `driver_failure_posix()` routine to report errors (see, for example, line 15). Notice that the failure routines make a call to the `uds_stop` routine, which will remove the internal port data. The handle (and the casted handle `ud`) is therefore **invalid pointers** after a `driver_failure` call and we should **return immediately**. The runtime system will send exit signals to all linked processes.

The `uds_input` routine is called when data is available on a file descriptor previously passed to the `driver_select` routine. This occurs typically when a read command is issued and no data is available. The `do_recv` routine is as follows:

```
( 1) static void do_recv(UdsData *ud)
( 2) {
( 3)     int res;
( 4)     char *ibuf;
( 5)     for(;;) {
( 6)         if ((res = buffered_read_package(ud,&ibuf)) < 0) {
( 7)             if (res == NORMAL_READ_FAILURE) {
( 8)                 driver_select(ud->port, (ErlDrvEvent) ud->fd, DO_READ, 1);
( 9)             } else {
(10)                 driver_failure_eof(ud->port);
(11)             }
(12)             return;
(13)         }
(14)         /* Got a package */
(15)         if (ud->type == portTypeCommand) {
(16)             ibuf[-1] = 'R'; /* There is always room for a single byte
(17)                                opcode before the actual buffer
(18)                                (where the packet header was) */
(19)             driver_output(ud->port,ibuf - 1, res + 1);
(20)             driver_select(ud->port, (ErlDrvEvent) ud->fd, DO_READ,0);
(21)             return;
(22)         } else {
(23)             ibuf[-1] = DIST_MAGIC_RECV_TAG; /* XXX */
(24)             driver_output(ud->port,ibuf - 1, res + 1);
(25)             driver_select(ud->port, (ErlDrvEvent) ud->fd, DO_READ,1);
(26)         }
(27)     }
(28) }
```

The routine tries to read data until a packet is read or the `buffered_read_package` routine returns a `NORMAL_READ_FAILURE` (an internally defined constant for the module, which means that the read operation resulted in an `EWOULDBLOCK`). If the port is in `command` mode, the reading stops when one package is read. If the port is in `data` mode, the reading continues until the socket buffer is empty (read failure). If no more data can be read and more is wanted (which is always the case when the socket is in `data` mode), `driver_select` is called to make the `uds_input` callback be called when more data is available for reading.

When the port is in `data` mode, all data is sent to Erlang in a format that suits the distribution. In fact, the raw data will never reach any Erlang process, but will be translated/interpreted by the emulator itself and then delivered in the correct format to the correct processes. In the current emulator version, received data is to be tagged with a single byte of 100. That is what the macro `DIST_MAGIC_RECV_TAG` is defined to. The tagging of data in the distribution can be changed in the future.

The `uds_input` routine handles other input events (like non-blocking `accept`), but most importantly handle data arriving at the socket by calling `do_recv`:

```
( 1) static void uds_input(ErlDrvData handle, ErlDrvEvent event)
( 2) {
( 3)     UdsData *ud = (UdsData *) handle;

( 4)     if (ud->type == portTypeListener) {
( 5)         UdsData *ad = ud->partner;
( 6)         struct sockaddr_un peer;
( 7)         int pl = sizeof(struct sockaddr_un);
( 8)         int fd;

( 9)         if ((fd = accept(ud->fd, (struct sockaddr *) &peer, &pl)) < 0) {
(10)             if (errno != EWOULDBLOCK) {
(11)                 driver_failure_posix(ud->port, errno);
(12)                 return;
(13)             }
(14)             return;
(15)         }
(16)         SET_NONBLOCKING(fd);
(17)         ad->fd = fd;
(18)         ad->partner = NULL;
(19)         ad->type = portTypeCommand;
(20)         ud->partner = NULL;
(21)         driver_select(ud->port, (ErlDrvEvent) ud->fd, DO_READ, 0);
(22)         driver_output(ad->port, "Aok",3);
(23)         return;
(24)     }
(25)     do_recv(ud);
(26) }
```

The important line is the last line in the function: the `do_read` routine is called to handle new input. The remaining function handles input on a listen socket, which means that it is to be possible to do an accept on the socket, which is also recognized as a read event.

The output mechanisms are similar to the input. The `do_send` routine is as follows:

```
( 1) static void do_send(UdsData *ud, char *buff, int bufflen)
( 2) {
( 3)     char header[4];
( 4)     int written;
( 5)     SysIOVec iov[2];
( 6)     ErlIOVec eio;
( 7)     ErlDrvBinary *binv[] = {NULL,NULL};

( 8)     put_packet_length(header, bufflen);
( 9)     iov[0].iov_base = (char *) header;
(10)     iov[0].iov_len = 4;
(11)     iov[1].iov_base = buff;
(12)     iov[1].iov_len = bufflen;
(13)     eio.iov = iov;
(14)     eio.binv = binv;
(15)     eio.vsize = 2;
(16)     eio.size = bufflen + 4;
(17)     written = 0;
(18)     if (driver_sizeq(ud->port) == 0) {
(19)         if ((written = writev(ud->fd, iov, 2)) == eio.size) {
(20)             ud->sent += written;
(21)             if (ud->type == portTypeCommand) {
(22)                 driver_output(ud->port, "Sok", 3);
(23)             }
(24)             return;
(25)         } else if (written < 0) {
(26)             if (errno != EWOULDBLOCK) {
(27)                 driver_failure_eof(ud->port);
(28)                 return;
(29)             } else {
(30)                 written = 0;
(31)             }
(32)         } else {
(33)             ud->sent += written;
(34)         }
(35)         /* Enqueue remaining */
(36)     }
(37)     driver_enqv(ud->port, &eio, written);
(38)     send_out_queue(ud);
(39) }
```

This driver uses the `writev` system call to send data onto the socket. A combination of `writev` and the driver output queues is very convenient. An `ErlIOVec` structure contains a `SysIOVec` (which is equivalent to the `struct iovec` structure defined in `uio.h`. The `ErlIOVec` also contains an array of `ErlDrvBinary` pointers, of the same length as the number of buffers in the I/O vector itself. One can use this to allocate the binaries for the queue "manually" in the driver, but here the binary array is filled with `NULL` values (line 7). The runtime system then allocates its own buffers when `driver_enqv` is called (line 37).

The routine builds an I/O vector containing the header bytes and the buffer (the opcode has been removed and the buffer length decreased by the output routine). If the queue is empty, we write the data directly to the socket (or at least try to). If any data is left, it is stored in the queue and then we try to send the queue (line 38). An acknowledgement is sent when the message is delivered completely (line 22). The `send_out_queue` sends acknowledgements if the sending is completed there. If the port is in `command` mode, the Erlang code serializes the send operations so that only one packet can be waiting for delivery at a time. Therefore the acknowledgement can be sent whenever the queue is empty.

The `send_out_queue` routine is as follows:

```
( 1) static int send_out_queue(UdsData *ud)
( 2) {
( 3)     for(;;) {
( 4)         int vlen;
( 5)         SysIOVec *tmp = driver_peekq(ud->port, &vlen);
( 6)         int wrote;
( 7)         if (tmp == NULL) {
( 8)             driver_select(ud->port, (ErlDrvEvent) ud->fd, DO_WRITE, 0);
( 9)             if (ud->type == portTypeCommand) {
(10)                 driver_output(ud->port, "Sok", 3);
(11)             }
(12)             return 0;
(13)         }
(14)         if (vlen > IO_VECTOR_MAX) {
(15)             vlen = IO_VECTOR_MAX;
(16)         }
(17)         if ((wrote = writev(ud->fd, tmp, vlen)) < 0) {
(18)             if (errno == EWOULDBLOCK) {
(19)                 driver_select(ud->port, (ErlDrvEvent) ud->fd,
(20)                               DO_WRITE, 1);
(21)                 return 0;
(22)             } else {
(23)                 driver_failure_eof(ud->port);
(24)                 return -1;
(25)             }
(26)         }
(27)         driver_deq(ud->port, wrote);
(28)         ud->sent += wrote;
(29)     }
(30) }
```

We simply pick out an I/O vector from the queue (which is the whole queue as a `SysIOVec`). If the I/O vector is too long (`IO_VECTOR_MAX` is defined to 16), the vector length is decreased (line 15), otherwise the `writev` call (line 17) fails. Writing is tried and anything written is dequeued (line 27). If the write fails with `EWOULDBLOCK` (notice that all sockets are in non-blocking mode), `driver_select` is called to make the `uds_output` routine be called when there is space to write again.

We continue trying to write until the queue is empty or the writing blocks.

The routine above is called from the `uds_output` routine:

```
( 1) static void uds_output(ErlDrvData handle, ErlDrvEvent event)
( 2) {
( 3)    UdsData *ud = (UdsData *) handle;
( 4)    if (ud->type == portTypeConnector) {
( 5)        ud->type = portTypeCommand;
( 6)        driver_select(ud->port, (ErlDrvEvent) ud->fd, DO_WRITE, 0);
( 7)        driver_output(ud->port, "Cok",3);
( 8)        return;
( 9)    }
(10)    send_out_queue(ud);
(11) }
```

The routine is simple: it first handles the fact that the output select will concern a socket in the business of connecting (and the connecting blocked). If the socket is in a connected state, it simply sends the output queue. This routine is called when it is possible to write to a socket where we have an output queue, so there is no question what to do.

The driver implements a control interface, which is a synchronous interface called when Erlang calls *`erlang:port_control/3`*. Only this interface can control the driver when it is in `data` mode. It can be called with the following opcodes:

`'C'`

Sets port in `command` mode.

`'I'`

Sets port in `intermediate` mode.

`'D'`

Sets port in `data` mode.

`'N'`

Gets identification number for listen port. This identification number is used in an accept command to the driver. It is returned as a big-endian 32-bit integer, which is the file identifier for the listen socket.

`'S'`

Gets statistics, which is the number of bytes received, the number of bytes sent, and the number of bytes pending in the output queue. This data is used when the distribution checks that a connection is alive (ticking). The statistics is returned as three 32-bit big-endian integers.

`'T'`

Sends a tick message, which is a packet of length 0. Ticking is done when the port is in `data` mode, so the command for sending data cannot be used (besides it ignores zero length packages in `command` mode). This is used by the ticker to send dummy data when no other traffic is present.

Note: It is important that the interface for sending ticks is not blocking. This implementation uses *`erlang:port_control/3`*, which does not block the caller. If `erlang:port_command` is used, use *`erlang:port_command/3`* and pass `[force]` as option list; otherwise the caller can be blocked indefinitely on a busy port and prevent the system from taking down a connection that is not functioning.

`'R'`

Gets creation number of a listen socket, which is used to dig out the number stored in the lock file to differentiate between invocations of Erlang nodes with the same name.

The control interface gets a buffer to return its value in, but is free to allocate its own buffer if the provided one is too small. The `uds_control` code is as follows:

```
( 1) static int uds_control(ErlDrvData handle, unsigned int command,
( 2)                        char* buf, int count, char** res, int res_size)
( 3) {
( 4) /* Local macro to ensure large enough buffer. */
( 5) #define ENSURE(N)                                   \
( 6)    do {                                            \
( 7)        if (res_size < N) {                         \
( 8)            *res = ALLOC(N);                        \
( 9)        }                                           \
(10)    } while(0)

(11)    UdsData *ud = (UdsData *) handle;

(12)    switch (command) {
(13)    case 'S':
(14)        {
(15)            ENSURE(13);
(16)            **res = 0;
(17)            put_packet_length((*res) + 1, ud->received);
(18)            put_packet_length((*res) + 5, ud->sent);
(19)            put_packet_length((*res) + 9, driver_sizeq(ud->port));
(20)            return 13;
(21)        }
(22)    case 'C':
(23)        if (ud->type < portTypeCommand) {
(24)            return report_control_error(res, res_size, "einval");
(25)        }
(26)        ud->type = portTypeCommand;
(27)        driver_select(ud->port, (ErlDrvEvent) ud->fd, DO_READ, 0);
(28)        ENSURE(1);
(29)        **res = 0;
(30)        return 1;
(31)    case 'I':
(32)        if (ud->type < portTypeCommand) {
(33)            return report_control_error(res, res_size, "einval");
(34)        }
(35)        ud->type = portTypeIntermediate;
(36)        driver_select(ud->port, (ErlDrvEvent) ud->fd, DO_READ, 0);
(37)        ENSURE(1);
(38)        **res = 0;
(39)        return 1;
(40)    case 'D':
(41)        if (ud->type < portTypeCommand) {
(42)            return report_control_error(res, res_size, "einval");
(43)        }
(44)        ud->type = portTypeData;
(45)        do_recv(ud);
(46)        ENSURE(1);
(47)        **res = 0;
(48)        return 1;
(49)    case 'N':
(50)        if (ud->type != portTypeListener) {
(51)            return report_control_error(res, res_size, "einval");
(52)        }
(53)        ENSURE(5);
(54)        (*res)[0] = 0;
(55)        put_packet_length((*res) + 1, ud->fd);
(56)        return 5;
(57)    case 'T': /* tick */
(58)        if (ud->type != portTypeData) {
(59)            return report_control_error(res, res_size, "einval");
(60)        }
(61)        do_send(ud,"",0);
(62)        ENSURE(1);
(63)        **res = 0;
```

```
(64)        return 1;
(65)    case 'R':
(66)        if (ud->type != portTypeListener) {
(67)            return report_control_error(res, res_size, "einval");
(68)        }
(69)        ENSURE(2);
(70)        (*res)[0] = 0;
(71)        (*res)[1] = ud->creation;
(72)        return 2;
(73)    default:
(74)        return report_control_error(res, res_size, "einval");
(75)    }
(76) #undef ENSURE
(77) }
```

The macro `ENSURE` (line 5-10) is used to ensure that the buffer is large enough for the answer. We switch on the command and take actions. We always have read select active on a port in `data` mode (achieved by calling `do_recv` on line 45), but we turn off read selection in `intermediate` and `command` modes (line 27 and 36).

The rest of the driver is more or less UDS-specific and not of general interest.

1.6.3 Putting It All Together

To test the distribution, the `net_kernel:start/1` function can be used. It is useful, as it starts the distribution on a running system, where tracing/debugging can be performed. The `net_kernel:start/1` routine takes a list as its single argument. The list first element in the list is to be the node name (without the "@hostname") as an atom. The second (and last) element is to be one of the atoms `shortnames` or `longnames`. In the example case, `shortnames` is preferred.

For `net_kernel` to find out which distribution module to use, command-line argument `-proto_dist` is used. It is followed by one or more distribution module names, with suffix "_dist" removed, that is, `uds_dist` as a distribution module is specified as `-proto_dist uds`.

If no `epmd` (TCP port mapper daemon) is used, also command-line option `-no_epmd` is to be specified, which makes Erlang skip the `epmd` startup, both as an OS process and as an Erlang ditto.

The path to the directory where the distribution modules reside must be known at boot. This can be achieved either by specifying `-pa <path>` on the command line or by building a boot script containing the applications used for your distribution protocol. (In the `uds_dist` protocol, only the `uds_dist` application needs to be added to the script.)

The distribution starts at boot if all the above is specified and an `-sname <name>` flag is present at the command line.

Example 1:

```
$ erl -pa $ERL_TOP/lib/kernel/examples/uds_dist/ebin -proto_dist uds -no_epmd
Erlang (BEAM) emulator version 5.0

Eshell V5.0  (abort with ^G)
1> net_kernel:start([bing,shortnames]).
{ok,<0.30.0>}
(bing@hador)2>
```

Example 2:

```
$ erl -pa $ERL_TOP/lib/kernel/examples/uds_dist/ebin -proto_dist uds \
      -no_epmd -sname bong
Erlang (BEAM) emulator version 5.0

Eshell V5.0  (abort with ^G)
(bong@hador)1>
```

The ERL_FLAGS environment variable can be used to store the complicated parameters in:

```
$ ERL_FLAGS=-pa $ERL_TOP/lib/kernel/examples/uds_dist/ebin \
      -proto_dist uds -no_epmd
$ export ERL_FLAGS
$ erl -sname bang
Erlang (BEAM) emulator version 5.0

Eshell V5.0  (abort with ^G)
(bang@hador)1>
```

ERL_FLAGS should not include the node name.

1.7 The Abstract Format

This section describes the standard representation of parse trees for Erlang programs as Erlang terms. This representation is known as the **abstract format**. Functions dealing with such parse trees are *compile:forms/1,2* and functions in the following modules:

- *epp(3)*
- *erl_eval(3)*
- *erl_lint(3)*
- *erl_parse(3)*
- *erl_pp(3)*
- *io(3)*

The functions are also used as input and output for parse transforms, see the *compile(3)* module.

We use the function Rep to denote the mapping from an Erlang source construct C to its abstract format representation R, and write R = Rep(C).

The word LINE in this section represents an integer, and denotes the number of the line in the source file where the construction occurred. Several instances of LINE in the same construction can denote different lines.

As operators are not terms in their own right, when operators are mentioned below, the representation of an operator is to be taken to be the atom with a printname consisting of the same characters as the operator.

1.7.1 Module Declarations and Forms

A module declaration consists of a sequence of forms, which are either function declarations or attributes.

- If D is a module declaration consisting of the forms F_1, ..., F_k, then Rep(D) = [Rep(F_1), ..., Rep(F_k)].
- If F is an attribute -export([Fun_1/A_1, ..., Fun_k/A_k]), then Rep(F) = {attribute,LINE,export,[{Fun_1,A_1}, ..., {Fun_k,A_k}]}.
- If F is an attribute -import(Mod,[Fun_1/A_1, ..., Fun_k/A_k]), then Rep(F) = {attribute,LINE,import,{Mod,[{Fun_1,A_1}, ..., {Fun_k,A_k}]}}.
- If F is an attribute -module(Mod), then Rep(F) = {attribute,LINE,module,Mod}.
- If F is an attribute -file(File,Line), then Rep(F) = {attribute,LINE,file,{File,Line}}.
- If F is a function declaration Name Fc_1 ; ... ; Name Fc_k, where each Fc_i is a function clause with a pattern sequence of the same length Arity, then Rep(F) = {function,LINE,Name,Arity, [Rep(Fc_1), ...,Rep(Fc_k)]}.
- If F is a function specification -Spec Name Ft_1; ...; Ft_k, where Spec is either the atom spec or the atom callback, and each Ft_i is a possibly constrained function type with an argument sequence of the

same length `Arity`, then Rep(F) = `{attribute,Line,Spec,{{Name,Arity},[Rep(Ft_1), ..., Rep(Ft_k)]}}`.

- If F is a function specification `-spec Mod:Name Ft_1; ...; Ft_k`, where each `Ft_i` is a possibly constrained function type with an argument sequence of the same length `Arity`, then Rep(F) = `{attribute,Line,spec,{{Mod,Name,Arity},[Rep(Ft_1), ..., Rep(Ft_k)]}}`.
- If F is a record declaration `-record(Name,{V_1, ..., V_k})`, where each `V_i` is a record field, then Rep(F) = `{attribute,LINE,record,{Name,[Rep(V_1), ..., Rep(V_k)]}}`. For Rep(V), see below.
- If F is a type declaration `-Type Name(V_1, ..., V_k) :: T`, where `Type` is either the atom `type` or the atom `opaque`, each `V_i` is a variable, and `T` is a type, then Rep(F) = `{attribute,LINE,Type,{Name,Rep(T),[Rep(V_1), ..., Rep(V_k)]}}`.
- If F is a wild attribute `-A(T)`, then Rep(F) = `{attribute,LINE,A,T}`.

Record Fields

Each field in a record declaration can have an optional, explicit, default initializer expression, and an optional type.

- If V is `A`, then Rep(V) = `{record_field,LINE,Rep(A)}`.
- If V is `A = E`, where `E` is an expression, then Rep(V) = `{record_field,LINE,Rep(A),Rep(E)}`.
- If V is `A :: T`, where `T` is a type, then Rep(V) = `{typed_record_field,{record_field,LINE,Rep(A)},Rep(T)}`.
- If V is `A = E :: T`, where `E` is an expression and `T` is a type, then Rep(V) = `{typed_record_field,{record_field,LINE,Rep(A),Rep(E)},Rep(T)}`.

Representation of Parse Errors and End-of-File

In addition to the representations of forms, the list that represents a module declaration (as returned by functions in *`epp(3)`* and *`erl_parse(3)`*) can contain the following:

- Tuples `{error,E}` and `{warning,W}`, denoting syntactically incorrect forms and warnings.
- `{eof,LOCATION}`, denoting an end-of-stream encountered before a complete form had been parsed. The word `LOCATION` represents an integer, and denotes the number of the last line in the source file.

1.7.2 Atomic Literals

There are five kinds of atomic literals, which are represented in the same way in patterns, expressions, and guards:

- If L is an atom literal, then Rep(L) = `{atom,LINE,L}`.
- If L is a character literal, then Rep(L) = `{char,LINE,L}`.
- If L is a float literal, then Rep(L) = `{float,LINE,L}`.
- If L is an integer literal, then Rep(L) = `{integer,LINE,L}`.
- If L is a string literal consisting of the characters `C_1`, ..., `C_k`, then Rep(L) = `{string,LINE,[C_1, ..., C_k]}`.

Notice that negative integer and float literals do not occur as such; they are parsed as an application of the unary negation operator.

1.7.3 Patterns

If Ps is a sequence of patterns `P_1, ..., P_k`, then Rep(Ps) = `[Rep(P_1), ..., Rep(P_k)]`. Such sequences occur as the list of arguments to a function or fun.

Individual patterns are represented as follows:

- If P is an atomic literal `L`, then Rep(P) = Rep(L).

- If P is a bitstring pattern `<<P_1:Size_1/TSL_1, ..., P_k:Size_k/TSL_k>>`, where each `Size_i` is an expression that can be evaluated to an integer, and each `TSL_i` is a type specificer list, then Rep(P) = `{bin,LINE,[{bin_element,LINE,Rep(P_1),Rep(Size_1),Rep(TSL_1)}, ..., {bin_element,LINE,Rep(P_k),Rep(Size_k),Rep(TSL_k)}]}`. For Rep(TSL), see below. An omitted `Size_i` is represented by `default`. An omitted `TSL_i` is represented by `default`.
- If P is a compound pattern `P_1 = P_2`, then Rep(P) = `{match,LINE,Rep(P_1),Rep(P_2)}`.
- If P is a cons pattern `[P_h | P_t]`, then Rep(P) = `{cons,LINE,Rep(P_h),Rep(P_t)}`.
- If P is a map pattern `#{A_1, ..., A_k}`, where each `A_i` is an association `P_i_1 := P_i_2`, then Rep(P) = `{map,LINE,[Rep(A_1), ..., Rep(A_k)]}`. For Rep(A), see below.
- If P is a nil pattern `[]`, then Rep(P) = `{nil,LINE}`.
- If P is an operator pattern `P_1 Op P_2`, where `Op` is a binary operator (this is either an occurrence of `++` applied to a literal string or character list, or an occurrence of an expression that can be evaluated to a number at compile time), then Rep(P) = `{op,LINE,Op,Rep(P_1),Rep(P_2)}`.
- If P is an operator pattern `Op P_0`, where `Op` is a unary operator (this is an occurrence of an expression that can be evaluated to a number at compile time), then Rep(P) = `{op,LINE,Op,Rep(P_0)}`.
- If P is a parenthesized pattern `( P_0 )`, then Rep(P) = `Rep(P_0)`, that is, parenthesized patterns cannot be distinguished from their bodies.
- If P is a record field index pattern `#Name.Field`, where `Field` is an atom, then Rep(P) = `{record_index,LINE,Name,Rep(Field)}`.
- If P is a record pattern `#Name{Field_1=P_1, ..., Field_k=P_k}`, where each `Field_i` is an atom or `_`, then Rep(P) = `{record,LINE,Name,[{record_field,LINE,Rep(Field_1),Rep(P_1)}, ..., {record_field,LINE,Rep(Field_k),Rep(P_k)}]}`.
- If P is a tuple pattern `{P_1, ..., P_k}`, then Rep(P) = `{tuple,LINE,[Rep(P_1), ..., Rep(P_k)]}`.
- If P is a universal pattern `_`, then Rep(P) = `{var,LINE,'_'}`.
- If P is a variable pattern `V`, then Rep(P) = `{var,LINE,A}`, where A is an atom with a printname consisting of the same characters as `V`.

Notice that every pattern has the same source form as some expression, and is represented in the same way as the corresponding expression.

1.7.4 Expressions

A body B is a non-empty sequence of expressions `E_1, ..., E_k`, and Rep(B) = `[Rep(E_1), ..., Rep(E_k)]`.

An expression E is one of the following:

- If E is an atomic literal `L`, then Rep(E) = Rep(L).
- If E is a bitstring comprehension `<<E_0 || Q_1, ..., Q_k>>`, where each `Q_i` is a qualifier, then Rep(E) = `{bc,LINE,Rep(E_0),[Rep(Q_1), ..., Rep(Q_k)]}`. For Rep(Q), see below.
- If E is a bitstring constructor `<<E_1:Size_1/TSL_1, ..., E_k:Size_k/TSL_k>>`, where each `Size_i` is an expression and each `TSL_i` is a type specificer list, then Rep(E) = `{bin,LINE,[{bin_element,LINE,Rep(E_1),Rep(Size_1),Rep(TSL_1)}, ..., {bin_element,LINE,Rep(E_k),Rep(Size_k),Rep(TSL_k)}]}`. For Rep(TSL), see below. An omitted `Size_i` is represented by `default`. An omitted `TSL_i` is represented by `default`.
- If E is a block expression `begin B end`, where `B` is a body, then Rep(E) = `{block,LINE,Rep(B)}`.
- If E is a case expression `case E_0 of Cc_1 ; ... ; Cc_k end`, where `E_0` is an expression and each `Cc_i` is a case clause, then Rep(E) = `{'case',LINE,Rep(E_0),[Rep(Cc_1), ..., Rep(Cc_k)]}`.
- If E is a catch expression `catch E_0`, then Rep(E) = `{'catch',LINE,Rep(E_0)}`.

- If E is a cons skeleton `[E_h | E_t]`, then Rep(E) = `{cons,LINE,Rep(E_h),Rep(E_t)}`.
- If E is a fun expression `fun Name/Arity`, then Rep(E) = `{'fun',LINE,{function,Name,Arity}}`.
- If E is a fun expression `fun Module:Name/Arity`, then Rep(E) = `{'fun',LINE,{function,Rep(Module),Rep(Name),Rep(Arity)}}`. (Before Erlang/OTP R15: Rep(E) = `{'fun',LINE,{function,Module,Name,Arity}}`.)
- If E is a fun expression `fun Fc_1 ; ... ; Fc_k end`, where each `Fc_i` is a function clause, then Rep(E) = `{'fun',LINE,{clauses,[Rep(Fc_1), ..., Rep(Fc_k)]}}`.
- If E is a fun expression `fun Name Fc_1 ; ... ; Name Fc_k end`, where `Name` is a variable and each `Fc_i` is a function clause, then Rep(E) = `{named_fun,LINE,Name,[Rep(Fc_1), ..., Rep(Fc_k)]}`.
- If E is a function call `E_0(E_1, ..., E_k)`, then Rep(E) = `{call,LINE,Rep(E_0),[Rep(E_1), ..., Rep(E_k)]}`.
- If E is a function call `E_m:E_0(E_1, ..., E_k)`, then Rep(E) = `{call,LINE,{remote,LINE,Rep(E_m),Rep(E_0)},[Rep(E_1), ..., Rep(E_k)]}`.
- If E is an if expression `if Ic_1 ; ... ; Ic_k end`, where each `Ic_i` is an if clause, then Rep(E) = `{'if',LINE,[Rep(Ic_1), ..., Rep(Ic_k)]}`.
- If E is a list comprehension `[E_0 || Q_1, ..., Q_k]`, where each `Q_i` is a qualifier, then Rep(E) = `{lc,LINE,Rep(E_0),[Rep(Q_1), ..., Rep(Q_k)]}`. For Rep(Q), see below.
- If E is a map creation `#{A_1, ..., A_k}`, where each `A_i` is an association `E_i_1 => E_i_2` or `E_i_1 := E_i_2`, then Rep(E) = `{map,LINE,[Rep(A_1), ..., Rep(A_k)]}`. For Rep(A), see below.
- If E is a map update `E_0#{A_1, ..., A_k}`, where each `A_i` is an association `E_i_1 => E_i_2` or `E_i_1 := E_i_2`, then Rep(E) = `{map,LINE,Rep(E_0),[Rep(A_1), ..., Rep(A_k)]}`. For Rep(A), see below.
- If E is a match operator expression `P = E_0`, where `P` is a pattern, then Rep(E) = `{match,LINE,Rep(P),Rep(E_0)}`.
- If E is nil, `[]`, then Rep(E) = `{nil,LINE}`.
- If E is an operator expression `E_1 Op E_2`, where `Op` is a binary operator other than match operator `=`, then Rep(E) = `{op,LINE,Op,Rep(E_1),Rep(E_2)}`.
- If E is an operator expression `Op E_0`, where `Op` is a unary operator, then Rep(E) = `{op,LINE,Op,Rep(E_0)}`.
- If E is a parenthesized expression `( E_0 )`, then Rep(E) = `Rep(E_0)`, that is, parenthesized expressions cannot be distinguished from their bodies.
- If E is a receive expression `receive Cc_1 ; ... ; Cc_k end`, where each `Cc_i` is a case clause, then Rep(E) = `{'receive',LINE,[Rep(Cc_1), ..., Rep(Cc_k)]}`.
- If E is a receive expression `receive Cc_1 ; ... ; Cc_k after E_0 -> B_t end`, where each `Cc_i` is a case clause, `E_0` is an expression, and `B_t` is a body, then Rep(E) = `{'receive',LINE,[Rep(Cc_1), ..., Rep(Cc_k)],Rep(E_0),Rep(B_t)}`.
- If E is a record creation `#Name{Field_1=E_1, ..., Field_k=E_k}`, where each `Field_i` is an atom or `_`, then Rep(E) = `{record,LINE,Name,[{record_field,LINE,Rep(Field_1),Rep(E_1)}, ..., {record_field,LINE,Rep(Field_k),Rep(E_k)}]}`.
- If E is a record field access `E_0#Name.Field`, where `Field` is an atom, then Rep(E) = `{record_field,LINE,Rep(E_0),Name,Rep(Field)}`.
- If E is a record field index `#Name.Field`, where `Field` is an atom, then Rep(E) = `{record_index,LINE,Name,Rep(Field)}`.
- If E is a record update `E_0#Name{Field_1=E_1, ..., Field_k=E_k}`, where each `Field_i` is an atom, then Rep(E) = `{record,LINE,Rep(E_0),Name,[{record_field,LINE,Rep(Field_1),Rep(E_1)}, ..., {record_field,LINE,Rep(Field_k),Rep(E_k)}]}`.

- If E is a tuple skeleton `{E_1, ..., E_k}`, then Rep(E) = `{tuple,LINE,[Rep(E_1), ..., Rep(E_k)]}`.
- If E is a try expression `try B catch Tc_1 ; ... ; Tc_k end`, where `B` is a body and each `Tc_i` is a catch clause, then Rep(E) = `{'try',LINE,Rep(B),[],[Rep(Tc_1), ..., Rep(Tc_k)],[]}`.
- If E is a try expression `try B of Cc_1 ; ... ; Cc_k catch Tc_1 ; ... ; Tc_n end`, where `B` is a body, each `Cc_i` is a case clause, and each `Tc_j` is a catch clause, then Rep(E) = `{'try',LINE,Rep(B),[Rep(Cc_1), ..., Rep(Cc_k)],[Rep(Tc_1), ..., Rep(Tc_n)],[]}`.
- If E is a try expression `try B after A end`, where `B` and `A` are bodies, then Rep(E) = `{'try',LINE,Rep(B),[],[],Rep(A)}`.
- If E is a try expression `try B of Cc_1 ; ... ; Cc_k after A end`, where `B` and `A` are a bodies, and each `Cc_i` is a case clause, then Rep(E) = `{'try',LINE,Rep(B),[Rep(Cc_1), ..., Rep(Cc_k)],[],Rep(A)}`.
- If E is a try expression `try B catch Tc_1 ; ... ; Tc_k after A end`, where `B` and `A` are bodies, and each `Tc_i` is a catch clause, then Rep(E) = `{'try',LINE,Rep(B),[],[Rep(Tc_1), ..., Rep(Tc_k)],Rep(A)}`.
- If E is a try expression `try B of Cc_1 ; ... ; Cc_k catch Tc_1 ; ... ; Tc_n after A end`, where `B` and `A` are a bodies, each `Cc_i` is a case clause, and each `Tc_j` is a catch clause, then Rep(E) = `{'try',LINE,Rep(B),[Rep(Cc_1), ..., Rep(Cc_k)],[Rep(Tc_1), ..., Rep(Tc_n)],Rep(A)}`.
- If E is a variable `V`, then Rep(E) = `{var,LINE,A}`, where `A` is an atom with a printname consisting of the same characters as `V`.

Qualifiers

A qualifier Q is one of the following:

- If Q is a filter `E`, where `E` is an expression, then Rep(Q) = `Rep(E)`.
- If Q is a generator `P <- E`, where `P` is a pattern and `E` is an expression, then Rep(Q) = `{generate,LINE,Rep(P),Rep(E)}`.
- If Q is a bitstring generator `P <= E`, where `P` is a pattern and `E` is an expression, then Rep(Q) = `{b_generate,LINE,Rep(P),Rep(E)}`.

Bitstring Element Type Specifiers

A type specifier list TSL for a bitstring element is a sequence of type specifiers `TS_1 - ... - TS_k`, and Rep(TSL) = `[Rep(TS_1), ..., Rep(TS_k)]`.

- If TS is a type specifier `A`, where `A` is an atom, then Rep(TS) = `A`.
- If TS is a type specifier `A:Value`, where `A` is an atom and `Value` is an integer, then Rep(TS) = `{A,Value}`.

Associations

An association A is one of the following:

- If A is an association `K => V`, then Rep(A) = `{map_field_assoc,LINE,Rep(K),Rep(V)}`.
- If A is an association `K := V`, then Rep(A) = `{map_field_exact,LINE,Rep(K),Rep(V)}`.

1.7.5 Clauses

There are function clauses, if clauses, case clauses, and catch clauses.

A clause C is one of the following:

- If C is a case clause `P -> B`, where `P` is a pattern and `B` is a body, then Rep(C) = `{clause,LINE,[Rep(P)],[],Rep(B)}`.

- If C is a case clause `P when Gs -> B`, where `P` is a pattern, `Gs` is a guard sequence, and `B` is a body, then Rep(C) = `{clause,LINE,[Rep(P)],Rep(Gs),Rep(B)}`.
- If C is a catch clause `P -> B`, where `P` is a pattern and `B` is a body, then Rep(C) = `{clause,LINE,[Rep({throw,P,_})],[],Rep(B)}`.
- If C is a catch clause `X : P -> B`, where `X` is an atomic literal or a variable pattern, `P` is a pattern, and `B` is a body, then Rep(C) = `{clause,LINE,[Rep({X,P,_})],[],Rep(B)}`.
- If C is a catch clause `P when Gs -> B`, where `P` is a pattern, `Gs` is a guard sequence, and `B` is a body, then Rep(C) = `{clause,LINE,[Rep({throw,P,_})],Rep(Gs),Rep(B)}`.
- If C is a catch clause `X : P when Gs -> B`, where `X` is an atomic literal or a variable pattern, `P` is a pattern, `Gs` is a guard sequence, and `B` is a body, then Rep(C) = `{clause,LINE,[Rep({X,P,_})],Rep(Gs),Rep(B)}`.
- If C is a function clause `( Ps ) -> B`, where `Ps` is a pattern sequence and `B` is a body, then Rep(C) = `{clause,LINE,Rep(Ps),[],Rep(B)}`.
- If C is a function clause `( Ps ) when Gs -> B`, where `Ps` is a pattern sequence, `Gs` is a guard sequence and `B` is a body, then Rep(C) = `{clause,LINE,Rep(Ps),Rep(Gs),Rep(B)}`.
- If C is an if clause `Gs -> B`, where `Gs` is a guard sequence and `B` is a body, then Rep(C) = `{clause,LINE,[],Rep(Gs),Rep(B)}`.

1.7.6 Guards

A guard sequence Gs is a sequence of guards `G_1; ...; G_k`, and Rep(Gs) = `[Rep(G_1), ..., Rep(G_k)]`. If the guard sequence is empty, then Rep(Gs) = `[]`.

A guard G is a non-empty sequence of guard tests `Gt_1, ..., Gt_k`, and Rep(G) = `[Rep(Gt_1), ..., Rep(Gt_k)]`.

A guard test Gt is one of the following:

- If Gt is an atomic literal `L`, then Rep(Gt) = Rep(L).
- If Gt is a bitstring constructor `<<Gt_1:Size_1/TSL_1, ..., Gt_k:Size_k/TSL_k>>`, where each `Size_i` is a guard test and each `TSL_i` is a type specificer list, then Rep(Gt) = `{bin,LINE,[{bin_element,LINE,Rep(Gt_1),Rep(Size_1),Rep(TSL_1)}, ..., {bin_element,LINE,Rep(Gt_k),Rep(Size_k),Rep(TSL_k)}]}`. For Rep(TSL), see above. An omitted `Size_i` is represented by `default`. An omitted `TSL_i` is represented by `default`.
- If Gt is a cons skeleton `[Gt_h | Gt_t]`, then Rep(Gt) = `{cons,LINE,Rep(Gt_h),Rep(Gt_t)}`.
- If Gt is a function call `A(Gt_1, ..., Gt_k)`, where `A` is an atom, then Rep(Gt) = `{call,LINE,Rep(A),[Rep(Gt_1), ..., Rep(Gt_k)]}`.
- If Gt is a function call `A_m:A(Gt_1, ..., Gt_k)`, where `A_m` is the atom `erlang` and `A` is an atom or an operator, then Rep(Gt) = `{call,LINE,{remote,LINE,Rep(A_m),Rep(A)},[Rep(Gt_1), ..., Rep(Gt_k)]}`.
- If Gt is a map creation `#{A_1, ..., A_k}`, where each `A_i` is an association `Gt_i_1 => Gt_i_2` or `Gt_i_1 := Gt_i_2`, then Rep(Gt) = `{map,LINE,[Rep(A_1), ..., Rep(A_k)]}`. For Rep(A), see above.
- If Gt is a map update `Gt_0#{A_1, ..., A_k}`, where each `A_i` is an association `Gt_i_1 => Gt_i_2` or `Gt_i_1 := Gt_i_2`, then Rep(Gt) = `{map,LINE,Rep(Gt_0),[Rep(A_1), ..., Rep(A_k)]}`. For Rep(A), see above.
- If Gt is nil, `[]`, then Rep(Gt) = `{nil,LINE}`.
- If Gt is an operator guard test `Gt_1 Op Gt_2`, where `Op` is a binary operator other than match operator `=`, then Rep(Gt) = `{op,LINE,Op,Rep(Gt_1),Rep(Gt_2)}`.
- If Gt is an operator guard test `Op Gt_0`, where `Op` is a unary operator, then Rep(Gt) = `{op,LINE,Op,Rep(Gt_0)}`.

- If Gt is a parenthesized guard test `( Gt_0 )`, then Rep(Gt) = `Rep(Gt_0)`, that is, parenthesized guard tests cannot be distinguished from their bodies.
- If Gt is a record creation `#Name{Field_1=Gt_1, ..., Field_k=Gt_k}`, where each `Field_i` is an atom or `_`, then Rep(Gt) = `{record,LINE,Name,[{record_field,LINE,Rep(Field_1),Rep(Gt_1)}, ..., {record_field,LINE,Rep(Field_k),Rep(Gt_k)}]}`.
- If Gt is a record field access `Gt_0#Name.Field`, where `Field` is an atom, then Rep(Gt) = `{record_field,LINE,Rep(Gt_0),Name,Rep(Field)}`.
- If Gt is a record field index `#Name.Field`, where `Field` is an atom, then Rep(Gt) = `{record_index,LINE,Name,Rep(Field)}`.
- If Gt is a tuple skeleton `{Gt_1, ..., Gt_k}`, then Rep(Gt) = `{tuple,LINE,[Rep(Gt_1), ..., Rep(Gt_k)]}`.
- If Gt is a variable pattern `V`, then Rep(Gt) = `{var,LINE,A}`, where A is an atom with a printname consisting of the same characters as `V`.

Notice that every guard test has the same source form as some expression, and is represented in the same way as the corresponding expression.

1.7.7 Types

- If T is an annotated type `A :: T_0`, where `A` is a variable, then Rep(T) = `{ann_type,LINE,[Rep(A),Rep(T_0)]}`.
- If T is an atom or integer literal L, then Rep(T) = Rep(L).
- If T is a bitstring type `<<_:M,_:_*N>>`, where `M` and `N` are singleton integer types, then Rep(T) = `{type,LINE,binary,[Rep(M),Rep(N)]}`.
- If T is the empty list type `[]`, then Rep(T) = `{type,Line,nil,[]}`.
- If T is a fun type `fun()`, then Rep(T) = `{type,LINE,'fun',[]}`.
- If T is a fun type `fun((...) -> T_0)`, then Rep(T) = `{type,LINE,'fun',[{type,LINE,any},Rep(T_0)]}`.
- If T is a fun type `fun(Ft)`, where `Ft` is a function type, then Rep(T) = `Rep(Ft)`. For Rep(Ft), see below.
- If T is an integer range type `L .. H`, where `L` and `H` are singleton integer types, then Rep(T) = `{type,LINE,range,[Rep(L),Rep(H)]}`.
- If T is a map type `map()`, then Rep(T) = `{type,LINE,map,any}`.
- If T is a map type `#{A_1, ..., A_k}`, where each `A_i` is an association type, then Rep(T) = `{type,LINE,map,[Rep(A_1), ..., Rep(A_k)]}`. For Rep(A), see below.
- If T is an operator type `T_1 Op T_2`, where `Op` is a binary operator (this is an occurrence of an expression that can be evaluated to an integer at compile time), then Rep(T) = `{op,LINE,Op,Rep(T_1),Rep(T_2)}`.
- If T is an operator type `Op T_0`, where `Op` is a unary operator (this is an occurrence of an expression that can be evaluated to an integer at compile time), then Rep(T) = `{op,LINE,Op,Rep(T_0)}`.
- If T is `( T_0 )`, then Rep(T) = `Rep(T_0)`, that is, parenthesized types cannot be distinguished from their bodies.
- If T is a predefined (or built-in) type `N(T_1, ..., T_k)`, then Rep(T) = `{type,LINE,N,[Rep(T_1), ..., Rep(T_k)]}`.
- If T is a record type `#Name{F_1, ..., F_k}`, where each `F_i` is a record field type, then Rep(T) = `{type,LINE,record,[Rep(Name),Rep(F_1), ..., Rep(F_k)]}`. For Rep(F), see below.
- If T is a remote type `M:N(T_1, ..., T_k)`, then Rep(T) = `{remote_type,LINE,[Rep(M),Rep(N),[Rep(T_1), ..., Rep(T_k)]]}`.
- If T is a tuple type `tuple()`, then Rep(T) = `{type,LINE,tuple,any}`.

- If T is a tuple type `{T_1, ..., T_k}`, then Rep(T) = `{type,LINE,tuple,[Rep(T_1), ..., Rep(T_k)]}`.
- If T is a type union `T_1 | ... | T_k`, then Rep(T) = `{type,LINE,union,[Rep(T_1), ..., Rep(T_k)]}`.
- If T is a type variable `V`, then Rep(T) = `{var,LINE,A}`, where `A` is an atom with a printname consisting of the same characters as `V`. A type variable is any variable except underscore (_).
- If T is a user-defined type `N(T_1, ..., T_k)`, then Rep(T) = `{user_type,LINE,N, [Rep(T_1), ..., Rep(T_k)]}`.

Function Types

A function type Ft is one of the following:

- If Ft is a constrained function type `Ft_1 when Fc`, where `Ft_1` is a function type and `Fc` is a function constraint, then Rep(T) = `{type,LINE,bounded_fun,[Rep(Ft_1),Rep(Fc)]}`. For Rep(Fc), see below.
- If Ft is a function type `(T_1, ..., T_n) -> T_0`, where each `T_i` is a type, then Rep(Ft) = `{type,LINE,'fun',[{type,LINE,product,[Rep(T_1), ..., Rep(T_n)]},Rep(T_0)]}`.

Function Constraints

A function constraint Fc is a non-empty sequence of constraints `C_1, ..., C_k`, and Rep(Fc) = `[Rep(C_1), ..., Rep(C_k)]`.

- If C is a constraint `V :: T`, where `V` is a type variable and `T` is a type, then Rep(C) = `{type,LINE,constraint,[{atom,LINE,is_subtype},[Rep(V),Rep(T)]]}`.

Association Types

- If A is an association type `K => V`, where `K` and `V` are types, then Rep(A) = `{type,LINE,map_field_assoc,[Rep(K),Rep(V)]}`.
- If A is an association type `K := V`, where `K` and `V` are types, then Rep(A) = `{type,LINE,map_field_exact,[Rep(K),Rep(V)]}`.

Record Field Types

- If F is a record field type `Name :: Type`, where `Type` is a type, then Rep(F) = `{type,LINE,field_type,[Rep(Name),Rep(Type)]}`.

1.7.8 The Abstract Format after Preprocessing

The compilation option `debug_info` can be specified to the compiler to have the abstract code stored in the `abstract_code` chunk in the Beam file (for debugging purposes).

As from Erlang/OTP R9C, the `abstract_code` chunk contains `{raw_abstract_v1,AbstractCode}`, where `AbstractCode` is the abstract code as described in this section.

In OTP releases before R9C, the abstract code after some more processing was stored in the Beam file. The first element of the tuple would be either `abstract_v1` (in OTP R7B) or `abstract_v2` (in OTP R8B).

1.8 tty - A Command-Line Interface

`tty` is a simple command-line interface program where keystrokes are collected and interpreted. Completed lines are sent to the shell for interpretation. A simple history mechanism saves previous lines, which can be edited before sending them to the shell. `tty` is started when Erlang is started with the following command:

```
erl
```

`tty` operates in one of two modes:

- Normal mode, in which text lines can be edited and sent to the shell.
- Shell break mode, which allows the user to kill the current shell, start multiple shells, and so on.

1.8.1 Normal Mode

In normal mode keystrokes from the user are collected and interpreted by `tty`. Most of the **Emacs** line-editing commands are supported. The following is a complete list of the supported line-editing commands.

Typographic conventions:

- `C-a` means pressing the **Ctrl** key and the letter `a` simultaneously.
- `M-f` means pressing the **Esc** key and the letter `f` in sequence.
- `Home` and `End` represent the keys with the same name on the keyboard.
- `Left` and `Right` represent the corresponding arrow keys.

Key Sequence	**Function**
Home	Beginning of line
C-a	Beginning of line
C-b	Backward character
C-Left	Backward word
M-b	Backward word
C-d	Delete character
M-d	Delete word
End	End of line
C-e	End of line
C-f	Forward character
C-Right	Forward word
M-f	Forward word
C-g	Enter shell break mode
C-k	Kill line
C-u	Backward kill line
C-l	Redraw line
C-n	Fetch next line from the history buffer
C-p	Fetch previous line from the history buffer

C-t	Transpose characters
C-w	Backward kill word
C-y	Insert previously killed text

Table 8.1: tty Text Editing

1.8.2 Shell Break Mode

In this mode the following can be done:

- Kill or suspend the current shell
- Connect to a suspended shell
- Start a new shell

1.9 How to Implement a Driver

Note:

This section was written a long time ago. Most of it is still valid, as it explains important concepts, but this was written for an older driver interface so the examples do not work anymore. The reader is encouraged to read the *`erl_driver`* and *`driver_entry`* documentation also.

1.9.1 Introduction

This section describes how to build your own driver for Erlang.

A driver in Erlang is a library written in C, which is linked to the Erlang emulator and called from Erlang. Drivers can be used when C is more suitable than Erlang, to speed up things, or to provide access to OS resources not directly accessible from Erlang.

A driver can be dynamically loaded, as a shared library (known as a DLL on Windows), or statically loaded, linked with the emulator when it is compiled and linked. Only dynamically loaded drivers are described here, statically linked drivers are beyond the scope of this section.

Warning:

When a driver is loaded it is executed in the context of the emulator, shares the same memory and the same thread. This means that all operations in the driver must be non-blocking, and that any crash in the driver brings the whole emulator down. In short, be careful.

1.9.2 Sample Driver

This section describes a simple driver for accessing a postgres database using the libpq C client library. Postgres is used because it is free and open source. For information on postgres, see **www.postgres.org**.

The driver is synchronous, it uses the synchronous calls of the client library. This is only for simplicity, but not good, as it halts the emulator while waiting for the database. This is improved below with an asynchronous sample driver.

The code is straightforward: all communication between Erlang and the driver is done with `port_control/3`, and the driver returns data back using the `rbuf`.

An Erlang driver only exports one function: the driver entry function. This is defined with a macro, `DRIVER_INIT`, which returns a pointer to a C `struct` containing the entry points that are called from the emulator. The `struct` defines the entries that the emulator calls to call the driver, with a `NULL` pointer for entries that are not defined and used by the driver.

The `start` entry is called when the driver is opened as a port with `open_port/2`. Here we allocate memory for a user data structure. This user data is passed every time the emulator calls us. First we store the driver handle, as it is needed in later calls. We allocate memory for the connection handle that is used by LibPQ. We also set the port to return allocated driver binaries, by setting flag `PORT_CONTROL_FLAG_BINARY`, calling `set_port_control_flags`. (This is because we do not know if our data will fit in the result buffer of `control`, which has a default size, 64 bytes, set up by the emulator.)

An entry `init` is called when the driver is loaded. However, we do not use this, as it is executed only once, and we want to have the possibility of several instances of the driver.

The `stop` entry is called when the port is closed.

The `control` entry is called from the emulator when the Erlang code calls `port_control/3`, to do the actual work. We have defined a simple set of commands: `connect` to log in to the database, `disconnect` to log out, and `select` to send a SQL-query and get the result. All results are returned through `rbuf`. The library `ei` in `erl_interface` is used to encode data in binary term format. The result is returned to the emulator as binary terms, so `binary_to_term` is called in Erlang to convert the result to term form.

The code is available in `pg_sync.c` in the `sample` directory of `erts`.

The driver entry contains the functions that will be called by the emulator. In this example, only `start`, `stop`, and `control` are provided:

```
/* Driver interface declarations */
static ErlDrvData start(ErlDrvPort port, char *command);
static void stop(ErlDrvData drv_data);
static int control(ErlDrvData drv_data, unsigned int command, char *buf,
                   int len, char **rbuf, int rlen);

static ErlDrvEntry pq_driver_entry = {
    NULL,                        /* init */
    start,
    stop,
    NULL,                        /* output */
    NULL,                        /* ready_input */
    NULL,                        /* ready_output */
    "pg_sync",                   /* the name of the driver */
    NULL,                        /* finish */
    NULL,                        /* handle */
    control,
    NULL,                        /* timeout */
    NULL,                        /* outputv */
    NULL,                        /* ready_async */
    NULL,                        /* flush */
    NULL,                        /* call */
    NULL                         /* event */
};
```

We have a structure to store state needed by the driver, in this case we only need to keep the database connection:

```
typedef struct our_data_s {
    PGconn* conn;
} our_data_t;
```

The control codes that we have defined are as follows:

```
/* Keep the following definitions in alignment with the
 * defines in erl_pq_sync.erl
 */

#define DRV_CONNECT             'C'
#define DRV_DISCONNECT          'D'
#define DRV_SELECT              'S'
```

This returns the driver structure. The macro `DRIVER_INIT` defines the only exported function. All the other functions are static, and will not be exported from the library.

```
/* INITIALIZATION AFTER LOADING */

/*
 * This is the init function called after this driver has been loaded.
 * It must *not* be declared static. Must return the address to
 * the driver entry.
 */

DRIVER_INIT(pq_drv)
{
    return &pq_driver_entry;
}
```

Here some initialization is done, `start` is called from `open_port`. The data will be passed to `control` and `stop`.

```
/* DRIVER INTERFACE */
static ErlDrvData start(ErlDrvPort port, char *command)
{
    our_data_t* data;

    data = (our_data_t*)driver_alloc(sizeof(our_data_t));
    data->conn = NULL;
    set_port_control_flags(port, PORT_CONTROL_FLAG_BINARY);
    return (ErlDrvData)data;
}
```

We call disconnect to log out from the database. (This should have been done from Erlang, but just in case.)

```
static int do_disconnect(our_data_t* data, ei_x_buff* x);

static void stop(ErlDrvData drv_data)
{
    our_data_t* data = (our_data_t*)drv_data;

    do_disconnect(data, NULL);
    driver_free(data);
}
```

We use the binary format only to return data to the emulator; input data is a string parameter for `connect` and `select`. The returned data consists of Erlang terms.

The functions `get_s` and `ei_x_to_new_binary` are utilities that are used to make the code shorter. `get_s` duplicates the string and zero-terminates it, as the postgres client library wants that. `ei_x_to_new_binary` takes an `ei_x_buff` buffer, allocates a binary, and copies the data there. This binary is returned in `*rbuf`. (Notice that this binary is freed by the emulator, not by us.)

```
static char* get_s(const char* buf, int len);
static int do_connect(const char *s, our_data_t* data, ei_x_buff* x);
static int do_select(const char* s, our_data_t* data, ei_x_buff* x);

/* As we are operating in binary mode, the return value from control
 * is irrelevant, as long as it is not negative.
 */
static int control(ErlDrvData drv_data, unsigned int command, char *buf,
                   int len, char **rbuf, int rlen)
{
    int r;
    ei_x_buff x;
    our_data_t* data = (our_data_t*)drv_data;
    char* s = get_s(buf, len);
    ei_x_new_with_version(&x);
    switch (command) {
        case DRV_CONNECT:    r = do_connect(s, data, &x);  break;
        case DRV_DISCONNECT: r = do_disconnect(data, &x);  break;
        case DRV_SELECT:     r = do_select(s, data, &x);   break;
        default:             r = -1;        break;
    }
    *rbuf = (char*)ei_x_to_new_binary(&x);
    ei_x_free(&x);
    driver_free(s);
    return r;
}
```

`do_connect` is where we log in to the database. If the connection was successful, we store the connection handle in the driver data, and return `'ok'`. Otherwise, we return the error message from postgres and store `NULL` in the driver data.

```
static int do_connect(const char *s, our_data_t* data, ei_x_buff* x)
{
    PGconn* conn = PQconnectdb(s);
    if (PQstatus(conn) != CONNECTION_OK) {
        encode_error(x, conn);
        PQfinish(conn);
        conn = NULL;
    } else {
        encode_ok(x);
    }
    data->conn = conn;
    return 0;
}
```

If we are connected (and if the connection handle is not `NULL`), we log out from the database. We need to check if we should encode an `'ok'`, as we can get here from function `stop`, which does not return data to the emulator:

```
static int do_disconnect(our_data_t* data, ei_x_buff* x)
{
    if (data->conn == NULL)
        return 0;
    PQfinish(data->conn);
    data->conn = NULL;
    if (x != NULL)
        encode_ok(x);
    return 0;
}
```

We execute a query and encode the result. Encoding is done in another C module, `pg_encode.c`, which is also provided as sample code.

```
static int do_select(const char* s, our_data_t* data, ei_x_buff* x)
{
   PGresult* res = PQexec(data->conn, s);
    encode_result(x, res, data->conn);
    PQclear(res);
    return 0;
}
```

Here we check the result from postgres. If it is data, we encode it as lists of lists with column data. Everything from postgres is C strings, so we use `ei_x_encode_string` to send the result as strings to Erlang. (The head of the list contains the column names.)

```
void encode_result(ei_x_buff* x, PGresult* res, PGconn* conn)
{
    int row, n_rows, col, n_cols;
    switch (PQresultStatus(res)) {
    case PGRES_TUPLES_OK:
        n_rows = PQntuples(res);
        n_cols = PQnfields(res);
        ei_x_encode_tuple_header(x, 2);
        encode_ok(x);
        ei_x_encode_list_header(x, n_rows+1);
        ei_x_encode_list_header(x, n_cols);
        for (col = 0; col < n_cols; ++col) {
            ei_x_encode_string(x, PQfname(res, col));
        }
        ei_x_encode_empty_list(x);
        for (row = 0; row < n_rows; ++row) {
            ei_x_encode_list_header(x, n_cols);
            for (col = 0; col < n_cols; ++col) {
                ei_x_encode_string(x, PQgetvalue(res, row, col));
            }
            ei_x_encode_empty_list(x);
        }
        ei_x_encode_empty_list(x);
        break;
    case PGRES_COMMAND_OK:
        ei_x_encode_tuple_header(x, 2);
        encode_ok(x);
        ei_x_encode_string(x, PQcmdTuples(res));
        break;
    default:
        encode_error(x, conn);
        break;
    }
}
```

1.9.3 Compiling and Linking the Sample Driver

The driver is to be compiled and linked to a shared library (DLL on Windows). With gcc, this is done with link flags `-shared` and `-fpic`. As we use the `ei` library, we should include it too. There are several versions of `ei`, compiled for debug or non-debug and multi-threaded or single-threaded. In the makefile for the samples, the `obj` directory is used for the `ei` library, meaning that we use the non-debug, single-threaded version.

1.9.4 Calling a Driver as a Port in Erlang

Before a driver can be called from Erlang, it must be loaded and opened. Loading is done using the `erl_ddll` module (the `erl_ddll` driver that loads dynamic driver is actually a driver itself). If loading is successfull, the port can be opened with `open_port/2`. The port name must match the name of the shared library and the name in the driver entry structure.

When the port has been opened, the driver can be called. In the `pg_sync` example, we do not have any data from the port, only the return value from the `port_control`.

The following code is the Erlang part of the synchronous postgres driver, `pg_sync.erl`:

```
-module(pg_sync).

-define(DRV_CONNECT, 1).
-define(DRV_DISCONNECT, 2).
-define(DRV_SELECT, 3).

-export([connect/1, disconnect/1, select/2]).

connect(ConnectStr) ->
    case erl_ddll:load_driver(".", "pg_sync") of
        ok -> ok;
        {error, already_loaded} -> ok;
        E -> exit({error, E})
    end,
    Port = open_port({spawn, ?MODULE}, []),
    case binary_to_term(port_control(Port, ?DRV_CONNECT, ConnectStr)) of
        ok -> {ok, Port};
        Error -> Error
    end.

disconnect(Port) ->
    R = binary_to_term(port_control(Port, ?DRV_DISCONNECT, "")),
    port_close(Port),
    R.

select(Port, Query) ->
    binary_to_term(port_control(Port, ?DRV_SELECT, Query)).
```

The API is simple:

- `connect/1` loads the driver, opens it, and logs on to the database, returning the Erlang port if successful.
- `select/2` sends a query to the driver and returns the result.
- `disconnect/1` closes the database connection and the driver. (However, it does not unload it.)

The connection string is to be a connection string for postgres.

The driver is loaded with `erl_ddll:load_driver/2`. If this is successful, or if it is already loaded, it is opened. This will call the `start` function in the driver.

We use the `port_control/3` function for all calls into the driver. The result from the driver is returned immediately and converted to terms by calling `binary_to_term/1`. (We trust that the terms returned from the driver are well-formed, otherwise the `binary_to_term` calls could be contained in a `catch`.)

1.9.5 Sample Asynchronous Driver

Sometimes database queries can take a long time to complete, in our `pg_sync` driver, the emulator halts while the driver is doing its job. This is often not acceptable, as no other Erlang process gets a chance to do anything. To improve on our postgres driver, we re-implement it using the asynchronous calls in LibPQ.

The asynchronous version of the driver is in the sample files `pg_async.c` and `pg_asyng.erl`.

```
/* Driver interface declarations */
static ErlDrvData start(ErlDrvPort port, char *command);
static void stop(ErlDrvData drv_data);
static int control(ErlDrvData drv_data, unsigned int command, char *buf,
                   int len, char **rbuf, int rlen);
static void ready_io(ErlDrvData drv_data, ErlDrvEvent event);

static ErlDrvEntry pq_driver_entry = {
    NULL,                       /* init */
    start,
    stop,
    NULL,                       /* output */
    ready_io,                   /* ready_input */
    ready_io,                   /* ready_output */
    "pg_async",                 /* the name of the driver */
    NULL,                       /* finish */
    NULL,                       /* handle */
    control,
    NULL,                       /* timeout */
    NULL,                       /* outputv */
    NULL,                       /* ready_async */
    NULL,                       /* flush */
    NULL,                       /* call */
    NULL                        /* event */
};

typedef struct our_data_t {
    PGconn* conn;
    ErlDrvPort port;
    int socket;
    int connecting;
} our_data_t;
```

Some things have changed from `pg_sync.c`: we use the entry `ready_io` for `ready_input` and `ready_output`, which is called from the emulator only when there is input to be read from the socket. (Actually, the socket is used in a `select` function inside the emulator, and when the socket is signaled, indicating there is data to read, the `ready_input` entry is called. More about this below.)

Our driver data is also extended, we keep track of the socket used for communication with postgres, and also the port, which is needed when we send data to the port with `driver_output`. We have a flag `connecting` to tell whether the driver is waiting for a connection or waiting for the result of a query. (This is needed, as the entry `ready_io` is called both when connecting and when there is a query result.)

```
static int do_connect(const char *s, our_data_t* data)
{
    PGconn* conn = PQconnectStart(s);
    if (PQstatus(conn) == CONNECTION_BAD) {
        ei_x_buff x;
        ei_x_new_with_version(&x);
        encode_error(&x, conn);
        PQfinish(conn);
        conn = NULL;
        driver_output(data->port, x.buff, x.index);
        ei_x_free(&x);
    }
    PQconnectPoll(conn);
    int socket = PQsocket(conn);
    data->socket = socket;
    driver_select(data->port, (ErlDrvEvent)socket, DO_READ, 1);
    driver_select(data->port, (ErlDrvEvent)socket, DO_WRITE, 1);
    data->conn = conn;
    data->connecting = 1;
    return 0;
}
```

The `connect` function looks a bit different too. We connect using the asynchronous `PQconnectStart` function. After the connection is started, we retrieve the socket for the connection with `PQsocket`. This socket is used with the `driver_select` function to wait for connection. When the socket is ready for input or for output, the `ready_io` function is called.

Notice that we only return data (with `driver_output`) if there is an error here, otherwise we wait for the connection to be completed, in which case our `ready_io` function is called.

```
static int do_select(const char* s, our_data_t* data)
{
    data->connecting = 0;
    PGconn* conn = data->conn;
    /* if there's an error return it now */
    if (PQsendQuery(conn, s) == 0) {
        ei_x_buff x;
        ei_x_new_with_version(&x);
        encode_error(&x, conn);
        driver_output(data->port, x.buff, x.index);
        ei_x_free(&x);
    }
    /* else wait for ready_output to get results */
    return 0;
}
```

The `do_select` function initiates a select, and returns if there is no immediate error. The result is returned when `ready_io` is called.

```
static void ready_io(ErlDrvData drv_data, ErlDrvEvent event)
{
    PGresult* res = NULL;
    our_data_t* data = (our_data_t*)drv_data;
    PGconn* conn = data->conn;
    ei_x_buff x;
    ei_x_new_with_version(&x);
    if (data->connecting) {
        ConnStatusType status;
        PQconnectPoll(conn);
        status = PQstatus(conn);
        if (status == CONNECTION_OK)
            encode_ok(&x);
        else if (status == CONNECTION_BAD)
            encode_error(&x, conn);
    } else {
        PQconsumeInput(conn);
        if (PQisBusy(conn))
            return;
        res = PQgetResult(conn);
        encode_result(&x, res, conn);
        PQclear(res);
        for (;;) {
            res = PQgetResult(conn);
            if (res == NULL)
                break;
            PQclear(res);
        }
    }
    if (x.index > 1) {
        driver_output(data->port, x.buff, x.index);
        if (data->connecting)
            driver_select(data->port, (ErlDrvEvent)data->socket, DO_WRITE, 0);
    }
    ei_x_free(&x);
}
```

The `ready_io` function is called when the socket we got from postgres is ready for input or output. Here we first check if we are connecting to the database. In that case, we check connection status and return OK if the connection is successful, or error if it is not. If the connection is not yet established, we simply return; `ready_io` is called again.

If we have a result from a connect, indicated by having data in the `x` buffer, we no longer need to select on output (`ready_output`), so we remove this by calling `driver_select`.

If we are not connecting, we wait for results from a `PQsendQuery`, so we get the result and return it. The encoding is done with the same functions as in the earlier example.

Error handling is to be added here, for example, checking that the socket is still open, but this is only a simple example.

The Erlang part of the asynchronous driver consists of the sample file `pg_async.erl`.

```
-module(pg_async).

-define(DRV_CONNECT, $C).
-define(DRV_DISCONNECT, $D).
-define(DRV_SELECT, $S).

-export([connect/1, disconnect/1, select/2]).

connect(ConnectStr) ->
    case erl_ddll:load_driver(".", "pg_async") of
        ok -> ok;
        {error, already_loaded} -> ok;
        _ -> exit({error, could_not_load_driver})
    end,
    Port = open_port({spawn, ?MODULE}, [binary]),
    port_control(Port, ?DRV_CONNECT, ConnectStr),
    case return_port_data(Port) of
        ok ->
            {ok, Port};
        Error ->
            Error
    end.

disconnect(Port) ->
    port_control(Port, ?DRV_DISCONNECT, ""),
    R = return_port_data(Port),
    port_close(Port),
    R.

select(Port, Query) ->
    port_control(Port, ?DRV_SELECT, Query),
    return_port_data(Port).

return_port_data(Port) ->
    receive
        {Port, {data, Data}} ->
            binary_to_term(Data)
    end.
```

The Erlang code is slightly different, as we do not return the result synchronously from `port_control`, instead we get it from `driver_output` as data in the message queue. The function `return_port_data` above receives data from the port. As the data is in binary format, we use `binary_to_term/1` to convert it to an Erlang term. Notice that the driver is opened in binary mode (`open_port/2` is called with option `[binary]`). This means that data sent from the driver to the emulator is sent as binaries. Without option `binary`, they would have been lists of integers.

1.9.6 An Asynchronous Driver Using driver_async

As a final example we demonstrate the use of `driver_async`. We also use the driver term interface. The driver is written in C++. This enables us to use an algorithm from STL. We use the `next_permutation` algorithm to get the next permutation of a list of integers. For large lists (> 100,000 elements), this takes some time, so we perform this as an asynchronous task.

The asynchronous API for drivers is complicated. First, the work must be prepared. In the example, this is done in `output`. We could have used `control`, but we want some variation in the examples. In our driver, we allocate a structure that contains anything that is needed for the asynchronous task to do the work. This is done in the main emulator thread. Then the asynchronous function is called from a driver thread, separate from the main emulator thread. Notice that the driver functions are not re-entrant, so they are not to be used. Finally, after the function is completed, the driver callback `ready_async` is called from the main emulator thread, this is where we return the result to Erlang. (We cannot return the result from within the asynchronous function, as we cannot call the driver functions.)

The following code is from the sample file `next_perm.cc`. The driver entry looks like before, but also contains the callback `ready_async`.

```
static ErlDrvEntry next_perm_driver_entry = {
    NULL,                        /* init */
    start,
    NULL,                        /* stop */
    output,
    NULL,                        /* ready_input */
    NULL,                        /* ready_output */
    "next_perm",                 /* the name of the driver */
    NULL,                        /* finish */
    NULL,                        /* handle */
    NULL,                        /* control */
    NULL,                        /* timeout */
    NULL,                        /* outputv */
    ready_async,
    NULL,                        /* flush */
    NULL,                        /* call */
    NULL                         /* event */
};
```

The `output` function allocates the work area of the asynchronous function. As we use C++, we use a struct, and stuff the data in it. We must copy the original data, it is not valid after we have returned from the `output` function, and the `do_perm` function is called later, and from another thread. We return no data here, instead it is sent later from the `ready_async` callback.

The `async_data` is passed to the `do_perm` function. We do not use a `async_free` function (the last argument to `driver_async`), it is only used if the task is cancelled programmatically.

```
struct our_async_data {
    bool prev;
    vector<int> data;
    our_async_data(ErlDrvPort p, int command, const char* buf, int len);
};

our_async_data::our_async_data(ErlDrvPort p, int command,
                               const char* buf, int len)
    : prev(command == 2),
      data((int*)buf, (int*)buf + len / sizeof(int))
{
}

static void do_perm(void* async_data);

static void output(ErlDrvData drv_data, char *buf, int len)
{
    if (*buf < 1 || *buf > 2) return;
    ErlDrvPort port = reinterpret_cast<ErlDrvPort>(drv_data);
    void* async_data = new our_async_data(port, *buf, buf+1, len);
    driver_async(port, NULL, do_perm, async_data, do_free);
}
```

In the `do_perm` we do the work, operating on the structure that was allocated in `output`.

```
static void do_perm(void* async_data)
{
    our_async_data* d = reinterpret_cast<our_async_data*>(async_data);
    if (d->prev)
        prev_permutation(d->data.begin(), d->data.end());
    else
        next_permutation(d->data.begin(), d->data.end());
}
```

In the `ready_async` function the output is sent back to the emulator. We use the driver term format instead of `ei`. This is the only way to send Erlang terms directly to a driver, without having the Erlang code to call `binary_to_term/1`. In the simple example this works well, and we do not need to use `ei` to handle the binary term format.

When the data is returned, we deallocate our data.

```
static void ready_async(ErlDrvData drv_data, ErlDrvThreadData async_data)
{
    ErlDrvPort port = reinterpret_cast<ErlDrvPort>(drv_data);
    our_async_data* d = reinterpret_cast<our_async_data*>(async_data);
    int n = d->data.size(), result_n = n*2 + 3;
    ErlDrvTermData *result = new ErlDrvTermData[result_n], *rp = result;
    for (vector<int>::iterator i = d->data.begin();
         i != d->data.end(); ++i) {
        *rp++ = ERL_DRV_INT;
        *rp++ = *i;
    }
    *rp++ = ERL_DRV_NIL;
    *rp++ = ERL_DRV_LIST;
    *rp++ = n+1;
    driver_output_term(port, result, result_n);
    delete[] result;
    delete d;
}
```

This driver is called like the others from Erlang. However, as we use `driver_output_term`, there is no need to call `binary_to_term`. The Erlang code is in the sample file `next_perm.erl`.

The input is changed into a list of integers and sent to the driver.

```
-module(next_perm).

-export([next_perm/1, prev_perm/1, load/0, all_perm/1]).

load() ->
    case whereis(next_perm) of
        undefined ->
            case erl_ddll:load_driver(".", "next_perm") of
                ok -> ok;
                {error, already_loaded} -> ok;
                E -> exit(E)
            end,
            Port = open_port({spawn, "next_perm"}, []),
            register(next_perm, Port);
        _ ->
            ok
    end.

list_to_integer_binaries(L) ->
    [<<I:32/integer-native>> || I <- L].

next_perm(L) ->
    next_perm(L, 1).

prev_perm(L) ->
    next_perm(L, 2).

next_perm(L, Nxt) ->
    load(),
    B = list_to_integer_binaries(L),
    port_control(next_perm, Nxt, B),
    receive
        Result ->
            Result
    end.

all_perm(L) ->
    New = prev_perm(L),
    all_perm(New, L, [New]).

all_perm(L, L, Acc) ->
    Acc;
all_perm(L, Orig, Acc) ->
    New = prev_perm(L),
    all_perm(New, Orig, [New | Acc]).
```

1.10 Inet Configuration

1.10.1 Introduction

This section describes how the Erlang runtime system is configured for IP communication. It also explains how you can configure it for your needs by a configuration file. The information is primarily intended for users with special configuration needs or problems. There is normally no need for specific settings for Erlang to function properly on a correctly IP-configured platform.

When Erlang starts up it reads the Kernel variable `inetrc`, which, if defined, is to specify the location and name of a user configuration file. Example:

```
% erl -kernel inetrc '"./cfg_files/erl_inetrc"'
```

Notice that the use of an `.inetrc` file, which was supported in earlier Erlang/OTP versions, is now obsolete.

A second way to specify the configuration file is to set environment variable `ERL_INETRC` to the full name of the file. Example (bash):

```
% export ERL_INETRC=./cfg_files/erl_inetrc
```

Notice that the Kernel variable `inetrc` overrides this environment variable.

If no user configuration file is specified and Erlang is started in non-distributed or short name distributed mode, Erlang uses default configuration settings and a native lookup method that works correctly under most circumstances. Erlang reads no information from system `inet` configuration files (such as `/etc/host.conf` and `/etc/nsswitch.conf`) in these modes, except for `/etc/resolv.conf` and `/etc/hosts` that is read and monitored for changes on Unix platforms for the internal DNS client *`inet_res(3)`*.

If Erlang is started in long name distributed mode, it needs to get the domain name from somewhere and reads system `inet` configuration files for this information. Any hosts and resolver information found is also recorded, but not used as long as Erlang is configured for native lookups. The information becomes useful if the lookup method is changed to `'file'` or `'dns'`, see below.

Native lookup (system calls) is always the default resolver method. This is true for all platforms, except VxWorks and OSE Delta where `'file'` or `'dns'` is used (in that priority order).

On Windows platforms, Erlang searches the system registry rather than looks for configuration files when started in long name distributed mode.

1.10.2 Configuration Data

Erlang records the following data in a local database if found in system `inet` configuration files (or system registry):

- Hostnames and host addresses
- Domain name
- Nameservers
- Search domains
- Lookup method

This data can also be specified explicitly in the user configuration file. This file is to contain lines of configuration parameters (each terminated with a full stop). Some parameters add data to the configuration (such as host and nameserver), others overwrite any previous settings (such as domain and lookup). The user configuration file is always examined last in the configuration process, making it possible for the user to override any default values or previously made settings. Call `inet:get_rc()` to view the state of the `inet` configuration database.

The valid configuration parameters are as follows:

`{file, Format, File}.`

`Format = atom()`

`File = string()`

Specify a system file that Erlang is to read configuration data from. `Format` tells the parser how the file is to be interpreted:

- `resolv` (Unix resolv.conf)
- `host_conf_freebsd` (FreeBSD host.conf)
- `host_conf_bsdos` (BSDOS host.conf)
- `host_conf_linux` (Linux host.conf)
- `nsswitch_conf` (Unix nsswitch.conf)
- `hosts` (Unix hosts)

`File` is to specify the filename with full path.

`{resolv_conf, File}.`

`File = string()`

Specify a system file that Erlang is to read resolver configuration from for the internal DNS client *`inet_res(3)`*, and monitor for changes, even if it does not exist. The path must be absolute.

This can override the configuration parameters `nameserver` and `search` depending on the contents of the specified file. They can also change any time in the future reflecting the file contents.

If the file is specified as an empty string `""`, no file is read or monitored in the future. This emulates the old behavior of not configuring the DNS client when the node is started in short name distributed mode.

If this parameter is not specified, it defaults to `/etc/resolv.conf` unless environment variable `ERL_INET_ETC_DIR` is set, which defines the directory for this file to some maybe other than `/etc`.

`{hosts_file, File}.`

`File = string()`

Specify a system file that Erlang is to read resolver configuration from for the internal hosts file resolver, and monitor for changes, even if it does not exist. The path must be absolute.

These host entries are searched after all added with `{file, hosts, File}` above or `{host, IP, Aliases}` below when lookup option `file` is used.

If the file is specified as an empty string `""`, no file is read or monitored in the future. This emulates the old behavior of not configuring the DNS client when the node is started in short name distributed mode.

If this parameter is not specified, it defaults to `/etc/hosts` unless environment variable `ERL_INET_ETC_DIR` is set, which defines the directory for this file to some maybe other than `/etc`.

`{registry, Type}.`

`Type = atom()`

Specify a system registry that Erlang is to read configuration data from. `win32` is the only valid option.

`{host, IP, Aliases}.`

`IP = tuple()`

`Aliases = [string()]`

Add host entry to the hosts table.

`{domain, Domain}.`

`Domain = string()`

Set domain name.

`{nameserver, IP [,Port]}.`

`IP = tuple()`

`Port = integer()`

Add address (and port, if other than default) of the primary nameserver to use for *`inet_res(3)`*.

`{alt_nameserver, IP [,Port]}.`

`IP = tuple()`

`Port = integer()`

Add address (and port, if other than default) of the secondary nameserver for *`inet_res(3)`*.

`{search, Domains}.`

`Domains = [string()]`

Add search domains for *`inet_res(3)`*.

`{lookup, Methods}.`

`Methods = [atom()]`

Specify lookup methods and in which order to try them. The valid methods are as follows:

- `native` (use system calls)
- `file` (use host data retrieved from system configuration files and/or the user configuration file)
- `dns` (use the Erlang DNS client *`inet_res(3)`* for nameserver queries)

The lookup method `string` tries to parse the hostname as an IPv4 or IPv6 string and return the resulting IP address. It is automatically tried first when `native` is **not** in the `Methods` list. To skip it in this case, the pseudo lookup method `nostring` can be inserted anywhere in the `Methods` list.

`{cache_size, Size}.`

`Size = integer()`

Set the resolver cache size. Defaults to 100 DNS records.

`{cache_refresh, Time}.`

`Time = integer()`

Set how often (in milliseconds) the resolver cache for *`inet_res(3)`* is refreshed (that is, expired DNS records are deleted). Defaults to 1 hour.

`{timeout, Time}.`

`Time = integer()`

Set the time to wait until retry (in milliseconds) for DNS queries made by *`inet_res(3)`*. Defaults to 2 seconds.

`{retry, N}.`

`N = integer()`

Set the number of DNS queries *`inet_res(3)`* will try before giving up. Defaults to 3.

`{inet6, Bool}.`

`Bool = true | false`

Tells the DNS client *`inet_res(3)`* to look up IPv6 addresses. Defaults to `false`.

`{usevc, Bool}.`

`Bool = true | false`

Tells the DNS client *`inet_res(3)`* to use TCP (Virtual Circuit) instead of UDP. Defaults to `false`.

`{edns, Version}.`

`Version = false | 0`

Sets the EDNS version that *`inet_res(3)`* will use. The only allowed version is zero. Defaults to `false`, which means not to use EDNS.

`{udp_payload_size, Size}.`

`N = integer()`

Sets the allowed UDP payload size *`inet_res(3)`* will advertise in EDNS queries. Also sets the limit when the DNS query will be deemed too large for UDP forcing a TCP query instead; this is not entirely correct, as

the advertised UDP payload size of the individual nameserver is what is to be used, but this simple strategy will do until a more intelligent (probing, caching) algorithm needs to be implemented. Default to 1280, which stems from the standard Ethernet MTU size.

`{udp, Module}.`

`Module = atom()`

Tell Erlang to use another primitive UDP module than `inet_udp`.

`{tcp, Module}.`

`Module = atom()`

Tell Erlang to use another primitive TCP module than `inet_tcp`.

`clear_hosts.`

Clear the hosts table.

`clear_ns.`

Clear the list of recorded nameservers (primary and secondary).

`clear_search.`

Clear the list of search domains.

1.10.3 User Configuration Example

Assume that a user does not want Erlang to use the native lookup method, but wants Erlang to read all information necessary from start and use that for resolving names and addresses. If lookup fails, Erlang is to request the data from a nameserver (using the Erlang DNS client, set to use EDNS allowing larger responses). The resolver configuration is updated when its configuration file changes. Also, DNS records are never to be cached. The user configuration file (in this example named `erl_inetrc`, stored in directory `./cfg_files`) can then look as follows (Unix):

```
%% -- ERLANG INET CONFIGURATION FILE --
%% read the hosts file
{file, hosts, "/etc/hosts"}.
%% add a particular host
{host, {134,138,177,105}, ["finwe"]}.
%% do not monitor the hosts file
{hosts_file, ""}.
%% read and monitor nameserver config from here
{resolv_conf, "/usr/local/etc/resolv.conf"}.
%% enable EDNS
{edns,0}.
%% disable caching
{cache_size, 0}.
%% specify lookup method
{lookup, [file, dns]}.
```

And Erlang can, for example, be started as follows:

```
% erl -sname my_node -kernel inetrc '"./cfg_files/erl_inetrc"'
```

1.11 External Term Format

1.11.1 Introduction

The external term format is mainly used in the distribution mechanism of Erlang.

As Erlang has a fixed number of types, there is no need for a programmer to define a specification for the external format used within some application. All Erlang terms have an external representation and the interpretation of the different terms is application-specific.

In Erlang the BIF `erlang:term_to_binary/1,2` is used to convert a term into the external format. To convert binary data encoding to a term, the BIF `erlang:binary_to_term/1` is used.

The distribution does this implicitly when sending messages across node boundaries.

The overall format of the term format is as follows:

1	1	N
`131`	`Tag`	`Data`

Table 11.1: Term Format

Note:

When messages are *passed between connected nodes* and a *distribution header* is used, the first byte containing the version number (131) is omitted from the terms that follow the distribution header. This is because the version number is implied by the version number in the distribution header.

The compressed term format is as follows:

1	1	4	N
`131`	`80`	`UncompressedSize`	`Zlib-compressedData`

Table 11.2: Compressed Term Format

Uncompressed size (unsigned 32-bit integer in big-endian byte order) is the size of the data before it was compressed. The compressed data has the following format when it has been expanded:

1	Uncompressed Size
`Tag`	`Data`

Table 11.3: Compressed Data Format when Expanded

Note:

As from ERTS 9.0 (OTP 20), atoms may contain any Unicode characters and are always encoded using the UTF-8 external formats *`ATOM_UTF8_EXT`* or *`SMALL_ATOM_UTF8_EXT`*. The old Latin-1 formats *`ATOM_EXT`* and *`SMALL_ATOM_EXT`* are deprecated and are only kept for backward compatibility when decoding terms encoded by older nodes.

Support for UTF-8 encoded atoms in the external format has been available since ERTS 5.10 (OTP R16). This abillity allows such old nodes to decode, store and encode any Unicode atoms received from a new OTP 20 node.

The maximum number of allowed characters in an atom is 255. In the UTF-8 case, each character can need 4 bytes to be encoded.

1.11.2 Distribution Header

As from ERTS 5.7.2 the old atom cache protocol was dropped and a new one was introduced. This protocol introduced the distribution header. Nodes with an ERTS version earlier than 5.7.2 can still communicate with new nodes, but no distribution header and no atom cache are used.

The distribution header only contains an atom cache reference section, but can in the future contain more information. The distribution header precedes one or more Erlang terms on the external format. For more information, see the documentation of the *protocol between connected nodes* in the *distribution protocol* documentation.

ATOM_CACHE_REF entries with corresponding `AtomCacheReferenceIndex` in terms encoded on the external format following a distribution header refer to the atom cache references made in the distribution header. The range is 0 <= `AtomCacheReferenceIndex` < 255, that is, at most 255 different atom cache references from the following terms can be made.

The distribution header format is as follows:

1	1	1	NumberOfAtomCacheRefs/2+1 | 0	N | 0
`131`	`68`	`NumberOfAtomCacheRefs`	`Flags`	`AtomCacheRefs`

Table 11.4: Distribution Header Format

`Flags` consist of `NumberOfAtomCacheRefs/2+1` bytes, unless `NumberOfAtomCacheRefs` is `0`. If `NumberOfAtomCacheRefs` is `0`, `Flags` and `AtomCacheRefs` are omitted. Each atom cache reference has a half byte flag field. Flags corresponding to a specific `AtomCacheReferenceIndex` are located in flag byte number `AtomCacheReferenceIndex/2`. Flag byte 0 is the first byte after the `NumberOfAtomCacheRefs` byte. Flags for an even `AtomCacheReferenceIndex` are located in the least significant half byte and flags for an odd `AtomCacheReferenceIndex` are located in the most significant half byte.

The flag field of an atom cache reference has the following format:

1 bit	3 bits
`NewCacheEntryFlag`	`SegmentIndex`

Table 11.5:

The most significant bit is the `NewCacheEntryFlag`. If set, the corresponding cache reference is new. The three least significant bits are the `SegmentIndex` of the corresponding atom cache entry. An atom cache consists of 8 segments, each of size 256, that is, an atom cache can contain 2048 entries.

After flag fields for atom cache references, another half byte flag field is located with the following format:

3 bits	1 bit
`CurrentlyUnused`	`LongAtoms`

Table 11.6:

The least significant bit in that half byte is flag `LongAtoms`. If it is set, 2 bytes are used for atom lengths instead of 1 byte in the distribution header.

After the `Flags` field follow the `AtomCacheRefs`. The first `AtomCacheRef` is the one corresponding to `AtomCacheReferenceIndex` 0. Higher indices follow in sequence up to index `NumberOfAtomCacheRefs - 1`.

If the `NewCacheEntryFlag` for the next `AtomCacheRef` has been set, a `NewAtomCacheRef` on the following format follows:

1	1 | 2	Length
`InternalSegmentIndex`	`Length`	`AtomText`

Table 11.7:

`InternalSegmentIndex` together with the `SegmentIndex` completely identify the location of an atom cache entry in the atom cache. `Length` is the number of bytes that `AtomText` consists of. Length is a 2 byte big-endian integer if flag `LongAtoms` has been set, otherwise a 1 byte integer. When distribution flag *`DFLAG_UTF8_ATOMS`* has been exchanged between both nodes in the *distribution handshake*, characters in `AtomText` are encoded in UTF-8, otherwise in Latin-1. The following `CachedAtomRef`s with the same `SegmentIndex` and `InternalSegmentIndex` as this `NewAtomCacheRef` refer to this atom until a new `NewAtomCacheRef` with the same `SegmentIndex` and `InternalSegmentIndex` appear.

For more information on encoding of atoms, see the *note on UTF-8 encoded atoms* in the beginning of this section.

If the `NewCacheEntryFlag` for the next `AtomCacheRef` has not been set, a `CachedAtomRef` on the following format follows:

1
`InternalSegmentIndex`

Table 11.8:

`InternalSegmentIndex` together with the `SegmentIndex` identify the location of the atom cache entry in the atom cache. The atom corresponding to this `CachedAtomRef` is the latest `NewAtomCacheRef` preceding this `CachedAtomRef` in another previously passed distribution header.

1.11.3 ATOM_CACHE_REF

1	1
`82`	`AtomCacheReferenceIndex`

Table 11.9: ATOM_CACHE_REF

Refers to the atom with `AtomCacheReferenceIndex` in the *distribution header*.

1.11.4 SMALL_INTEGER_EXT

1	1
`97`	`Int`

Table 11.10: SMALL_INTEGER_EXT

Unsigned 8-bit integer.

1.11.5 INTEGER_EXT

1	4
`98`	`Int`

Table 11.11: INTEGER_EXT

Signed 32-bit integer in big-endian format.

1.11.6 FLOAT_EXT

1	31
`99`	`Float string`

Table 11.12: FLOAT_EXT

A float is stored in string format. The format used in sprintf to format the float is "%.20e" (there are more bytes allocated than necessary). To unpack the float, use sscanf with format "%lf".

This term is used in minor version 0 of the external format; it has been superseded by *`NEW_FLOAT_EXT`*.

1.11.7 REFERENCE_EXT

1	N	4	1

101	Node	ID	Creation

Table 11.13: REFERENCE_EXT

Encodes a reference object (an object generated with *erlang:make_ref/0*). The `Node` term is an encoded atom, that is, *`ATOM_UTF8_EXT`*, *`SMALL_ATOM_UTF8_EXT`*, or *`ATOM_CACHE_REF`*. The `ID` field contains a big-endian unsigned integer, but **is to be regarded as uninterpreted data**, as this field is node-specific. `Creation` is a byte containing a node serial number, which makes it possible to separate old (crashed) nodes from a new one.

In `ID`, only 18 bits are significant; the rest are to be 0. In `Creation`, only two bits are significant; the rest are to be 0. See *`NEW_REFERENCE_EXT`*.

1.11.8 PORT_EXT

1	N	4	1
102	Node	ID	Creation

Table 11.14: PORT_EXT

Encodes a port object (obtained from *`erlang:open_port/2`*). The `ID` is a node-specific identifier for a local port. Port operations are not allowed across node boundaries. The `Creation` works just like in *`REFERENCE_EXT`*.

1.11.9 PID_EXT

1	N	4	4	1
103	Node	ID	Serial	Creation

Table 11.15: PID_EXT

Encodes a process identifier object (obtained from *`erlang:spawn/3`* or friends). The `ID` and `Creation` fields works just like in *`REFERENCE_EXT`*, while the `Serial` field is used to improve safety. In `ID`, only 15 bits are significant; the rest are to be 0.

1.11.10 SMALL_TUPLE_EXT

1	1	N
104	Arity	Elements

Table 11.16: SMALL_TUPLE_EXT

Encodes a tuple. The `Arity` field is an unsigned byte that determines how many elements that follows in section `Elements`.

1.11.11 LARGE_TUPLE_EXT

1	4	N
`105`	`Arity`	`Elements`

Table 11.17: LARGE_TUPLE_EXT

Same as *`SMALL_TUPLE_EXT`* except that `Arity` is an unsigned 4 byte integer in big-endian format.

1.11.12 MAP_EXT

1	4	N
`116`	`Arity`	`Pairs`

Table 11.18: MAP_EXT

Encodes a map. The `Arity` field is an unsigned 4 byte integer in big-endian format that determines the number of key-value pairs in the map. Key and value pairs (`Ki => Vi`) are encoded in section `Pairs` in the following order: `K1, V1, K2, V2,..., Kn, Vn`. Duplicate keys are **not allowed** within the same map.

As from Erlang/OTP 17.0

1.11.13 NIL_EXT

1
`106`

Table 11.19: NIL_EXT

The representation for an empty list, that is, the Erlang syntax `[]`.

1.11.14 STRING_EXT

1	2	Len
`107`	`Length`	`Characters`

Table 11.20: STRING_EXT

String does **not** have a corresponding Erlang representation, but is an optimization for sending lists of bytes (integer in the range 0-255) more efficiently over the distribution. As field `Length` is an unsigned 2 byte integer (big-endian), implementations must ensure that lists longer than 65535 elements are encoded as *`LIST_EXT`*.

1.11.15 LIST_EXT

1	4		
`108`	`Length`	`Elements`	`Tail`

Table 11.21: LIST_EXT

`Length` is the number of elements that follows in section `Elements`. `Tail` is the final tail of the list; it is *`NIL_EXT`* for a proper list, but can be any type if the list is improper (for example, `[a|b]`).

1.11.16 BINARY_EXT

1	4	Len
`109`	`Len`	`Data`

Table 11.22: BINARY_EXT

Binaries are generated with bit syntax expression or with *`erlang:list_to_binary/1`*, *`erlang:term_to_binary/1`*, or as input from binary ports. The `Len` length field is an unsigned 4 byte integer (big-endian).

1.11.17 SMALL_BIG_EXT

1	1	1	n
`110`	`n`	`Sign`	`d(0)` ... `d(n-1)`

Table 11.23: SMALL_BIG_EXT

Bignums are stored in unary form with a `Sign` byte, that is, 0 if the binum is positive and 1 if it is negative. The digits are stored with the least significant byte stored first. To calculate the integer, the following formula can be used:

`B` = 256
`(d0*B^0 + d1*B^1 + d2*B^2 + ... d(N-1)*B^(n-1))`

1.11.18 LARGE_BIG_EXT

1	4	1	n
`111`	`n`	`Sign`	`d(0)` ... `d(n-1)`

Table 11.24: LARGE_BIG_EXT

Same as *`SMALL_BIG_EXT`* except that the length field is an unsigned 4 byte integer.

1.11.19 NEW_REFERENCE_EXT

1	2	N	1	N'
114	Len	Node	Creation	ID ...

Table 11.25: NEW_REFERENCE_EXT

`Node` and `Creation` are as in *REFERENCE_EXT*.

`ID` contains a sequence of big-endian unsigned integers (4 bytes each, so `N'` is a multiple of 4), but is to be regarded as uninterpreted data.

`N'` = 4 * `Len`.

In the first word (4 bytes) of `ID`, only 18 bits are significant, the rest are to be 0. In `Creation`, only two bits are significant, the rest are to be 0.

`NEW_REFERENCE_EXT` was introduced with distribution version 4. In version 4, `N'` is to be at most 12.

See *REFERENCE_EXT*.

1.11.20 FUN_EXT

1	4	N1	N2	N3	N4	N5
117	NumFree	Pid	Module	Index	Uniq	Free vars ...

Table 11.26: FUN_EXT

`Pid`

A process identifier as in *PID_EXT*. Represents the process in which the fun was created.

`Module`

Encoded as an atom, using *ATOM_UTF8_EXT*, *SMALL_ATOM_UTF8_EXT*, or *ATOM_CACHE_REF*. This is the module that the fun is implemented in.

`Index`

An integer encoded using *SMALL_INTEGER_EXT* or *INTEGER_EXT*. It is typically a small index into the module's fun table.

`Uniq`

An integer encoded using *SMALL_INTEGER_EXT* or *INTEGER_EXT*. `Uniq` is the hash value of the parse for the fun.

`Free vars`

`NumFree` number of terms, each one encoded according to its type.

1.11.21 NEW_FUN_EXT

1	4	1	16	4	4	N1	N2	N3	N4	N5

112	Size	Arity	Uniq	Index	NumFree	Module	OldIndex	OldUniq	Pid	Free Vars

Table 11.27: NEW_FUN_EXT

This is the new encoding of internal funs: `fun F/A` and `fun(Arg1,..) -> ... end`.

`Size`

The total number of bytes, including field `Size`.

`Arity`

The arity of the function implementing the fun.

`Uniq`

The 16 bytes MD5 of the significant parts of the Beam file.

`Index`

An index number. Each fun within a module has an unique index. `Index` is stored in big-endian byte order.

`NumFree`

The number of free variables.

`Module`

Encoded as an atom, using *`ATOM_UTF8_EXT`*, *`SMALL_ATOM_UTF8_EXT`*, or *`ATOM_CACHE_REF`*. Is the module that the fun is implemented in.

`OldIndex`

An integer encoded using *`SMALL_INTEGER_EXT`* or *`INTEGER_EXT`*. Is typically a small index into the module's fun table.

`OldUniq`

An integer encoded using *`SMALL_INTEGER_EXT`* or *`INTEGER_EXT`*. `Uniq` is the hash value of the parse tree for the fun.

`Pid`

A process identifier as in *`PID_EXT`*. Represents the process in which the fun was created.

`Free vars`

`NumFree` number of terms, each one encoded according to its type.

1.11.22 EXPORT_EXT

1	N1	N2	N3
113	Module	Function	Arity

Table 11.28: EXPORT_EXT

This term is the encoding for external funs: `fun M:F/A`.

`Module` and `Function` are atoms (encoded using *`ATOM_UTF8_EXT`*, *`SMALL_ATOM_UTF8_EXT`*, or *`ATOM_CACHE_REF`*).

`Arity` is an integer encoded using *`SMALL_INTEGER_EXT`*.

1.11.23 BIT_BINARY_EXT

1	4	1	Len
`77`	`Len`	`Bits`	`Data`

Table 11.29: BIT_BINARY_EXT

This term represents a bitstring whose length in bits does not have to be a multiple of 8. The `Len` field is an unsigned 4 byte integer (big-endian). The `Bits` field is the number of bits (1-8) that are used in the last byte in the data field, counting from the most significant bit to the least significant.

1.11.24 NEW_FLOAT_EXT

1	8
`70`	`IEEE float`

Table 11.30: NEW_FLOAT_EXT

A float is stored as 8 bytes in big-endian IEEE format.

This term is used in minor version 1 of the external format.

1.11.25 ATOM_UTF8_EXT

1	2	Len
`118`	`Len`	`AtomName`

Table 11.31: ATOM_UTF8_EXT

An atom is stored with a 2 byte unsigned length in big-endian order, followed by `Len` bytes containing the `AtomName` encoded in UTF-8.

For more information on encoding of atoms, see the *note on UTF-8 encoded atoms* in the beginning of this section.

1.11.26 SMALL_ATOM_UTF8_EXT

1	1	Len
`119`	`Len`	`AtomName`

Table 11.32: SMALL_ATOM_UTF8_EXT

An atom is stored with a 1 byte unsigned length, followed by `Len` bytes containing the `AtomName` encoded in UTF-8. Longer atoms encoded in UTF-8 can be represented using *`ATOM_UTF8_EXT`*.

For more information on encoding of atoms, see the *note on UTF-8 encoded atoms* in the beginning of this section.

1.11.27 ATOM_EXT (deprecated)

1	2	Len
`100`	`Len`	`AtomName`

Table 11.33: ATOM_EXT

An atom is stored with a 2 byte unsigned length in big-endian order, followed by `Len` numbers of 8-bit Latin-1 characters that forms the `AtomName`. The maximum allowed value for `Len` is 255.

1.11.28 SMALL_ATOM_EXT (deprecated)

1	1	Len
`115`	`Len`	`AtomName`

Table 11.34: SMALL_ATOM_EXT

An atom is stored with a 1 byte unsigned length, followed by `Len` numbers of 8-bit Latin-1 characters that forms the `AtomName`.

Note:

`SMALL_ATOM_EXT` was introduced in ERTS 5.7.2 and require an exchange of distribution flag *`DFLAG_SMALL_ATOM_TAGS`* in the *distribution handshake*.

1.12 Distribution Protocol

This description is far from complete. It will be updated if the protocol is updated. However, the protocols, both from Erlang nodes to the Erlang Port Mapper Daemon (EPMD) and between Erlang nodes are stable since many years.

The distribution protocol can be divided into four parts:

- Low-level socket connection (1)
- Handshake, interchange node name, and authenticate (2)
- Authentication (done by *`net_kernel(3)`*) (3)
- Connected (4)

A node fetches the port number of another node through the EPMD (at the other host) to initiate a connection request.

For each host, where a distributed Erlang node is running, also an EPMD is to be running. The EPMD can be started explicitly or automatically as a result of the Erlang node startup.

By default the EPMD listens on port 4369.

(3) and (4) above are performed at the same level but the `net_kernel` disconnects the other node if it communicates using an invalid cookie (after 1 second).

The integers in all multibyte fields are in big-endian order.

Warning:

The Erlang Distribution protocol is not by itself secure and does not aim to be so. In order to get secure distribution the distributed nodes should be configured to use distribution over tls. See the *Using SSL for Erlang Distribution* User's Guide for details on how to setup a secure distributed node.

1.12.1 EPMD Protocol

The requests served by the EPMD are summarized in the following figure.

Figure 12.1: Summary of EPMD Requests

Each request `*_REQ` is preceded by a 2 byte length field. Thus, the overall request format is as follows:

2	n
`Length`	`Request`

Table 12.1: Request Format

Register a Node in EPMD

When a distributed node is started it registers itself in the EPMD. The message `ALIVE2_REQ` described below is sent from the node to the EPMD. The response from the EPMD is `ALIVE2_RESP`.

1	2	1	1	2	2	2	Nlen	2	Elen
`120`	`PortNo`	`NodeType`	`Protocol`	`HighestVersion`	`LowestVersion`	`Nlen`	`NodeName`	`Elen`	`Extra`

Table 12.2: ALIVE2_REQ (120)

`PortNo`

The port number on which the node accept connection requests.

`NodeType`

77 = normal Erlang node, 72 = hidden node (C-node), ...

`Protocol`

0 = TCP/IPv4, ...

`HighestVersion`

The highest distribution version that this node can handle. The value in Erlang/OTP R6B and later is 5.

`LowestVersion`

The lowest distribution version that this node can handle. The value in Erlang/OTP R6B and later is 5.

`Nlen`

The length (in bytes) of field `NodeName`.

`NodeName`

The node name as an UTF-8 encoded string of `Nlen` bytes.

`Elen`

The length of field `Extra`.

`Extra`

Extra field of `Elen` bytes.

The connection created to the EPMD must be kept as long as the node is a distributed node. When the connection is closed, the node is automatically unregistered from the EPMD.

The response message `ALIVE2_RESP` is as follows:

1	1	2
`121`	`Result`	`Creation`

Table 12.3: ALIVE2_RESP (121)

Result = 0 -> ok, result > 0 -> error.

Unregister a Node from EPMD

A node unregisters itself from the EPMD by closing the TCP connection to EPMD established when the node was registered.

Get the Distribution Port of Another Node

When one node wants to connect to another node it starts with a `PORT_PLEASE2_REQ` request to the EPMD on the host where the node resides to get the distribution port that the node listens to.

1	N
`122`	`NodeName`

Table 12.4: PORT_PLEASE2_REQ (122)

where N = `Length` - 1.

1	1
`119`	`Result`

Table 12.5: PORT2_RESP (119) Response Indicating Error, Result > 0

or

1	1	2	1	1	2	2	2	Nlen	2	Elen
`119`	`Result`	`PortNo`	`NodeType`	`Protocol`	`HighestVersion`	`LowestVersion`	`Nlen`	`NodeName`	`Elen`	`>Extra`

Table 12.6: PORT2_RESP, Result = 0

If `Result` > 0, the packet only consists of `[119, Result]`.

The EPMD closes the socket when it has sent the information.

Get All Registered Names from EPMD

This request is used through the Erlang function *`net_adm:names/1,2`*. A TCP connection is opened to the EPMD and this request is sent.

1
`110`

Table 12.7: NAMES_REQ (110)

The response for a `NAMES_REQ` is as follows:

4	
`EPMDPortNo`	`NodeInfo*`

Table 12.8: NAMES_RESP

`NodeInfo` is a string written for each active node. When all `NodeInfo` has been written the connection is closed by the EPMD.

`NodeInfo` is, as expressed in Erlang:

```
io:format("name ~ts at port ~p~n", [NodeName, Port]).
```

Dump All Data from EPMD

This request is not really used, it is to be regarded as a debug feature.

1
`100`

Table 12.9: DUMP_REQ

The response for a `DUMP_REQ` is as follows:

4	

EPMDPortNo	NodeInfo*

Table 12.10: DUMP_RESP

`NodeInfo` is a string written for each node kept in the EPMD. When all `NodeInfo` has been written the connection is closed by the EPMD.

`NodeInfo` is, as expressed in Erlang:

```
io:format("active name     ~ts at port ~p, fd = ~p~n",
          [NodeName, Port, Fd]).
```

or

```
io:format("old/unused name ~ts at port ~p, fd = ~p ~n",
          [NodeName, Port, Fd]).
```

Kill EPMD

This request kills the running EPMD. It is almost never used.

1
107

Table 12.11: KILL_REQ

The response for a `KILL_REQ` is as follows:

2
OKString

Table 12.12: KILL_RESP

where `OKString` is "OK".

STOP_REQ (Not Used)

1	n
115	NodeName

Table 12.13: STOP_REQ

where n = `Length` - 1.

The current implementation of Erlang does not care if the connection to the EPMD is broken.

The response for a `STOP_REQ` is as follows:

7
`OKString`

Table 12.14: STOP_RESP

where `OKString` is "STOPPED".

A negative response can look as follows:

7
`NOKString`

Table 12.15: STOP_NOTOK_RESP

where `NOKString` is "NOEXIST".

1.12.2 Distribution Handshake

This section describes the distribution handshake protocol introduced in Erlang/OTP R6. This description was previously located in `$ERL_TOP/lib/kernel/internal_doc/distribution_handshake.txt` and has more or less been copied and "formatted" here. It has been almost unchanged since 1999, but the handshake has not changed much since then either.

General

The TCP/IP distribution uses a handshake that expects a connection-based protocol, that is, the protocol does not include any authentication after the handshake procedure.

This is not entirely safe, as it is vulnerable against takeover attacks, but it is a tradeoff between fair safety and performance.

The cookies are never sent in cleartext and the handshake procedure expects the client (called `A`) to be the first one to prove that it can generate a sufficient digest. The digest is generated with the MD5 message digest algorithm and the challenges are expected to be random numbers.

Definitions

A challenge is a 32-bit integer in big-endian order. Below the function `gen_challenge()` returns a random 32-bit integer used as a challenge.

A digest is a (16 bytes) MD5 hash of the challenge (as text) concatenated with the cookie (as text). Below, the function `gen_digest(Challenge, Cookie)` generates a digest as described above.

An `out_cookie` is the cookie used in outgoing communication to a certain node, so that `A`'s `out_cookie` for `B` is to correspond with `B`'s `in_cookie` for `A` and conversely. `A`'s `out_cookie` for `B` and `A`'s `in_cookie` for `B` need **not** be the same. Below the function `out_cookie(Node)` returns the current node's `out_cookie` for `Node`.

An `in_cookie` is the cookie expected to be used by another node when communicating with us, so that `A`'s `in_cookie` for `B` corresponds with `B`'s `out_cookie` for `A`. Below the function `in_cookie(Node)` returns the current node's `in_cookie` for `Node`.

The cookies are text strings that can be viewed as passwords.

Every message in the handshake starts with a 16-bit big-endian integer, which contains the message length (not counting the two initial bytes). In Erlang this corresponds to option `{packet, 2}` in *`gen_tcp(3)`*. Notice that after the handshake, the distribution switches to 4 byte packet headers.

The Handshake in Detail

Imagine two nodes, A that initiates the handshake and B that accepts the connection.

1) connect/accept

A connects to B through TCP/IP and B accepts the connection.

2) `send_name`/`receive_name`

A sends an initial identification to B, which receives the message. The message looks as follows (every "square" is one byte and the packet header is removed):

```
+---+--------+--------+-----+-----+-----+-----+-----+-----+-...-+-----+
|'n'|Version0|Version1|Flag0|Flag1|Flag2|Flag3|Name0|Name1| ... |NameN|
+---+--------+--------+-----+-----+-----+-----+-----+-----+-... +-----+
```

'n' is the message tag. 'Version0' and 'Version1' is the distribution version selected by A, based on information from the EPMD. (16-bit big-endian) 'Flag0' ... 'Flag3' are capability flags, the capabilities are defined in `$ERL_TOP/lib/kernel/include/dist.hrl`. (32-bit big-endian) 'Name0' ... 'NameN' is the full node name of A, as a string of bytes (the packet length denotes how long it is).

3) `recv_status`/`send_status`

B sends a status message to A, which indicates if the connection is allowed. The following status codes are defined:

`ok`

The handshake will continue.

`ok_simultaneous`

The handshake will continue, but A is informed that B has another ongoing connection attempt that will be shut down (simultaneous connect where A's name is greater than B's name, compared literally).

`nok`

The handshake will not continue, as B already has an ongoing handshake, which it itself has initiated (simultaneous connect where B's name is greater than A's).

`not_allowed`

The connection is disallowed for some (unspecified) security reason.

`alive`

A connection to the node is already active, which either means that node A is confused or that the TCP connection breakdown of a previous node with this name has not yet reached node B. See step 3B below.

The format of the status message is as follows:

```
+---+-------+-------+-...-+-------+
|'s'|Status0|Status1| ... |StatusN|
+---+-------+-------+-...-+-------+
```

's' is the message tag. 'Status0' ... 'StatusN' is the status as a string (not terminated).

3B) `send_status`/`recv_status`

If status was `alive`, node A answers with another status message containing either `true`, which means that the connection is to continue (the old connection from this node is broken), or `false`, which means that the connection is to be closed (the connection attempt was a mistake.

4) `recv_challenge`/`send_challenge`

If the status was `ok` or `ok_simultaneous`, the handshake continues with B sending A another message, the challenge. The challenge contains the same type of information as the "name" message initially sent from A to B, plus a 32-bit challenge:

```
+---+--------+--------+-----+-----+-----+-----+-----+-----+-----+-----+-...-+-----+
|'n'|Version0|Version1|Flag0|Flag1|Flag2|Flag3|Chal0|Chal1|Chal2|Chal3|Name0|Name1| ... |NameN|
+---+--------+--------+-----+-----+-----+-----+-----+-----+-----+-----+-... +-----+
```

'Chal0' ... 'Chal3' is the challenge as a 32-bit big-endian integer and the other fields are B's version, flags, and full node name.

5) `send_challenge_reply`/`recv_challenge_reply`

Now A has generated a digest and its own challenge. Those are sent together in a package to B:

```
+---+-----+-----+-----+-----+-----+-----+-----+-...-+------+
|'r'|Chal0|Chal1|Chal2|Chal3|Dige0|Dige1|Dige2|Dige3| ... |Dige15|
+---+-----+-----+-----+-----+-----+-----+-----+-...-+------+
```

'r' is the tag. 'Chal0' ... 'Chal3' is A's challenge for B to handle. 'Dige0' ... 'Dige15' is the digest that A constructed from the challenge B sent in the previous step.

6) `recv_challenge_ack`/`send_challenge_ack`

B checks that the digest received from A is correct and generates a digest from the challenge received from A. The digest is then sent to A. The message is as follows:

```
+---+-----+-----+-----+-----+-...-+------+
|'a'|Dige0|Dige1|Dige2|Dige3| ... |Dige15|
+---+-----+-----+-----+-----+-...-+------+
```

'a' is the tag. 'Dige0' ... 'Dige15' is the digest calculated by B for A's challenge.

7) check

A checks the digest from B and the connection is up.

Semigraphic View

```
A (initiator)                                          B (acceptor)

TCP connect ------------------------------------>
                                                       TCP accept


send_name ------------------------------------->
                                                       recv_name

  <---------------------------------------------- send_status
recv_status
(if status was 'alive'
 send_status - - - - - - - - - - - - - - - - - ->
                                                       recv_status)
                                                       ChB = gen_challenge()
                          (ChB)
  <---------------------------------------------- send_challenge
recv_challenge
ChA = gen_challenge(),
OCA = out_cookie(B),
DiA = gen_digest(ChB, OCA)
                          (ChA, DiA)
send_challenge_reply --------------------------->
                                                       recv_challenge_reply
                                                       ICB = in_cookie(A),
                                                       check:
                                                       DiA == gen_digest (ChB, ICB)?
                                                       - if OK:
                                                        OCB = out_cookie(A),
                                                        DiB = gen_digest (ChA, OCB)
                          (DiB)
  <---------------------------------------------- send_challenge_ack
recv_challenge_ack                                      DONE
ICA = in_cookie(B),                                    - else:
check:                                                  CLOSE
DiB == gen_digest(ChA, ICA)?
- if OK:
 DONE
- else:
 CLOSE
```

Distribution Flags

The following capability flags are defined:

`-define(DFLAG_PUBLISHED,16#1).`

The node is to be published and part of the global namespace.

`-define(DFLAG_ATOM_CACHE,16#2).`

The node implements an atom cache (obsolete).

`-define(DFLAG_EXTENDED_REFERENCES,16#4).`

The node implements extended (3 × 32 bits) references. This is required today. If not present, the connection is refused.

`-define(DFLAG_DIST_MONITOR,16#8).`

The node implements distributed process monitoring.

`-define(DFLAG_FUN_TAGS,16#10).`

The node uses separate tag for funs (lambdas) in the distribution protocol.

`-define(DFLAG_DIST_MONITOR_NAME,16#20).`

The node implements distributed named process monitoring.

`-define(DFLAG_HIDDEN_ATOM_CACHE,16#40).`

The (hidden) node implements atom cache (obsolete).

`-define(DFLAG_NEW_FUN_TAGS,16#80).`

The node understand new fun tags.

`-define(DFLAG_EXTENDED_PIDS_PORTS,16#100).`

The node can handle extended pids and ports. This is required today. If not present, the connection is refused.

```
-define(DFLAG_EXPORT_PTR_TAG,16#200).
-define(DFLAG_BIT_BINARIES,16#400).
-define(DFLAG_NEW_FLOATS,16#800).
```

The node understands new float format.

```
-define(DFLAG_UNICODE_IO,16#1000).
-define(DFLAG_DIST_HDR_ATOM_CACHE,16#2000).
```

The node implements atom cache in distribution header.

`-define(DFLAG_SMALL_ATOM_TAGS, 16#4000).`

The node understand the `SMALL_ATOM_EXT` tag.

`-define(DFLAG_UTF8_ATOMS, 16#10000).`

The node understand UTF-8 encoded atoms.

1.12.3 Protocol between Connected Nodes

As from ERTS 5.7.2 the runtime system passes a distribution flag in the handshake stage that enables the use of a *distribution header* on all messages passed. Messages passed between nodes have in this case the following format:

4	d	n	m
`Length`	`DistributionHeader`	`ControlMessage`	`Message`

Table 12.16: Format of Messages Passed between Nodes (as from ERTS 5.7.2)

`Length`

Equal to d + n + m.

`ControlMessage`

A tuple passed using the external format of Erlang.

`Message`

The message sent to another node using the '!' (in external format). Notice that `Message` is only passed in combination with a `ControlMessage` encoding a send ('!').

Notice that *the version number is omitted from the terms that follow a distribution header* .

Nodes with an ERTS version earlier than 5.7.2 does not pass the distribution flag that enables the distribution header. Messages passed between nodes have in this case the following format:

4	1	n	m
`Length`	`Type`	`ControlMessage`	`Message`

Table 12.17: Format of Messages Passed between Nodes (before ERTS 5.7.2)

`Length`

Equal to 1 + n + m.

`Type`

Equal to `112` (pass through).

`ControlMessage`

A tuple passed using the external format of Erlang.

`Message`

The message sent to another node using the '!' (in external format). Notice that `Message` is only passed in combination with a `ControlMessage` encoding a send ('!').

The `ControlMessage` is a tuple, where the first element indicates which distributed operation it encodes:

`LINK`

`{1, FromPid, ToPid}`

`SEND`

`{2, Unused, ToPid}`

Followed by `Message`.

`Unused` is kept for backward compatibility.

`EXIT`

`{3, FromPid, ToPid, Reason}`

`UNLINK`

`{4, FromPid, ToPid}`

`NODE_LINK`

`{5}`

`REG_SEND`

`{6, FromPid, Unused, ToName}`

Followed by `Message`.

`Unused` is kept for backward compatibility.

`GROUP_LEADER`

`{7, FromPid, ToPid}`

`EXIT2`

`{8, FromPid, ToPid, Reason}`

1.12.4 New Ctrlmessages for distrvsn = 1 (Erlang/OTP R4)

`SEND_TT`

`{12, Unused, ToPid, TraceToken}`

Followed by `Message`.

`Unused` is kept for backward compatibility.

`EXIT_TT`

`{13, FromPid, ToPid, TraceToken, Reason}`

`REG_SEND_TT`

`{16, FromPid, Unused, ToName, TraceToken}`

Followed by `Message`.

`Unused` is kept for backward compatibility.

`EXIT2_TT`

`{18, FromPid, ToPid, TraceToken, Reason}`

1.12.5 New Ctrlmessages for distrvsn = 2

`distrvsn` 2 was never used.

1.12.6 New Ctrlmessages for distrvsn = 3 (Erlang/OTP R5C)

None, but the version number was increased anyway.

1.12.7 New Ctrlmessages for distrvsn = 4 (Erlang/OTP R6)

These are only recognized by Erlang nodes, not by hidden nodes.

`MONITOR_P`

`{19, FromPid, ToProc, Ref}`, where `FromPid` = monitoring process and `ToProc` = monitored process pid or name (atom)

`DEMONITOR_P`

`{20, FromPid, ToProc, Ref}`, where `FromPid` = monitoring process and `ToProc` = monitored process pid or name (atom)

We include `FromPid` just in case we want to trace this.

`MONITOR_P_EXIT`

`{21, FromProc, ToPid, Ref, Reason}`, where `FromProc` = monitored process pid or name (atom), `ToPid` = monitoring process, and `Reason` = exit reason for the monitored process

2 Reference Manual

erl_prim_loader

Erlang module

This module is used to load all Erlang modules into the system. The start script is also fetched with this low-level loader.

`erl_prim_loader` knows about the environment and how to fetch modules.

Command-line flag `-loader Loader` can be used to choose the method used by `erl_prim_loader`. Two `Loader` methods are supported by the Erlang runtime system: `efile` and `inet`.

Exports

`get_file(Filename) -> {ok, Bin, FullName} | error`

Types:

```
Filename = atom() | string()
Bin = binary()
FullName = string()
```

Fetches a file using the low-level loader. `Filename` is either an absolute filename or only the name of the file, for example, `"lists.beam"`. If an internal path is set to the loader, this path is used to find the file. `FullName` is the complete name of the fetched file. `Bin` is the contents of the file as a binary.

`Filename` can also be a file in an archive, for example, `$OTPROOT/lib/mnesia-4.4.7.ez/mnesia-4.4.7/ebin/mnesia.beam`. For information about archive files, see *`code(3)`*.

`get_path() -> {ok, Path}`

Types:

```
Path = [Dir :: string()]
```

Gets the path set in the loader. The path is set by the *`init(3)`* process according to information found in the start script.

`list_dir(Dir) -> {ok, Filenames} | error`

Types:

```
Dir = string()
Filenames = [Filename :: string()]
```

Lists all the files in a directory. Returns `{ok, Filenames}` if successful, otherwise `error`. `Filenames` is a list of the names of all the files in the directory. The names are not sorted.

`Dir` can also be a directory in an archive, for example, `$OTPROOT/lib/mnesia-4.4.7.ez/mnesia-4.4.7/ebin`. For information about archive files, see *`code(3)`*.

`read_file_info(Filename) -> {ok, FileInfo} | error`

Types:

```
Filename = string()
FileInfo = file:file_info()
```

Retrieves information about a file. Returns `{ok, FileInfo}` if successful, otherwise `error`. `FileInfo` is a record `file_info`, defined in the Kernel include file `file.hrl`. Include the following directive in the module from which the function is called:

```
-include_lib("kernel/include/file.hrl").
```

For more information about the record `file_info`, see *`file(3)`*.

`Filename` can also be a file in an archive, for example, `$OTPROOT/lib/mnesia-4.4.7.ez/mnesia-4.4.7/ebin/mnesia`. For information about archive files, see *`code(3)`*.

`read_link_info(Filename) -> {ok, FileInfo} | error`

Types:

```
Filename = string()
FileInfo = file:file_info()
```

Works like *`read_file_info/1`* except that if `Filename` is a symbolic link, information about the link is returned in the `file_info` record and the `type` field of the record is set to `symlink`.

If `Filename` is not a symbolic link, this function returns exactly the same result as `read_file_info/1`. On platforms that do not support symbolic links, this function is always equivalent to `read_file_info/1`.

`set_path(Path) -> ok`

Types:

```
Path = [Dir :: string()]
```

Sets the path of the loader if *`init(3)`* interprets a `path` command in the start script.

Command-Line Flags

The `erl_prim_loader` module interprets the following command-line flags:

`-loader Loader`

Specifies the name of the loader used by `erl_prim_loader`. `Loader` can be `efile` (use the local file system) or `inet` (load using the `boot_server` on another Erlang node).

If flag `-loader` is omitted, it defaults to `efile`.

`-loader_debug`

Makes the `efile` loader write some debug information, such as the reason for failures, while it handles files.

`-hosts Hosts`

Specifies which other Erlang nodes the `inet` loader can use. This flag is mandatory if flag `-loader inet` is present. On each host, there must be on Erlang node with the *`erl_boot_server(3)`*, which handles the load requests. `Hosts` is a list of IP addresses (hostnames are not acceptable).

`-setcookie Cookie`

Specifies the cookie of the Erlang runtime system. This flag is mandatory if flag `-loader inet` is present.

See Also

`init(3)`, *`erl_boot_server(3)`*

erlang

Erlang module

By convention, most Built-In Functions (BIFs) are included in this module. Some of the BIFs are viewed more or less as part of the Erlang programming language and are **auto-imported**. Thus, it is not necessary to specify the module name. For example, the calls `atom_to_list(Erlang)` and `erlang:atom_to_list(Erlang)` are identical.

Auto-imported BIFs are listed without module prefix. BIFs listed with module prefix are not auto-imported.

BIFs can fail for various reasons. All BIFs fail with reason `badarg` if they are called with arguments of an incorrect type. The other reasons are described in the description of each individual BIF.

Some BIFs can be used in guard tests and are marked with "Allowed in guard tests".

Data Types

`ext_binary()`

A binary data object, structured according to the Erlang external term format.

`iovec()`

A list of binaries. This datatype is useful to use together with *`enif_inspect_iovec`*.

```
message_queue_data() = off_heap | on_heap
```

See *`process_flag(message_queue_data, MQD)`*.

```
timestamp() =
    {MegaSecs :: integer() >= 0,
     Secs :: integer() >= 0,
     MicroSecs :: integer() >= 0}
```

See *`erlang:timestamp/0`*.

```
time_unit() =
    integer() >= 1 |
    second |
    millisecond |
    microsecond |
    nanosecond |
    native |
    perf_counter |
    deprecated_time_unit()
```

Supported time unit representations:

`PartsPerSecond :: integer() >= 1`

Time unit expressed in parts per second. That is, the time unit equals `1/PartsPerSecond` second.

`second`

Symbolic representation of the time unit represented by the integer `1`.

`millisecond`

Symbolic representation of the time unit represented by the integer `1000`.

`microsecond`

Symbolic representation of the time unit represented by the integer `1000000`.

`nanosecond`

Symbolic representation of the time unit represented by the integer `1000000000`.

`native`

Symbolic representation of the native time unit used by the Erlang runtime system.

The `native` time unit is determined at runtime system start, and remains the same until the runtime system terminates. If a runtime system is stopped and then started again (even on the same machine), the `native` time unit of the new runtime system instance can differ from the `native` time unit of the old runtime system instance.

One can get an approximation of the `native` time unit by calling *`erlang:convert_time_unit(1, second, native)`*. The result equals the number of whole `native` time units per second. If the number of `native` time units per second does not add up to a whole number, the result is rounded downwards.

> **Note:**
>
> The value of the `native` time unit gives you more or less no information about the quality of time values. It sets a limit for the *resolution* and for the *precision* of time values, but it gives no information about the *accuracy* of time values. The resolution of the `native` time unit and the resolution of time values can differ significantly.

`perf_counter`

Symbolic representation of the performance counter time unit used by the Erlang runtime system.

The `perf_counter` time unit behaves much in the same way as the `native` time unit. That is, it can differ between runtime restarts. To get values of this type, call *`os:perf_counter/0`*.

`deprecated_time_unit()`

Deprecated symbolic representations kept for backwards-compatibility.

The `time_unit/0` type can be extended. To convert time values between time units, use *`erlang:convert_time_unit/3`*.

```
deprecated_time_unit() =
    seconds | milli_seconds | micro_seconds | nano_seconds
```

The *`time_unit()`* type also consist of the following **deprecated** symbolic time units:

`seconds`

Same as *`second`*.

`milli_seconds`

Same as *`millisecond`*.

`micro_seconds`

Same as *`microsecond`*.

`nano_seconds`

Same as *`nanosecond`*.

Exports

```
abs(Float) -> float()
abs(Int) -> integer() >= 0
```

Types:

```
Int = integer()
```

Types:

```
Float = float()
Int = integer()
```

Returns an integer or float that is the arithmetical absolute value of `Float` or `Int`, for example:

```
> abs(-3.33).
3.33
> abs(-3).
3
```

Allowed in guard tests.

```
erlang:adler32(Data) -> integer() >= 0
```

Types:

```
Data = iodata()
```

Computes and returns the adler32 checksum for `Data`.

```
erlang:adler32(OldAdler, Data) -> integer() >= 0
```

Types:

```
OldAdler = integer() >= 0
Data = iodata()
```

Continues computing the adler32 checksum by combining the previous checksum, `OldAdler`, with the checksum of `Data`.

The following code:

```
X = erlang:adler32(Data1),
Y = erlang:adler32(X,Data2).
```

assigns the same value to `Y` as this:

```
Y = erlang:adler32([Data1,Data2]).
```

```
erlang:adler32_combine(FirstAdler, SecondAdler, SecondSize) ->
                          integer() >= 0
```

Types:

```
FirstAdler = SecondAdler = SecondSize = integer() >= 0
```

Combines two previously computed adler32 checksums. This computation requires the size of the data object for the second checksum to be known.

The following code:

```
Y = erlang:adler32(Data1),
Z = erlang:adler32(Y,Data2).
```

assigns the same value to `Z` as this:

```
X = erlang:adler32(Data1),
Y = erlang:adler32(Data2),
Z = erlang:adler32_combine(X,Y,iolist_size(Data2)).
```

`erlang:append_element(Tuple1, Term) -> Tuple2`

Types:

```
Tuple1 = Tuple2 = tuple()
Term = term()
```

Returns a new tuple that has one element more than `Tuple1`, and contains the elements in `Tuple1` followed by `Term` as the last element. Semantically equivalent to `list_to_tuple(tuple_to_list(Tuple1) ++ [Term])`, but much faster. Example:

```
> erlang:append_element({one, two}, three).
{one,two,three}
```

`apply(Fun, Args) -> term()`

Types:

```
Fun = function()
Args = [term()]
```

Calls a fun, passing the elements in `Args` as arguments.

If the number of elements in the arguments are known at compile time, the call is better written as `Fun(Arg1, Arg2, ... ArgN)`.

Warning:

Earlier, `Fun` could also be specified as `{Module, Function}`, equivalent to `apply(Module, Function, Args)`. **This use is deprecated and will stop working in a future release.**

`apply(Module, Function, Args) -> term()`

Types:

```
Module = module()
Function = atom()
Args = [term()]
```

Returns the result of applying `Function` in `Module` to `Args`. The applied function must be exported from `Module`. The arity of the function is the length of `Args`. Example:

```
> apply(lists, reverse, [[a, b, c]]).
[c,b,a]
> apply(erlang, atom_to_list, ['Erlang']).
"Erlang"
```

If the number of arguments are known at compile time, the call is better written as `Module:Function(Arg1, Arg2, ..., ArgN)`.

Failure: *`error_handler:undefined_function/3`* is called if the applied function is not exported. The error handler can be redefined (see *`process_flag/2`*). If `error_handler` is undefined, or if the user has redefined the default `error_handler` so the replacement module is undefined, an error with reason `undef` is generated.

`atom_to_binary(Atom, Encoding) -> binary()`

Types:

```
Atom = atom()
Encoding = latin1 | unicode | utf8
```

Returns a binary corresponding to the text representation of `Atom`. If `Encoding` is `latin1`, one byte exists for each character in the text representation. If `Encoding` is `utf8` or `unicode`, the characters are encoded using UTF-8 where characters may require multiple bytes.

Note:

As from Erlang/OTP 20, atoms can contain any Unicode character and `atom_to_binary(Atom, latin1)` may fail if the text representation for `Atom` contains a Unicode character > 255.

Example:

```
> atom_to_binary('Erlang', latin1).
<<"Erlang">>
```

`atom_to_list(Atom) -> string()`

Types:

```
Atom = atom()
```

Returns a string corresponding to the text representation of `Atom`, for example:

```
> atom_to_list('Erlang').
"Erlang"
```

`binary_part(Subject, PosLen) -> binary()`

Types:

```
Subject = binary()
PosLen = {Start :: integer() >= 0, Length :: integer()}
```

Extracts the part of the binary described by `PosLen`.

Negative length can be used to extract bytes at the end of a binary, for example:

```
1> Bin = <<1,2,3,4,5,6,7,8,9,10>>.
2> binary_part(Bin,{byte_size(Bin), -5}).
<<6,7,8,9,10>>
```

Failure: `badarg` if `PosLen` in any way references outside the binary.

`Start` is zero-based, that is:

```
1> Bin = <<1,2,3>>
2> binary_part(Bin,{0,2}).
<<1,2>>
```

For details about the `PosLen` semantics, see *`binary(3)`*.

Allowed in guard tests.

`binary_part(Subject, Start, Length) -> binary()`

Types:

```
Subject = binary()
Start = integer() >= 0
Length = integer()
```

The same as `binary_part(Subject, {Start, Length})`.

Allowed in guard tests.

`binary_to_atom(Binary, Encoding) -> atom()`

Types:

```
Binary = binary()
Encoding = latin1 | unicode | utf8
```

Returns the atom whose text representation is `Binary`. If `Encoding` is `latin1`, no translation of bytes in the binary is done. If `Encoding` is `utf8` or `unicode`, the binary must contain valid UTF-8 sequences.

Note:

As from Erlang/OTP 20, `binary_to_atom(Binary, utf8)` is capable of encoding any Unicode character. Earlier versions would fail if the binary contained Unicode characters > 255. For more information about Unicode support in atoms, see the *note on UTF-8 encoded atoms* in section "External Term Format" in the User's Guide.

Examples:

```
> binary_to_atom(<<"Erlang">>, latin1).
'Erlang'
> binary_to_atom(<<1024/utf8>>, utf8).
'Ѐ'
```

`binary_to_existing_atom(Binary, Encoding) -> atom()`

Types:

```
Binary = binary()
Encoding = latin1 | unicode | utf8
```

As *`binary_to_atom/2`*, but the atom must exist.

Failure: `badarg` if the atom does not exist.

Note:

Note that the compiler may optimize away atoms. For example, the compiler will rewrite `atom_to_list(some_atom)` to `"some_atom"`. If that expression is the only mention of the atom `some_atom` in the containing module, the atom will not be created when the module is loaded, and a subsequent call to `binary_to_existing_atom(<<"some_atom">>, utf8)` will fail.

`binary_to_float(Binary) -> float()`

Types:

```
Binary = binary()
```

Returns the float whose text representation is `Binary`, for example:

```
> binary_to_float(<<"2.2017764e+0">>).
2.2017764
```

Failure: `badarg` if `Binary` contains a bad representation of a float.

`binary_to_integer(Binary) -> integer()`

Types:

`Binary = binary()`

Returns an integer whose text representation is `Binary`, for example:

```
> binary_to_integer(<<"123">>).
123
```

Failure: `badarg` if `Binary` contains a bad representation of an integer.

`binary_to_integer(Binary, Base) -> integer()`

Types:

`Binary = binary()`

`Base = 2..36`

Returns an integer whose text representation in base `Base` is `Binary`, for example:

```
> binary_to_integer(<<"3FF">>, 16).
1023
```

Failure: `badarg` if `Binary` contains a bad representation of an integer.

`binary_to_list(Binary) -> [byte()]`

Types:

`Binary = binary()`

Returns a list of integers corresponding to the bytes of `Binary`.

`binary_to_list(Binary, Start, Stop) -> [byte()]`

Types:

`Binary = binary()`

`Start = Stop = integer() >= 1`

1..byte_size(`Binary`)

As `binary_to_list/1`, but returns a list of integers corresponding to the bytes from position `Start` to position `Stop` in `Binary`. The positions in the binary are numbered starting from 1.

Note:

The one-based indexing for binaries used by this function is deprecated. New code is to use *`binary:bin_to_list/3`* in STDLIB instead. All functions in module `binary` consistently use zero-based indexing.

`binary_to_term(Binary) -> term()`

Types:

`Binary = ext_binary()`

Returns an Erlang term that is the result of decoding binary object `Binary`, which must be encoded according to the *Erlang external term format*.

```
> Bin = term_to_binary(hello).
<<131,100,0,5,104,101,108,108,111>>
> hello = binary_to_term(Bin).
hello
```

Warning:

When decoding binaries from untrusted sources, consider using `binary_to_term/2` to prevent Denial of Service attacks.

See also *`term_to_binary/1`* and *`binary_to_term/2`*.

`binary_to_term(Binary, Opts) -> term()`

Types:

`Binary = ext_binary()`
`Opts = [safe]`

As `binary_to_term/1`, but takes options that affect decoding of the binary.

Option:

`safe`

Use this option when receiving binaries from an untrusted source.

When enabled, it prevents decoding data that can be used to attack the Erlang system. In the event of receiving unsafe data, decoding fails with a `badarg` error.

This prevents creation of new atoms directly, creation of new atoms indirectly (as they are embedded in certain structures, such as process identifiers, refs, and funs), and creation of new external function references. None of those resources are garbage collected, so unchecked creation of them can exhaust available memory.

Failure: `badarg` if `safe` is specified and unsafe data is decoded.

```
> binary_to_term(<<131,100,0,5,104,101,108,108,111>>, [safe]).
** exception error: bad argument
> hello.
hello
> binary_to_term(<<131,100,0,5,104,101,108,108,111>>, [safe]).
hello
```

See also *`term_to_binary/1`*, *`binary_to_term/1`*, and *`list_to_existing_atom/1`*.

`bit_size(Bitstring) -> integer() >= 0`

Types:

`Bitstring = bitstring()`

Returns an integer that is the size in bits of `Bitstring`, for example:

```
> bit_size(<<433:16,3:3>>).
19
> bit_size(<<1,2,3>>).
24
```

Allowed in guard tests.

`bitstring_to_list(Bitstring) -> [byte() | bitstring()]`

Types:

`Bitstring = bitstring()`

Returns a list of integers corresponding to the bytes of `Bitstring`. If the number of bits in the binary is not divisible by 8, the last element of the list is a bitstring containing the remaining 1-7 bits.

`erlang:bump_reductions(Reductions) -> true`

Types:

`Reductions = integer() >= 1`

This implementation-dependent function increments the reduction counter for the calling process. In the Beam emulator, the reduction counter is normally incremented by one for each function and BIF call. A context switch is forced when the counter reaches the maximum number of reductions for a process (2000 reductions in Erlang/OTP R12B).

Warning:

This BIF can be removed in a future version of the Beam machine without prior warning. It is unlikely to be implemented in other Erlang implementations.

`byte_size(Bitstring) -> integer() >= 0`

Types:

`Bitstring = bitstring()`

Returns an integer that is the number of bytes needed to contain `Bitstring`. That is, if the number of bits in `Bitstring` is not divisible by 8, the resulting number of bytes is rounded **up**. Examples:

```
> byte_size(<<433:16,3:3>>).
3
> byte_size(<<1,2,3>>).
3
```

Allowed in guard tests.

`erlang:cancel_timer(TimerRef) -> Result`

Types:

```
TimerRef = reference()
Time = integer() >= 0
Result = Time | false
```

Cancels a timer. The same as calling *`erlang:cancel_timer(TimerRef, [])`*.

`erlang:cancel_timer(TimerRef, Options) -> Result | ok`

Types:

```
TimerRef = reference()
Async = Info = boolean()
Option = {async, Async} | {info, Info}
Options = [Option]
Time = integer() >= 0
Result = Time | false
```

Cancels a timer that has been created by *`erlang:start_timer`* or *`erlang:send_after`*. `TimerRef` identifies the timer, and was returned by the BIF that created the timer.

`Options`:

`{async, Async}`

Asynchronous request for cancellation. `Async` defaults to `false`, which causes the cancellation to be performed synchronously. When `Async` is set to `true`, the cancel operation is performed asynchronously. That is, `cancel_timer()` sends an asynchronous request for cancellation to the timer service that manages the timer, and then returns `ok`.

`{info, Info}`

Requests information about the `Result` of the cancellation. `Info` defaults to `true`, which means the `Result` is given. When `Info` is set to `false`, no information about the result of the cancellation is given.

- When `Async` is `false`: if `Info` is `true`, the `Result` is returned by `erlang:cancel_timer()`. otherwise `ok` is returned.
- When `Async` is `true`: if `Info` is `true`, a message on the form `{cancel_timer, TimerRef, Result}` is sent to the caller of `erlang:cancel_timer()` when the cancellation operation has been performed, otherwise no message is sent.

More `Options` may be added in the future.

If `Result` is an integer, it represents the time in milliseconds left until the canceled timer would have expired.

If `Result` is `false`, a timer corresponding to `TimerRef` could not be found. This can be either because the timer had expired, already had been canceled, or because `TimerRef` never corresponded to a timer. Even if the timer had expired, it does not tell you if the time-out message has arrived at its destination yet.

Note:

The timer service that manages the timer can be co-located with another scheduler than the scheduler that the calling process is executing on. If so, communication with the timer service takes much longer time than if it is located locally. If the calling process is in critical path, and can do other things while waiting for the result of this operation, or is not interested in the result of the operation, you want to use option `{async, true}`. If using option `{async, false}`, the calling process blocks until the operation has been performed.

See also *`erlang:send_after/4`*, *`erlang:start_timer/4`*, and *`erlang:read_timer/2`*.

`ceil(Number) -> integer()`

Types:

```
Number = number()
```

Returns the smallest integer not less than `Number`. For example:

```
> ceil(5.5).
6
```

Allowed in guard tests.

`check_old_code(Module) -> boolean()`

Types:

```
Module = module()
```

Returns `true` if `Module` has old code, otherwise `false`.

See also *`code(3)`*.

`check_process_code(Pid, Module) -> CheckResult`

Types:

```
Pid = pid()
Module = module()
CheckResult = boolean()
```

The same as *`check_process_code(Pid, Module, [])`*.

`check_process_code(Pid, Module, OptionList) -> CheckResult | async`

Types:

```
Pid = pid()
Module = module()
RequestId = term()
Option = {async, RequestId} | {allow_gc, boolean()}
OptionList = [Option]
CheckResult = boolean() | aborted
```

Checks if the node local process identified by `Pid` executes old code for `Module`.

`Options`:

`{allow_gc, boolean()}`

Determines if garbage collection is allowed when performing the operation. If `{allow_gc, false}` is passed, and a garbage collection is needed to determine the result of the operation, the operation is aborted (see information on `CheckResult` below). The default is to allow garbage collection, that is, `{allow_gc, true}`.

`{async, RequestId}`

The function `check_process_code/3` returns the value `async` immediately after the request has been sent. When the request has been processed, the process that called this function is passed a message on the form `{check_process_code, RequestId, CheckResult}`.

If `Pid` equals `self()`, and no `async` option has been passed, the operation is performed at once. Otherwise a request for the operation is sent to the process identified by `Pid`, and is handled when appropriate. If no `async` option has been passed, the caller blocks until `CheckResult` is available and can be returned.

`CheckResult` informs about the result of the request as follows:

`true`

The process identified by `Pid` executes old code for `Module`. That is, the current call of the process executes old code for this module, or the process has references to old code for this module, or the process contains funs that references old code for this module.

`false`

The process identified by `Pid` does not execute old code for `Module`.

`aborted`

The operation was aborted, as the process needed to be garbage collected to determine the operation result, and the operation was requested by passing option `{allow_gc, false}`.

Note:

Up until ERTS version 8.*, the check process code operation checks for all types of references to the old code. That is, direct references (e.g. return addresses on the process stack), indirect references (`fun`s in process context), and references to literals in the code.

As of ERTS version 9.0, the check process code operation only checks for direct references to the code. Indirect references via `fun`s will be ignored. If such `fun`s exist and are used after a purge of the old code, an exception will be raised upon usage (same as the case when the `fun` is received by the process after the purge). Literals will be taken care of (copied) at a later stage. This behavior can as of ERTS version 8.1 be enabled when *building OTP*, and will automatically be enabled if dirty scheduler support is enabled.

See also *`code(3)`*.

Failures:

`badarg`
If `Pid` is not a node local process identifier.

`badarg`
If `Module` is not an atom.

`badarg`
If `OptionList` is an invalid list of options.

`erlang:convert_time_unit(Time, FromUnit, ToUnit) -> ConvertedTime`

Types:

```
Time = ConvertedTime = integer()
FromUnit = ToUnit = time_unit()
```

Converts the `Time` value of time unit `FromUnit` to the corresponding `ConvertedTime` value of time unit `ToUnit`. The result is rounded using the floor function.

Warning:

You can lose accuracy and precision when converting between time units. To minimize such loss, collect all data at `native` time unit and do the conversion on the end result.

`erlang:crc32(Data) -> integer() >= 0`

Types:

```
Data = iodata()
```

Computes and returns the crc32 (IEEE 802.3 style) checksum for `Data`.

```
erlang:crc32(OldCrc, Data) -> integer() >= 0
```

Types:

```
OldCrc = integer() >= 0
Data = iodata()
```

Continues computing the crc32 checksum by combining the previous checksum, `OldCrc`, with the checksum of `Data`.

The following code:

```
X = erlang:crc32(Data1),
Y = erlang:crc32(X,Data2).
```

assigns the same value to `Y` as this:

```
Y = erlang:crc32([Data1,Data2]).
```

```
erlang:crc32_combine(FirstCrc, SecondCrc, SecondSize) ->
                        integer() >= 0
```

Types:

```
FirstCrc = SecondCrc = SecondSize = integer() >= 0
```

Combines two previously computed crc32 checksums. This computation requires the size of the data object for the second checksum to be known.

The following code:

```
Y = erlang:crc32(Data1),
Z = erlang:crc32(Y,Data2).
```

assigns the same value to `Z` as this:

```
X = erlang:crc32(Data1),
Y = erlang:crc32(Data2),
Z = erlang:crc32_combine(X,Y,iolist_size(Data2)).
```

```
date() -> Date
```

Types:

```
Date = calendar:date()
```

Returns the current date as `{Year, Month, Day}`.

The time zone and Daylight Saving Time correction depend on the underlying OS. Example:

```
> date().
{1995,2,19}
```

```
erlang:decode_packet(Type, Bin, Options) ->
                        {ok, Packet, Rest} |
                        {more, Length} |
```

```
                        {error, Reason}
```

Types:

```
Type =
    raw |
    0 |
    1 |
    2 |
    4 |
    asn1 |
    cdr |
    sunrm |
    fcgi |
    tpkt |
    line |
    http |
    http_bin |
    httph |
    httph_bin
Bin = binary()
Options = [Opt]
Opt =
    {packet_size, integer() >= 0} |
    {line_length, integer() >= 0}
Packet = binary() | HttpPacket
Rest = binary()
Length = integer() >= 0 | undefined
Reason = term()
HttpPacket =
    HttpRequest | HttpResponse | HttpHeader | http_eoh | HttpError
HttpRequest = {http_request, HttpMethod, HttpUri, HttpVersion}
HttpResponse =
    {http_response, HttpVersion, integer(), HttpString}
HttpHeader =
    {http_header,
     integer(),
     HttpField,
     Reserved :: term(),
     Value :: HttpString}
HttpError = {http_error, HttpString}
HttpMethod =
    'OPTIONS' |
    'GET' |
    'HEAD' |
    'POST' |
    'PUT' |
    'DELETE' |
    'TRACE' |
    HttpString
HttpUri =
```

```
        '*' |
        {absoluteURI,
         http | https,
         Host :: HttpString,
         Port :: inet:port_number() | undefined,
         Path :: HttpString} |
        {scheme, Scheme :: HttpString, HttpString} |
        {abs_path, HttpString} |
        HttpString
    HttpVersion =
        {Major :: integer() >= 0, Minor :: integer() >= 0}
    HttpField =
        'Cache-Control' |
        'Connection' |
        'Date' |
        'Pragma' |
        'Transfer-Encoding' |
        'Upgrade' |
        'Via' |
        'Accept' |
        'Accept-Charset' |
        'Accept-Encoding' |
        'Accept-Language' |
        'Authorization' |
        'From' |
        'Host' |
        'If-Modified-Since' |
        'If-Match' |
        'If-None-Match' |
        'If-Range' |
        'If-Unmodified-Since' |
        'Max-Forwards' |
        'Proxy-Authorization' |
        'Range' |
        'Referer' |
        'User-Agent' |
        'Age' |
        'Location' |
        'Proxy-Authenticate' |
        'Public' |
        'Retry-After' |
        'Server' |
        'Vary' |
        'Warning' |
        'Www-Authenticate' |
        'Allow' |
        'Content-Base' |
        'Content-Encoding' |
        'Content-Language' |
        'Content-Length' |
        'Content-Location' |
        'Content-Md5' |
```

```
        'Content-Range' |
        'Content-Type' |
        'Etag' |
        'Expires' |
        'Last-Modified' |
        'Accept-Ranges' |
        'Set-Cookie' |
        'Set-Cookie2' |
        'X-Forwarded-For' |
        'Cookie' |
        'Keep-Alive' |
        'Proxy-Connection' |
        HttpString
    HttpString = string() | binary()
```

Decodes the binary `Bin` according to the packet protocol specified by `Type`. Similar to the packet handling done by sockets with option `{packet,Type}`.

If an entire packet is contained in `Bin`, it is returned together with the remainder of the binary as `{ok,Packet,Rest}`.

If `Bin` does not contain the entire packet, `{more,Length}` is returned. `Length` is either the expected **total size** of the packet, or `undefined` if the expected packet size is unknown. `decode_packet` can then be called again with more data added.

If the packet does not conform to the protocol format, `{error,Reason}` is returned.

`Types`:

`raw | 0`

No packet handling is done. The entire binary is returned unless it is empty.

`1 | 2 | 4`

Packets consist of a header specifying the number of bytes in the packet, followed by that number of bytes. The length of the header can be one, two, or four bytes; the order of the bytes is big-endian. The header is stripped off when the packet is returned.

`line`

A packet is a line-terminated by a delimiter byte, default is the latin-1 newline character. The delimiter byte is included in the returned packet unless the line was truncated according to option `line_length`.

`asn1 | cdr | sunrm | fcgi | tpkt`

The header is **not** stripped off.

The meanings of the packet types are as follows:

`asn1` - ASN.1 BER
`sunrm` - Sun's RPC encoding
`cdr` - CORBA (GIOP 1.1)
`fcgi` - Fast CGI
`tpkt` - TPKT format [RFC1006]

`http | httph | http_bin | httph_bin`

The Hypertext Transfer Protocol. The packets are returned with the format according to `HttpPacket` described earlier. A packet is either a request, a response, a header, or an end of header mark. Invalid lines are returned as `HttpError`.

Recognized request methods and header fields are returned as atoms. Others are returned as strings. Strings of unrecognized header fields are formatted with only capital letters first and after hyphen characters, for example, `"Sec-Websocket-Key"`.

The protocol type `http` is only to be used for the first line when an `HttpRequest` or an `HttpResponse` is expected. The following calls are to use `httph` to get `HttpHeader`s until `http_eoh` is returned, which marks the end of the headers and the beginning of any following message body.

The variants `http_bin` and `httph_bin` return strings (`HttpString`) as binaries instead of lists.

Options:

`{packet_size, integer() >= 0}`

Sets the maximum allowed size of the packet body. If the packet header indicates that the length of the packet is longer than the maximum allowed length, the packet is considered invalid. Defaults to 0, which means no size limit.

`{line_length, integer() >= 0}`

For packet type `line`, lines longer than the indicated length are truncated.

Option `line_length` also applies to `http*` packet types as an alias for option `packet_size` if `packet_size` itself is not set. This use is only intended for backward compatibility.

`{line_delimiter, 0 =< byte() =< 255}`

For packet type `line`, sets the delimiting byte. Default is the latin-1 character `$\n`.

Examples:

```
> erlang:decode_packet(1,<<3,"abcd">>,[]).
{ok,<<"abc">>,<<"d">>}
> erlang:decode_packet(1,<<5,"abcd">>,[]).
{more,6}
```

`erlang:delete_element(Index, Tuple1) -> Tuple2`

Types:

`Index = integer() >= 1`

1..tuple_size(Tuple1)

`Tuple1 = Tuple2 = tuple()`

Returns a new tuple with element at `Index` removed from tuple `Tuple1`, for example:

```
> erlang:delete_element(2, {one, two, three}).
{one,three}
```

`delete_module(Module) -> true | undefined`

Types:

`Module = module()`

Makes the current code for `Module` become old code and deletes all references for this module from the export table. Returns `undefined` if the module does not exist, otherwise `true`.

Warning:

This BIF is intended for the code server (see *code(3)*) and is not to be used elsewhere.

Failure: `badarg` if there already is an old version of `Module`.

`demonitor(MonitorRef) -> true`

Types:

```
MonitorRef = reference()
```

If `MonitorRef` is a reference that the calling process obtained by calling *monitor/2*, this monitoring is turned off. If the monitoring is already turned off, nothing happens.

Once `demonitor(MonitorRef)` has returned, it is guaranteed that no `{'DOWN', MonitorRef, _, _, _}` message, because of the monitor, will be placed in the caller message queue in the future. However, a `{'DOWN', MonitorRef, _, _, _}` message can have been placed in the caller message queue before the call. It is therefore usually advisable to remove such a `'DOWN'` message from the message queue after monitoring has been stopped. *demonitor(MonitorRef, [flush])* can be used instead of `demonitor(MonitorRef)` if this cleanup is wanted.

Note:

Before Erlang/OTP R11B (ERTS 5.5) `demonitor/1` behaved completely asynchronously, that is, the monitor was active until the "demonitor signal" reached the monitored entity. This had one undesirable effect. You could never know when you were guaranteed **not** to receive a `DOWN` message because of the monitor.

The current behavior can be viewed as two combined operations: asynchronously send a "demonitor signal" to the monitored entity and ignore any future results of the monitor.

Failure: It is an error if `MonitorRef` refers to a monitoring started by another process. Not all such cases are cheap to check. If checking is cheap, the call fails with `badarg`, for example if `MonitorRef` is a remote reference.

`demonitor(MonitorRef, OptionList) -> boolean()`

Types:

```
MonitorRef = reference()
OptionList = [Option]
Option = flush | info
```

The returned value is `true` unless `info` is part of `OptionList`.

`demonitor(MonitorRef, [])` is equivalent to *demonitor(MonitorRef)*.

`Options`:

`flush`

Removes (one) `{_, MonitorRef, _, _, _}` message, if there is one, from the caller message queue after monitoring has been stopped.

Calling `demonitor(MonitorRef, [flush])` is equivalent to the following, but more efficient:

```
demonitor(MonitorRef),
receive
    {_, MonitorRef, _, _, _} ->
        true
after 0 ->
        true
end
```

`info`

The returned value is one of the following:

`true`

The monitor was found and removed. In this case, no `'DOWN'` message corresponding to this monitor has been delivered and will not be delivered.

`false`

The monitor was not found and could not be removed. This probably because someone already has placed a `'DOWN'` message corresponding to this monitor in the caller message queue.

If option `info` is combined with option `flush`, `false` is returned if a flush was needed, otherwise `true`.

Note:

More options can be added in a future release.

Failures:

`badarg`
If `OptionList` is not a list.

`badarg`
If `Option` is an invalid option.

`badarg`
The same failure as for *`demonitor/1`*.

`disconnect_node(Node) -> boolean() | ignored`

Types:

`Node = node()`

Forces the disconnection of a node. This appears to the node `Node` as if the local node has crashed. This BIF is mainly used in the Erlang network authentication protocols.

Returns `true` if disconnection succeeds, otherwise `false`. If the local node is not alive, `ignored` is returned.

`erlang:display(Term) -> true`

Types:

`Term = term()`

Prints a text representation of `Term` on the standard output.

Warning:

This BIF is intended for debugging only.

element(N, Tuple) -> term()

Types:

N = integer() >= 1

1..tuple_size(Tuple)

Tuple = tuple()

Returns the Nth element (numbering from 1) of Tuple, for example:

```
> element(2, {a, b, c}).
b
```

Allowed in guard tests.

erase() -> [{Key, Val}]

Types:

Key = Val = term()

Returns the process dictionary and deletes it, for example:

```
> put(key1, {1, 2, 3}),
put(key2, [a, b, c]),
erase().
[{key1,{1,2,3}},{key2,[a,b,c]}]
```

erase(Key) -> Val | undefined

Types:

Key = Val = term()

Returns the value Val associated with Key and deletes it from the process dictionary. Returns undefined if no value is associated with Key. Example:

```
> put(key1, {merry, lambs, are, playing}),
X = erase(key1),
{X, erase(key1)}.
{{merry,lambs,are,playing},undefined}
```

error(Reason) -> no_return()

Types:

Reason = term()

Stops the execution of the calling process with the reason Reason, where Reason is any term. The exit reason is {Reason, Where}, where Where is a list of the functions most recently called (the current function first). As evaluating this function causes the process to terminate, it has no return value. Example:

```
> catch error(foobar).
{'EXIT',{foobar,[{erl_eval,do_apply,5},
                 {erl_eval,expr,5},
                 {shell,exprs,6},
                 {shell,eval_exprs,6},
                 {shell,eval_loop,3}]}}
```

`error(Reason, Args) -> no_return()`

Types:

```
Reason = term()
Args = [term()]
```

Stops the execution of the calling process with the reason `Reason`, where `Reason` is any term. The exit reason is `{Reason, Where}`, where `Where` is a list of the functions most recently called (the current function first). `Args` is expected to be the list of arguments for the current function; in Beam it is used to provide the arguments for the current function in the term `Where`. As evaluating this function causes the process to terminate, it has no return value.

`exit(Reason) -> no_return()`

Types:

```
Reason = term()
```

Stops the execution of the calling process with exit reason `Reason`, where `Reason` is any term. As evaluating this function causes the process to terminate, it has no return value. Example:

```
> exit(foobar).
** exception exit: foobar
> catch exit(foobar).
{'EXIT',foobar}
```

`exit(Pid, Reason) -> true`

Types:

```
Pid = pid() | port()
Reason = term()
```

Sends an exit signal with exit reason `Reason` to the process or port identified by `Pid`.

The following behavior applies if `Reason` is any term, except `normal` or `kill`:

- If `Pid` is not trapping exits, `Pid` itself exits with exit reason `Reason`.
- If `Pid` is trapping exits, the exit signal is transformed into a message `{'EXIT', From, Reason}` and delivered to the message queue of `Pid`.
- `From` is the process identifier of the process that sent the exit signal. See also *`process_flag/2`*.

If `Reason` is the atom `normal`, `Pid` does not exit. If it is trapping exits, the exit signal is transformed into a message `{'EXIT', From, normal}` and delivered to its message queue.

If `Reason` is the atom `kill`, that is, if `exit(Pid, kill)` is called, an untrappable exit signal is sent to `Pid`, which unconditionally exits with exit reason `killed`.

`erlang:external_size(Term) -> integer() >= 0`

Types:

```
Term = term()
```

Calculates, without doing the encoding, the maximum byte size for a term encoded in the Erlang external term format. The following condition applies always:

```
> Size1 = byte_size(term_to_binary()),
> Size2 = erlang:external_size(),
> true = Size1 =< Size2.
true
```

This is equivalent to a call to:

```
erlang:external_size(Term, [])
```

`erlang:external_size(Term, Options) -> integer() >= 0`

Types:

```
Term = term()
Options = [{minor_version, Version :: integer() >= 0}]
```

Calculates, without doing the encoding, the maximum byte size for a term encoded in the Erlang external term format. The following condition applies always:

```
> Size1 = byte_size(term_to_binary(, )),
> Size2 = erlang:external_size(, ),
> true = Size1 =< Size2.
true
```

Option `{minor_version, Version}` specifies how floats are encoded. For a detailed description, see *`term_to_binary/2`*.

`float(Number) -> float()`

Types:

```
Number = number()
```

Returns a float by converting `Number` to a float, for example:

```
> float(55).
55.0
```

Allowed in guard tests.

Note:

If used on the top level in a guard, it tests whether the argument is a floating point number; for clarity, use *`is_float/1`* instead.

When `float/1` is used in an expression in a guard, such as '`float(A) == 4.0`', it converts a number as described earlier.

`float_to_binary(Float) -> binary()`

Types:

```
Float = float()
```

The same as `float_to_binary(Float,[{scientific,20}])`.

`float_to_binary(Float, Options) -> binary()`

Types:

```
Float = float()
Options = [Option]
Option =
```

```
    {decimals, Decimals :: 0..253} |
    {scientific, Decimals :: 0..249} |
    compact
```

Returns a binary corresponding to the text representation of `Float` using fixed decimal point formatting. `Options` behaves in the same way as *`float_to_list/2`*. Examples:

```
> float_to_binary(7.12, [{decimals, 4}]).
<<"7.1200">>
> float_to_binary(7.12, [{decimals, 4}, compact]).
<<"7.12">>
```

`float_to_list(Float) -> string()`

Types:

```
Float = float()
```

The same as `float_to_list(Float,[{scientific,20}])`.

`float_to_list(Float, Options) -> string()`

Types:

```
Float = float()
Options = [Option]
Option =
    {decimals, Decimals :: 0..253} |
    {scientific, Decimals :: 0..249} |
    compact
```

Returns a string corresponding to the text representation of `Float` using fixed decimal point formatting.

Available options:

- If option `decimals` is specified, the returned value contains at most `Decimals` number of digits past the decimal point. If the number does not fit in the internal static buffer of 256 bytes, the function throws `badarg`.
- If option `compact` is specified, the trailing zeros at the end of the list are truncated. This option is only meaningful together with option `decimals`.
- If option `scientific` is specified, the float is formatted using scientific notation with `Decimals` digits of precision.
- If `Options` is `[]`, the function behaves as *`float_to_list/1`*.

Examples:

```
> float_to_list(7.12, [{decimals, 4}]).
"7.1200"
> float_to_list(7.12, [{decimals, 4}, compact]).
"7.12"
```

`floor(Number) -> integer()`

Types:

```
Number = number()
```

Returns the largest integer not greater than `Number`. For example:

```
> floor(-10.5).
-11
```

Allowed in guard tests.

`erlang:fun_info(Fun) -> [{Item, Info}]`

Types:

```
Fun = function()
Item =
    arity |
    env |
    index |
    name |
    module |
    new_index |
    new_uniq |
    pid |
    type |
    uniq
Info = term()
```

Returns a list with information about the fun `Fun`. Each list element is a tuple. The order of the tuples is undefined, and more tuples can be added in a future release.

Warning:

This BIF is mainly intended for debugging, but it can sometimes be useful in library functions that need to verify, for example, the arity of a fun.

Two types of funs have slightly different semantics:

- A fun created by `fun M:F/A` is called an **external** fun. Calling it will always call the function `F` with arity `A` in the latest code for module `M`. Notice that module `M` does not even need to be loaded when the fun `fun M:F/A` is created.
- All other funs are called **local**. When a local fun is called, the same version of the code that created the fun is called (even if a newer version of the module has been loaded).

The following elements are always present in the list for both local and external funs:

`{type, Type}`

`Type` is `local` or `external`.

`{module, Module}`

`Module` (an atom) is the module name.

If `Fun` is a local fun, `Module` is the module in which the fun is defined.

If `Fun` is an external fun, `Module` is the module that the fun refers to.

`{name, Name}`

`Name` (an atom) is a function name.

If `Fun` is a local fun, `Name` is the name of the local function that implements the fun. (This name was generated by the compiler, and is only of informational use. As it is a local function, it cannot be called directly.) If no code is currently loaded for the fun, `[]` is returned instead of an atom.

If `Fun` is an external fun, `Name` is the name of the exported function that the fun refers to.

`{arity, Arity}`

`Arity` is the number of arguments that the fun is to be called with.

`{env, Env}`

`Env` (a list) is the environment or free variables for the fun. For external funs, the returned list is always empty.

The following elements are only present in the list if `Fun` is local:

`{pid, Pid}`

`Pid` is the process identifier of the process that originally created the fun.

`{index, Index}`

`Index` (an integer) is an index into the module fun table.

`{new_index, Index}`

`Index` (an integer) is an index into the module fun table.

`{new_uniq, Uniq}`

`Uniq` (a binary) is a unique value for this fun. It is calculated from the compiled code for the entire module.

`{uniq, Uniq}`

`Uniq` (an integer) is a unique value for this fun. As from Erlang/OTP R15, this integer is calculated from the compiled code for the entire module. Before Erlang/OTP R15, this integer was based on only the body of the fun.

`erlang:fun_info(Fun, Item) -> {Item, Info}`

Types:

```
Fun = function()
Item = fun_info_item()
Info = term()
fun_info_item() =
    arity |
    env |
    index |
    name |
    module |
    new_index |
    new_uniq |
    pid |
    type |
    uniq
```

Returns information about `Fun` as specified by `Item`, in the form `{Item,Info}`.

For any fun, `Item` can be any of the atoms `module`, `name`, `arity`, `env`, or `type`.

For a local fun, `Item` can also be any of the atoms `index`, `new_index`, `new_uniq`, `uniq`, and `pid`. For an external fun, the value of any of these items is always the atom `undefined`.

See *`erlang:fun_info/1`*.

`erlang:fun_to_list(Fun) -> string()`

Types:

```
Fun = function()
```

Returns a string corresponding to the text representation of `Fun`.

`erlang:function_exported(Module, Function, Arity) -> boolean()`

Types:

```
Module = module()
Function = atom()
Arity = arity()
```

Returns `true` if the module `Module` is loaded and contains an exported function `Function/Arity`, or if there is a BIF (a built-in function implemented in C) with the specified name, otherwise returns `false`.

Note:

This function used to return `false` for BIFs before Erlang/OTP 18.0.

`garbage_collect() -> true`

Forces an immediate garbage collection of the executing process. The function is not to be used unless it has been noticed (or there are good reasons to suspect) that the spontaneous garbage collection will occur too late or not at all.

Warning:

Improper use can seriously degrade system performance.

`garbage_collect(Pid) -> GCResult`

Types:

```
Pid = pid()
GCResult = boolean()
```

The same as *`garbage_collect(Pid, [])`*.

`garbage_collect(Pid, OptionList) -> GCResult | async`

Types:

```
Pid = pid()
RequestId = term()
Option = {async, RequestId} | {type, major | minor}
OptionList = [Option]
GCResult = boolean()
```

Garbage collects the node local process identified by `Pid`.

`Option`:

`{async, RequestId}`

The function `garbage_collect/2` returns the value `async` immediately after the request has been sent. When the request has been processed, the process that called this function is passed a message on the form `{garbage_collect, RequestId, GCResult}`.

`{type, 'major' | 'minor'}`
: Triggers garbage collection of requested type. Default value is `'major'`, which would trigger a fullsweep GC. The option `'minor'` is considered a hint and may lead to either minor or major GC run.

If `Pid` equals `self()`, and no `async` option has been passed, the garbage collection is performed at once, that is, the same as calling *`garbage_collect/0`*. Otherwise a request for garbage collection is sent to the process identified by `Pid`, and will be handled when appropriate. If no `async` option has been passed, the caller blocks until `GCResult` is available and can be returned.

`GCResult` informs about the result of the garbage collection request as follows:

`true`
: The process identified by `Pid` has been garbage collected.

`false`
: No garbage collection was performed, as the process identified by `Pid` terminated before the request could be satisfied.

Notice that the same caveats apply as for *`garbage_collect/0`*.

Failures:

`badarg`
: If `Pid` is not a node local process identifier.

`badarg`
: If `OptionList` is an invalid list of options.

`get() -> [{Key, Val}]`

Types:

`Key = Val = term()`

Returns the process dictionary as a list of `{Key, Val}` tuples, for example:

```
> put(key1, merry),
put(key2, lambs),
put(key3, {are, playing}),
get().
[{key1,merry},{key2,lambs},{key3,{are,playing}}]
```

`get(Key) -> Val | undefined`

Types:

`Key = Val = term()`

Returns the value `Val` associated with `Key` in the process dictionary, or `undefined` if `Key` does not exist. Example:

```
> put(key1, merry),
put(key2, lambs),
put({any, [valid, term]}, {are, playing}),
get({any, [valid, term]}).
{are,playing}
```

`erlang:get_cookie() -> Cookie | nocookie`

Types:

`Cookie = atom()`

Returns the magic cookie of the local node if the node is alive, otherwise the atom `nocookie`.

`get_keys() -> [Key]`

Types:

```
Key = term()
```

Returns a list of all keys present in the process dictionary, for example:

```
> put(dog, {animal,1}),
put(cow, {animal,2}),
put(lamb, {animal,3}),
get_keys().
[dog,cow,lamb]
```

`get_keys(Val) -> [Key]`

Types:

```
Val = Key = term()
```

Returns a list of keys that are associated with the value `Val` in the process dictionary, for example:

```
> put(mary, {1, 2}),
put(had, {1, 2}),
put(a, {1, 2}),
put(little, {1, 2}),
put(dog, {1, 3}),
put(lamb, {1, 2}),
get_keys({1, 2}).
[mary,had,a,little,lamb]
```

`erlang:get_stacktrace() -> [`***`stack_item()`***`]`

Types:

```
stack_item() =
    {Module :: module(),
     Function :: atom(),
     Arity :: arity() | (Args :: [term()]),
     Location ::
         [{file, Filename :: string()} |
          {line, Line :: integer() >= 1}]}
```

Gets the call stack back-trace (**stacktrace**) for an exception that has just been caught in the calling process as a list of `{Module,Function,Arity,Location}` tuples. Field `Arity` in the first tuple can be the argument list of that function call instead of an arity integer, depending on the exception.

If there has not been any exceptions in a process, the stacktrace is `[]`. After a code change for the process, the stacktrace can also be reset to `[]`.

`erlang:get_stacktrace/0` is only guaranteed to return a stacktrace if called (directly or indirectly) from within the scope of a `try` expression. That is, the following call works:

```
try Expr
catch
  C:R ->
   {C,R,erlang:get_stacktrace()}
end
```

As does this call:

```
try Expr
catch
  C:R ->
   {C,R,helper()}
end

helper() ->
  erlang:get_stacktrace().
```

Warning:

In a future release, `erlang:get_stacktrace/0` will return `[]` if called from outside a `try` expression.

The stacktrace is the same data as operator `catch` returns, for example:

```
{'EXIT',{badarg,Stacktrace}} = catch abs(x)
```

`Location` is a (possibly empty) list of two-tuples that can indicate the location in the source code of the function. The first element is an atom describing the type of information in the second element. The following items can occur:

`file`
: The second element of the tuple is a string (list of characters) representing the filename of the source file of the function.

`line`
: The second element of the tuple is the line number (an integer > 0) in the source file where the exception occurred or the function was called.

See also *`error/1`* and *`error/2`*.

`group_leader() -> pid()`

Returns the process identifier of the group leader for the process evaluating the function.

Every process is a member of some process group and all groups have a **group leader**. All I/O from the group is channeled to the group leader. When a new process is spawned, it gets the same group leader as the spawning process. Initially, at system startup, `init` is both its own group leader and the group leader of all processes.

`group_leader(GroupLeader, Pid) -> true`

Types:

`GroupLeader = Pid = pid()`

Sets the group leader of `Pid` to `GroupLeader`. Typically, this is used when a process started from a certain shell is to have another group leader than `init`.

See also *`group_leader/0`*.

`halt() -> no_return()`

The same as *`halt(0, [])`*. Example:

```
> halt().
os_prompt%
```

`halt(Status) -> no_return()`

Types:

```
Status = integer() >= 0 | abort | string()
```

The same as *`halt(Status, [])`*. Example:

```
> halt(17).
os_prompt% echo $?
17
os_prompt%
```

`halt(Status, Options) -> no_return()`

Types:

```
Status = integer() >= 0 | abort | string()
Options = [Option]
Option = {flush, boolean()}
```

`Status` must be a non-negative integer, a string, or the atom `abort`. Halts the Erlang runtime system. Has no return value. Depending on `Status`, the following occurs:

integer()
: The runtime system exits with integer value `Status` as status code to the calling environment (OS).

> **Note:**
>
> On many platforms, the OS supports only status codes 0-255. A too large status code is truncated by clearing the high bits.

string()
: An Erlang crash dump is produced with `Status` as slogan. Then the runtime system exits with status code `1`. The string will be truncated if longer than 200 characters.

> **Note:**
>
> Before ERTS 9.1 (OTP-20.1) only code points in the range 0-255 was accepted in the string. Now any unicode string is valid.

`abort`
: The runtime system aborts producing a core dump, if that is enabled in the OS.

For integer `Status`, the Erlang runtime system closes all ports and allows async threads to finish their operations before exiting. To exit without such flushing, use `Option` as `{flush,false}`.

For statuses `string()` and `abort`, option `flush` is ignored and flushing is **not** done.

`hd(List) -> term()`

Types:

```
List = [term(), ...]
```

Returns the head of `List`, that is, the first element, for example:

```
> hd([1,2,3,4,5]).
1
```

Allowed in guard tests.

Failure: `badarg` if `List` is the empty list `[]`.

`erlang:hibernate(Module, Function, Args) -> no_return()`

Types:

```
Module = module()
Function = atom()
Args = [term()]
```

Puts the calling process into a wait state where its memory allocation has been reduced as much as possible. This is useful if the process does not expect to receive any messages soon.

The process is awaken when a message is sent to it, and control resumes in `Module:Function` with the arguments specified by `Args` with the call stack emptied, meaning that the process terminates when that function returns. Thus `erlang:hibernate/3` never returns to its caller.

If the process has any message in its message queue, the process is awakened immediately in the same way as described earlier.

In more technical terms, `erlang:hibernate/3` discards the call stack for the process, and then garbage collects the process. After this, all live data is in one continuous heap. The heap is then shrunken to the exact same size as the live data that it holds (even if that size is less than the minimum heap size for the process).

If the size of the live data in the process is less than the minimum heap size, the first garbage collection occurring after the process is awakened ensures that the heap size is changed to a size not smaller than the minimum heap size.

Notice that emptying the call stack means that any surrounding `catch` is removed and must be re-inserted after hibernation. One effect of this is that processes started using `proc_lib` (also indirectly, such as `gen_server` processes), are to use *`proc_lib:hibernate/3`* instead, to ensure that the exception handler continues to work when the process wakes up.

`erlang:insert_element(Index, Tuple1, Term) -> Tuple2`

Types:

```
Index = integer() >= 1
```

1..tuple_size(Tuple1) + 1

```
Tuple1 = Tuple2 = tuple()
Term = term()
```

Returns a new tuple with element `Term` inserted at position `Index` in tuple `Tuple1`. All elements from position `Index` and upwards are pushed one step higher in the new tuple `Tuple2`. Example:

```
> erlang:insert_element(2, {one, two, three}, new).
{one,new,two,three}
```

`integer_to_binary(Integer) -> binary()`

Types:

```
Integer = integer()
```

Returns a binary corresponding to the text representation of `Integer`, for example:

```
> integer_to_binary(77).
<<"77">>
```

`integer_to_binary(Integer, Base) -> binary()`

Types:

```
Integer = integer()
Base = 2..36
```

Returns a binary corresponding to the text representation of `Integer` in base `Base`, for example:

```
> integer_to_binary(1023, 16).
<<"3FF">>
```

`integer_to_list(Integer) -> string()`

Types:

```
Integer = integer()
```

Returns a string corresponding to the text representation of `Integer`, for example:

```
> integer_to_list(77).
"77"
```

`integer_to_list(Integer, Base) -> string()`

Types:

```
Integer = integer()
Base = 2..36
```

Returns a string corresponding to the text representation of `Integer` in base `Base`, for example:

```
> integer_to_list(1023, 16).
"3FF"
```

`iolist_size(Item) -> integer() >= 0`

Types:

```
Item = iolist() | binary()
```

Returns an integer, that is the size in bytes, of the binary that would be the result of `iolist_to_binary(Item)`, for example:

```
> iolist_size([1,2|<<3,4>>]).
4
```

`iolist_to_binary(IoListOrBinary) -> binary()`

Types:

```
IoListOrBinary = iolist() | binary()
```

Returns a binary that is made from the integers and binaries in `IoListOrBinary`, for example:

```
> Bin1 = <<1,2,3>>.
<<1,2,3>>
> Bin2 = <<4,5>>.
<<4,5>>
> Bin3 = <<6>>.
<<6>>
> iolist_to_binary([Bin1,1,[2,3,Bin2],4|Bin3]).
<<1,2,3,1,2,3,4,5,4,6>>
```

`erlang:iolist_to_iovec(IoListOrBinary) -> iovec()`

Types:

`IoListOrBinary = iolist() | binary()`

Returns an iovec that is made from the integers and binaries in `IoListOrBinary`.

`is_alive() -> boolean()`

Returns `true` if the local node is alive (that is, if the node can be part of a distributed system), otherwise `false`.

`is_atom(Term) -> boolean()`

Types:

`Term = term()`

Returns `true` if `Term` is an atom, otherwise `false`.

Allowed in guard tests.

`is_binary(Term) -> boolean()`

Types:

`Term = term()`

Returns `true` if `Term` is a binary, otherwise `false`.

A binary always contains a complete number of bytes.

Allowed in guard tests.

`is_bitstring(Term) -> boolean()`

Types:

`Term = term()`

Returns `true` if `Term` is a bitstring (including a binary), otherwise `false`.

Allowed in guard tests.

`is_boolean(Term) -> boolean()`

Types:

`Term = term()`

Returns `true` if `Term` is the atom `true` or the atom `false` (that is, a boolean). Otherwise returns `false`.

Allowed in guard tests.

`erlang:is_builtin(Module, Function, Arity) -> boolean()`

Types:

```
Module = module()
Function = atom()
Arity = arity()
```

This BIF is useful for builders of cross-reference tools.

Returns `true` if `Module:Function/Arity` is a BIF implemented in C, otherwise `false`.

`is_float(Term) -> boolean()`

Types:

```
Term = term()
```

Returns `true` if `Term` is a floating point number, otherwise `false`.

Allowed in guard tests.

`is_function(Term) -> boolean()`

Types:

```
Term = term()
```

Returns `true` if `Term` is a fun, otherwise `false`.

Allowed in guard tests.

`is_function(Term, Arity) -> boolean()`

Types:

```
Term = term()
Arity = arity()
```

Returns `true` if `Term` is a fun that can be applied with `Arity` number of arguments, otherwise `false`.

Allowed in guard tests.

`is_integer(Term) -> boolean()`

Types:

```
Term = term()
```

Returns `true` if `Term` is an integer, otherwise `false`.

Allowed in guard tests.

`is_list(Term) -> boolean()`

Types:

```
Term = term()
```

Returns `true` if `Term` is a list with zero or more elements, otherwise `false`.

Allowed in guard tests.

`is_map(Term) -> boolean()`

Types:

```
Term = term()
```

Returns `true` if `Term` is a map, otherwise `false`.

Allowed in guard tests.

`is_number(Term) -> boolean()`

Types:

```
Term = term()
```

Returns `true` if `Term` is an integer or a floating point number. Otherwise returns `false`.

Allowed in guard tests.

`is_pid(Term) -> boolean()`

Types:

```
Term = term()
```

Returns `true` if `Term` is a process identifier, otherwise `false`.

Allowed in guard tests.

`is_port(Term) -> boolean()`

Types:

```
Term = term()
```

Returns `true` if `Term` is a port identifier, otherwise `false`.

Allowed in guard tests.

`is_process_alive(Pid) -> boolean()`

Types:

```
Pid = pid()
```

`Pid` must refer to a process at the local node.

Returns `true` if the process exists and is alive, that is, is not exiting and has not exited. Otherwise returns `false`.

`is_record(Term, RecordTag) -> boolean()`

Types:

```
Term = term()
RecordTag = atom()
```

Returns `true` if `Term` is a tuple and its first element is `RecordTag`. Otherwise returns `false`.

Note:

Normally the compiler treats calls to `is_record/2` especially. It emits code to verify that `Term` is a tuple, that its first element is `RecordTag`, and that the size is correct. However, if `RecordTag` is not a literal atom, the BIF `is_record/2` is called instead and the size of the tuple is not verified.

Allowed in guard tests, if `RecordTag` is a literal atom.

`is_record(Term, RecordTag, Size) -> boolean()`

Types:

```
Term = term()
RecordTag = atom()
Size = integer() >= 0
```

`RecordTag` must be an atom.

Returns `true` if `Term` is a tuple, its first element is `RecordTag`, and its size is `Size`. Otherwise returns `false`.

Allowed in guard tests if `RecordTag` is a literal atom and `Size` is a literal integer.

Note:

This BIF is documented for completeness. Usually `is_record/2` is to be used.

`is_reference(Term) -> boolean()`

Types:

```
Term = term()
```

Returns `true` if `Term` is a reference, otherwise `false`.

Allowed in guard tests.

`is_tuple(Term) -> boolean()`

Types:

```
Term = term()
```

Returns `true` if `Term` is a tuple, otherwise `false`.

Allowed in guard tests.

`length(List) -> integer() >= 0`

Types:

```
List = [term()]
```

Returns the length of `List`, for example:

```
> length([1,2,3,4,5,6,7,8,9]).
9
```

Allowed in guard tests.

`link(PidOrPort) -> true`

Types:

```
PidOrPort = pid() | port()
```

Creates a link between the calling process and another process (or port) `PidOrPort`, if there is not such a link already. If a process attempts to create a link to itself, nothing is done. Returns `true`.

If `PidOrPort` does not exist, the behavior of the BIF depends on if the calling process is trapping exits or not (see *`process_flag/2`*):

- If the calling process is not trapping exits, and checking `PidOrPort` is cheap (that is, if `PidOrPort` is local), `link/1` fails with reason `noproc`.
- Otherwise, if the calling process is trapping exits, and/or `PidOrPort` is remote, `link/1` returns `true`, but an exit signal with reason `noproc` is sent to the calling process.

`list_to_atom(String) -> atom()`

Types:

```
String = string()
```

Returns the atom whose text representation is `String`.

As from Erlang/OTP 20, `String` may contain any Unicode character. Earlier versions allowed only ISO-latin-1 characters as the implementation did not allow Unicode characters above 255. For more information on Unicode support in atoms, see *note on UTF-8 encoded atoms* in section "External Term Format" in the User's Guide.

Example:

```
> list_to_atom("Erlang").
'Erlang'
```

`list_to_binary(IoList) -> binary()`

Types:

```
IoList = iolist()
```

Returns a binary that is made from the integers and binaries in `IoList`, for example:

```
> Bin1 = <<1,2,3>>.
<<1,2,3>>
> Bin2 = <<4,5>>.
<<4,5>>
> Bin3 = <<6>>.
<<6>>
> list_to_binary([Bin1,1,[2,3,Bin2],4|Bin3]).
<<1,2,3,1,2,3,4,5,4,6>>
```

`list_to_bitstring(BitstringList) -> bitstring()`

Types:

```
BitstringList = bitstring_list()
bitstring_list() =
    maybe_improper_list(byte() | bitstring() | bitstring_list(),
                        bitstring() | [])
```

Returns a bitstring that is made from the integers and bitstrings in `BitstringList`. (The last tail in `BitstringList` is allowed to be a bitstring.) Example:

```
> Bin1 = <<1,2,3>>.
<<1,2,3>>
> Bin2 = <<4,5>>.
<<4,5>>
> Bin3 = <<6,7:4>>.
<<6,7:4>>
> list_to_bitstring([Bin1,1,[2,3,Bin2],4|Bin3]).
<<1,2,3,1,2,3,4,5,4,6,7:4>>
```

`list_to_existing_atom(String) -> atom()`

Types:

```
String = string()
```

Returns the atom whose text representation is `String`, but only if there already exists such atom.

Failure: `badarg` if there does not already exist an atom whose text representation is `String`.

Note:

Note that the compiler may optimize away atoms. For example, the compiler will rewrite `atom_to_list(some_atom)` to `"some_atom"`. If that expression is the only mention of the atom `some_atom` in the containing module, the atom will not be created when the module is loaded, and a subsequent call to `list_to_existing_atom("some_atom")` will fail.

`list_to_float(String) -> float()`

Types:

```
String = string()
```

Returns the float whose text representation is `String`, for example:

```
> list_to_float("2.2017764e+0").
2.2017764
```

Failure: `badarg` if `String` contains a bad representation of a float.

`list_to_integer(String) -> integer()`

Types:

```
String = string()
```

Returns an integer whose text representation is `String`, for example:

```
> list_to_integer("123").
123
```

Failure: `badarg` if `String` contains a bad representation of an integer.

`list_to_integer(String, Base) -> integer()`

Types:

```
String = string()
Base = 2..36
```

Returns an integer whose text representation in base `Base` is `String`, for example:

```
> list_to_integer("3FF", 16).
1023
```

Failure: `badarg` if `String` contains a bad representation of an integer.

`list_to_pid(String) -> pid()`

Types:

```
String = string()
```

Returns a process identifier whose text representation is a `String`, for example:

```
> list_to_pid("<0.4.1>").
<0.4.1>
```

Failure: `badarg` if `String` contains a bad representation of a process identifier.

Warning:

This BIF is intended for debugging and is not to be used in application programs.

`list_to_port(String) -> port()`

Types:

```
String = string()
```

Returns a port identifier whose text representation is a `String`, for example:

```
> list_to_port("#Port<0.4>").
#Port<0.4>
```

Failure: `badarg` if `String` contains a bad representation of a port identifier.

Warning:

This BIF is intended for debugging and is not to be used in application programs.

`list_to_ref(String) -> reference()`

Types:

```
String = string()
```

Returns a reference whose text representation is a `String`, for example:

```
> list_to_ref("#Ref<0.4192537678.4073193475.71181>").
#Ref<0.4192537678.4073193475.71181>
```

Failure: `badarg` if `String` contains a bad representation of a reference.

Warning:

This BIF is intended for debugging and is not to be used in application programs.

`list_to_tuple(List) -> tuple()`

Types:

```
List = [term()]
```

Returns a tuple corresponding to `List`, for example

```
> list_to_tuple([share, ['Ericsson_B', 163]]).
{share, ['Ericsson_B', 163]}
```

`List` can contain any Erlang terms.

`load_module(Module, Binary) -> {module, Module} | {error, Reason}`

Types:

```
Module = module()
Binary = binary()
Reason = badfile | not_purged | on_load
```

If `Binary` contains the object code for module `Module`, this BIF loads that object code. If the code for module `Module` already exists, all export references are replaced so they point to the newly loaded code. The previously loaded code is kept in the system as old code, as there can still be processes executing that code.

Returns either `{module, Module}`, or `{error, Reason}` if loading fails. `Reason` is one of the following:

`badfile`
: The object code in `Binary` has an incorrect format **or** the object code contains code for another module than `Module`.

`not_purged`
: `Binary` contains a module that cannot be loaded because old code for this module already exists.

Warning:

This BIF is intended for the code server (see *`code(3)`*) and is not to be used elsewhere.

`erlang:load_nif(Path, LoadInfo) -> ok | Error`

Types:

```
Path = string()
LoadInfo = term()
Error = {error, {Reason, Text :: string()}}
Reason =
    load_failed | bad_lib | load | reload | upgrade | old_code
```

Loads and links a dynamic library containing native implemented functions (NIFs) for a module. `Path` is a file path to the shareable object/dynamic library file minus the OS-dependent file extension (`.so` for Unix and `.dll` for Windows). Notice that on most OSs the library has to have a different name on disc when an upgrade of the nif is done. If the name is the same, but the contents differ, the old library may be loaded instead. For information on how to implement a NIF library, see *`erl_nif(3)`*.

`LoadInfo` can be any term. It is passed on to the library as part of the initialization. A good practice is to include a module version number to support future code upgrade scenarios.

The call to `load_nif/2` must be made **directly** from the Erlang code of the module that the NIF library belongs to. It returns either `ok`, or `{error,{Reason,Text}}` if loading fails. `Reason` is one of the following atoms while `Text` is a human readable string that can give more information about the failure:

`load_failed`
: The OS failed to load the NIF library.

`bad_lib`
: The library did not fulfill the requirements as a NIF library of the calling module.

`load | upgrade`
: The corresponding library callback was unsuccessful.

`reload`
: A NIF library is already loaded for this module instance. The previously deprecated `reload` feature was removed in OTP 20.

`old_code`
: The call to `load_nif/2` was made from the old code of a module that has been upgraded; this is not allowed.

`notsup`
: Lack of support. Such as loading NIF library for a HiPE compiled module.

`erlang:loaded() -> [Module]`

Types:

`Module = module()`

Returns a list of all loaded Erlang modules (current and old code), including preloaded modules.

See also *`code(3)`*.

`erlang:localtime() -> DateTime`

Types:

`DateTime =` ***`calendar:datetime()`***

Returns the current local date and time, `{{Year, Month, Day}, {Hour, Minute, Second}}`, for example:

```
> erlang:localtime().
{{1996,11,6},{14,45,17}}
```

The time zone and Daylight Saving Time correction depend on the underlying OS.

`erlang:localtime_to_universaltime(Localtime) -> Universaltime`

Types:

`Localtime = Universaltime =` ***`calendar:datetime()`***

Converts local date and time to Universal Time Coordinated (UTC), if supported by the underlying OS. Otherwise no conversion is done and `Localtime` is returned. Example:

```
> erlang:localtime_to_universaltime({{1996,11,6},{14,45,17}}).
{{1996,11,6},{13,45,17}}
```

Failure: `badarg` if `Localtime` denotes an invalid date and time.

`erlang:localtime_to_universaltime(Localtime, IsDst) -> Universaltime`

Types:

`Localtime = Universaltime =` ***`calendar:datetime()`***
`IsDst = true | false | undefined`

Converts local date and time to Universal Time Coordinated (UTC) as `erlang:localtime_to_universaltime/1`, but the caller decides if Daylight Saving Time is active.

If `IsDst == true`, `Localtime` is during Daylight Saving Time, if `IsDst == false` it is not. If `IsDst == undefined`, the underlying OS can guess, which is the same as calling `erlang:localtime_to_universaltime(Localtime)`.

Examples:

```
> erlang:localtime_to_universaltime({{1996,11,6},{14,45,17}}, true).
{{1996,11,6},{12,45,17}}
> erlang:localtime_to_universaltime({{1996,11,6},{14,45,17}}, false).
{{1996,11,6},{13,45,17}}
> erlang:localtime_to_universaltime({{1996,11,6},{14,45,17}}, undefined).
{{1996,11,6},{13,45,17}}
```

Failure: `badarg` if `Localtime` denotes an invalid date and time.

`make_ref() -> reference()`

Returns a *unique reference*. The reference is unique among connected nodes.

Warning:

Known issue: When a node is restarted multiple times with the same node name, references created on a newer node can be mistaken for a reference created on an older node with the same node name.

`erlang:make_tuple(Arity, InitialValue) -> tuple()`

Types:

```
Arity = arity()
InitialValue = term()
```

Creates a new tuple of the specified `Arity`, where all elements are `InitialValue`, for example:

```
> erlang:make_tuple(4, []).
{[],[],[],[]}
```

`erlang:make_tuple(Arity, DefaultValue, InitList) -> tuple()`

Types:

```
Arity = arity()
DefaultValue = term()
InitList = [{Position :: integer() >= 1, term()}]
```

Creates a tuple of size `Arity`, where each element has value `DefaultValue`, and then fills in values from `InitList`. Each list element in `InitList` must be a two-tuple, where the first element is a position in the newly created tuple and the second element is any term. If a position occurs more than once in the list, the term corresponding to the last occurrence is used. Example:

```
> erlang:make_tuple(5, [], [{2,ignored},{5,zz},{2,aa}]).
{[],aa,[],[],zz}
```

`map_size(Map) -> integer() >= 0`

Types:

```
Map = map()
```

Returns an integer, which is the number of key-value pairs in `Map`, for example:

```
> map_size(#{a=>1, b=>2, c=>3}).
3
```

Allowed in guard tests.

```
erlang:match_spec_test(MatchAgainst, MatchSpec, Type) ->
                          TestResult
```

Types:

```
MatchAgainst = [term()] | tuple()
MatchSpec = term()
Type = table | trace
TestResult =
    {ok, term(), [return_trace], [{error | warning, string()}]} |
    {error, [{error | warning, string()}]}
```

Tests a match specification used in calls to *`ets:select/2`* and *`erlang:trace_pattern/3`*. The function tests both a match specification for "syntactic" correctness and runs the match specification against the object. If the match specification contains errors, the tuple `{error, Errors}` is returned, where `Errors` is a list of natural language descriptions of what was wrong with the match specification.

If `Type` is `table`, the object to match against is to be a tuple. The function then returns `{ok,Result,[],Warnings}`, where `Result` is what would have been the result in a real `ets:select/2` call, or `false` if the match specification does not match the object tuple.

If `Type` is `trace`, the object to match against is to be a list. The function returns `{ok, Result, Flags, Warnings}`, where `Result` is one of the following:

- `true` if a trace message is to be emitted
- `false` if a trace message is not to be emitted
- The message term to be appended to the trace message

`Flags` is a list containing all the trace flags to be enabled, currently this is only `return_trace`.

This is a useful debugging and test tool, especially when writing complicated match specifications.

See also *`ets:test_ms/2`*.

```
max(Term1, Term2) -> Maximum
```

Types:

```
Term1 = Term2 = Maximum = term()
```

Returns the largest of `Term1` and `Term2`. If the terms are equal, `Term1` is returned.

```
erlang:md5(Data) -> Digest
```

Types:

```
Data = iodata()
Digest = binary()
```

Computes an MD5 message digest from `Data`, where the length of the digest is 128 bits (16 bytes). `Data` is a binary or a list of small integers and binaries.

For more information about MD5, see **RFC 1321 - The MD5 Message-Digest Algorithm**.

Warning:

The MD5 Message-Digest Algorithm is **not** considered safe for code-signing or software-integrity purposes.

`erlang:md5_final(Context) -> Digest`

Types:

```
Context = Digest = binary()
```

Finishes the update of an MD5 `Context` and returns the computed `MD5` message digest.

`erlang:md5_init() -> Context`

Types:

```
Context = binary()
```

Creates an MD5 context, to be used in the following calls to `md5_update/2`.

`erlang:md5_update(Context, Data) -> NewContext`

Types:

```
Context = binary()
Data = iodata()
NewContext = binary()
```

Update an MD5 `Context` with `Data` and returns a `NewContext`.

`erlang:memory() -> [{Type, Size}]`

Types:

```
Type = memory_type()
Size = integer() >= 0
memory_type() =
    total |
    processes |
    processes_used |
    system |
    atom |
    atom_used |
    binary |
    code |
    ets |
    low |
    maximum
```

Returns a list with information about memory dynamically allocated by the Erlang emulator. Each list element is a tuple `{Type, Size}`. The first element `Type` is an atom describing memory type. The second element `Size` is the memory size in bytes.

Memory types:

`total`

The total amount of memory currently allocated. This is the same as the sum of the memory size for `processes` and `system`.

`processes`

The total amount of memory currently allocated for the Erlang processes.

`processes_used`

The total amount of memory currently used by the Erlang processes. This is part of the memory presented as `processes` memory.

`system`

The total amount of memory currently allocated for the emulator that is not directly related to any Erlang process. Memory presented as `processes` is not included in this memory. *`instrument(3)`* can be used to get a more detailed breakdown of what memory is part of this type.

`atom`

The total amount of memory currently allocated for atoms. This memory is part of the memory presented as `system` memory.

`atom_used`

The total amount of memory currently used for atoms. This memory is part of the memory presented as `atom` memory.

`binary`

The total amount of memory currently allocated for binaries. This memory is part of the memory presented as `system` memory.

`code`

The total amount of memory currently allocated for Erlang code. This memory is part of the memory presented as `system` memory.

`ets`

The total amount of memory currently allocated for ETS tables. This memory is part of the memory presented as `system` memory.

`low`

Only on 64-bit halfword emulator. The total amount of memory allocated in low memory areas that are restricted to < 4 GB, although the system can have more memory.

Can be removed in a future release of the halfword emulator.

`maximum`

The maximum total amount of memory allocated since the emulator was started. This tuple is only present when the emulator is run with instrumentation.

For information on how to run the emulator with instrumentation, see *`instrument(3)`* and/or *`erl(1)`*.

Note:

The `system` value is not complete. Some allocated memory that is to be part of this value is not.

When the emulator is run with instrumentation, the `system` value is more accurate, but memory directly allocated for `malloc` (and friends) is still not part of the `system` value. Direct calls to `malloc` are only done from OS-specific runtime libraries and perhaps from user-implemented Erlang drivers that do not use the memory allocation functions in the driver interface.

As the `total` value is the sum of `processes` and `system`, the error in `system` propagates to the `total` value.

The different amounts of memory that are summed are **not** gathered atomically, which introduces an error in the result.

The different values have the following relation to each other. Values beginning with an uppercase letter is not part of the result.

```
total      = processes + system
processes  = processes_used + ProcessesNotUsed
system     = atom + binary + code + ets + OtherSystem
atom       = atom_used + AtomNotUsed
RealTotal  = processes + RealSystem
RealSystem = system + MissedSystem
```

More tuples in the returned list can be added in a future release.

Note:

The `total` value is supposed to be the total amount of memory dynamically allocated by the emulator. Shared libraries, the code of the emulator itself, and the emulator stacks are not supposed to be included. That is, the `total` value is **not** supposed to be equal to the total size of all pages mapped to the emulator.

Also, because of fragmentation and prereservation of memory areas, the size of the memory segments containing the dynamically allocated memory blocks can be much larger than the total size of the dynamically allocated memory blocks.

Note:

As from ERTS 5.6.4, `erlang:memory/0` requires that all *`erts_alloc(3)`* allocators are enabled (default behavior).

Failure: `notsup` if an *`erts_alloc(3)`* allocator has been disabled.

```
erlang:memory(Type :: memory_type()) -> integer() >= 0
erlang:memory(TypeList :: [memory_type()]) ->
                 [{memory_type(), integer() >= 0}]
```

Types:

```
memory_type() =
    total |
    processes |
    processes_used |
    system |
    atom |
    atom_used |
```

```
binary |
code |
ets |
low |
maximum
```

Returns the memory size in bytes allocated for memory of type `Type`. The argument can also be specified as a list of `memory_type()` atoms, in which case a corresponding list of `{memory_type(), Size :: integer >= 0}` tuples is returned.

Note:

As from ERTS 5.6.4, `erlang:memory/1` requires that all *`erts_alloc(3)`* allocators are enabled (default behavior).

Failures:

`badarg`
: If `Type` is not one of the memory types listed in the description of *`erlang:memory/0`*.

`badarg`
: If `maximum` is passed as `Type` and the emulator is not run in instrumented mode.

`notsup`
: If an *`erts_alloc(3)`* allocator has been disabled.

See also *`erlang:memory/0`*.

```
min(Term1, Term2) -> Minimum
```

Types:

```
Term1 = Term2 = Minimum = term()
```

Returns the smallest of `Term1` and `Term2`. If the terms are equal, `Term1` is returned.

```
module_loaded(Module) -> boolean()
```

Types:

```
Module = module()
```

Returns `true` if the module `Module` is loaded, otherwise `false`. It does not attempt to load the module.

Warning:

This BIF is intended for the code server (see *`code(3)`*) and is not to be used elsewhere.

```
monitor(Type :: process, Item :: monitor_process_identifier()) ->
           MonitorRef
monitor(Type :: port, Item :: monitor_port_identifier()) ->
           MonitorRef
monitor(Type :: time_offset, Item :: clock_service) -> MonitorRef
```

Types:

```
MonitorRef = reference()
registered_name() = atom()
registered_process_identifier() =
```

```
    registered_name() | {registered_name(), node()}
monitor_process_identifier() =
    pid() | registered_process_identifier()
monitor_port_identifier() = port() | registered_name()
```

Sends a monitor request of type `Type` to the entity identified by `Item`. If the monitored entity does not exist or it changes monitored state, the caller of `monitor/2` is notified by a message on the following format:

```
{Tag, MonitorRef, Type, Object, Info}
```

Note:

The monitor request is an asynchronous signal. That is, it takes time before the signal reaches its destination.

`Type` can be one of the following atoms: `process`, `port` or `time_offset`.

A `process` or `port` monitor is triggered only once, after that it is removed from both monitoring process and the monitored entity. Monitors are fired when the monitored process or port terminates, does not exist at the moment of creation, or if the connection to it is lost. If the connection to it is lost, we do not know if it still exists. The monitoring is also turned off when *demonitor/1* is called.

A `process` or `port` monitor by name resolves the `RegisteredName` to `pid()` or `port()` only once at the moment of monitor instantiation, later changes to the name registration will not affect the existing monitor.

When a `process` or `port` monitor is triggered, a `'DOWN'` message is sent that has the following pattern:

```
{'DOWN', MonitorRef, Type, Object, Info}
```

In the monitor message `MonitorRef` and `Type` are the same as described earlier, and:

`Object`

The monitored entity, which triggered the event. When monitoring a local process or port, `Object` will be equal to the `pid()` or `port()` that was being monitored. When monitoring process or port by name, `Object` will have format `{RegisteredName, Node}` where `RegisteredName` is the name which has been used with `monitor/2` call and `Node` is local or remote node name (for ports monitored by name, `Node` is always local node name).

`Info`

Either the exit reason of the process, `noproc` (process or port did not exist at the time of monitor creation), or `noconnection` (no connection to the node where the monitored process resides).

If an attempt is made to monitor a process on an older node (where remote process monitoring is not implemented or where remote process monitoring by registered name is not implemented), the call fails with `badarg`.

Note:

The format of the `'DOWN'` message changed in ERTS 5.2 (Erlang/OTP R9B) for monitoring **by registered name**. Element `Object` of the `'DOWN'` message could in earlier versions sometimes be the process identifier of the monitored process and sometimes be the registered name. Now element `Object` is always a tuple consisting of the registered name and the node name. Processes on new nodes (ERTS 5.2 or higher versions) always get `'DOWN'` messages on the new format even if they are monitoring processes on old nodes. Processes on old nodes always get `'DOWN'` messages on the old format.

Monitoring a `process`

Creates monitor between the current process and another process identified by `Item`, which can be a `pid()` (local or remote), an atom `RegisteredName` or a tuple `{RegisteredName, Node}` for a registered process, located elsewhere.

Monitoring a `port`

Creates monitor between the current process and a port identified by `Item`, which can be a `port()` (only local), an atom `RegisteredName` or a tuple `{RegisteredName, Node}` for a registered port, located on this node. Note, that attempt to monitor a remote port will result in `badarg`.

Monitoring a `time_offset`

Monitors changes in *`time offset`* between *Erlang monotonic time* and *Erlang system time*. One valid `Item` exists in combination with the `time_offset Type`, namely the atom `clock_service`. Notice that the atom `clock_service` is **not** the registered name of a process. In this case it serves as an identifier of the runtime system internal clock service at current runtime system instance.

The monitor is triggered when the time offset is changed. This either if the time offset value is changed, or if the offset is changed from preliminary to final during *finalization of the time offset* when the *single time warp mode* is used. When a change from preliminary to final time offset is made, the monitor is triggered once regardless of whether the time offset value was changed or not.

If the runtime system is in *multi time warp mode*, the time offset is changed when the runtime system detects that the *OS system time* has changed. The runtime system does, however, not detect this immediately when it occurs. A task checking the time offset is scheduled to execute at least once a minute, so under normal operation this is to be detected within a minute, but during heavy load it can take longer time.

The monitor is **not** automatically removed after it has been triggered. That is, repeated changes of the time offset trigger the monitor repeatedly.

When the monitor is triggered a `'CHANGE'` message is sent to the monitoring process. A `'CHANGE'` message has the following pattern:

```
{'CHANGE', MonitorRef, Type, Item, NewTimeOffset}
```

where `MonitorRef`, `Type`, and `Item` are the same as described above, and `NewTimeOffset` is the new time offset.

When the `'CHANGE'` message has been received you are guaranteed not to retrieve the old time offset when calling *`erlang:time_offset()`*. Notice that you can observe the change of the time offset when calling `erlang:time_offset()` before you get the `'CHANGE'` message.

Making several calls to `monitor/2` for the same `Item` and/or `Type` is not an error; it results in as many independent monitoring instances.

The monitor functionality is expected to be extended. That is, other `Type`s and `Item`s are expected to be supported in a future release.

Note:

If or when `monitor/2` is extended, other possible values for `Tag`, `Object`, and `Info` in the monitor message will be introduced.

`monitor_node(Node, Flag) -> true`

Types:

```
Node = node()
Flag = boolean()
```

Monitor the status of the node `Node`. If `Flag` is `true`, monitoring is turned on. If `Flag` is `false`, monitoring is turned off.

Making several calls to `monitor_node(Node, true)` for the same `Node` is not an error; it results in as many independent monitoring instances.

If `Node` fails or does not exist, the message `{nodedown, Node}` is delivered to the process. If a process has made two calls to `monitor_node(Node, true)` and `Node` terminates, two `nodedown` messages are delivered to the process. If there is no connection to `Node`, an attempt is made to create one. If this fails, a `nodedown` message is delivered.

Nodes connected through hidden connections can be monitored as any other nodes.

Failure: `badarg` if the local node is not alive.

`erlang:monitor_node(Node, Flag, Options) -> true`

Types:

```
Node = node()
Flag = boolean()
Options = [Option]
Option = allow_passive_connect
```

Behaves as *`monitor_node/2`* except that it allows an extra option to be specified, namely `allow_passive_connect`. This option allows the BIF to wait the normal network connection time-out for the **monitored node** to connect itself, even if it cannot be actively connected from this node (that is, it is blocked). The state where this can be useful can only be achieved by using the Kernel option `dist_auto_connect once`. If that option is not used, option `allow_passive_connect` has no effect.

Note:

Option `allow_passive_connect` is used internally and is seldom needed in applications where the network topology and the Kernel options in effect are known in advance.

Failure: `badarg` if the local node is not alive or the option list is malformed.

`erlang:monotonic_time() -> integer()`

Returns the current *Erlang monotonic time* in `native` *time unit*. This is a monotonically increasing time since some unspecified point in time.

Note:

This is a *monotonically increasing* time, but **not** a *strictly monotonically increasing* time. That is, consecutive calls to `erlang:monotonic_time/0` can produce the same result.

Different runtime system instances will use different unspecified points in time as base for their Erlang monotonic clocks. That is, it is **pointless** comparing monotonic times from different runtime system instances. Different runtime system instances can also place this unspecified point in time different relative runtime system start. It can be placed in the future (time at start is a negative value), the past (time at start is a positive value), or the runtime system start (time at start is zero). The monotonic time at runtime system start can be retrieved by calling *`erlang:system_info(start_time)`*.

`erlang:monotonic_time(Unit) -> integer()`

Types:

```
Unit = time_unit()
```

Returns the current *Erlang monotonic time* converted into the `Unit` passed as argument.

Same as calling `erlang:convert_time_unit( erlang:monotonic_time(), native, Unit)`, however optimized for commonly used `Units`.

`erlang:nif_error(Reason) -> no_return()`

Types:

```
Reason = term()
```

Works exactly like `error/1`, but Dialyzer thinks that this BIF will return an arbitrary term. When used in a stub function for a NIF to generate an exception when the NIF library is not loaded, Dialyzer does not generate false warnings.

`erlang:nif_error(Reason, Args) -> no_return()`

Types:

```
Reason = term()
Args = [term()]
```

Works exactly like `error/2`, but Dialyzer thinks that this BIF will return an arbitrary term. When used in a stub function for a NIF to generate an exception when the NIF library is not loaded, Dialyzer does not generate false warnings.

`node() -> Node`

Types:

```
Node = node()
```

Returns the name of the local node. If the node is not alive, `nonode@nohost` is returned instead.

Allowed in guard tests.

`node(Arg) -> Node`

Types:

```
Arg = pid() | port() | reference()
Node = node()
```

Returns the node where `Arg` originates. `Arg` can be a process identifier, a reference, or a port. If the local node is not alive, `nonode@nohost` is returned.

Allowed in guard tests.

`nodes() -> Nodes`

Types:

```
Nodes = [node()]
```

Returns a list of all visible nodes in the system, except the local node. Same as `nodes(visible)`.

`nodes(Arg) -> Nodes`

Types:

```
Arg = NodeType | [NodeType]
NodeType = visible | hidden | connected | this | known
Nodes = [node()]
```

Returns a list of nodes according to the argument specified. The returned result, when the argument is a list, is the list of nodes satisfying the disjunction(s) of the list elements.

`NodeTypes`:

`visible`

Nodes connected to this node through normal connections.

`hidden`

Nodes connected to this node through hidden connections.

`connected`

All nodes connected to this node.

`this`

This node.

`known`

Nodes that are known to this node. That is, connected nodes and nodes referred to by process identifiers, port identifiers, and references located on this node. The set of known nodes is garbage collected. Notice that this garbage collection can be delayed. For more information, see *`erlang:system_info(delayed_node_table_gc)`*.

Some equalities: `[node()] = nodes(this)`, `nodes(connected) = nodes([visible, hidden])`, and `nodes() = nodes(visible)`.

`now() -> Timestamp`

Types:

```
Timestamp = timestamp()
timestamp() =
    {MegaSecs :: integer() >= 0,
     Secs :: integer() >= 0,
     MicroSecs :: integer() >= 0}
```

Warning:

This function is deprecated. Do not use it.

For more information, see section *Time and Time Correction* in the User's Guide. Specifically, section *Dos and Dont's* describes what to use instead of `erlang:now/0`.

Returns the tuple `{MegaSecs, Secs, MicroSecs}`, which is the elapsed time since 00:00 GMT, January 1, 1970 (zero hour), if provided by the underlying OS. Otherwise some other point in time is chosen. It is also guaranteed that the following calls to this BIF return continuously increasing values. Hence, the return value from `erlang:now/0` can be used to generate unique time stamps. If it is called in a tight loop on a fast machine, the time of the node can become skewed.

Can only be used to check the local time of day if the time-zone information of the underlying OS is properly configured.

```
open_port(PortName, PortSettings) -> port()
```

Types:

```
PortName =
    {spawn, Command :: string() | binary()} |
    {spawn_driver, Command :: string() | binary()} |
    {spawn_executable, FileName :: file:name()} |
    {fd, In :: integer() >= 0, Out :: integer() >= 0}
PortSettings = [Opt]
Opt =
    {packet, N :: 1 | 2 | 4} |
    stream |
    {line, L :: integer() >= 0} |
    {cd, Dir :: string() | binary()} |
    {env, Env :: [{Name :: string(), Val :: string() | false}]} |
    {args, [string() | binary()]} |
    {arg0, string() | binary()} |
    exit_status |
    use_stdio |
    nouse_stdio |
    stderr_to_stdout |
    in |
    out |
    binary |
    eof |
    {parallelism, Boolean :: boolean()} |
    hide
```

Returns a port identifier as the result of opening a new Erlang port. A port can be seen as an external Erlang process.

The name of the executable as well as the arguments specifed in `cd`, `env`, `args`, and `arg0` are subject to Unicode filename translation if the system is running in Unicode filename mode. To avoid translation or to force, for example UTF-8, supply the executable and/or arguments as a binary in the correct encoding. For details, see the module *`file(3)`*, the function *`file:native_name_encoding/0`* in Kernel, and the *`Using Unicode in Erlang`* User's Guide.

> **Note:**
>
> The characters in the name (if specified as a list) can only be > 255 if the Erlang virtual machine is started in Unicode filename translation mode. Otherwise the name of the executable is limited to the ISO Latin-1 character set.

`PortNames`:

`{spawn, Command}`

Starts an external program. `Command` is the name of the external program to be run. `Command` runs outside the Erlang work space unless an Erlang driver with the name `Command` is found. If found, that driver is started. A driver runs in the Erlang work space, which means that it is linked with the Erlang runtime system.

When starting external programs on Solaris, the system call `vfork` is used in preference to `fork` for performance reasons, although it has a history of being less robust. If there are problems using `vfork`, setting environment variable `ERL_NO_VFORK` to any value causes `fork` to be used instead.

For external programs, `PATH` is searched (or an equivalent method is used to find programs, depending on the OS). This is done by invoking the shell on certain platforms. The first space-separated token of the command is considered as the name of the executable (or driver). This (among other things) makes this option unsuitable for

running programs with spaces in filenames or directory names. If spaces in executable filenames are desired, use `{spawn_executable, Command}` instead.

`{spawn_driver, Command}`

Works like `{spawn, Command}`, but demands the first (space-separated) token of the command to be the name of a loaded driver. If no driver with that name is loaded, a `badarg` error is raised.

`{spawn_executable, FileName}`

Works like `{spawn, FileName}`, but only runs external executables. `FileName` in its whole is used as the name of the executable, including any spaces. If arguments are to be passed, the `PortSettings` `args` and `arg0` can be used.

The shell is usually not invoked to start the program, it is executed directly. `PATH` (or equivalent) is not searched. To find a program in `PATH` to execute, use *`os:find_executable/1`*.

Only if a shell script or `.bat` file is executed, the appropriate command interpreter is invoked implicitly, but there is still no command-argument expansion or implicit `PATH` search.

If `FileName` cannot be run, an error exception is raised, with the POSIX error code as the reason. The error reason can differ between OSs. Typically the error `enoent` is raised when an attempt is made to run a program that is not found and `eacces` is raised when the specified file is not executable.

`{fd, In, Out}`

Allows an Erlang process to access any currently opened file descriptors used by Erlang. The file descriptor `In` can be used for standard input, and the file descriptor `Out` for standard output. It is only used for various servers in the Erlang OS (`shell` and `user`). Hence, its use is limited.

`PortSettings` is a list of settings for the port. The valid settings are as follows:

`{packet, N}`

Messages are preceded by their length, sent in `N` bytes, with the most significant byte first. The valid values for `N` are 1, 2, and 4.

`stream`

Output messages are sent without packet lengths. A user-defined protocol must be used between the Erlang process and the external object.

`{line, L}`

Messages are delivered on a per line basis. Each line (delimited by the OS-dependent newline sequence) is delivered in a single message. The message data format is `{Flag, Line}`, where `Flag` is `eol` or `noeol`, and `Line` is the data delivered (without the newline sequence).

`L` specifies the maximum line length in bytes. Lines longer than this are delivered in more than one message, with `Flag` set to `noeol` for all but the last message. If end of file is encountered anywhere else than immediately following a newline sequence, the last line is also delivered with `Flag` set to `noeol`. Otherwise lines are delivered with `Flag` set to `eol`.

The `{packet, N}` and `{line, L}` settings are mutually exclusive.

`{cd, Dir}`

Only valid for `{spawn, Command}` and `{spawn_executable, FileName}`. The external program starts using `Dir` as its working directory. `Dir` must be a string.

`{env, Env}`

Only valid for `{spawn, Command}`, and `{spawn_executable, FileName}`. The environment of the started process is extended using the environment specifications in `Env`.

`Env` is to be a list of tuples `{Name, Val}`, where `Name` is the name of an environment variable, and `Val` is the value it is to have in the spawned port process. Both `Name` and `Val` must be strings. The one exception is `Val` being the atom `false` (in analogy with *`os:getenv/1`*, which removes the environment variable.

`{args, [ string() | binary() ]}`

Only valid for `{spawn_executable, FileName}` and specifies arguments to the executable. Each argument is specified as a separate string and (on Unix) eventually ends up as one element each in the argument vector. On other platforms, a similar behavior is mimicked.

The arguments are not expanded by the shell before they are supplied to the executable. Most notably this means that file wildcard expansion does not occur. To expand wildcards for the arguments, use *`filelib:wildcard/1`*. Notice that even if the program is a Unix shell script, meaning that the shell ultimately is invoked, wildcard expansion does not occur, and the script is provided with the untouched arguments. On Windows, wildcard expansion is always up to the program itself, therefore this is not an issue.

The executable name (also known as `argv[0]`) is not to be specified in this list. The proper executable name is automatically used as `argv[0]`, where applicable.

If you explicitly want to set the program name in the argument vector, option `arg0` can be used.

`{arg0, string() | binary()}`

Only valid for `{spawn_executable, FileName}` and explicitly specifies the program name argument when running an executable. This can in some circumstances, on some OSs, be desirable. How the program responds to this is highly system-dependent and no specific effect is guaranteed.

`exit_status`

Only valid for `{spawn, Command}`, where `Command` refers to an external program, and for `{spawn_executable, FileName}`.

When the external process connected to the port exits, a message of the form `{Port, {exit_status,Status}}` is sent to the connected process, where `Status` is the exit status of the external process. If the program aborts on Unix, the same convention is used as the shells do (that is, 128+signal).

If option `eof` is specified also, the messages `eof` and `exit_status` appear in an unspecified order.

If the port program closes its `stdout` without exiting, option `exit_status` does not work.

`use_stdio`

Only valid for `{spawn, Command}` and `{spawn_executable, FileName}`. It allows the standard input and output (file descriptors 0 and 1) of the spawned (Unix) process for communication with Erlang.

`nouse_stdio`

The opposite of `use_stdio`. It uses file descriptors 3 and 4 for communication with Erlang.

`stderr_to_stdout`

Affects ports to external programs. The executed program gets its standard error file redirected to its standard output file. `stderr_to_stdout` and `nouse_stdio` are mutually exclusive.

`overlapped_io`

Affects ports to external programs on Windows only. The standard input and standard output handles of the port program are, if this option is supplied, opened with flag `FILE_FLAG_OVERLAPPED`, so that the port program can (and must) do overlapped I/O on its standard handles. This is not normally the case for simple port programs, but an option of value for the experienced Windows programmer. **On all other platforms, this option is silently discarded.**

`in`

The port can only be used for input.

`out`

The port can only be used for output.

`binary`

All I/O from the port is binary data objects as opposed to lists of bytes.

`eof`

The port is not closed at the end of the file and does not produce an exit signal. Instead, it remains open and a `{Port, eof}` message is sent to the process holding the port.

`hide`

When running on Windows, suppresses creation of a new console window when spawning the port program. (This option has no effect on other platforms.)

`{parallelism, Boolean}`

Sets scheduler hint for port parallelism. If set to `true`, the virtual machine schedules port tasks; when doing so, it improves parallelism in the system. If set to `false`, the virtual machine tries to perform port tasks immediately, improving latency at the expense of parallelism. The default can be set at system startup by passing command-line argument *+spp* to `erl(1)`.

Default is `stream` for all port types and `use_stdio` for spawned ports.

Failure: if the port cannot be opened, the exit reason is `badarg`, `system_limit`, or the POSIX error code that most closely describes the error, or `einval` if no POSIX code is appropriate:

`badarg`
Bad input arguments to `open_port`.

`system_limit`
All available ports in the Erlang emulator are in use.

`enomem`
Not enough memory to create the port.

`eagain`
No more available OS processes.

`enametoolong`
Too long external command.

`emfile`
No more available file descriptors (for the OS process that the Erlang emulator runs in).

`enfile`
Full file table (for the entire OS).

`eacces`
`Command` specified in `{spawn_executable, Command}` does not point out an executable file.

`enoent`
`FileName` specified in `{spawn_executable, FileName}` does not point out an existing file.

During use of a port opened using `{spawn, Name}`, `{spawn_driver, Name}`, or `{spawn_executable, Name}`, errors arising when sending messages to it are reported to the owning process using signals of the form `{'EXIT', Port, PosixCode}`. For the possible values of `PosixCode`, see *file(3)*.

The maximum number of ports that can be open at the same time can be configured by passing command-line flag *+Q* to `erl(1)`.

`erlang:phash(Term, Range) -> Hash`

Types:

```
Term = term()
Range = Hash = integer() >= 1
```

Range = 1..2^32, Hash = 1..Range

Portable hash function that gives the same hash for the same Erlang term regardless of machine architecture and ERTS version (the BIF was introduced in ERTS 4.9.1.1). The function returns a hash value for `Term` within the range `1..Range`. The maximum value for `Range` is 2^32.

```
erlang:phash2(Term) -> Hash
erlang:phash2(Term, Range) -> Hash
```

Types:

```
Term = term()
Range = integer() >= 1
```

1..2^32

```
Hash = integer() >= 0
```

0..Range-1

Portable hash function that gives the same hash for the same Erlang term regardless of machine architecture and ERTS version (the BIF was introduced in ERTS 5.2). The function returns a hash value for `Term` within the range `0..Range-1`. The maximum value for `Range` is 2^32. When without argument `Range`, a value in the range 0..2^27-1 is returned.

This BIF is always to be used for hashing terms. It distributes small integers better than `phash/2`, and it is faster for bignums and binaries.

Notice that the range `0..Range-1` is different from the range of `phash/2`, which is `1..Range`.

```
pid_to_list(Pid) -> string()
```

Types:

```
Pid = pid()
```

Returns a string corresponding to the text representation of `Pid`.

```
erlang:port_call(Port, Operation, Data) -> term()
```

Types:

```
Port = port() | atom()
Operation = integer()
Data = term()
```

Performs a synchronous call to a port. The meaning of `Operation` and `Data` depends on the port, that is, on the port driver. Not all port drivers support this feature.

`Port` is a port identifier, referring to a driver.

`Operation` is an integer, which is passed on to the driver.

`Data` is any Erlang term. This data is converted to binary term format and sent to the port.

Returns a term from the driver. The meaning of the returned data also depends on the port driver.

Failures:

`badarg`
: If `Port` is not an identifier of an open port, or the registered name of an open port. If the calling process was previously linked to the closed port, identified by `Port`, the exit signal from the port is guaranteed to be delivered before this `badarg` exception occurs.

`badarg`
: If `Operation` does not fit in a 32-bit integer.

`badarg`
: If the port driver does not support synchronous control operations.

`badarg`
: If the port driver so decides for any reason (probably something wrong with `Operation` or `Data`).

`port_close(Port) -> true`

Types:

```
Port = port() | atom()
```

Closes an open port. Roughly the same as `Port ! {self(), close}` except for the error behavior (see below), being synchronous, and that the port does **not** reply with `{Port, closed}`. Any process can close a port with `port_close/1`, not only the port owner (the connected process). If the calling process is linked to the port identified by `Port`, the exit signal from the port is guaranteed to be delivered before `port_close/1` returns.

For comparison: `Port ! {self(), close}` only fails with `badarg` if `Port` does not refer to a port or a process. If `Port` is a closed port, nothing happens. If `Port` is an open port and the calling process is the port owner, the port replies with `{Port, closed}` when all buffers have been flushed and the port really closes. If the calling process is not the port owner, the **port owner** fails with `badsig`.

Notice that any process can close a port using `Port ! {PortOwner, close}` as if it itself was the port owner, but the reply always goes to the port owner.

As from Erlang/OTP R16, `Port ! {PortOwner, close}` is truly asynchronous. Notice that this operation has always been documented as an asynchronous operation, while the underlying implementation has been synchronous. `port_close/1` is however still fully synchronous because of its error behavior.

Failure: `badarg` if `Port` is not an identifier of an open port, or the registered name of an open port. If the calling process was previously linked to the closed port, identified by `Port`, the exit signal from the port is guaranteed to be delivered before this `badarg` exception occurs.

`port_command(Port, Data) -> true`

Types:

```
Port = port() | atom()
Data = iodata()
```

Sends data to a port. Same as `Port ! {PortOwner, {command, Data}}` except for the error behavior and being synchronous (see below). Any process can send data to a port with `port_command/2`, not only the port owner (the connected process).

For comparison: `Port ! {PortOwner, {command, Data}}` only fails with `badarg` if `Port` does not refer to a port or a process. If `Port` is a closed port, the data message disappears without a sound. If `Port` is open and the calling process is not the port owner, the **port owner** fails with `badsig`. The port owner fails with `badsig` also if `Data` is an invalid I/O list.

Notice that any process can send to a port using `Port ! {PortOwner, {command, Data}}` as if it itself was the port owner.

If the port is busy, the calling process is suspended until the port is not busy any more.

As from Erlang/OTP R16, `Port ! {PortOwner, {command, Data}}` is truly asynchronous. Notice that this operation has always been documented as an asynchronous operation, while the underlying implementation has been synchronous. `port_command/2` is however still fully synchronous because of its error behavior.

Failures:

`badarg`

If `Port` is not an identifier of an open port, or the registered name of an open port. If the calling process was previously linked to the closed port, identified by `Port`, the exit signal from the port is guaranteed to be delivered before this `badarg` exception occurs.

`badarg`

If `Data` is an invalid I/O list.

`port_command(Port, Data, OptionList) -> boolean()`

Types:

```
Port = port() | atom()
Data = iodata()
Option = force | nosuspend
OptionList = [Option]
```

Sends data to a port. `port_command(Port, Data, [])` equals `port_command(Port, Data)`.

If the port command is aborted, `false` is returned, otherwise `true`.

If the port is busy, the calling process is suspended until the port is not busy anymore.

`Options`:

`force`

The calling process is not suspended if the port is busy, instead the port command is forced through. The call fails with a `notsup` exception if the driver of the port does not support this. For more information, see driver flag *`![CDATA[ERL_DRV_FLAG_SOFT_BUSY]]`*.

`nosuspend`

The calling process is not suspended if the port is busy, instead the port command is aborted and `false` is returned.

Note:

More options can be added in a future release.

Failures:

`badarg`

If `Port` is not an identifier of an open port, or the registered name of an open port. If the calling process was previously linked to the closed port, identified by `Port`, the exit signal from the port is guaranteed to be delivered before this `badarg` exception occurs.

`badarg`

If `Data` is an invalid I/O list.

`badarg`

If `OptionList` is an invalid option list.

`notsup`

If option `force` has been passed, but the driver of the port does not allow forcing through a busy port.

`port_connect(Port, Pid) -> true`

Types:

```
Port = port() | atom()
Pid = pid()
```

Sets the port owner (the connected port) to `Pid`. Roughly the same as `Port ! {Owner, {connect, Pid}}` except for the following:

- The error behavior differs, see below.
- The port does **not** reply with `{Port,connected}`.
- `port_connect/1` is synchronous, see below.
- The new port owner gets linked to the port.

The old port owner stays linked to the port and must call `unlink(Port)` if this is not desired. Any process can set the port owner to be any process with `port_connect/2`.

For comparison: `Port ! {self(), {connect, Pid}}` only fails with `badarg` if `Port` does not refer to a port or a process. If `Port` is a closed port, nothing happens. If `Port` is an open port and the calling process is the port owner, the port replies with `{Port, connected}` to the old port owner. Notice that the old port owner is still linked to the port, while the new is not. If `Port` is an open port and the calling process is not the port owner, the **port owner** fails with `badsig`. The port owner fails with `badsig` also if `Pid` is not an existing local process identifier.

Notice that any process can set the port owner using `Port ! {PortOwner, {connect, Pid}}` as if it itself was the port owner, but the reply always goes to the port owner.

As from Erlang/OTP R16, `Port ! {PortOwner, {connect, Pid}}` is truly asynchronous. Notice that this operation has always been documented as an asynchronous operation, while the underlying implementation has been synchronous. `port_connect/2` is however still fully synchronous because of its error behavior.

Failures:

`badarg`
: If `Port` is not an identifier of an open port, or the registered name of an open port. If the calling process was previously linked to the closed port, identified by `Port`, the exit signal from the port is guaranteed to be delivered before this `badarg` exception occurs.

`badarg`
: If the process identified by `Pid` is not an existing local process.

`port_control(Port, Operation, Data) -> iodata() | binary()`

Types:

```
Port = port() | atom()
Operation = integer()
Data = iodata()
```

Performs a synchronous control operation on a port. The meaning of `Operation` and `Data` depends on the port, that is, on the port driver. Not all port drivers support this control feature.

Returns a list of integers in the range 0..255, or a binary, depending on the port driver. The meaning of the returned data also depends on the port driver.

Failures:

`badarg`
: If `Port` is not an open port or the registered name of an open port.

`badarg`
: If `Operation` cannot fit in a 32-bit integer.

`badarg`
: If the port driver does not support synchronous control operations.

`badarg`
: If the port driver so decides for any reason (probably something wrong with `Operation` or `Data`).

`erlang:port_info(Port) -> Result`

Types:

```
Port = port() | atom()
ResultItem =
    {registered_name, RegisteredName :: atom()} |
    {id, Index :: integer() >= 0} |
    {connected, Pid :: pid()} |
    {links, Pids :: [pid()]} |
    {name, String :: string()} |
    {input, Bytes :: integer() >= 0} |
    {output, Bytes :: integer() >= 0} |
    {os_pid, OsPid :: integer() >= 0 | undefined}
Result = [ResultItem] | undefined
```

Returns a list containing tuples with information about `Port`, or `undefined` if the port is not open. The order of the tuples is undefined, and all the tuples are not mandatory. If the port is closed and the calling process was previously linked to the port, the exit signal from the port is guaranteed to be delivered before `port_info/1` returns `undefined`.

The result contains information about the following `Item`s:

- `registered_name` (if the port has a registered name)
- `id`
- `connected`
- `links`
- `name`
- `input`
- `output`

For more information about the different `Item`s, see *`port_info/2`*.

Failure: `badarg` if `Port` is not a local port identifier, or an atom.

`erlang:port_info(Port, Item :: connected) -> {connected, Pid} | undefined`

Types:

```
Port = port() | atom()
Pid = pid()
```

`Pid` is the process identifier of the process connected to the port.

If the port identified by `Port` is not open, `undefined` is returned. If the port is closed and the calling process was previously linked to the port, the exit signal from the port is guaranteed to be delivered before `port_info/2` returns `undefined`.

Failure: `badarg` if `Port` is not a local port identifier, or an atom.

```
erlang:port_info(Port, Item :: id) -> {id, Index} | undefined
```

Types:

```
Port = port() | atom()
Index = integer() >= 0
```

`Index` is the internal index of the port. This index can be used to separate ports.

If the port identified by `Port` is not open, `undefined` is returned. If the port is closed and the calling process was previously linked to the port, the exit signal from the port is guaranteed to be delivered before `port_info/2` returns `undefined`.

Failure: `badarg` if `Port` is not a local port identifier, or an atom.

```
erlang:port_info(Port, Item :: input) ->
                    {input, Bytes} | undefined
```

Types:

```
Port = port() | atom()
Bytes = integer() >= 0
```

`Bytes` is the total number of bytes read from the port.

If the port identified by `Port` is not open, `undefined` is returned. If the port is closed and the calling process was previously linked to the port, the exit signal from the port is guaranteed to be delivered before `port_info/2` returns `undefined`.

Failure: `badarg` if `Port` is not a local port identifier, or an atom.

```
erlang:port_info(Port, Item :: links) -> {links, Pids} | undefined
```

Types:

```
Port = port() | atom()
Pids = [pid()]
```

`Pids` is a list of the process identifiers of the processes that the port is linked to.

If the port identified by `Port` is not open, `undefined` is returned. If the port is closed and the calling process was previously linked to the port, the exit signal from the port is guaranteed to be delivered before `port_info/2` returns `undefined`.

Failure: `badarg` if `Port` is not a local port identifier, or an atom.

```
erlang:port_info(Port, Item :: locking) ->
                    {locking, Locking} | undefined
```

Types:

```
Port = port() | atom()
Locking = false | port_level | driver_level
```

`Locking` is one of the following:

- `false` (emulator without SMP support)
- `port_level` (port-specific locking)
- `driver_level` (driver-specific locking)

Notice that these results are highly implementation-specific and can change in a future release.

If the port identified by `Port` is not open, `undefined` is returned. If the port is closed and the calling process was previously linked to the port, the exit signal from the port is guaranteed to be delivered before `port_info/2` returns `undefined`.

Failure: `badarg` if `Port` is not a local port identifier, or an atom.

```
erlang:port_info(Port, Item :: memory) ->
                    {memory, Bytes} | undefined
```

Types:

```
Port = port() | atom()
Bytes = integer() >= 0
```

`Bytes` is the total number of bytes allocated for this port by the runtime system. The port itself can have allocated memory that is not included in `Bytes`.

If the port identified by `Port` is not open, `undefined` is returned. If the port is closed and the calling process was previously linked to the port, the exit signal from the port is guaranteed to be delivered before `port_info/2` returns `undefined`.

Failure: `badarg` if `Port` is not a local port identifier, or an atom.

```
erlang:port_info(Port, Item :: monitors) ->
                    {monitors, Monitors} | undefined
```

Types:

```
Port = port() | atom()
Monitors = [{process, pid()}]
```

`Monitors` represent processes monitored by this port.

If the port identified by `Port` is not open, `undefined` is returned. If the port is closed and the calling process was previously linked to the port, the exit signal from the port is guaranteed to be delivered before `port_info/2` returns `undefined`.

Failure: `badarg` if `Port` is not a local port identifier, or an atom.

```
erlang:port_info(Port, Item :: monitored_by) ->
                    {monitored_by, MonitoredBy} | undefined
```

Types:

```
Port = port() | atom()
MonitoredBy = [pid()]
```

Returns list of pids that are monitoring given port at the moment.

If the port identified by `Port` is not open, `undefined` is returned. If the port is closed and the calling process was previously linked to the port, the exit signal from the port is guaranteed to be delivered before `port_info/2` returns `undefined`.

Failure: `badarg` if `Port` is not a local port identifier, or an atom.

```
erlang:port_info(Port, Item :: name) -> {name, Name} | undefined
```

Types:

```
Port = port() | atom()
Name = string()
```

`Name` is the command name set by *`open_port/2`*.

If the port identified by `Port` is not open, `undefined` is returned. If the port is closed and the calling process was previously linked to the port, the exit signal from the port is guaranteed to be delivered before `port_info/2` returns `undefined`.

Failure: `badarg` if `Port` is not a local port identifier, or an atom.

```
erlang:port_info(Port, Item :: os_pid) ->
                    {os_pid, OsPid} | undefined
```

Types:

```
Port = port() | atom()
OsPid = integer() >= 0 | undefined
```

`OsPid` is the process identifier (or equivalent) of an OS process created with *`open_port({spawn | spawn_executable, Command}, Options)`*. If the port is not the result of spawning an OS process, the value is `undefined`.

If the port identified by `Port` is not open, `undefined` is returned. If the port is closed and the calling process was previously linked to the port, the exit signal from the port is guaranteed to be delivered before `port_info/2` returns `undefined`.

Failure: `badarg` if `Port` is not a local port identifier, or an atom.

```
erlang:port_info(Port, Item :: output) ->
                    {output, Bytes} | undefined
```

Types:

```
Port = port() | atom()
Bytes = integer() >= 0
```

`Bytes` is the total number of bytes written to the port from Erlang processes using *`port_command/2`*, *`port_command/3`*, or `Port ! {Owner, {command, Data}}`.

If the port identified by `Port` is not open, `undefined` is returned. If the port is closed and the calling process was previously linked to the port, the exit signal from the port is guaranteed to be delivered before `port_info/2` returns `undefined`.

Failure: `badarg` if `Port` is not a local port identifier, or an atom.

```
erlang:port_info(Port, Item :: parallelism) ->
                    {parallelism, Boolean} | undefined
```

Types:

```
Port = port() | atom()
Boolean = boolean()
```

`Boolean` corresponds to the port parallelism hint used by this port. For more information, see option *`parallelism`* of *`open_port/2`*.

```
erlang:port_info(Port, Item :: queue_size) ->
                    {queue_size, Bytes} | undefined
```

Types:

```
Port = port() | atom()
Bytes = integer() >= 0
```

`Bytes` is the total number of bytes queued by the port using the ERTS driver queue implementation.

If the port identified by `Port` is not open, `undefined` is returned. If the port is closed and the calling process was previously linked to the port, the exit signal from the port is guaranteed to be delivered before `port_info/2` returns `undefined`.

Failure: `badarg` if `Port` is not a local port identifier, or an atom.

```
erlang:port_info(Port, Item :: registered_name) ->
                    {registered_name, RegisteredName} |
                    [] |
                    undefined
```

Types:

```
Port = port() | atom()
RegisteredName = atom()
```

`RegisteredName` is the registered name of the port. If the port has no registered name, `[]` is returned.

If the port identified by `Port` is not open, `undefined` is returned. If the port is closed and the calling process was previously linked to the port, the exit signal from the port is guaranteed to be delivered before `port_info/2` returns `undefined`.

Failure: `badarg` if `Port` is not a local port identifier, or an atom.

```
port_to_list(Port) -> string()
```

Types:

```
Port = port()
```

Returns a string corresponding to the text representation of the port identifier `Port`.

```
erlang:ports() -> [port()]
```

Returns a list of port identifiers corresponding to all the ports existing on the local node.

Notice that an exiting port exists, but is not open.

```
pre_loaded() -> [module()]
```

Returns a list of Erlang modules that are preloaded in the system. As all loading of code is done through the file system, the file system must have been loaded previously. Hence, at least the module `init` must be preloaded.

```
erlang:process_display(Pid, Type) -> true
```

Types:

```
Pid = pid()
Type = backtrace
```

Writes information about the local process `Pid` on standard error. The only allowed value for the atom `Type` is `backtrace`, which shows the contents of the call stack, including information about the call chain, with the current function printed first. The format of the output is not further defined.

```
process_flag(Flag :: trap_exit, Boolean) -> OldBoolean
```

Types:

```
Boolean = OldBoolean = boolean()
```

When `trap_exit` is set to `true`, exit signals arriving to a process are converted to `{'EXIT', From, Reason}` messages, which can be received as ordinary messages. If `trap_exit` is set to `false`, the process exits if it receives

an exit signal other than `normal` and the exit signal is propagated to its linked processes. Application processes are normally not to trap exits.

Returns the old value of the flag.

See also *`exit/2`*.

```
process_flag(Flag :: error_handler, Module) -> OldModule
```

Types:

```
Module = OldModule = atom()
```

Used by a process to redefine the error handler for undefined function calls and undefined registered processes. Inexperienced users are not to use this flag, as code auto-loading depends on the correct operation of the error handling module.

Returns the old value of the flag.

```
process_flag(Flag :: min_heap_size, MinHeapSize) -> OldMinHeapSize
```

Types:

```
MinHeapSize = OldMinHeapSize = integer() >= 0
```

Changes the minimum heap size for the calling process.

Returns the old value of the flag.

```
process_flag(Flag :: min_bin_vheap_size, MinBinVHeapSize) ->
                OldMinBinVHeapSize
```

Types:

```
MinBinVHeapSize = OldMinBinVHeapSize = integer() >= 0
```

Changes the minimum binary virtual heap size for the calling process.

Returns the old value of the flag.

```
process_flag(Flag :: max_heap_size, MaxHeapSize) -> OldMaxHeapSize
```

Types:

```
MaxHeapSize = OldMaxHeapSize = max_heap_size()
max_heap_size() =
    integer() >= 0 |
    #{size => integer() >= 0,
      kill => boolean(),
      error_logger => boolean()}
```

This flag sets the maximum heap size for the calling process. If `MaxHeapSize` is an integer, the system default values for `kill` and `error_logger` are used.

`size`

The maximum size in words of the process. If set to zero, the heap size limit is disabled. `badarg` is be thrown if the value is smaller than *`min_heap_size`*. The size check is only done when a garbage collection is triggered.

`size` is the entire heap of the process when garbage collection is triggered. This includes all generational heaps, the process stack, any *messages that are considered to be part of the heap*, and any extra memory that the garbage collector needs during collection.

`size` is the same as can be retrieved using *`erlang:process_info(Pid, total_heap_size)`*, or by adding `heap_block_size`, `old_heap_block_size` and `mbuf_size` from *`erlang:process_info(Pid, garbage_collection_info)`*.

`kill`

When set to `true`, the runtime system sends an untrappable exit signal with reason `kill` to the process if the maximum heap size is reached. The garbage collection that triggered the `kill` is not completed, instead the process exits as soon as possible. When set to `false`, no exit signal is sent to the process, instead it continues executing.

If `kill` is not defined in the map, the system default will be used. The default system default is `true`. It can be changed by either option *+hmaxk* in `erl(1)`, or *`erlang:system_flag(max_heap_size, MaxHeapSize)`*.

`error_logger`

When set to `true`, the runtime system sends a message to the current *`error_logger`* containing details about the process when the maximum heap size is reached. One `error_logger` report is sent each time the limit is reached.

If `error_logger` is not defined in the map, the system default is used. The default system default is `true`. It can be changed by either the option *+hmaxel* int `erl(1)`, or *`erlang:system_flag(max_heap_size, MaxHeapSize)`*.

The heap size of a process is quite hard to predict, especially the amount of memory that is used during the garbage collection. When contemplating using this option, it is recommended to first run it in production with `kill` set to `false` and inspect the `error_logger` reports to see what the normal peak sizes of the processes in the system is and then tune the value accordingly.

`process_flag(Flag :: message_queue_data, MQD) -> OldMQD`

Types:

```
MQD = OldMQD = message_queue_data()
message_queue_data() = off_heap | on_heap
```

This flag determines how messages in the message queue are stored, as follows:

`off_heap`

All messages in the message queue will be stored outside of the process heap. This implies that **no** messages in the message queue will be part of a garbage collection of the process.

`on_heap`

All messages in the message queue will eventually be placed on heap. They can however temporarily be stored off heap. This is how messages always have been stored up until ERTS 8.0.

The default `message_queue_data` process flag is determined by command-line argument *+hmqd* in `erl(1)`.

If the process potentially can get many messages in its queue, you are advised to set the flag to `off_heap`. This because a garbage collection with many messages placed on the heap can become extremely expensive and the process can consume large amounts of memory. Performance of the actual message passing is however generally better when not using flag `off_heap`.

When changing this flag messages will be moved. This work has been initiated but not completed when this function call returns.

Returns the old value of the flag.

`process_flag(Flag :: priority, Level) -> OldLevel`

Types:

```
Level = OldLevel = priority_level()
priority_level() = low | normal | high | max
```

Sets the process priority. `Level` is an atom. Four priority levels exist: `low`, `normal`, `high`, and `max`. Default is `normal`.

Note:

Priority level `max` is reserved for internal use in the Erlang runtime system, and is **not** to be used by others.

Internally in each priority level, processes are scheduled in a round robin fashion.

Execution of processes on priority `normal` and `low` are interleaved. Processes on priority `low` are selected for execution less frequently than processes on priority `normal`.

When runnable processes on priority `high` exist, no processes on priority `low` or `normal` are selected for execution. Notice however that this does **not** mean that no processes on priority `low` or `normal` can run when processes are running on priority `high`. On the runtime system with SMP support, more processes can be running in parallel than processes on priority `high`. That is, a `low` and a `high` priority process can execute at the same time.

When runnable processes on priority `max` exist, no processes on priority `low`, `normal`, or `high` are selected for execution. As with priority `high`, processes on lower priorities can execute in parallel with processes on priority `max`.

Scheduling is pre-emptive. Regardless of priority, a process is pre-empted when it has consumed more than a certain number of reductions since the last time it was selected for execution.

Note:

Do not depend on the scheduling to remain exactly as it is today. Scheduling, at least on the runtime system with SMP support, is likely to be changed in a future release to use available processor cores better.

There is **no** automatic mechanism for avoiding priority inversion, such as priority inheritance or priority ceilings. When using priorities, take this into account and handle such scenarios by yourself.

Making calls from a `high` priority process into code that you has no control over can cause the `high` priority process to wait for a process with lower priority. That is, effectively decreasing the priority of the `high` priority process during the call. Even if this is not the case with one version of the code that you have no control over, it can be the case in a future version of it. This can, for example, occur if a `high` priority process triggers code loading, as the code server runs on priority `normal`.

Other priorities than `normal` are normally not needed. When other priorities are used, use them with care, **especially** priority `high`. A process on priority `high` is only to perform work for short periods. Busy looping for long periods in a `high` priority process causes most likely problems, as important OTP servers run on priority `normal`.

Returns the old value of the flag.

`process_flag(Flag :: save_calls, N) -> OldN`

Types:

```
N = OldN = 0..10000
```

`N` must be an integer in the interval 0..10000. If `N` > 0, call saving is made active for the process. This means that information about the `N` most recent global function calls, BIF calls, sends, and receives made by the process are saved in a list, which can be retrieved with `process_info(Pid, last_calls)`. A global function call is one in which the module of the function is explicitly mentioned. Only a fixed amount of information is saved, as follows:

- A tuple `{Module, Function, Arity}` for function calls
- The atoms `send`, `'receive'`, and `timeout` for sends and receives (`'receive'` when a message is received and `timeout` when a receive times out)

If `N` = 0, call saving is disabled for the process, which is the default. Whenever the size of the call saving list is set, its contents are reset.

Returns the old value of the flag.

`process_flag(Flag :: sensitive, Boolean) -> OldBoolean`

Types:

```
Boolean = OldBoolean = boolean()
```

Sets or clears flag `sensitive` for the current process. When a process has been marked as sensitive by calling `process_flag(sensitive, true)`, features in the runtime system that can be used for examining the data or inner working of the process are silently disabled.

Features that are disabled include (but are not limited to) the following:

- Tracing. Trace flags can still be set for the process, but no trace messages of any kind are generated. (If flag `sensitive` is turned off, trace messages are again generated if any trace flags are set.)
- Sequential tracing. The sequential trace token is propagated as usual, but no sequential trace messages are generated.

`process_info/1,2` cannot be used to read out the message queue or the process dictionary (both are returned as empty lists).

Stack back-traces cannot be displayed for the process.

In crash dumps, the stack, messages, and the process dictionary are omitted.

If `{save_calls,N}` has been set for the process, no function calls are saved to the call saving list. (The call saving list is not cleared. Also, send, receive, and time-out events are still added to the list.)

Returns the old value of the flag.

`process_flag(Pid, Flag, Value) -> OldValue`

Types:

```
Pid = pid()
Flag = save_calls
Value = OldValue = integer() >= 0
```

Sets certain flags for the process `Pid`, in the same manner as *`process_flag/2`*. Returns the old value of the flag. The valid values for `Flag` are only a subset of those allowed in `process_flag/2`, namely `save_calls`.

Failure: `badarg` if `Pid` is not a local process.

`process_info(Pid) -> Info`

Types:

```
Pid = pid()
Info = [InfoTuple] | undefined
InfoTuple = process_info_result_item()
process_info_result_item() =
    {backtrace, Bin :: binary()} |
    {binary,
```

```
 BinInfo ::
     [{integer() >= 0,
       integer() >= 0,
       integer() >= 0}]} |
{catchlevel, CatchLevel :: integer() >= 0} |
{current_function,
 {Module :: module(), Function :: atom(), Arity :: arity()}} |
{current_location,
 {Module :: module(),
  Function :: atom(),
  Arity :: arity(),
  Location ::
      [{file, Filename :: string()} |
       {line, Line :: integer() >= 1}]}} |
{current_stacktrace, Stack :: [stack_item()]} |
{dictionary, Dictionary :: [{Key :: term(), Value :: term()}]} |
{error_handler, Module :: module()} |
{garbage_collection, GCInfo :: [{atom(), integer() >= 0}]} |
{garbage_collection_info,
 GCInfo :: [{atom(), integer() >= 0}]} |
{group_leader, GroupLeader :: pid()} |
{heap_size, Size :: integer() >= 0} |
{initial_call, mfa()} |
{links, PidsAndPorts :: [pid() | port()]} |
{last_calls, false | (Calls :: [mfa()])} |
{memory, Size :: integer() >= 0} |
{message_queue_len, MessageQueueLen :: integer() >= 0} |
{messages, MessageQueue :: [term()]} |
{min_heap_size, MinHeapSize :: integer() >= 0} |
{min_bin_vheap_size, MinBinVHeapSize :: integer() >= 0} |
{max_heap_size, MaxHeapSize :: max_heap_size()} |
{monitored_by, Pids :: [pid()]} |
{monitors,
 Monitors ::
     [{process | port,
       Pid ::
           pid() |
           port() |
           {RegName :: atom(), Node :: node()}}]} |
{message_queue_data, MQD :: message_queue_data()} |
{priority, Level :: priority_level()} |
{reductions, Number :: integer() >= 0} |
{registered_name, [] | (Atom :: atom())} |
{sequential_trace_token,
 [] | (SequentialTraceToken :: term())} |
{stack_size, Size :: integer() >= 0} |
{status,
 Status ::
     exiting |
     garbage_collecting |
     waiting |
     running |
```

```
            runnable |
            suspended} |
        {suspending,
         SuspendeeList ::
            [{Suspendee :: pid(),
              ActiveSuspendCount :: integer() >= 0,
              OutstandingSuspendCount :: integer() >= 0}]} |
        {total_heap_size, Size :: integer() >= 0} |
        {trace, InternalTraceFlags :: integer() >= 0} |
        {trap_exit, Boolean :: boolean()}
    priority_level() = low | normal | high | max
    stack_item() =
        {Module :: module(),
         Function :: atom(),
         Arity :: arity() | (Args :: [term()]),
         Location ::
            [{file, Filename :: string()} |
             {line, Line :: integer() >= 1}]}
    max_heap_size() =
        integer() >= 0 |
        #{size => integer() >= 0,
          kill => boolean(),
          error_logger => boolean()}
    message_queue_data() = off_heap | on_heap
```

Returns a list containing `InfoTuple`s with miscellaneous information about the process identified by `Pid`, or `undefined` if the process is not alive.

The order of the `InfoTuple`s is undefined and all `InfoTuple`s are not mandatory. The `InfoTuple`s part of the result can be changed without prior notice.

The `InfoTuple`s with the following items are part of the result:

- `current_function`
- `initial_call`
- `status`
- `message_queue_len`
- `messages`
- `links`
- `dictionary`
- `trap_exit`
- `error_handler`
- `priority`
- `group_leader`
- `total_heap_size`
- `heap_size`
- `stack_size`
- `reductions`
- `garbage_collection`

If the process identified by `Pid` has a registered name, also an `InfoTuple` with item `registered_name` is included.

For information about specific `InfoTuple`s, see *`process_info/2`*.

Warning:

This BIF is intended for **debugging only**. For all other purposes, use *`process_info/2`*.

Failure: `badarg` if `Pid` is not a local process.

```
process_info(Pid, Item) -> InfoTuple | [] | undefined
process_info(Pid, ItemList) -> InfoTupleList | [] | undefined
```

Types:

```
   Pid = pid()
   ItemList = [Item]
   Item = process_info_item()
   InfoTupleList = [InfoTuple]
   InfoTuple = process_info_result_item()
   process_info_item() =
       backtrace |
       binary |
       catchlevel |
       current_function |
       current_location |
       current_stacktrace |
       dictionary |
       error_handler |
       garbage_collection |
       garbage_collection_info |
       group_leader |
       heap_size |
       initial_call |
       links |
       last_calls |
       memory |
       message_queue_len |
       messages |
       min_heap_size |
       min_bin_vheap_size |
       monitored_by |
       monitors |
       message_queue_data |
       priority |
       reductions |
       registered_name |
       sequential_trace_token |
       stack_size |
       status |
       suspending |
       total_heap_size |
```

```
        trace |
        trap_exit
    process_info_result_item() =
        {backtrace, Bin :: binary()} |
        {binary,
         BinInfo ::
             [{integer() >= 0,
               integer() >= 0,
               integer() >= 0}]} |
        {catchlevel, CatchLevel :: integer() >= 0} |
        {current_function,
         {Module :: module(), Function :: atom(), Arity :: arity()}} |
        {current_location,
         {Module :: module(),
          Function :: atom(),
          Arity :: arity(),
          Location ::
              [{file, Filename :: string()} |
               {line, Line :: integer() >= 1}]}} |
        {current_stacktrace, Stack :: [stack_item()]} |
        {dictionary, Dictionary :: [{Key :: term(), Value :: term()}]} |
        {error_handler, Module :: module()} |
        {garbage_collection, GCInfo :: [{atom(), integer() >= 0}]} |
        {garbage_collection_info,
         GCInfo :: [{atom(), integer() >= 0}]} |
        {group_leader, GroupLeader :: pid()} |
        {heap_size, Size :: integer() >= 0} |
        {initial_call, mfa()} |
        {links, PidsAndPorts :: [pid() | port()]} |
        {last_calls, false | (Calls :: [mfa()])} |
        {memory, Size :: integer() >= 0} |
        {message_queue_len, MessageQueueLen :: integer() >= 0} |
        {messages, MessageQueue :: [term()]} |
        {min_heap_size, MinHeapSize :: integer() >= 0} |
        {min_bin_vheap_size, MinBinVHeapSize :: integer() >= 0} |
        {max_heap_size, MaxHeapSize :: max_heap_size()} |
        {monitored_by, Pids :: [pid()]} |
        {monitors,
         Monitors ::
             [{process | port,
               Pid ::
                   pid() |
                   port() |
                   {RegName :: atom(), Node :: node()}}]} |
        {message_queue_data, MQD :: message_queue_data()} |
        {priority, Level :: priority_level()} |
        {reductions, Number :: integer() >= 0} |
        {registered_name, [] | (Atom :: atom())} |
        {sequential_trace_token,
         [] | (SequentialTraceToken :: term())} |
        {stack_size, Size :: integer() >= 0} |
        {status,
```

```
        Status ::
            exiting |
            garbage_collecting |
            waiting |
            running |
            runnable |
            suspended} |
        {suspending,
         SuspendeeList ::
            [{Suspendee :: pid(),
              ActiveSuspendCount :: integer() >= 0,
              OutstandingSuspendCount :: integer() >= 0}]} |
        {total_heap_size, Size :: integer() >= 0} |
        {trace, InternalTraceFlags :: integer() >= 0} |
        {trap_exit, Boolean :: boolean()}
    stack_item() =
        {Module :: module(),
         Function :: atom(),
         Arity :: arity() | (Args :: [term()]),
         Location ::
            [{file, Filename :: string()} |
             {line, Line :: integer() >= 1}]}
    priority_level() = low | normal | high | max
    max_heap_size() =
        integer() >= 0 |
        #{size => integer() >= 0,
          kill => boolean(),
          error_logger => boolean()}
    message_queue_data() = off_heap | on_heap
```

Returns information about the process identified by `Pid`, as specified by `Item` or `ItemList`. Returns `undefined` if the process is not alive.

If the process is alive and a single `Item` is specified, the returned value is the corresponding `InfoTuple`, unless `Item =:= registered_name` and the process has no registered name. In this case, `[]` is returned. This strange behavior is because of historical reasons, and is kept for backward compatibility.

If `ItemList` is specified, the result is `InfoTupleList`. The `InfoTuple`s in `InfoTupleList` are included with the corresponding `Item`s in the same order as the `Item`s were included in `ItemList`. Valid `Item`s can be included multiple times in `ItemList`.

Note:

If `registered_name` is part of `ItemList` and the process has no name registered, a `{registered_name, []}`, `InfoTuple` **will** be included in the resulting `InfoTupleList`. This behavior is different when a single `Item =:= registered_name` is specified, and when `process_info/1` is used.

Valid `InfoTuple`s with corresponding `Item`s:

`{backtrace, Bin}`

Binary `Bin` contains the same information as the output from `erlang:process_display(Pid, backtrace)`. Use `binary_to_list/1` to obtain the string of characters from the binary.

`{binary, BinInfo}`

`BinInfo` is a list containing miscellaneous information about binaries on the heap of this process. This `InfoTuple` can be changed or removed without prior notice. In the current implementation `BinInfo` is a list of tuples. The tuples contain; `BinaryId`, `BinarySize`, `BinaryRefcCount`.

The message queue is on the heap depending on the process flag *`message_queue_data`*.

`{catchlevel, CatchLevel}`

`CatchLevel` is the number of currently active catches in this process. This `InfoTuple` can be changed or removed without prior notice.

`{current_function, {Module, Function, Arity}}`

`Module`, `Function`, `Arity` is the current function call of the process.

`{current_location, {Module, Function, Arity, Location}}`

`Module`, `Function`, `Arity` is the current function call of the process. `Location` is a list of two-tuples describing the location in the source code.

`{current_stacktrace, Stack}`

Returns the current call stack back-trace (**stacktrace**) of the process. The stack has the same format as returned by *`erlang:get_stacktrace/0`*. The depth of the stacktrace is truncated according to the `backtrace_depth` system flag setting.

`{dictionary, Dictionary}`

`Dictionary` is the process dictionary.

`{error_handler, Module}`

`Module` is the error handler module used by the process (for undefined function calls, for example).

`{garbage_collection, GCInfo}`

`GCInfo` is a list containing miscellaneous information about garbage collection for this process. The content of `GCInfo` can be changed without prior notice.

`{garbage_collection_info, GCInfo}`

`GCInfo` is a list containing miscellaneous detailed information about garbage collection for this process. The content of `GCInfo` can be changed without prior notice. For details about the meaning of each item, see *`gc_minor_start`* in *`erlang:trace/3`*.

`{group_leader, GroupLeader}`

`GroupLeader` is the group leader for the I/O of the process.

`{heap_size, Size}`

`Size` is the size in words of the youngest heap generation of the process. This generation includes the process stack. This information is highly implementation-dependent, and can change if the implementation changes.

`{initial_call, {Module, Function, Arity}}`

`Module`, `Function`, `Arity` is the initial function call with which the process was spawned.

`{links, PidsAndPorts}`

`PidsAndPorts` is a list of process identifiers and port identifiers, with processes or ports to which the process has a link.

`{last_calls, false|Calls}`

The value is `false` if call saving is not active for the process (see *`process_flag/3`*). If call saving is active, a list is returned, in which the last element is the most recent called.

`{memory, Size}`

`Size` is the size in bytes of the process. This includes call stack, heap, and internal structures.

`{message_queue_len, MessageQueueLen}`

`MessageQueueLen` is the number of messages currently in the message queue of the process. This is the length of the list `MessageQueue` returned as the information item `messages` (see below).

`{messages, MessageQueue}`

`MessageQueue` is a list of the messages to the process, which have not yet been processed.

`{min_heap_size, MinHeapSize}`

`MinHeapSize` is the minimum heap size for the process.

`{min_bin_vheap_size, MinBinVHeapSize}`

`MinBinVHeapSize` is the minimum binary virtual heap size for the process.

`{monitored_by, Pids}`

A list of process identifiers monitoring the process (with `monitor/2`).

`{monitors, Monitors}`

A list of monitors (started by `monitor/2`) that are active for the process. For a local process monitor or a remote process monitor by a process identifier, the list consists of:

`{process, Pid}`
: Process is monitored by pid.

`{process, {RegName, Node}}`
: Local or remote process is monitored by name.

`{port, PortId}`
: Local port is monitored by port id.

`{port, {RegName, Node}}`
: Local port is monitored by name. Please note, that remote port monitors are not supported, so `Node` will always be the local node name.

`{message_queue_data, MQD}`

Returns the current state of process flag `message_queue_data`. `MQD` is either `off_heap` or `on_heap`. For more information, see the documentation of *`process_flag(message_queue_data, MQD)`*.

`{priority, Level}`

`Level` is the current priority level for the process. For more information on priorities, see *`process_flag(priority, Level)`*.

`{reductions, Number}`

`Number` is the number of reductions executed by the process.

`{registered_name, Atom}`

`Atom` is the registered process name. If the process has no registered name, this tuple is not present in the list.

`{sequential_trace_token, [] | SequentialTraceToken}`

`SequentialTraceToken` is the sequential trace token for the process. This `InfoTuple` can be changed or removed without prior notice.

`{stack_size, Size}`

`Size` is the stack size, in words, of the process.

`{status, Status}`

`Status` is the status of the process and is one of the following:

- `exiting`
- `garbage_collecting`
- `waiting` (for a message)
- `running`
- `runnable` (ready to run, but another process is running)
- `suspended` (suspended on a "busy" port or by the BIF `erlang:suspend_process/1,2`)

`{suspending, SuspendeeList}`

`SuspendeeList` is a list of `{Suspendee, ActiveSuspendCount, OutstandingSuspendCount}` tuples. `Suspendee` is the process identifier of a process that has been, or is to be, suspended by the process identified by `Pid` through the BIF *`erlang:suspend_process/2`* or *`erlang:suspend_process/1`*.

`ActiveSuspendCount` is the number of times `Suspendee` has been suspended by `Pid`. `OutstandingSuspendCount` is the number of not yet completed suspend requests sent by `Pid`, that is:

- If `ActiveSuspendCount =/= 0`, `Suspendee` is currently in the suspended state.
- If `OutstandingSuspendCount =/= 0`, option `asynchronous` of `erlang:suspend_process/2` has been used and the suspendee has not yet been suspended by `Pid`.

Notice that `ActiveSuspendCount` and `OutstandingSuspendCount` are not the total suspend count on `Suspendee`, only the parts contributed by `Pid`.

`{total_heap_size, Size}`

`Size` is the total size, in words, of all heap fragments of the process. This includes the process stack and any unreceived messages that are considered to be part of the heap.

`{trace, InternalTraceFlags}`

`InternalTraceFlags` is an integer representing the internal trace flag for this process. This `InfoTuple` can be changed or removed without prior notice.

`{trap_exit, Boolean}`

`Boolean` is `true` if the process is trapping exits, otherwise `false`.

Notice that not all implementations support all these `Item`s.

Failures:

`badarg`
If `Pid` is not a local process.

`badarg`
If `Item` is an invalid item.

`processes() -> [pid()]`

Returns a list of process identifiers corresponding to all the processes currently existing on the local node.

Notice that an exiting process exists, but is not alive. That is, `is_process_alive/1` returns `false` for an exiting process, but its process identifier is part of the result returned from `processes/0`.

Example:

```
> processes().
[<0.0.0>,<0.2.0>,<0.4.0>,<0.5.0>,<0.7.0>,<0.8.0>]
```

`purge_module(Module) -> true`

Types:

```
Module = atom()
```

Removes old code for `Module`. Before this BIF is used, *`check_process_code/2`*is to be called to check that no processes execute old code in the module.

Warning:

This BIF is intended for the code server (see *`code(3)`*) and is not to be used elsewhere.

Note:

As from ERTS 8.0 (Erlang/OTP 19), any lingering processes that still execute the old code is killed by this function. In earlier versions, such incorrect use could cause much more fatal failures, like emulator crash.

Failure: `badarg` if there is no old code for `Module`.

`put(Key, Val) -> term()`

Types:

```
Key = Val = term()
```

Adds a new `Key` to the process dictionary, associated with the value `Val`, and returns `undefined`. If `Key` exists, the old value is deleted and replaced by `Val`, and the function returns the old value. Example:

```
> X = put(name, walrus), Y = put(name, carpenter),
Z = get(name),
{X, Y, Z}.
{undefined,walrus,carpenter}
```

Note:

The values stored when `put` is evaluated within the scope of a `catch` are not retracted if a `throw` is evaluated, or if an error occurs.

`erlang:raise(Class, Reason, Stacktrace) -> no_return()`

Types:

```
Class = error | exit | throw
Reason = term()
Stacktrace = raise_stacktrace()
raise_stacktrace() =
    [{module(), atom(), arity() | [term()]} |
     {function(), [term()]}] |
    [{module(), atom(), arity() | [term()], [{atom(), term()}]} |
```

```
{function(), [term()], [{atom(), term()}]}]
```

Stops the execution of the calling process with an exception of the specified class, reason, and call stack backtrace (**stacktrace**).

`Class` is `error`, `exit`, or `throw`. So, if it were not for the stacktrace, `erlang:raise(Class, Reason, Stacktrace)` is equivalent to `erlang:Class(Reason)`.

`Reason` is any term. `Stacktrace` is a list as returned from `get_stacktrace()`, that is, a list of four-tuples `{Module, Function, Arity | Args, Location}`, where `Module` and `Function` are atoms, and the third element is an integer arity or an argument list. The stacktrace can also contain `{Fun, Args, Location}` tuples, where `Fun` is a local fun and `Args` is an argument list.

Element `Location` at the end is optional. Omitting it is equivalent to specifying an empty list.

The stacktrace is used as the exception stacktrace for the calling process; it is truncated to the current maximum stacktrace depth.

As evaluating this function causes the process to terminate, it has no return value unless the arguments are invalid, in which case the function **returns the error reason** `badarg`. If you want to be sure not to return, you can call `error(erlang:raise(Class, Reason, Stacktrace))` and hope to distinguish exceptions later.

`erlang:read_timer(TimerRef) -> Result`

Types:

```
TimerRef = reference()
Time = integer() >= 0
Result = Time | false
```

Reads the state of a timer. The same as calling *`erlang:read_timer(TimerRef, [])`*.

`erlang:read_timer(TimerRef, Options) -> Result | ok`

Types:

```
TimerRef = reference()
Async = boolean()
Option = {async, Async}
Options = [Option]
Time = integer() >= 0
Result = Time | false
```

Reads the state of a timer that has been created by either *`erlang:start_timer`* or *`erlang:send_after`*. `TimerRef` identifies the timer, and was returned by the BIF that created the timer.

`Options`:

`{async, Async}`

> Asynchronous request for state information. `Async` defaults to `false`, which causes the operation to be performed synchronously. In this case, the `Result` is returned by `erlang:read_timer`. When `Async` is `true`, `erlang:read_timer` sends an asynchronous request for the state information to the timer service that manages the timer, and then returns `ok`. A message on the format `{read_timer, TimerRef, Result}` is sent to the caller of `erlang:read_timer` when the operation has been processed.

More `Options`s can be added in the future.

If `Result` is an integer, it represents the time in milliseconds left until the timer expires.

If `Result` is `false`, a timer corresponding to `TimerRef` could not be found. This because the timer had expired, or been canceled, or because `TimerRef` never has corresponded to a timer. Even if the timer has expired, it does not tell you whether or not the time-out message has arrived at its destination yet.

Note:

The timer service that manages the timer can be co-located with another scheduler than the scheduler that the calling process is executing on. If so, communication with the timer service takes much longer time than if it is located locally. If the calling process is in a critical path, and can do other things while waiting for the result of this operation, you want to use option `{async, true}`. If using option `{async, false}`, the calling process is blocked until the operation has been performed.

See also *`erlang:send_after/4`*, *`erlang:start_timer/4`*, and *`erlang:cancel_timer/2`*.

`ref_to_list(Ref) -> string()`

Types:

```
Ref = reference()
```

Returns a string corresponding to the text representation of `Ref`.

Warning:

This BIF is intended for debugging and is not to be used in application programs.

`register(RegName, PidOrPort) -> true`

Types:

```
RegName = atom()
PidOrPort = port() | pid()
```

Associates the name `RegName` with a process identifier (pid) or a port identifier. `RegName`, which must be an atom, can be used instead of the pid or port identifier in send operator (`RegName ! Message`). Example:

```
> register(db, Pid).
true
```

Failures:

`badarg`
: If `PidOrPort` is not an existing local process or port.

`badarg`
: If `RegName` is already in use.

`badarg`
: If the process or port is already registered (already has a name).

`badarg`
: If `RegName` is the atom `undefined`.

`registered() -> [RegName]`

Types:

```
RegName = atom()
```

Returns a list of names that have been registered using *`register/2`*, for example:

```
> registered().
[code_server, file_server, init, user, my_db]
```

`erlang:resume_process(Suspendee) -> true`

Types:

`Suspendee = pid()`

Decreases the suspend count on the process identified by `Suspendee`. `Suspendee` is previously to have been suspended through *`erlang:suspend_process/2`* or *`erlang:suspend_process/1`* by the process calling `erlang:resume_process(Suspendee)`. When the suspend count on `Suspendee` reaches zero, `Suspendee` is resumed, that is, its state is changed from suspended into the state it had before it was suspended.

Warning:

This BIF is intended for debugging only.

Failures:

`badarg`
: If `Suspendee` is not a process identifier.

`badarg`
: If the process calling `erlang:resume_process/1` had not previously increased the suspend count on the process identified by `Suspendee`.

`badarg`
: If the process identified by `Suspendee` is not alive.

`round(Number) -> integer()`

Types:

`Number = number()`

Returns an integer by rounding `Number`, for example:

```
round(5.5).
6
```

Allowed in guard tests.

`self() -> pid()`

Returns the process identifier of the calling process, for example:

```
> self().
<0.26.0>
```

Allowed in guard tests.

`erlang:send(Dest, Msg) -> Msg`

Types:

`Dest = dst()`

`Msg = term()`

`dst() =`

```
        pid() |
        port() |
        (RegName :: atom()) |
        {RegName :: atom(), Node :: node()}
```

Sends a message and returns `Msg`. This is the same as `Dest ! Msg`.

`Dest` can be a remote or local process identifier, a (local) port, a locally registered name, or a tuple `{RegName, Node}` for a registered name at another node.

`erlang:send(Dest, Msg, Options) -> Res`

Types:

```
    Dest = dst()
    Msg = term()
    Options = [nosuspend | noconnect]
    Res = ok | nosuspend | noconnect
    dst() =
        pid() |
        port() |
        (RegName :: atom()) |
        {RegName :: atom(), Node :: node()}
```

Either sends a message and returns `ok`, or does not send the message but returns something else (see below). Otherwise the same as *`erlang:send/2`*. For more detailed explanation and warnings, see *`erlang:send_nosuspend/2,3`*.

Options:

`nosuspend`
: If the sender would have to be suspended to do the send, `nosuspend` is returned instead.

`noconnect`
: If the destination node would have to be auto-connected to do the send, `noconnect` is returned instead.

Warning:

As with `erlang:send_nosuspend/2,3`: use with extreme care.

`erlang:send_after(Time, Dest, Msg) -> TimerRef`

Types:

```
    Time = integer() >= 0
    Dest = pid() | atom()
    Msg = term()
    TimerRef = reference()
```

Starts a timer. The same as calling *`erlang:send_after(Time, Dest, Msg, [])`*.

`erlang:send_after(Time, Dest, Msg, Options) -> TimerRef`

Types:

```
Time = integer()
Dest = pid() | atom()
Msg = term()
Options = [Option]
Abs = boolean()
Option = {abs, Abs}
TimerRef = reference()
```

Starts a timer. When the timer expires, the message `Msg` is sent to the process identified by `Dest`. Apart from the format of the time-out message, this function works exactly as *`erlang:start_timer/4`*.

`erlang:send_nosuspend(Dest, Msg) -> boolean()`

Types:

```
Dest = dst()
Msg = term()
dst() =
    pid() |
    port() |
    (RegName :: atom()) |
    {RegName :: atom(), Node :: node()}
```

The same as *`erlang:send(Dest, Msg, [nosuspend])`*, but returns `true` if the message was sent and `false` if the message was not sent because the sender would have had to be suspended.

This function is intended for send operations to an unreliable remote node without ever blocking the sending (Erlang) process. If the connection to the remote node (usually not a real Erlang node, but a node written in C or Java) is overloaded, this function **does not send the message** and returns `false`.

The same occurs if `Dest` refers to a local port that is busy. For all other destinations (allowed for the ordinary send operator `'!'`), this function sends the message and returns `true`.

This function is only to be used in rare circumstances where a process communicates with Erlang nodes that can disappear without any trace, causing the TCP buffers and the drivers queue to be over-full before the node is shut down (because of tick time-outs) by `net_kernel`. The normal reaction to take when this occurs is some kind of premature shutdown of the other node.

Notice that ignoring the return value from this function would result in an **unreliable** message passing, which is contradictory to the Erlang programming model. The message is **not** sent if this function returns `false`.

In many systems, transient states of overloaded queues are normal. Although this function returns `false` does not mean that the other node is guaranteed to be non-responsive, it could be a temporary overload. Also, a return value of `true` does only mean that the message can be sent on the (TCP) channel without blocking; the message is not guaranteed to arrive at the remote node. For a disconnected non-responsive node, the return value is `true` (mimics the behavior of operator `!`). The expected behavior and the actions to take when the function returns `false` are application- and hardware-specific.

Warning:

Use with extreme care.

`erlang:send_nosuspend(Dest, Msg, Options) -> boolean()`

Types:

```
Dest = dst()
Msg = term()
Options = [noconnect]
dst() =
    pid() |
    port() |
    (RegName :: atom()) |
    {RegName :: atom(), Node :: node()}
```

The same as *`erlang:send(Dest, Msg, [nosuspend | Options])`*, but with a Boolean return value.

This function behaves like *`erlang:send_nosuspend/2`*, but takes a third parameter, a list of options. The only option is `noconnect`, which makes the function return `false` if the remote node is not currently reachable by the local node. The normal behavior is to try to connect to the node, which can stall the process during a short period. The use of option `noconnect` makes it possible to be sure not to get the slightest delay when sending to a remote process. This is especially useful when communicating with nodes that expect to always be the connecting part (that is, nodes written in C or Java).

Whenever the function returns `false` (either when a suspend would occur or when `noconnect` was specified and the node was not already connected), the message is guaranteed **not** to have been sent.

Warning:

Use with extreme care.

`erlang:set_cookie(Node, Cookie) -> true`

Types:

```
Node = node()
Cookie = atom()
```

Sets the magic cookie of `Node` to the atom `Cookie`. If `Node` is the local node, the function also sets the cookie of all other unknown nodes to `Cookie` (see section *Distributed Erlang* in the Erlang Reference Manual in System Documentation).

Failure: `function_clause` if the local node is not alive.

`setelement(Index, Tuple1, Value) -> Tuple2`

Types:

```
Index = integer() >= 1
```

1..tuple_size(Tuple1

```
Tuple1 = Tuple2 = tuple()
Value = term()
```

Returns a tuple that is a copy of argument `Tuple1` with the element specified by integer argument `Index` (the first element is the element with index 1) replaced by argument `Value`, for example:

```
> setelement(2, {10, green, bottles}, red).
{10,red,bottles}
```

`size(Item) -> integer() >= 0`

Types:

`Item = tuple() | binary()`

Returns the number of elements in a tuple or the number of bytes in a binary or bitstring, for example:

```
> size({morni, mulle, bwange}).
3
> size(<<11, 22, 33>>).
3
```

For bitstrings, the number of whole bytes is returned. That is, if the number of bits in the bitstring is not divisible by 8, the resulting number of bytes is rounded **down**.

Allowed in guard tests.

See also *`tuple_size/1`*, *`byte_size/1`*, and *`bit_size/1`*.

`spawn(Fun) -> pid()`

Types:

`Fun = function()`

Returns the process identifier of a new process started by the application of `Fun` to the empty list `[]`. Otherwise works like *`spawn/3`*.

`spawn(Node, Fun) -> pid()`

Types:

`Node = node()`

`Fun = function()`

Returns the process identifier of a new process started by the application of `Fun` to the empty list `[]` on `Node`. If `Node` does not exist, a useless pid is returned. Otherwise works like *`spawn/3`*.

`spawn(Module, Function, Args) -> pid()`

Types:

`Module = module()`

`Function = atom()`

`Args = [term()]`

Returns the process identifier of a new process started by the application of `Module:Function` to `Args`.

`error_handler:undefined_function(Module, Function, Args)` is evaluated by the new process if `Module:Function/Arity` does not exist (where `Arity` is the length of `Args`). The error handler can be redefined (see *`process_flag/2`*). If `error_handler` is undefined, or the user has redefined the default `error_handler` and its replacement is undefined, a failure with reason `undef` occurs.

Example:

```
> spawn(speed, regulator, [high_speed, thin_cut]).
<0.13.1>
```

`spawn(Node, Module, Function, Args) -> pid()`

Types:

```
Node = node()
Module = module()
Function = atom()
Args = [term()]
```

Returns the process identifier (pid) of a new process started by the application of `Module:Function` to `Args` on `Node`. If `Node` does not exist, a useless pid is returned. Otherwise works like *spawn/3*.

`spawn_link(Fun) -> pid()`

Types:

```
Fun = function()
```

Returns the process identifier of a new process started by the application of `Fun` to the empty list `[]`. A link is created between the calling process and the new process, atomically. Otherwise works like *spawn/3*.

`spawn_link(Node, Fun) -> pid()`

Types:

```
Node = node()
Fun = function()
```

Returns the process identifier (pid) of a new process started by the application of `Fun` to the empty list `[]` on `Node`. A link is created between the calling process and the new process, atomically. If `Node` does not exist, a useless pid is returned and an exit signal with reason `noconnection` is sent to the calling process. Otherwise works like *spawn/3*.

`spawn_link(Module, Function, Args) -> pid()`

Types:

```
Module = module()
Function = atom()
Args = [term()]
```

Returns the process identifier of a new process started by the application of `Module:Function` to `Args`. A link is created between the calling process and the new process, atomically. Otherwise works like *spawn/3*.

`spawn_link(Node, Module, Function, Args) -> pid()`

Types:

```
Node = node()
Module = module()
Function = atom()
Args = [term()]
```

Returns the process identifier (pid) of a new process started by the application of `Module:Function` to `Args` on `Node`. A link is created between the calling process and the new process, atomically. If `Node` does not exist, a useless pid is returned and an exit signal with reason `noconnection` is sent to the calling process. Otherwise works like *spawn/3*.

`spawn_monitor(Fun) -> {pid(), reference()}`

Types:

```
Fun = function()
```

Returns the process identifier of a new process, started by the application of `Fun` to the empty list `[]`, and a reference for a monitor created to the new process. Otherwise works like *`spawn/3`*.

```
spawn_monitor(Module, Function, Args) -> {pid(), reference()}
```

Types:

```
Module = module()
Function = atom()
Args = [term()]
```

A new process is started by the application of `Module:Function` to `Args`. The process is monitored at the same time. Returns the process identifier and a reference for the monitor. Otherwise works like *`spawn/3`*.

```
spawn_opt(Fun, Options) -> pid() | {pid(), reference()}
```

Types:

```
Fun = function()
Options = [spawn_opt_option()]
priority_level() = low | normal | high | max
max_heap_size() =
    integer() >= 0 |
    #{size => integer() >= 0,
      kill => boolean(),
      error_logger => boolean()}
message_queue_data() = off_heap | on_heap
spawn_opt_option() =
    link |
    monitor |
    {priority, Level :: priority_level()} |
    {fullsweep_after, Number :: integer() >= 0} |
    {min_heap_size, Size :: integer() >= 0} |
    {min_bin_vheap_size, VSize :: integer() >= 0} |
    {max_heap_size, Size :: max_heap_size()} |
    {message_queue_data, MQD :: message_queue_data()}
```

Returns the process identifier (pid) of a new process started by the application of `Fun` to the empty list `[]`. Otherwise works like *`spawn_opt/4`*.

If option `monitor` is specified, the newly created process is monitored, and both the pid and reference for the monitor are returned.

```
spawn_opt(Node, Fun, Options) -> pid() | {pid(), reference()}
```

Types:

```
Node = node()
Fun = function()
Options = [spawn_opt_option()]
priority_level() = low | normal | high | max
max_heap_size() =
    integer() >= 0 |
    #{size => integer() >= 0,
```

```
        kill => boolean(),
        error_logger => boolean()}
message_queue_data() = off_heap | on_heap
spawn_opt_option() =
    link |
    monitor |
    {priority, Level :: priority_level()} |
    {fullsweep_after, Number :: integer() >= 0} |
    {min_heap_size, Size :: integer() >= 0} |
    {min_bin_vheap_size, VSize :: integer() >= 0} |
    {max_heap_size, Size :: max_heap_size()} |
    {message_queue_data, MQD :: message_queue_data()}
```

Returns the process identifier (pid) of a new process started by the application of `Fun` to the empty list `[]` on `Node`. If `Node` does not exist, a useless pid is returned. Otherwise works like *`spawn_opt/4`*.

```
spawn_opt(Module, Function, Args, Options) ->
             pid() | {pid(), reference()}
```

Types:

```
Module = module()
Function = atom()
Args = [term()]
Options = [spawn_opt_option()]
priority_level() = low | normal | high | max
max_heap_size() =
    integer() >= 0 |
    #{size => integer() >= 0,
      kill => boolean(),
      error_logger => boolean()}
message_queue_data() = off_heap | on_heap
spawn_opt_option() =
    link |
    monitor |
    {priority, Level :: priority_level()} |
    {fullsweep_after, Number :: integer() >= 0} |
    {min_heap_size, Size :: integer() >= 0} |
    {min_bin_vheap_size, VSize :: integer() >= 0} |
    {max_heap_size, Size :: max_heap_size()} |
    {message_queue_data, MQD :: message_queue_data()}
```

Works as *`spawn/3`*, except that an extra option list is specified when creating the process.

If option `monitor` is specified, the newly created process is monitored, and both the pid and reference for the monitor are returned.

Options:

`link`

Sets a link to the parent process (like *`spawn_link/3`* does).

`monitor`

Monitors the new process (like *`monitor/2`* does).

`{priority, Level`

Sets the priority of the new process. Equivalent to executing *`process_flag(priority, Level)`* in the start function of the new process, except that the priority is set before the process is selected for execution for the first time. For more information on priorities, see *`process_flag(priority, Level)`*.

`{fullsweep_after, Number}`

Useful only for performance tuning. Do not use this option unless you know that there is problem with execution times or memory consumption, and ensure that the option improves matters.

The Erlang runtime system uses a generational garbage collection scheme, using an "old heap" for data that has survived at least one garbage collection. When there is no more room on the old heap, a fullsweep garbage collection is done.

Option `fullsweep_after` makes it possible to specify the maximum number of generational collections before forcing a fullsweep, even if there is room on the old heap. Setting the number to zero disables the general collection algorithm, that is, all live data is copied at every garbage collection.

A few cases when it can be useful to change `fullsweep_after`:

- If binaries that are no longer used are to be thrown away as soon as possible. (Set `Number` to zero.)
- A process that mostly have short-lived data is fullsweeped seldom or never, that is, the old heap contains mostly garbage. To ensure a fullsweep occasionally, set `Number` to a suitable value, such as 10 or 20.
- In embedded systems with a limited amount of RAM and no virtual memory, you might want to preserve memory by setting `Number` to zero. (The value can be set globally, see *`erlang:system_flag/2`*.)

`{min_heap_size, Size}`

Useful only for performance tuning. Do not use this option unless you know that there is problem with execution times or memory consumption, and ensure that the option improves matters.

Gives a minimum heap size, in words. Setting this value higher than the system default can speed up some processes because less garbage collection is done. However, setting a too high value can waste memory and slow down the system because of worse data locality. Therefore, use this option only for fine-tuning an application and to measure the execution time with various `Size` values.

`{min_bin_vheap_size, VSize}`

Useful only for performance tuning. Do not use this option unless you know that there is problem with execution times or memory consumption, and ensure that the option improves matters.

Gives a minimum binary virtual heap size, in words. Setting this value higher than the system default can speed up some processes because less garbage collection is done. However, setting a too high value can waste memory. Therefore, use this option only for fine-tuning an application and to measure the execution time with various `VSize` values.

`{max_heap_size, Size}`

Sets the `max_heap_size` process flag. The default `max_heap_size` is determined by command-line argument *`+hmax`* in `erl(1)`. For more information, see the documentation of *`process_flag(max_heap_size, Size)`*.

`{message_queue_data, MQD}`

Sets the state of the `message_queue_data` process flag. `MQD` is to be either `off_heap` or `on_heap`. The default `message_queue_data` process flag is determined by command-line argument *`+hmqd`* in `erl(1)`. For more information, see the documentation of *`process_flag(message_queue_data, MQD)`*.

`spawn_opt(Node, Module, Function, Args, Options) ->`

```
            pid() | {pid(), reference()}
```

Types:

```
Node = node()
Module = module()
Function = atom()
Args = [term()]
Options = [spawn_opt_option()]
priority_level() = low | normal | high | max
max_heap_size() =
    integer() >= 0 |
    #{size => integer() >= 0,
      kill => boolean(),
      error_logger => boolean()}
message_queue_data() = off_heap | on_heap
spawn_opt_option() =
    link |
    monitor |
    {priority, Level :: priority_level()} |
    {fullsweep_after, Number :: integer() >= 0} |
    {min_heap_size, Size :: integer() >= 0} |
    {min_bin_vheap_size, VSize :: integer() >= 0} |
    {max_heap_size, Size :: max_heap_size()} |
    {message_queue_data, MQD :: message_queue_data()}
```

Returns the process identifier (pid) of a new process started by the application of `Module:Function` to `Args` on `Node`. If `Node` does not exist, a useless pid is returned. Otherwise works like *`spawn_opt/4`*.

Note:

Option `monitor` is not supported by `spawn_opt/5`.

`split_binary(Bin, Pos) -> {binary(), binary()}`

Types:

```
Bin = binary()
Pos = integer() >= 0
```

0..byte_size(Bin)

Returns a tuple containing the binaries that are the result of splitting `Bin` into two parts at position `Pos`. This is not a destructive operation. After the operation, there are three binaries altogether. Example:

```
> B = list_to_binary("0123456789").
<<"0123456789">>
> byte_size(B).
10
> {B1, B2} = split_binary(B,3).
{<<"012">>,<<"3456789">>}
> byte_size(B1).
3
> byte_size(B2).
7
```

`erlang:start_timer(Time, Dest, Msg) -> TimerRef`

Types:

```
Time = integer() >= 0
Dest = pid() | atom()
Msg = term()
TimerRef = reference()
```

Starts a timer. The same as calling *`erlang:start_timer(Time, Dest, Msg, [])`*.

`erlang:start_timer(Time, Dest, Msg, Options) -> TimerRef`

Types:

```
Time = integer()
Dest = pid() | atom()
Msg = term()
Options = [Option]
Abs = boolean()
Option = {abs, Abs}
TimerRef = reference()
```

Starts a timer. When the timer expires, the message `{timeout, TimerRef, Msg}` is sent to the process identified by `Dest`.

`Options`:

`{abs, false}`

This is the default. It means the `Time` value is interpreted as a time in milliseconds **relative** current *Erlang monotonic time*.

`{abs, true}`

Absolute `Time` value. The `Time` value is interpreted as an absolute Erlang monotonic time in milliseconds.

More `Options` can be added in the future.

The absolute point in time, the timer is set to expire on, must be in the interval `[` *`erlang:system_info(start_time)`*, *`erlang:system_info(end_time)`*`]`. If a relative time is specified, the `Time` value is not allowed to be negative.

If `Dest` is a `pid()`, it must be a `pid()` of a process created on the current runtime system instance. This process has either terminated or not. If `Dest` is an `atom()`, it is interpreted as the name of a locally registered process. The process referred to by the name is looked up at the time of timer expiration. No error is returned if the name does not refer to a process.

If `Dest` is a `pid()`, the timer is automatically canceled if the process referred to by the `pid()` is not alive, or if the process exits. This feature was introduced in ERTS 5.4.11. Notice that timers are not automatically canceled when `Dest` is an `atom()`.

See also *`erlang:send_after/4`*, *`erlang:cancel_timer/2`*, and *`erlang:read_timer/2`*.

Failure: `badarg` if the arguments do not satisfy the requirements specified here.

`statistics(Item :: active_tasks) -> [ActiveTasks]`

Types:

```
ActiveTasks = integer() >= 0
```

Returns the same as *statistics(active_tasks_all)* with the exception that no information about the dirty IO run queue and its associated schedulers is part of the result. That is, only tasks that are expected to be CPU bound are part of the result.

```
statistics(Item :: active_tasks_all) -> [ActiveTasks]
```

Types:

```
ActiveTasks = integer() >= 0
```

Returns a list where each element represents the amount of active processes and ports on each run queue and its associated schedulers. That is, the number of processes and ports that are ready to run, or are currently running. Values for normal run queues and their associated schedulers are located first in the resulting list. The first element corresponds to scheduler number 1 and so on. If support for dirty schedulers exist, an element with the value for the dirty CPU run queue and its associated dirty CPU schedulers follow and then as last element the value for the the dirty IO run queue and its associated dirty IO schedulers follow. The information is **not** gathered atomically. That is, the result is not necessarily a consistent snapshot of the state, but instead quite efficiently gathered.

Note:

Each normal scheduler has one run queue that it manages. If dirty schedulers schedulers are supported, all dirty CPU schedulers share one run queue, and all dirty IO schedulers share one run queue. That is, we have multiple normal run queues, one dirty CPU run queue and one dirty IO run queue. Work can **not** migrate between the different types of run queues. Only work in normal run queues can migrate to other normal run queues. This has to be taken into account when evaluating the result.

See also *statistics(total_active_tasks)*, *statistics(run_queue_lengths)*, *statistics(run_queue_lengths_all)*, *statistics(total_run_queue_lengths)*, and *statistics(total_run_queue_lengths_all)*.

```
statistics(Item :: context_switches) -> {ContextSwitches, 0}
```

Types:

```
ContextSwitches = integer() >= 0
```

Returns the total number of context switches since the system started.

```
statistics(Item :: exact_reductions) ->
              {Total_Exact_Reductions,
               Exact_Reductions_Since_Last_Call}
```

Types:

```
Total_Exact_Reductions = Exact_Reductions_Since_Last_Call = integer() >= 0
```

Returns the number of exact reductions.

Note:

`statistics(exact_reductions)` is a more expensive operation than *statistics(reductions)*, especially on an Erlang machine with SMP support.

```
statistics(Item :: garbage_collection) ->
```

```
              {Number_of_GCs, Words_Reclaimed, 0}
```

Types:

```
   Number_of_GCs = Words_Reclaimed = integer() >= 0
```

Returns information about garbage collection, for example:

```
> statistics(garbage_collection).
{85,23961,0}
```

This information can be invalid for some implementations.

```
statistics(Item :: io) -> {{input, Input}, {output, Output}}
```

Types:

```
   Input = Output = integer() >= 0
```

Returns `Input`, which is the total number of bytes received through ports, and `Output`, which is the total number of bytes output to ports.

```
statistics(Item :: microstate_accounting) ->
              [MSAcc_Thread] | undefined
```

Types:

```
   MSAcc_Thread =
       #{type := MSAcc_Thread_Type,
         id := MSAcc_Thread_Id,
         counters := MSAcc_Counters}
   MSAcc_Thread_Type = scheduler | async | aux
   MSAcc_Thread_Id = integer() >= 0
   MSAcc_Counters = #{MSAcc_Thread_State => integer() >= 0}
   MSAcc_Thread_State =
       alloc |
       aux |
       bif |
       busy_wait |
       check_io |
       emulator |
       ets |
       gc |
       gc_fullsweep |
       nif |
       other |
       port |
       send |
       sleep |
       timers
```

Microstate accounting can be used to measure how much time the Erlang runtime system spends doing various tasks. It is designed to be as lightweight as possible, but some overhead exists when this is enabled. Microstate accounting is meant to be a profiling tool to help finding performance bottlenecks. To `start`/`stop`/`reset` microstate accounting, use system flag *`microstate_accounting`*.

`statistics(microstate_accounting)` returns a list of maps representing some of the OS threads within ERTS. Each map contains `type` and `id` fields that can be used to identify what thread it is, and also a counters field that contains data about how much time has been spent in the various states.

Example:

```
> erlang:statistics(microstate_accounting).
[#{counters => #{aux => 1899182914,
                 check_io => 2605863602,
                 emulator => 45731880463,
                 gc => 1512206910,
                 other => 5421338456,
                 port => 221631,
                 sleep => 5150294100},
   id => 1,
   type => scheduler}|...]
```

The time unit is the same as returned by *`os:perf_counter/0`*. So, to convert it to milliseconds, you can do something like this:

```
lists:map(
  fun(#{ counters := Cnt } = M) ->
          MsCnt = maps:map(fun(_K, PerfCount) ->
                                   erlang:convert_time_unit(PerfCount, perf_counter, 1000)
                           end, Cnt),
         M#{ counters := MsCnt }
  end, erlang:statistics(microstate_accounting)).
```

Notice that these values are not guaranteed to be the exact time spent in each state. This is because of various optimisation done to keep the overhead as small as possible.

`MSAcc_Thread_Type`s:

`scheduler`
: The main execution threads that do most of the work.

`dirty_cpu_scheduler`
: The threads for long running cpu intensive work.

`dirty_io_scheduler`
: The threads for long running I/O work.

`async`
: Async threads are used by various linked-in drivers (mainly the file drivers) do offload non-CPU intensive work.

`aux`
: Takes care of any work that is not specifically assigned to a scheduler.

The following `MSAcc_Thread_State`s are available. All states are exclusive, meaning that a thread cannot be in two states at once. So, if you add the numbers of all counters in a thread, you get the total runtime for that thread.

`aux`
: Time spent handling auxiliary jobs.

`check_io`
: Time spent checking for new I/O events.

`emulator`
: Time spent executing Erlang processes.

`gc`
: Time spent doing garbage collection. When extra states are enabled this is the time spent doing non-fullsweep garbage collections.

`other`
: Time spent doing unaccounted things.

`port`
: Time spent executing ports.

`sleep`
: Time spent sleeping.

More fine-grained `MSAcc_Thread_State`s can be added through configure (such as `./configure --with-microstate-accounting=extra`). Enabling these states causes performance degradation when microstate accounting is turned off and increases the overhead when it is turned on.

`alloc`
: Time spent managing memory. Without extra states this time is spread out over all other states.

`bif`
: Time spent in BIFs. Without extra states this time is part of the `emulator` state.

`busy_wait`
: Time spent busy waiting. This is also the state where a scheduler no longer reports that it is active when using *`statistics(scheduler_wall_time)`*. So, if you add all other states but this and sleep, and then divide that by all time in the thread, you should get something very similar to the `scheduler_wall_time` fraction. Without extra states this time is part of the `other` state.

`ets`
: Time spent executing ETS BIFs. Without extra states this time is part of the `emulator` state.

`gc_full`
: Time spent doing fullsweep garbage collection. Without extra states this time is part of the `gc` state.

`nif`
: Time spent in NIFs. Without extra states this time is part of the `emulator` state.

`send`
: Time spent sending messages (processes only). Without extra states this time is part of the `emulator` state.

`timers`
: Time spent managing timers. Without extra states this time is part of the `other` state.

The utility module *`msacc(3)`* can be used to more easily analyse these statistics.

Returns `undefined` if system flag *`microstate_accounting`* is turned off.

The list of thread information is unsorted and can appear in different order between calls.

> **Note:**
>
> The threads and states are subject to change without any prior notice.

```
statistics(Item :: reductions) ->
               {Total_Reductions, Reductions_Since_Last_Call}
```

Types:

```
   Total_Reductions = Reductions_Since_Last_Call = integer() >= 0
```

Returns information about reductions, for example:

```
> statistics(reductions).
{2046,11}
```

Note:

As from ERTS 5.5 (Erlang/OTP R11B), this value does not include reductions performed in current time slices of currently scheduled processes. If an exact value is wanted, use *statistics(exact_reductions)*.

```
statistics(Item :: run_queue) -> integer() >= 0
```

Returns the total length of all normal run-queues. That is, the number of processes and ports that are ready to run on all available normal run-queues. Dirty run queues are not part of the result. The information is gathered atomically. That is, the result is a consistent snapshot of the state, but this operation is much more expensive compared to *statistics(total_run_queue_lengths)*, especially when a large amount of schedulers is used.

```
statistics(Item :: run_queue_lengths) -> [RunQueueLength]
```

Types:

```
RunQueueLength = integer() >= 0
```

Returns the same as *statistics(run_queue_lengths_all)* with the exception that no information about the dirty IO run queue is part of the result. That is, only run queues with work that is expected to be CPU bound is part of the result.

```
statistics(Item :: run_queue_lengths_all) -> [RunQueueLength]
```

Types:

```
RunQueueLength = integer() >= 0
```

Returns a list where each element represents the amount of processes and ports ready to run for each run queue. Values for normal run queues are located first in the resulting list. The first element corresponds to the normal run queue of scheduler number 1 and so on. If support for dirty schedulers exist, values for the dirty CPU run queue and the dirty IO run queue follow (in that order) at the end. The information is **not** gathered atomically. That is, the result is not necessarily a consistent snapshot of the state, but instead quite efficiently gathered.

Note:

Each normal scheduler has one run queue that it manages. If dirty schedulers schedulers are supported, all dirty CPU schedulers share one run queue, and all dirty IO schedulers share one run queue. That is, we have multiple normal run queues, one dirty CPU run queue and one dirty IO run queue. Work can **not** migrate between the different types of run queues. Only work in normal run queues can migrate to other normal run queues. This has to be taken into account when evaluating the result.

See also *statistics(run_queue_lengths)*, *statistics(total_run_queue_lengths_all)*, *statistics(total_run_queue_lengths)*, *statistics(active_tasks)*, *statistics(active_tasks_all)*, and *statistics(total_active_tasks)*, *statistics(total_active_tasks_all)*.

```
statistics(Item :: runtime) ->
              {Total_Run_Time, Time_Since_Last_Call}
```

Types:

```
Total_Run_Time = Time_Since_Last_Call = integer() >= 0
```

Returns information about runtime, in milliseconds.

This is the sum of the runtime for all threads in the Erlang runtime system and can therefore be greater than the wall clock time.

Warning:

This value might wrap due to limitations in the underlying functionality provided by the operating system that is used.

Example:

```
> statistics(runtime).
{1690,1620}
```

```
statistics(Item :: scheduler_wall_time) ->
              [{SchedulerId, ActiveTime, TotalTime}] | undefined
```

Types:

```
SchedulerId = integer() >= 1
ActiveTime = TotalTime = integer() >= 0
```

Returns a list of tuples with `{SchedulerId, ActiveTime, TotalTime}`, where `SchedulerId` is an integer ID of the scheduler, `ActiveTime` is the duration the scheduler has been busy, and `TotalTime` is the total time duration since *`scheduler_wall_time`* activation for the specific scheduler. Note that activation time can differ significantly between schedulers. Currently dirty schedulers are activated at system start while normal schedulers are activated some time after the `scheduler_wall_time` functionality is enabled. The time unit is undefined and can be subject to change between releases, OSs, and system restarts. `scheduler_wall_time` is only to be used to calculate relative values for scheduler utilization. `ActiveTime` can never exceed `TotalTime`.

The definition of a busy scheduler is when it is not idle and is not scheduling (selecting) a process or port, that is:

- Executing process code
- Executing linked-in driver or NIF code
- Executing BIFs, or any other runtime handling
- Garbage collecting
- Handling any other memory management

Notice that a scheduler can also be busy even if the OS has scheduled out the scheduler thread.

Returns `undefined` if system flag *`scheduler_wall_time`* is turned off.

The list of scheduler information is unsorted and can appear in different order between calls.

As of ERTS version 9.0, also dirty CPU schedulers will be included in the result. That is, all scheduler threads that are expected to handle CPU bound work. If you also want information about dirty I/O schedulers, use *`statistics(scheduler_wall_time_all)`* instead.

Normal schedulers will have scheduler identifiers in the range `1 =< SchedulerId =<` *`erlang:system_info(schedulers)`*. Dirty CPU schedulers will have scheduler identifiers in the range `erlang:system_info(schedulers) < SchedulerId =< erlang:system_info(schedulers) +` *`erlang:system_info(dirty_cpu_schedulers)`*.

Note:

The different types of schedulers handle specific types of jobs. Every job is assigned to a specific scheduler type. Jobs can migrate between different schedulers of the same type, but never between schedulers of different types. This fact has to be taken under consideration when evaluating the result returned.

Using `scheduler_wall_time` to calculate scheduler utilization:

```
> erlang:system_flag(scheduler_wall_time, true).
false
> Ts0 = lists:sort(erlang:statistics(scheduler_wall_time)), ok.
ok
```

Some time later the user takes another snapshot and calculates scheduler utilization per scheduler, for example:

```
> Ts1 = lists:sort(erlang:statistics(scheduler_wall_time)), ok.
ok
> lists:map(fun({{I, A0, T0}, {I, A1, T1}}) ->
 {I, (A1 - A0)/(T1 - T0)} end, lists:zip(Ts0,Ts1)).
[{1,0.9743474730177548},
 {2,0.9744843782751444},
 {3,0.9995902361669045},
 {4,0.9738012596572161},
 {5,0.9717956667018103},
 {6,0.9739235846420741},
 {7,0.973237033077876},
 {8,0.9741297293248656}]
```

Using the same snapshots to calculate a total scheduler utilization:

```
> {A, T} = lists:foldl(fun({{_, A0, T0}, {_, A1, T1}}, {Ai,Ti}) ->
 {Ai + (A1 - A0), Ti + (T1 - T0)} end, {0, 0}, lists:zip(Ts0,Ts1)),
 TotalSchedulerUtilization = A/T.
0.9769136803764825
```

Total scheduler utilization will equal `1.0` when all schedulers have been active all the time between the two measurements.

Another (probably more) useful value is to calculate total scheduler utilization weighted against maximum amount of available CPU time:

```
> WeightedSchedulerUtilization = (TotalSchedulerUtilization
                                  * (erlang:system_info(schedulers)
                                     + erlang:system_info(dirty_cpu_schedulers)))
                                 / erlang:system_info(logical_processors_available).
0.9769136803764825
```

This weighted scheduler utilization will reach `1.0` when schedulers are active the same amount of time as maximum available CPU time. If more schedulers exist than available logical processors, this value may be greater than `1.0`.

As of ERTS version 9.0, the Erlang runtime system with SMP support will as default have more schedulers than logical processors. This due to the dirty schedulers.

Note:

`scheduler_wall_time` is by default disabled. To enable it, use `erlang:system_flag(scheduler_wall_time, true)`.

```
statistics(Item :: scheduler_wall_time_all) ->
              [{SchedulerId, ActiveTime, TotalTime}] | undefined
```

Types:

```
SchedulerId = integer() >= 1
ActiveTime = TotalTime = integer() >= 0
```

The same as *`statistics(scheduler_wall_time)`*, except that it also include information about all dirty I/O schedulers.

Dirty IO schedulers will have scheduler identifiers in the range *`erlang:system_info(schedulers)`* + *`erlang:system_info(dirty_cpu_schedulers)`* < `SchedulerId` =< `erlang:system_info(schedulers)` + `erlang:system_info(dirty_cpu_schedulers)` + *`erlang:system_info(dirty_io_schedulers)`*.

Note:

Note that work executing on dirty I/O schedulers are expected to mainly wait for I/O. That is, when you get high scheduler utilization on dirty I/O schedulers, CPU utilization is **not** expected to be high due to this work.

```
statistics(Item :: total_active_tasks) -> ActiveTasks
```

Types:

```
ActiveTasks = integer() >= 0
```

The same as calling `lists:sum(`*`statistics(active_tasks)`*`)`, but more efficient.

```
statistics(Item :: total_active_tasks_all) -> ActiveTasks
```

Types:

```
ActiveTasks = integer() >= 0
```

The same as calling `lists:sum(`*`statistics(active_tasks_all)`*`)`, but more efficient.

```
statistics(Item :: total_run_queue_lengths) ->
              TotalRunQueueLengths
```

Types:

```
TotalRunQueueLengths = integer() >= 0
```

The same as calling `lists:sum(`*`statistics(run_queue_lengths)`*`)`, but more efficient.

```
statistics(Item :: total_run_queue_lengths_all) ->
              TotalRunQueueLengths
```

Types:

```
TotalRunQueueLengths = integer() >= 0
```

The same as calling `lists:sum(`*`statistics(run_queue_lengths_all)`*`)`, but more efficient.

```
statistics(Item :: wall_clock) ->
              {Total_Wallclock_Time,
               Wallclock_Time_Since_Last_Call}
```

Types:

```
Total_Wallclock_Time = Wallclock_Time_Since_Last_Call = integer() >= 0
```

Returns information about wall clock. `wall_clock` can be used in the same manner as `runtime`, except that real time is measured as opposed to runtime or CPU time.

```
erlang:suspend_process(Suspendee) -> true
```

Types:

```
Suspendee = pid()
```

Suspends the process identified by `Suspendee`. The same as calling *`erlang:suspend_process(Suspendee, [])`*.

Warning:

This BIF is intended for debugging only.

```
erlang:suspend_process(Suspendee, OptList) -> boolean()
```

Types:

```
Suspendee = pid()
OptList = [Opt]
Opt = unless_suspending | asynchronous
```

Increases the suspend count on the process identified by `Suspendee` and puts it in the suspended state if it is not already in that state. A suspended process is not scheduled for execution until the process has been resumed.

A process can be suspended by multiple processes and can be suspended multiple times by a single process. A suspended process does not leave the suspended state until its suspend count reaches zero. The suspend count of `Suspendee` is decreased when *`erlang:resume_process(Suspendee)`* is called by the same process that called `erlang:suspend_process(Suspendee)`. All increased suspend counts on other processes acquired by a process are automatically decreased when the process terminates.

Options (`Opts`):

`asynchronous`

A suspend request is sent to the process identified by `Suspendee`. `Suspendee` eventually suspends unless it is resumed before it could suspend. The caller of `erlang:suspend_process/2` returns immediately, regardless of whether `Suspendee` has suspended yet or not. The point in time when `Suspendee` suspends cannot be deduced from other events in the system. It is only guaranteed that `Suspendee` **eventually** suspends (unless it is resumed). If option `asynchronous` has **not** been passed, the caller of `erlang:suspend_process/2` is blocked until `Suspendee` has suspended.

`unless_suspending`

The process identified by `Suspendee` is suspended unless the calling process already is suspending `Suspendee`. If `unless_suspending` is combined with option `asynchronous`, a suspend request is sent unless the calling process already is suspending `Suspendee` or if a suspend request already has been sent and is in transit. If the calling process already is suspending `Suspendee`, or if combined with option `asynchronous` and a send request already is in transit, `false` is returned and the suspend count on `Suspendee` remains unchanged.

If the suspend count on the process identified by `Suspendee` is increased, `true` is returned, otherwise `false`.

Warning:

This BIF is intended for debugging only.

Failures:

`badarg`
: If `Suspendee` is not a process identifier.

`badarg`
: If the process identified by `Suspendee` is the same process as the process calling `erlang:suspend_process/2`.

`badarg`
: If the process identified by `Suspendee` is not alive.

`badarg`
: If the process identified by `Suspendee` resides on another node.

`badarg`
: If `OptList` is not a proper list of valid `Opts`.

`system_limit`
: If the process identified by `Suspendee` has been suspended more times by the calling process than can be represented by the currently used internal data structures. The system limit is > 2,000,000,000 suspends and will never be lower.

```
erlang:system_flag(Flag :: backtrace_depth, Depth) -> OldDepth
```

Types:

```
   Depth = OldDepth = integer() >= 0
```

Sets the maximum depth of call stack back-traces in the exit reason element of `'EXIT'` tuples. The flag also limits the stacktrace depth returned by `process_info` item `current_stacktrace`.

Returns the old value of the flag.

```
erlang:system_flag(Flag :: cpu_topology, CpuTopology) ->
                      OldCpuTopology
```

Types:

```
   CpuTopology = OldCpuTopology = cpu_topology()
   cpu_topology() = [LevelEntry :: level_entry()] | undefined
   level_entry() =
       {LevelTag :: level_tag(), SubLevel :: sub_level()} |
       {LevelTag :: level_tag(),
        InfoList :: info_list(),
        SubLevel :: sub_level()}
   level_tag() = core | node | processor | thread
   sub_level() =
       [LevelEntry :: level_entry()] |
```

```
    (LogicalCpuId :: {logical, integer() >= 0})
info_list() = []
```

Warning:

This argument is deprecated. Instead of using this argument, use command-line argument `+sct` in `erl(1)`.

When this argument is removed, a final CPU topology to use is determined at emulator boot time.

Sets the user-defined `CpuTopology`. The user-defined CPU topology overrides any automatically detected CPU topology. By passing `undefined` as `CpuTopology`, the system reverts to the CPU topology automatically detected. The returned value equals the value returned from `erlang:system_info(cpu_topology)` before the change was made.

Returns the old value of the flag.

The CPU topology is used when binding schedulers to logical processors. If schedulers are already bound when the CPU topology is changed, the schedulers are sent a request to rebind according to the new CPU topology.

The user-defined CPU topology can also be set by passing command-line argument `+sct` to `erl(1)`.

For information on type `CpuTopology` and more, see *`erlang:system_info(cpu_topology)`* as well as command-line flags `+sct` and `+sbt` in `erl(1)`.

```
erlang:system_flag(Flag :: dirty_cpu_schedulers_online,
                   DirtyCPUSchedulersOnline) ->
                      OldDirtyCPUSchedulersOnline
```

Types:

```
DirtyCPUSchedulersOnline = OldDirtyCPUSchedulersOnline = integer() >= 1
```

Sets the number of dirty CPU schedulers online. Range is `1 <= DirtyCPUSchedulersOnline <= N`, where `N` is the smallest of the return values of `erlang:system_info(dirty_cpu_schedulers)` and `erlang:system_info(schedulers_online)`.

Returns the old value of the flag.

The number of dirty CPU schedulers online can change if the number of schedulers online changes. For example, if 12 schedulers and 6 dirty CPU schedulers are online, and `system_flag/2` is used to set the number of schedulers online to 6, then the number of dirty CPU schedulers online is automatically decreased by half as well, down to 3. Similarly, the number of dirty CPU schedulers online increases proportionally to increases in the number of schedulers online.

For more information, see *`erlang:system_info(dirty_cpu_schedulers)`* and *`erlang:system_info(dirty_cpu_schedulers_online)`*.

```
erlang:system_flag(Flag :: fullsweep_after, Number) -> OldNumber
```

Types:

```
Number = OldNumber = integer() >= 0
```

Sets system flag `fullsweep_after`. `Number` is a non-negative integer indicating how many times generational garbage collections can be done without forcing a fullsweep collection. The value applies to new processes, while processes already running are not affected.

Returns the old value of the flag.

In low-memory systems (especially without virtual memory), setting the value to `0` can help to conserve memory.

This value can also be set through (OS) environment variable `ERL_FULLSWEEP_AFTER`.

```
erlang:system_flag(Flag :: microstate_accounting, Action) ->
                      OldState
```

Types:

```
Action = true | false | reset
OldState = true | false
```

Turns on/off microstate accounting measurements. When passing reset, all counters are reset to 0.

For more information see *statistics(microstate_accounting)*.

```
erlang:system_flag(Flag :: min_heap_size, MinHeapSize) ->
                      OldMinHeapSize
```

Types:

```
MinHeapSize = OldMinHeapSize = integer() >= 0
```

Sets the default minimum heap size for processes. The size is specified in words. The new `min_heap_size` effects only processes spawned after the change of `min_heap_size` has been made. `min_heap_size` can be set for individual processes by using *spawn_opt/4* or *process_flag/2*.

Returns the old value of the flag.

```
erlang:system_flag(Flag :: min_bin_vheap_size, MinBinVHeapSize) ->
                      OldMinBinVHeapSize
```

Types:

```
MinBinVHeapSize = OldMinBinVHeapSize = integer() >= 0
```

Sets the default minimum binary virtual heap size for processes. The size is specified in words. The new `min_bin_vhheap_size` effects only processes spawned after the change of `min_bin_vheap_size` has been made. `min_bin_vheap_size` can be set for individual processes by using *spawn_opt/2,3,4* or *process_flag/2*.

Returns the old value of the flag.

```
erlang:system_flag(Flag :: max_heap_size, MaxHeapSize) ->
                      OldMaxHeapSize
```

Types:

```
MaxHeapSize = OldMaxHeapSize = max_heap_size()
max_heap_size() =
    integer() >= 0 |
    #{size => integer() >= 0,
      kill => boolean(),
      error_logger => boolean()}
```

Sets the default maximum heap size settings for processes. The size is specified in words. The new `max_heap_size` effects only processes spawned efter the change has been made. `max_heap_size` can be set for individual processes using *spawn_opt/2,3,4* or *process_flag/2*.

Returns the old value of the flag.

```
erlang:system_flag(Flag :: multi_scheduling, BlockState) ->
                      OldBlockState
```

Types:

```
BlockState = block | unblock | block_normal | unblock_normal
OldBlockState = blocked | disabled | enabled
```

If multi-scheduling is enabled, more than one scheduler thread is used by the emulator. Multi-scheduling can be blocked in two different ways. Either all schedulers but one is blocked, or all **normal** schedulers but one is blocked. When only normal schedulers are blocked, dirty schedulers are free to continue to schedule processes.

If `BlockState =:= block`, multi-scheduling is blocked. That is, one and only one scheduler thread will execute. If `BlockState =:= unblock` and no one else blocks multi-scheduling, and this process has blocked only once, multi-scheduling is unblocked.

If `BlockState =:= block_normal`, normal multi-scheduling is blocked. That is, only one normal scheduler thread will execute, but multiple dirty schedulers can execute. If `BlockState =:= unblock_normal` and no one else blocks normal multi-scheduling, and this process has blocked only once, normal multi-scheduling is unblocked.

One process can block multi-scheduling and normal multi-scheduling multiple times. If a process has blocked multiple times, it must unblock exactly as many times as it has blocked before it has released its multi-scheduling block. If a process that has blocked multi-scheduling or normal multi-scheduling exits, it automatically releases its blocking of multi-scheduling and normal multi-scheduling.

The return values are `disabled`, `blocked`, `blocked_normal`, or `enabled`. The returned value describes the state just after the call to `erlang:system_flag(multi_scheduling, BlockState)` has been made. For information about the return values, see *`erlang:system_info(multi_scheduling)`*.

Note:

Blocking of multi-scheduling and normal multi-scheduling is normally not needed. If you feel that you need to use these features, consider it a few more times again. Blocking multi-scheduling is only to be used as a last resort, as it is most likely a **very inefficient** way to solve the problem.

See also *`erlang:system_info(multi_scheduling)`*, *`erlang:system_info(normal_multi_scheduling_blockers)`*, *`erlang:system_info(multi_scheduling_blockers)`*, and *`erlang:system_info(schedulers)`*.

```
erlang:system_flag(Flag :: scheduler_bind_type, How) ->
                      OldBindType
```

Types:

```
How = scheduler_bind_type() | default_bind
OldBindType = scheduler_bind_type()
scheduler_bind_type() =
    no_node_processor_spread |
    no_node_thread_spread |
    no_spread |
    processor_spread |
    spread |
    thread_spread |
    thread_no_node_processor_spread |
```

`unbound`

Warning:

This argument is deprecated. Instead of using this argument, use command-line argument `+sbt` in `erl(1)`. When this argument is removed, a final scheduler bind type to use is determined at emulator boot time.

Controls if and how schedulers are bound to logical processors.

When `erlang:system_flag(scheduler_bind_type, How)` is called, an asynchronous signal is sent to all schedulers online, causing them to try to bind or unbind as requested.

Note:

If a scheduler fails to bind, this is often silently ignored, as it is not always possible to verify valid logical processor identifiers. If an error is reported, it is reported to `error_logger`. To verify that the schedulers have bound as requested, call `erlang:system_info(scheduler_bindings)`.

Schedulers can be bound on newer Linux, Solaris, FreeBSD, and Windows systems, but more systems will be supported in future releases.

In order for the runtime system to be able to bind schedulers, the CPU topology must be known. If the runtime system fails to detect the CPU topology automatically, it can be defined. For more information on how to define the CPU topology, see command-line flag `+sct` in `erl(1)`.

The runtime system does by default **not** bind schedulers to logical processors.

Note:

If the Erlang runtime system is the only OS process binding threads to logical processors, this improves the performance of the runtime system. However, if other OS processes (for example, another Erlang runtime system) also bind threads to logical processors, there can be a performance penalty instead. Sometimes this performance penalty can be severe. If so, it is recommended to not bind the schedulers.

Schedulers can be bound in different ways. Argument `How` determines how schedulers are bound and can be any of the following:

`unbound`
: Same as command-line argument `+sbt u` in `erl(1)`.

`no_spread`
: Same as command-line argument `+sbt ns` in `erl(1)`.

`thread_spread`
: Same as command-line argument `+sbt ts` in `erl(1)`.

`processor_spread`
: Same as command-line argument `+sbt ps` in `erl(1)`.

`spread`
: Same as command-line argument `+sbt s` in `erl(1)`.

`no_node_thread_spread`
: Same as command-line argument `+sbt nnts` in `erl(1)`.

`no_node_processor_spread`
: Same as command-line argument `+sbt nnps` in `erl(1)`.

`thread_no_node_processor_spread`
: Same as command-line argument `+sbt tnnps` in `erl(1)`.

`default_bind`
: Same as command-line argument `+sbt db` in `erl(1)`.

The returned value equals `How` before flag `scheduler_bind_type` was changed.

Failures:

`notsup`
: If binding of schedulers is not supported.

`badarg`
: If `How` is not one of the documented alternatives.

`badarg`
: If CPU topology information is unavailable.

The scheduler bind type can also be set by passing command-line argument `+sbt` to `erl(1)`.

For more information, see *`erlang:system_info(scheduler_bind_type)`*, *`erlang:system_info(scheduler_bindings)`*, as well as command-line flags `+sbt` and `+sct` in `erl(1)`.

```
erlang:system_flag(Flag :: scheduler_wall_time, Boolean) ->
                       OldBoolean
```

Types:

```
Boolean = OldBoolean = boolean()
```

Turns on or off scheduler wall time measurements.

For more information, see *`statistics(scheduler_wall_time)`*.

```
erlang:system_flag(Flag :: schedulers_online, SchedulersOnline) ->
                       OldSchedulersOnline
```

Types:

```
SchedulersOnline = OldSchedulersOnline = integer() >= 1
```

Sets the number of schedulers online. Range is `1 <= SchedulersOnline <= erlang:system_info(schedulers)`.

Returns the old value of the flag.

If the emulator was built with support for *dirty schedulers*, changing the number of schedulers online can also change the number of dirty CPU schedulers online. For example, if 12 schedulers and 6 dirty CPU schedulers are online, and `system_flag/2` is used to set the number of schedulers online to 6, then the number of dirty CPU schedulers online is automatically decreased by half as well, down to 3. Similarly, the number of dirty CPU schedulers online increases proportionally to increases in the number of schedulers online.

For more information, see *`erlang:system_info(schedulers)`* and *`erlang:system_info(schedulers_online)`*.

```
erlang:system_flag(Flag :: trace_control_word, TCW) -> OldTCW
```

Types:

```
TCW = OldTCW = integer() >= 0
```

Sets the value of the node trace control word to `TCW`, which is to be an unsigned integer. For more information, see function *`set_tcw`* in section "Match Specifications in Erlang" in the User's Guide.

Returns the old value of the flag.

```
erlang:system_flag(Flag :: time_offset, Value :: finalize) ->
```

```
                      OldState
```

Types:

```
OldState = preliminary | final | volatile
```

Finalizes the *time offset* when *single time warp mode* is used. If another time warp mode is used, the time offset state is left unchanged.

Returns the old state identifier, that is:

- If `preliminary` is returned, finalization was performed and the time offset is now final.
- If `final` is returned, the time offset was already in the final state. This either because another `erlang:system_flag(time_offset, finalize)` call or because *no time warp mode* is used.
- If `volatile` is returned, the time offset cannot be finalized because *multi-time warp mode* is used.

```
erlang:system_info(Item :: allocated_areas) -> [tuple()]
erlang:system_info(Item :: allocator) ->
                      {Allocator, Version, Features, Settings}
erlang:system_info(Item :: alloc_util_allocators) -> [Alloc]
erlang:system_info(Item :: {allocator, Alloc}) -> [term()]
erlang:system_info(Item :: {allocator_sizes, Alloc}) -> [term()]
```

Types:

```
Allocator = undefined | glibc
Version = [integer() >= 0]
Features = [atom()]
Settings =
    [{Subsystem :: atom(),
      [{Parameter :: atom(), Value :: term()}]}]
Alloc = atom()
```

Returns various information about the allocators of the current system (emulator) as specified by `Item`:

`allocated_areas`

Returns a list of tuples with information about miscellaneous allocated memory areas.

Each tuple contains an atom describing the type of memory as first element and the amount of allocated memory in bytes as second element. When information about allocated and used memory is present, also a third element is present, containing the amount of used memory in bytes.

`erlang:system_info(allocated_areas)` is intended for debugging, and the content is highly implementation-dependent. The content of the results therefore changes when needed without prior notice.

Notice that the sum of these values is **not** the total amount of memory allocated by the emulator. Some values are part of other values, and some memory areas are not part of the result. For information about the total amount of memory allocated by the emulator, see *`erlang:memory/0,1`*.

`allocator`

Returns `{Allocator, Version, Features, Settings}`, where:

- `Allocator` corresponds to the `malloc()` implementation used. If `Allocator` equals `undefined`, the `malloc()` implementation used cannot be identified. `glibc` can be identified.
- `Version` is a list of integers (but not a string) representing the version of the `malloc()` implementation used.
- `Features` is a list of atoms representing the allocation features used.

- `Settings` is a list of subsystems, their configurable parameters, and used values. Settings can differ between different combinations of platforms, allocators, and allocation features. Memory sizes are given in bytes.

See also "System Flags Effecting erts_alloc" in *`erts_alloc(3)`*.

`alloc_util_allocators`

Returns a list of the names of all allocators using the ERTS internal `alloc_util` framework as atoms. For more information, see section *The alloc_util framework* in `erts_alloc(3)`.

`{allocator, Alloc}`

Returns information about the specified allocator. As from ERTS 5.6.1, the return value is a list of `{instance, InstanceNo, InstanceInfo}` tuples, where `InstanceInfo` contains information about a specific instance of the allocator. If `Alloc` is not a recognized allocator, `undefined` is returned. If `Alloc` is disabled, `false` is returned.

Notice that the information returned is highly implementation-dependent and can be changed or removed at any time without prior notice. It was initially intended as a tool when developing new allocators, but as it can be of interest for others it has been briefly documented.

The recognized allocators are listed in *`erts_alloc(3)`*. Information about super carriers can be obtained from ERTS 8.0 with `{allocator, erts_mmap}` or from ERTS 5.10.4; the returned list when calling with `{allocator, mseg_alloc}` also includes an `{erts_mmap, _}` tuple as one element in the list.

After reading the `erts_alloc(3)` documentation, the returned information more or less speaks for itself, but it can be worth explaining some things. Call counts are presented by two values, the first value is giga calls, and the second value is calls. `mbcs` and `sbcs` denote multi-block carriers, and single-block carriers, respectively. Sizes are presented in bytes. When a size is not presented, it is the amount of something. Sizes and amounts are often presented by three values:

- The first is the current value.
- The second is the maximum value since the last call to `erlang:system_info({allocator, Alloc})`.
- The third is the maximum value since the emulator was started.

If only one value is present, it is the current value. `fix_alloc` memory block types are presented by two values. The first value is the memory pool size and the second value is the used memory size.

`{allocator_sizes, Alloc}`

Returns various size information for the specified allocator. The information returned is a subset of the information returned by *`erlang:system_info({allocator, Alloc})`*.

```
erlang:system_info(Item :: cpu_topology) -> CpuTopology
erlang:system_info(Item ::
                       {cpu_topology, defined | detected | used}) ->
                      CpuTopology
```

Types:

```
CpuTopology = cpu_topology()
cpu_topology() = [LevelEntry :: level_entry()] | undefined
```

All `LevelEntry`s of a list must contain the same `LevelTag`, except on the top level where both `node` and `processor` `LevelTag`s can coexist.

```
level_entry() =
    {LevelTag :: level_tag(), SubLevel :: sub_level()} |
    {LevelTag :: level_tag(),
```

```
        InfoList :: info_list(),
        SubLevel :: sub_level()}
   {LevelTag, SubLevel} == {LevelTag, [], SubLevel}
   level_tag() = core | node | processor | thread
```

More `LevelTag`s can be introduced in a future release.

```
   sub_level() =
       [LevelEntry :: level_entry()] |
       (LogicalCpuId :: {logical, integer() >= 0})
   info_list() = []
```

The `info_list()` can be extended in a future release.

Returns various information about the CPU topology of the current system (emulator) as specified by `Item`:

`cpu_topology`

Returns the `CpuTopology` currently used by the emulator. The CPU topology is used when binding schedulers to logical processors. The CPU topology used is the *user-defined CPU topology*, if such exists, otherwise the *automatically detected CPU topology*, if such exists. If no CPU topology exists, `undefined` is returned.

`node` refers to Non-Uniform Memory Access (NUMA) nodes. `thread` refers to hardware threads (for example, Intel hyper-threads).

A level in term `CpuTopology` can be omitted if only one entry exists and `InfoList` is empty.

`thread` can only be a sublevel to `core`. `core` can be a sublevel to `processor` or `node`. `processor` can be on the top level or a sublevel to `node`. `node` can be on the top level or a sublevel to `processor`. That is, NUMA nodes can be processor internal or processor external. A CPU topology can consist of a mix of processor internal and external NUMA nodes, as long as each logical CPU belongs to **one** NUMA node. Cache hierarchy is not part of the `CpuTopology` type, but will be in a future release. Other things can also make it into the CPU topology in a future release. So, expect the `CpuTopology` type to change.

`{cpu_topology, defined}`

Returns the user-defined `CpuTopology`. For more information, see command-line flag `+sct` in `erl(1)` and argument *`cpu_topology`*.

`{cpu_topology, detected}`

Returns the automatically detected `CpuTopologyy`. The emulator detects the CPU topology on some newer Linux, Solaris, FreeBSD, and Windows systems. On Windows system with more than 32 logical processors, the CPU topology is not detected.

For more information, see argument *`cpu_topology`*.

`{cpu_topology, used}`

Returns `CpuTopology` used by the emulator. For more information, see argument *`cpu_topology`*.

```
erlang:system_info(Item :: fullsweep_after) ->
                      {fullsweep_after, integer() >= 0}
erlang:system_info(Item :: garbage_collection) ->
                      [{atom(), integer()}]
erlang:system_info(Item :: max_heap_size) ->
                      {max_heap_size,
                       MaxHeapSize :: max_heap_size()}
erlang:system_info(Item :: message_queue_data) ->
```

```
                        message_queue_data()
erlang:system_info(Item :: min_heap_size) ->
                        {min_heap_size,
                         MinHeapSize :: integer() >= 1}
erlang:system_info(Item :: min_bin_vheap_size) ->
                        {min_bin_vheap_size,
                         MinBinVHeapSize :: integer() >= 1}
```

Types:

```
   message_queue_data() = off_heap | on_heap
   max_heap_size() =
       integer() >= 0 |
       #{size => integer() >= 0,
         kill => boolean(),
         error_logger => boolean()}
```

Returns information about the default process heap settings:

`fullsweep_after`

Returns `{fullsweep_after, integer() >= 0}`, which is the `fullsweep_after` garbage collection setting used by default. For more information, see `garbage_collection` described below.

`garbage_collection`

Returns a list describing the default garbage collection settings. A process spawned on the local node by a `spawn` or `spawn_link` uses these garbage collection settings. The default settings can be changed by using *`erlang:system_flag/2`*. *`spawn_opt/2,3,4`* can spawn a process that does not use the default settings.

`max_heap_size`

Returns `{max_heap_size, MaxHeapSize}`, where `MaxHeapSize` is the current system-wide maximum heap size settings for spawned processes. This setting can be set using the command-line flags *`+hmax`*, *`+hmaxk`* and *`+hmaxel`* in `erl(1)`. It can also be changed at runtime using *`erlang:system_flag(max_heap_size, MaxHeapSize)`*. For more details about the `max_heap_size` process flag, see *`process_flag(max_heap_size, MaxHeapSize)`*.

`message_queue_data`

Returns the default value of the `message_queue_data` process flag, which is either `off_heap` or `on_heap`. This default is set by command-line argument *`+hmqd`* in `erl(1)`. For more information on the `message_queue_data` process flag, see documentation of *`process_flag(message_queue_data, MQD)`*.

`min_heap_size`

Returns `{min_heap_size, MinHeapSize}`, where `MinHeapSize` is the current system-wide minimum heap size for spawned processes.

`min_bin_vheap_size`

Returns `{min_bin_vheap_size, MinBinVHeapSize}`, where `MinBinVHeapSize` is the current system-wide minimum binary virtual heap size for spawned processes.

```
erlang:system_info(Item :: atom_count) -> integer() >= 1
erlang:system_info(Item :: atom_limit) -> integer() >= 1
erlang:system_info(Item :: build_type) ->
                        opt |
                        debug |
```

```
                      purify |
                      quantify |
                      purecov |
                      gcov |
                      valgrind |
                      gprof |
                      lcnt |
                      frmptr
erlang:system_info(Item :: c_compiler_used) -> {atom(), term()}
erlang:system_info(Item :: check_io) -> [term()]
erlang:system_info(Item :: compat_rel) -> integer()
erlang:system_info(Item :: creation) -> integer()
erlang:system_info(Item :: debug_compiled) -> boolean()
erlang:system_info(Item :: delayed_node_table_gc) ->
                      infinity | integer() >= 0
erlang:system_info(Item :: dirty_cpu_schedulers) ->
                      integer() >= 0
erlang:system_info(Item :: dirty_cpu_schedulers_online) ->
                      integer() >= 0
erlang:system_info(Item :: dirty_io_schedulers) ->
                      integer() >= 0
erlang:system_info(Item :: dist) -> binary()
erlang:system_info(Item :: dist_buf_busy_limit) ->
                      integer() >= 0
erlang:system_info(Item :: dist_ctrl) ->
                      {Node :: node(),
                       ControllingEntity :: port() | pid()}
erlang:system_info(Item :: driver_version) -> string()
erlang:system_info(Item :: dynamic_trace) ->
                      none | dtrace | systemtap
erlang:system_info(Item :: dynamic_trace_probes) -> boolean()
erlang:system_info(Item :: elib_malloc) -> false
erlang:system_info(Item :: eager_check_io) -> boolean()
erlang:system_info(Item :: ets_limit) -> integer() >= 1
erlang:system_info(Item :: heap_sizes) -> [integer() >= 0]
erlang:system_info(Item :: heap_type) -> private
erlang:system_info(Item :: info) -> binary()
erlang:system_info(Item :: kernel_poll) -> boolean()
erlang:system_info(Item :: loaded) -> binary()
erlang:system_info(Item ::
                       logical_processors |
                       logical_processors_available |
                       logical_processors_online) ->
                      unknown | integer() >= 1
erlang:system_info(Item :: machine) -> string()
erlang:system_info(Item :: modified_timing_level) ->
```

```
                      integer() | undefined
erlang:system_info(Item :: multi_scheduling) ->
                      disabled |
                      blocked |
                      blocked_normal |
                      enabled
erlang:system_info(Item :: multi_scheduling_blockers) ->
                      [Pid :: pid()]
erlang:system_info(Item :: nif_version) -> string()
erlang:system_info(Item :: normal_multi_scheduling_blockers) ->
                      [Pid :: pid()]
erlang:system_info(Item :: otp_release) -> string()
erlang:system_info(Item :: os_monotonic_time_source) ->
                      [{atom(), term()}]
erlang:system_info(Item :: os_system_time_source) ->
                      [{atom(), term()}]
erlang:system_info(Item :: port_count) -> integer() >= 0
erlang:system_info(Item :: port_limit) -> integer() >= 1
erlang:system_info(Item :: process_count) -> integer() >= 1
erlang:system_info(Item :: process_limit) -> integer() >= 1
erlang:system_info(Item :: procs) -> binary()
erlang:system_info(Item :: scheduler_bind_type) ->
                      spread |
                      processor_spread |
                      thread_spread |
                      thread_no_node_processor_spread |
                      no_node_processor_spread |
                      no_node_thread_spread |
                      no_spread |
                      unbound
erlang:system_info(Item :: scheduler_bindings) -> tuple()
erlang:system_info(Item :: scheduler_id) ->
                      SchedulerId :: integer() >= 1
erlang:system_info(Item :: schedulers | schedulers_online) ->
                      integer() >= 1
erlang:system_info(Item :: smp_support) -> boolean()
erlang:system_info(Item :: start_time) -> integer()
erlang:system_info(Item :: system_version) -> string()
erlang:system_info(Item :: system_architecture) -> string()
erlang:system_info(Item :: threads) -> boolean()
erlang:system_info(Item :: thread_pool_size) -> integer() >= 0
erlang:system_info(Item :: time_correction) -> true | false
erlang:system_info(Item :: time_offset) ->
                      preliminary | final | volatile
erlang:system_info(Item :: time_warp_mode) ->
                      no_time_warp |
                      single_time_warp |
```

```
                      multi_time_warp
erlang:system_info(Item :: tolerant_timeofday) ->
                      enabled | disabled
erlang:system_info(Item :: trace_control_word) ->
                      integer() >= 0
erlang:system_info(Item :: update_cpu_info) -> changed | unchanged
erlang:system_info(Item :: version) -> string()
```

Returns various information about the current system (emulator) as specified by `Item`:

`atom_count`

Returns the number of atoms currently existing at the local node. The value is given as an integer.

`atom_limit`

Returns the maximum number of atoms allowed. This limit can be increased at startup by passing command-line flag `+t` to `erl(1)`.

`build_type`

Returns an atom describing the build type of the runtime system. This is normally the atom `opt` for optimized. Other possible return values are `debug`, `purify`, `quantify`, `purecov`, `gcov`, `valgrind`, `gprof`, and `lcnt`. Possible return values can be added or removed at any time without prior notice.

`c_compiler_used`

Returns a two-tuple describing the C compiler used when compiling the runtime system. The first element is an atom describing the name of the compiler, or `undefined` if unknown. The second element is a term describing the version of the compiler, or `undefined` if unknown.

`check_io`

Returns a list containing miscellaneous information about the emulators internal I/O checking. Notice that the content of the returned list can vary between platforms and over time. It is only guaranteed that a list is returned.

`compat_rel`

Returns the compatibility mode of the local node as an integer. The integer returned represents the Erlang/OTP release that the current emulator has been set to be backward compatible with. The compatibility mode can be configured at startup by using command-line flag `+R` in `erl(1)`.

`cpu_topology`

See *above*.

`creation`

Returns the creation of the local node as an integer. The creation is changed when a node is restarted. The creation of a node is stored in process identifiers, port identifiers, and references. This makes it (to some extent) possible to distinguish between identifiers from different incarnations of a node. The valid creations are integers in the range 1..3, but this will probably change in a future release. If the node is not alive, `0` is returned.

`debug_compiled`

Returns `true` if the emulator has been debug-compiled, otherwise `false`.

`delayed_node_table_gc`

Returns the amount of time in seconds garbage collection of an entry in a node table is delayed. This limit can be set on startup by passing command-line flag `+zdntgc` to `erl(1)`. For more information, see the documentation of the command-line flag.

`dirty_cpu_schedulers`

Returns the number of dirty CPU scheduler threads used by the emulator. Dirty CPU schedulers execute CPU-bound native functions, such as NIFs, linked-in driver code, and BIFs that cannot be managed cleanly by the normal emulator schedulers.

The number of dirty CPU scheduler threads is determined at emulator boot time and cannot be changed after that. However, the number of dirty CPU scheduler threads online can be changed at any time. The number of dirty CPU schedulers can be set at startup by passing command-line flag *+SDcpu* or *+SDPcpu* in `erl(1)`.

See also *erlang:system_flag(dirty_cpu_schedulers_online, DirtyCPUSchedulersOnline)*, *erlang:system_info(dirty_cpu_schedulers_online)*, *erlang:system_info(dirty_io_schedulers)*, *erlang:system_info(schedulers)*, *erlang:system_info(schedulers_online)*, and *erlang:system_flag(schedulers_online, SchedulersOnline)*.

`dirty_cpu_schedulers_online`

Returns the number of dirty CPU schedulers online. The return value satisfies `1 <= DirtyCPUSchedulersOnline <= N`, where `N` is the smallest of the return values of `erlang:system_info(dirty_cpu_schedulers)` and `erlang:system_info(schedulers_online)`.

The number of dirty CPU schedulers online can be set at startup by passing command-line flag *+SDcpu* in `erl(1)`.

For more information, see *erlang:system_info(dirty_cpu_schedulers)*, *erlang:system_info(dirty_io_schedulers)*, *erlang:system_info(schedulers_online)*, and *erlang:system_flag(dirty_cpu_schedulers_online, DirtyCPUSchedulersOnline)*.

`dirty_io_schedulers`

Returns the number of dirty I/O schedulers as an integer. Dirty I/O schedulers execute I/O-bound native functions, such as NIFs and linked-in driver code, which cannot be managed cleanly by the normal emulator schedulers.

This value can be set at startup by passing command-line argument *+SDio* in `erl(1)`.

For more information, see *erlang:system_info(dirty_cpu_schedulers)*, *erlang:system_info(dirty_cpu_schedulers_online)*, and *erlang:system_flag(dirty_cpu_schedulers_online, DirtyCPUSchedulersOnline)*.

`dist`

Returns a binary containing a string of distribution information formatted as in Erlang crash dumps. For more information, see section *How to interpret the Erlang crash dumps* in the User's Guide.

`dist_buf_busy_limit`

Returns the value of the distribution buffer busy limit in bytes. This limit can be set at startup by passing command-line flag *+zdbbl* to `erl(1)`.

`dist_ctrl`

Returns a list of tuples `{Node, ControllingEntity}`, one entry for each connected remote node. `Node` is the node name and `ControllingEntity` is the port or process identifier responsible for the communication to that node. More specifically, `ControllingEntity` for nodes connected through TCP/IP (the normal case) is the socket used in communication with the specific node.

`driver_version`

Returns a string containing the Erlang driver version used by the runtime system. It has the form *"<major ver>.<minor ver>"*.

`dynamic_trace`

Returns an atom describing the dynamic trace framework compiled into the virtual machine. It can be `dtrace`, `systemtap`, or `none`. For a commercial or standard build, it is always `none`. The other return values indicate a custom configuration (for example, `./configure --with-dynamic-trace=dtrace`). For more information about dynamic tracing, see *`dyntrace(3)`* manual page and the `README.dtrace`/`README.systemtap` files in the Erlang source code top directory.

`dynamic_trace_probes`

Returns a `boolean()` indicating if dynamic trace probes (`dtrace` or `systemtap`) are built into the emulator. This can only be `true` if the virtual machine was built for dynamic tracing (that is, `system_info(dynamic_trace)` returns `dtrace` or `systemtap`).

`end_time`

The last *Erlang monotonic time* in `native` *time unit* that can be represented internally in the current Erlang runtime system instance. The time between the *start time* and the end time is at least a quarter of a millennium.

`elib_malloc`

This option will be removed in a future release. The return value will always be `false`, as the `elib_malloc` allocator has been removed.

`eager_check_io`

Returns the value of command-line flag `+secio` in `erl(1)`, which is either `true` or `false`. For information about the different values, see the documentation of the command-line flag.

`ets_limit`

Returns the maximum number of ETS tables allowed. This limit can be increased at startup by passing command-line flag `+e` to `erl(1)` or by setting environment variable `ERL_MAX_ETS_TABLES` before starting the Erlang runtime system.

`heap_sizes`

Returns a list of integers representing valid heap sizes in words. All Erlang heaps are sized from sizes in this list.

`heap_type`

Returns the heap type used by the current emulator. One heap type exists:

`private`

Each process has a heap reserved for its use and no references between heaps of different processes are allowed. Messages passed between processes are copied between heaps.

`info`

Returns a binary containing a string of miscellaneous system information formatted as in Erlang crash dumps. For more information, see section *How to interpret the Erlang crash dumps* in the User's Guide.

`kernel_poll`

Returns `true` if the emulator uses some kind of kernel-poll implementation, otherwise `false`.

`loaded`

Returns a binary containing a string of loaded module information formatted as in Erlang crash dumps. For more information, see section *How to interpret the Erlang crash dumps* in the User's Guide.

`logical_processors`

Returns the detected number of logical processors configured in the system. The return value is either an integer, or the atom `unknown` if the emulator cannot detect the configured logical processors.

`logical_processors_available`

Returns the detected number of logical processors available to the Erlang runtime system. The return value is either an integer, or the atom `unknown` if the emulator cannot detect the available logical processors. The number of available logical processors is less than or equal to the number of *logical processors online*.

`logical_processors_online`

Returns the detected number of logical processors online on the system. The return value is either an integer, or the atom `unknown` if the emulator cannot detect logical processors online. The number of logical processors online is less than or equal to the number of *logical processors configured*.

`machine`

Returns a string containing the Erlang machine name.

`modified_timing_level`

Returns the modified timing-level (an integer) if modified timing is enabled, otherwise `undefined`. For more information about modified timing, see command-line flag `+T` in `erl(1)`

`multi_scheduling`

Returns one of the following:

`disabled`

The emulator has only one scheduler thread. The emulator does not have SMP support, or have been started with only one scheduler thread.

`blocked`

The emulator has more than one scheduler thread, but all scheduler threads except one are blocked. That is, only one scheduler thread schedules Erlang processes and executes Erlang code.

`blocked_normal`

The emulator has more than one scheduler thread, but all normal scheduler threads except one are blocked. Notice that dirty schedulers are not blocked, and can schedule Erlang processes and execute native code.

`enabled`

The emulator has more than one scheduler thread, and no scheduler threads are blocked. That is, all available scheduler threads schedule Erlang processes and execute Erlang code.

See also *`erlang:system_flag(multi_scheduling, BlockState)`*, *`erlang:system_info(multi_scheduling_blockers)`*, *`erlang:system_info(normal_multi_scheduling_blockers)`*, and *`erlang:system_info(schedulers)`*.

`multi_scheduling_blockers`

Returns a list of `Pid`s when multi-scheduling is blocked, otherwise the empty list is returned. The `Pid`s in the list represent all the processes currently blocking multi-scheduling. A `Pid` occurs only once in the list, even if the corresponding process has blocked multiple times.

See also *`erlang:system_flag(multi_scheduling, BlockState)`*, *`erlang:system_info(multi_scheduling)`*, *`erlang:system_info(normal_multi_scheduling_blockers)`*, and *`erlang:system_info(schedulers)`*.

`nif_version`

Returns a string containing the version of the Erlang NIF interface used by the runtime system. It is on the form "<major ver>.<minor ver>".

`normal_multi_scheduling_blockers`

Returns a list of `Pid`s when normal multi-scheduling is blocked (that is, all normal schedulers but one is blocked), otherwise the empty list is returned. The `Pid`s in the list represent all the processes currently blocking normal multi-scheduling. A `Pid` occurs only once in the list, even if the corresponding process has blocked multiple times.

See also *`erlang:system_flag(multi_scheduling, BlockState)`*, *`erlang:system_info(multi_scheduling)`*, *`erlang:system_info(multi_scheduling_blockers)`*, and *`erlang:system_info(schedulers)`*.

`otp_release`

Returns a string containing the OTP release number of the OTP release that the currently executing ERTS application is part of.

As from Erlang/OTP 17, the OTP release number corresponds to the major OTP version number. No `erlang:system_info()` argument gives the exact OTP version. This is because the exact OTP version in the general case is difficult to determine. For more information, see the description of versions in *System principles* in System Documentation.

`os_monotonic_time_source`

Returns a list containing information about the source of *OS monotonic time* that is used by the runtime system.

If `[]` is returned, no OS monotonic time is available. The list contains two-tuples with `Key`s as first element, and `Value`s as second element. The order of these tuples is undefined. The following tuples can be part of the list, but more tuples can be introduced in the future:

`{function, Function}`

`Function` is the name of the function used. This tuple always exists if OS monotonic time is available to the runtime system.

`{clock_id, ClockId}`

This tuple only exists if `Function` can be used with different clocks. `ClockId` corresponds to the clock identifier used when calling `Function`.

`{resolution, OsMonotonicTimeResolution}`

Highest possible *resolution* of current OS monotonic time source as parts per second. If no resolution information can be retrieved from the OS, `OsMonotonicTimeResolution` is set to the resolution of the time unit of `Function`s return value. That is, the actual resolution can be lower than `OsMonotonicTimeResolution`. Notice that the resolution does not say anything about the *accuracy* or whether the *precision* aligns with the resolution. You do, however, know that the precision is not better than `OsMonotonicTimeResolution`.

`{extended, Extended}`

`Extended` equals `yes` if the range of time values has been extended; otherwise `Extended` equals `no`. The range must be extended if `Function` returns values that wrap fast. This typically is the case when the return value is a 32-bit value.

`{parallel, Parallel}`

`Parallel` equals `yes` if `Function` is called in parallel from multiple threads. If it is not called in parallel, because calls must be serialized, `Parallel` equals `no`.

`{time, OsMonotonicTime}`

`OsMonotonicTime` equals current OS monotonic time in `native` *time unit*.

`os_system_time_source`

Returns a list containing information about the source of *OS system time* that is used by the runtime system.

The list contains two-tuples with `Key`s as first element, and `Value`s as second element. The order if these tuples is undefined. The following tuples can be part of the list, but more tuples can be introduced in the future:

`{function, Function}`

`Function` is the name of the funcion used.

`{clock_id, ClockId}`

Exists only if `Function` can be used with different clocks. `ClockId` corresponds to the clock identifier used when calling `Function`.

`{resolution, OsSystemTimeResolution}`

Highest possible *resolution* of current OS system time source as parts per second. If no resolution information can be retrieved from the OS, `OsSystemTimeResolution` is set to the resolution of the time unit of `Function`s return value. That is, the actual resolution can be lower than `OsSystemTimeResolution`. Notice that the resolution does not say anything about the *accuracy* or whether the *precision* do align with the resolution. You do, however, know that the precision is not better than `OsSystemTimeResolution`.

`{parallel, Parallel}`

`Parallel` equals `yes` if `Function` is called in parallel from multiple threads. If it is not called in parallel, because calls needs to be serialized, `Parallel` equals `no`.

`{time, OsSystemTime}`

`OsSystemTime` equals current OS system time in `native` *time unit*.

`port_parallelism`

Returns the default port parallelism scheduling hint used. For more information, see command-line argument `+spp` in `erl(1)`.

`port_count`

Returns the number of ports currently existing at the local node. The value is given as an integer. This is the same value as returned by `length(erlang:ports())`, but more efficient.

`port_limit`

Returns the maximum number of simultaneously existing ports at the local node as an integer. This limit can be configured at startup by using command-line flag `+Q` in `erl(1)`.

`process_count`

Returns the number of processes currently existing at the local node. The value is given as an integer. This is the same value as returned by `length(processes())`, but more efficient.

`process_limit`

Returns the maximum number of simultaneously existing processes at the local node. The value is given as an integer. This limit can be configured at startup by using command-line flag `+P` in `erl(1)`.

`procs`

Returns a binary containing a string of process and port information formatted as in Erlang crash dumps. For more information, see section *How to interpret the Erlang crash dumps* in the User's Guide.

`scheduler_bind_type`

Returns information about how the user has requested schedulers to be bound or not bound.

Notice that although a user has requested schedulers to be bound, they can silently have failed to bind. To inspect the scheduler bindings, call *erlang:system_info(scheduler_bindings)*.

For more information, see command-line argument *+sbt* in erl(1) and *erlang:system_info(scheduler_bindings)*.

scheduler_bindings

Returns information about the currently used scheduler bindings.

A tuple of a size equal to *erlang:system_info(schedulers)* is returned. The tuple elements are integers or the atom unbound. Logical processor identifiers are represented as integers. The Nth element of the tuple equals the current binding for the scheduler with the scheduler identifier equal to N. For example, if the schedulers are bound, element(erlang:system_info(scheduler_id), erlang:system_info(scheduler_bindings)) returns the identifier of the logical processor that the calling process is executing on.

Notice that only schedulers online can be bound to logical processors.

For more information, see command-line argument *+sbt* in erl(1) and *erlang:system_info(schedulers_online)*.

scheduler_id

Returns the scheduler ID (SchedulerId) of the scheduler thread that the calling process is executing on. SchedulerId is a positive integer, where 1 <= SchedulerId <= erlang:system_info(schedulers).

See also *erlang:system_info(schedulers)*.

schedulers

Returns the number of scheduler threads used by the emulator. Scheduler threads online schedules Erlang processes and Erlang ports, and execute Erlang code and Erlang linked-in driver code.

The number of scheduler threads is determined at emulator boot time and cannot be changed later. However, the number of schedulers online can be changed at any time.

See also *erlang:system_flag(schedulers_online, SchedulersOnline)*, *erlang:system_info(schedulers_online)*, *erlang:system_info(scheduler_id)*, *erlang:system_flag(multi_scheduling, BlockState)*, *erlang:system_info(multi_scheduling)*, *erlang:system_info(normal_multi_scheduling_blockers)* and *erlang:system_info(multi_scheduling_blockers)*.

schedulers_online

Returns the number of schedulers online. The scheduler identifiers of schedulers online satisfy the relationship 1 <= SchedulerId <= erlang:system_info(schedulers_online).

For more information, see *erlang:system_info(schedulers)* and *erlang:system_flag(schedulers_online, SchedulersOnline)*.

smp_support

Returns true if the emulator has been compiled with SMP support, otherwise false is returned.

start_time

The *Erlang monotonic time* in native *time unit* at the time when current Erlang runtime system instance started.

See also *erlang:system_info(end_time)*.

`system_version`

Returns a string containing version number and some important properties, such as the number of schedulers.

`system_architecture`

Returns a string containing the processor and OS architecture the emulator is built for.

`threads`

Returns `true` if the emulator has been compiled with thread support, otherwise `false` is returned.

`thread_pool_size`

Returns the number of async threads in the async thread pool used for asynchronous driver calls (*`erl_driver:driver_async()`*). The value is given as an integer.

`time_correction`

Returns a boolean value indicating whether *time correction* is enabled or not.

`time_offset`

Returns the state of the time offset:

`preliminary`

The time offset is preliminary, and will be changed and finalized later. The preliminary time offset is used during the preliminary phase of the *single time warp mode*.

`final`

The time offset is final. This either because *no time warp mode* is used, or because the time offset have been finalized when *single time warp mode* is used.

`volatile`

The time offset is volatile. That is, it can change at any time. This is because *multi-time warp mode* is used.

`time_warp_mode`

Returns a value identifying the *time warp mode* that is used:

`no_time_warp`
The *no time warp mode* is used.

`single_time_warp`
The *single time warp mode* is used.

`multi_time_warp`
The *multi-time warp mode* is used.

`tolerant_timeofday`

Returns whether a pre ERTS 7.0 backwards compatible compensation for sudden changes of system time is `enabled` or `disabled`. Such compensation is `enabled` when the *time offset* is `final`, and *time correction* is enabled.

`trace_control_word`

Returns the value of the node trace control word. For more information, see function `get_tcw` in section *Match Specifications in Erlang* in the User's Guide.

`update_cpu_info`

The runtime system rereads the CPU information available and updates its internally stored information about the *detected CPU topology* and the number of logical processors *configured*, *online*, and *available*.

If the CPU information has changed since the last time it was read, the atom `changed` is returned, otherwise the atom `unchanged`. If the CPU information has changed, you probably want to *adjust the number of schedulers online*. You typically want to have as many schedulers online as *logical processors available*.

`version`

Returns a string containing the version number of the emulator.

`wordsize`

Same as `{wordsize, internal}`.

`{wordsize, internal}`

Returns the size of Erlang term words in bytes as an integer, that is, 4 is returned on a 32-bit architecture, and 8 is returned on a pure 64-bit architecture. On a halfword 64-bit emulator, 4 is returned, as the Erlang terms are stored using a virtual word size of half the system word size.

`{wordsize, external}`

Returns the true word size of the emulator, that is, the size of a pointer. The value is given in bytes as an integer. On a pure 32-bit architecture, 4 is returned. On both a half word and on a pure 64-bit architecture, 8 is returned.

Note:

Argument `scheduler` has changed name to `scheduler_id` to avoid mix up with argument `schedulers`. Argument `scheduler` was introduced in ERTS 5.5 and renamed in ERTS 5.5.1.

`erlang:system_monitor() -> MonSettings`

Types:

```
MonSettings = undefined | {MonitorPid, Options}
MonitorPid = pid()
Options = [system_monitor_option()]
system_monitor_option() =
    busy_port |
    busy_dist_port |
    {long_gc, integer() >= 0} |
    {long_schedule, integer() >= 0} |
    {large_heap, integer() >= 0}
```

Returns the current system monitoring settings set by *`erlang:system_monitor/2`* as `{MonitorPid, Options}`, or `undefined` if no settings exist. The order of the options can be different from the one that was set.

`erlang:system_monitor(Arg) -> MonSettings`

Types:

```
Arg = MonSettings = undefined | {MonitorPid, Options}
MonitorPid = pid()
Options = [system_monitor_option()]
system_monitor_option() =
    busy_port |
    busy_dist_port |
    {long_gc, integer() >= 0} |
    {long_schedule, integer() >= 0} |
```

```
    {large_heap, integer() >= 0}
```

When called with argument `undefined`, all system performance monitoring settings are cleared.

Calling the function with `{MonitorPid, Options}` as argument is the same as calling *`erlang:system_monitor(MonitorPid, Options)`*.

Returns the previous system monitor settings just like *`erlang:system_monitor/0`*.

```
erlang:system_monitor(MonitorPid, Options) -> MonSettings
```

Types:

```
MonitorPid = pid()
Options = [system_monitor_option()]
MonSettings = undefined | {OldMonitorPid, OldOptions}
OldMonitorPid = pid()
OldOptions = [system_monitor_option()]
system_monitor_option() =
    busy_port |
    busy_dist_port |
    {long_gc, integer() >= 0} |
    {long_schedule, integer() >= 0} |
    {large_heap, integer() >= 0}
```

Sets the system performance monitoring options. `MonitorPid` is a local process identifier (pid) receiving system monitor messages. The second argument is a list of monitoring options:

`{long_gc, Time}`

If a garbage collection in the system takes at least `Time` wall clock milliseconds, a message `{monitor, GcPid, long_gc, Info}` is sent to `MonitorPid`. `GcPid` is the pid that was garbage collected. `Info` is a list of two-element tuples describing the result of the garbage collection.

One of the tuples is `{timeout, GcTime}`, where `GcTime` is the time for the garbage collection in milliseconds. The other tuples are tagged with `heap_size`, `heap_block_size`, `stack_size`, `mbuf_size`, `old_heap_size`, and `old_heap_block_size`. These tuples are explained in the description of trace message *`gc_minor_start`* (see *`erlang:trace/3`*). New tuples can be added, and the order of the tuples in the `Info` list can be changed at any time without prior notice.

`{long_schedule, Time}`

If a process or port in the system runs uninterrupted for at least `Time` wall clock milliseconds, a message `{monitor, PidOrPort, long_schedule, Info}` is sent to `MonitorPid`. `PidOrPort` is the process or port that was running. `Info` is a list of two-element tuples describing the event.

If a `pid()`, the tuples `{timeout, Millis}`, `{in, Location}`, and `{out, Location}` are present, where `Location` is either an MFA (`{Module, Function, Arity}`) describing the function where the process was scheduled in/out, or the atom `undefined`.

If a `port()`, the tuples `{timeout, Millis}` and `{port_op,Op}` are present. `Op` is one of `proc_sig`, `timeout`, `input`, `output`, `event`, or `dist_cmd`, depending on which driver callback was executing.

`proc_sig` is an internal operation and is never to appear, while the others represent the corresponding driver callbacks `timeout`, `ready_input`, `ready_output`, `event`, and `outputv` (when the port is used by distribution). Value `Millis` in tuple `timeout` informs about the uninterrupted execution time of the process or port, which always is equal to or higher than the `Time` value supplied when starting the trace. New tuples can be added to the `Info` list in a future release. The order of the tuples in the list can be changed at any time without prior notice.

This can be used to detect problems with NIFs or drivers that take too long to execute. 1 ms is considered a good maximum time for a driver callback or a NIF. However, a time-sharing system is usually to consider everything < 100 ms as "possible" and fairly "normal". However, longer schedule times can indicate swapping or a misbehaving NIF/driver. Misbehaving NIFs and drivers can cause bad resource utilization and bad overall system performance.

`{large_heap, Size}`

If a garbage collection in the system results in the allocated size of a heap being at least `Size` words, a message `{monitor, GcPid, large_heap, Info}` is sent to `MonitorPid`. `GcPid` and `Info` are the same as for `long_gc` earlier, except that the tuple tagged with `timeout` is not present.

The monitor message is sent if the sum of the sizes of all memory blocks allocated for all heap generations after a garbage collection is equal to or higher than `Size`.

When a process is killed by *`max_heap_size`*, it is killed before the garbage collection is complete and thus no large heap message is sent.

`busy_port`

If a process in the system gets suspended because it sends to a busy port, a message `{monitor, SusPid, busy_port, Port}` is sent to `MonitorPid`. `SusPid` is the pid that got suspended when sending to `Port`.

`busy_dist_port`

If a process in the system gets suspended because it sends to a process on a remote node whose inter-node communication was handled by a busy port, a message `{monitor, SusPid, busy_dist_port, Port}` is sent to `MonitorPid`. `SusPid` is the pid that got suspended when sending through the inter-node communication port `Port`.

Returns the previous system monitor settings just like *`erlang:system_monitor/0`*.

Note:

If a monitoring process gets so large that it itself starts to cause system monitor messages when garbage collecting, the messages enlarge the process message queue and probably make the problem worse.

Keep the monitoring process neat and do not set the system monitor limits too tight.

Failures:

`badarg`
If `MonitorPid` does not exist.

`badarg`
If `MonitorPid` is not a local process.

```
erlang:system_profile() -> ProfilerSettings
```

Types:

```
ProfilerSettings = undefined | {ProfilerPid, Options}
ProfilerPid = pid() | port()
Options = [system_profile_option()]
system_profile_option() =
    exclusive |
    runnable_ports |
    runnable_procs |
    scheduler |
    timestamp |
    monotonic_timestamp |
```

```
strict_monotonic_timestamp
```

Returns the current system profiling settings set by *erlang:system_profile/2* as `{ProfilerPid, Options}`, or `undefined` if there are no settings. The order of the options can be different from the one that was set.

```
erlang:system_profile(ProfilerPid, Options) -> ProfilerSettings
```

Types:

```
ProfilerPid = pid() | port() | undefined
Options = [system_profile_option()]
ProfilerSettings =
    undefined | {pid() | port(), [system_profile_option()]}
system_profile_option() =
    exclusive |
    runnable_ports |
    runnable_procs |
    scheduler |
    timestamp |
    monotonic_timestamp |
    strict_monotonic_timestamp
```

Sets system profiler options. `ProfilerPid` is a local process identifier (pid) or port receiving profiling messages. The receiver is excluded from all profiling. The second argument is a list of profiling options:

`exclusive`

If a synchronous call to a port from a process is done, the calling process is considered not runnable during the call runtime to the port. The calling process is notified as `inactive`, and later `active` when the port callback returns.

`monotonic_timestamp`

Time stamps in profile messages use *Erlang monotonic time*. The time stamp (Ts) has the same format and value as produced by `erlang:monotonic_time(nanosecond)`.

`runnable_procs`

If a process is put into or removed from the run queue, a message, `{profile, Pid, State, Mfa, Ts}`, is sent to `ProfilerPid`. Running processes that are reinserted into the run queue after having been pre-empted do not trigger this message.

`runnable_ports`

If a port is put into or removed from the run queue, a message, `{profile, Port, State, 0, Ts}`, is sent to `ProfilerPid`.

`scheduler`

If a scheduler is put to sleep or awoken, a message, `{profile, scheduler, Id, State, NoScheds, Ts}`, is sent to `ProfilerPid`.

`strict_monotonic_timestamp`

Time stamps in profile messages consist of *Erlang monotonic time* and a monotonically increasing integer. The time stamp (Ts) has the same format and value as produced by `{erlang:monotonic_time(nanosecond), erlang:unique_integer([monotonic])}`.

`timestamp`

Time stamps in profile messages include a time stamp (Ts) that has the same form as returned by `erlang:now()`. This is also the default if no time stamp flag is specified. If `cpu_timestamp` has been

enabled through *erlang:trace/3*, this also effects the time stamp produced in profiling messages when flag `timestamp` is enabled.

Note:

`erlang:system_profile` behavior can change in a future release.

`erlang:system_time() -> integer()`

Returns current *Erlang system time* in `native` *time unit*.

Calling `erlang:system_time()` is equivalent to *erlang:monotonic_time()* + *erlang:time_offset()*.

Note:

This time is **not** a monotonically increasing time in the general case. For more information, see the documentation of *time warp modes* in the User's Guide.

`erlang:system_time(Unit) -> integer()`

Types:

`Unit = time_unit()`

Returns current *Erlang system time* converted into the `Unit` passed as argument.

Calling `erlang:system_time(Unit)` is equivalent to *erlang:convert_time_unit(erlang:system_time(), native, Unit)*.

Note:

This time is **not** a monotonically increasing time in the general case. For more information, see the documentation of *time warp modes* in the User's Guide.

`term_to_binary(Term) -> ext_binary()`

Types:

`Term = term()`

Returns a binary data object that is the result of encoding `Term` according to the *Erlang external term format*.

This can be used for various purposes, for example, writing a term to a file in an efficient way, or sending an Erlang term to some type of communications channel not supported by distributed Erlang.

```
> Bin = term_to_binary(hello).
<<131,100,0,5,104,101,108,108,111>>
> hello = binary_to_term(Bin).
hello
```

See also *binary_to_term/1*.

Note:

There is no guarantee that this function will return the same encoded representation for the same term.

`term_to_binary(Term, Options) -> ext_binary()`

Types:

```
Term = term()
Options =
    [compressed |
     {compressed, Level :: 0..9} |
     {minor_version, Version :: 0..1}]
```

Returns a binary data object that is the result of encoding `Term` according to the Erlang external term format.

If option `compressed` is provided, the external term format is compressed. The compressed format is automatically recognized by `binary_to_term/1` as from Erlang/OTP R7B.

A compression level can be specified by giving option `{compressed, Level}`. `Level` is an integer with range 0..9, where:

- `0` - No compression is done (it is the same as giving no `compressed` option).
- `1` - Takes least time but may not compress as well as the higher levels.
- `6` - Default level when option `compressed` is provided.
- `9` - Takes most time and tries to produce a smaller result. Notice "tries" in the preceding sentence; depending on the input term, level 9 compression either does or does not produce a smaller result than level 1 compression.

Option `{minor_version, Version}` can be used to control some encoding details. This option was introduced in Erlang/OTP R11B-4. The valid values for `Version` are:

`0`

Floats are encoded using a textual representation. This option is useful to ensure that releases before Erlang/OTP R11B-4 can decode resulting binary.

This version encode atoms that can be represented by a latin1 string using latin1 encoding while only atoms that cannot be represented by latin1 are encoded using utf8.

`1`

This is as of Erlang/OTP 17.0 the default. It forces any floats in the term to be encoded in a more space-efficient and exact way (namely in the 64-bit IEEE format, rather than converted to a textual representation). As from Erlang/OTP R11B-4, `binary_to_term/1` can decode this representation.

This version encode atoms that can be represented by a latin1 string using latin1 encoding while only atoms that cannot be represented by latin1 are encoded using utf8.

`2`

Drops usage of the latin1 atom encoding and unconditionally use utf8 encoding for all atoms. This will be changed to the default in a future major release of Erlang/OTP. Erlang/OTP systems as of R16B can decode this representation.

See also *`binary_to_term/1`*.

`throw(Any) -> no_return()`

Types:

```
Any = term()
```

A non-local return from a function. If evaluated within a `catch`, `catch` returns value `Any`. Example:

```
> catch throw({hello, there}).
{hello,there}
```

Failure: `nocatch` if not evaluated within a catch.

`time() -> Time`

Types:

`Time = calendar:time()`

Returns the current time as `{Hour, Minute, Second}`.

The time zone and Daylight Saving Time correction depend on the underlying OS. Example:

```
> time().
{9,42,44}
```

`erlang:time_offset() -> integer()`

Returns the current time offset between *Erlang monotonic time* and *Erlang system time* in `native` *time unit*. Current time offset added to an Erlang monotonic time gives corresponding Erlang system time.

The time offset may or may not change during operation depending on the *time warp mode* used.

Note:

A change in time offset can be observed at slightly different points in time by different processes.

If the runtime system is in *multi-time warp mode*, the time offset is changed when the runtime system detects that the *OS system time* has changed. The runtime system will, however, not detect this immediately when it occurs. A task checking the time offset is scheduled to execute at least once a minute; so, under normal operation this is to be detected within a minute, but during heavy load it can take longer time.

`erlang:time_offset(Unit) -> integer()`

Types:

`Unit = time_unit()`

Returns the current time offset between *Erlang monotonic time* and *Erlang system time* converted into the `Unit` passed as argument.

Same as calling `erlang:convert_time_unit(erlang:time_offset(), native, Unit)` however optimized for commonly used `Units`.

`erlang:timestamp() -> Timestamp`

Types:

```
Timestamp = timestamp()
timestamp() =
    {MegaSecs :: integer() >= 0,
     Secs :: integer() >= 0,
     MicroSecs :: integer() >= 0}
```

Returns current *Erlang system time* on the format `{MegaSecs, Secs, MicroSecs}`. This format is the same as `os:timestamp/0` and the deprecated `erlang:now/0` use. The reason for the existence of `erlang:timestamp()` is purely to simplify use for existing code that assumes this time stamp format. Current Erlang system time can more efficiently be retrieved in the time unit of your choice using `erlang:system_time/1`.

The `erlang:timestamp()` BIF is equivalent to:

```
timestamp() ->
    ErlangSystemTime = erlang:system_time(microsecond),
    MegaSecs = ErlangSystemTime div 1000000000000,
    Secs = ErlangSystemTime div 1000000 - MegaSecs*1000000,
    MicroSecs = ErlangSystemTime rem 1000000,
    {MegaSecs, Secs, MicroSecs}.
```

It, however, uses a native implementation that does not build garbage on the heap and with slightly better performance.

Note:

This time is **not** a monotonically increasing time in the general case. For more information, see the documentation of *time warp modes* in the User's Guide.

`tl(List) -> term()`

Types:

```
List = [term(), ...]
```

Returns the tail of `List`, that is, the list minus the first element, for example:

```
> tl([geesties, guilies, beasties]).
[guilies, beasties]
```

Allowed in guard tests.

Failure: `badarg` if `List` is the empty list `[]`.

`erlang:trace(PidPortSpec, How, FlagList) -> integer()`

Types:

```
PidPortSpec =
    pid() |
    port() |
    all |
    processes |
    ports |
    existing |
    existing_processes |
    existing_ports |
    new |
    new_processes |
    new_ports
How = boolean()
FlagList = [trace_flag()]
trace_flag() =
    all |
    send |
    'receive' |
    procs |
    ports |
    call |
    arity |
    return_to |
```

```
silent |
running |
exiting |
running_procs |
running_ports |
garbage_collection |
timestamp |
cpu_timestamp |
monotonic_timestamp |
strict_monotonic_timestamp |
set_on_spawn |
set_on_first_spawn |
set_on_link |
set_on_first_link |
{tracer, pid() | port()} |
{tracer, module(), term()}
```

Turns on (if `How == true`) or off (if `How == false`) the trace flags in `FlagList` for the process or processes represented by `PidPortSpec`.

`PidPortSpec` is either a process identifier (pid) for a local process, a port identifier, or one of the following atoms:

`all`
: All currently existing processes and ports and all that will be created in the future.

`processes`
: All currently existing processes and all that will be created in the future.

`ports`
: All currently existing ports and all that will be created in the future.

`existing`
: All currently existing processes and ports.

`existing_processes`
: All currently existing processes.

`existing_ports`
: All currently existing ports.

`new`
: All processes and ports that will be created in the future.

`new_processes`
: All processes that will be created in the future.

`new_ports`
: All ports that will be created in the future.

`FlagList` can contain any number of the following flags (the "message tags" refers to the list of *`trace messages`*):

`all`

Sets all trace flags except `tracer` and `cpu_timestamp`, which are in their nature different than the others.

`send`

Traces sending of messages.

Message tags: *`send`* and *`send_to_non_existing_process`*.

`'receive'`

Traces receiving of messages.

Message tags: *`'receive'`*.

`call`

Traces certain function calls. Specify which function calls to trace by calling *`erlang:trace_pattern/3`*.

Message tags: *`call`* and *`return_from`*.

`silent`

Used with the `call` trace flag. The `call`, `return_from`, and `return_to` trace messages are inhibited if this flag is set, but they are executed as normal if there are match specifications.

Silent mode is inhibited by executing `erlang:trace(_, false, [silent|_])`, or by a match specification executing the function `{silent, false}`.

The `silent` trace flag facilitates setting up a trace on many or even all processes in the system. The trace can then be activated and deactivated using the match specification function `{silent,Bool}`, giving a high degree of control of which functions with which arguments that trigger the trace.

Message tags: *`call`*, *`return_from`*, and *`return_to`*. Or rather, the absence of.

`return_to`

Used with the `call` trace flag. Traces the return from a traced function back to its caller. Only works for functions traced with option `local` to *`erlang:trace_pattern/3`*.

The semantics is that a trace message is sent when a call traced function returns, that is, when a chain of tail recursive calls ends. Only one trace message is sent per chain of tail recursive calls, so the properties of tail recursiveness for function calls are kept while tracing with this flag. Using `call` and `return_to` trace together makes it possible to know exactly in which function a process executes at any time.

To get trace messages containing return values from functions, use the `{return_trace}` match specification action instead.

Message tags: *`return_to`*.

`procs`

Traces process-related events.

Message tags: *`spawn`*, *`spawned`*, *`exit`*, *`register`*, *`unregister`*, *`link`*, *`unlink`*, *`getting_linked`*, and *`getting_unlinked`*.

`ports`

Traces port-related events.

Message tags: *`open`*, *`closed`*, *`register`*, *`unregister`*, *`getting_linked`*, and *`getting_unlinked`*.

`running`

Traces scheduling of processes.

Message tags: *`in`* and *`out`*.

`exiting`

Traces scheduling of exiting processes.

Message tags: *`in_exiting`*, *`out_exiting`*, and *`out_exited`*.

`running_procs`

Traces scheduling of processes just like `running`. However, this option also includes schedule events when the process executes within the context of a port without being scheduled out itself.

Message tags: *`in`* and *`out`*.

`running_ports`

Traces scheduling of ports.

Message tags: *`in`* and *`out`*.

`garbage_collection`

Traces garbage collections of processes.

Message tags: *`gc_minor_start`*, *`gc_max_heap_size`*, and *`gc_minor_end`*.

`timestamp`

Includes a time stamp in all trace messages. The time stamp (Ts) has the same form as returned by `erlang:now()`.

`cpu_timestamp`

A global trace flag for the Erlang node that makes all trace time stamps using flag `timestamp` to be in CPU time, not wall clock time. That is, `cpu_timestamp` is not be used if `monotonic_timestamp` or `strict_monotonic_timestamp` is enabled. Only allowed with `PidPortSpec==all`. If the host machine OS does not support high-resolution CPU time measurements, `trace/3` exits with `badarg`. Notice that most OS do not synchronize this value across cores, so be prepared that time can seem to go backwards when using this option.

`monotonic_timestamp`

Includes an *Erlang monotonic time* time stamp in all trace messages. The time stamp (Ts) has the same format and value as produced by *`erlang:monotonic_time(nanosecond)`*. This flag overrides flag `cpu_timestamp`.

`strict_monotonic_timestamp`

Includes an time stamp consisting of *Erlang monotonic time* and a monotonically increasing integer in all trace messages. The time stamp (Ts) has the same format and value as produced by *`{erlang:monotonic_time(nanosecond), erlang:unique_integer([monotonic])}`*. This flag overrides flag `cpu_timestamp`.

`arity`

Used with the `call` trace flag. `{M, F, Arity}` is specified instead of `{M, F, Args}` in call trace messages.

`set_on_spawn`

Makes any process created by a traced process inherit its trace flags, including flag `set_on_spawn`.

`set_on_first_spawn`

Makes the first process created by a traced process inherit its trace flags, excluding flag `set_on_first_spawn`.

`set_on_link`

Makes any process linked by a traced process inherit its trace flags, including flag `set_on_link`.

`set_on_first_link`

Makes the first process linked to by a traced process inherit its trace flags, excluding flag `set_on_first_link`.

`{tracer, Tracer}`

Specifies where to send the trace messages. `Tracer` must be the process identifier of a local process or the port identifier of a local port.

`{tracer, TracerModule, TracerState}`

Specifies that a tracer module is to be called instead of sending a trace message. The tracer module can then ignore or change the trace message. For more details on how to write a tracer module, see *`erl_tracer(3)`*.

If no `tracer` is specified, the calling process receives all the trace messages.

The effect of combining `set_on_first_link` with `set_on_link` is the same as `set_on_first_link` alone. Likewise for `set_on_spawn` and `set_on_first_spawn`.

The tracing process receives the **trace messages** described in the following list. `Pid` is the process identifier of the traced process in which the traced event has occurred. The third tuple element is the message tag.

If flag `timestamp`, `strict_monotonic_timestamp`, or `monotonic_timestamp` is specified, the first tuple element is `trace_ts` instead, and the time stamp is added as an extra element last in the message tuple. If multiple time stamp flags are passed, `timestamp` has precedence over `strict_monotonic_timestamp`, which in turn has precedence over `monotonic_timestamp`. All time stamp flags are remembered, so if two are passed and the one with highest precedence later is disabled, the other one becomes active.

Trace messages:

`{trace, PidPort, send, Msg, To}`

When `PidPort` sends message `Msg` to process `To`.

`{trace, PidPort, send_to_non_existing_process, Msg, To}`

When `PidPort` sends message `Msg` to the non-existing process `To`.

`{trace, PidPort, 'receive', Msg}`

When `PidPort` receives message `Msg`. If `Msg` is set to time-out, a receive statement can have timed out, or the process received a message with the payload `timeout`.

`{trace, Pid, call, {M, F, Args}}`

When `Pid` calls a traced function. The return values of calls are never supplied, only the call and its arguments.

Trace flag `arity` can be used to change the contents of this message, so that `Arity` is specified instead of `Args`.

`{trace, Pid, return_to, {M, F, Arity}}`

When `Pid` returns **to** the specified function. This trace message is sent if both the flags `call` and `return_to` are set, and the function is set to be traced on **local** function calls. The message is only sent when returning from a chain of tail recursive function calls, where at least one call generated a `call` trace message (that is, the functions match specification matched, and `{message, false}` was not an action).

`{trace, Pid, return_from, {M, F, Arity}, ReturnValue}`

When `Pid` returns **from** the specified function. This trace message is sent if flag `call` is set, and the function has a match specification with a `return_trace` or `exception_trace` action.

`{trace, Pid, exception_from, {M, F, Arity}, {Class, Value}}`

When `Pid` exits **from** the specified function because of an exception. This trace message is sent if flag `call` is set, and the function has a match specification with an `exception_trace` action.

`{trace, Pid, spawn, Pid2, {M, F, Args}}`

When `Pid` spawns a new process `Pid2` with the specified function call as entry point.

`Args` is supposed to be the argument list, but can be any term if the spawn is erroneous.

`{trace, Pid, spawned, Pid2, {M, F, Args}}`

When `Pid` is spawned by process `Pid2` with the specified function call as entry point.

`Args` is supposed to be the argument list, but can be any term if the spawn is erroneous.

`{trace, Pid, exit, Reason}`

When `Pid` exits with reason `Reason`.

`{trace, PidPort, register, RegName}`

When `PidPort` gets the name `RegName` registered.

`{trace, PidPort, unregister, RegName}`

When `PidPort` gets the name `RegName` unregistered. This is done automatically when a registered process or port exits.

`{trace, Pid, link, Pid2}`

When `Pid` links to a process `Pid2`.

`{trace, Pid, unlink, Pid2}`

When `Pid` removes the link from a process `Pid2`.

`{trace, PidPort, getting_linked, Pid2}`

When `PidPort` gets linked to a process `Pid2`.

`{trace, PidPort, getting_unlinked, Pid2}`

When `PidPort` gets unlinked from a process `Pid2`.

`{trace, Pid, exit, Reason}`

When `Pid` exits with reason `Reason`.

`{trace, Port, open, Pid, Driver}`

When `Pid` opens a new port `Port` with the running `Driver`.

`Driver` is the name of the driver as an atom.

`{trace, Port, closed, Reason}`

When `Port` closes with `Reason`.

`{trace, Pid, in | in_exiting, {M, F, Arity} | 0}`

When `Pid` is scheduled to run. The process runs in function `{M, F, Arity}`. On some rare occasions, the current function cannot be determined, then the last element is `0`.

`{trace, Pid, out | out_exiting | out_exited, {M, F, Arity} | 0}`

When `Pid` is scheduled out. The process was running in function {M, F, Arity}. On some rare occasions, the current function cannot be determined, then the last element is `0`.

`{trace, Port, in, Command | 0}`

When `Port` is scheduled to run. `Command` is the first thing the port will execute, it can however run several commands before being scheduled out. On some rare occasions, the current function cannot be determined, then the last element is `0`.

The possible commands are `call`, `close`, `command`, `connect`, `control`, `flush`, `info`, `link`, `open`, and `unlink`.

`{trace, Port, out, Command | 0}`

When `Port` is scheduled out. The last command run was `Command`. On some rare occasions, the current function cannot be determined, then the last element is `0`. `Command` can contain the same commands as `in`

`{trace, Pid, gc_minor_start, Info}`

Sent when a young garbage collection is about to be started. `Info` is a list of two-element tuples, where the first element is a key, and the second is the value. Do not depend on any order of the tuples. The following keys are defined:

`heap_size`
: The size of the used part of the heap.

`heap_block_size`
: The size of the memory block used for storing the heap and the stack.

`old_heap_size`
: The size of the used part of the old heap.

`old_heap_block_size`
: The size of the memory block used for storing the old heap.

`stack_size`
: The size of the stack.

`recent_size`
: The size of the data that survived the previous garbage collection.

`mbuf_size`
: The combined size of message buffers associated with the process.

`bin_vheap_size`
: The total size of unique off-heap binaries referenced from the process heap.

`bin_vheap_block_size`
: The total size of binaries allowed in the virtual heap in the process before doing a garbage collection.

`bin_old_vheap_size`
: The total size of unique off-heap binaries referenced from the process old heap.

`bin_old_vheap_block_size`
: The total size of binaries allowed in the virtual old heap in the process before doing a garbage collection.

All sizes are in words.

`{trace, Pid, gc_max_heap_size, Info}`

Sent when the *`max_heap_size`* is reached during garbage collection. `Info` contains the same kind of list as in message `gc_start`, but the sizes reflect the sizes that triggered `max_heap_size` to be reached.

`{trace, Pid, gc_minor_end, Info}`

Sent when young garbage collection is finished. `Info` contains the same kind of list as in message `gc_minor_start`, but the sizes reflect the new sizes after garbage collection.

`{trace, Pid, gc_major_start, Info}`

Sent when fullsweep garbage collection is about to be started. `Info` contains the same kind of list as in message `gc_minor_start`.

`{trace, Pid, gc_major_end, Info}`

Sent when fullsweep garbage collection is finished. `Info` contains the same kind of list as in message `gc_minor_start`, but the sizes reflect the new sizes after a fullsweep garbage collection.

If the tracing process/port dies or the tracer module returns `remove`, the flags are silently removed.

Each process can only be traced by one tracer. Therefore, attempts to trace an already traced process fail.

Returns a number indicating the number of processes that matched `PidPortSpec`. If `PidPortSpec` is a process identifier, the return value is `1`. If `PidPortSpec` is `all` or `existing`, the return value is the number of processes running. If `PidPortSpec` is `new`, the return value is `0`.

Failure: `badarg` if the specified arguments are not supported. For example, `cpu_timestamp` is not supported on all platforms.

`erlang:trace_delivered(Tracee) -> Ref`

Types:

```
Tracee = pid() | all
Ref = reference()
```

The delivery of trace messages (generated by *`erlang:trace/3`*, *`seq_trace(3)`*, or *`erlang:system_profile/2`*) is dislocated on the time-line compared to other events in the system. If you know that `Tracee` has passed some specific point in its execution, and you want to know when at least all trace messages corresponding to events up to this point have reached the tracer, use `erlang:trace_delivered(Tracee)`.

When it is guaranteed that all trace messages are delivered to the tracer up to the point that `Tracee` reached at the time of the call to `erlang:trace_delivered(Tracee)`, then a `{trace_delivered, Tracee, Ref}` message is sent to the caller of `erlang:trace_delivered(Tracee)` .

Notice that message `trace_delivered` does **not** imply that trace messages have been delivered. Instead it implies that all trace messages that **are to be delivered** have been delivered. It is not an error if `Tracee` is not, and has not been traced by someone, but if this is the case, **no** trace messages have been delivered when the `trace_delivered` message arrives.

Notice that `Tracee` must refer to a process currently or previously existing on the same node as the caller of `erlang:trace_delivered(Tracee)` resides on. The special `Tracee` atom `all` denotes all processes that currently are traced in the node.

When used together with a *Tracer Module*, any message sent in the trace callback is guaranteed to have reached its recipient before the `trace_delivered` message is sent.

Example: Process `A` is `Tracee`, port `B` is tracer, and process `C` is the port owner of `B`. `C` wants to close `B` when `A` exits. To ensure that the trace is not truncated, `C` can call `erlang:trace_delivered(A)` when `A` exits, and wait for message `{trace_delivered, A, Ref}` before closing `B`.

Failure: `badarg` if `Tracee` does not refer to a process (dead or alive) on the same node as the caller of `erlang:trace_delivered(Tracee)` resides on.

`erlang:trace_info(PidPortFuncEvent, Item) -> Res`

Types:

```
PidPortFuncEvent =
    pid() |
    port() |
    new |
    new_processes |
    new_ports |
    {Module, Function, Arity} |
    on_load |
    send |
    'receive'
Module = module()
Function = atom()
Arity = arity()
Item =
    flags |
    tracer |
    traced |
    match_spec |
    meta |
```

```
    meta_match_spec |
    call_count |
    call_time |
    all
Res = trace_info_return()
trace_info_return() =
    undefined |
    {flags, [trace_info_flag()]} |
    {tracer, pid() | port() | []} |
    {tracer, module(), term()} |
    trace_info_item_result() |
    {all, [trace_info_item_result()] | false | undefined}
trace_info_item_result() =
    {traced, global | local | false | undefined} |
    {match_spec, trace_match_spec() | false | undefined} |
    {meta, pid() | port() | false | undefined | []} |
    {meta, module(), term()} |
    {meta_match_spec, trace_match_spec() | false | undefined} |
    {call_count, integer() >= 0 | boolean() | undefined} |
    {call_time,
     [{pid(),
       integer() >= 0,
       integer() >= 0,
       integer() >= 0}] |
     boolean() |
     undefined}
trace_info_flag() =
    send |
    'receive' |
    set_on_spawn |
    call |
    return_to |
    procs |
    set_on_first_spawn |
    set_on_link |
    running |
    garbage_collection |
    timestamp |
    monotonic_timestamp |
    strict_monotonic_timestamp |
    arity
trace_match_spec() =
    [{[term()] | '_' | match_variable(), [term()], [term()]}]
match_variable() = atom()
```

Approximation of '$1' | '$2' | '$3' | ...

Returns trace information about a port, process, function, or event.

To get information about a port or process, `PidPortFuncEvent` is to be a process identifier (pid), port identifier, or one of the atoms `new`, `new_processes`, or `new_ports`. The atom `new` or `new_processes` means that the default trace state for processes to be created is returned. The atom `new_ports` means that the default trace state for ports to be created is returned.

Valid `Item`s for ports and processes:

`flags`

Returns a list of atoms indicating what kind of traces is enabled for the process. The list is empty if no traces are enabled, and one or more of the followings atoms if traces are enabled: `send`, `'receive'`, `set_on_spawn`, `call`, `return_to`, `procs`, `ports`, `set_on_first_spawn`, `set_on_link`, `running`, `running_procs`, `running_ports`, `silent`, `exiting`, `monotonic_timestamp`, `strict_monotonic_timestamp`, `garbage_collection`, `timestamp`, and `arity`. The order is arbitrary.

`tracer`

Returns the identifier for process, port, or a tuple containing the tracer module and tracer state tracing this process. If this process is not traced, the return value is `[]`.

To get information about a function, `PidPortFuncEvent` is to be the three-element tuple `{Module, Function, Arity}` or the atom `on_load`. No wildcards are allowed. Returns `undefined` if the function does not exist, or `false` if the function is not traced. If `PidPortFuncEvent` is `on_load`, the information returned refers to the default value for code that will be loaded.

Valid `Item`s for functions:

`traced`

Returns `global` if this function is traced on global function calls, `local` if this function is traced on local function calls (that is, local and global function calls), and `false` if local or global function calls are not traced.

`match_spec`

Returns the match specification for this function, if it has one. If the function is locally or globally traced but has no match specification defined, the returned value is `[]`.

`meta`

Returns the meta-trace tracer process, port, or trace module for this function, if it has one. If the function is not meta-traced, the returned value is `false`. If the function is meta-traced but has once detected that the tracer process is invalid, the returned value is `[]`.

`meta_match_spec`

Returns the meta-trace match specification for this function, if it has one. If the function is meta-traced but has no match specification defined, the returned value is `[]`.

`call_count`

Returns the call count value for this function or `true` for the pseudo function `on_load` if call count tracing is active. Otherwise `false` is returned.

See also *`erlang:trace_pattern/3`*.

`call_time`

Returns the call time values for this function or `true` for the pseudo function `on_load` if call time tracing is active. Otherwise `false` is returned. The call time values returned, `[{Pid, Count, S, Us}]`, is a list of each process that executed the function and its specific counters.

See also *`erlang:trace_pattern/3`*.

`all`

Returns a list containing the `{Item, Value}` tuples for all other items, or returns `false` if no tracing is active for this function.

To get information about an event, `PidPortFuncEvent` is to be one of the atoms `send` or `'receive'`.

One valid `Item` for events exists:

`match_spec`

Returns the match specification for this event, if it has one, or `true` if no match specification has been set.

The return value is `{Item, Value}`, where `Value` is the requested information as described earlier. If a pid for a dead process was specified, or the name of a non-existing function, `Value` is `undefined`.

```
erlang:trace_pattern(MFA, MatchSpec) -> integer() >= 0
```

Types:

```
MFA = trace_pattern_mfa() | send | 'receive'
MatchSpec =
    (MatchSpecList :: trace_match_spec()) |
    boolean() |
    restart |
    pause
trace_pattern_mfa() = {atom(), atom(), arity() | '_'} | on_load
trace_match_spec() =
    [{[term()] | '_' | match_variable(), [term()], [term()]}]
match_variable() = atom()
```

Approximation of '$1' | '$2' | '$3' | ...

The same as *`erlang:trace_pattern(Event, MatchSpec, [])`*, retained for backward compatibility.

```
erlang:trace_pattern(MFA :: send, MatchSpec, FlagList :: []) ->
                        integer() >= 0
```

Types:

```
MatchSpec = (MatchSpecList :: trace_match_spec()) | boolean()
trace_match_spec() =
    [{[term()] | '_' | match_variable(), [term()], [term()]}]
match_variable() = atom()
```

Approximation of '$1' | '$2' | '$3' | ...

Sets trace pattern for **message sending**. Must be combined with *`erlang:trace/3`* to set the `send` trace flag for one or more processes. By default all messages sent from `send` traced processes are traced. To limit traced send events based on the message content, the sender and/or the receiver, use `erlang:trace_pattern/3`.

Argument `MatchSpec` can take the following forms:

`MatchSpecList`

A list of match specifications. The matching is done on the list `[Receiver, Msg]`. `Receiver` is the process or port identity of the receiver and `Msg` is the message term. The pid of the sending process can be accessed with the guard function `self/0`. An empty list is the same as `true`. For more information, see section *Match Specifications in Erlang* in the User's Guide.

`true`

Enables tracing for all sent messages (from `send` traced processes). Any match specification is removed. **This is the default**.

`false`

Disables tracing for all sent messages. Any match specification is removed.

Argument `FlagList` must be `[]` for send tracing.

The return value is always `1`.

Examples:

Only trace messages to a specific process `Pid`:

```
> erlang:trace_pattern(send, [{[Pid, '_'],[],[]}], []).
1
```

Only trace messages matching `{reply, _}`:

```
> erlang:trace_pattern(send, [{['_', {reply,'_'}],[],[]}], []).
1
```

Only trace messages sent to the sender itself:

```
> erlang:trace_pattern(send, [{['$1', '_'],[{'=:=','$1',{self}}],[]}], []).
1
```

Only trace messages sent to other nodes:

```
> erlang:trace_pattern(send, [{['$1', '_'],[{'=/=',{node,'$1'},{node}}],[]}], []).
1
```

Note:

A match specification for `send` trace can use all guard and body functions except `caller`.

```
erlang:trace_pattern(MFA :: 'receive', MatchSpec, FlagList :: []) ->
                        integer() >= 0
```

Types:

```
MatchSpec = (MatchSpecList :: trace_match_spec()) | boolean()
trace_match_spec() =
    [{[term()] | '_' | match_variable(), [term()], [term()]}]
match_variable() = atom()
```

Approximation of '$1' | '$2' | '$3' | ...

Sets trace pattern for **message receiving**. Must be combined with *`erlang:trace/3`* to set the `'receive'` trace flag for one or more processes. By default all messages received by `'receive'` traced processes are traced. To limit traced receive events based on the message content, the sender and/or the receiver, use `erlang:trace_pattern/3`.

Argument `MatchSpec` can take the following forms:

`MatchSpecList`

A list of match specifications. The matching is done on the list `[Node, Sender, Msg]`. `Node` is the node name of the sender. `Sender` is the process or port identity of the sender, or the atom `undefined` if the sender is not known (which can be the case for remote senders). `Msg` is the message term. The pid of the receiving process can be accessed with the guard function `self/0`. An empty list is the same as `true`. For more information, see section *Match Specifications in Erlang* in the User's Guide.

`true`

Enables tracing for all received messages (to `'receive'` traced processes). Any match specification is removed. **This is the default**.

`false`

Disables tracing for all received messages. Any match specification is removed.

Argument `FlagList` must be `[]` for receive tracing.

The return value is always `1`.

Examples:

Only trace messages from a specific process `Pid`:

```
> erlang:trace_pattern('receive', [{['_',Pid, '_'],[],[]}], []).
1
```

Only trace messages matching `{reply, _}`:

```
> erlang:trace_pattern('receive', [{['_','_', {reply,'_'}],[],[]}], []).
1
```

Only trace messages from other nodes:

```
> erlang:trace_pattern('receive', [{['$1', '_', '_'],[{'=/=','$1',{node}}],[]}], []).
1
```

Note:

A match specification for `'receive'` trace can use all guard and body functions except `caller`, `is_seq_trace`, `get_seq_token`, `set_seq_token`, `enable_trace`, `disable_trace`, `trace`, `silent`, and `process_dump`.

```
erlang:trace_pattern(MFA, MatchSpec, FlagList) ->
                        integer() >= 0
```

Types:

```
MFA = trace_pattern_mfa()
MatchSpec =
    (MatchSpecList :: trace_match_spec()) |
    boolean() |
    restart |
    pause
FlagList = [trace_pattern_flag()]
trace_pattern_mfa() = {atom(), atom(), arity() | '_'} | on_load
trace_match_spec() =
    [{[term()] | '_' | match_variable(), [term()], [term()]}]
trace_pattern_flag() =
    global |
    local |
    meta |
```

```
        {meta, Pid :: pid()} |
        {meta, TracerModule :: module(), TracerState :: term()} |
        call_count |
        call_time
    match_variable() = atom()
```

Approximation of '$1' | '$2' | '$3' | ...

Enables or disables **call tracing** for one or more functions. Must be combined with *`erlang:trace/3`* to set the `call` trace flag for one or more processes.

Conceptually, call tracing works as follows. Inside the Erlang virtual machine, a set of processes and a set of functions are to be traced. If a traced process calls a traced function, the trace action is taken. Otherwise, nothing happens.

To add or remove one or more processes to the set of traced processes, use *`erlang:trace/3`*.

To add or remove functions to the set of traced functions, use `erlang:trace_pattern/3`.

The BIF `erlang:trace_pattern/3` can also add match specifications to a function. A match specification comprises a pattern that the function arguments must match, a guard expression that must evaluate to `true`, and an action to be performed. The default action is to send a trace message. If the pattern does not match or the guard fails, the action is not executed.

Argument `MFA` is to be a tuple, such as `{Module, Function, Arity}`, or the atom `on_load` (described below). It can be the module, function, and arity for a function (or a BIF in any module). The atom `'_'` can be used as a wildcard in any of the following ways:

`{Module,Function,'_'}`

All functions of any arity named `Function` in module `Module`.

`{Module,'_','_'}`

All functions in module `Module`.

`{'_','_','_'}`

All functions in all loaded modules.

Other combinations, such as `{Module,'_',Arity}`, are not allowed. Local functions match wildcards only if option `local` is in `FlagList`.

If argument `MFA` is the atom `on_load`, the match specification and flag list are used on all modules that are newly loaded.

Argument `MatchSpec` can take the following forms:

`false`

Disables tracing for the matching functions. Any match specification is removed.

`true`

Enables tracing for the matching functions. Any match specification is removed.

`MatchSpecList`

A list of match specifications. An empty list is equivalent to `true`. For a description of match specifications, see section *Match Specifications in Erlang* in the User's Guide.

`restart`

For the `FlagList` options `call_count` and `call_time`: restarts the existing counters. The behavior is undefined for other `FlagList` options.

`pause`

For the `FlagList` options `call_count` and `call_time`: pauses the existing counters. The behavior is undefined for other `FlagList` options.

Parameter `FlagList` is a list of options. The following are the valid options:

`global`

Turns on or off call tracing for global function calls (that is, calls specifying the module explicitly). Only exported functions match and only global calls generate trace messages. **This is the default**.

`local`

Turns on or off call tracing for all types of function calls. Trace messages are sent whenever any of the specified functions are called, regardless of how they are called. If flag `return_to` is set for the process, a `return_to` message is also sent when this function returns to its caller.

`meta | {meta, Pid} | {meta, TracerModule, TracerState}`

Turns on or off meta-tracing for all types of function calls. Trace messages are sent to the tracer whenever any of the specified functions are called. If no tracer is specified, `self()` is used as a default tracer process.

Meta-tracing traces all processes and does not care about the process trace flags set by `erlang:trace/3`, the trace flags are instead fixed to `[call, timestamp]`.

The match specification function `{return_trace}` works with meta-trace and sends its trace message to the same tracer.

`call_count`

Starts (`MatchSpec == true`) or stops (`MatchSpec == false`) call count tracing for all types of function calls. For every function, a counter is incremented when the function is called, in any process. No process trace flags need to be activated.

If call count tracing is started while already running, the count is restarted from zero. To pause running counters, use `MatchSpec == pause`. Paused and running counters can be restarted from zero with `MatchSpec == restart`.

To read the counter value, use *`erlang:trace_info/2`*.

`call_time`

Starts (`MatchSpec == true`) or stops (`MatchSpec == false`) call time tracing for all types of function calls. For every function, a counter is incremented when the function is called. Time spent in the function is accumulated in two other counters, seconds and microseconds. The counters are stored for each call traced process.

If call time tracing is started while already running, the count and time restart from zero. To pause running counters, use `MatchSpec == pause`. Paused and running counters can be restarted from zero with `MatchSpec == restart`.

To read the counter value, use *`erlang:trace_info/2`*.

The options `global` and `local` are mutually exclusive, and `global` is the default (if no options are specified). The options `call_count` and `meta` perform a kind of local tracing, and cannot be combined with `global`. A function can be globally or locally traced. If global tracing is specified for a set of functions, then local, meta, call time, and call count tracing for the matching set of local functions is disabled, and conversely.

When disabling trace, the option must match the type of trace set on the function. That is, local tracing must be disabled with option `local` and global tracing with option `global` (or no option), and so on.

Part of a match specification list cannot be changed directly. If a function has a match specification, it can be replaced with a new one. To change an existing match specification, use the BIF *erlang:trace_info/2* to retrieve the existing match specification.

Returns the number of functions matching argument `MFA`. This is zero if none matched.

`trunc(Number) -> integer()`

Types:

```
Number = number()
```

Returns an integer by truncating `Number`, for example:

```
> trunc(5.5).
5
```

Allowed in guard tests.

`tuple_size(Tuple) -> integer() >= 0`

Types:

```
Tuple = tuple()
```

Returns an integer that is the number of elements in `Tuple`, for example:

```
> tuple_size({morni, mulle, bwange}).
3
```

Allowed in guard tests.

`tuple_to_list(Tuple) -> [term()]`

Types:

```
Tuple = tuple()
```

Returns a list corresponding to `Tuple`. `Tuple` can contain any Erlang terms. Example:

```
> tuple_to_list({share, {'Ericsson_B', 163}}).
[share,{'Ericsson_B',163}]
```

`erlang:unique_integer() -> integer()`

Generates and returns an *integer unique on current runtime system instance*. The same as calling *erlang:unique_integer([])*.

`erlang:unique_integer(ModifierList) -> integer()`

Types:

```
ModifierList = [Modifier]
Modifier = positive | monotonic
```

Generates and returns an *integer unique on current runtime system instance*. The integer is unique in the sense that this BIF, using the same set of modifiers, does not return the same integer more than once on the current runtime system instance. Each integer value can of course be constructed by other means.

By default, when `[]` is passed as `ModifierList`, both negative and positive integers can be returned. This to use the range of integers that do not need heap memory allocation as much as possible. By default the returned integers are also only guaranteed to be unique, that is, any returned integer can be smaller or larger than previously returned integers.

`Modifiers`:

positive

Returns only positive integers.

Notice that by passing the `positive` modifier you will get heap allocated integers (bignums) quicker.

monotonic

Returns *strictly monotonically increasing* integers corresponding to creation time. That is, the integer returned is always larger than previously returned integers on the current runtime system instance.

These values can be used to determine order between events on the runtime system instance. That is, if both `X = erlang:unique_integer([monotonic])` and `Y = erlang:unique_integer([monotonic])` are executed by different processes (or the same process) on the same runtime system instance and `X < Y`, we know that `X` was created before `Y`.

Warning:

Strictly monotonically increasing values are inherently quite expensive to generate and scales poorly. This is because the values need to be synchronized between CPU cores. That is, do not pass the `monotonic` modifier unless you really need strictly monotonically increasing values.

All valid `Modifiers` can be combined. Repeated (valid) `Modifiers` in the `ModifierList` are ignored.

Note:

The set of integers returned by `erlang:unique_integer/1` using different sets of `Modifiers` **will overlap**. For example, by calling `unique_integer([monotonic])`, and `unique_integer([positive, monotonic])` repeatedly, you will eventually see some integers that are returned by both calls.

Failures:

`badarg`
if `ModifierList` is not a proper list.

`badarg`
if `Modifier` is not a valid modifier.

`erlang:universaltime() -> DateTime`

Types:

`DateTime = calendar:datetime()`

Returns the current date and time according to Universal Time Coordinated (UTC) in the form `{{Year, Month, Day}, {Hour, Minute, Second}}` if supported by the underlying OS. Otherwise `erlang:universaltime()` is equivalent to `erlang:localtime()`. Example:

```
> erlang:universaltime().
{{1996,11,6},{14,18,43}}
```

`erlang:universaltime_to_localtime(Universaltime) -> Localtime`

Types:

`Localtime = Universaltime = ***calendar:datetime()***`

Converts Universal Time Coordinated (UTC) date and time to local date and time in the form `{{Year, Month, Day}, {Hour, Minute, Second}}` if supported by the underlying OS. Otherwise no conversion is done, and `Universaltime` is returned. Example:

```
> erlang:universaltime_to_localtime({{1996,11,6},{14,18,43}}).
{{1996,11,7},{15,18,43}}
```

Failure: `badarg` if `Universaltime` denotes an invalid date and time.

`unlink(Id) -> true`

Types:

`Id = pid() | port()`

Removes the link, if there is one, between the calling process and the process or port referred to by `Id`.

Returns `true` and does not fail, even if there is no link to `Id`, or if `Id` does not exist.

Once `unlink(Id)` has returned, it is guaranteed that the link between the caller and the entity referred to by `Id` has no effect on the caller in the future (unless the link is setup again). If the caller is trapping exits, an `{'EXIT', Id, _}` message from the link can have been placed in the caller's message queue before the call.

Notice that the `{'EXIT', Id, _}` message can be the result of the link, but can also be the result of `Id` calling `exit/2`. Therefore, it **can** be appropriate to clean up the message queue when trapping exits after the call to `unlink(Id)`, as follows:

```
unlink(Id),
receive
    {'EXIT', Id, _} ->
        true
after 0 ->
        true
end
```

Note:

Before Erlang/OTP R11B (ERTS 5.5) `unlink/1` behaved completely asynchronously, that is, the link was active until the "unlink signal" reached the linked entity. This had an undesirable effect, as you could never know when you were guaranteed **not** to be effected by the link.

The current behavior can be viewed as two combined operations: asynchronously send an "unlink signal" to the linked entity and ignore any future results of the link.

`unregister(RegName) -> true`

Types:

`RegName = atom()`

Removes the registered name `RegName` associated with a process identifier or a port identifier, for example:

```
> unregister(db).
true
```

Users are advised not to unregister system processes.

Failure: `badarg` if `RegName` is not a registered name.

`whereis(RegName) -> pid() | port() | undefined`

Types:

```
RegName = atom()
```

Returns the process identifier or port identifier with the registered name `RegName`. Returns `undefined` if the name is not registered. Example:

```
> whereis(db).
<0.43.0>
```

`erlang:yield() -> true`

Voluntarily lets other processes (if any) get a chance to execute. Using this function is similar to `receive after 1 -> ok end`, except that `yield()` is faster.

Warning:

There is seldom or never any need to use this BIF, especially in the SMP emulator, as other processes have a chance to run in another scheduler thread anyway. Using this BIF without a thorough grasp of how the scheduler works can cause performance degradation.

init

Erlang module

This module is preloaded and contains the code for the `init` system process that coordinates the startup of the system. The first function evaluated at startup is `boot(BootArgs)`, where `BootArgs` is a list of command-line arguments supplied to the Erlang runtime system from the local operating system; see *`erl(1)`*.

`init` reads the boot script, which contains instructions on how to initiate the system. For more information about boot scripts, see *`script(4)`*.

`init` also contains functions to restart, reboot, and stop the system.

Exports

`boot(BootArgs) -> no_return()`

Types:

```
BootArgs = [binary()]
```

Starts the Erlang runtime system. This function is called when the emulator is started and coordinates system startup.

`BootArgs` are all command-line arguments except the emulator flags, that is, flags and plain arguments; see *`erl(1)`*.

`init` interprets some of the flags, see section *Command-Line Flags* below. The remaining flags ("user flags") and plain arguments are passed to the `init` loop and can be retrieved by calling *`get_arguments/0`* and *`get_plain_arguments/0`*, respectively.

`get_argument(Flag) -> {ok, Arg} | error`

Types:

```
Flag = atom()
Arg = [Values :: [string()]]
```

Returns all values associated with the command-line user flag `Flag`. If `Flag` is provided several times, each `Values` is returned in preserved order. Example:

```
% erl -a b c -a d
...
1> init:get_argument(a).
{ok,[["b","c"],["d"]]}
```

The following flags are defined automatically and can be retrieved using this function:

`root`

The installation directory of Erlang/OTP, `$ROOT`:

```
2> init:get_argument(root).
{ok,[["/usr/local/otp/releases/otp_beam_solaris8_r10b_patched"]]}
```

`progname`

The name of the program which started Erlang:

```
3> init:get_argument(progname).
{ok,[["erl"]]}
```

`home`

The home directory:

```
4> init:get_argument(home).
{ok,[["/home/harry"]]}
```

Returns `error` if no value is associated with `Flag`.

`get_arguments() -> Flags`

Types:

```
Flags = [{Flag :: atom(), Values :: [string()]}]
```

Returns all command-line flags and the system-defined flags, see *`get_argument/1`*.

`get_plain_arguments() -> [Arg]`

Types:

```
Arg = string()
```

Returns any plain command-line arguments as a list of strings (possibly empty).

`get_status() -> {InternalStatus, ProvidedStatus}`

Types:

```
InternalStatus = internal_status()
ProvidedStatus = term()
internal_status() = starting | started | stopping
```

The current status of the `init` process can be inspected. During system startup (initialization), `InternalStatus` is `starting`, and `ProvidedStatus` indicates how far the boot script has been interpreted. Each `{progress, Info}` term interpreted in the boot script affects `ProvidedStatus`, that is, `ProvidedStatus` gets the value of `Info`.

`reboot() -> ok`

All applications are taken down smoothly, all code is unloaded, and all ports are closed before the system terminates. If command-line flag `-heart` was specified, the `heart` program tries to reboot the system. For more information, see *`heart(3)`*.

To limit the shutdown time, the time `init` is allowed to spend taking down applications, command-line flag `-shutdown_time` is to be used.

`restart() -> ok`

The system is restarted **inside** the running Erlang node, which means that the emulator is not restarted. All applications are taken down smoothly, all code is unloaded, and all ports are closed before the system is booted again in the same way as initially started. The same `BootArgs` are used again.

To limit the shutdown time, the time `init` is allowed to spend taking down applications, command-line flag `-shutdown_time` is to be used.

`script_id() -> Id`

Types:

```
Id = term()
```

Gets the identity of the boot script used to boot the system. `Id` can be any Erlang term. In the delivered boot scripts, `Id` is `{Name, Vsn}`. `Name` and `Vsn` are strings.

`stop() -> ok`

The same as *`stop(0)`*.

`stop(Status) -> ok`

Types:

```
Status = integer() >= 0 | string()
```

All applications are taken down smoothly, all code is unloaded, and all ports are closed before the system terminates by calling `halt(Status)`. If command-line flag `-heart` was specified, the `heart` program is terminated before the Erlang node terminates. For more information, see *`heart(3)`*.

To limit the shutdown time, the time `init` is allowed to spend taking down applications, command-line flag `-shutdown_time` is to be used.

Command-Line Flags

Warning:

The support for loading of code from archive files is experimental. The only purpose of releasing it before it is ready is to obtain early feedback. The file format, semantics, interfaces, and so on, can be changed in a future release. The `-code_path_choice` flag is also experimental.

The `init` module interprets the following command-line flags:

`--`

Everything following `--` up to the next flag is considered plain arguments and can be retrieved using *`get_plain_arguments/0`*.

`-code_path_choice Choice`

Can be set to `strict` or `relaxed`. It controls how each directory in the code path is to be interpreted:

- Strictly as it appears in the `boot script`, or
- `init` is to be more relaxed and try to find a suitable directory if it can choose from a regular `ebin` directory and an `ebin` directory in an archive file.

This flag is particular useful when you want to elaborate with code loading from archives without editing the `boot script`. For more information about interpretation of boot scripts, see *`script(4)`*. The flag has also a similar effect on how the code server works; see *`code(3)`*.

`-epmd_module Module`

Specifies the module to use for registration and lookup of node names. Defaults to `erl_epmd`.

`-eval Expr`

Scans, parses, and evaluates an arbitrary expression `Expr` during system initialization. If any of these steps fail (syntax error, parse error, or exception during evaluation), Erlang stops with an error message. In the following example Erlang is used as a hexadecimal calculator:

```
% erl -noshell -eval 'R = 16#1F+16#A0, io:format("~.16B~n", [R])' \\
-s erlang halt
BF
```

If multiple `-eval` expressions are specified, they are evaluated sequentially in the order specified. `-eval` expressions are evaluated sequentially with `-s` and `-run` function calls (this also in the order specified). As with `-s` and `-run`, an evaluation that does not terminate blocks the system initialization process.

`-extra`

Everything following `-extra` is considered plain arguments and can be retrieved using *`get_plain_arguments/0`*.

`-run Mod [Func [Arg1, Arg2, ...]]`

Evaluates the specified function call during system initialization. `Func` defaults to `start`. If no arguments are provided, the function is assumed to be of arity 0. Otherwise it is assumed to be of arity 1, taking the list `[Arg1,Arg2,...]` as argument. All arguments are passed as strings. If an exception is raised, Erlang stops with an error message.

Example:

```
% erl -run foo -run foo bar -run foo bar baz 1 2
```

This starts the Erlang runtime system and evaluates the following functions:

```
foo:start()
foo:bar()
foo:bar(["baz", "1", "2"]).
```

The functions are executed sequentially in an initialization process, which then terminates normally and passes control to the user. This means that a `-run` call that does not return blocks further processing; to avoid this, use some variant of `spawn` in such cases.

`-s Mod [Func [Arg1, Arg2, ...]]`

Evaluates the specified function call during system initialization. `Func` defaults to `start`. If no arguments are provided, the function is assumed to be of arity 0. Otherwise it is assumed to be of arity 1, taking the list `[Arg1,Arg2,...]` as argument. All arguments are passed as atoms. If an exception is raised, Erlang stops with an error message.

Example:

```
% erl -s foo -s foo bar -s foo bar baz 1 2
```

This starts the Erlang runtime system and evaluates the following functions:

```
foo:start()
foo:bar()
foo:bar([baz, '1', '2']).
```

The functions are executed sequentially in an initialization process, which then terminates normally and passes control to the user. This means that a `-s` call that does not return blocks further processing; to avoid this, use some variant of `spawn` in such cases.

Because of the limited length of atoms, it is recommended to use `-run` instead.

Example

```
% erl -- a b -children thomas claire -ages 7 3 -- x y
...

1> init:get_plain_arguments().
["a","b","x","y"]
2> init:get_argument(children).
{ok,[["thomas","claire"]]}
3> init:get_argument(ages).
{ok, [["7","3"]]}
4> init:get_argument(silly).
error
```

See Also

erl_prim_loader(3), *heart(3)*

zlib

Erlang module

This module provides an API for the zlib library (**www.zlib.net**). It is used to compress and decompress data. The data format is described by **RFC 1950**, **RFC 1951**, and **RFC 1952**.

A typical (compress) usage is as follows:

```
Z = zlib:open(),
ok = zlib:deflateInit(Z,default),

Compress = fun(end_of_data, _Cont) -> [];
              (Data, Cont) ->
                 [zlib:deflate(Z, Data)|Cont(Read(),Cont)]
           end,
Compressed = Compress(Read(),Compress),
Last = zlib:deflate(Z, [], finish),
ok = zlib:deflateEnd(Z),
zlib:close(Z),
list_to_binary([Compressed|Last])
```

In all functions errors, `{'EXIT',{Reason,Backtrace}}`, can be thrown, where `Reason` describes the error.

Typical `Reasons`s:

`badarg`
: Bad argument.

`not_initialized`
: The stream hasn't been initialized, eg. if *`inflateInit/1`* wasn't called prior to a call to *`inflate/2`*.

`not_on_controlling_process`
: The stream was used by a process that doesn't control it. Use *`set_controlling_process/2`* if you need to transfer a stream to a different process.

`data_error`
: The data contains errors.

`stream_error`
: Inconsistent stream state.

`{need_dictionary,Adler32}`
: See *`inflate/2`*.

Data Types

`zstream() = term()`

A zlib stream, see *`open/0`*.

```
zlevel() =
    none | default | best_compression | best_speed | 0..9
zflush() = none | sync | full | finish
zmemlevel() = 1..9
zmethod() = deflated
zstrategy() = default | filtered | huffman_only | rle
zwindowbits() = -15..-8 | 8..47
```

Normally in the range `-15..-8 | 8..15`.

Exports

`adler32(Z, Data) -> CheckSum`

Types:

```
Z = zstream()
Data = iodata()
CheckSum = integer()
```

Calculates the Adler-32 checksum for `Data`.

Warning:

This function is deprecated and will be removed in a future release. Use *`erlang:adler32/1`* instead.

`adler32(Z, PrevAdler, Data) -> CheckSum`

Types:

```
Z = zstream()
PrevAdler = integer()
Data = iodata()
CheckSum = integer()
```

Updates a running Adler-32 checksum for `Data`. If `Data` is the empty binary or the empty iolist, this function returns the required initial value for the checksum.

Example:

```
Crc = lists:foldl(fun(Data,Crc0) ->
                      zlib:adler32(Z, Crc0, Data),
                  end, zlib:adler32(Z,<< >>), Datas)
```

Warning:

This function is deprecated and will be removed in a future release. Use *`erlang:adler32/2`* instead.

`adler32_combine(Z, Adler1, Adler2, Size2) -> Adler`

Types:

```
Z = zstream()
Adler = Adler1 = Adler2 = Size2 = integer()
```

Combines two Adler-32 checksums into one. For two binaries or iolists, `Data1` and `Data2` with sizes of `Size1` and `Size2`, with Adler-32 checksums `Adler1` and `Adler2`.

This function returns the `Adler` checksum of `[Data1,Data2]`, requiring only `Adler1`, `Adler2`, and `Size2`.

Warning:

This function is deprecated and will be removed in a future release. Use *`erlang:adler32_combine/3`* instead.

`close(Z) -> ok`

Types:

```
Z = zstream()
```

Closes the stream referenced by `Z`.

`compress(Data) -> Compressed`

Types:

```
Data = iodata()
Compressed = binary()
```

Compresses data with zlib headers and checksum.

`crc32(Z) -> CRC`

Types:

```
Z = zstream()
CRC = integer()
```

Gets the current calculated CRC checksum.

Warning:

This function is deprecated and will be removed in a future release. Use *`erlang:crc32/1`* on the uncompressed data instead.

`crc32(Z, Data) -> CRC`

Types:

```
Z = zstream()
Data = iodata()
CRC = integer()
```

Calculates the CRC checksum for `Data`.

Warning:

This function is deprecated and will be removed in a future release. Use *`erlang:crc32/1`* instead.

`crc32(Z, PrevCRC, Data) -> CRC`

Types:

```
Z = zstream()
PrevCRC = integer()
Data = iodata()
CRC = integer()
```

Updates a running CRC checksum for `Data`. If `Data` is the empty binary or the empty iolist, this function returns the required initial value for the CRC.

Example:

```
Crc = lists:foldl(fun(Data,Crc0) ->
                      zlib:crc32(Z, Crc0, Data),
                  end, zlib:crc32(Z,<< >>), Datas)
```

Warning:

This function is deprecated and will be removed in a future release. Use *erlang:crc32/2* instead.

`crc32_combine(Z, CRC1, CRC2, Size2) -> CRC`

Types:

```
Z = zstream()
CRC = CRC1 = CRC2 = Size2 = integer()
```

Combines two CRC checksums into one. For two binaries or iolists, `Data1` and `Data2` with sizes of `Size1` and `Size2`, with CRC checksums `CRC1` and `CRC2`.

This function returns the `CRC` checksum of `[Data1,Data2]`, requiring only `CRC1`, `CRC2`, and `Size2`.

Warning:

This function is deprecated and will be removed in a future release. Use *erlang:crc32_combine/3* instead.

`deflate(Z, Data) -> Compressed`

Types:

```
Z = zstream()
Data = iodata()
Compressed = iolist()
```

Same as `deflate(Z, Data, none)`.

`deflate(Z, Data, Flush) -> Compressed`

Types:

```
Z = zstream()
Data = iodata()
Flush = zflush()
Compressed = iolist()
```

Compresses as much data as possible, and stops when the input buffer becomes empty. It can introduce some output latency (reading input without producing any output) except when forced to flush.

If `Flush` is set to `sync`, all pending output is flushed to the output buffer and the output is aligned on a byte boundary, so that the decompressor can get all input data available so far. Flushing can degrade compression for some compression algorithms; thus, use it only when necessary.

If `Flush` is set to `full`, all output is flushed as with `sync`, and the compression state is reset so that decompression can restart from this point if previous compressed data has been damaged or if random access is desired. Using `full` too often can seriously degrade the compression.

If `Flush` is set to `finish`, pending input is processed, pending output is flushed, and `deflate/3` returns. Afterwards the only possible operations on the stream are *deflateReset/1* or *deflateEnd/1*.

`Flush` can be set to `finish` immediately after *`deflateInit`* if all compression is to be done in one step.

Example:

```
zlib:deflateInit(Z),
B1 = zlib:deflate(Z,Data),
B2 = zlib:deflate(Z,<< >>,finish),
zlib:deflateEnd(Z),
list_to_binary([B1,B2])
```

`deflateEnd(Z) -> ok`

Types:

`Z = zstream()`

Ends the deflate session and cleans all data used. Notice that this function throws a `data_error` exception if the last call to *`deflate/3`* was not called with `Flush` set to `finish`.

`deflateInit(Z) -> ok`

Types:

`Z = zstream()`

Same as `zlib:deflateInit(Z, default)`.

`deflateInit(Z, Level) -> ok`

Types:

`Z = zstream()`
`Level = zlevel()`

Initializes a zlib stream for compression.

`Level` decides the compression level to be used:

- 0 (`none`), gives no compression
- 1 (`best_speed`) gives best speed
- 9 (`best_compression`) gives best compression

`deflateInit(Z, Level, Method, WindowBits, MemLevel, Strategy) -> ok`

Types:

`Z = zstream()`
`Level = zlevel()`
`Method = zmethod()`
`WindowBits = zwindowbits()`
`MemLevel = zmemlevel()`
`Strategy = zstrategy()`

Initiates a zlib stream for compression.

`Level`

Compression level to use:

- 0 (`none`), gives no compression

- 1 (`best_speed`) gives best speed
- 9 (`best_compression`) gives best compression

`Method`

Compression method to use, currently the only supported method is `deflated`.

`WindowBits`

The base two logarithm of the window size (the size of the history buffer). It is to be in the range 8 through 15. Larger values result in better compression at the expense of memory usage. Defaults to 15 if *`deflateInit/2`* is used. A negative `WindowBits` value suppresses the zlib header (and checksum) from the stream. Notice that the zlib source mentions this only as a undocumented feature.

> **Warning:**
>
> Due to a known bug in the underlying zlib library, `WindowBits` values 8 and -8 do not work as expected. In zlib versions before 1.2.9 values 8 and -8 are automatically changed to 9 and -9. **From zlib version 1.2.9 value -8 is rejected** causing `zlib:deflateInit/6` to fail (8 is still changed to 9). It also seem possible that future versions of zlib may fix this bug and start accepting 8 and -8 as is.
>
> Conclusion: Avoid values 8 and -8 unless you know your zlib version supports them.

`MemLevel`

Specifies how much memory is to be allocated for the internal compression state: `MemLevel`=1 uses minimum memory but is slow and reduces compression ratio; `MemLevel`=9 uses maximum memory for optimal speed. Defaults to 8.

`Strategy`

Tunes the compression algorithm. Use the following values:

- `default` for normal data
- `filtered` for data produced by a filter (or predictor)
- `huffman_only` to force Huffman encoding only (no string match)
- `rle` to limit match distances to one (run-length encoding)

Filtered data consists mostly of small values with a somewhat random distribution. In this case, the compression algorithm is tuned to compress them better. The effect of `filtered` is to force more Huffman coding and less string matching; it is somewhat intermediate between `default` and `huffman_only`. `rle` is designed to be almost as fast as `huffman_only`, but gives better compression for PNG image data.

`Strategy` affects only the compression ratio, but not the correctness of the compressed output even if it is not set appropriately.

`deflateParams(Z, Level, Strategy) -> ok`

Types:

```
Z = zstream()
Level = zlevel()
Strategy = zstrategy()
```

Dynamically updates the compression level and compression strategy. The interpretation of `Level` and `Strategy` is as in *`deflateInit/6`*. This can be used to switch between compression and straight copy of the input data, or to switch to a different kind of input data requiring a different strategy. If the compression level is changed, the input available so far is compressed with the old level (and can be flushed); the new level takes effect only at the next call of *`deflate/3`*.

Before the call of `deflateParams`, the stream state must be set as for a call of `deflate/3`, as the currently available input may have to be compressed and flushed.

`deflateReset(Z) -> ok`

Types:

```
Z = zstream()
```

Equivalent to *`deflateEnd/1`* followed by *`deflateInit/1,2,6`*, but does not free and reallocate all the internal compression state. The stream keeps the same compression level and any other attributes.

`deflateSetDictionary(Z, Dictionary) -> Adler32`

Types:

```
Z = zstream()
Dictionary = iodata()
Adler32 = integer()
```

Initializes the compression dictionary from the specified byte sequence without producing any compressed output.

This function must be called immediately after *`deflateInit/1,2,6`* or *`deflateReset/1`*, before any call of *`deflate/3`*.

The compressor and decompressor must use the same dictionary (see *`inflateSetDictionary/2`*).

The Adler checksum of the dictionary is returned.

`getBufSize(Z) -> integer() >= 0`

Types:

```
Z = zstream()
```

Gets the size of the intermediate buffer.

Warning:

This function is deprecated and will be removed in a future release.

`gunzip(Data) -> Decompressed`

Types:

```
Data = iodata()
Decompressed = binary()
```

Uncompresses data with gz headers and checksum.

`gzip(Data) -> Compressed`

Types:

```
Data = iodata()
Compressed = binary()
```

Compresses data with gz headers and checksum.

`inflate(Z, Data) -> Decompressed`

Types:

```
Z = zstream()
Data = iodata()
Decompressed = iolist()
```

Equivalent to *`inflate(Z, Data, [])`*

`inflate(Z, Data, Options) -> Decompressed`

Types:

```
Z = zstream()
Data = iodata()
Options = [{exception_on_need_dict, boolean()}]
Decompressed =
    iolist() |
    {need_dictionary, Adler32 :: integer(), Output :: iolist()}
```

Decompresses as much data as possible. It can introduce some output latency (reading input without producing any output).

Currently the only available option is `{exception_on_need_dict,boolean()}` which controls whether the function should throw an exception when a preset dictionary is required for decompression. When set to false, a `need_dictionary` tuple will be returned instead. See *`inflateSetDictionary/2`* for details.

Warning:

This option defaults to `true` for backwards compatibility but we intend to remove the exception behavior in a future release. New code that needs to handle dictionaries manually should always specify `{exception_on_need_dict,false}`.

`inflateChunk(Z) -> Decompressed | {more, Decompressed}`

Types:

```
Z = zstream()
Decompressed = iolist()
```

Warning:

This function is deprecated and will be removed in a future release. Use *`safeInflate/2`* instead.

Reads the next chunk of uncompressed data, initialized by *`inflateChunk/2`*.

This function is to be repeatedly called, while it returns `{more, Decompressed}`.

`inflateChunk(Z, Data) -> Decompressed | {more, Decompressed}`

Types:

```
Z = zstream()
Data = iodata()
Decompressed = iolist()
```

Warning:

This function is deprecated and will be removed in a future release. Use *safeInflate/2* instead.

Like *inflate/2*, but decompresses no more data than will fit in the buffer configured through *setBufSize/2* . Is is useful when decompressing a stream with a high compression ratio, such that a small amount of compressed input can expand up to 1000 times.

This function returns `{more, Decompressed}`, when there is more output available, and *inflateChunk/1* is to be used to read it.

This function can introduce some output latency (reading input without producing any output).

An exception will be thrown if a preset dictionary is required for further decompression. See *inflateSetDictionary/2* for details.

Example:

```
walk(Compressed, Handler) ->
    Z = zlib:open(),
    zlib:inflateInit(Z),
    % Limit single uncompressed chunk size to 512kb
    zlib:setBufSize(Z, 512 * 1024),
    loop(Z, Handler, zlib:inflateChunk(Z, Compressed)),
    zlib:inflateEnd(Z),
    zlib:close(Z).

loop(Z, Handler, {more, Uncompressed}) ->
    Handler(Uncompressed),
    loop(Z, Handler, zlib:inflateChunk(Z));
loop(Z, Handler, Uncompressed) ->
    Handler(Uncompressed).
```

`inflateEnd(Z) -> ok`

Types:

```
Z = zstream()
```

Ends the inflate session and cleans all data used. Notice that this function throws a `data_error` exception if no end of stream was found (meaning that not all data has been uncompressed).

`inflateGetDictionary(Z) -> Dictionary`

Types:

```
Z = zstream()
Dictionary = binary()
```

Returns the decompression dictionary currently in use by the stream. This function must be called between *inflateInit/1,2* and *inflateEnd*.

Only supported if ERTS was compiled with zlib >= 1.2.8.

`inflateInit(Z) -> ok`

Types:

```
Z = zstream()
```

Initializes a zlib stream for decompression.

`inflateInit(Z, WindowBits) -> ok`

Types:

```
Z = zstream()
WindowBits = zwindowbits()
```

Initializes a decompression session on zlib stream.

`WindowBits` is the base two logarithm of the maximum window size (the size of the history buffer). It is to be in the range 8 through 15. Default to 15 if *`inflateInit/1`* is used.

If a compressed stream with a larger window size is specified as input, *`inflate/2`* throws the `data_error` exception.

A negative `WindowBits` value makes zlib ignore the zlib header (and checksum) from the stream. Notice that the zlib source mentions this only as a undocumented feature.

`inflateReset(Z) -> ok`

Types:

```
Z = zstream()
```

Equivalent to *`inflateEnd/1`* followed by *`inflateInit/1`*, but does not free and reallocate all the internal decompression state. The stream will keep attributes that could have been set by `inflateInit/1,2`.

`inflateSetDictionary(Z, Dictionary) -> ok`

Types:

```
Z = zstream()
Dictionary = iodata()
```

Initializes the decompression dictionary from the specified uncompressed byte sequence. This function must be called as a response to an inflate operation (eg. *`safeInflate/2`*) returning `{need_dictionary,Adler,Output}` or in the case of deprecated functions, throwing an `{'EXIT', {{need_dictionary,Adler},_StackTrace}}` exception.

The dictionary chosen by the compressor can be determined from the Adler value returned or thrown by the call to the inflate function. The compressor and decompressor must use the same dictionary (See *`deflateSetDictionary/2`*).

After setting the dictionary the inflate operation should be retried without new input.

Example:

```
deprecated_unpack(Z, Compressed, Dict) ->
     case catch zlib:inflate(Z, Compressed) of
          {'EXIT',{{need_dictionary,_DictID},_}} ->
                 ok = zlib:inflateSetDictionary(Z, Dict),
                 Uncompressed = zlib:inflate(Z, []);
          Uncompressed ->
                 Uncompressed
     end.

new_unpack(Z, Compressed, Dict) ->
    case zlib:inflate(Z, Compressed, [{exception_on_need_dict, false}]) of
        {need_dictionary, _DictId, Output} ->
            ok = zlib:inflateSetDictionary(Z, Dict),
            [Output | zlib:inflate(Z, [])];
        Uncompressed ->
            Uncompressed
    end.
```

`open() -> zstream()`

Opens a zlib stream.

`safeInflate(Z, Data) -> Result`

Types:

```
Z = zstream()
Data = iodata()
Result =
    {continue, Output :: iolist()} |
    {finished, Output :: iolist()} |
    {need_dictionary, Adler32 :: integer(), Output :: iolist()}
```

Like *`inflate/2`*, but returns once it has expanded beyond a small implementation-defined threshold. It's useful when decompressing untrusted input which could have been maliciously crafted to expand until the system runs out of memory.

This function returns `{continue | finished, Output}`, where Output is the data that was decompressed in this call. New input can be queued up on each call if desired, and the function will return `{finished, Output}` once all queued data has been decompressed.

This function can introduce some output latency (reading input without producing any output).

If a preset dictionary is required for further decompression, this function returns a `need_dictionary` tuple. See *`inflateSetDictionary/2`*) for details.

Example:

```
walk(Compressed, Handler) ->
    Z = zlib:open(),
    zlib:inflateInit(Z),
    loop(Z, Handler, zlib:safeInflate(Z, Compressed)),
    zlib:inflateEnd(Z),
    zlib:close(Z).

loop(Z, Handler, {continue, Output}) ->
    Handler(Output),
    loop(Z, Handler, zlib:safeInflate(Z, []));
loop(Z, Handler, {finished, Output}) ->
    Handler(Output).
```

`setBufSize(Z, Size) -> ok`

Types:

`Z = zstream()`

`Size = integer() >= 0`

Sets the intermediate buffer size.

Warning:

This function is deprecated and will be removed in a future release.

`set_controlling_process(Z, Pid) -> ok`

Types:

`Z = zstream()`

`Pid = pid()`

Changes the controlling process of `Z` to `Pid`, which must be a local process.

`uncompress(Data) -> Decompressed`

Types:

`Data = iodata()`

`Decompressed = binary()`

Uncompresses data with zlib headers and checksum.

`unzip(Data) -> Decompressed`

Types:

`Data = iodata()`

`Decompressed = binary()`

Uncompresses data without zlib headers and checksum.

`zip(Data) -> Compressed`

Types:

`Data = iodata()`

`Compressed = binary()`

Compresses data without zlib headers and checksum.

epmd

Command

`epmd [-d|-debug] [DbgExtra...] [-address Addresses] [-port No] [-daemon] [-relaxed_command_check]`

Starts the port mapper daemon.

`epmd [-d|-debug] [-port No] [-names|-kill|-stop Name]`

Communicates with a running port mapper daemon.

This daemon acts as a name server on all hosts involved in distributed Erlang computations. When an Erlang node starts, the node has a name and it obtains an address from the host OS kernel. The name and address are sent to the `epmd` daemon running on the local host. In a TCP/IP environment, the address consists of the IP address and a port number. The node name is an atom on the form of `Name@Node`. The job of the `epmd` daemon is to keep track of which node name listens on which address. Hence, `epmd` maps symbolic node names to machine addresses.

The TCP/IP `epmd` daemon only keeps track of the `Name` (first) part of an Erlang node name. The `Host` part (whatever is after the `@`) is implicit in the node name where the `epmd` daemon was contacted, as is the IP address where the Erlang node can be reached. Consistent and correct TCP naming services are therefore required for an Erlang network to function correctly.

Starting the port mapper daemon

The daemon is started automatically by command *`erl(1)`* if the node is to be distributed and no running instance is present. If automatically launched environment variables must be used to change the behavior of the daemon; see section *Environment Variables*.

If argument `-daemon` is not specified, `epmd` runs as a normal program with the controlling terminal of the shell in which it is started. Normally, it is to be run as a daemon.

Regular startup options are described in section *Regular Options*.

The `DbgExtra` options are described in section *DbgExtra Options*.

Communicating with a running port mapper daemon

Communicating with the running `epmd` daemon by the `epmd` program is done primarily for debugging purposes.

The different queries are described in section *Interactive options*.

Regular Options

These options are available when starting the name server. The name server is normally started automatically by command *`erl(1)`* (if not already available), but it can also be started at system startup.

`-address List`

Lets this instance of `epmd` listen only on the comma-separated list of IP addresses and on the loopback address (which is implicitly added to the list if it has not been specified). This can also be set using environment variable `ERL_EPMD_ADDRESS`; see section *Environment Variables*.

`-port No`

Lets this instance of `epmd` listen to another TCP port than default 4369. This can also be set using environment variable `ERL_EPMD_PORT`; see section *Environment Variables*.

`-d | -debug`

Enables debug output. The more `-d` flags specified, the more debug output you will get (to a certain limit). This option is most useful when the `epmd` daemon is not started as a daemon.

`-daemon`

Starts `epmd` detached from the controlling terminal. Logging ends up in syslog when available and correctly configured. If the `epmd` daemon is started at boot, this option is definitely to be used. It is also used when command `erl` automatically starts `epmd`.

`-relaxed_command_check`

Starts the `epmd` program with relaxed command checking (mostly for backward compatibility). This affects the following:

- With relaxed command checking, the `epmd` daemon can be killed from the local host with, for example, command `epmd -kill` even if active nodes are registered. Normally only daemons with an empty node database can be killed with `epmd -kill`.
- Command `epmd -stop` (and the corresponding messages to `epmd`, as can be specified using *`erl_interface:ei(3)`*) is normally always ignored. This because it can cause a strange situation where two nodes of the same name can be alive at the same time. A node unregisters itself by only closing the connection to `epmd`, which is why command `stop` was only intended for use in debugging situations.

  With relaxed command checking enabled, you can forcibly unregister live nodes.

Relaxed command checking can also be enabled by setting environment variable `ERL_EPMD_RELAXED_COMMAND_CHECK` before starting `epmd`.

Use relaxed command checking only on systems with very limited interactive usage.

DbgExtra Options

Note:

These options are only for debugging and testing `epmd` clients. They are not to be used in normal operation.

`-packet_timeout Seconds`

Sets the number of seconds a connection can be inactive before `epmd` times out and closes the connection. Defaults to 60.

`-delay_accept Seconds`

To simulate a busy server, you can insert a delay between when `epmd` gets notified that a new connection is requested and when the connection gets accepted.

`-delay_write Seconds`

Also a simulation of a busy server. Inserts a delay before a reply is sent.

Interactive Options

These options make `epmd` run as an interactive command, displaying the results of sending queries to an already running instance of `epmd`. The `epmd` contacted is always on the local node, but option `-port` can be used to select between instances if several are running using different ports on the host.

`-port No`

Contacts the `epmd` listening on the specified TCP port number (default 4369). This can also be set using environment variable `ERL_EPMD_PORT`; see section *Environment Variables*.

`-names`

Lists names registered with the currently running `epmd`.

`-kill`

Kills the currently running `epmd`.

Killing the running `epmd` is only allowed if `epmd -names` shows an empty database or if `-relaxed_command_check` was specified when the running instance of `epmd` was started.

Notice that `-relaxed_command_check` is specified when starting the daemon that is to accept killing when it has live nodes registered. When running `epmd` interactively, `-relaxed_command_check` has no effect. A daemon that is started without relaxed command checking must be killed using, for example, signals or some other OS-specific method if it has active clients registered.

`-stop Name`

Forcibly unregisters a live node from the `epmd` database.

This command can only be used when contacting `epmd` instances started with flag `-relaxed_command_check`.

Notice that relaxed command checking must enabled for the `epmd` daemon contacted. When running `epmd` interactively, `-relaxed_command_check` has no effect.

Environment Variables

`ERL_EPMD_ADDRESS`

Can be set to a comma-separated list of IP addresses, in which case the `epmd` daemon will listen only on the specified address(es) and on the loopback address (which is implicitly added to the list if it has not been specified). The default behavior is to listen on all available IP addresses.

`ERL_EPMD_PORT`

Can contain the port number `epmd` will use. The default port will work fine in most cases. A different port can be specified to allow several instances of `epmd`, representing independent clusters of nodes, to co-exist on the same host. All nodes in a cluster must use the same `epmd` port number.

`ERL_EPMD_RELAXED_COMMAND_CHECK`

If set before start, the `epmd` daemon behaves as if option `-relaxed_command_check` was specified at startup. Consequently, if this option is set before starting the Erlang virtual machine, the automatically started `epmd` accepts the `-kill` and `-stop` commands without restrictions.

Logging

On some operating systems **syslog** will be used for error reporting when `epmd` runs as a daemon. To enable the error logging, you must edit the /etc/syslog.conf file and add an entry:

```
!epmd
*.*<TABs>/var/log/epmd.log
```

where `<TABs>` are at least one real tab character. Spaces are silently ignored.

Access Restrictions

The `epmd` daemon accepts messages from both the local host and remote hosts. However, only the query commands are answered (and acted upon) if the query comes from a remote host. It is always an error to try to register a node name if the client is not a process on the same host as the `epmd` instance is running on. Such requests are considered hostile and the connection is closed immediately.

The following queries are accepted from remote nodes:

- Port queries, that is, on which port the node with a specified name listens

- Name listing, that is, gives a list of all names registered on the host

To restrict access further, firewall software must be used.

erl

Command

The `erl` program starts an Erlang runtime system. The exact details (for example, whether `erl` is a script or a program and which other programs it calls) are system-dependent.

Windows users probably want to use the `werl` program instead, which runs in its own window with scrollbars and supports command-line editing. The `erl` program on Windows provides no line editing in its shell, and on Windows 95 there is no way to scroll back to text that has scrolled off the screen. The `erl` program must be used, however, in pipelines or if you want to redirect standard input or output.

Note:

As from ERTS 5.9 (Erlang/OTP R15B) the runtime system does by default **not** bind schedulers to logical processors. For more information, see system flag `+sbt`.

Exports

`erl <arguments>`

Starts an Erlang runtime system.

The arguments can be divided into **emulator flags**, **flags**, and **plain arguments**:

- Any argument starting with character `+` is interpreted as an *emulator flag*.

  As indicated by the name, emulator flags control the behavior of the emulator.
- Any argument starting with character `-` (hyphen) is interpreted as a *flag*, which is to be passed to the Erlang part of the runtime system, more specifically to the `init` system process, see *`init(3)`*.

  The `init` process itself interprets some of these flags, the **init flags**. It also stores any remaining flags, the **user flags**. The latter can be retrieved by calling `init:get_argument/1`.

  A small number of "-" flags exist, which now actually are emulator flags, see the description below.
- Plain arguments are not interpreted in any way. They are also stored by the `init` process and can be retrieved by calling `init:get_plain_arguments/0`. Plain arguments can occur before the first flag, or after a `--` flag. Also, the `-extra` flag causes everything that follows to become plain arguments.

Examples:

```
% erl +W w -sname arnie +R 9 -s my_init -extra +bertie
(arnie@host)1> init:get_argument(sname).
{ok,[["arnie"]]}
(arnie@host)2> init:get_plain_arguments().
["+bertie"]
```

Here `+W w` and `+R 9` are emulator flags. `-s my_init` is an init flag, interpreted by `init`. `-sname arnie` is a user flag, stored by `init`. It is read by Kernel and causes the Erlang runtime system to become distributed. Finally, everything after `-extra` (that is, `+bertie`) is considered as plain arguments.

```
% erl -myflag 1
1> init:get_argument(myflag).
{ok,[["1"]]}
2> init:get_plain_arguments().
[]
```

Here the user flag `-myflag 1` is passed to and stored by the `init` process. It is a user-defined flag, presumably used by some user-defined application.

Flags

In the following list, init flags are marked "(init flag)". Unless otherwise specified, all other flags are user flags, for which the values can be retrieved by calling `init:get_argument/1`. Notice that the list of user flags is not exhaustive, there can be more application-specific flags that instead are described in the corresponding application documentation.

`--` (init flag)

Everything following `--` up to the next flag (`-flag` or `+flag`) is considered plain arguments and can be retrieved using `init:get_plain_arguments/0`.

`-Application Par Val`

Sets the application configuration parameter `Par` to the value `Val` for the application `Application`; see *`app(4)`* and *`application(3)`*.

`-args_file FileName`

Command-line arguments are read from the file `FileName`. The arguments read from the file replace flag '`-args_file FileName`' on the resulting command line.

The file `FileName` is to be a plain text file and can contain comments and command-line arguments. A comment begins with a # character and continues until the next end of line character. Backslash (\\) is used as quoting character. All command-line arguments accepted by `erl` are allowed, also flag `-args_file FileName`. Be careful not to cause circular dependencies between files containing flag `-args_file`, though.

The flag `-extra` is treated in special way. Its scope ends at the end of the file. Arguments following an `-extra` flag are moved on the command line into the `-extra` section, that is, the end of the command line following after an `-extra` flag.

`-async_shell_start`

The initial Erlang shell does not read user input until the system boot procedure has been completed (Erlang/OTP 5.4 and later). This flag disables the start synchronization feature and lets the shell start in parallel with the rest of the system.

`-boot File`

Specifies the name of the boot file, `File.boot`, which is used to start the system; see *`init(3)`*. Unless `File` contains an absolute path, the system searches for `File.boot` in the current and `$ROOT/bin` directories.

Defaults to `$ROOT/bin/start.boot`.

`-boot_var Var Dir`

If the boot script contains a path variable `Var` other than `$ROOT`, this variable is expanded to `Dir`. Used when applications are installed in another directory than `$ROOT/lib`; see *`systools:make_script/1,2`* in SASL.

`-code_path_cache`

Enables the code path cache of the code server; see *`code(3)`*.

`-compile Mod1 Mod2 ...`

Compiles the specified modules and then terminates (with non-zero exit code if the compilation of some file did not succeed). Implies `-noinput`.

Not recommended; use *`erlc`* instead.

`-config Config`

Specifies the name of a configuration file, `Config.config`, which is used to configure applications; see *`app(4)`* and *`application(3)`*.

`-connect_all false`

If this flag is present, `global` does not maintain a fully connected network of distributed Erlang nodes, and then global name registration cannot be used; see *`global(3)`*.

`-cookie Cookie`

Obsolete flag without any effect and common misspelling for `-setcookie`. Use `-setcookie` instead.

`-detached`

Starts the Erlang runtime system detached from the system console. Useful for running daemons and backgrounds processes. Implies `-noinput`.

`-emu_args`

Useful for debugging. Prints the arguments sent to the emulator.

`-emu_type Type`

Start an emulator of a different type. For example, to start the lock-counter emualator, use `-emu_type lcnt`. (The emulator must already be built. Use the `configure` option `--enable-lock-counter` to build the lock-counter emulator.)

`-env Variable Value`

Sets the host OS environment variable `Variable` to the value `Value` for the Erlang runtime system. Example:

```
% erl -env DISPLAY gin:0
```

In this example, an Erlang runtime system is started with environment variable `DISPLAY` set to `gin:0`.

`-epmd_module Module` (init flag)

Configures the module responsible to communicate to *epmd*. Defaults to `erl_epmd`.

`-eval Expr` (init flag)

Makes `init` evaluate the expression `Expr`; see *`init(3)`*.

`-extra` (init flag)

Everything following `-extra` is considered plain arguments and can be retrieved using `init:get_plain_arguments/0`.

`-heart`

Starts heartbeat monitoring of the Erlang runtime system; see *`heart(3)`*.

`-hidden`

Starts the Erlang runtime system as a hidden node, if it is run as a distributed node. Hidden nodes always establish hidden connections to all other nodes except for nodes in the same global group. Hidden connections are not published on any of the connected nodes, that is, none of the connected nodes are part of the result from `nodes/0` on the other node. See also hidden global groups; *`global_group(3)`*.

`-hosts Hosts`

Specifies the IP addresses for the hosts on which Erlang boot servers are running, see *erl_boot_server(3)*. This flag is mandatory if flag `-loader inet` is present.

The IP addresses must be specified in the standard form (four decimal numbers separated by periods, for example, `"150.236.20.74"`. Hosts names are not acceptable, but a broadcast address (preferably limited to the local network) is.

`-id Id`

Specifies the identity of the Erlang runtime system. If it is run as a distributed node, `Id` must be identical to the name supplied together with flag `-sname` or `-name`.

`-init_debug`

Makes `init` write some debug information while interpreting the boot script.

`-instr` (emulator flag)

Selects an instrumented Erlang runtime system (virtual machine) to run, instead of the ordinary one. When running an instrumented runtime system, some resource usage data can be obtained and analyzed using the `instrument` module. Functionally, it behaves exactly like an ordinary Erlang runtime system.

`-loader Loader`

Specifies the method used by `erl_prim_loader` to load Erlang modules into the system; see *erl_prim_loader(3)*. Two `Loader` methods are supported:

- `efile`, which means use the local file system, this is the default.
- `inet`, which means use a boot server on another machine. The flags `-id`, `-hosts` and `-setcookie` must also be specified.

If `Loader` is something else, the user-supplied `Loader` port program is started.

`-make`

Makes the Erlang runtime system invoke `make:all()` in the current working directory and then terminate; see *make(3)*. Implies `-noinput`.

`-man Module`

Displays the manual page for the Erlang module `Module`. Only supported on Unix.

`-mode interactive | embedded`

Indicates if the system is to load code dynamically (`interactive`), or if all code is to be loaded during system initialization (`embedded`); see *code(3)*. Defaults to `interactive`.

`-name Name`

Makes the Erlang runtime system into a distributed node. This flag invokes all network servers necessary for a node to become distributed; see *net_kernel(3)*. It is also ensured that `epmd` runs on the current host before Erlang is started; see *epmd(1)*.and the *-start_epmd* option.

The node name will be `Name@Host`, where `Host` is the fully qualified host name of the current host. For short names, use flag `-sname` instead.

Warning:

Starting a distributed node without also specifying *-proto_dist inet_tls* will expose the node to attacks that may give the attacker complete access to the node and in extension the cluster. When using unsecure distributed nodes, make sure that the network is configured to keep potential attackers out.

`-noinput`

Ensures that the Erlang runtime system never tries to read any input. Implies `-noshell`.

`-noshell`

Starts an Erlang runtime system with no shell. This flag makes it possible to have the Erlang runtime system as a component in a series of Unix pipes.

`-nostick`

Disables the sticky directory facility of the Erlang code server; see *`code(3)`*.

`-oldshell`

Invokes the old Erlang shell from Erlang/OTP 3.3. The old shell can still be used.

`-pa Dir1 Dir2 ...`

Adds the specified directories to the beginning of the code path, similar to *`code:add_pathsa/1`*. Note that the order of the given directories will be reversed in the resulting path.

As an alternative to `-pa`, if several directories are to be prepended to the code path and the directories have a common parent directory, that parent directory can be specified in environment variable `ERL_LIBS`; see *`code(3)`*.

`-pz Dir1 Dir2 ...`

Adds the specified directories to the end of the code path, similar to `code:add_pathsz/1`; see *`code(3)`*.

`-path Dir1 Dir2 ...`

Replaces the path specified in the boot script; see *`script(4)`*.

`-proto_dist Proto`

Specifies a protocol for Erlang distribution:

`inet_tcp`
: TCP over IPv4 (the default)

`inet_tls`
: Distribution over TLS/SSL, See the *Using SSL for Erlang Distribution* User's Guide for details on how to setup a secure distributed node.

`inet6_tcp`
: TCP over IPv6

For example, to start up IPv6 distributed nodes:

```
% erl -name test@ipv6node.example.com -proto_dist inet6_tcp
```

`-remsh Node`

Starts Erlang with a remote shell connected to `Node`.

`-rsh Program`

Specifies an alternative to `rsh` for starting a slave node on a remote host; see *`slave(3)`*.

`-run Mod [Func [Arg1, Arg2, ...]]` (init flag)

Makes `init` call the specified function. `Func` defaults to `start`. If no arguments are provided, the function is assumed to be of arity 0. Otherwise it is assumed to be of arity 1, taking the list `[Arg1,Arg2,...]` as argument. All arguments are passed as strings. See *`init(3)`*.

`-s Mod [Func [Arg1, Arg2, ...]]` (init flag)

Makes `init` call the specified function. `Func` defaults to `start`. If no arguments are provided, the function is assumed to be of arity 0. Otherwise it is assumed to be of arity 1, taking the list `[Arg1,Arg2,...]` as argument. All arguments are passed as atoms. See *`init(3)`*.

`-setcookie Cookie`

Sets the magic cookie of the node to `Cookie`; see *`erlang:set_cookie/2`*.

`-shutdown_time Time`

Specifies how long time (in milliseconds) the `init` process is allowed to spend shutting down the system. If `Time` milliseconds have elapsed, all processes still existing are killed. Defaults to `infinity`.

`-sname Name`

Makes the Erlang runtime system into a distributed node, similar to `-name`, but the host name portion of the node name `Name@Host` will be the short name, not fully qualified.

This is sometimes the only way to run distributed Erlang if the Domain Name System (DNS) is not running. No communication can exist between nodes running with flag `-sname` and those running with flag `-name`, as node names must be unique in distributed Erlang systems.

> **Warning:**
>
> Starting a distributed node without also specifying *`-proto_dist inet_tls`* will expose the node to attacks that may give the attacker complete access to the node and in extension the cluster. When using unsecure distributed nodes, make sure that the network is configured to keep potential attackers out.

`-start_epmd true | false`

Specifies whether Erlang should start *epmd* on startup. By default this is `true`, but if you prefer to start epmd manually, set this to `false`.

This only applies if Erlang is started as a distributed node, i.e. if `-name` or `-sname` is specified. Otherwise, epmd is not started even if `-start_epmd true` is given.

Note that a distributed node will fail to start if epmd is not running.

`-smp [enable|auto|disable]`

`-smp enable` and `-smp` start the Erlang runtime system with SMP support enabled. This can fail if no runtime system with SMP support is available. `-smp auto` starts the Erlang runtime system with SMP support enabled if it is available and more than one logical processor is detected. `-smp disable` starts a runtime system without SMP support. The runtime system without SMP support is deprecated and will be removed in a future major release.

> **Note:**
>
> See also flag*+S*.

`-version` (emulator flag)

Makes the emulator print its version number. The same as `erl +V`.

Emulator Flags

`erl` invokes the code for the Erlang emulator (virtual machine), which supports the following flags:

`+a size`

Suggested stack size, in kilowords, for threads in the async thread pool. Valid range is 16-8192 kilowords. The default suggested stack size is 16 kilowords, that is, 64 kilobyte on 32-bit architectures. This small default size has been chosen because the number of async threads can be large. The default size is enough for drivers delivered with Erlang/OTP, but might not be large enough for other dynamically linked-in drivers that use the *`driver_async()`* functionality. Notice that the value passed is only a suggestion, and it can even be ignored on some platforms.

`+A size`

Sets the number of threads in async thread pool. Valid range is 0-1024. Defaults to 10 if thread support is available.

`+B [c | d | i]`

Option `c` makes `Ctrl-C` interrupt the current shell instead of invoking the emulator break handler. Option `d` (same as specifying `+B` without an extra option) disables the break handler. Option `i` makes the emulator ignore any break signal.

If option `c` is used with `oldshell` on Unix, `Ctrl-C` will restart the shell process rather than interrupt it.

Notice that on Windows, this flag is only applicable for `werl`, not `erl` (`oldshell`). Notice also that `Ctrl-Break` is used instead of `Ctrl-C` on Windows.

`+c true | false`

Enables or disables *time correction*:

`true`
: Enables time correction. This is the default if time correction is supported on the specific platform.

`false`
: Disables time correction.

For backward compatibility, the boolean value can be omitted. This is interpreted as `+c false`.

`+C no_time_warp | single_time_warp | multi_time_warp`

Sets *time warp mode*:

`no_time_warp`
: *No time warp mode* (the default)

`single_time_warp`
: *Single time warp mode*

`multi_time_warp`
: *Multi-time warp mode*

`+d`

If the emulator detects an internal error (or runs out of memory), it, by default, generates both a crash dump and a core dump. The core dump is, however, not very useful as the content of process heaps is destroyed by the crash dump generation.

Option `+d` instructs the emulator to produce only a core dump and no crash dump if an internal error is detected.

Calling *`erlang:halt/1`* with a string argument still produces a crash dump. On Unix systems, sending an emulator process a `SIGUSR1` signal also forces a crash dump.

`+e Number`

Sets the maximum number of ETS tables.

`+ec`

Forces option `compressed` on all ETS tables. Only intended for test and evaluation.

`+fnl`

The virtual machine works with filenames as if they are encoded using the ISO Latin-1 encoding, disallowing Unicode characters with code points > 255.

For more information about Unicode filenames, see section *Unicode Filenames* in the STDLIB User's Guide. Notice that this value also applies to command-line parameters and environment variables (see section *Unicode in Environment and Parameters* in the STDLIB User's Guide).

`+fnu[{w|i|e}]`

The virtual machine works with filenames as if they are encoded using UTF-8 (or some other system-specific Unicode encoding). This is the default on operating systems that enforce Unicode encoding, that is, Windows and MacOS X.

The `+fnu` switch can be followed by `w`, `i`, or `e` to control how wrongly encoded filenames are to be reported:

- `w` means that a warning is sent to the `error_logger` whenever a wrongly encoded filename is "skipped" in directory listings. This is the default.
- `i` means that those wrongly encoded filenames are silently ignored.
- `e` means that the API function returns an error whenever a wrongly encoded filename (or directory name) is encountered.

Notice that *`file:read_link/1`* always returns an error if the link points to an invalid filename.

For more information about Unicode filenames, see section *Unicode Filenames* in the STDLIB User's Guide. Notice that this value also applies to command-line parameters and environment variables (see section *Unicode in Environment and Parameters* in the STDLIB User's Guide).

`+fna[{w|i|e}]`

Selection between `+fnl` and `+fnu` is done based on the current locale settings in the OS. This means that if you have set your terminal for UTF-8 encoding, the filesystem is expected to use the same encoding for filenames. This is default on all operating systems, except MacOS X and Windows.

The `+fna` switch can be followed by `w`, `i`, or `e`. This has effect if the locale settings cause the behavior of `+fnu` to be selected; see the description of `+fnu` above. If the locale settings cause the behavior of `+fnl` to be selected, then `w`, `i`, or `e` have no effect.

For more information about Unicode filenames, see section *Unicode Filenames* in the STDLIB User's Guide. Notice that this value also applies to command-line parameters and environment variables (see section *Unicode in Environment and Parameters* in the STDLIB User's Guide).

`+hms Size`

Sets the default heap size of processes to the size `Size`.

`+hmbs Size`

Sets the default binary virtual heap size of processes to the size `Size`.

`+hmax Size`

Sets the default maximum heap size of processes to the size `Size`. Defaults to `0`, which means that no maximum heap size is used. For more information, see *`process_flag(max_heap_size, MaxHeapSize)`*.

`+hmaxel true|false`

Sets whether to send an error logger message or not for processes reaching the maximum heap size. Defaults to `true`. For more information, see *`process_flag(max_heap_size, MaxHeapSize)`*.

`+hmaxk true|false`

Sets whether to kill processes reaching the maximum heap size or not. Default to `true`. For more information, see *`process_flag(max_heap_size, MaxHeapSize)`*.

`+hpds Size`

Sets the initial process dictionary size of processes to the size `Size`.

`+hmqd off_heap|on_heap`

Sets the default value for process flag `message_queue_data`. Defaults to `on_heap`. If `+hmqd` is not passed, `on_heap` will be the default. For more information, see *`process_flag(message_queue_data, MQD)`*.

`+K true | false`

Enables or disables the kernel poll functionality if supported by the emulator. Defaults to `false` (disabled). If the emulator does not support kernel poll, and flag `+K` is passed to the emulator, a warning is issued at startup.

`+l`

Enables autoload tracing, displaying information while loading code.

`+L`

Prevents loading information about source filenames and line numbers. This saves some memory, but exceptions do not contain information about the filenames and line numbers.

`+MFlag Value`

Memory allocator-specific flags. For more information, see *`erts_alloc(3)`*.

`+pc Range`

Sets the range of characters that the system considers printable in heuristic detection of strings. This typically affects the shell, debugger, and `io:format` functions (when `~tp` is used in the format string).

Two values are supported for `Range`:

`latin1`
: The default. Only characters in the ISO Latin-1 range can be considered printable. This means that a character with a code point > 255 is never considered printable and that lists containing such characters are displayed as lists of integers rather than text strings by tools.

`unicode`
: All printable Unicode characters are considered when determining if a list of integers is to be displayed in string syntax. This can give unexpected results if, for example, your font does not cover all Unicode characters.

See also *`io:printable_range/0`* in STDLIB.

`+P Number`

Sets the maximum number of simultaneously existing processes for this system if a `Number` is passed as value. Valid range for `Number` is `[1024-134217727]`

NOTE: The actual maximum chosen may be much larger than the `Number` passed. Currently the runtime system often, but not always, chooses a value that is a power of 2. This might, however, be changed in the future. The actual value chosen can be checked by calling *erlang:system_info(process_limit)*.

The default value is `262144`

`+Q Number`

Sets the maximum number of simultaneously existing ports for this system if a Number is passed as value. Valid range for `Number` is `[1024-134217727]`

NOTE: The actual maximum chosen may be much larger than the actual `Number` passed. Currently the runtime system often, but not always, chooses a value that is a power of 2. This might, however, be changed in the future. The actual value chosen can be checked by calling *erlang:system_info(port_limit)*.

The default value used is normally `65536`. However, if the runtime system is able to determine maximum amount of file descriptors that it is allowed to open and this value is larger than `65536`, the chosen value will increased to a value larger or equal to the maximum amount of file descriptors that can be opened.

On Windows the default value is set to `8196` because the normal OS limitations are set higher than most machines can handle.

`+R ReleaseNumber`

Sets the compatibility mode.

The distribution mechanism is not backward compatible by default. This flag sets the emulator in compatibility mode with an earlier Erlang/OTP release `ReleaseNumber`. The release number must be in the range `<current release>-2..<current release>`. This limits the emulator, making it possible for it to communicate with Erlang nodes (as well as C- and Java nodes) running that earlier release.

> **Note:**
>
> Ensure that all nodes (Erlang-, C-, and Java nodes) of a distributed Erlang system is of the same Erlang/OTP release, or from two different Erlang/OTP releases X and Y, where **all** Y nodes have compatibility mode X.

`+r`

Forces ETS memory block to be moved on realloc.

`+rg ReaderGroupsLimit`

Limits the number of reader groups used by read/write locks optimized for read operations in the Erlang runtime system. By default the reader groups limit is 64.

When the number of schedulers is less than or equal to the reader groups limit, each scheduler has its own reader group. When the number of schedulers is larger than the reader groups limit, schedulers share reader groups. Shared reader groups degrade read lock and read unlock performance while many reader groups degrade write lock performance. So, the limit is a tradeoff between performance for read operations and performance for write operations. Each reader group consumes 64 byte in each read/write lock.

Notice that a runtime system using shared reader groups benefits from *binding schedulers to logical processors*, as the reader groups are distributed better between schedulers.

`+S Schedulers:SchedulerOnline`

Sets the number of scheduler threads to create and scheduler threads to set online when SMP support has been enabled. The maximum for both values is 1024. If the Erlang runtime system is able to determine the number of logical processors configured and logical processors available, `Schedulers` defaults to logical processors configured, and `SchedulersOnline` defaults to logical processors available; otherwise the default values are 1. `Schedulers` can be omitted if `:SchedulerOnline` is not and conversely. The number of schedulers online can be changed at runtime through *`erlang:system_flag(schedulers_online, SchedulersOnline)`*.

If `Schedulers` or `SchedulersOnline` is specified as a negative number, the value is subtracted from the default number of logical processors configured or logical processors available, respectively.

Specifying value `0` for `Schedulers` or `SchedulersOnline` resets the number of scheduler threads or scheduler threads online, respectively, to its default value.

This option is ignored if the emulator does not have SMP support enabled (see flag *`-smp`*).

`+SP SchedulersPercentage:SchedulersOnlinePercentage`

Similar to *+S* but uses percentages to set the number of scheduler threads to create, based on logical processors configured, and scheduler threads to set online, based on logical processors available, when SMP support has been enabled. Specified values must be > 0. For example, `+SP 50:25` sets the number of scheduler threads to 50% of the logical processors configured, and the number of scheduler threads online to 25% of the logical processors available. `SchedulersPercentage` can be omitted if `:SchedulersOnlinePercentage` is not and conversely. The number of schedulers online can be changed at runtime through *erlang:system_flag(schedulers_online, SchedulersOnline)*.

This option interacts with *+S* settings. For example, on a system with 8 logical cores configured and 8 logical cores available, the combination of the options `+S 4:4 +SP 50:25` (in either order) results in 2 scheduler threads (50% of 4) and 1 scheduler thread online (25% of 4).

This option is ignored if the emulator does not have SMP support enabled (see flag *-smp*).

`+SDcpu DirtyCPUSchedulers:DirtyCPUSchedulersOnline`

Sets the number of dirty CPU scheduler threads to create and dirty CPU scheduler threads to set online when threading support has been enabled. The maximum for both values is 1024, and each value is further limited by the settings for normal schedulers:

- The number of dirty CPU scheduler threads created cannot exceed the number of normal scheduler threads created.
- The number of dirty CPU scheduler threads online cannot exceed the number of normal scheduler threads online.

For details, see the *+S* and *+SP*. By default, the number of dirty CPU scheduler threads created equals the number of normal scheduler threads created, and the number of dirty CPU scheduler threads online equals the number of normal scheduler threads online. `DirtyCPUSchedulers` can be omitted if `:DirtyCPUSchedulersOnline` is not and conversely. The number of dirty CPU schedulers online can be changed at runtime through *erlang:system_flag(dirty_cpu_schedulers_online, DirtyCPUSchedulersOnline)*.

The amount of dirty CPU schedulers is limited by the amount of normal schedulers in order to limit the effect on processes executing on ordinary schedulers. If the amount of dirty CPU schedulers was allowed to be unlimited, dirty CPU bound jobs would potentially starve normal jobs.

This option is ignored if the emulator does not have threading support enabled.

`+SDPcpu DirtyCPUSchedulersPercentage:DirtyCPUSchedulersOnlinePercentage`

Similar to *+SDcpu* but uses percentages to set the number of dirty CPU scheduler threads to create and the number of dirty CPU scheduler threads to set online when threading support has been enabled. Specified values must be > 0. For example, `+SDPcpu 50:25` sets the number of dirty CPU scheduler threads to 50% of the logical processors configured and the number of dirty CPU scheduler threads online to 25% of the logical processors available. `DirtyCPUSchedulersPercentage` can be omitted if `:DirtyCPUSchedulersOnlinePercentage` is not and conversely. The number of dirty CPU schedulers online can be changed at runtime through *erlang:system_flag(dirty_cpu_schedulers_online, DirtyCPUSchedulersOnline)*.

This option interacts with *+SDcpu* settings. For example, on a system with 8 logical cores configured and 8 logical cores available, the combination of the options `+SDcpu 4:4 +SDPcpu 50:25` (in either order) results in 2 dirty CPU scheduler threads (50% of 4) and 1 dirty CPU scheduler thread online (25% of 4).

This option is ignored if the emulator does not have threading support enabled.

`+SDio DirtyIOSchedulers`

Sets the number of dirty I/O scheduler threads to create when threading support has been enabled. Valid range is 0-1024. By default, the number of dirty I/O scheduler threads created is 10, same as the default number of threads in the *async thread pool*.

The amount of dirty IO schedulers is not limited by the amount of normal schedulers *like the amount of dirty CPU schedulers*. This since only I/O bound work is expected to execute on dirty I/O schedulers. If the user should schedule CPU bound jobs on dirty I/O schedulers, these jobs might starve ordinary jobs executing on ordinary schedulers.

This option is ignored if the emulator does not have threading support enabled.

`+sFlag Value`

Scheduling specific flags.

`+sbt BindType`

Sets scheduler bind type.

Schedulers can also be bound using flag `+stbt`. The only difference between these two flags is how the following errors are handled:

- Binding of schedulers is not supported on the specific platform.
- No available CPU topology. That is, the runtime system was not able to detect the CPU topology automatically, and no *user-defined CPU topology* was set.

If any of these errors occur when `+sbt` has been passed, the runtime system prints an error message, and refuses to start. If any of these errors occur when `+stbt` has been passed, the runtime system silently ignores the error, and start up using unbound schedulers.

Valid `BindType`s:

`u`
: `unbound` - Schedulers are not bound to logical processors, that is, the operating system decides where the scheduler threads execute, and when to migrate them. This is the default.

`ns`
: `no_spread` - Schedulers with close scheduler identifiers are bound as close as possible in hardware.

`ts`
: `thread_spread` - Thread refers to hardware threads (such as Intel's hyper-threads). Schedulers with low scheduler identifiers, are bound to the first hardware thread of each core, then schedulers with higher scheduler identifiers are bound to the second hardware thread of each core,and so on.

`ps`
: `processor_spread` - Schedulers are spread like `thread_spread`, but also over physical processor chips.

`s`
: `spread` - Schedulers are spread as much as possible.

`nnts`
: `no_node_thread_spread` - Like `thread_spread`, but if multiple Non-Uniform Memory Access (NUMA) nodes exist, schedulers are spread over one NUMA node at a time, that is, all logical processors of one NUMA node are bound to schedulers in sequence.

`nnps`
: `no_node_processor_spread` - Like `processor_spread`, but if multiple NUMA nodes exist, schedulers are spread over one NUMA node at a time, that is, all logical processors of one NUMA node are bound to schedulers in sequence.

`tnnps`

`thread_no_node_processor_spread` - A combination of `thread_spread`, and `no_node_processor_spread`. Schedulers are spread over hardware threads across NUMA nodes, but schedulers are only spread over processors internally in one NUMA node at a time.

`db`

`default_bind` - Binds schedulers the default way. Defaults to `thread_no_node_processor_spread` (which can change in the future).

Binding of schedulers is only supported on newer Linux, Solaris, FreeBSD, and Windows systems.

If no CPU topology is available when flag `+sbt` is processed and `BindType` is any other type than `u`, the runtime system fails to start. CPU topology can be defined using flag `+sct`. Notice that flag `+sct` can have to be passed before flag `+sbt` on the command line (if no CPU topology has been automatically detected).

The runtime system does by default **not** bind schedulers to logical processors.

> **Note:**
>
> If the Erlang runtime system is the only operating system process that binds threads to logical processors, this improves the performance of the runtime system. However, if other operating system processes (for example another Erlang runtime system) also bind threads to logical processors, there can be a performance penalty instead. This performance penalty can sometimes be severe. If so, you are advised not to bind the schedulers.

How schedulers are bound matters. For example, in situations when there are fewer running processes than schedulers online, the runtime system tries to migrate processes to schedulers with low scheduler identifiers. The more the schedulers are spread over the hardware, the more resources are available to the runtime system in such situations.

> **Note:**
>
> If a scheduler fails to bind, this is often silently ignored, as it is not always possible to verify valid logical processor identifiers. If an error is reported, it is reported to the `error_logger`. If you want to verify that the schedulers have bound as requested, call *`erlang:system_info(scheduler_bindings)`*.

`+sbwt none|very_short|short|medium|long|very_long`

Sets scheduler busy wait threshold. Defaults to `medium`. The threshold determines how long schedulers are to busy wait when running out of work before going to sleep.

> **Note:**
>
> This flag can be removed or changed at any time without prior notice.

`+scl true|false`

Enables or disables scheduler compaction of load. By default scheduler compaction of load is enabled. When enabled, load balancing strives for a load distribution, which causes as many scheduler threads as possible to be fully loaded (that is, not run out of work). This is accomplished by migrating load (for example, runnable processes) into a smaller set of schedulers when schedulers frequently run out of work. When disabled, the frequency with which schedulers run out of work is not taken into account by the load balancing logic.

`+scl false` is similar to *`+sub true`*, but `+sub true` also balances scheduler utilization between schedulers.

`+sct CpuTopology`

- `<Id> = integer(); when 0 =< <Id> =< 65535`
- `<IdRange> = <Id>-<Id>`
- `<IdOrIdRange> = <Id> | <IdRange>`
- `<IdList> = <IdOrIdRange>,<IdOrIdRange> | <IdOrIdRange>`
- `<LogicalIds> = L<IdList>`
- `<ThreadIds> = T<IdList> | t<IdList>`
- `<CoreIds> = C<IdList> | c<IdList>`
- `<ProcessorIds> = P<IdList> | p<IdList>`
- `<NodeIds> = N<IdList> | n<IdList>`
- `<IdDefs> = <LogicalIds><ThreadIds><CoreIds><ProcessorIds><NodeIds> | <LogicalIds><ThreadIds><CoreIds><NodeIds><ProcessorIds>`
- `CpuTopology = <IdDefs>:<IdDefs> | <IdDefs>`

Sets a user-defined CPU topology. The user-defined CPU topology overrides any automatically detected CPU topology. The CPU topology is used when *binding schedulers to logical processors*.

Uppercase letters signify real identifiers and lowercase letters signify fake identifiers only used for description of the topology. Identifiers passed as real identifiers can be used by the runtime system when trying to access specific hardware; if they are incorrect the behavior is undefined. Faked logical CPU identifiers are not accepted, as there is no point in defining the CPU topology without real logical CPU identifiers. Thread, core, processor, and node identifiers can be omitted. If omitted, the thread ID defaults to `t0`, the core ID defaults to `c0`, the processor ID defaults to `p0`, and the node ID is left undefined. Either each logical processor must belong to only one NUMA node, or no logical processors must belong to any NUMA nodes.

Both increasing and decreasing `<IdRange>`s are allowed.

NUMA node identifiers are system wide. That is, each NUMA node on the system must have a unique identifier. Processor identifiers are also system wide. Core identifiers are processor wide. Thread identifiers are core wide.

The order of the identifier types implies the hierarchy of the CPU topology. The valid orders are as follows:

- `<LogicalIds><ThreadIds><CoreIds><ProcessorIds><NodeIds>`, that is, thread is part of a core that is part of a processor, which is part of a NUMA node.
- `<LogicalIds><ThreadIds><CoreIds><NodeIds><ProcessorIds>`, that is, thread is part of a core that is part of a NUMA node, which is part of a processor.

A CPU topology can consist of both processor external, and processor internal NUMA nodes as long as each logical processor belongs to only one NUMA node. If `<ProcessorIds>` is omitted, its default position is before `<NodeIds>`. That is, the default is processor external NUMA nodes.

If a list of identifiers is used in an `<IdDefs>`:

- `<LogicalIds>` must be a list of identifiers.
- At least one other identifier type besides `<LogicalIds>` must also have a list of identifiers.
- All lists of identifiers must produce the same number of identifiers.

A simple example. A single quad core processor can be described as follows:

```
% erl +sct L0-3c0-3
1> erlang:system_info(cpu_topology).
[{processor,[{core,{logical,0}},
             {core,{logical,1}},
             {core,{logical,2}},
             {core,{logical,3}}]}]
```

A more complicated example with two quad core processors, each processor in its own NUMA node. The ordering of logical processors is a bit weird. This to give a better example of identifier lists:

```
% erl +sct L0-1,3-2c0-3p0N0:L7,4,6-5c0-3p1N1
1> erlang:system_info(cpu_topology).
[{node,[{processor,[{core,{logical,0}},
                    {core,{logical,1}},
                    {core,{logical,3}},
                    {core,{logical,2}}]}]},
 {node,[{processor,[{core,{logical,7}},
                    {core,{logical,4}},
                    {core,{logical,6}},
                    {core,{logical,5}}]}]}]
```

As long as real identifiers are correct, it is OK to pass a CPU topology that is not a correct description of the CPU topology. When used with care this can be very useful. This to trick the emulator to bind its schedulers as you want. For example, if you want to run multiple Erlang runtime systems on the same machine, you want to reduce the number of schedulers used and manipulate the CPU topology so that they bind to different logical CPUs. An example, with two Erlang runtime systems on a quad core machine:

```
% erl +sct L0-3c0-3 +sbt db +S3:2 -detached -noinput -noshell -sname one
% erl +sct L3-0c0-3 +sbt db +S3:2 -detached -noinput -noshell -sname two
```

In this example, each runtime system have two schedulers each online, and all schedulers online will run on different cores. If we change to one scheduler online on one runtime system, and three schedulers online on the other, all schedulers online will still run on different cores.

Notice that a faked CPU topology that does not reflect how the real CPU topology looks like is likely to decrease the performance of the runtime system.

For more information, see *`erlang:system_info(cpu_topology)`*.

`+secio true|false`

Enables or disables eager check I/O scheduling. Defaults to `true`. The default was changed from `false` as from ERTS 7.0. The behavior before this flag was introduced corresponds to `+secio false`.

The flag effects when schedulers will check for I/O operations possible to execute, and when such I/O operations will execute. As the parameter name implies, schedulers are more eager to check for I/O when `true` is passed. This, however, also implies that execution of outstanding I/O operation is not prioritized to the same extent as when `false` is passed.

`erlang:system_info(eager_check_io)` returns the value of this parameter used when starting the virtual machine.

`+sfwi Interval`

Sets scheduler-forced wakeup interval. All run queues are scanned each `Interval` milliseconds. While there are sleeping schedulers in the system, one scheduler is woken for each non-empty run queue found. `Interval` default to `0`, meaning this feature is disabled.

Note:

This feature has been introduced as a temporary workaround for long-executing native code, and native code that does not bump reductions properly in OTP. When these bugs have be fixed, this flag will be removed.

`+spp Bool`

Sets default scheduler hint for port parallelism. If set to `true`, the virtual machine schedules port tasks when it improves parallelism in the system. If set to `false`, the virtual machine tries to perform port tasks immediately, improving latency at the expense of parallelism. Default to `false`. The default used can be inspected in runtime by calling *`erlang:system_info(port_parallelism)`*. The default can be overridden on port creation by passing option *`parallelism`* to *`erlang:open_port/2`*

.

`+sss size`

Suggested stack size, in kilowords, for scheduler threads. Valid range is 20-8192 kilowords. The default suggested stack size is 128 kilowords.

`+sssdcpu size`

Suggested stack size, in kilowords, for dirty CPU scheduler threads. Valid range is 20-8192 kilowords. The default suggested stack size is 40 kilowords.

`+sssdio size`

Suggested stack size, in kilowords, for dirty IO scheduler threads. Valid range is 20-8192 kilowords. The default suggested stack size is 40 kilowords.

`+stbt BindType`

Tries to set the scheduler bind type. The same as flag *`+sbt`* except how some errors are handled. For more information, see *`+sbt`*.

`+sub true|false`

Enables or disables *scheduler utilization* balancing of load. By default scheduler utilization balancing is disabled and instead scheduler compaction of load is enabled, which strives for a load distribution that causes as many scheduler threads as possible to be fully loaded (that is, not run out of work). When scheduler utilization balancing is enabled, the system instead tries to balance scheduler utilization between schedulers. That is, strive for equal scheduler utilization on all schedulers.

`+sub true` is only supported on systems where the runtime system detects and uses a monotonically increasing high-resolution clock. On other systems, the runtime system fails to start.

`+sub true` implies *`+scl false`*. The difference between `+sub true` and `+scl false` is that `+scl false` does not try to balance the scheduler utilization.

`+swct very_eager|eager|medium|lazy|very_lazy`

Sets scheduler wake cleanup threshold. Defaults to `medium`. Controls how eager schedulers are to be requesting wakeup because of certain cleanup operations. When a lazy setting is used, more outstanding cleanup operations can be left undone while a scheduler is idling. When an eager setting is used, schedulers are more frequently woken, potentially increasing CPU-utilization.

Note:

This flag can be removed or changed at any time without prior notice.

`+sws default|legacy`

Sets scheduler wakeup strategy. Default strategy changed in ERTS 5.10 (Erlang/OTP R16A). This strategy was known as `proposal` in Erlang/OTP R15. The `legacy` strategy was used as default from R13 up to and including R15.

> **Note:**
>
> This flag can be removed or changed at any time without prior notice.

`+swt very_low|low|medium|high|very_high`

Sets scheduler wakeup threshold. Defaults to `medium`. The threshold determines when to wake up sleeping schedulers when more work than can be handled by currently awake schedulers exists. A low threshold causes earlier wakeups, and a high threshold causes later wakeups. Early wakeups distribute work over multiple schedulers faster, but work does more easily bounce between schedulers.

> **Note:**
>
> This flag can be removed or changed at any time without prior notice.

`+t size`

Sets the maximum number of atoms the virtual machine can handle. Defaults to 1,048,576.

`+T Level`

Enables modified timing and sets the modified timing level. Valid range is 0-9. The timing of the runtime system is changed. A high level usually means a greater change than a low level. Changing the timing can be very useful for finding timing-related bugs.

Modified timing affects the following:

Process spawning
: A process calling `spawn`, `spawn_link`, `spawn_monitor`, or `spawn_opt` is scheduled out immediately after completing the call. When higher modified timing levels are used, the caller also sleeps for a while after it is scheduled out.

Context reductions
: The number of reductions a process is allowed to use before it is scheduled out is increased or reduced.

Input reductions
: The number of reductions performed before checking I/O is increased or reduced.

> **Note:**
>
> Performance suffers when modified timing is enabled. This flag is **only** intended for testing and debugging.
>
> `return_to` and `return_from` trace messages are lost when tracing on the spawn BIFs.
>
> This flag can be removed or changed at any time without prior notice.

`+v`

Verbose.

`+V`

Makes the emulator print its version number.

`+W w | i | e`

Sets the mapping of warning messages for `error_logger`. Messages sent to the error logger using one of the warning routines can be mapped to errors (`+W e`), warnings (`+W w`), or information reports (`+W i`). Defaults to warnings. The current mapping can be retrieved using `error_logger:warning_map/0`. For more information, see *`error_logger:warning_map/0`* in Kernel.

`+zFlag Value`

Miscellaneous flags:

`+zdbbl size`

Sets the distribution buffer busy limit (*`dist_buf_busy_limit`*) in kilobytes. Valid range is 1-2097151. Defaults to 1024.

A larger buffer limit allows processes to buffer more outgoing messages over the distribution. When the buffer limit has been reached, sending processes will be suspended until the buffer size has shrunk. The buffer limit is per distribution channel. A higher limit gives lower latency and higher throughput at the expense of higher memory use.

`+zdntgc time`

Sets the delayed node table garbage collection time (*`delayed_node_table_gc`*) in seconds. Valid values are either `infinity` or an integer in the range 0-100000000. Defaults to 60.

Node table entries that are not referred linger in the table for at least the amount of time that this parameter determines. The lingering prevents repeated deletions and insertions in the tables from occurring.

Environment Variables

`ERL_CRASH_DUMP`

If the emulator needs to write a crash dump, the value of this variable is the filename of the crash dump file. If the variable is not set, the name of the crash dump file is `erl_crash.dump` in the current directory.

`ERL_CRASH_DUMP_NICE`

Unix systems: If the emulator needs to write a crash dump, it uses the value of this variable to set the nice value for the process, thus lowering its priority. Valid range is 1-39 (higher values are replaced with 39). The highest value, 39, gives the process the lowest priority.

`ERL_CRASH_DUMP_SECONDS`

Unix systems: This variable gives the number of seconds that the emulator is allowed to spend writing a crash dump. When the given number of seconds have elapsed, the emulator is terminated.

`ERL_CRASH_DUMP_SECONDS=0`
: If the variable is set to `0` seconds, the runtime system does not even attempt to write the crash dump file. It only terminates. This is the default if option `-heart` is passed to `erl` and `ERL_CRASH_DUMP_SECONDS` is not set.

`ERL_CRASH_DUMP_SECONDS=S`
: If the variable is set to a positive value `S`, wait for `S` seconds to complete the crash dump file and then terminates the runtime system with a `SIGALRM` signal.

`ERL_CRASH_DUMP_SECONDS=-1`
: A negative value causes the termination of the runtime system to wait indefinitely until the crash dump file has been completly written. This is the default if option `-heart` is **not** passed to `erl` and `ERL_CRASH_DUMP_SECONDS` is not set.

See also *`heart(3)`*.

`ERL_CRASH_DUMP_BYTES`

This variable sets the maximum size of a crash dump file in bytes. The crash dump will be truncated if this limit is exceeded. If the variable is not set, no size limit is enforced by default. If the variable is set to `0`, the runtime system does not even attempt to write a crash dump file.

Introduced in ERTS 8.1.2 (Erlang/OTP 19.2).

`ERL_AFLAGS`

The content of this variable is added to the beginning of the command line for `erl`.

Flag `-extra` is treated in a special way. Its scope ends at the end of the environment variable content. Arguments following an `-extra` flag are moved on the command line into section `-extra`, that is, the end of the command line following an `-extra` flag.

`ERL_ZFLAGS` and `ERL_FLAGS`

The content of these variables are added to the end of the command line for `erl`.

Flag `-extra` is treated in a special way. Its scope ends at the end of the environment variable content. Arguments following an `-extra` flag are moved on the command line into section `-extra`, that is, the end of the command line following an `-extra` flag.

`ERL_LIBS`

Contains a list of additional library directories that the code server searches for applications and adds to the code path; see *`code(3)`*.

`ERL_EPMD_ADDRESS`

Can be set to a comma-separated list of IP addresses, in which case the *`epmd`* daemon listens only on the specified address(es) and on the loopback address (which is implicitly added to the list if it has not been specified).

`ERL_EPMD_PORT`

Can contain the port number to use when communicating with *`epmd`*. The default port works fine in most cases. A different port can be specified to allow nodes of independent clusters to co-exist on the same host. All nodes in a cluster must use the same `epmd` port number.

Signals

On Unix systems, the Erlang runtime will interpret two types of signals.

`SIGUSR1`

A `SIGUSR1` signal forces a crash dump.

`SIGTERM`

A `SIGTERM` will produce a `stop` message to the `init` process. This is equivalent to a `init:stop/0` call.

Introduced in ERTS 8.3 (Erlang/OTP 19.3)

The signal `SIGUSR2` is reserved for internal usage. No other signals are handled.

Configuration

The standard Erlang/OTP system can be reconfigured to change the default behavior on startup.

The `.erlang` startup file

When Erlang/OTP is started, the system searches for a file named `.erlang` in the directory where Erlang/OTP is started. If not found, the user's home directory is searched for an `.erlang` file.

If an `.erlang` file is found, it is assumed to contain valid Erlang expressions. These expressions are evaluated as if they were input to the shell.

A typical `.erlang` file contains a set of search paths, for example:

```
io:format("executing user profile in HOME/.erlang\n",[]).
code:add_path("/home/calvin/test/ebin").
code:add_path("/home/hobbes/bigappl-1.2/ebin").
io:format(".erlang rc finished\n",[]).
```

user_default and shell_default

Functions in the shell that are not prefixed by a module name are assumed to be functional objects (funs), built-in functions (BIFs), or belong to the module `user_default` or `shell_default`.

To include private shell commands, define them in a module `user_default` and add the following argument as the first line in the `.erlang` file:

```
code:load_abs("..../user_default").
```

erl

If the contents of `.erlang` are changed and a private version of `user_default` is defined, the Erlang/OTP environment can be customized. More powerful changes can be made by supplying command-line arguments in the startup script `erl`. For more information, see *`init(3)`*.

See Also

`epmd(1)`, *`erl_prim_loader(3)`*, *`erts_alloc(3)`*, *`init(3)`*, *`application(3)`*, *`auth(3)`*, *`code(3)`*, *`erl_boot_server(3)`*, *`heart(3)`*, *`net_kernel(3)`*, *`make(3)`*

erlc

Command

The `erlc` program provides a common way to run all compilers in the Erlang system. Depending on the extension of each input file, `erlc` invokes the appropriate compiler. Regardless of which compiler is used, the same flags are used to provide parameters, such as include paths and output directory.

The current working directory, `"."`, is not included in the code path when running the compiler. This to avoid loading Beam files from the current working directory that could potentially be in conflict with the compiler or the Erlang/OTP system used by the compiler.

Exports

`erlc flags file1.ext file2.ext...`

Compiles one or more files. The files must include the extension, for example, `.erl` for Erlang source code, or `.yrl` for Yecc source code. `Erlc` uses the extension to invoke the correct compiler.

Generally Useful Flags

The following flags are supported:

`-I <Directory>`

Instructs the compiler to search for include files in the `Directory`. When encountering an `-include` or `-include_lib` directive, the compiler searches for header files in the following directories:

- `"."`, the current working directory of the file server
- The base name of the compiled file
- The directories specified using option `-I`; the directory specified last is searched first

`-o <Directory>`

The directory where the compiler is to place the output files. Defaults to the current working directory.

`-D<Name>`

Defines a macro.

`-D<Name>=<Value>`

Defines a macro with the specified value. The value can be any Erlang term. Depending on the platform, the value may need to be quoted if the shell itself interprets certain characters. On Unix, terms containing tuples and lists must be quoted. Terms containing spaces must be quoted on all platforms.

`-W<Error>`

Makes all warnings into errors.

`-W<Number>`

Sets warning level to `Number`. Defaults to `1`. To turn off warnings, use `-W0`.

`-W`

Same as `-W1`. Default.

`-v`

Enables verbose output.

`-b <Output_type>`

Specifies the type of output file. `Output_type` is the same as the file extension of the output file, but without the period. This option is ignored by compilers that have a single output format.

`-smp`

Compiles using the SMP emulator. This is mainly useful for compiling native code, which must be compiled with the same runtime system that it is to be run on.

`-M`

Produces a Makefile rule to track header dependencies. The rule is sent to `stdout`. No object file is produced.

`-MF <Makefile>`

As option `-M`, except that the Makefile is written to `Makefile`. No object file is produced.

`-MD`

Same as `-M -MF <File>.Pbeam`.

`-MT <Target>`

In conjunction with option `-M` or `-MF`, changes the name of the rule emitted to `Target`.

`-MQ <Target>`

As option `-MT`, except that characters special to `make/1` are quoted.

`-MP`

In conjunction with option `-M` or `-MF`, adds a phony target for each dependency.

`-MG`

In conjunction with option `-M` or `-MF`, considers missing headers as generated files and adds them to the dependencies.

`--`

Signals that no more options will follow. The rest of the arguments is treated as filenames, even if they start with hyphens.

`+<Term>`

A flag starting with a plus (`+`) rather than a hyphen is converted to an Erlang term and passed unchanged to the compiler. For example, option `export_all` for the Erlang compiler can be specified as follows:

```
erlc +export_all file.erl
```

Depending on the platform, the value may need to be quoted if the shell itself interprets certain characters. On Unix, terms containing tuples and lists must be quoted. Terms containing spaces must be quoted on all platforms.

Special Flags

The following flags are useful in special situations, such as rebuilding the OTP system:

`-pa <Directory>`

Appends `Directory` to the front of the code path in the invoked Erlang emulator. This can be used to invoke another compiler than the default one.

`-pz <Directory>`

Appends `Directory` to the code path in the invoked Erlang emulator.

Supported Compilers

The following compilers are supported:

`.erl`

Erlang source code. It generates a `.beam` file.

Options `-P`, `-E`, and `-S` are equivalent to `+'P'`, `+'E'`, and `+'S'`, except that it is not necessary to include the single quotes to protect them from the shell.

Supported options: `-I`, `-o`, `-D`, `-v`, `-W`, `-b`.

`.S`

Erlang assembler source code. It generates a `.beam` file.

Supported options: same as for `.erl`.

`.core`

Erlang core source code. It generates a `.beam` file.

Supported options: same as for `.erl`.

`.yrl`

Yecc source code. It generates an `.erl` file.

Use option `-I` with the name of a file to use that file as a customized prologue file (option `includefile`).

Supported options: `-o`, `-v`, `-I`, `-W`.

`.mib`

MIB for SNMP. It generates a `.bin` file.

Supported options: `-I`, `-o`, `-W`.

`.bin`

A compiled MIB for SNMP. It generates a `.hrl` file.

Supported options: `-o`, `-v`.

`.rel`

Script file. It generates a boot file.

Use option `-I` to name directories to be searched for application files (equivalent to the `path` in the option list for `systools:make_script/2`).

Supported option: `-o`.

`.asn1`

ASN1 file. It creates an `.erl`, `.hrl`, and `.asn1db` file from an `.asn1` file. Also compiles the `.erl` using the Erlang compiler unless option `+noobj` is specified.

Supported options: `-I`, `-o`, `-b`, `-W`.

`.idl`

IC file. It runs the IDL compiler.

Supported options: `-I`, `-o`.

Environment Variables

`ERLC_EMULATOR`

The command for starting the emulator. Defaults to `erl` in the same directory as the `erlc` program itself, or, if it does not exist, `erl` in any of the directories specified in environment variable `PATH`.

See Also

`erl(1)`, *`compile(3)`*, *`yecc(3)`*, *`snmp(3)`*

werl

Command

On Windows, the preferred way to start the Erlang system for interactive use is as follows:

```
werl <arguments>
```

This starts Erlang in its own window, with fully functioning command-line editing and scrollbars. All flags except `-oldshell` work as they do for *erl(1)*.

- To copy text to the clipboard, use `Ctrl-C`.
- To paste text, use `Ctrl-V`.
- To interrupt the runtime system or the shell process (depending on what has been specified with system flag `+B`), use `Ctrl-Break`.

In cases where you want to redirect standard input and/or standard output or use Erlang in a pipeline, `werl` is not suitable, and the `erl` program is to be used instead.

The `werl` window is in many ways modeled after the `xterm` window present on other platforms, as the `xterm` model fits well with line-oriented command-based interaction. This means that selecting text is line-oriented rather than rectangle-oriented.

- To select text in the `werl` window, press and hold the left mouse button and drag the mouse over the text you want to select. If the selection crosses line boundaries, the selected text consists of complete lines where applicable (just like in a word processor).
- To select more text than fits in the window, start by selecting a small part in the beginning of the text you want, then use the scrollbar to view the end of the desired selection, point to it, and press the **right** mouse button. The whole area between your first selection and the point where you right-clicked is included in the selection.
- To copy the selected text to the clipboard, either use `Ctrl-C`, use the menu, or press the copy button in the toolbar.

Pasted text is inserted at the current prompt position and is interpreted by Erlang as usual keyboard input.

- To retrieve previous command lines, press the `Up arrow` or use `Ctrl-P`.

A drop-down box in the toolbar contains the command history. Selecting a command in the drop-down box inserts the command at the prompt, as if you used the keyboard to retrieve the command.

- To stop the Erlang emulator, close the `werl` window.

escript

Command

`escript` provides support for running short Erlang programs without having to compile them first, and an easy way to retrieve the command-line arguments.

It is possible to bundle `escript`(s) with an Erlang runtime system to make it self-sufficient and relocatable. In such a standalone system, the `escript`(s) should be located in the top `bin` directory of the standalone system and given `.escript` as file extension. Further the (built-in) `escript` program should be copied to the same directory and given the scripts original name (without the `.escript` extension). This will enable use of the bundled Erlang runtime system.

The (built-in) `escript` program first determines which Erlang runtime system to use and then starts it to execute your script. Usually the runtime system is located in the same Erlang installation as the `escript` program itself. But for standalone systems with one or more escripts it may be the case that the `escript` program in your path actually starts the runtime system bundled with the escript. This is intentional, and typically happens when the standalone system `bin` directory is not in the execution path (as it may cause its `erl` program to override the desired one) and the `escript`(s) are referred to via symbolic links from a `bin` directory in the path.

Exports

```
script-name script-arg1 script-arg2...
escript escript-flags script-name script-arg1 script-arg2...
```

`escript` runs a script written in Erlang.

Example:

```
$ chmod u+x factorial
$ cat factorial
#!/usr/bin/env escript
%% -*- erlang -*-
%%! -smp enable -sname factorial -mnesia debug verbose
main([String]) ->
    try
        N = list_to_integer(String),
        F = fac(N),
        io:format("factorial ~w = ~w\n", [N,F])
    catch
        _:_ ->
            usage()
    end;
main(_) ->
    usage().

usage() ->
    io:format("usage: factorial integer\n"),
    halt(1).

fac(0) -> 1;
fac(N) -> N * fac(N-1).
$ ./factorial 5
factorial 5 = 120
$ ./factorial
usage: factorial integer
$ ./factorial five
usage: factorial integer
```

The header of the Erlang script in the example differs from a normal Erlang module. The first line is intended to be the interpreter line, which invokes `escript`.

However, if you invoke the `escript` as follows, the contents of the first line does not matter, but it cannot contain Erlang code as it will be ignored:

```
$ escript factorial 5
```

The second line in the example contains an optional directive to the `Emacs` editor, which causes it to enter the major mode for editing Erlang source files. If the directive is present, it must be located on the second line.

If a comment selecting the *encoding* exists, it can be located on the second line.

Note:

The encoding specified by the above mentioned comment applies to the script itself. The encoding of the I/O-server, however, must be set explicitly as follows:

```
io:setopts([{encoding, unicode}])
```

The default encoding of the I/O-server for `standard_io` is `latin1`, as the script runs in a non-interactive terminal (see section *Summary of Options*) in the STDLIB User's Guide.

On the third line (or second line depending on the presence of the Emacs directive), arguments can be specified to the emulator, for example:

```
%%! -smp enable -sname factorial -mnesia debug verbose
```

Such an argument line must start with `%%!` and the remaining line is interpreted as arguments to the emulator.

If you know the location of the `escript` executable, the first line can directly give the path to `escript`, for example:

```
#!/usr/local/bin/escript
```

As any other type of scripts, Erlang scripts do not work on Unix platforms if the execution bit for the script file is not set. (To turn on the execution bit, use `chmod +x script-name`.)

The remaining Erlang script file can either contain Erlang **source code**, an **inlined beam file**, or an **inlined archive file**.

An Erlang script file must always contain the `main/1` function. When the script is run, the `main/1` function is called with a list of strings representing the arguments specified to the script (not changed or interpreted in any way).

If the `main/1` function in the script returns successfully, the exit status for the script is `0`. If an exception is generated during execution, a short message is printed and the script terminates with exit status `127`.

To return your own non-zero exit code, call `halt(ExitCode)`, for example:

```
halt(1).
```

To retrieve the pathname of the script, call *`escript:script_name()`* from your script (the pathname is usually, but not always, absolute).

If the file contains source code (as in the example above), it is processed by the *`epp`* preprocessor. This means that you, for example, can use predefined macros (such as `?MODULE`) and include directives like the `-include_lib` directive. For example, use

```
-include_lib("kernel/include/file.hrl").
```

to include the record definitions for the records used by function *`file:read_link_info/1`*. You can also select encoding by including an encoding comment here, but if a valid encoding comment exists on the second line, it takes precedence.

The script is checked for syntactic and semantic correctness before it is run. If there are warnings (such as unused variables), they are printed and the script will still be run. If there are errors, they are printed and the script will not be run and its exit status is `127`.

Both the module declaration and the export declaration of the `main/1` function are optional.

By default, the script will be interpreted. You can force it to be compiled by including the following line somewhere in the script file:

```
-mode(compile).
```

Execution of interpreted code is slower than compiled code. If much of the execution takes place in interpreted code, it can be worthwhile to compile it, although the compilation itself takes a little while. Also, `native` can be supplied instead of `compile`. This compiles the script using the native flag and may or may not be worthwhile depending on the escript characteristics.

As mentioned earlier, a script can contains precompiled `beam` code. In a precompiled script, the interpretation of the script header is the same as in a script containing source code. This means that you can make a `beam` file executable by prepending the file with the lines starting with `#!` and `%%!` mentioned above. In a precompiled script, the `main/1` function must be exported.

Another option is to have an entire Erlang archive in the script. In an archive script, the interpretation of the script header is the same as in a script containing source code. This means that you can make an archive file executable by prepending the file with the lines starting with `#!` and `%%!` mentioned above. In an archive script, the `main/1`

function must be exported. By default the `main/1` function in the module with the same name as the basename of the `escript` file is invoked. This behavior can be overridden by setting flag `-escript main Module` as one of the emulator flags. `Module` must be the name of a module that has an exported `main/1` function. For more information about archives and code loading, see *`code(3)`*.

It is often very convenient to have a header in the escript, especially on Unix platforms. However, the header is optional, so you directly can "execute" an Erlang module, Beam file, or archive file without adding any header to them. But then you have to invoke the script as follows:

```
$ escript factorial.erl 5
factorial 5 = 120
$ escript factorial.beam 5
factorial 5 = 120
$ escript factorial.zip 5
factorial 5 = 120
```

`escript:create(FileOrBin, Sections) -> ok | {ok, binary()} | {error, term()}`

Types:

```
FileOrBin = filename() | 'binary'
Sections = [Header] Body | Body
Header = shebang | {shebang, Shebang}    | comment | {comment, Comment}
   | {emu_args, EmuArgs}
Shebang = string() | 'default' | 'undefined'
Comment = string() | 'default' | 'undefined'
EmuArgs = string() | 'undefined'
Body = {source, SourceCode} | {beam, BeamCode}    | {archive, ZipArchive}
   | {archive, ZipFiles, ZipOptions}
SourceCode = BeamCode = file:filename() | binary()
ZipArchive =  zip:filename() | binary()
ZipFiles = [ZipFile]
ZipFile = file:filename()    | {file:filename(), binary()}    |
{file:filename(), binary(), file:file_info()}
ZipOptions = [ zip:create_option()]
```

Creates an escript from a list of sections. The sections can be specified in any order. An escript begins with an optional `Header` followed by a mandatory `Body`. If the header is present, it does always begin with a `shebang`, possibly followed by a `comment` and `emu_args`. The `shebang` defaults to `"/usr/bin/env escript"`. The `comment` defaults to `"This is an -*- erlang -*- file"`. The created escript can either be returned as a binary or written to file.

As an example of how the function can be used, we create an interpreted escript that uses `emu_args` to set some emulator flag. In this case, it happens to disable the `smp_support`. We also extract the different sections from the newly created script:

```
> Source = "%% Demo\nmain(_Args) ->\n    io:format(erlang:system_info(smp_support)).\n".
"%% Demo\nmain(_Args) ->\n    io:format(erlang:system_info(smp_support)).\n"
> io:format("~s\n", [Source]).
%% Demo
main(_Args) ->
    io:format(erlang:system_info(smp_support)).

ok
> {ok, Bin} = escript:create(binary, [shebang, comment, {emu_args, "-smp disable"},
                                      {source, list_to_binary(Source)}]).
{ok,<<"#!/usr/bin/env escript\n%% This is an -*- erlang -*- file\n%%!-smp disabl"...>>}
> file:write_file("demo.escript", Bin).
ok
> os:cmd("escript demo.escript").
"false"
> escript:extract("demo.escript", []).
{ok,[{shebang,default}, {comment,default}, {emu_args,"-smp disable"},
     {source,<<"%% Demo\nmain(_Args) ->\n    io:format(erlang:system_info(smp_su"...>>}]}
```

An escript without header can be created as follows:

```
> file:write_file("demo.erl",
                  ["%% demo.erl\n-module(demo).\n-export([main/1]).\n\n", Source]).
ok
> {ok, _, BeamCode} = compile:file("demo.erl", [binary, debug_info]).
{ok,demo,
    <<70,79,82,49,0,0,2,208,66,69,65,77,65,116,111,109,0,0,0,
      79,0,0,0,9,4,100,...>>}
> escript:create("demo.beam", [{beam, BeamCode}]).
ok
> escript:extract("demo.beam", []).
{ok,[{shebang,undefined}, {comment,undefined}, {emu_args,undefined},
     {beam,<<70,79,82,49,0,0,3,68,66,69,65,77,65,116,
             111,109,0,0,0,83,0,0,0,9,...>>}]}
> os:cmd("escript demo.beam").
"true"
```

Here we create an archive script containing both Erlang code and Beam code, then we iterate over all files in the archive and collect their contents and some information about them:

```
> {ok, SourceCode} = file:read_file("demo.erl").
{ok,<<"%% demo.erl\n-module(demo).\n-export([main/1]).\n\n%% Demo\nmain(_Arg"...>>}
> escript:create("demo.escript",
                 [shebang,
                  {archive, [{"demo.erl", SourceCode},
                             {"demo.beam", BeamCode}], []}]).
ok
> {ok, [{shebang,default}, {comment,undefined}, {emu_args,undefined},
     {archive, ArchiveBin}]} = escript:extract("demo.escript", []).
{ok,[{shebang,default}, {comment,undefined}, {emu_args,undefined},
     {{archive,<<80,75,3,4,20,0,0,0,8,0,118,7,98,60,105,
                152,61,93,107,0,0,0,118,0,...>>}]}
> file:write_file("demo.zip", ArchiveBin).
ok
> zip:foldl(fun(N, I, B, A) -> [{N, I(), B()} | A] end, [], "demo.zip").
{ok,[{"demo.beam",
      {file_info,748,regular,read_write,
                 {{2010,3,2},{0,59,22}},
                 {{2010,3,2},{0,59,22}},
                 {{2010,3,2},{0,59,22}},
                 54,1,0,0,0,0,0},
      <<70,79,82,49,0,0,2,228,66,69,65,77,65,116,111,109,0,0,0,
        83,0,0,...>>},
     {"demo.erl",
      {file_info,118,regular,read_write,
                 {{2010,3,2},{0,59,22}},
                 {{2010,3,2},{0,59,22}},
                 {{2010,3,2},{0,59,22}},
                 54,1,0,0,0,0,0},
      <<"%% demo.erl\n-module(demo).\n-export([main/1]).\n\n%% Demo\nmain(_Arg"...>>}]}
```

`escript:extract(File, Options) -> {ok, Sections} | {error, term()}`

Types:

```
File = filename()
Options = [] | [compile_source]
Sections = Headers Body
Headers = {shebang, Shebang} {comment, Comment} {emu_args, EmuArgs}
Shebang = string() | 'default' | 'undefined'
Comment = string() | 'default' | 'undefined'
EmuArgs = string() | 'undefined'
Body = {source, SourceCode}    | {source, BeamCode}    | {beam, BeamCode}
   | {archive, ZipArchive}
SourceCode = BeamCode = ZipArchive = binary()
```

Parses an escript and extracts its sections. This is the reverse of *create/2*.

All sections are returned even if they do not exist in the escript. If a particular section happens to have the same value as the default value, the extracted value is set to the atom `default`. If a section is missing, the extracted value is set to the atom `undefined`.

Option `compile_source` only affects the result if the escript contains `source` code. In this case the Erlang code is automatically compiled and `{source, BeamCode}` is returned instead of `{source, SourceCode}`.

Example:

```
> escript:create("demo.escript",
                 [shebang, {archive, [{"demo.erl", SourceCode},
                                      {"demo.beam", BeamCode}], []}]).
ok
> {ok, [{shebang,default}, {comment,undefined}, {emu_args,undefined},
     {archive, ArchiveBin}]} =
              escript:extract("demo.escript", []).
{ok,[{{archive,<<80,75,3,4,20,0,0,0,8,0,118,7,98,60,105,
                152,61,93,107,0,0,0,118,0,...>>}
     {emu_args,undefined}]}
```

`escript:script_name() -> File`

Types:

`File = filename()`

Returns the name of the escript that is executed. If the function is invoked outside the context of an escript, the behavior is undefined.

Options Accepted By escript

`-c`

Compiles the escript regardless of the value of the mode attribute.

`-d`

Debugs the escript. Starts the debugger, loads the module containing the `main/1` function into the debugger, sets a breakpoint in `main/1`, and invokes `main/1`. If the module is precompiled, it must be explicitly compiled with option `debug_info`.

`-i`

Interprets the escript regardless of the value of the mode attribute.

`-s`

Performs a syntactic and semantic check of the script file. Warnings and errors (if any) are written to the standard output, but the script will not be run. The exit status is `0` if any errors are found, otherwise `127`.

`-n`

Compiles the escript using flag `+native`.

erlsrv

Command

This utility is specific to Windows NT/2000/XP (and later versions of Windows). It allows Erlang emulators to run as services on the Windows system, allowing embedded systems to start without any user needing to log on. The emulator started in this way can be manipulated through the Windows services applet in a manner similar to other services.

Notice that `erlsrv` is not a general service utility for Windows, but designed for embedded Erlang systems.

`erlsrv` also provides a command-line interface for registering, changing, starting, and stopping services.

To manipulate services, the logged on user is to have administrator privileges on the machine. The Erlang machine itself is (default) run as the local administrator. This can be changed with the Services applet in Windows.

The processes created by the service can, as opposed to normal services, be "killed" with the task manager. Killing an emulator that is started by a service triggers the "OnFail" action specified for that service, which can be a reboot.

The following parameters can be specified for each Erlang service:

`StopAction`

Tells `erlsrv` how to stop the Erlang emulator. Default is to kill it (Win32 TerminateProcess), but this action can specify any Erlang shell command that will be executed in the emulator to make it stop. The emulator is expected to stop within 30 seconds after the command is issued in the shell. If the emulator is not stopped, it reports a running state to the service manager.

`OnFail`

Can be one of the following:

`reboot`

The Windows system is rebooted whenever the emulator stops (a more simple form of watchdog). This can be useful for less critical systems, otherwise use the heart functionality to accomplish this.

`restart`

Makes the Erlang emulator be restarted (with whatever parameters are registered for the service at the occasion) when it stops. If the emulator stops again within 10 seconds, it is not restarted to avoid an infinite loop, which could hang the Windows system.

`restart_always`

Similar to `restart`, but does not try to detect cyclic restarts; it is expected that some other mechanism is present to avoid the problem.

`ignore` (the default)

Reports the service as stopped to the service manager whenever it fails; it must be manually restarted.

On a system where release handling is used, this is always to be set to `ignore`. Use `heart` to restart the service on failure instead.

`Machine`

The location of the Erlang emulator. The default is the `erl.exe` located in the same directory as `erlsrv.exe`. Do not specify `werl.exe` as this emulator, it will not work.

If the system uses release handling, this is to be set to a program similar to `start_erl.exe`.

`Env`

Specifies an **extra** environment for the emulator. The environment variables specified here are added to the system-wide environment block that is normally present when a service starts up. Variables present in both the system-wide environment and in the service environment specification will be set to the value specified in the service.

`WorkDir`

The working directory for the Erlang emulator. Must be on a local drive (no network drives are mounted when a service starts). Default working directory for services is `%SystemDrive%%SystemPath%`. Debug log files will be placed in this directory.

`Priority`

The process priority of the emulator. Can be one of the following:

`realtime`

Not recommended, as the machine will possibly be inaccessible to interactive users.

`high`

Can be used if two Erlang nodes are to reside on one dedicated system and one is to have precedence over the other.

`low`

Can be used if interactive performance is not to be affected by the emulator process.

`default` (the default>

`SName or Name`

Specifies the short or long node name of the Erlang emulator. The Erlang services are always distributed. Default is to use the service name as (short) nodename.

`DebugType`

Specifies that output from the Erlang shell is to be sent to a "debug log". The log file is named <servicename>`.debug` or <servicename>`.debug.`<N>, where <N> is an integer from 1 through 99. The log file is placed in the working directory of the service (as specified in `WorkDir`).

Can be one of the following:

`new`

Uses a separate log file for every invocation of the service (<servicename>`.debug.`<N>).

`reuse`

Reuses the same log file (<servicename>`.debug`).

`console`

Opens an interactive Windows console window for the Erlang shell of the service. Automatically disables the `StopAction`. A service started with an interactive console window does not survive logouts. `OnFail` actions do not work with debug consoles either.

`none` (the default)

The output of the Erlang shell is discarded.

> **Note:**
>
> The `console` option is **not** intended for production. It is **only** a convenient way to debug Erlang services during development.
>
> The `new` and `reuse` options might seem convenient in a production system, but consider that the logs grow indefinitely during the system lifetime and cannot be truncated, except if the service is restarted.
>
> In short, the `DebugType` is intended for debugging only. Logs during production are better produced with the standard Erlang logging facilities.

`Args`

Passes extra arguments to the emulator startup program `erl.exe` (or `start_erl.exe`). Arguments that cannot be specified here are `-noinput` (`StopActions` would not work), `-name`, and `-sname` (they are specified in any way). The most common use is for specifying cookies and flags to be passed to `init:boot()` (`-s`).

`InternalServiceName`

Specifies the Windows-internal service name (not the display name, which is the one `erlsrv` uses to identify the service).

This internal name cannot be changed, it is fixed even if the service is renamed. `erlsrv` generates a unique internal name when a service is created. It is recommended to keep to the default if release handling is to be used for the application.

The internal service name can be seen in the Windows service manager if viewing `Properties` for an Erlang service.

`Comment`

A textual comment describing the service. Not mandatory, but shows up as the service description in the Windows service manager.

The naming of the service in a system that uses release handling must follow the convention **NodeName_Release**, where **NodeName** is the first part of the Erlang node name (up to, but not including the "@") and **Release** is the current release of the application.

Exports

`erlsrv {set | add} <service-name> [<service options>]`

The `set` and `add` commands modifies or adds an Erlang service, respectively. The simplest form of an `add` command is without any options in which case all default values (described above) apply. The service name is mandatory.

Every option can be specified without parameters, the default value is then applied. Values to the options are supplied **only** when the default is not to be used. For example, `erlsrv set myservice -prio -arg` sets the default priority and removes all arguments.

Service options:

`-st[opaction] [<erlang shell command>]`

Defines the `StopAction`, the command given to the Erlang shell when the service is stopped. Default is none.

`-on[fail] [{reboot | restart | restart_always}]`

The action to take when the Erlang emulator stops unexpectedly. Default is to ignore.

`-m[achine] [<erl-command>]`

The complete path to the Erlang emulator. Never use the `werl` program for this. Defaults to the `erl.exe` in the same directory as `erlsrv.exe`. When release handling is used, this is to be set to a program similar to `start_erl.exe`.

`-e[nv] [<variable>[=<value>]] ...`

Edits the environment block for the service. Every environment variable specified is added to the system environment block. If a variable specified here has the same name as a system-wide environment variable, the specified value overrides the system-wide. Environment variables are added to this list by specifying <variable>=<value> and deleted from the list by specifying <variable> alone. The environment block is automatically sorted. Any number of `-env` options can be specified in one command. Default is to use the system environment block unmodified (except for two additions, see section *Environment* below).

`-w[orkdir] [<directory>]`

The initial working directory of the Erlang emulator. Defaults to the system directory.

`-p[riority] [{low|high|realtime}]`

The priority of the Erlang emulator. Default to the Windows default priority.

`{-sn[ame] | -n[ame]} [<node-name>]`

The node name of the Erlang machine. Distribution is mandatory. Defaults to `-sname <service name>`.

`-d[ebugtype] [{new|reuse|console}]`

Specifies where shell output is to be sent. Default is that shell output is discarded. To be used only for debugging.

`-ar[gs] [<limited erl arguments>]`

Extra arguments to the Erlang emulator. Avoid `-noinput`, `-noshell`, and `-sname`/`-name`. Default is no extra arguments. Remember that the services cookie file is not necessarily the same as the interactive users. The service runs as the local administrator. Specify all arguments together in one string, use double quotes (") to specify an argument string containing spaces, and use quoted quotes (\") to specify a quote within the argument string if necessary.

`-i[nternalservicename] [<internal name>]`

Only allowed for `add`. Specifies a Windows-internal service name for the service, which by default is set to something unique (prefixed with the original service name) by `erlsrv` when adding a new service. Specifying this is a purely cosmethic action and is **not** recommended if release handling is to be performed. The internal service name cannot be changed once the service is created. The internal name is **not** to be confused with the ordinary service name, which is the name used to identify a service to `erlsrv`.

`-c[omment] [<short description>]`

Specifies a textual comment describing the service. This comment shows up as the service description in the Windows service manager.

`erlsrv {start | start_disabled | stop | disable | enable} <service-name>`

These commands are only added for convenience, the normal way to manipulate the state of a service is through the control panels services applet.

The `start` and `stop` commands communicates with the service manager for starting and stopping a service. The commands wait until the service is started or stopped. When disabling a service, it is not stopped, the disabled state does not take effect until the service is stopped. Enabling a service sets it in automatic mode, which is started at boot. This command cannot set the service to manual.

The `start_disabled` command operates on a service regardless of if it is enabled/disabled or started/stopped. It does this by first enabling it (regardless of if it is enabled or not), then starting it (if not already started), and then disabling it. The result is a disabled but started service, regardless of its earlier state. This is useful for starting services temporarily during a release upgrade. The difference between using `start_disabled` and the sequence `enable`, `start`, and `disable` is that all other `erlsrv` commands are locked out during the sequence of operations in `start_disable`, making the operation atomic from an `erlsrv` user's point of view.

`erlsrv remove <service-name>`

Removes the service completely with all its registered options. It is stopped before it is removed.

`erlsrv list [<service-name>]`

If no service name is specified, a brief listing of all Erlang services is presented. If a service name is supplied, all options for that service are presented.

`erlsrv help`

Displays a brief help text.

Environment

The environment of an Erlang machine started as a service contains two special variables:

`ERLSRV_SERVICE_NAME`
: The name of the service that started the machine.

`ERLSRV_EXECUTABLE`
: The full path to the `erlsrv.exe`, which can be used to manipulate the service. This comes in handy when defining a heart command for your service.

A command file for restarting a service looks as follows:

```
@echo off
%ERLSRV_EXECUTABLE% stop %ERLSRV_SERVICE_NAME%
%ERLSRV_EXECUTABLE% start %ERLSRV_SERVICE_NAME%
```

This command file is then set as heart command.

The environment variables can also be used to detect that we are running as a service and make port programs react correctly to the control events generated on logout (see the next section).

Port Programs

When a program runs in the service context, it must handle the control events that are sent to every program in the system when the interactive user logs off. This is done in different ways for programs running in the console subsystem and programs running as window applications. An application running in the console subsystem (normal for port programs) uses the win32 function `SetConsoleCtrlHandler` to register a control handler that returns `true` in answer to the `CTRL_LOGOFF_EVENT` and `CTRL_SHUTDOWN_EVENT` events. Other applications only forward `WM_ENDSESSION` and `WM_QUERYENDSESSION` to the default window procedure.

A brief example in C of how to set the console control handler:

```
#include <windows.h>
/*
** A Console control handler that ignores the log off events,
** and lets the default handler take care of other events.
*/
BOOL WINAPI service_aware_handler(DWORD ctrl){
    if(ctrl == CTRL_LOGOFF_EVENT)
        return TRUE;
    if(ctrl == CTRL_SHUTDOWN_EVENT)
        return TRUE;
    return FALSE;
}

void initialize_handler(void){
    char buffer[2];
    /*
     * We assume we are running as a service if this
     * environment variable is defined.
     */
    if(GetEnvironmentVariable("ERLSRV_SERVICE_NAME",buffer,
                              (DWORD) 2)){
        /*
        ** Actually set the control handler
        */
        SetConsoleCtrlHandler(&service_aware_handler, TRUE);
    }
}
```

Notes

Although the options are described in a Unix-like format, the case of the options or commands is not relevant, and both character "/" and "-" can be used for options.

Notice that the program resides in the emulator's `bin` directory, not in the `bin` directory directly under the Erlang root. The reasons for this are the subtle problem of upgrading the emulator on a running system, where a new version of the runtime system should not need to overwrite existing (and probably used) executables.

To manipulate the Erlang services easily, put the `<erlang_root>\erts-<version>\bin` directory in the path instead of `<erlang_root>\bin`. The `erlsrv` program can be found from inside Erlang by using the `os:find_executable/1` Erlang function.

For release handling to work, use `start_erl` as the Erlang machine. As stated *above*, the service name is significant.

See Also

`start_erl(1)`, *`release_handler(3)`*

start_erl

Command

The `start_erl` program is specific to Windows NT/2000/XP (and later versions of Windows). Although there are programs with the same name on other platforms, their functionality is different.

This program is distributed both in compiled form (under <Erlang root>\\erts-<version>\\bin) and in source form (under <Erlang root>\\erts-<version>\\src). The purpose of the source code is to ease customization of the program for local needs, such as cyclic restart detection. There is also a "make"-file, written for the `nmake` program distributed with Microsoft Visual C++. This program can, however, be compiled with any Win32 C compiler (possibly with minor modifications).

This program aids release handling on Windows systems. The program is to be called by the `erlsrv` program, read up the release data file `start_erl.data`, and start Erlang. Some options to `start_erl` are added and removed by the release handler during upgrade with emulator restart (more specifically option `-data`).

Exports

`start_erl [<erl options>] ++ [<start_erl options>]`

The `start_erl` program in its original form recognizes the following options:

`++`

Mandatory. Delimits `start_erl` options from normal Erlang options. Everything on the command line **before** `++` is interpreted as options to be sent to the `erl` program. Everything **after** `++` is interpreted as options to `start_erl` itself.

`-reldir <release root>`

Mandatory if environment variable `RELDIR` is not specified and no `-rootdir` option is specified. Tells `start_erl` where the root of the release tree is located in the file system (typically <Erlang root>\\releases). The `start_erl.data` file is expected to be located in this directory (unless otherwise specified). If only option `-rootdir` is specified, the directory is assumed to be <Erlang root>\\releases.

`-rootdir <Erlang root directory>`

Mandatory if `-reldir` is not specified and no `RELDIR` exists in the environment. This specifies the Erlang installation root directory (under which the `lib`, `releases`, and `erts-<Version>` directories are located). If only `-reldir` (or environment variable `RELDIR`) is specified, the Erlang root is assumed to be the directory exactly one level above the release directory.

`-data <data file name>`

Optional. Specifies another data file than `start_erl.data` in the <release root>. It is specified relative to the <release root> or absolute (including drive letter, and so on). This option is used by the release handler during upgrade and is not to be used during normal operation. Normally the release data file is not to be named differently.

`-bootflags <boot flags file name>`

Optional. Specifies a file name relative to the release directory (that is, the subdirectory of <release root> where the `.boot` file and others are located). The contents of this file is appended to the command line when Erlang is started. This makes it easy to start the emulator with different options for different releases.

Notes

- As the source code is distributed, it can easily be modified to accept other options. The program must still accept option `-data` with the semantics described above for the release handler to work correctly.
- The Erlang emulator is found by examining the registry keys for the emulator version specified in the release data file. The new emulator must be properly installed before the upgrade for this to work.
- Although the program is located together with files specific to the emulator version, it is not expected to be specific to the emulator version. The release handler does **not** change option `-machine` to `erlsrv` during emulator restart. Locate the (possibly customized) `start_erl` program so that it is not overwritten during upgrade.
- The default options of the `erlsrv` program are not sufficient for release handling. The machine started by `erlsrv` is be specified as the `start_erl` program and the arguments are to contain `++` followed by the desired options.

See Also

`erlsrv(1)`, *`release_handler(3)`*

run_erl

Command

The `run_erl` program is specific to Unix systems. This program redirects the standard input and standard output streams so that all output can be logged. It also lets the program `to_erl` connect to the Erlang console, making it possible to monitor and debug an embedded system remotely.

For more information about the use, see the *Embedded System User's Guide* in System Documentation.

Exports

`run_erl [-daemon] pipe_dir/ log_dir "exec command arg1 arg2 ..."`

Arguments:

`-daemon`

This option is highly recommended. It makes `run_erl` run in the background completely detached from any controlling terminal and the command returns to the caller immediately. Without this option, `run_erl` must be started using several tricks in the shell to detach it completely from the terminal in use when starting it. The option must be the first argument to `run_erl` on the command line.

`pipe_dir`

The named pipe, usually `/tmp/`. It must be suffixed by a `/` (slash), that is, `/tmp/epipes/`, not `/tmp/epipes`.

`log_dir`

The log files, that is:

- One log file, `run_erl.log`, which logs progress and warnings from the `run_erl` program itself.
- Up to five log files at maximum 100 KB each with the content of the standard streams from and to the command. (Both the number of logs and sizes can be changed by environment variables, see section *Environment Variables* below.)

  When the logs are full, `run_erl` deletes and reuses the oldest log file.

`"exec command arg1 arg2 ..."`

A space-separated string specifying the program to be executed. The second field is typically a command name such as `erl`.

Notes concerning the Log Files

While running, `run_erl` sends all output, uninterpreted, to a log file. The file is named `erlang.log.N`, where `N` is an integer. When the log is "full" (default log size is 100 KB), `run_erl` starts to log in file `erlang.log.(N+1)`, until `N` reaches a certain number (default 5), whereupon `N` starts at 1 again and the oldest files start getting overwritten.

If no output comes from the Erlang shell, but the Erlang machine still seems to be alive, an "ALIVE" message is written to the log; it is a time stamp and is written, by default, after 15 minutes of inactivity. Also, if output from Erlang is logged, but more than 5 minutes (default) has passed since last time we got anything from Erlang, a time stamp is written in the log. The "ALIVE" messages look as follows:

```
===== ALIVE <date-time-string>
```

The other time stamps look as follows:

```
===== <date-time-string>
```

`date-time-string` is the date and time the message is written, default in local time (can be changed to UTC if needed). It is formatted with the ANSI-C function `strftime` using the format string `%a %b %e %T %Z %Y`, which produces messages like `===== ALIVE Thu May 15 10:13:36 MEST 2003`; this can be changed, see the next section.

Environment Variables

The following environment variables are recognized by `run_erl` and change the logging behavior. For more information, see the previous section.

`RUN_ERL_LOG_ALIVE_MINUTES`

How long to wait for output (in minutes) before writing an "ALIVE" message to the log. Defaults to 15, minimum is 1.

`RUN_ERL_LOG_ACTIVITY_MINUTES`

How long Erlang needs to be inactive before output is preceded with a time stamp. Defaults to `RUN_ERL_LOG_ALIVE_MINUTES div 3`, minimum is 1.

`RUN_ERL_LOG_ALIVE_FORMAT`

Specifies another format string to be used in the `strftime` C library call. That is, specifying this to `"%e-%b-%Y, %T %Z"` gives log messages with time stamps like `15-May-2003, 10:23:04 MET`. For more information, see the documentation for the C library function `strftime`. Defaults to `"%a %b %e %T %Z %Y"`.

`RUN_ERL_LOG_ALIVE_IN_UTC`

If set to anything else than `0`, it makes all times displayed by `run_erl` to be in UTC (GMT, CET, MET, without Daylight Saving Time), rather than in local time. This does not affect data coming from Erlang, only the logs output directly by `run_erl`. Application SASL can be modified accordingly by setting the Erlang application variable `utc_log` to `true`.

`RUN_ERL_LOG_GENERATIONS`

Controls the number of log files written before older files are reused. Defaults to 5, minimum is 2, maximum is 1000.

Note that, as a way to indicate the newest file, `run_erl` will delete the oldest log file to maintain a "hole" in the file sequences. For example, if log files #1, #2, #4 and #5 exists, that means #2 is the latest and #4 is the oldest. You will therefore at most get one less log file than the value set by `RUN_ERL_LOG_GENERATIONS`.

`RUN_ERL_LOG_MAXSIZE`

The size, in bytes, of a log file before switching to a new log file. Defaults to 100000, minimum is 1000, maximum is about 2^30.

`RUN_ERL_DISABLE_FLOWCNTRL`

If defined, disables input and output flow control for the pty opend by `run_erl`. Useful if you want to remove any risk of accidentally blocking the flow control by using Ctrl-S (instead of Ctrl-D to detach), which can result in blocking of the entire Beam process, and in the case of running heart as supervisor even the heart process becomes blocked when writing log message to terminal, leaving the heart process unable to do its work.

See Also

`start(1)`, `start_erl(1)`

start

Command

The `start` script is an example script on how to start up the Erlang system in embedded mode on Unix.

For more information about the use, see the *Embedded System User's Guide* in System Documentation.

Exports

`start [ data_file ]`

Argument:

`data_file`

Optional. Specifies what `start_erl.data` file to use.

Environment variable `RELDIR` can be set before calling this example, which sets the directory where to find the release files.

See Also

`run_erl(1)`, *`start_erl(1)`*

erl_driver

C Library

An Erlang driver is a library containing a set of native driver callback functions that the Erlang Virtual Machine calls when certain events occur. There can be multiple instances of a driver, each instance is associated with an Erlang port.

Warning:

Use this functionality with extreme care.

A driver callback is executed as a direct extension of the native code of the VM. Execution is not made in a safe environment. The VM **cannot** provide the same services as provided when executing Erlang code, such as pre-emptive scheduling or memory protection. If the driver callback function does not behave well, the whole VM will misbehave.

- A driver callback that crash will crash the whole VM.
- An erroneously implemented driver callback can cause a VM internal state inconsistency, which can cause a crash of the VM, or miscellaneous misbehaviors of the VM at any point after the call to the driver callback.
- A driver callback doing *lengthy work* before returning degrades responsiveness of the VM and can cause miscellaneous strange behaviors. Such strange behaviors include, but are not limited to, extreme memory usage and bad load balancing between schedulers. Strange behaviors that can occur because of lengthy work can also vary between Erlang/OTP releases.

As from ERTS 5.5.3 the driver interface has been extended (see *`extended marker`*). The extended interface introduces *version management*, the possibility to pass capability flags (see *`driver_flags`*) to the runtime system at driver initialization, and some new driver API functions.

Note:

As from ERTS 5.9 old drivers must be recompiled and use the extended interface. They must also be adjusted to the *64-bit capable driver interface*.

The driver calls back to the emulator, using the API functions declared in `erl_driver.h`. They are used for outputting data from the driver, using timers, and so on.

Each driver instance is associated with a port. Every port has a port owner process. Communication with the port is normally done through the port owner process. Most of the functions take the `port` handle as an argument. This identifies the driver instance. Notice that this port handle must be stored by the driver, it is not given when the driver is called from the emulator (see *`driver_entry`*).

Some of the functions take a parameter of type `ErlDrvBinary`, a driver binary. It is to be both allocated and freed by the caller. Using a binary directly avoids one extra copying of data.

Many of the output functions have a "header buffer", with `hbuf` and `hlen` parameters. This buffer is sent as a list before the binary (or list, depending on port mode) that is sent. This is convenient when matching on messages received from the port. (Although in the latest Erlang versions there is the binary syntax, which enables you to match on the beginning of a binary.)

In the runtime system with SMP support, drivers are locked either on driver level or port level (driver instance level). By default driver level locking will be used, that is, only one emulator thread will execute code in the driver at a time. If port level locking is used, multiple emulator threads can execute code in the driver at the same time. Only one thread at a time will call driver callbacks corresponding to the same port, though. To enable port level locking, set the `ERL_DRV_FLAG_USE_PORT_LOCKING` *driver flag* in the *`driver_entry`* used by the driver. When port

level locking is used, the driver writer is responsible for synchronizing all accesses to data shared by the ports (driver instances).

Most drivers written before the runtime system with SMP support existed can run in the runtime system with SMP support, without being rewritten, if driver level locking is used.

Note:

It is assumed that drivers do not access other drivers. If drivers access each other, they must provide their own mechanism for thread-safe synchronization. Such "inter-driver communication" is strongly discouraged.

Previously, in the runtime system without SMP support, specific driver callbacks were always called from the same thread. This is **not** the case in the runtime system with SMP support. Regardless of locking scheme used, calls to driver callbacks can be made from different threads. For example, two consecutive calls to exactly the same callback for exactly the same port can be made from two different threads. This is for **most** drivers not a problem, but it can be. Drivers that depend on all callbacks that are called in the same thread, **must** be rewritten before they are used in the runtime system with SMP support.

Note:

Regardless of locking scheme used, calls to driver callbacks can be made from different threads.

Most functions in this API are **not** thread-safe, that is, they **cannot** be called from any thread. Functions that are not documented as thread-safe can only be called from driver callbacks or function calls descending from a driver callback call. Notice that driver callbacks can be called from different threads. This, however, is not a problem for any function in this API, as the emulator has control over these threads.

Warning:

Functions not explicitly documented as thread-safe are **not** thread safe. Also notice that some functions are **only** thread-safe when used in a runtime system with SMP support.

A function not explicitly documented as thread-safe can, at some point in time, have a thread-safe implementation in the runtime system. Such an implementation can however change to a thread **unsafe** implementation at any time **without any notice**.

Only use functions explicitly documented as thread-safe from arbitrary threads.

As mentioned in the *warning* text at the beginning of this section, it is of vital importance that a driver callback returns relatively fast. It is difficult to give an exact maximum amount of time that a driver callback is allowed to work, but usually a well-behaving driver callback is to return within 1 millisecond. This can be achieved using different approaches. If you have full control over the code to execute in the driver callback, the best approach is to divide the work into multiple chunks of work, and trigger multiple calls to the *time-out callback* using zero time-outs. Function `erl_drv_consume_timeslice` can be useful to determine when to trigger such time-out callback calls. However, sometimes it cannot be implemented this way, for example when calling third-party libraries. In this case, you typically want to dispatch the work to another thread. Information about thread primitives is provided below.

Functionality

All functions that a driver needs to do with Erlang are performed through driver API functions. Functions exist for the following functionality:

Timer functions

Control the timer that a driver can use. The timer has the emulator call the `timeout` entry function after a specified time. Only one timer is available for each driver instance.

Queue handling

Every driver instance has an associated queue. This queue is a `SysIOVec`, which works as a buffer. It is mostly used for the driver to buffer data that is to be written to a device, it is a byte stream. If the port owner process closes the driver, and the queue is not empty, the driver is not closed. This enables the driver to flush its buffers before closing.

The queue can be manipulated from any threads if a port data lock is used. For more information, see `ErlDrvPDL`.

Output functions

With these functions, the driver sends data back to the emulator. The data is received as messages by the port owner process, see `erlang:open_port/2`. The vector function and the function taking a driver binary are faster, as they avoid copying the data buffer. There is also a fast way of sending terms from the driver, without going through the binary term format.

Failure

The driver can exit and signal errors up to Erlang. This is only for severe errors, when the driver cannot possibly keep open.

Asynchronous calls

Erlang/OTP R7B and later versions have provision for asynchronous function calls, using a thread pool provided by Erlang. There is also a select call, which can be used for asynchronous drivers.

Multi-threading

A POSIX thread like API for multi-threading is provided. The Erlang driver thread API only provides a subset of the functionality provided by the POSIX thread API. The subset provided is more or less the basic functionality needed for multi-threaded programming:

- *Threads*
- *Mutexes*
- *Condition variables*
- *Read/write locks*
- *Thread-specific data*

The Erlang driver thread API can be used in conjunction with the POSIX thread API on UN-ices and with the Windows native thread API on Windows. The Erlang driver thread API has the advantage of being portable, but there can exist situations where you want to use functionality from the POSIX thread API or the Windows native thread API.

The Erlang driver thread API only returns error codes when it is reasonable to recover from an error condition. If it is not reasonable to recover from an error condition, the whole runtime system is terminated. For example, if a create mutex operation fails, an error code is returned, but if a lock operation on a mutex fails, the whole runtime system is terminated.

Notice that there is no "condition variable wait with time-out" in the Erlang driver thread API. This because of issues with `pthread_cond_timedwait`. When the system clock suddenly is changed, it is not always guaranteed that you will wake up from the call as expected. An Erlang runtime system must be able to cope with sudden changes of the system clock. Therefore, we have omitted it from the Erlang driver thread API. In the Erlang driver case, time-outs can and are to be handled with the timer functionality of the Erlang driver API.

In order for the Erlang driver thread API to function, thread support must be enabled in the runtime system. An Erlang driver can check if thread support is enabled by use of *driver_system_info*. Notice that some functions in the Erlang driver API are thread-safe only when the runtime system has SMP support, also this information can be retrieved through *driver_system_info*. Also notice that many functions in the Erlang driver API are **not** thread-safe, regardless of whether SMP support is enabled or not. If a function is not documented as thread-safe, it is **not** thread-safe.

> **Note:**
>
> When executing in an emulator thread, it is **very important** that you unlock **all** locks you have locked before letting the thread out of your control; otherwise you are **very likely** to deadlock the whole emulator.
>
> If you need to use thread-specific data in an emulator thread, only have the thread-specific data set while the thread is under your control, and clear the thread-specific data before you let the thread out of your control.

In the future, debug functionality will probably be integrated with the Erlang driver thread API. All functions that create entities take a `name` argument. Currently the `name` argument is unused, but it will be used when the debug functionality is implemented. If you name all entities created well, the debug functionality will be able to give you better error reports.

Adding/removing drivers

A driver can add and later remove drivers.

Monitoring processes

A driver can monitor a process that does not own a port.

Version management

Version management is enabled for drivers that have set the *extended_marker* field of their *driver_entry* to `ERL_DRV_EXTENDED_MARKER`. `erl_driver.h` defines:

- `ERL_DRV_EXTENDED_MARKER`
- `ERL_DRV_EXTENDED_MAJOR_VERSION`, which is incremented when driver incompatible changes are made to the Erlang runtime system. Normally it suffices to recompile drivers when `ERL_DRV_EXTENDED_MAJOR_VERSION` has changed, but it can, under rare circumstances, mean that drivers must be slightly modified. If so, this will of course be documented.
- `ERL_DRV_EXTENDED_MINOR_VERSION`, which is incremented when new features are added. The runtime system uses the minor version of the driver to determine what features to use.

The runtime system normally refuses to load a driver if the major versions differ, or if the major versions are equal and the minor version used by the driver is greater than the one used by the runtime system. Old drivers with lower major versions are however allowed after a bump of the major version during a transition period of two major releases. Such old drivers can, however, fail if deprecated features are used.

The emulator refuses to load a driver that does not use the extended driver interface, to allow for 64-bit capable drivers, as incompatible type changes for the callbacks *output*, *control*, and *call* were introduced in Erlang/OTP R15B. A driver written with the old types would compile with warnings and when called return garbage sizes to the emulator, causing it to read random memory and create huge incorrect result blobs.

Therefore it is not enough to only recompile drivers written with version management for pre R15B types; the types must be changed in the driver suggesting other rewrites, especially regarding size variables. **Investigate all warnings when recompiling.**

Also, the API driver functions `driver_output*` and `driver_vec_to_buf`, `driver_alloc/realloc*`, and the `driver_*` queue functions were changed to have larger length arguments and return values. This is a lesser problem, as code that passes smaller types gets them auto-converted in the calls, and as long as the driver does not handle sizes that overflow an `int`, all will work as before.

Time measurement

Support for time measurement in drivers:

- *ErlDrvTime*
- *ErlDrvTimeUnit*
- *erl_drv_monotonic_time*
- *erl_drv_time_offset*
- *erl_drv_convert_time_unit*

Rewrites for 64-Bit Driver Interface

ERTS 5.9 introduced two new integer types, *ErlDrvSizeT* and *ErlDrvSSizeT*, which can hold 64-bit sizes if necessary.

To not update a driver and only recompile, it probably works when building for a 32-bit machine creating a false sense of security. Hopefully that will generate many important warnings. But when recompiling the same driver later on for a 64-bit machine, there **will** be warnings and almost certainly crashes. So it is a **bad** idea to postpone updating the driver and not fixing the warnings.

When recompiling with `gcc`, use flag `-Wstrict-prototypes` to get better warnings. Try to find a similar flag if you use another compiler.

The following is a checklist for rewriting a pre ERTS 5.9 driver, most important first:

Return types for driver callbacks

Rrewrite driver callback *control* to use return type `ErlDrvSSizeT` instead of `int`.

Rewrite driver callback *call* to use return type `ErlDrvSSizeT` instead of `int`.

> **Note:**
>
> These changes are essential not to crash the emulator or worse cause malfunction. Without them a driver can return garbage in the high 32 bits to the emulator, causing it to build a huge result from random bytes, either crashing on memory allocation or succeeding with a random result from the driver call.

Arguments to driver callbacks

Driver callback *output* now gets `ErlDrvSizeT` as 3rd argument instead of previously `int`.

Driver callback *control* now gets `ErlDrvSizeT` as 4th and 6th arguments instead of previously `int`.

Driver callback *call* now gets `ErlDrvSizeT` as 4th and 6th arguments instead of previously `int`.

Sane compiler's calling conventions probably make these changes necessary only for a driver to handle data chunks that require 64-bit size fields (mostly larger than 2 GB, as that is what an `int` of 32 bits can hold). But it is possible to think of non-sane calling conventions that would make the driver callbacks mix up the arguments causing malfunction.

> **Note:**
>
> The argument type change is from signed to unsigned. This can cause problems for, for example, loop termination conditions or error conditions if you only change the types all over the place.

Larger `size` field in `ErlIOVec`

The `size` field in *ErlIOVec* has been changed to `ErlDrvSizeT` from `int`. Check all code that use that field.

Automatic type-casting probably makes these changes necessary only for a driver that encounters sizes > 32 bits.

> **Note:**
>
> The `size` field changed from signed to unsigned. This can cause problems for, for example, loop termination conditions or error conditions if you only change the types all over the place.

Arguments and return values in the driver API

Many driver API functions have changed argument type and/or return value to `ErlDrvSizeT` from mostly `int`. Automatic type-casting probably makes these changes necessary only for a driver that encounters sizes > 32 bits.

`driver_output`
: 3rd argument

`driver_output2`
: 3rd and 5th arguments

`driver_output_binary`
: 3rd, 5th, and 6th arguments

`driver_outputv`
: 3rd and 5th arguments

`driver_vec_to_buf`
: 3rd argument and return value

`driver_alloc`
: 1st argument

`driver_realloc`
: 2nd argument

`driver_alloc_binary`
: 1st argument

`driver_realloc_binary`
: 2nd argument

`driver_enq`
: 3rd argument

`driver_pushq`
: 3rd argument

`driver_deq`
: 2nd argument and return value

`driver_sizeq`
: Return value

`driver_enq_bin`
: 3rd and 4th arguments

`driver_pushq_bin`
: 3rd and 4th arguments

`driver_enqv`
: 3rd argument

`driver_pushqv`
: 3rd argument

`driver_peekqv`
: Return value

> **Note:**
>
> This is a change from signed to unsigned. This can cause problems for, for example, loop termination conditions and error conditions if you only change the types all over the place.

Data Types

`ErlDrvSizeT`

An unsigned integer type to be used as `size_t`.

`ErlDrvSSizeT`

A signed integer type, the size of `ErlDrvSizeT`.

`ErlDrvSysInfo`

```
typedef struct ErlDrvSysInfo {
   int driver_major_version;
   int driver_minor_version;
   char *erts_version;
   char *otp_release;
   int thread_support;
   int smp_support;
   int async_threads;
   int scheduler_threads;
   int nif_major_version;
   int nif_minor_version;
   int dirty_scheduler_support;
} ErlDrvSysInfo;
```

The `ErlDrvSysInfo` structure is used for storage of information about the Erlang runtime system. *`driver_system_info`* writes the system information when passed a reference to a `ErlDrvSysInfo` structure. The fields in the structure are as follows:

`driver_major_version`

The value of *`ERL_DRV_EXTENDED_MAJOR_VERSION`* when the runtime system was compiled. This value is the same as the value of *`ERL_DRV_EXTENDED_MAJOR_VERSION`* used when compiling the driver; otherwise the runtime system would have refused to load the driver.

`driver_minor_version`

The value of *`ERL_DRV_EXTENDED_MINOR_VERSION`* when the runtime system was compiled. This value can differ from the value of *`ERL_DRV_EXTENDED_MINOR_VERSION`* used when compiling the driver.

`erts_version`

A string containing the version number of the runtime system (the same as returned by *`erlang:system_info(version)`*).

`otp_release`

A string containing the OTP release number (the same as returned by *`erlang:system_info(otp_release)`*).

`thread_support`

A value `!= 0` if the runtime system has thread support; otherwise `0`.

`smp_support`

A value `!= 0` if the runtime system has SMP support; otherwise `0`.

`async_threads`

The number of async threads in the async thread pool used by *`driver_async`* (the same as returned by *`erlang:system_info(thread_pool_size)`*).

`scheduler_threads`

The number of scheduler threads used by the runtime system (the same as returned by *`erlang:system_info(schedulers)`*).

`nif_major_version`

The value of `ERL_NIF_MAJOR_VERSION` when the runtime system was compiled.

`nif_minor_version`

The value of `ERL_NIF_MINOR_VERSION` when the runtime system was compiled.

`dirty_scheduler_support`

A value `!= 0` if the runtime system has support for dirty scheduler threads; otherwise `0`.

`ErlDrvBinary`

```
typedef struct ErlDrvBinary {
   ErlDrvSint orig_size;
   char orig_bytes[];
} ErlDrvBinary;
```

The `ErlDrvBinary` structure is a binary, as sent between the emulator and the driver. All binaries are reference counted; when `driver_binary_free` is called, the reference count is decremented, when it reaches zero, the binary is deallocated. `orig_size` is the binary size and `orig_bytes` is the buffer. `ErlDrvBinary` has not a fixed size, its size is `orig_size + 2 * sizeof(int)`.

Note:

The `refc` field has been removed. The reference count of an `ErlDrvBinary` is now stored elsewhere. The reference count of an `ErlDrvBinary` can be accessed through *`driver_binary_get_refc`*, *`driver_binary_inc_refc`*, and *`driver_binary_dec_refc`*.

Some driver calls, such as `driver_enq_binary`, increment the driver reference count, and others, such as `driver_deq` decrement it.

Using a driver binary instead of a normal buffer is often faster, as the emulator needs not to copy the data, only the pointer is used.

A driver binary allocated in the driver, with `driver_alloc_binary`, is to be freed in the driver (unless otherwise stated) with `driver_free_binary`. (Notice that this does not necessarily deallocate it, if the driver is still referred in the emulator, the ref-count will not go to zero.)

Driver binaries are used in the `driver_output2` and `driver_outputv` calls, and in the queue. Also the driver callback *`outputv`* uses driver binaries.

If the driver for some reason wants to keep a driver binary around, for example in a static variable, the reference count is to be incremented, and the binary can later be freed in the *`stop`* callback, with `driver_free_binary`.

Notice that as a driver binary is shared by the driver and the emulator. A binary received from the emulator or sent to the emulator must not be changed by the driver.

Since ERTS 5.5 (Erlang/OTP R11B), `orig_bytes` is guaranteed to be properly aligned for storage of an array of doubles (usually 8-byte aligned).

`ErlDrvData`

A handle to driver-specific data, passed to the driver callbacks. It is a pointer, and is most often type cast to a specific pointer in the driver.

`SysIOVec`

A system I/O vector, as used by `writev` on Unix and `WSASend` on Win32. It is used in `ErlIOVec`.

`ErlIOVec`

```
typedef struct ErlIOVec {
  int vsize;
  ErlDrvSizeT size;
  SysIOVec* iov;
  ErlDrvBinary** binv;
} ErlIOVec;
```

The I/O vector used by the emulator and drivers is a list of binaries, with a `SysIOVec` pointing to the buffers of the binaries. It is used in `driver_outputv` and the *`outputv`* driver callback. Also, the driver queue is an `ErlIOVec`.

`ErlDrvMonitor`

When a driver creates a monitor for a process, a `ErlDrvMonitor` is filled in. This is an opaque data type that can be assigned to, but not compared without using the supplied compare function (that is, it behaves like a struct).

The driver writer is to provide the memory for storing the monitor when calling *`driver_monitor_process`*. The address of the data is not stored outside of the driver, so `ErlDrvMonitor` can be used as any other data, it can be copied, moved in memory, forgotten, and so on.

`ErlDrvNowData`

The `ErlDrvNowData` structure holds a time stamp consisting of three values measured from some arbitrary point in the past. The three structure members are:

`megasecs`
: The number of whole megaseconds elapsed since the arbitrary point in time

`secs`
: The number of whole seconds elapsed since the arbitrary point in time

`microsecs`
: The number of whole microseconds elapsed since the arbitrary point in time

`ErlDrvPDL`

If certain port-specific data must be accessed from other threads than those calling the driver callbacks, a port data lock can be used to synchronize the operations on the data. Currently, the only port-specific data that the emulator associates with the port data lock is the driver queue.

Normally a driver instance has no port data lock. If the driver instance wants to use a port data lock, it must create the port data lock by calling *`driver_pdl_create`*.

> **Note:**
>
> Once the port data lock has been created, every access to data associated with the port data lock must be done while the port data lock is locked. The port data lock is locked and unlocked by *`driver_pdl_lock`*, and *`driver_pdl_unlock`*, respectively.

A port data lock is reference counted, and when the reference count reaches zero, it is destroyed. The emulator at least increments the reference count once when the lock is created and decrements it once the port associated with the lock terminates. The emulator also increments the reference count when an async job is enqueued and decrements it when an async job has been invoked. Also, the driver is responsible for ensuring that the reference count does not reach zero before the last use of the lock by the driver has been made. The reference count can be read, incremented, and decremented by *`driver_pdl_get_refc`*, *`driver_pdl_inc_refc`*, and *`driver_pdl_dec_refc`*, respectively.

`ErlDrvTid`

Thread identifier.

See also *erl_drv_thread_create*, *erl_drv_thread_exit*, *erl_drv_thread_join*, *erl_drv_thread_self*, and *erl_drv_equal_tids*.

`ErlDrvThreadOpts`

```
int suggested_stack_size;
```

Thread options structure passed to *erl_drv_thread_create*. The following fields exists:

`suggested_stack_size`
: A suggestion, in kilowords, on how large a stack to use. A value < 0 means default size.

See also *erl_drv_thread_opts_create*, *erl_drv_thread_opts_destroy*, and *erl_drv_thread_create*.

`ErlDrvMutex`

Mutual exclusion lock. Used for synchronizing access to shared data. Only one thread at a time can lock a mutex.

See also *erl_drv_mutex_create*, *erl_drv_mutex_destroy*, *erl_drv_mutex_lock*, *erl_drv_mutex_trylock*, and *erl_drv_mutex_unlock*.

`ErlDrvCond`

Condition variable. Used when threads must wait for a specific condition to appear before continuing execution. Condition variables must be used with associated mutexes.

See also *erl_drv_cond_create*, *erl_drv_cond_destroy*, *erl_drv_cond_signal*, *erl_drv_cond_broadcast*, and *erl_drv_cond_wait*.

`ErlDrvRWLock`

Read/write lock. Used to allow multiple threads to read shared data while only allowing one thread to write the same data. Multiple threads can read lock an rwlock at the same time, while only one thread can read/write lock an rwlock at a time.

See also *erl_drv_rwlock_create*, *erl_drv_rwlock_destroy*, *erl_drv_rwlock_rlock*, *erl_drv_rwlock_tryrlock*, *erl_drv_rwlock_runlock*, *erl_drv_rwlock_rwlock*, *erl_drv_rwlock_tryrwlock*, and *erl_drv_rwlock_rwunlock*.

`ErlDrvTSDKey`

Key that thread-specific data can be associated with.

See also *erl_drv_tsd_key_create*, *erl_drv_tsd_key_destroy*, *erl_drv_tsd_set*, and *erl_drv_tsd_get*.

`ErlDrvTime`

A signed 64-bit integer type for time representation.

`ErlDrvTimeUnit`

An enumeration of time units supported by the driver API:

`ERL_DRV_SEC`
: Seconds

`ERL_DRV_MSEC`
: Milliseconds

`ERL_DRV_USEC`
: Microseconds

`ERL_DRV_NSEC`
: Nanoseconds

Exports

`void add_driver_entry(ErlDrvEntry *de)`

Adds a driver entry to the list of drivers known by Erlang. The *`init`* function of parameter `de` is called.

> **Note:**
>
> To use this function for adding drivers residing in dynamically loaded code is dangerous. If the driver code for the added driver resides in the same dynamically loaded module (that is, `.so` file) as a normal dynamically loaded driver (loaded with the `erl_ddll` interface), the caller is to call *`driver_lock_driver`* before adding driver entries.
>
> **Use of this function is generally deprecated.**

`void *driver_alloc(ErlDrvSizeT size)`

Allocates a memory block of the size specified in `size`, and returns it. This fails only on out of memory, in which case `NULL` is returned. (This is most often a wrapper for `malloc`).

Memory allocated must be explicitly freed with a corresponding call to *`driver_free`* (unless otherwise stated).

This function is thread-safe.

`ErlDrvBinary *driver_alloc_binary(ErlDrvSizeT size)`

Allocates a driver binary with a memory block of at least `size` bytes, and returns a pointer to it, or `NULL` on failure (out of memory). When a driver binary has been sent to the emulator, it must not be changed. Every allocated binary is to be freed by a corresponding call to *`driver_free_binary`* (unless otherwise stated).

Notice that a driver binary has an internal reference counter. This means that calling `driver_free_binary`, it may not actually dispose of it. If it is sent to the emulator, it can be referenced there.

The driver binary has a field, `orig_bytes`, which marks the start of the data in the binary.

This function is thread-safe.

`long driver_async(ErlDrvPort port, unsigned int* key, void (*async_invoke)(void*), void* async_data, void (*async_free)(void*))`

Performs an asynchronous call. The function `async_invoke` is invoked in a thread separate from the emulator thread. This enables the driver to perform time-consuming, blocking operations without blocking the emulator.

The async thread pool size can be set with command-line argument *`+A`* in *`erl(1)`*. If an async thread pool is unavailable, the call is made synchronously in the thread calling `driver_async`. The current number of async threads in the async thread pool can be retrieved through *`driver_system_info`*.

If a thread pool is available, a thread is used. If argument `key` is `NULL`, the threads from the pool are used in a round-robin way, each call to `driver_async` uses the next thread in the pool. With argument `key` set, this behavior is changed. The two same values of `*key` always get the same thread.

To ensure that a driver instance always uses the same thread, the following call can be used:

```
unsigned int myKey = driver_async_port_key(myPort);

r = driver_async(myPort, &myKey, myData, myFunc);
```

It is enough to initialize `myKey` once for each driver instance.

If a thread is already working, the calls are queued up and executed in order. Using the same thread for each driver instance ensures that the calls are made in sequence.

The `async_data` is the argument to the functions `async_invoke` and `async_free`. It is typically a pointer to a structure containing a pipe or event that can be used to signal that the async operation completed. The data is to be freed in `async_free`.

When the async operation is done, *`ready_async`* driver entry function is called. If `ready_async` is `NULL` in the driver entry, the `async_free` function is called instead.

The return value is `-1` if the `driver_async` call fails.

Note:

As from ERTS 5.5.4.3 the default stack size for threads in the async-thread pool is 16 kilowords, that is, 64 kilobyte on 32-bit architectures. This small default size has been chosen because the amount of async-threads can be quite large. The default stack size is enough for drivers delivered with Erlang/OTP, but is possibly not sufficiently large for other dynamically linked-in drivers that use the `driver_async` functionality. A suggested stack size for threads in the async-thread pool can be configured through command-line argument *`+a`* in *`erl(1)`*.

`unsigned int driver_async_port_key(ErlDrvPort port)`

Calculates a key for later use in *`driver_async`*. The keys are evenly distributed so that a fair mapping between port IDs and async thread IDs is achieved.

Note:

Before Erlang/OTP R16, the port ID could be used as a key with proper casting, but after the rewrite of the port subsystem, this is no longer the case. With this function, you can achieve the same distribution based on port IDs as before Erlang/OTP R16.

`long driver_binary_dec_refc(ErlDrvBinary *bin)`

Decrements the reference count on `bin` and returns the reference count reached after the decrement.

This function is thread-safe.

Note:

The reference count of driver binary is normally to be decremented by calling *`driver_free_binary`*.

`driver_binary_dec_refc` does **not** free the binary if the reference count reaches zero. **Only** use `driver_binary_dec_refc` when you are sure **not** to reach a reference count of zero.

`long driver_binary_get_refc(ErlDrvBinary *bin)`

Returns the current reference count on `bin`.

This function is thread-safe.

`long driver_binary_inc_refc(ErlDrvBinary *bin)`

Increments the reference count on `bin` and returns the reference count reached after the increment.

This function is thread-safe.

`ErlDrvTermData driver_caller(ErlDrvPort port)`

Returns the process ID of the process that made the current call to the driver. The process ID can be used with *`driver_send_term`* to send back data to the caller. `driver_caller` only returns valid data when currently executing in one of the following driver callbacks:

`start`
: Called from *`erlang:open_port/2`*.

`output`
: Called from *`erlang:send/2`* and *`erlang:port_command/2`*.

`outputv`
: Called from *`erlang:send/2`* and *`erlang:port_command/2`*.

`control`
: Called from *`erlang:port_control/3`*.

`call`
: Called from *`erlang:port_call/3`*.

Notice that this function is **not** thread-safe, not even when the emulator with SMP support is used.

`int driver_cancel_timer(ErlDrvPort port)`

Cancels a timer set with *`driver_set_timer`*.

The return value is `0`.

`int driver_compare_monitors(const ErlDrvMonitor *monitor1, const ErlDrvMonitor *monitor2)`

Compares two `ErlDrvMonitor`s. Can also be used to imply some artificial order on monitors, for whatever reason.

Returns `0` if `monitor1` and `monitor2` are equal, < `0` if `monitor1` < `monitor2`, and > `0` if `monitor1` > `monitor2`.

`ErlDrvTermData driver_connected(ErlDrvPort port)`

Returns the port owner process.

Notice that this function is **not** thread-safe, not even when the emulator with SMP support is used.

`ErlDrvPort driver_create_port(ErlDrvPort port, ErlDrvTermData owner_pid, char* name, ErlDrvData drv_data)`

Creates a new port executing the same driver code as the port creating the new port.

`port`
: The port handle of the port (driver instance) creating the new port.

`owner_pid`
: The process ID of the Erlang process to become owner of the new port. This process will be linked to the new port. You usually want to use `driver_caller(port)` as `owner_pid`.

`name`
: The port name of the new port. You usually want to use the same port name as the driver name (*`driver_name`* field of the *`driver_entry`*).

`drv_data`

The driver-defined handle that is passed in later calls to driver callbacks. Notice that the *driver start callback* is not called for this new driver instance. The driver-defined handle is normally created in the *driver start callback* when a port is created through *`erlang:open_port/2`*.

The caller of `driver_create_port` is allowed to manipulate the newly created port when `driver_create_port` has returned. When *port level locking* is used, the creating port is only allowed to manipulate the newly created port until the current driver callback, which was called by the emulator, returns.

`int driver_demonitor_process(ErlDrvPort port, const ErlDrvMonitor *monitor)`

Cancels a monitor created earlier.

Returns `0` if a monitor was removed and > 0 if the monitor no longer exists.

`ErlDrvSizeT driver_deq(ErlDrvPort port, ErlDrvSizeT size)`

Dequeues data by moving the head pointer forward in the driver queue by `size` bytes. The data in the queue is deallocated.

Returns the number of bytes remaining in the queue on success, otherwise `-1`.

This function can be called from any thread if a *port data lock* associated with the `port` is locked by the calling thread during the call.

`int driver_enq(ErlDrvPort port, char* buf, ErlDrvSizeT len)`

Enqueues data in the driver queue. The data in `buf` is copied (`len` bytes) and placed at the end of the driver queue. The driver queue is normally used in a FIFO way.

The driver queue is available to queue output from the emulator to the driver (data from the driver to the emulator is queued by the emulator in normal Erlang message queues). This can be useful if the driver must wait for slow devices, and so on, and wants to yield back to the emulator. The driver queue is implemented as an `ErlIOVec`.

When the queue contains data, the driver does not close until the queue is empty.

The return value is `0`.

This function can be called from any thread if a *port data lock* associated with the `port` is locked by the calling thread during the call.

`int driver_enq_bin(ErlDrvPort port, ErlDrvBinary *bin, ErlDrvSizeT offset, ErlDrvSizeT len)`

Enqueues a driver binary in the driver queue. The data in `bin` at `offset` with length `len` is placed at the end of the queue. This function is most often faster than *`driver_enq`*, because no data must be copied.

This function can be called from any thread if a *port data lock* associated with the `port` is locked by the calling thread during the call.

The return value is `0`.

`int driver_enqv(ErlDrvPort port, ErlIOVec *ev, ErlDrvSizeT skip)`

Enqueues the data in `ev`, skipping the first `skip` bytes of it, at the end of the driver queue. It is faster than *`driver_enq`*, because no data must be copied.

The return value is `0`.

This function can be called from any thread if a *port data lock* associated with the `port` is locked by the calling thread during the call.

`int driver_failure(ErlDrvPort port, int error)`
`int driver_failure_atom(ErlDrvPort port, char *string)`
`int driver_failure_posix(ErlDrvPort port, int error)`

Signals to Erlang that the driver has encountered an error and is to be closed. The port is closed and the tuple `{'EXIT', error, Err}` is sent to the port owner process, where error is an error atom (`driver_failure_atom` and `driver_failure_posix`) or an integer (`driver_failure`).

The driver is to fail only when in severe error situations, when the driver cannot possibly keep open, for example, buffer allocation gets out of memory. For normal errors it is more appropriate to send error codes with *`driver_output`*.

The return value is `0`.

`int driver_failure_eof(ErlDrvPort port)`

Signals to Erlang that the driver has encountered an EOF and is to be closed, unless the port was opened with option `eof`, in which case `eof` is sent to the port. Otherwise the port is closed and an `'EXIT'` message is sent to the port owner process.

The return value is `0`.

`void driver_free(void *ptr)`

Frees the memory pointed to by `ptr`. The memory is to have been allocated with `driver_alloc`. All allocated memory is to be deallocated, only once. There is no garbage collection in drivers.

This function is thread-safe.

`void driver_free_binary(ErlDrvBinary *bin)`

Frees a driver binary `bin`, allocated previously with *`driver_alloc_binary`*. As binaries in Erlang are reference counted, the binary can still be around.

This function is thread-safe.

`ErlDrvTermData driver_get_monitored_process(ErlDrvPort port, const ErlDrvMonitor *monitor)`

Returns the process ID associated with a living monitor. It can be used in the *`process_exit`* callback to get the process identification for the exiting process.

Returns `driver_term_nil` if the monitor no longer exists.

`int driver_get_now(ErlDrvNowData *now)`

Warning:

This function is deprecated. Do not use it. Use *`erl_drv_monotonic_time`* (perhaps in combination with *`erl_drv_time_offset`*) instead.

Reads a time stamp into the memory pointed to by parameter `now`. For information about specific fields, see *`ErlDrvNowData`*.

The return value is `0`, unless the `now` pointer is invalid, in which case it is < `0`.

`int driver_lock_driver(ErlDrvPort port)`

Locks the driver used by the port `port` in memory for the rest of the emulator process' lifetime. After this call, the driver behaves as one of Erlang's statically linked-in drivers.

`ErlDrvTermData driver_mk_atom(char* string)`

Returns an atom given a name `string`. The atom is created and does not change, so the return value can be saved and reused, which is faster than looking up the atom several times.

Notice that this function is **not** thread-safe, not even when the emulator with SMP support is used.

`ErlDrvTermData driver_mk_port(ErlDrvPort port)`

Converts a port handle to the Erlang term format, usable in *`erl_drv_output_term`* and *`erl_drv_send_term`*.

Notice that this function is **not** thread-safe, not even when the emulator with SMP support is used.

`int driver_monitor_process(ErlDrvPort port, ErlDrvTermData process, ErlDrvMonitor *monitor)`

Starts monitoring a process from a driver. When a process is monitored, a process exit results in a call to the provided *`process_exit`* callback in the *`ErlDrvEntry`* structure. The `ErlDrvMonitor` structure is filled in, for later removal or compare.

Parameter `process` is to be the return value of an earlier call to *`driver_caller`* or *`driver_connected`* call.

Returns `0` on success, < 0 if no callback is provided, and > 0 if the process is no longer alive.

`int driver_output(ErlDrvPort port, char *buf, ErlDrvSizeT len)`

Sends data from the driver up to the emulator. The data is received as terms or binary data, depending on how the driver port was opened.

The data is queued in the port owner process' message queue. Notice that this does not yield to the emulator (as the driver and the emulator run in the same thread).

Parameter `buf` points to the data to send, and `len` is the number of bytes.

The return value for all output functions is `0` for normal use. If the driver is used for distribution, it can fail and return `-1`.

`int driver_output_binary(ErlDrvPort port, char *hbuf, ErlDrvSizeT hlen, ErlDrvBinary* bin, ErlDrvSizeT offset, ErlDrvSizeT len)`

Sends data to a port owner process from a driver binary. It has a header buffer (`hbuf` and `hlen`) just like *`driver_output2`*. Parameter `hbuf` can be `NULL`.

Parameter `offset` is an offset into the binary and `len` is the number of bytes to send.

Driver binaries are created with *`driver_alloc_binary`*.

The data in the header is sent as a list and the binary as an Erlang binary in the tail of the list.

For example, if `hlen` is `2`, the port owner process receives `[H1, H2 | <<T>>]`.

The return value is `0` for normal use.

Notice that, using the binary syntax in Erlang, the driver application can match the header directly from the binary, so the header can be put in the binary, and `hlen` can be set to `0`.

`int driver_output_term(ErlDrvPort port, ErlDrvTermData* term, int n)`

Warning:

This function is deprecated. Use *`erl_drv_output_term`* instead.

Parameters `term` and `n` work as in *`erl_drv_output_term`*.

Notice that this function is **not** thread-safe, not even when the emulator with SMP support is used.

`int driver_output2(ErlDrvPort port, char *hbuf, ErlDrvSizeT hlen, char *buf, ErlDrvSizeT len)`

First sends `hbuf` (length in `hlen`) data as a list, regardless of port settings. Then sends `buf` as a binary or list. For example, if `hlen` is `3`, the port owner process receives `[H1, H2, H3 | T]`.

The point of sending data as a list header, is to facilitate matching on the data received.

The return value is `0` for normal use.

`int driver_outputv(ErlDrvPort port, char* hbuf, ErlDrvSizeT hlen, ErlIOVec *ev, ErlDrvSizeT skip)`

Sends data from an I/O vector, `ev`, to the port owner process. It has a header buffer (`hbuf` and `hlen`), just like *`driver_output2`*.

Parameter `skip` is a number of bytes to skip of the `ev` vector from the head.

You get vectors of `ErlIOVec` type from the driver queue (see below), and the *`outputv`* driver entry function. You can also make them yourself, if you want to send several `ErlDrvBinary` buffers at once. Often it is faster to use *`driver_output`* or .

For example, if `hlen` is `2` and `ev` points to an array of three binaries, the port owner process receives `[H1, H2, <<B1>>, <<B2>> | <<B3>>]`.

The return value is `0` for normal use.

The comment for `driver_output_binary` also applies for `driver_outputv`.

`ErlDrvPDL driver_pdl_create(ErlDrvPort port)`

Creates a port data lock associated with the `port`.

Note:

Once a port data lock has been created, it must be locked during all operations on the driver queue of the `port`.

Returns a newly created port data lock on success, otherwise `NULL`. The function fails if `port` is invalid or if a port data lock already has been associated with the `port`.

`long driver_pdl_dec_refc(ErlDrvPDL pdl)`

Decrements the reference count of the port data lock passed as argument (`pdl`).

The current reference count after the decrement has been performed is returned.

This function is thread-safe.

`long driver_pdl_get_refc(ErlDrvPDL pdl)`

Returns the current reference count of the port data lock passed as argument (`pdl`).

This function is thread-safe.

`long driver_pdl_inc_refc(ErlDrvPDL pdl)`

Increments the reference count of the port data lock passed as argument (`pdl`).

The current reference count after the increment has been performed is returned.

This function is thread-safe.

`void driver_pdl_lock(ErlDrvPDL pdl)`

Locks the port data lock passed as argument (`pdl`).

This function is thread-safe.

`void driver_pdl_unlock(ErlDrvPDL pdl)`

Unlocks the port data lock passed as argument (`pdl`).

This function is thread-safe.

`SysIOVec *driver_peekq(ErlDrvPort port, int *vlen)`

Retrieves the driver queue as a pointer to an array of `SysIOVec`s. It also returns the number of elements in `vlen`. This is one of two ways to get data out of the queue.

Nothing is removed from the queue by this function, that must be done with *`driver_deq`*.

The returned array is suitable to use with the Unix system call `writev`.

This function can be called from any thread if a *port data lock* associated with the `port` is locked by the calling thread during the call.

`ErlDrvSizeT driver_peekqv(ErlDrvPort port, ErlIOVec *ev)`

Retrieves the driver queue into a supplied `ErlIOVec ev`. It also returns the queue size. This is one of two ways to get data out of the queue.

If `ev` is `NULL`, all ones that is `-1` type cast to `ErlDrvSizeT` are returned.

Nothing is removed from the queue by this function, that must be done with *`driver_deq`*.

This function can be called from any thread if a *port data lock* associated with the `port` is locked by the calling thread during the call.

`int driver_pushq(ErlDrvPort port, char* buf, ErlDrvSizeT len)`

Puts data at the head of the driver queue. The data in `buf` is copied (`len` bytes) and placed at the beginning of the queue.

The return value is `0`.

This function can be called from any thread if a *port data lock* associated with the `port` is locked by the calling thread during the call.

`int driver_pushq_bin(ErlDrvPort port, ErlDrvBinary *bin, ErlDrvSizeT offset, ErlDrvSizeT len)`

Puts data in the binary `bin`, at `offset` with length `len` at the head of the driver queue. It is most often faster than *`driver_pushq`*, because no data must be copied.

This function can be called from any thread if a *port data lock* associated with the `port` is locked by the calling thread during the call.

The return value is `0`.

`int driver_pushqv(ErlDrvPort port, ErlIOVec *ev, ErlDrvSizeT skip)`

Puts the data in `ev`, skipping the first `skip` bytes of it, at the head of the driver queue. It is faster than *`driver_pushq`*, because no data must be copied.

The return value is `0`.

This function can be called from any thread if a *port data lock* associated with the `port` is locked by the calling thread during the call.

`int driver_read_timer(ErlDrvPort port, unsigned long *time_left)`

Reads the current time of a timer, and places the result in `time_left`. This is the time in milliseconds, before the time-out occurs.

The return value is `0`.

`void *driver_realloc(void *ptr, ErlDrvSizeT size)`

Resizes a memory block, either in place, or by allocating a new block, copying the data, and freeing the old block. A pointer is returned to the reallocated memory. On failure (out of memory), `NULL` is returned. (This is most often a wrapper for `realloc`.)

This function is thread-safe.

`ErlDrvBinary *driver_realloc_binary(ErlDrvBinary *bin, ErlDrvSizeT size)`

Resizes a driver binary, while keeping the data.

Returns the resized driver binary on success. Returns `NULL` on failure (out of memory).

This function is thread-safe.

`int driver_select(ErlDrvPort port, ErlDrvEvent event, int mode, int on)`

This function is used by drivers to provide the emulator with events to check for. This enables the emulator to call the driver when something has occurred asynchronously.

Parameter `event` identifies an OS-specific event object. On Unix systems, the functions `select`/`poll` are used. The event object must be a socket or pipe (or other object that `select`/`poll` can use). On Windows, the Win32 API function `WaitForMultipleObjects` is used. This places other restrictions on the event object; see the Win32 SDK documentation.

Parameter `on` is to be `1` for setting events and `0` for clearing them.

Parameter `mode` is a bitwise OR combination of `ERL_DRV_READ`, `ERL_DRV_WRITE`, and `ERL_DRV_USE`. The first two specify whether to wait for read events and/or write events. A fired read event calls *`ready_input`* and a fired write event calls *`ready_output`*.

Note:

Some OS (Windows) do not differentiate between read and write events. The callback for a fired event then only depends on the value of `mode`.

`ERL_DRV_USE` specifies if we are using the event object or if we want to close it. On an emulator with SMP support, it is not safe to clear all events and then close the event object after `driver_select` has returned. Another thread can still be using the event object internally. To safely close an event object, call `driver_select` with `ERL_DRV_USE` and `on==0`, which clears all events and then either calls *`stop_select`* or schedules it to be called when it is safe to close the event object. `ERL_DRV_USE` is to be set together with the first event for an event object. It is harmless to set `ERL_DRV_USE` even if it already has been done. Clearing all events but keeping `ERL_DRV_USE` set indicates that we are using the event object and probably will set events for it again.

Note:

`ERL_DRV_USE` was added in Erlang/OTP R13. Old drivers still work as before, but it is recommended to update them to use `ERL_DRV_USE` and `stop_select` to ensure that event objects are closed in a safe way.

The return value is `0`, unless `ready_input/ready_output` is `NULL`, in which case it is `-1`.

```
int driver_send_term(ErlDrvPort port, ErlDrvTermData receiver,
ErlDrvTermData* term, int n)
```

Warning:

This function is deprecated. Use *`erl_drv_send_term`* instead.

Note:

The parameters of this function cannot be properly checked by the runtime system when executed by arbitrary threads. This can cause the function not to fail when it should.

Parameters `term` and `n` work as in *`erl_drv_output_term`*.

This function is only thread-safe when the emulator with SMP support is used.

```
int driver_set_timer(ErlDrvPort port, unsigned long time)
```

Sets a timer on the driver, which will count down and call the driver when it is timed out. Parameter `time` is the time in milliseconds before the timer expires.

When the timer reaches `0` and expires, the driver entry function *`timeout`* is called.

Notice that only one timer exists on each driver instance; setting a new timer replaces an older one.

Return value is `0`, unless the `timeout` driver function is `NULL`, in which case it is `-1`.

```
ErlDrvSizeT driver_sizeq(ErlDrvPort port)
```

Returns the number of bytes currently in the driver queue.

This function can be called from any thread if a *port data lock* associated with the `port` is locked by the calling thread during the call.

void driver_system_info(ErlDrvSysInfo *sys_info_ptr, size_t size)

Writes information about the Erlang runtime system into the *ErlDrvSysInfo* structure referred to by the first argument. The second argument is to be the size of the *ErlDrvSysInfo* structure, that is, sizeof(ErlDrvSysInfo).

For information about specific fields, see *ErlDrvSysInfo*.

ErlDrvSizeT driver_vec_to_buf(ErlIOVec *ev, char *buf, ErlDrvSizeT len)

Collects several segments of data, referenced by ev, by copying them in order to the buffer buf, of the size len.

If the data is to be sent from the driver to the port owner process, it is faster to use *driver_outputv*.

The return value is the space left in the buffer, that is, if ev contains less than len bytes it is the difference, and if ev contains len bytes or more, it is 0. This is faster if there is more than one header byte, as the binary syntax can construct integers directly from the binary.

void erl_drv_busy_msgq_limits(ErlDrvPort port, ErlDrvSizeT *low, ErlDrvSizeT *high)

Sets and gets limits that will be used for controlling the busy state of the port message queue.

The port message queue is set into a busy state when the amount of command data queued on the message queue reaches the high limit. The port message queue is set into a not busy state when the amount of command data queued on the message queue falls below the low limit. Command data is in this context data passed to the port using either Port ! {Owner, {command, Data}} or port_command/[2,3]. Notice that these limits only concerns command data that have not yet reached the port. The *busy port* feature can be used for data that has reached the port.

Valid limits are values in the range [ERL_DRV_BUSY_MSGQ_LIM_MIN, ERL_DRV_BUSY_MSGQ_LIM_MAX]. Limits are automatically adjusted to be sane. That is, the system adjusts values so that the low limit used is lower than or equal to the high limit used. By default the high limit is 8 kB and the low limit is 4 kB.

By passing a pointer to an integer variable containing the value ERL_DRV_BUSY_MSGQ_READ_ONLY, the currently used limit is read and written back to the integer variable. A new limit can be set by passing a pointer to an integer variable containing a valid limit. The passed value is written to the internal limit. The internal limit is then adjusted. After this the adjusted limit is written back to the integer variable from which the new value was read. Values are in bytes.

The busy message queue feature can be disabled either by setting the ERL_DRV_FLAG_NO_BUSY_MSGQ *driver flag* in the *driver_entry* used by the driver, or by calling this function with ERL_DRV_BUSY_MSGQ_DISABLED as a limit (either low or high). When this feature has been disabled, it cannot be enabled again. When reading the limits, both are ERL_DRV_BUSY_MSGQ_DISABLED if this feature has been disabled.

Processes sending command data to the port are suspended if either the port is busy or if the port message queue is busy. Suspended processes are resumed when neither the port or the port message queue is busy.

For information about busy port functionality, see *set_busy_port*.

void erl_drv_cond_broadcast(ErlDrvCond *cnd)

Broadcasts on a condition variable. That is, if other threads are waiting on the condition variable being broadcast on, **all** of them are woken.

cnd is a pointer to a condition variable to broadcast on.

This function is thread-safe.

`ErlDrvCond *erl_drv_cond_create(char *name)`

Creates a condition variable and returns a pointer to it.

`name` is a string identifying the created condition variable. It is used to identify the condition variable in planned future debug functionality.

Returns `NULL` on failure. The driver creating the condition variable is responsible for destroying it before the driver is unloaded.

This function is thread-safe.

`void erl_drv_cond_destroy(ErlDrvCond *cnd)`

Destroys a condition variable previously created by *`erl_drv_cond_create`*.

`cnd` is a pointer to a condition variable to destroy.

This function is thread-safe.

`char *erl_drv_cond_name(ErlDrvCond *cnd)`

Returns a pointer to the name of the condition.

`cnd` is a pointer to an initialized condition.

Note:

This function is intended for debugging purposes only.

`void erl_drv_cond_signal(ErlDrvCond *cnd)`

Signals on a condition variable. That is, if other threads are waiting on the condition variable being signaled, **one** of them is woken.

`cnd` is a pointer to a condition variable to signal on.

This function is thread-safe.

`void erl_drv_cond_wait(ErlDrvCond *cnd, ErlDrvMutex *mtx)`

Waits on a condition variable. The calling thread is blocked until another thread wakes it by signaling or broadcasting on the condition variable. Before the calling thread is blocked, it unlocks the mutex passed as argument. When the calling thread is woken, it locks the same mutex before returning. That is, the mutex currently must be locked by the calling thread when calling this function.

`cnd` is a pointer to a condition variable to wait on. `mtx` is a pointer to a mutex to unlock while waiting.

Note:

`erl_drv_cond_wait` can return even if no one has signaled or broadcast on the condition variable. Code calling `erl_drv_cond_wait` is always to be prepared for `erl_drv_cond_wait` returning even if the condition that the thread was waiting for has not occurred. That is, when returning from `erl_drv_cond_wait`, always check if the condition has occurred, and if not call `erl_drv_cond_wait` again.

This function is thread-safe.

`int erl_drv_consume_timeslice(ErlDrvPort port, int percent)`

Gives the runtime system a hint about how much CPU time the current driver callback call has consumed since the last hint, or since the the start of the callback if no previous hint has been given.

`port`
: Port handle of the executing port.

`percent`
: Approximate consumed fraction of a full time-slice in percent.

The time is specified as a fraction, in percent, of a full time-slice that a port is allowed to execute before it is to surrender the CPU to other runnable ports or processes. Valid range is `[1, 100]`. The scheduling time-slice is not an exact entity, but can usually be approximated to about 1 millisecond.

Notice that it is up to the runtime system to determine if and how to use this information. Implementations on some platforms can use other means to determine the consumed fraction of the time-slice. Lengthy driver callbacks should, regardless of this, frequently call this function to determine if it is allowed to continue execution or not.

This function returns a non-zero value if the time-slice has been exhausted, and zero if the callback is allowed to continue execution. If a non-zero value is returned, the driver callback is to return as soon as possible in order for the port to be able to yield.

This function is provided to better support co-operative scheduling, improve system responsiveness, and to make it easier to prevent misbehaviors of the VM because of a port monopolizing a scheduler thread. It can be used when dividing lengthy work into some repeated driver callback calls, without the need to use threads.

See also the important *warning* text at the beginning of this manual page.

`ErlDrvTime erl_drv_convert_time_unit(ErlDrvTime val, ErlDrvTimeUnit from, ErlDrvTimeUnit to)`

Converts the `val` value of time unit `from` to the corresponding value of time unit `to`. The result is rounded using the floor function.

`val`
: Value to convert time unit for.

`from`
: Time unit of `val`.

`to`
: Time unit of returned value.

Returns `ERL_DRV_TIME_ERROR` if called with an invalid time unit argument.

See also *`ErlDrvTime`* and *`ErlDrvTimeUnit`*.

`int erl_drv_equal_tids(ErlDrvTid tid1, ErlDrvTid tid2)`

Compares two thread identifiers, `tid1` and `tid2`, for equality.

Returns `0` it they are not equal, and a value not equal to `0` if they are equal.

Note:

A thread identifier can be reused very quickly after a thread has terminated. Therefore, if a thread corresponding to one of the involved thread identifiers has terminated since the thread identifier was saved, the result of `erl_drv_equal_tids` does possibly not give the expected result.

This function is thread-safe.

`int erl_drv_getenv(const char *key, char *value, size_t *value_size)`

Retrieves the value of an environment variable.

`key`
: A `NULL`-terminated string containing the name of the environment variable.

`value`
: A pointer to an output buffer.

`value_size`
: A pointer to an integer. The integer is used both for passing input and output sizes (see below).

When this function is called, `*value_size` is to contain the size of the `value` buffer.

On success, `0` is returned, the value of the environment variable has been written to the `value` buffer, and `*value_size` contains the string length (excluding the terminating `NULL` character) of the value written to the `value` buffer.

On failure, that is, no such environment variable was found, a value < `0` is returned. When the size of the `value` buffer is too small, a value > `0` is returned and `*value_size` has been set to the buffer size needed.

> **Warning:**
>
> Do **not** use libc's `getenv` or similar C library interfaces from a driver.

This function is thread-safe.

`void erl_drv_init_ack(ErlDrvPort port, ErlDrvData res)`

Acknowledges the start of the port.

`port`
: The port handle of the port (driver instance) doing the acknowledgment.

`res`
: The result of the port initialization. Can be the same values as the return value of *`start`*, that is, any of the error codes or the `ErlDrvData` that is to be used for this port.

When this function is called the initiating `erlang:open_port` call is returned as if the *`start`* function had just been called. It can only be used when flag *`ERL_DRV_FLAG_USE_INIT_ACK`* has been set on the linked-in driver.

`ErlDrvTime erl_drv_monotonic_time(ErlDrvTimeUnit time_unit)`

Returns *Erlang monotonic time*. Notice that negative values are not uncommon.

`time_unit` is time unit of returned value.

Returns `ERL_DRV_TIME_ERROR` if called with an invalid time unit argument, or if called from a thread that is not a scheduler thread.

See also *`ErlDrvTime`* and *`ErlDrvTimeUnit`*.

`ErlDrvMutex *erl_drv_mutex_create(char *name)`

Creates a mutex and returns a pointer to it.

`name` is a string identifying the created mutex. It is used to identify the mutex in planned future debug functionality.

Returns `NULL` on failure. The driver creating the mutex is responsible for destroying it before the driver is unloaded.

This function is thread-safe.

`void erl_drv_mutex_destroy(ErlDrvMutex *mtx)`

Destroys a mutex previously created by *`erl_drv_mutex_create`*. The mutex must be in an unlocked state before it is destroyed.

`mtx` is a pointer to a mutex to destroy.

This function is thread-safe.

`void erl_drv_mutex_lock(ErlDrvMutex *mtx)`

Locks a mutex. The calling thread is blocked until the mutex has been locked. A thread that has currently locked the mutex **cannot** lock the same mutex again.

`mtx` is a pointer to a mutex to lock.

> **Warning:**
>
> If you leave a mutex locked in an emulator thread when you let the thread out of your control, you will **very likely** deadlock the whole emulator.

This function is thread-safe.

`char *erl_drv_mutex_name(ErlDrvMutex *mtx)`

Returns a pointer to the mutex name.

`mtx` is a pointer to an initialized mutex.

> **Note:**
>
> This function is intended for debugging purposes only.

`int erl_drv_mutex_trylock(ErlDrvMutex *mtx)`

Tries to lock a mutex. A thread that has currently locked the mutex **cannot** try to lock the same mutex again.

`mtx` is a pointer to a mutex to try to lock.

Returns `0` on success, otherwise `EBUSY`.

> **Warning:**
>
> If you leave a mutex locked in an emulator thread when you let the thread out of your control, you will **very likely** deadlock the whole emulator.

This function is thread-safe.

`void erl_drv_mutex_unlock(ErlDrvMutex *mtx)`

Unlocks a mutex. The mutex currently must be locked by the calling thread.

`mtx` is a pointer to a mutex to unlock.

This function is thread-safe.

`int erl_drv_output_term(ErlDrvTermData port, ErlDrvTermData* term, int n)`

Sends data in the special driver term format to the port owner process. This is a fast way to deliver term data from a driver. It needs no binary conversion, so the port owner process receives data as normal Erlang terms. The *`erl_drv_send_term`* functions can be used for sending to any process on the local node.

Note:

Parameter `port` is **not** an ordinary port handle, but a port handle converted using *`driver_mk_port`*.

Parameter `term` points to an array of `ErlDrvTermData` with `n` elements. This array contains terms described in the driver term format. Every term consists of 1-4 elements in the array. The first term has a term type and then arguments. Parameter `port` specifies the sending port.

Tuples, maps, and lists (except strings, see below) are built in reverse polish notation, so that to build a tuple, the elements are specified first, and then the tuple term, with a count. Likewise for lists and maps.

- A tuple must be specified with the number of elements. (The elements precede the `ERL_DRV_TUPLE` term.)
- A map must be specified with the number of key-value pairs `N`. The key-value pairs must precede the `ERL_DRV_MAP` in this order: `key1,value1,key2,value2,...,keyN,valueN`. Duplicate keys are not allowed.
- A list must be specified with the number of elements, including the tail, which is the last term preceding `ERL_DRV_LIST`.

The special term `ERL_DRV_STRING_CONS` is used to "splice" in a string in a list, a string specified this way is not a list in itself, but the elements are elements of the surrounding list.

```
Term type            Arguments
---------            ---------
ERL_DRV_NIL
ERL_DRV_ATOM         ErlDrvTermData atom (from driver_mk_atom(char *string))
ERL_DRV_INT          ErlDrvSInt integer
ERL_DRV_UINT         ErlDrvUInt integer
ERL_DRV_INT64        ErlDrvSInt64 *integer_ptr
ERL_DRV_UINT64       ErlDrvUInt64 *integer_ptr
ERL_DRV_PORT         ErlDrvTermData port (from driver_mk_port(ErlDrvPort port))
ERL_DRV_BINARY       ErlDrvBinary *bin, ErlDrvUInt len, ErlDrvUInt offset
ERL_DRV_BUF2BINARY   char *buf, ErlDrvUInt len
ERL_DRV_STRING       char *str, int len
ERL_DRV_TUPLE        int sz
ERL_DRV_LIST         int sz
ERL_DRV_PID          ErlDrvTermData pid (from driver_connected(ErlDrvPort port)
                     or driver_caller(ErlDrvPort port))
ERL_DRV_STRING_CONS  char *str, int len
ERL_DRV_FLOAT        double *dbl
ERL_DRV_EXT2TERM     char *buf, ErlDrvUInt len
ERL_DRV_MAP          int sz
```

The unsigned integer data type `ErlDrvUInt` and the signed integer data type `ErlDrvSInt` are 64 bits wide on a 64-bit runtime system and 32 bits wide on a 32-bit runtime system. They were introduced in ERTS 5.6 and replaced some of the `int` arguments in the list above.

The unsigned integer data type `ErlDrvUInt64` and the signed integer data type `ErlDrvSInt64` are always 64 bits wide. They were introduced in ERTS 5.7.4.

To build the tuple `{tcp, Port, [100 | Binary]}`, the following call can be made.

```
ErlDrvBinary* bin = ...
ErlDrvPort port = ...
ErlDrvTermData spec[] = {
    ERL_DRV_ATOM, driver_mk_atom("tcp"),
    ERL_DRV_PORT, driver_mk_port(drvport),
        ERL_DRV_INT, 100,
        ERL_DRV_BINARY, bin, 50, 0,
        ERL_DRV_LIST, 2,
    ERL_DRV_TUPLE, 3,
};
erl_drv_output_term(driver_mk_port(drvport), spec, sizeof(spec) / sizeof(spec[0]));
```

Here `bin` is a driver binary of length at least 50 and `drvport` is a port handle. Notice that `ERL_DRV_LIST` comes after the elements of the list, likewise `ERL_DRV_TUPLE`.

The `ERL_DRV_STRING_CONS` term is a way to construct strings. It works differently from how `ERL_DRV_STRING` works. `ERL_DRV_STRING_CONS` builds a string list in reverse order (as opposed to how `ERL_DRV_LIST` works), concatenating the strings added to a list. The tail must be specified before `ERL_DRV_STRING_CONS`.

`ERL_DRV_STRING` constructs a string, and ends it. (So it is the same as `ERL_DRV_NIL` followed by `ERL_DRV_STRING_CONS`.)

```
/* to send [x, "abc", y] to the port: */
ErlDrvTermData spec[] = {
    ERL_DRV_ATOM, driver_mk_atom("x"),
    ERL_DRV_STRING, (ErlDrvTermData)"abc", 3,
    ERL_DRV_ATOM, driver_mk_atom("y"),
    ERL_DRV_NIL,
    ERL_DRV_LIST, 4
};
erl_drv_output_term(driver_mk_port(drvport), spec, sizeof(spec) / sizeof(spec[0]));
```

```
/* to send "abc123" to the port: */
ErlDrvTermData spec[] = {
    ERL_DRV_NIL,        /* with STRING_CONS, the tail comes first */
    ERL_DRV_STRING_CONS, (ErlDrvTermData)"123", 3,
    ERL_DRV_STRING_CONS, (ErlDrvTermData)"abc", 3,
};
erl_drv_output_term(driver_mk_port(drvport), spec, sizeof(spec) / sizeof(spec[0]));
```

The `ERL_DRV_EXT2TERM` term type is used for passing a term encoded with the *external format*, that is, a term that has been encoded by *`erlang:term_to_binary`*, *`erl_interface:ei(3)`*, and so on. For example, if `binp` is a pointer to an `ErlDrvBinary` that contains term `{17, 4711}` encoded with the *external format*, and you want to wrap it in a two-tuple with the tag `my_tag`, that is, `{my_tag, {17, 4711}}`, you can do as follows:

```
ErlDrvTermData spec[] = {
        ERL_DRV_ATOM, driver_mk_atom("my_tag"),
        ERL_DRV_EXT2TERM, (ErlDrvTermData) binp->orig_bytes, binp->orig_size
    ERL_DRV_TUPLE, 2,
};
erl_drv_output_term(driver_mk_port(drvport), spec, sizeof(spec) / sizeof(spec[0]));
```

To build the map `#{key1 => 100, key2 => {200, 300}}`, the following call can be made.

```
ErlDrvPort port = ...
ErlDrvTermData spec[] = {
    ERL_DRV_ATOM, driver_mk_atom("key1"),
        ERL_DRV_INT, 100,
    ERL_DRV_ATOM, driver_mk_atom("key2"),
        ERL_DRV_INT, 200,
        ERL_DRV_INT, 300,
    ERL_DRV_TUPLE, 2,
    ERL_DRV_MAP, 2
};
erl_drv_output_term(driver_mk_port(drvport), spec, sizeof(spec) / sizeof(spec[0]));
```

If you want to pass a binary and do not already have the content of the binary in an `ErlDrvBinary`, you can benefit from using `ERL_DRV_BUF2BINARY` instead of creating an `ErlDrvBinary` through *`driver_alloc_binary`* and then pass the binary through `ERL_DRV_BINARY`. The runtime system often allocates binaries smarter if `ERL_DRV_BUF2BINARY` is used. However, if the content of the binary to pass already resides in an `ErlDrvBinary`, it is normally better to pass the binary using `ERL_DRV_BINARY` and the `ErlDrvBinary` in question.

The `ERL_DRV_UINT`, `ERL_DRV_BUF2BINARY`, and `ERL_DRV_EXT2TERM` term types were introduced in ERTS 5.6.

This function is only thread-safe when the emulator with SMP support is used.

`int erl_drv_putenv(const char *key, char *value)`

Sets the value of an environment variable.

`key` is a `NULL`-terminated string containing the name of the environment variable.

`value` is a `NULL`-terminated string containing the new value of the environment variable.

Returns `0` on success, otherwise a value `!= 0`.

Note:

The result of passing the empty string (`""`) as a value is platform-dependent. On some platforms the variable value is set to the empty string, on others the environment variable is removed.

Warning:

Do **not** use libc's `putenv` or similar C library interfaces from a driver.

This function is thread-safe.

`ErlDrvRWLock *erl_drv_rwlock_create(char *name)`

Creates an rwlock and returns a pointer to it.

`name` is a string identifying the created rwlock. It is used to identify the rwlock in planned future debug functionality.

Returns `NULL` on failure. The driver creating the rwlock is responsible for destroying it before the driver is unloaded.

This function is thread-safe.

`void erl_drv_rwlock_destroy(ErlDrvRWLock *rwlck)`

Destroys an rwlock previously created by *`erl_drv_rwlock_create`*. The rwlock must be in an unlocked state before it is destroyed.

`rwlck` is a pointer to an rwlock to destroy.

This function is thread-safe.

`char *erl_drv_rwlock_name(ErlDrvRWLock *rwlck)`

Returns a pointer to the name of the rwlock.

`rwlck` is a pointer to an initialized rwlock.

> **Note:**
>
> This function is intended for debugging purposes only.

`void erl_drv_rwlock_rlock(ErlDrvRWLock *rwlck)`

Read locks an rwlock. The calling thread is blocked until the rwlock has been read locked. A thread that currently has read or read/write locked the rwlock **cannot** lock the same rwlock again.

`rwlck` is a pointer to the rwlock to read lock.

> **Warning:**
>
> If you leave an rwlock locked in an emulator thread when you let the thread out of your control, you will **very likely** deadlock the whole emulator.

This function is thread-safe.

`void erl_drv_rwlock_runlock(ErlDrvRWLock *rwlck)`

Read unlocks an rwlock. The rwlock currently must be read locked by the calling thread.

`rwlck` is a pointer to an rwlock to read unlock.

This function is thread-safe.

`void erl_drv_rwlock_rwlock(ErlDrvRWLock *rwlck)`

Read/write locks an rwlock. The calling thread is blocked until the rwlock has been read/write locked. A thread that currently has read or read/write locked the rwlock **cannot** lock the same rwlock again.

`rwlck` is a pointer to an rwlock to read/write lock.

> **Warning:**
>
> If you leave an rwlock locked in an emulator thread when you let the thread out of your control, you will **very likely** deadlock the whole emulator.

This function is thread-safe.

`void erl_drv_rwlock_rwunlock(ErlDrvRWLock *rwlck)`

Read/write unlocks an rwlock. The rwlock currently must be read/write locked by the calling thread.

`rwlck` is a pointer to an rwlock to read/write unlock.

This function is thread-safe.

`int erl_drv_rwlock_tryrlock(ErlDrvRWLock *rwlck)`

Tries to read lock an rwlock.

`rwlck` is a pointer to an rwlock to try to read lock.

Returns `0` on success, otherwise `EBUSY`. A thread that currently has read or read/write locked the rwlock **cannot** try to lock the same rwlock again.

> **Warning:**
>
> If you leave an rwlock locked in an emulator thread when you let the thread out of your control, you will **very likely** deadlock the whole emulator.

This function is thread-safe.

`int erl_drv_rwlock_tryrwlock(ErlDrvRWLock *rwlck)`

Tries to read/write lock an rwlock. A thread that currently has read or read/write locked the rwlock **cannot** try to lock the same rwlock again.

`rwlck`is pointer to an rwlock to try to read/write lock.

Returns `0` on success, otherwise `EBUSY`.

> **Warning:**
>
> If you leave an rwlock locked in an emulator thread when you let the thread out of your control, you will **very likely** deadlock the whole emulator.

This function is thread-safe.

`int erl_drv_send_term(ErlDrvTermData port, ErlDrvTermData receiver, ErlDrvTermData* term, int n)`

This function is the only way for a driver to send data to **other** processes than the port owner process. Parameter `receiver` specifies the process to receive the data.

> **Note:**
>
> Parameter `port` is **not** an ordinary port handle, but a port handle converted using *`driver_mk_port`*.

Parameters `port`, `term`, and `n` work as in *`erl_drv_output_term`*.

This function is only thread-safe when the emulator with SMP support is used.

`void erl_drv_set_os_pid(ErlDrvPort port, ErlDrvSInt pid)`

Sets the `os_pid` seen when doing *`erlang:port_info/2`* on this port.

`port` is the port handle of the port (driver instance) to set the pid on. `pid`is the pid to set.

`int erl_drv_thread_create(char *name, ErlDrvTid *tid, void * (*func)(void *), void *arg, ErlDrvThreadOpts *opts)`

Creates a new thread.

`name`
: A string identifying the created thread. It is used to identify the thread in planned future debug functionality.

`tid`
: A pointer to a thread identifier variable.

`func`
: A pointer to a function to execute in the created thread.

`arg`
: A pointer to argument to the `func` function.

`opts`
: A pointer to thread options to use or `NULL`.

Returns `0` on success, otherwise an `errno` value is returned to indicate the error. The newly created thread begins executing in the function pointed to by `func`, and `func` is passed `arg` as argument. When `erl_drv_thread_create` returns, the thread identifier of the newly created thread is available in `*tid`. `opts` can be either a `NULL` pointer, or a pointer to an *`ErlDrvThreadOpts`* structure. If `opts` is a `NULL` pointer, default options are used, otherwise the passed options are used.

Warning:

You are not allowed to allocate the *`ErlDrvThreadOpts`* structure by yourself. It must be allocated and initialized by *`erl_drv_thread_opts_create`*.

The created thread terminates either when `func` returns or if *`erl_drv_thread_exit`* is called by the thread. The exit value of the thread is either returned from `func` or passed as argument to *`erl_drv_thread_exit`*. The driver creating the thread is responsible for joining the thread, through *`erl_drv_thread_join`*, before the driver is unloaded. "Detached" threads cannot be created, that is, threads that do not need to be joined.

Warning:

All created threads must be joined by the driver before it is unloaded. If the driver fails to join all threads created before it is unloaded, the runtime system most likely crashes when the driver code is unloaded.

This function is thread-safe.

`void erl_drv_thread_exit(void *exit_value)`

Terminates the calling thread with the exit value passed as argument. `exit_value` is a pointer to an exit value or `NULL`.

You are only allowed to terminate threads created with *`erl_drv_thread_create`*.

The exit value can later be retrieved by another thread through *`erl_drv_thread_join`*.

This function is thread-safe.

`int erl_drv_thread_join(ErlDrvTid tid, void **exit_value)`

Joins the calling thread with another thread, that is, the calling thread is blocked until the thread identified by `tid` has terminated.

`tid` is the thread identifier of the thread to join. `exit_value` is a pointer to a pointer to an exit value, or `NULL`.

Returns `0` on success, otherwise an `errno` value is returned to indicate the error.

A thread can only be joined once. The behavior of joining more than once is undefined, an emulator crash is likely. If `exit_value == NULL`, the exit value of the terminated thread is ignored, otherwise the exit value of the terminated thread is stored at `*exit_value`.

This function is thread-safe.

`char *erl_drv_thread_name(ErlDrvTid tid)`

Returns a pointer to the name of the thread.

`tid` is a thread identifier.

Note:

This function is intended for debugging purposes only.

`ErlDrvThreadOpts *erl_drv_thread_opts_create(char *name)`

Allocates and initializes a thread option structure.

`name` is a string identifying the created thread options. It is used to identify the thread options in planned future debug functionality.

Returns `NULL` on failure. A thread option structure is used for passing options to *`erl_drv_thread_create`*. If the structure is not modified before it is passed to *`erl_drv_thread_create`*, the default values are used.

Warning:

You are not allowed to allocate the *`ErlDrvThreadOpts`* structure by yourself. It must be allocated and initialized by `erl_drv_thread_opts_create`.

This function is thread-safe.

`void erl_drv_thread_opts_destroy(ErlDrvThreadOpts *opts)`

Destroys thread options previously created by *`erl_drv_thread_opts_create`*.

`opts` is a pointer to thread options to destroy.

This function is thread-safe.

`ErlDrvTid erl_drv_thread_self(void)`

Returns the thread identifier of the calling thread.

This function is thread-safe.

`ErlDrvTime erl_drv_time_offset(ErlDrvTimeUnit time_unit)`

Returns the current time offset between *Erlang monotonic time* and *Erlang system time* converted into the `time_unit` passed as argument.

`time_unit` is time unit of returned value.

Returns `ERL_DRV_TIME_ERROR` if called with an invalid time unit argument, or if called from a thread that is not a scheduler thread.

See also *`ErlDrvTime`* and *`ErlDrvTimeUnit`*.

`void *erl_drv_tsd_get(ErlDrvTSDKey key)`

Returns the thread-specific data associated with `key` for the calling thread.

`key` is a thread-specific data key.

Returns `NULL` if no data has been associated with `key` for the calling thread.

This function is thread-safe.

`int erl_drv_tsd_key_create(char *name, ErlDrvTSDKey *key)`

Creates a thread-specific data key.

`name` is a string identifying the created key. It is used to identify the key in planned future debug functionality.

`key` is a pointer to a thread-specific data key variable.

Returns `0` on success, otherwise an `errno` value is returned to indicate the error. The driver creating the key is responsible for destroying it before the driver is unloaded.

This function is thread-safe.

`void erl_drv_tsd_key_destroy(ErlDrvTSDKey key)`

Destroys a thread-specific data key previously created by *`erl_drv_tsd_key_create`*. All thread-specific data using this key in all threads must be cleared (see *`erl_drv_tsd_set`*) before the call to `erl_drv_tsd_key_destroy`.

`key` is a thread-specific data key to destroy.

> **Warning:**
>
> A destroyed key is very likely to be reused soon. Therefore, if you fail to clear the thread-specific data using this key in a thread before destroying the key, you will **very likely** get unexpected errors in other parts of the system.

This function is thread-safe.

`void erl_drv_tsd_set(ErlDrvTSDKey key, void *data)`

Sets thread-specific data associated with `key` for the calling thread. You are only allowed to set thread-specific data for threads while they are fully under your control. For example, if you set thread-specific data in a thread calling a driver callback function, it must be cleared, that is, set to `NULL`, before returning from the driver callback function.

`key` is a thread-specific data key.

`data` is a pointer to data to associate with `key` in the calling thread.

> **Warning:**
>
> If you fail to clear thread-specific data in an emulator thread before letting it out of your control, you might never be able to clear this data with later unexpected errors in other parts of the system as a result.

This function is thread-safe.

`char *erl_errno_id(int error)`

Returns the atom name of the Erlang error, given the error number in `error`. The error atoms are `einval`, `enoent`, and so on. It can be used to make error terms from the driver.

`int remove_driver_entry(ErlDrvEntry *de)`

Removes a driver entry `de` previously added with *`add_driver_entry`*.

Driver entries added by the `erl_ddll` Erlang interface cannot be removed by using this interface.

`void set_busy_port(ErlDrvPort port, int on)`

Sets and unsets the busy state of the port. If `on` is non-zero, the port is set to busy. If it is zero, the port is set to not busy. You typically want to combine this feature with the *busy port message queue* functionality.

Processes sending command data to the port are suspended if either the port or the port message queue is busy. Suspended processes are resumed when neither the port or the port message queue is busy. Command data is in this context data passed to the port using either `Port ! {Owner, {command, Data}}` or `port_command/[2,3]`.

If the *ERL_DRV_FLAG_SOFT_BUSY* has been set in the *`driver_entry`*, data can be forced into the driver through *`erlang:port_command(Port, Data, [force])`* even if the driver has signaled that it is busy.

For information about busy port message queue functionality, see *`erl_drv_busy_msgq_limits`*.

`void set_port_control_flags(ErlDrvPort port, int flags)`

Sets flags for how the *`control`* driver entry function will return data to the port owner process. (The `control` function is called from *`erlang:port_control/3`*.)

Currently there are only two meaningful values for `flags`: `0` means that data is returned in a list, and `PORT_CONTROL_FLAG_BINARY` means data is returned as a binary from `control`.

See Also

`driver_entry(3)`, *`erlang(3)`*, *`erl_ddll(3)`*, section *How to Implement an Alternative Carrier for the Erlang Distribution*> in the User's Guide

driver_entry

C Library

Warning:

Use this functionality with extreme care.

A driver callback is executed as a direct extension of the native code of the VM. Execution is not made in a safe environment. The VM **cannot** provide the same services as provided when executing Erlang code, such as pre-emptive scheduling or memory protection. If the driver callback function does not behave well, the whole VM will misbehave.

- A driver callback that crash will crash the whole VM.
- An erroneously implemented driver callback can cause a VM internal state inconsistency, which can cause a crash of the VM, or miscellaneous misbehaviors of the VM at any point after the call to the driver callback.
- A driver callback doing *lengthy work* before returning degrades responsiveness of the VM, and can cause miscellaneous strange behaviors. Such strange behaviors include, but are not limited to, extreme memory usage, and bad load balancing between schedulers. Strange behaviors that can occur because of lengthy work can also vary between Erlang/OTP releases.

As from ERTS 5.9 (Erlang/OTP R15B) the driver interface has been changed with larger types for the callbacks `output`, `control`, and `call`. See driver *version management* in `erl_driver`.

Note:

Old drivers (compiled with an `erl_driver.h` from an ERTS version earlier than 5.9) must be updated and have to use the extended interface (with *version management*).

The `driver_entry` structure is a C struct that all Erlang drivers define. It contains entry points for the Erlang driver, which are called by the Erlang emulator when Erlang code accesses the driver.

The `erl_driver` driver API functions need a port handle that identifies the driver instance (and the port in the emulator). This is only passed to the `start` function, but not to the other functions. The `start` function returns a driver-defined handle that is passed to the other functions. A common practice is to have the `start` function allocate some application-defined structure and stash the `port` handle in it, to use it later with the driver API functions.

The driver callback functions are called synchronously from the Erlang emulator. If they take too long before completing, they can cause time-outs in the emulator. Use the queue or asynchronous calls if necessary, as the emulator must be responsive.

The driver structure contains the driver name and some 15 function pointers, which are called at different times by the emulator.

The only exported function from the driver is `driver_init`. This function returns the `driver_entry` structure that points to the other functions in the driver. The `driver_init` function is declared with a macro, `DRIVER_INIT(drivername)`. (This is because different operating systems have different names for it.)

When writing a driver in C++, the driver entry is to be of `"C"` linkage. One way to do this is to put the following line somewhere before the driver entry:

```
extern "C" DRIVER_INIT(drivername);
```

When the driver has passed the `driver_entry` over to the emulator, the driver is **not** allowed to modify the `driver_entry`.

If compiling a driver for static inclusion through `--enable-static-drivers`, you must define `STATIC_ERLANG_DRIVER` before the `DRIVER_INIT` declaration.

> **Note:**
>
> Do **not** declare the `driver_entry const`. This because the emulator must modify the `handle` and the `handle2` fields. A statically allocated, and `const`-declared `driver_entry` can be located in read-only memory, which causes the emulator to crash.

Data Types

`ErlDrvEntry`

```
typedef struct erl_drv_entry {
    int (*init)(void);          /* Called at system startup for statically
                                   linked drivers, and after loading for
                                   dynamically loaded drivers */
#ifndef ERL_SYS_DRV
    ErlDrvData (*start)(ErlDrvPort port, char *command);
                                /* Called when open_port/2 is invoked,
                                   return value -1 means failure */
#else
    ErlDrvData (*start)(ErlDrvPort port, char *command, SysDriverOpts* opts);
                                /* Special options, only for system driver */
#endif
    void (*stop)(ErlDrvData drv_data);
                                /* Called when port is closed, and when the
                                   emulator is halted */
    void (*output)(ErlDrvData drv_data, char *buf, ErlDrvSizeT len);
                                /* Called when we have output from Erlang to
                                   the port */
    void (*ready_input)(ErlDrvData drv_data, ErlDrvEvent event);
                                /* Called when we have input from one of
                                   the driver's handles */
    void (*ready_output)(ErlDrvData drv_data, ErlDrvEvent event);
                                /* Called when output is possible to one of
                                   the driver's handles */
    char *driver_name;          /* Name supplied as command in
                                   erlang:open_port/2 */
    void (*finish)(void);       /* Called before unloading the driver -
                                   dynamic drivers only */
    void *handle;               /* Reserved, used by emulator internally */
    ErlDrvSSizeT (*control)(ErlDrvData drv_data, unsigned int command,
                            char *buf, ErlDrvSizeT len,
       char **rbuf, ErlDrvSizeT rlen);
                                /* "ioctl" for drivers - invoked by
                                   port_control/3 */
    void (*timeout)(ErlDrvData drv_data);
                                /* Handling of time-out in driver */
    void (*outputv)(ErlDrvData drv_data, ErlIOVec *ev);
                                /* Called when we have output from Erlang
                                   to the port */
    void (*ready_async)(ErlDrvData drv_data, ErlDrvThreadData thread_data);
    void (*flush)(ErlDrvData drv_data);
                                /* Called when the port is about to be
                                   closed, and there is data in the
                                   driver queue that must be flushed
                                   before 'stop' can be called */
    ErlDrvSSizeT (*call)(ErlDrvData drv_data, unsigned int command,
                         char *buf, ErlDrvSizeT len,
    char **rbuf, ErlDrvSizeT rlen, unsigned int *flags);
                                /* Works mostly like 'control', a synchronous
                                   call into the driver */
    void (*event)(ErlDrvData drv_data, ErlDrvEvent event,
                  ErlDrvEventData event_data);
                                /* Called when an event selected by
                                   driver_event() has occurred */
    int extended_marker;        /* ERL_DRV_EXTENDED_MARKER */
    int major_version;          /* ERL_DRV_EXTENDED_MAJOR_VERSION */
    int minor_version;          /* ERL_DRV_EXTENDED_MINOR_VERSION */
    int driver_flags;           /* ERL_DRV_FLAGs */
    void *handle2;              /* Reserved, used by emulator internally */
    void (*process_exit)(ErlDrvData drv_data, ErlDrvMonitor *monitor);
                                /* Called when a process monitor fires */
    void (*stop_select)(ErlDrvEvent event, void* reserved);
                                /* Called to close an event object */
 } ErlDrvEntry;
```

`int (*init)(void)`

Called directly after the driver has been loaded by *`erl_ddll:load_driver/2`* (actually when the driver is added to the driver list). The driver is to return `0`, or, if the driver cannot initialize, `-1`.

`ErlDrvData (*start)(ErlDrvPort port, char* command)`

Called when the driver is instantiated, when *`erlang:open_port/2`* is called. The driver is to return a number >= 0 or a pointer, or, if the driver cannot be started, one of three error codes:

`ERL_DRV_ERROR_GENERAL`
: General error, no error code

`ERL_DRV_ERROR_ERRNO`
: Error with error code in `errno`

`ERL_DRV_ERROR_BADARG`
: Error, `badarg`

If an error code is returned, the port is not started.

`void (*stop)(ErlDrvData drv_data)`

Called when the port is closed, with *`erlang:port_close/1`* or `Port ! {self(), close}`. Notice that terminating the port owner process also closes the port. If `drv_data` is a pointer to memory allocated in `start`, then `stop` is the place to deallocate that memory.

`void (*output)(ErlDrvData drv_data, char *buf, ErlDrvSizeT len)`

Called when an Erlang process has sent data to the port. The data is pointed to by `buf`, and is `len` bytes. Data is sent to the port with `Port ! {self(), {command, Data}}` or with `erlang:port_command/2`. Depending on how the port was opened, it is to be either a list of integers `0...255` or a binary. See *`erlang:open_port/2`* and *`erlang:port_command/2`*.

```
void (*ready_input)(ErlDrvData drv_data, ErlDrvEvent event)
void (*ready_output)(ErlDrvData drv_data, ErlDrvEvent event)
```

Called when a driver event (specified in parameter `event`) is signaled. This is used to help asynchronous drivers "wake up" when something occurs.

On Unix the `event` is a pipe or socket handle (or something that the `select` system call understands).

On Windows the `event` is an `Event` or `Semaphore` (or something that the `WaitForMultipleObjects` API function understands). (Some trickery in the emulator allows more than the built-in limit of 64 `Events` to be used.)

To use this with threads and asynchronous routines, create a pipe on Unix and an `Event` on Windows. When the routine completes, write to the pipe (use `SetEvent` on Windows), this makes the emulator call `ready_input` or `ready_output`.

False events can occur. That is, calls to `ready_input` or `ready_output` although no real events are signaled. In reality, it is rare (and OS-dependant), but a robust driver must nevertheless be able to handle such cases.

`char *driver_name`

The driver name. It must correspond to the atom used in *`erlang:open_port/2`*, and the name of the driver library file (without the extension).

`void (*finish)(void)`

Called by the `erl_ddll` driver when the driver is unloaded. (It is only called in dynamic drivers.)

The driver is only unloaded as a result of calling *`erl_ddll:unload_driver/1`*, or when the emulator halts.

`void *handle`

This field is reserved for the emulator's internal use. The emulator will modify this field, so it is important that the `driver_entry` is not declared `const`.

`ErlDrvSSizeT (*control)(ErlDrvData drv_data, unsigned int command, char *buf, ErlDrvSizeT len, char **rbuf, ErlDrvSizeT rlen)`

A special routine invoked with *`erlang:port_control/3`*. It works a little like an "ioctl" for Erlang drivers. The data specified to `port_control/3` arrives in `buf` and `len`. The driver can send data back, using `*rbuf` and `rlen`.

This is the fastest way of calling a driver and get a response. It makes no context switch in the Erlang emulator and requires no message passing. It is suitable for calling C function to get faster execution, when Erlang is too slow.

If the driver wants to return data, it is to return it in `rbuf`. When `control` is called, `*rbuf` points to a default buffer of `rlen` bytes, which can be used to return data. Data is returned differently depending on the port control flags (those that are set with *`erl_driver:set_port_control_flags`*).

If the flag is set to `PORT_CONTROL_FLAG_BINARY`, a binary is returned. Small binaries can be returned by writing the raw data into the default buffer. A binary can also be returned by setting `*rbuf` to point to a binary allocated with *`erl_driver:driver_alloc_binary`*. This binary is freed automatically after `control` has returned. The driver can retain the binary for **read only** access with *`erl_driver:driver_binary_inc_refc`* to be freed later with *`erl_driver:driver_free_binary`*. It is never allowed to change the binary after `control` has returned. If `*rbuf` is set to `NULL`, an empty list is returned.

If the flag is set to `0`, data is returned as a list of integers. Either use the default buffer or set `*rbuf` to point to a larger buffer allocated with *`erl_driver:driver_alloc`*. The buffer is freed automatically after `control` has returned.

Using binaries is faster if more than a few bytes are returned.

The return value is the number of bytes returned in `*rbuf`.

`void (*timeout)(ErlDrvData drv_data)`

Called any time after the driver's timer reaches `0`. The timer is activated with *`erl_driver:driver_set_timer`*. No priorities or ordering exist among drivers, so if several drivers time out at the same time, anyone of them is called first.

`void (*outputv)(ErlDrvData drv_data, ErlIOVec *ev)`

Called whenever the port is written to. If it is `NULL`, the `output` function is called instead. This function is faster than `output`, as it takes an `ErlIOVec` directly, which requires no copying of the data. The port is to be in binary mode, see *`erlang:open_port/2`*.

`ErlIOVec` contains both a `SysIOVec`, suitable for `writev`, and one or more binaries. If these binaries are to be retained when the driver returns from `outputv`, they can be queued (using, for example, *`erl_driver:driver_enq_bin`*) or, if they are kept in a static or global variable, the reference counter can be incremented.

`void (*ready_async)(ErlDrvData drv_data, ErlDrvThreadData thread_data)`

Called after an asynchronous call has completed. The asynchronous call is started with *`erl_driver:driver_async`*. This function is called from the Erlang emulator thread, as opposed to the asynchronous function, which is called in some thread (if multi-threading is enabled).

`void (*flush)(ErlDrvData drv_data)`

Called when the port is about to be closed, and there is data in the driver queue that must be flushed before 'stop' can be called.

`ErlDrvSSizeT (*call)(ErlDrvData drv_data, unsigned int command, char *buf, ErlDrvSizeT len, char **rbuf, ErlDrvSizeT rlen, unsigned int *flags)`

Called from *erlang:port_call/3*. It works a lot like the `control` callback, but uses the external term format for input and output.

`command` is an integer, obtained from the call from Erlang (the second argument to `erlang:port_call/3`).

`buf` and `len` provide the arguments to the call (the third argument to `erlang:port_call/3`). They can be decoded using `ei` functions.

`rbuf` points to a return buffer, `rlen` bytes long. The return data is to be a valid Erlang term in the external (binary) format. This is converted to an Erlang term and returned by `erlang:port_call/3` to the caller. If more space than `rlen` bytes is needed to return data, `*rbuf` can be set to memory allocated with *erl_driver:driver_alloc*. This memory is freed automatically after `call` has returned.

The return value is the number of bytes returned in `*rbuf`. If `ERL_DRV_ERROR_GENERAL` is returned (or in fact, anything < 0), `erlang:port_call/3` throws a `BAD_ARG`.

`void (*event)(ErlDrvData drv_data, ErlDrvEvent event, ErlDrvEventData event_data)`

Intentionally left undocumented.

`int extended_marker`

This field is either to be equal to `ERL_DRV_EXTENDED_MARKER` or `0`. An old driver (not aware of the extended driver interface) is to set this field to `0`. If this field is `0`, all the following fields **must** also be `0`, or `NULL` if it is a pointer field.

`int major_version`

This field is to equal `ERL_DRV_EXTENDED_MAJOR_VERSION` if field `extended_marker` equals `ERL_DRV_EXTENDED_MARKER`.

`int minor_version`

This field is to equal `ERL_DRV_EXTENDED_MINOR_VERSION` if field `extended_marker` equals `ERL_DRV_EXTENDED_MARKER`.

`int driver_flags`

This field is used to pass driver capability and other information to the runtime system. If field `extended_marker` equals `ERL_DRV_EXTENDED_MARKER`, it is to contain `0` or driver flags (`ERL_DRV_FLAG_*`) OR'ed bitwise. The following driver flags exist:

`ERL_DRV_FLAG_USE_PORT_LOCKING`

The runtime system uses port-level locking on all ports executing this driver instead of driver-level locking when the driver is run in a runtime system with SMP support. For more information, see *erl_driver*.

`ERL_DRV_FLAG_SOFT_BUSY`

Marks that driver instances can handle being called in the *output* and/or *outputv* callbacks although a driver instance has marked itself as busy (see *erl_driver:set_busy_port*). As from ERTS 5.7.4 this flag is required for drivers used by the Erlang distribution (the behavior has always been required by drivers used by the distribution).

`ERL_DRV_FLAG_NO_BUSY_MSGQ`

Disables busy port message queue functionality. For more information, see *erl_driver:erl_drv_busy_msgq_limits*.

`ERL_DRV_FLAG_USE_INIT_ACK`

When this flag is specified, the linked-in driver must manually acknowledge that the port has been successfully started using *`erl_driver:erl_drv_init_ack()`*. This allows the implementor to make the `erlang:open_port` exit with `badarg` after some initial asynchronous initialization has been done.

`void *handle2`

This field is reserved for the emulator's internal use. The emulator modifies this field, so it is important that the `driver_entry` is not declared `const`.

`void (*process_exit)(ErlDrvData drv_data, ErlDrvMonitor *monitor)`

Called when a monitored process exits. The `drv_data` is the data associated with the port for which the process is monitored (using *`erl_driver:driver_monitor_process`*) and the `monitor` corresponds to the `ErlDrvMonitor` structure filled in when creating the monitor. The driver interface function *`erl_driver:driver_get_monitored_process`* can be used to retrieve the process ID of the exiting process as an `ErlDrvTermData`.

`void (*stop_select)(ErlDrvEvent event, void* reserved)`

Called on behalf of *`erl_driver:driver_select`* when it is safe to close an event object.

A typical implementation on Unix is to do `close((int)event)`.

Argument `reserved` is intended for future use and is to be ignored.

In contrast to most of the other callback functions, `stop_select` is called independent of any port. No `ErlDrvData` argument is passed to the function. No driver lock or port lock is guaranteed to be held. The port that called `driver_select` can even be closed at the time `stop_select` is called. But it can also be the case that `stop_select` is called directly by `erl_driver:driver_select`.

It is not allowed to call any functions in the *driver API* from `stop_select`. This strict limitation is because the volatile context that `stop_select` can be called.

See Also

`erl_driver(3)`, *`erlang(3)`*, *`erl_ddll(3)`*

erts_alloc

C Library

`erts_alloc` is an Erlang runtime system internal memory allocator library. `erts_alloc` provides the Erlang runtime system with a number of memory allocators.

Allocators

The following allocators are present:

`temp_alloc`
: Allocator used for temporary allocations.

`eheap_alloc`
: Allocator used for Erlang heap data, such as Erlang process heaps.

`binary_alloc`
: Allocator used for Erlang binary data.

`ets_alloc`
: Allocator used for `ets` data.

`driver_alloc`
: Allocator used for driver data.

`literal_alloc`
: Allocator used for constant terms in Erlang code.

`sl_alloc`
: Allocator used for memory blocks that are expected to be short-lived.

`ll_alloc`
: Allocator used for memory blocks that are expected to be long-lived, for example, Erlang code.

`fix_alloc`
: A fast allocator used for some frequently used fixed size data types.

`exec_alloc`
: Allocator used by the *`HiPE`* application for native executable code on specific architectures (x86_64).

`std_alloc`
: Allocator used for most memory blocks not allocated through any of the other allocators described above.

`sys_alloc`
: This is normally the default `malloc` implementation used on the specific OS.

`mseg_alloc`
: A memory segment allocator. It is used by other allocators for allocating memory segments and is only available on systems that have the `mmap` system call. Memory segments that are deallocated are kept for a while in a segment cache before they are destroyed. When segments are allocated, cached segments are used if possible instead of creating new segments. This to reduce the number of system calls made.

`sys_alloc` and `literal_alloc` are always enabled and cannot be disabled. `exec_alloc` is only available if it is needed and cannot be disabled. `mseg_alloc` is always enabled if it is available and an allocator that uses it is enabled. All other allocators can be *enabled or disabled*. By default all allocators are enabled. When an allocator is disabled, `sys_alloc` is used instead of the disabled allocator.

The main idea with the `erts_alloc` library is to separate memory blocks that are used differently into different memory areas, to achieve less memory fragmentation. By putting less effort in finding a good fit for memory blocks that are frequently allocated than for those less frequently allocated, a performance gain can be achieved.

The alloc_util Framework

Internally a framework called `alloc_util` is used for implementing allocators. `sys_alloc` and `mseg_alloc` do not use this framework, so the following does **not** apply to them.

An allocator manages multiple areas, called carriers, in which memory blocks are placed. A carrier is either placed in a separate memory segment (allocated through `mseg_alloc`), or in the heap segment (allocated through `sys_alloc`).

- Multiblock carriers are used for storage of several blocks.
- Singleblock carriers are used for storage of one block.
- Blocks that are larger than the value of the singleblock carrier threshold (*`sbct`*) parameter are placed in singleblock carriers.
- Blocks that are smaller than the value of parameter `sbct` are placed in multiblock carriers.

Normally an allocator creates a "main multiblock carrier". Main multiblock carriers are never deallocated. The size of the main multiblock carrier is determined by the value of parameter *`mmbcs`*.

Sizes of multiblock carriers allocated through `mseg_alloc` are decided based on the following parameters:

- The values of the largest multiblock carrier size (*`lmbcs`*)
- The smallest multiblock carrier size (*`smbcs`*)
- The multiblock carrier growth stages (*`mbcgs`*)

If `nc` is the current number of multiblock carriers (the main multiblock carrier excluded) managed by an allocator, the size of the next `mseg_alloc` multiblock carrier allocated by this allocator is roughly `smbcs+nc*(lmbcs-smbcs)/mbcgs` when `nc <= mbcgs`, and `lmbcs` when `nc > mbcgs`. If the value of parameter `sbct` is larger than the value of parameter `lmbcs`, the allocator may have to create multiblock carriers that are larger than the value of parameter `lmbcs`, though. Singleblock carriers allocated through `mseg_alloc` are sized to whole pages.

Sizes of carriers allocated through `sys_alloc` are decided based on the value of the `sys_alloc` carrier size (*`ycs`*) parameter. The size of a carrier is the least number of multiples of the value of parameter `ycs` satisfying the request.

Coalescing of free blocks are always performed immediately. Boundary tags (headers and footers) in free blocks are used, which makes the time complexity for coalescing constant.

The memory allocation strategy used for multiblock carriers by an allocator can be configured using parameter *`as`*. The following strategies are available:

Best fit

Strategy: Find the smallest block satisfying the requested block size.

Implementation: A balanced binary search tree is used. The time complexity is proportional to log N, where N is the number of sizes of free blocks.

Address order best fit

Strategy: Find the smallest block satisfying the requested block size. If multiple blocks are found, choose the one with the lowest address.

Implementation: A balanced binary search tree is used. The time complexity is proportional to log N, where N is the number of free blocks.

Address order first fit

Strategy: Find the block with the lowest address satisfying the requested block size.

Implementation: A balanced binary search tree is used. The time complexity is proportional to log N, where N is the number of free blocks.

Address order first fit carrier best fit

Strategy: Find the **carrier** with the lowest address that can satisfy the requested block size, then find a block within that carrier using the "best fit" strategy.

Implementation: Balanced binary search trees are used. The time complexity is proportional to log N, where N is the number of free blocks.

Address order first fit carrier address order best fit

Strategy: Find the **carrier** with the lowest address that can satisfy the requested block size, then find a block within that carrier using the "address order best fit" strategy.

Implementation: Balanced binary search trees are used. The time complexity is proportional to log N, where N is the number of free blocks.

Good fit

Strategy: Try to find the best fit, but settle for the best fit found during a limited search.

Implementation: The implementation uses segregated free lists with a maximum block search depth (in each list) to find a good fit fast. When the maximum block search depth is small (by default 3), this implementation has a time complexity that is constant. The maximum block search depth can be configured using parameter *mbsd*.

A fit

Strategy: Do not search for a fit, inspect only one free block to see if it satisfies the request. This strategy is only intended to be used for temporary allocations.

Implementation: Inspect the first block in a free-list. If it satisfies the request, it is used, otherwise a new carrier is created. The implementation has a time complexity that is constant.

As from ERTS 5.6.1 the emulator refuses to use this strategy on other allocators than `temp_alloc`. This because it only causes problems for other allocators.

Apart from the ordinary allocators described above, some pre-allocators are used for some specific data types. These pre-allocators pre-allocate a fixed amount of memory for certain data types when the runtime system starts. As long as pre-allocated memory is available, it is used. When no pre-allocated memory is available, memory is allocated in ordinary allocators. These pre-allocators are typically much faster than the ordinary allocators, but can only satisfy a limited number of requests.

System Flags Effecting erts_alloc

Warning:

Only use these flags if you are sure what you are doing. Unsuitable settings can cause serious performance degradation and even a system crash at any time during operation.

Memory allocator system flags have the following syntax: `+M<S><P> <V>`, where `<S>` is a letter identifying a subsystem, `<P>` is a parameter, and `<V>` is the value to use. The flags can be passed to the Erlang emulator (*erl(1)*) as command-line arguments.

System flags effecting specific allocators have an uppercase letter as `<S>`. The following letters are used for the allocators:

- `B: binary_alloc`
- `D: std_alloc`
- `E: ets_alloc`
- `F: fix_alloc`
- `H: eheap_alloc`

- `I: literal_alloc`
- `L: ll_alloc`
- `M: mseg_alloc`
- `R: driver_alloc`
- `S: sl_alloc`
- `T: temp_alloc`
- `X: exec_alloc`
- `Y: sys_alloc`

Flags for Configuration of mseg_alloc

`+MMamcbf <size>`

Absolute maximum cache bad fit (in kilobytes). A segment in the memory segment cache is not reused if its size exceeds the requested size with more than the value of this parameter. Defaults to `4096`.

`+MMrmcbf <ratio>`

Relative maximum cache bad fit (in percent). A segment in the memory segment cache is not reused if its size exceeds the requested size with more than relative maximum cache bad fit percent of the requested size. Defaults to `20`.

`+MMsco true|false`

Sets *super carrier* only flag. Defaults to `true`. When a super carrier is used and this flag is `true`, `mseg_alloc` only creates carriers in the super carrier. Notice that the `alloc_util` framework can create `sys_alloc` carriers, so if you want all carriers to be created in the super carrier, you therefore want to disable use of `sys_alloc` carriers by also passing *`+Musac false`*. When the flag is `false`, `mseg_alloc` tries to create carriers outside of the super carrier when the super carrier is full.

> **Note:**
>
> Setting this flag to `false` is not supported on all systems. The flag is then ignored.

`+MMscrfsd <amount>`

Sets *super carrier* reserved free segment descriptors. Defaults to `65536`. This parameter determines the amount of memory to reserve for free segment descriptors used by the super carrier. If the system runs out of reserved memory for free segment descriptors, other memory is used. This can however cause fragmentation issues, so you want to ensure that this never happens. The maximum amount of free segment descriptors used can be retrieved from the `erts_mmap` tuple part of the result from calling *`erlang:system_info({allocator, mseg_alloc})`*.

`+MMscrpm true|false`

Sets *super carrier* reserve physical memory flag. Defaults to `true`. When this flag is `true`, physical memory is reserved for the whole super carrier at once when it is created. The reservation is after that left unchanged. When this flag is set to `false`, only virtual address space is reserved for the super carrier upon creation. The system attempts to reserve physical memory upon carrier creations in the super carrier, and attempt to unreserve physical memory upon carrier destructions in the super carrier.

> **Note:**
>
> What reservation of physical memory means, highly depends on the operating system, and how it is configured. For example, different memory overcommit settings on Linux drastically change the behavior.
>
> Setting this flag to `false` is possibly not supported on all systems. The flag is then ignored.

`+MMscs <size in MB>`

Sets super carrier size (in MB). Defaults to `0`, that is, the super carrier is by default disabled. The super carrier is a large continuous area in the virtual address space. `mseg_alloc` always tries to create new carriers in the super carrier if it exists. Notice that the `alloc_util` framework can create `sys_alloc` carriers. For more information, see *`+MMsco`*.

`+MMmcs <amount>`

Maximum cached segments. The maximum number of memory segments stored in the memory segment cache. Valid range is `[0, 30]`. Defaults to `10`.

Flags for Configuration of sys_alloc

`+MYe true`

Enables `sys_alloc`.

> **Note:**
>
> `sys_alloc` cannot be disabled.

`+MYm libc`

`malloc` library to use. Only `libc` is available. `libc` enables the standard `libc` `malloc` implementation. By default `libc` is used.

`+MYtt <size>`

Trim threshold size (in kilobytes). This is the maximum amount of free memory at the top of the heap (allocated by `sbrk`) that is kept by `malloc` (not released to the operating system). When the amount of free memory at the top of the heap exceeds the trim threshold, `malloc` releases it (by calling `sbrk`). Trim threshold is specified in kilobytes. Defaults to `128`.

> **Note:**
>
> This flag has effect only when the emulator is linked with the GNU C library, and uses its `malloc` implementation.

`+MYtp <size>`

Top pad size (in kilobytes). This is the amount of extra memory that is allocated by `malloc` when `sbrk` is called to get more memory from the operating system. Defaults to `0`.

> **Note:**
>
> This flag has effect only when the emulator is linked with the GNU C library, and uses its `malloc` implementation.

Flags for Configuration of Allocators Based on alloc_util

If `u` is used as subsystem identifier (that is, `<S> = u`), all allocators based on `alloc_util` are effected. If `B`, `D`, `E`, `F`, `H`, `L`, `R`, `S`, or `T` is used as subsystem identifier, only the specific allocator identifier is effected.

`+M<S>acul <utilization>|de`

Abandon carrier utilization limit. A valid `<utilization>` is an integer in the range `[0, 100]` representing utilization in percent. When a utilization value > 0 is used, allocator instances are allowed to abandon multiblock carriers. If `de` (default enabled) is passed instead of a `<utilization>`, a recommended non-zero utilization value is used. The value chosen depends on the allocator type and can be changed between ERTS versions. Defaults to `de`, but this can be changed in the future.

Carriers are abandoned when memory utilization in the allocator instance falls below the utilization value used. Once a carrier is abandoned, no new allocations are made in it. When an allocator instance gets an increased multiblock carrier need, it first tries to fetch an abandoned carrier from an allocator instance of the same allocator type. If no abandoned carrier can be fetched, it creates a new empty carrier. When an abandoned carrier has been fetched, it will function as an ordinary carrier. This feature has special requirements on the *allocation strategy* used. Only the strategies `aoff`, `aoffcbf`, and `aoffcaobf` support abandoned carriers.

This feature also requires *multiple thread specific instances* to be enabled. When enabling this feature, multiple thread-specific instances are enabled if not already enabled, and the `aoffcbf` strategy is enabled if the current strategy does not support abandoned carriers. This feature can be enabled on all allocators based on the `alloc_util` framework, except `temp_alloc` (which would be pointless).

`+M<S>as bf|aobf|aoff|aoffcbf|aoffcaobf|gf|af`

Allocation strategy. The following strategies are valid:

- `bf` (best fit)
- `aobf` (address order best fit)
- `aoff` (address order first fit)
- `aoffcbf` (address order first fit carrier best fit)
- `aoffcaobf` (address order first fit carrier address order best fit)
- `gf` (good fit)
- `af` (a fit)

See the description of allocation strategies in section *The alloc_util Framework*.

`+M<S>asbcst <size>`

Absolute singleblock carrier shrink threshold (in kilobytes). When a block located in an `mseg_alloc` singleblock carrier is shrunk, the carrier is left unchanged if the amount of unused memory is less than this threshold, otherwise the carrier is shrunk. See also *`rsbcst`*.

`+M<S>e true|false`

Enables allocator `<S>`.

`+M<S>lmbcs <size>`

Largest (`mseg_alloc`) multiblock carrier size (in kilobytes). See the description on how sizes for `mseg_alloc` multiblock carriers are decided in section *The alloc_util Framework*. On 32-bit Unix style OS this limit cannot be set > 128 MB.

`+M<S>mbcgs <ratio>`

(`mseg_alloc`) multiblock carrier growth stages. See the description on how sizes for `mseg_alloc` multiblock carriers are decided in section *The alloc_util Framework*.

`+M<S>mbsd <depth>`

Maximum block search depth. This flag has effect only if the good fit strategy is selected for allocator `<S>`. When the good fit strategy is used, free blocks are placed in segregated free-lists. Each free-list contains blocks of sizes in a specific range. The maxiumum block search depth sets a limit on the maximum number of blocks to inspect in a free-list during a search for suitable block satisfying the request.

`+M<S>mmbcs <size>`

Main multiblock carrier size. Sets the size of the main multiblock carrier for allocator `<S>`. The main multiblock carrier is allocated through `sys_alloc` and is never deallocated.

`+M<S>mmmbc <amount>`

Maximum `mseg_alloc` multiblock carriers. Maximum number of multiblock carriers allocated through `mseg_alloc` by allocator `<S>`. When this limit is reached, new multiblock carriers are allocated through `sys_alloc`.

`+M<S>mmsbc <amount>`

Maximum `mseg_alloc` singleblock carriers. Maximum number of singleblock carriers allocated through `mseg_alloc` by allocator `<S>`. When this limit is reached, new singleblock carriers are allocated through `sys_alloc`.

`+M<S>ramv <bool>`

Realloc always moves. When enabled, reallocate operations are more or less translated into an allocate, copy, free sequence. This often reduces memory fragmentation, but costs performance.

`+M<S>rmbcmt <ratio>`

Relative multiblock carrier move threshold (in percent). When a block located in a multiblock carrier is shrunk, the block is moved if the ratio of the size of the returned memory compared to the previous size is more than this threshold, otherwise the block is shrunk at the current location.

`+M<S>rsbcmt <ratio>`

Relative singleblock carrier move threshold (in percent). When a block located in a singleblock carrier is shrunk to a size smaller than the value of parameter *`sbct`*, the block is left unchanged in the singleblock carrier if the ratio of unused memory is less than this threshold, otherwise it is moved into a multiblock carrier.

`+M<S>rsbcst <ratio>`

Relative singleblock carrier shrink threshold (in percent). When a block located in an `mseg_alloc` singleblock carrier is shrunk, the carrier is left unchanged if the ratio of unused memory is less than this threshold, otherwise the carrier is shrunk. See also *`asbcst`*.

`+M<S>sbct <size>`

Singleblock carrier threshold (in kilobytes). Blocks larger than this threshold are placed in singleblock carriers. Blocks smaller than this threshold are placed in multiblock carriers. On 32-bit Unix style OS this threshold cannot be set > 8 MB.

`+M<S>smbcs <size>`

Smallest (`mseg_alloc`) multiblock carrier size (in kilobytes). See the description on how sizes for `mseg_alloc` multiblock carriers are decided in section *The alloc_util Framework*.

`+M<S>t true|false`

Multiple, thread-specific instances of the allocator. This option has only effect on the runtime system with SMP support. Default behavior on the runtime system with SMP support is `NoSchedulers+1` instances. Each scheduler uses a lock-free instance of its own and other threads use a common instance.

Before ERTS 5.9 it was possible to configure a smaller number of thread-specific instances than schedulers. This is, however, not possible anymore.

Flags for Configuration of alloc_util

All allocators based on `alloc_util` are effected.

`+Muycs <size>`

`sys_alloc` carrier size. Carriers allocated through `sys_alloc` are allocated in sizes that are multiples of the `sys_alloc` carrier size. This is not true for main multiblock carriers and carriers allocated during a memory shortage, though.

`+Mummc <amount>`

Maximum `mseg_alloc` carriers. Maximum number of carriers placed in separate memory segments. When this limit is reached, new carriers are placed in memory retrieved from `sys_alloc`.

`+Musac <bool>`

Allow `sys_alloc` carriers. Defaults to `true`. If set to `false`, `sys_alloc` carriers are never created by allocators using the `alloc_util` framework.

Special Flag for literal_alloc

`+MIscs <size in MB>`

`literal_alloc` super carrier size (in MB). The amount of **virtual** address space reserved for literal terms in Erlang code on 64-bit architectures. Defaults to `1024` (that is, 1 GB), which is usually sufficient. The flag is ignored on 32-bit architectures.

Special Flag for exec_alloc

`+MXscs <size in MB>`

`exec_alloc` super carrier size (in MB). The amount of **virtual** address space reserved for native executable code used by the *`HiPE`* application on specific architectures (x86_64). Defaults to `512`.

Instrumentation Flags

`+Mim true|false`

A map over current allocations is kept by the emulator. The allocation map can be retrieved through module *`instrument(3)`*. `+Mim true` implies `+Mis true`. `+Mim true` is the same as flag `-`*`instr`* in `erl(1)`.

`+Mis true|false`

Status over allocated memory is kept by the emulator. The allocation status can be retrieved through module *`instrument(3)`*.

`+Mit X`

Reserved for future use. Do **not** use this flag.

> **Note:**
>
> When instrumentation of the emulator is enabled, the emulator uses more memory and runs slower.

Other Flags

`+Mea min|max|r9c|r10b|r11b|config`

Options:

`min`

Disables all allocators that can be disabled.

`max`

Enables all allocators (default).

`r9c|r10b|r11b`

Configures all allocators as they were configured in respective Erlang/OTP release. These will eventually be removed.

`config`

Disables features that cannot be enabled while creating an allocator configuration with *`erts_alloc_config(3)`*.

> **Note:**
>
> This option is to be used only while running `erts_alloc_config(3)`, **not** when using the created configuration.

`+Mlpm all|no`

Lock physical memory. Defaults to `no`, that is, no physical memory is locked. If set to `all`, all memory mappings made by the runtime system are locked into physical memory. If set to `all`, the runtime system fails to start if this feature is not supported, the user has not got enough privileges, or the user is not allowed to lock enough physical memory. The runtime system also fails with an out of memory condition if the user limit on the amount of locked memory is reached.

Notes

Only some default values have been presented here. For information about the currently used settings and the current status of the allocators, see *`erlang:system_info(allocator)`* and *`erlang:system_info({allocator, Alloc})`*.

> **Note:**
>
> Most of these flags are highly implementation-dependent and can be changed or removed without prior notice.
>
> `erts_alloc` is not obliged to strictly use the settings that have been passed to it (it can even ignore them).

The *`erts_alloc_config(3)`* tool can be used to aid creation of an `erts_alloc` configuration that is suitable for a limited number of runtime scenarios.

See Also

`erl(1)`, *`erlang(3)`*, *`erts_alloc_config(3)`*, *`instrument(3)`*

erl_nif

C Library

A NIF library contains native implementation of some functions of an Erlang module. The native implemented functions (NIFs) are called like any other functions without any difference to the caller. Each NIF must have an implementation in Erlang that is invoked if the function is called before the NIF library is successfully loaded. A typical such stub implementation is to throw an exception. But it can also be used as a fallback implementation if the NIF library is not implemented for some architecture.

Warning:

Use this functionality with extreme care.

A native function is executed as a direct extension of the native code of the VM. Execution is not made in a safe environment. The VM **cannot** provide the same services as provided when executing Erlang code, such as pre-emptive scheduling or memory protection. If the native function does not behave well, the whole VM will misbehave.

- A native function that crash will crash the whole VM.
- An erroneously implemented native function can cause a VM internal state inconsistency, which can cause a crash of the VM, or miscellaneous misbehaviors of the VM at any point after the call to the native function.
- A native function doing *lengthy work* before returning degrades responsiveness of the VM, and can cause miscellaneous strange behaviors. Such strange behaviors include, but are not limited to, extreme memory usage, and bad load balancing between schedulers. Strange behaviors that can occur because of lengthy work can also vary between Erlang/OTP releases.

A minimal example of a NIF library can look as follows:

```
/* niftest.c */
#include <erl_nif.h>

static ERL_NIF_TERM hello(ErlNifEnv* env, int argc, const ERL_NIF_TERM argv[])
{
    return enif_make_string(env, "Hello world!", ERL_NIF_LATIN1);
}

static ErlNifFunc nif_funcs[] =
{
    {"hello", 0, hello}
};

ERL_NIF_INIT(niftest,nif_funcs,NULL,NULL,NULL,NULL)
```

The Erlang module can look as follows:

```
-module(niftest).

-export([init/0, hello/0]).

init() ->
      erlang:load_nif("./niftest", 0).

hello() ->
      "NIF library not loaded".
```

Compile and test can look as follows (on Linux):

```
$> gcc -fPIC -shared -o niftest.so niftest.c -I $ERL_ROOT/usr/include/
$> erl

1> c(niftest).
{ok,niftest}
2> niftest:hello().
"NIF library not loaded"
3> niftest:init().
ok
4> niftest:hello().
"Hello world!"
```

A better solution for a real module is to take advantage of the new directive `on_load` (see section *Running a Function When a Module is Loaded* in the Erlang Reference Manual) to load the NIF library automatically when the module is loaded.

Note:

A NIF does not have to be exported, it can be local to the module. However, unused local stub functions will be optimized away by the compiler, causing loading of the NIF library to fail.

Once loaded, a NIF library is persistent. It will not be unloaded until the module code version that it belongs to is purged.

Functionality

All interaction between NIF code and the Erlang runtime system is performed by calling NIF API functions. Functions exist for the following functionality:

Read and write Erlang terms

Any Erlang terms can be passed to a NIF as function arguments and be returned as function return values. The terms are of C-type *`ERL_NIF_TERM`* and can only be read or written using API functions. Most functions to read the content of a term are prefixed `enif_get_` and usually return `true` (or `false`) if the term is of the expected type (or not). The functions to write terms are all prefixed `enif_make_` and usually return the created `ERL_NIF_TERM`. There are also some functions to query terms, like `enif_is_atom`, `enif_is_identical`, and `enif_compare`.

All terms of type `ERL_NIF_TERM` belong to an environment of type *`ErlNifEnv`*. The lifetime of a term is controlled by the lifetime of its environment object. All API functions that read or write terms has the environment that the term belongs to as the first function argument.

Binaries

Terms of type binary are accessed with the help of struct type *`ErlNifBinary`*, which contains a pointer (`data`) to the raw binary data and the length (`size`) of the data in bytes. Both `data` and `size` are read-only and are only to be written using calls to API functions. Instances of `ErlNifBinary` are, however, always allocated by the user (usually as local variables).

The raw data pointed to by `data` is only mutable after a call to *`enif_alloc_binary`* or *`enif_realloc_binary`*. All other functions that operate on a binary leave the data as read-only. A mutable binary must in the end either be freed with *`enif_release_binary`* or made read-only by transferring it to an Erlang term with *`enif_make_binary`*. However, it does not have to occur in the same NIF call. Read-only binaries do not have to be released.

`enif_make_new_binary` can be used as a shortcut to allocate and return a binary in the same NIF call.

Binaries are sequences of whole bytes. Bitstrings with an arbitrary bit length have no support yet.

Resource objects

The use of resource objects is a safe way to return pointers to native data structures from a NIF. A resource object is only a block of memory allocated with *enif_alloc_resource*. A handle ("safe pointer") to this memory block can then be returned to Erlang by the use of *enif_make_resource*. The term returned by enif_make_resource is opaque in nature. It can be stored and passed between processes, but the only real end usage is to pass it back as an argument to a NIF. The NIF can then call *enif_get_resource* and get back a pointer to the memory block, which is guaranteed to still be valid. A resource object is not deallocated until the last handle term is garbage collected by the VM and the resource is released with *enif_release_resource* (not necessarily in that order).

All resource objects are created as instances of some **resource type**. This makes resources from different modules to be distinguishable. A resource type is created by calling *enif_open_resource_type* when a library is loaded. Objects of that resource type can then later be allocated and enif_get_resource verifies that the resource is of the expected type. A resource type can have a user-supplied destructor function, which is automatically called when resources of that type are released (by either the garbage collector or enif_release_resource). Resource types are uniquely identified by a supplied name string and the name of the implementing module.

The following is a template example of how to create and return a resource object.

```
ERL_NIF_TERM term;
MyStruct* obj = enif_alloc_resource(my_resource_type, sizeof(MyStruct));

/* initialize struct ... */

term = enif_make_resource(env, obj);

if (keep_a_reference_of_our_own) {
    /* store 'obj' in static variable, private data or other resource object */
}
else {
    enif_release_resource(obj);
    /* resource now only owned by "Erlang" */
}
return term;
```

Notice that once enif_make_resource creates the term to return to Erlang, the code can choose to either keep its own native pointer to the allocated struct and release it later, or release it immediately and rely only on the garbage collector to deallocate the resource object eventually when it collects the term.

Another use of resource objects is to create binary terms with user-defined memory management. *enif_make_resource_binary* creates a binary term that is connected to a resource object. The destructor of the resource is called when the binary is garbage collected, at which time the binary data can be released. An example of this can be a binary term consisting of data from a mmap'ed file. The destructor can then do munmap to release the memory region.

Resource types support upgrade in runtime by allowing a loaded NIF library to take over an already existing resource type and by that "inherit" all existing objects of that type. The destructor of the new library is thereafter called for the inherited objects and the library with the old destructor function can be safely unloaded. Existing resource objects, of a module that is upgraded, must either be deleted or taken over by the new NIF library. The unloading of a library is postponed as long as there exist resource objects with a destructor function in the library.

Module upgrade and static data

A loaded NIF library is tied to the Erlang module instance that loaded it. If the module is upgraded, the new module instance needs to load its own NIF library (or maybe choose not to). The new module instance can, however, choose to load the exact same NIF library as the old code if it wants to. Sharing the dynamic library means that static data defined by the library is shared as well. To avoid unintentionally shared static data between

module instances, each Erlang module version can keep its own private data. This private data can be set when the NIF library is loaded and later retrieved by calling *enif_priv_data*.

Threads and concurrency

A NIF is thread-safe without any explicit synchronization as long as it acts as a pure function and only reads the supplied arguments. When you write to a shared state either through static variables or *enif_priv_data*, you need to supply your own explicit synchronization. This includes terms in process-independent environments that are shared between threads. Resource objects also require synchronization if you treat them as mutable.

The library initialization callbacks `load` and `upgrade` are thread-safe even for shared state data.

Version Management

When a NIF library is built, information about the NIF API version is compiled into the library. When a NIF library is loaded, the runtime system verifies that the library is of a compatible version. `erl_nif.h` defines the following:

`ERL_NIF_MAJOR_VERSION`

Incremented when NIF library incompatible changes are made to the Erlang runtime system. Normally it suffices to recompile the NIF library when the `ERL_NIF_MAJOR_VERSION` has changed, but it can, under rare circumstances, mean that NIF libraries must be slightly modified. If so, this will of course be documented.

`ERL_NIF_MINOR_VERSION`

Incremented when new features are added. The runtime system uses the minor version to determine what features to use.

The runtime system normally refuses to load a NIF library if the major versions differ, or if the major versions are equal and the minor version used by the NIF library is greater than the one used by the runtime system. Old NIF libraries with lower major versions are, however, allowed after a bump of the major version during a transition period of two major releases. Such old NIF libraries can however fail if deprecated features are used.

Time Measurement

Support for time measurement in NIF libraries:

- *ErlNifTime*
- *ErlNifTimeUnit*
- *enif_monotonic_time()*
- *enif_time_offset()*
- *enif_convert_time_unit()*

I/O Queues

The Erlang nif library contains function for easily working with I/O vectors as used by the unix system call `writev`. The I/O Queue is not thread safe, so some other synchronization mechanism has to be used.

- *SysIOVec*
- *ErlNifIOVec*
- *enif_ioq_create()*
- *enif_ioq_destroy()*
- *enif_ioq_enq_binary()*
- *enif_ioq_enqv()*
- *enif_ioq_deq()*
- *enif_ioq_peek()*
- *enif_inspect_iovec()*

- *enif_free_iovec()*

Typical usage when writing to a file descriptor looks like this:

```
int writeiovec(ErlNifEnv *env, ERL_NIF_TERM term, ERL_NIF_TERM *tail,
               ErlNifIOQueue *q, int fd) {

    ErlNifIOVec vec, *iovec = &vec;
    SysIOVec *sysiovec;
    int saved_errno;
    int iovcnt, n;

    if (!enif_inspect_iovec(env, 64, term, tail, &iovec))
        return -2;

    if (enif_ioq_size(q) > 0) {
        /* If the I/O queue contains data we enqueue the iovec and
           then peek the data to write out of the queue. */
        if (!enif_ioq_enqv(q, iovec, 0))
            return -3;

        sysiovec = enif_ioq_peek(q, &iovcnt);
    } else {
        /* If the I/O queue is empty we skip the trip through it. */
        iovcnt = iovec->iovcnt;
        sysiovec = iovec->iov;
    }

    /* Attempt to write the data */
    n = writev(fd, sysiovec, iovcnt);
    saved_errno = errno;

    if (enif_ioq_size(q) == 0) {
        /* If the I/O queue was initially empty we enqueue any
           remaining data into the queue for writing later. */
        if (n >= 0 && !enif_ioq_enqv(q, iovec, n))
            return -3;
    } else {
        /* Dequeue any data that was written from the queue. */
        if (n > 0 && !enif_ioq_deq(q, n, NULL))
            return -4;
    }

    /* return n, which is either number of bytes written or -1 if
       some error happened */
    errno = saved_errno;
    return n;
}
```

Long-running NIFs

As mentioned in the *warning* text at the beginning of this manual page, it is of **vital importance** that a native function returns relatively fast. It is difficult to give an exact maximum amount of time that a native function is allowed to work, but usually a well-behaving native function is to return to its caller within 1 millisecond. This can be achieved using different approaches. If you have full control over the code to execute in the native function, the best approach is to divide the work into multiple chunks of work and call the native function multiple times. This is, however, not always possible, for example when calling third-party libraries.

The *enif_consume_timeslice()* function can be used to inform the runtime system about the length of the NIF call. It is typically always to be used unless the NIF executes very fast.

If the NIF call is too lengthy, this must be handled in one of the following ways to avoid degraded responsiveness, scheduler load balancing problems, and other strange behaviors:

Yielding NIF

If the functionality of a long-running NIF can be split so that its work can be achieved through a series of shorter NIF calls, the application has two options:

- Make that series of NIF calls from the Erlang level.
- Call a NIF that first performs a chunk of the work, then invokes the `enif_schedule_nif` function to schedule another NIF call to perform the next chunk. The final call scheduled in this manner can then return the overall result.

Breaking up a long-running function in this manner enables the VM to regain control between calls to the NIFs.

This approach is always preferred over the other alternatives described below. This both from a performance perspective and a system characteristics perspective.

Threaded NIF

This is accomplished by dispatching the work to another thread managed by the NIF library, return from the NIF, and wait for the result. The thread can send the result back to the Erlang process using `enif_send`. Information about thread primitives is provided below.

Dirty NIF

Note:

Dirty NIF support is available only when the emulator is configured with dirty scheduler support. As of ERTS version 9.0, dirty scheduler support is enabled by default on the runtime system with SMP support. The Erlang runtime without SMP support does **not** support dirty schedulers even when the dirty scheduler support is explicitly enabled. To check at runtime for the presence of dirty scheduler threads, code can use the `enif_system_info()` API function.

A NIF that cannot be split and cannot execute in a millisecond or less is called a "dirty NIF", as it performs work that the ordinary schedulers of the Erlang runtime system cannot handle cleanly. Applications that make use of such functions must indicate to the runtime that the functions are dirty so they can be handled specially. This is handled by executing dirty jobs on a separate set of schedulers called dirty schedulers. A dirty NIF executing on a dirty scheduler does not have the same duration restriction as a normal NIF.

It is important to classify the dirty job correct. An I/O bound job should be classified as such, and a CPU bound job should be classified as such. If you should classify CPU bound jobs as I/O bound jobs, dirty I/O schedulers might starve ordinary schedulers. I/O bound jobs are expected to either block waiting for I/O, and/or spend a limited amount of time moving data.

To schedule a dirty NIF for execution, the application has two options:

- Set the appropriate flags value for the dirty NIF in its `ErlNifFunc` entry.
- Call `enif_schedule_nif`, pass to it a pointer to the dirty NIF to be executed, and indicate with argument `flags` whether it expects the operation to be CPU-bound or I/O-bound.

A job that alternates between I/O bound and CPU bound can be reclassified and rescheduled using `enif_schedule_nif` so that it executes on the correct type of dirty scheduler at all times. For more information see the documentation of the `erl(1)` command line arguments `+SDcpu`, and `+SDio`.

While a process executes a dirty NIF, some operations that communicate with it can take a very long time to complete. Suspend or garbage collection of a process executing a dirty NIF cannot be done until the dirty NIF has returned. Thus, other processes waiting for such operations to complete might have to wait for a very long time. Blocking multi-scheduling, that is, calling `erlang:system_flag(multi_scheduling, block)`, can also take a very long time to complete. This becaue all ongoing dirty operations on all dirty schedulers must complete before the block operation can complete.

Many operations communicating with a process executing a dirty NIF can, however, complete while it executes the dirty NIF. For example, retrieving information about it through *erlang:process_info*, setting its group leader, register/unregister its name, and so on.

Termination of a process executing a dirty NIF can only be completed up to a certain point while it executes the dirty NIF. All Erlang resources, such as its registered name and its ETS tables, are released. All links and monitors are triggered. The execution of the NIF is, however, **not** stopped. The NIF can safely continue execution, allocate heap memory, and so on, but it is of course better to stop executing as soon as possible. The NIF can check whether a current process is alive using *enif_is_current_process_alive*. Communication using *enif_send* and *enif_port_command* is also dropped when the sending process is not alive. Deallocation of certain internal resources, such as process heap and process control block, is delayed until the dirty NIF has completed.

Initialization

`ERL_NIF_INIT(MODULE, ErlNifFunc funcs[], load, NULL, upgrade, unload)`

This is the magic macro to initialize a NIF library. It is to be evaluated in global file scope.

`MODULE` is the name of the Erlang module as an identifier without string quotations. It is stringified by the macro.

`funcs` is a static array of function descriptors for all the implemented NIFs in this library.

`load`, `upgrade` and `unload` are pointers to functions. One of `load` or `upgrade` is called to initialize the library. `unload` is called to release the library. All are described individually below.

The fourth argument `NULL` is ignored. It was earlier used for the deprectated `reload` callback which is no longer supported since OTP 20.

If compiling a NIF for static inclusion through `--enable-static-nifs`, you must define `STATIC_ERLANG_NIF` before the `ERL_NIF_INIT` declaration.

`int (*load)(ErlNifEnv* env, void** priv_data, ERL_NIF_TERM load_info)`

`load` is called when the NIF library is loaded and no previously loaded library exists for this module.

`*priv_data` can be set to point to some private data if the library needs to keep a state between NIF calls. `enif_priv_data` returns this pointer. `*priv_data` is initialized to `NULL` when `load` is called.

`load_info` is the second argument to *erlang:load_nif/2*.

The library fails to load if `load` returns anything other than `0`. `load` can be `NULL` if initialization is not needed.

```
int (*upgrade)(ErlNifEnv* env, void** priv_data, void** old_priv_data,
ERL_NIF_TERM load_info)
```

`upgrade` is called when the NIF library is loaded and there is old code of this module with a loaded NIF library.

Works as `load`, except that `*old_priv_data` already contains the value set by the last call to `load` or `upgrade` for the old module code. `*priv_data` is initialized to `NULL` when `upgrade` is called. It is allowed to write to both `*priv_data` and `*old_priv_data.`

The library fails to load if `upgrade` returns anything other than `0` or if `upgrade` is `NULL`.

`void (*unload)(ErlNifEnv* env, void* priv_data)`

`unload` is called when the module code that the NIF library belongs to is purged as old. New code of the same module may or may not exist.

Data Types

`ERL_NIF_TERM`

Variables of type `ERL_NIF_TERM` can refer to any Erlang term. This is an opaque type and values of it can only by used either as arguments to API functions or as return values from NIFs. All `ERL_NIF_TERM`s belong to an environment (*`ErlNifEnv`*). A term cannot be destructed individually, it is valid until its environment is destructed.

`ErlNifEnv`

`ErlNifEnv` represents an environment that can host Erlang terms. All terms in an environment are valid as long as the environment is valid. `ErlNifEnv` is an opaque type; pointers to it can only be passed on to API functions. Two types of environments exist:

Process-bound environment

Passed as the first argument to all NIFs. All function arguments passed to a NIF belong to that environment. The return value from a NIF must also be a term belonging to the same environment.

A process-bound environment contains transient information about the calling Erlang process. The environment is only valid in the thread where it was supplied as argument until the NIF returns. It is thus useless and dangerous to store pointers to process-bound environments between NIF calls.

Process-independent environment

Created by calling *`enif_alloc_env`*. This environment can be used to store terms between NIF calls and to send terms with *`enif_send`*. A process-independent environment with all its terms is valid until you explicitly invalidate it with *`enif_free_env`* or `enif_send`.

All contained terms of a list/tuple/map must belong to the same environment as the list/tuple/map itself. Terms can be copied between environments with *`enif_make_copy`*.

`ErlNifFunc`

```
typedef struct {
    const char* name;
    unsigned arity;
    ERL_NIF_TERM (*fptr)(ErlNifEnv* env, int argc, const ERL_NIF_TERM argv[]);
    unsigned flags;
} ErlNifFunc;
```

Describes a NIF by its name, arity, and implementation.

`fptr`

A pointer to the function that implements the NIF.

`argv`

Contains the function arguments passed to the NIF.

`argc`

The array length, that is, the function arity. `argv[N-1]` thus denotes the Nth argument to the NIF. Notice that the argument `argc` allows for the same C function to implement several Erlang functions with different arity (but probably with the same name).

`flags`

Is `0` for a regular NIF (and so its value can be omitted for statically initialized `ErlNifFunc` instances).

`flags` can be used to indicate that the NIF is a *dirty NIF* that is to be executed on a dirty scheduler thread.

If the dirty NIF is expected to be CPU-bound, its `flags` field is to be set to `ERL_NIF_DIRTY_JOB_CPU_BOUND` or `ERL_NIF_DIRTY_JOB_IO_BOUND`.

> **Note:**
>
> If one of the `ERL_NIF_DIRTY_JOB_*_BOUND` flags is set, and the runtime system has no support for dirty schedulers, the runtime system refuses to load the NIF library.

`ErlNifBinary`

```
typedef struct {
    unsigned size;
    unsigned char* data;
} ErlNifBinary;
```

`ErlNifBinary` contains transient information about an inspected binary term. `data` is a pointer to a buffer of `size` bytes with the raw content of the binary.

Notice that `ErlNifBinary` is a semi-opaque type and you are only allowed to read fields `size` and `data`.

`ErlNifBinaryToTerm`

An enumeration of the options that can be specified to *`enif_binary_to_term`*. For default behavior, use value `0`.

When receiving data from untrusted sources, use option `ERL_NIF_BIN2TERM_SAFE`.

`ErlNifMonitor`

This is an opaque data type that identifies a monitor.

The nif writer is to provide the memory for storing the monitor when calling *`enif_monitor_process`*. The address of the data is not stored by the runtime system, so `ErlNifMonitor` can be used as any other data, it can be copied, moved in memory, forgotten, and so on. To compare two monitors, *`enif_compare_monitors`* must be used.

`ErlNifPid`

A process identifier (pid). In contrast to pid terms (instances of `ERL_NIF_TERM`), `ErlNifPid`s are self-contained and not bound to any *environment*. `ErlNifPid` is an opaque type.

`ErlNifPort`

A port identifier. In contrast to port ID terms (instances of `ERL_NIF_TERM`), `ErlNifPort`s are self-contained and not bound to any *environment*. `ErlNifPort` is an opaque type.

`ErlNifResourceType`

Each instance of `ErlNifResourceType` represents a class of memory-managed resource objects that can be garbage collected. Each resource type has a unique name and a destructor function that is called when objects of its type are released.

`ErlNifResourceTypeInit`

```
typedef struct {
    ErlNifResourceDtor* dtor;
    ErlNifResourceStop* stop;
    ErlNifResourceDown* down;
} ErlNifResourceTypeInit;
```

Initialization structure read by *enif_open_resource_type_x*.

`ErlNifResourceDtor`

```
typedef void ErlNifResourceDtor(ErlNifEnv* env, void* obj);
```

The function prototype of a resource destructor function.

The `obj` argument is a pointer to the resource. The only allowed use for the resource in the destructor is to access its user data one final time. The destructor is guaranteed to be the last callback before the resource is deallocated.

`ErlNifResourceDown`

```
typedef void ErlNifResourceDown(ErlNifEnv* env, void* obj, const ErlNifPid* pid, const ErlNifMonitor* mo
```

The function prototype of a resource down function, called on the behalf of *enif_monitor_process*. `obj` is the resource, `pid` is the identity of the monitored process that is exiting, and `mon` is the identity of the monitor.

`ErlNifResourceStop`

```
typedef void ErlNifResourceStop(ErlNifEnv* env, void* obj, ErlNifEvent event, int is_direct_call);
```

The function prototype of a resource stop function, called on the behalf of *enif_select*. `obj` is the resource, `event` is OS event, `is_direct_call` is true if the call is made directly from `enif_select` or false if it is a scheduled call (potentially from another thread).

`ErlNifCharEncoding`

```
typedef enum {
    ERL_NIF_LATIN1
}ErlNifCharEncoding;
```

The character encoding used in strings and atoms. The only supported encoding is `ERL_NIF_LATIN1` for ISO Latin-1 (8-bit ASCII).

`ErlNifSysInfo`

Used by *`enif_system_info`* to return information about the runtime system. Contains the same content as *`ErlDrvSysInfo`*.

`ErlNifSInt64`

A native signed 64-bit integer type.

`ErlNifUInt64`

A native unsigned 64-bit integer type.

`ErlNifTime`

A signed 64-bit integer type for representation of time.

`ErlNifTimeUnit`

An enumeration of time units supported by the NIF API:

`ERL_NIF_SEC`
: Seconds

`ERL_NIF_MSEC`
: Milliseconds

`ERL_NIF_USEC`
: Microseconds

`ERL_NIF_NSEC`
: Nanoseconds

`ErlNifUniqueInteger`

An enumeration of the properties that can be requested from *`enif_unique_integer`*. For default properties, use value `0`.

`ERL_NIF_UNIQUE_POSITIVE`

Return only positive integers.

`ERL_NIF_UNIQUE_MONOTONIC`

Return only *strictly monotonically increasing* integer corresponding to creation time.

`ErlNifHash`

An enumeration of the supported hash types that can be generated using *`enif_hash`*.

`ERL_NIF_INTERNAL_HASH`

Non-portable hash function that only guarantees the same hash for the same term within one Erlang VM instance.

It takes 32-bit salt values and generates hashes within `0..2^32-1`.

`ERL_NIF_PHASH2`

Portable hash function that gives the same hash for the same Erlang term regardless of machine architecture and ERTS version.

It ignores salt values and generates hashes within `0..2^27-1`.

Slower than `ERL_NIF_INTERNAL_HASH.` It corresponds to *`erlang:phash2/1`*.

`SysIOVec`

A system I/O vector, as used by `writev` on Unix and `WSASend` on Win32. It is used in `ErlNifIOVec` and by *`enif_ioq_peek`*.

`ErlNifIOVec`

```
typedef struct {
  int iovcnt;
  size_t size;
  SysIOVec* iov;
} ErlNifIOVec;
```

An I/O vector containing `iovcnt` `SysIOVec`s pointing to the data. It is used by *`enif_inspect_iovec`* and *`enif_ioq_enqv`*.

`ErlNifIOQueueOpts`

Options to configure a `ErlNifIOQueue`.

ERL_NIF_IOQ_NORMAL

Create a normal I/O Queue

Exports

`void *enif_alloc(size_t size)`

Allocates memory of `size` bytes.

Returns `NULL` if the allocation fails.

The returned pointer is suitably aligned for any built-in type that fit in the allocated memory.

`int enif_alloc_binary(size_t size, ErlNifBinary* bin)`

Allocates a new binary of size `size` bytes. Initializes the structure pointed to by `bin` to refer to the allocated binary. The binary must either be released by *`enif_release_binary`* or ownership transferred to an Erlang term with *`enif_make_binary`*. An allocated (and owned) `ErlNifBinary` can be kept between NIF calls.

Returns `true` on success, or `false` if allocation fails.

`ErlNifEnv *enif_alloc_env()`

Allocates a new process-independent environment. The environment can be used to hold terms that are not bound to any process. Such terms can later be copied to a process environment with *enif_make_copy* or be sent to a process as a message with *enif_send*.

Returns pointer to the new environment.

`void *enif_alloc_resource(ErlNifResourceType* type, unsigned size)`

Allocates a memory-managed resource object of type `type` and size `size` bytes.

`size_t enif_binary_to_term(ErlNifEnv *env, const unsigned char* data, size_t size, ERL_NIF_TERM *term, ErlNifBinaryToTerm opts)`

Creates a term that is the result of decoding the binary data at `data`, which must be encoded according to the Erlang external term format. No more than `size` bytes are read from `data`. Argument `opts` corresponds to the second argument to *erlang:binary_to_term/2* and must be either `0` or `ERL_NIF_BIN2TERM_SAFE`.

On success, stores the resulting term at `*term` and returns the number of bytes read. Returns `0` if decoding fails or if `opts` is invalid.

See also *ErlNifBinaryToTerm*, *erlang:binary_to_term/2*, and *enif_term_to_binary*.

`void enif_clear_env(ErlNifEnv* env)`

Frees all terms in an environment and clears it for reuse. The environment must have been allocated with *enif_alloc_env*.

`int enif_compare(ERL_NIF_TERM lhs, ERL_NIF_TERM rhs)`

Returns an integer < `0` if `lhs` < `rhs`, `0` if `lhs` = `rhs`, and > `0` if `lhs` > `rhs`. Corresponds to the Erlang operators `==`, `/=`, `=<`, `<`, `>=`, and `>` (but **not** `=:=` or `=/=`).

`int enif_compare_monitors(const ErlNifMonitor *monitor1, const ErlNifMonitor *monitor2)`

Compares two *ErlNifMonitor*s. Can also be used to imply some artificial order on monitors, for whatever reason.

Returns `0` if `monitor1` and `monitor2` are equal, < `0` if `monitor1` < `monitor2`, and > `0` if `monitor1` > `monitor2`.

`void enif_cond_broadcast(ErlNifCond *cnd)`

Same as *erl_drv_cond_broadcast*.

`ErlNifCond *enif_cond_create(char *name)`

Same as *erl_drv_cond_create*.

`void enif_cond_destroy(ErlNifCond *cnd)`

Same as *erl_drv_cond_destroy*.

`void enif_cond_signal(ErlNifCond *cnd)`

Same as *erl_drv_cond_signal*.

void enif_cond_wait(ErlNifCond *cnd, ErlNifMutex *mtx)

Same as *erl_drv_cond_wait*.

int enif_consume_timeslice(ErlNifEnv *env, int percent)

Gives the runtime system a hint about how much CPU time the current NIF call has consumed since the last hint, or since the start of the NIF if no previous hint has been specified. The time is specified as a percent of the timeslice that a process is allowed to execute Erlang code until it can be suspended to give time for other runnable processes. The scheduling timeslice is not an exact entity, but can usually be approximated to about 1 millisecond.

Notice that it is up to the runtime system to determine if and how to use this information. Implementations on some platforms can use other means to determine consumed CPU time. Lengthy NIFs should regardless of this frequently call `enif_consume_timeslice` to determine if it is allowed to continue execution.

Argument `percent` must be an integer between 1 and 100. This function must only be called from a NIF-calling thread, and argument `env` must be the environment of the calling process.

Returns `1` if the timeslice is exhausted, otherwise `0`. If `1` is returned, the NIF is to return as soon as possible in order for the process to yield.

This function is provided to better support co-operative scheduling, improve system responsiveness, and make it easier to prevent misbehaviors of the VM because of a NIF monopolizing a scheduler thread. It can be used to divide *length work* into a number of repeated NIF calls without the need to create threads.

See also the *warning* text at the beginning of this manual page.

ErlNifTime enif_convert_time_unit(ErlNifTime val, ErlNifTimeUnit from, ErlNifTimeUnit to)

Converts the `val` value of time unit `from` to the corresponding value of time unit `to`. The result is rounded using the floor function.

`val`
: Value to convert time unit for.

`from`
: Time unit of `val`.

`to`
: Time unit of returned value.

Returns `ERL_NIF_TIME_ERROR` if called with an invalid time unit argument.

See also *ErlNifTime* and *ErlNifTimeUnit*.

ERL_NIF_TERM enif_cpu_time(ErlNifEnv *)

Returns the CPU time in the same format as *erlang:timestamp()*. The CPU time is the time the current logical CPU has spent executing since some arbitrary point in the past. If the OS does not support fetching this value, `enif_cpu_time` invokes *enif_make_badarg*.

int enif_demonitor_process(ErlNifEnv* env, void* obj, const ErlNifMonitor* mon)

Cancels a monitor created earlier with *enif_monitor_process*. Argument `obj` is a pointer to the resource holding the monitor and `*mon` identifies the monitor.

Returns `0` if the monitor was successfully identified and removed. Returns a non-zero value if the monitor could not be identified, which means it was either

- never created for this resource

- already cancelled
- already triggered
- just about to be triggered by a concurrent thread

This function is only thread-safe when the emulator with SMP support is used. It can only be used in a non-SMP emulator from a NIF-calling thread.

`int enif_equal_tids(ErlNifTid tid1, ErlNifTid tid2)`

Same as *`erl_drv_equal_tids`*.

`void enif_free(void* ptr)`

Frees memory allocated by *`enif_alloc`*.

`void enif_free_env(ErlNifEnv* env)`

Frees an environment allocated with *`enif_alloc_env`*. All terms created in the environment are freed as well.

`void enif_free_iovec(ErlNifIOvec* iov)`

Frees an io vector returned from *`enif_inspect_iovec`*. This is needed only if a `NULL` environment is passed to *`enif_inspect_iovec`*.

```
ErlNifIOVec *iovec = NULL;
size_t max_elements = 128;
ERL_NIF_TERM tail;
if (!enif_inspect_iovec(NULL, max_elements, term, &tail, iovec))
  return 0;

// Do things with the iovec

/* Free the iovector, possibly in another thread or nif function call */
enif_free_iovec(iovec);
```

`int enif_get_atom(ErlNifEnv* env, ERL_NIF_TERM term, char* buf, unsigned size, ErlNifCharEncoding encode)`

Writes a `NULL`-terminated string in the buffer pointed to by `buf` of size `size`, consisting of the string representation of the atom `term` with encoding *encode*.

Returns the number of bytes written (including terminating `NULL` character) or `0` if `term` is not an atom with maximum length of `size-1`.

`int enif_get_atom_length(ErlNifEnv* env, ERL_NIF_TERM term, unsigned* len, ErlNifCharEncoding encode)`

Sets `*len` to the length (number of bytes excluding terminating `NULL` character) of the atom `term` with encoding `encode`.

Returns `true` on success, or `false` if `term` is not an atom.

`int enif_get_double(ErlNifEnv* env, ERL_NIF_TERM term, double* dp)`

Sets `*dp` to the floating-point value of `term`.

Returns `true` on success, or `false` if `term` is not a float.

`int enif_get_int(ErlNifEnv* env, ERL_NIF_TERM term, int* ip)`

Sets `*ip` to the integer value of `term`.

Returns `true` on success, or `false` if `term` is not an integer or is outside the bounds of type `int`.

`int enif_get_int64(ErlNifEnv* env, ERL_NIF_TERM term, ErlNifSInt64* ip)`

Sets `*ip` to the integer value of `term`.

Returns `true` on success, or `false` if `term` is not an integer or is outside the bounds of a signed 64-bit integer.

`int enif_get_local_pid(ErlNifEnv* env, ERL_NIF_TERM term, ErlNifPid* pid)`

If `term` is the pid of a node local process, this function initializes the pid variable `*pid` from it and returns `true`. Otherwise returns `false`. No check is done to see if the process is alive.

`int enif_get_local_port(ErlNifEnv* env, ERL_NIF_TERM term, ErlNifPort* port_id)`

If `term` identifies a node local port, this function initializes the port variable `*port_id` from it and returns `true`. Otherwise returns `false`. No check is done to see if the port is alive.

`int enif_get_list_cell(ErlNifEnv* env, ERL_NIF_TERM list, ERL_NIF_TERM* head, ERL_NIF_TERM* tail)`

Sets `*head` and `*tail` from list `list`.

Returns `true` on success, or `false` if it is not a list or the list is empty.

`int enif_get_list_length(ErlNifEnv* env, ERL_NIF_TERM term, unsigned* len)`

Sets `*len` to the length of list `term`.

Returns `true` on success, or `false` if `term` is not a proper list.

`int enif_get_long(ErlNifEnv* env, ERL_NIF_TERM term, long int* ip)`

Sets `*ip` to the long integer value of `term`.

Returns `true` on success, or `false` if `term` is not an integer or is outside the bounds of type `long int`.

`int enif_get_map_size(ErlNifEnv* env, ERL_NIF_TERM term, size_t *size)`

Sets `*size` to the number of key-value pairs in the map `term`.

Returns `true` on success, or `false` if `term` is not a map.

`int enif_get_map_value(ErlNifEnv* env, ERL_NIF_TERM map, ERL_NIF_TERM key, ERL_NIF_TERM* value)`

Sets `*value` to the value associated with `key` in the map `map`.

Returns `true` on success, or `false` if `map` is not a map or if `map` does not contain `key`.

`int enif_get_resource(ErlNifEnv* env, ERL_NIF_TERM term, ErlNifResourceType* type, void** objp)`

Sets `*objp` to point to the resource object referred to by `term`.

Returns `true` on success, or `false` if `term` is not a handle to a resource object of type `type`.

`int enif_get_string(ErlNifEnv* env, ERL_NIF_TERM list, char* buf, unsigned size, ErlNifCharEncoding encode)`

Writes a `NULL`-terminated string in the buffer pointed to by `buf` with size `size`, consisting of the characters in the string `list`. The characters are written using encoding *encode*.

Returns one of the following:

- The number of bytes written (including terminating `NULL` character)
- `-size` if the string was truncated because of buffer space
- `0` if `list` is not a string that can be encoded with `encode` or if `size` was < `1`.

The written string is always `NULL`-terminated, unless buffer `size` is < `1`.

`int enif_get_tuple(ErlNifEnv* env, ERL_NIF_TERM term, int* arity, const ERL_NIF_TERM** array)`

If `term` is a tuple, this function sets `*array` to point to an array containing the elements of the tuple, and sets `*arity` to the number of elements. Notice that the array is read-only and `(*array)[N-1]` is the Nth element of the tuple. `*array` is undefined if the arity of the tuple is zero.

Returns `true` on success, or `false` if `term` is not a tuple.

`int enif_get_uint(ErlNifEnv* env, ERL_NIF_TERM term, unsigned int* ip)`

Sets `*ip` to the unsigned integer value of `term`.

Returns `true` on success, or `false` if `term` is not an unsigned integer or is outside the bounds of type `unsigned int`.

`int enif_get_uint64(ErlNifEnv* env, ERL_NIF_TERM term, ErlNifUInt64* ip)`

Sets `*ip` to the unsigned integer value of `term`.

Returns `true` on success, or `false` if `term` is not an unsigned integer or is outside the bounds of an unsigned 64-bit integer.

`int enif_get_ulong(ErlNifEnv* env, ERL_NIF_TERM term, unsigned long* ip)`

Sets `*ip` to the unsigned long integer value of `term`.

Returns `true` on success, or `false` if `term` is not an unsigned integer or is outside the bounds of type `unsigned long`.

`int enif_getenv(const char* key, char* value, size_t *value_size)`

Same as *`erl_drv_getenv`*.

`int enif_has_pending_exception(ErlNifEnv* env, ERL_NIF_TERM* reason)`

Returns `true` if a pending exception is associated with the environment `env`. If `reason` is a `NULL` pointer, ignore it. Otherwise, if a pending exception associated with `env` exists, set `*reason` to the value of the exception term. For example, if *`enif_make_badarg`* is called to set a pending `badarg` exception, a later call to `enif_has_pending_exception(env, &reason)` sets `*reason` to the atom `badarg`, then return `true`.

See also *`enif_make_badarg`* and *`enif_raise_exception`*.

`ErlNifUInt64 enif_hash(ErlNifHash type, ERL_NIF_TERM term, ErlNifUInt64 salt)`

Hashes `term` according to the specified *`ErlNifHash`* `type`.

Ranges of taken salt (if any) and returned value depend on the hash type.

`int enif_inspect_binary(ErlNifEnv* env, ERL_NIF_TERM bin_term, ErlNifBinary* bin)`

Initializes the structure pointed to by `bin` with information about binary term `bin_term`.

Returns `true` on success, or `false` if `bin_term` is not a binary.

`int enif_inspect_iolist_as_binary(ErlNifEnv* env, ERL_NIF_TERM term, ErlNifBinary* bin)`

Initializes the structure pointed to by `bin` with a continuous buffer with the same byte content as `iolist`. As with `inspect_binary`, the data pointed to by `bin` is transient and does not need to be released.

Returns `true` on success, or `false` if `iolist` is not an iolist.

`int enif_inspect_iovec(ErlNifEnv* env, size_t max_elements, ERL_NIF_TERM iovec_term, ERL_NIF_TERM* tail, ErlNifIOVec** iovec)`

Fills `iovec` with the list of binaries provided in `iovec_term`. The number of elements handled in the call is limited to `max_elements`, and `tail` is set to the remainder of the list. Note that the output may be longer than `max_elements` on some platforms.

To create a list of binaries from an arbitrary iolist, use *`erlang:iolist_to_iovec/1`*.

When calling this function, `iovec` should contain a pointer to `NULL` or a ErlNifIOVec structure that should be used if possible. e.g.

```
/* Don't use a pre-allocated structure */
ErlNifIOVec *iovec = NULL;
enif_inspect_iovec(env, max_elements, term, &tail, &iovec);

/* Use a stack-allocated vector as an optimization for vectors with few elements */
ErlNifIOVec vec, *iovec = &vec;
enif_inspect_iovec(env, max_elements, term, &tail, &iovec);
```

The contents of the `iovec` is valid until the called nif function returns. If the `iovec` should be valid after the nif call returns, it is possible to call this function with a `NULL` environment. If no environment is given the `iovec` owns the data in the vector and it has to be explicitly freed using *`enif_free_iovec`* .

Returns `true` on success, or `false` if `iovec_term` not an iovec.

`ErlNifIOQueue *enif_ioq_create(ErlNifIOQueueOpts opts)`

Create a new I/O Queue that can be used to store data. `opts` has to be set to `ERL_NIF_IOQ_NORMAL`.

`void enif_ioq_destroy(ErlNifIOQueue *q)`

Destroy the I/O queue and free all of it's contents

`int enif_ioq_deq(ErlNifIOQueue *q, size_t count, size_t *size)`

Dequeue `count` bytes from the I/O queue. If `size` is not `NULL`, the new size of the queue is placed there.

Returns `true` on success, or `false` if the I/O does not contain `count` bytes. On failure the queue is left un-altered.

`int enif_ioq_enq_binary(ErlNifIOQueue *q, ErlNifBinary *bin, size_t skip)`

Enqueue the `bin` into `q` skipping the first `skip` bytes.

Returns `true` on success, or `false` if `skip` is greater than the size of `bin`. Any ownership of the binary data is transferred to the queue and `bin` is to be considered read-only for the rest of the NIF call and then as released.

`int enif_ioq_enqv(ErlNifIOQueue *q, ErlNifIOVec *iovec, size_t skip)`

Enqueue the `iovec` into `q` skipping the first `skip` bytes.

Returns `true` on success, or `false` if `skip` is greater than the size of `iovec`.

`SysIOVec *enif_ioq_peek(ErlNifIOQueue *q, int *iovlen)`

Get the I/O queue as a pointer to an array of `SysIOVec`s. It also returns the number of elements in `iovlen`. This is the only way to get data out of the queue.

Nothing is removed from the queue by this function, that must be done with *`enif_ioq_deq`*.

The returned array is suitable to use with the Unix system call `writev`.

`size_t enif_ioq_size(ErlNifIOQueue *q)`

Get the size of `q`.

`int enif_is_atom(ErlNifEnv* env, ERL_NIF_TERM term)`

Returns `true` if `term` is an atom.

`int enif_is_binary(ErlNifEnv* env, ERL_NIF_TERM term)`

Returns `true` if `term` is a binary.

`int enif_is_current_process_alive(ErlNifEnv* env)`

Returns `true` if the currently executing process is currently alive, otherwise `false`.

This function can only be used from a NIF-calling thread, and with an environment corresponding to currently executing processes.

`int enif_is_empty_list(ErlNifEnv* env, ERL_NIF_TERM term)`

Returns `true` if `term` is an empty list.

`int enif_is_exception(ErlNifEnv* env, ERL_NIF_TERM term)`

Return true if `term` is an exception.

`int enif_is_fun(ErlNifEnv* env, ERL_NIF_TERM term)`

Returns `true` if `term` is a fun.

`int enif_is_identical(ERL_NIF_TERM lhs, ERL_NIF_TERM rhs)`

Returns `true` if the two terms are identical. Corresponds to the Erlang operators `=:=` and `=/=`.

`int enif_is_list(ErlNifEnv* env, ERL_NIF_TERM term)`

Returns `true` if `term` is a list.

`int enif_is_map(ErlNifEnv* env, ERL_NIF_TERM term)`

Returns `true` if `term` is a map, otherwise `false`.

`int enif_is_number(ErlNifEnv* env, ERL_NIF_TERM term)`

Returns `true` if `term` is a number.

`int enif_is_pid(ErlNifEnv* env, ERL_NIF_TERM term)`

Returns `true` if `term` is a pid.

`int enif_is_port(ErlNifEnv* env, ERL_NIF_TERM term)`

Returns `true` if `term` is a port.

`int enif_is_port_alive(ErlNifEnv* env, ErlNifPort *port_id)`

Returns `true` if `port_id` is alive.

This function is only thread-safe when the emulator with SMP support is used. It can only be used in a non-SMP emulator from a NIF-calling thread.

`int enif_is_process_alive(ErlNifEnv* env, ErlNifPid *pid)`

Returns `true` if `pid` is alive.

This function is only thread-safe when the emulator with SMP support is used. It can only be used in a non-SMP emulator from a NIF-calling thread.

`int enif_is_ref(ErlNifEnv* env, ERL_NIF_TERM term)`

Returns `true` if `term` is a reference.

`int enif_is_tuple(ErlNifEnv* env, ERL_NIF_TERM term)`

Returns `true` if `term` is a tuple.

`int enif_keep_resource(void* obj)`

Adds a reference to resource object `obj` obtained from *`enif_alloc_resource`*. Each call to `enif_keep_resource` for an object must be balanced by a call to *`enif_release_resource`* before the object is destructed.

`ERL_NIF_TERM enif_make_atom(ErlNifEnv* env, const char* name)`

Creates an atom term from the `NULL`-terminated C-string `name` with ISO Latin-1 encoding. If the length of `name` exceeds the maximum length allowed for an atom (255 characters), `enif_make_atom` invokes *`enif_make_badarg`*.

`ERL_NIF_TERM enif_make_atom_len(ErlNifEnv* env, const char* name, size_t len)`

Create an atom term from the string `name` with length `len`. `NULL` characters are treated as any other characters. If `len` exceeds the maximum length allowed for an atom (255 characters), `enif_make_atom` invokes *`enif_make_badarg`*.

`ERL_NIF_TERM enif_make_badarg(ErlNifEnv* env)`

Makes a `badarg` exception to be returned from a NIF, and associates it with environment `env`. Once a NIF or any function it calls invokes `enif_make_badarg`, the runtime ensures that a `badarg` exception is raised when the NIF returns, even if the NIF attempts to return a non-exception term instead.

The return value from `enif_make_badarg` can be used only as the return value from the NIF that invoked it (directly or indirectly) or be passed to *`enif_is_exception`*, but not to any other NIF API function.

See also *`enif_has_pending_exception`* and *`enif_raise_exception`*.

Note:

Before ERTS 7.0 (Erlang/OTP 18), the return value from `enif_make_badarg` had to be returned from the NIF. This requirement is now lifted as the return value from the NIF is ignored if `enif_make_badarg` has been invoked.

`ERL_NIF_TERM enif_make_binary(ErlNifEnv* env, ErlNifBinary* bin)`

Makes a binary term from `bin`. Any ownership of the binary data is transferred to the created term and `bin` is to be considered read-only for the rest of the NIF call and then as released.

`ERL_NIF_TERM enif_make_copy(ErlNifEnv* dst_env, ERL_NIF_TERM src_term)`

Makes a copy of term `src_term`. The copy is created in environment `dst_env`. The source term can be located in any environment.

`ERL_NIF_TERM enif_make_double(ErlNifEnv* env, double d)`

Creates a floating-point term from a `double`. If argument `double` is not finite or is NaN, `enif_make_double` invokes *`enif_make_badarg`*.

`int enif_make_existing_atom(ErlNifEnv* env, const char* name, ERL_NIF_TERM* atom, ErlNifCharEncoding encode)`

Tries to create the term of an already existing atom from the `NULL`-terminated C-string `name` with encoding *encode*.

If the atom already exists, this function stores the term in `*atom` and returns `true`, otherwise `false`. Also returns `false` if the length of `name` exceeds the maximum length allowed for an atom (255 characters).

`int enif_make_existing_atom_len(ErlNifEnv* env, const char* name, size_t len, ERL_NIF_TERM* atom, ErlNifCharEncoding encoding)`

Tries to create the term of an already existing atom from the string `name` with length `len` and encoding *encode*. `NULL` characters are treated as any other characters.

If the atom already exists, this function stores the term in `*atom` and returns `true`, otherwise `false`. Also returns `false` if `len` exceeds the maximum length allowed for an atom (255 characters).

```
ERL_NIF_TERM enif_make_int(ErlNifEnv* env, int i)
```

Creates an integer term.

```
ERL_NIF_TERM enif_make_int64(ErlNifEnv* env, ErlNifSInt64 i)
```

Creates an integer term from a signed 64-bit integer.

```
ERL_NIF_TERM enif_make_list(ErlNifEnv* env, unsigned cnt, ...)
```

Creates an ordinary list term of length `cnt`. Expects `cnt` number of arguments (after `cnt`) of type `ERL_NIF_TERM` as the elements of the list.

Returns an empty list if `cnt` is 0.

```
ERL_NIF_TERM enif_make_list1(ErlNifEnv* env, ERL_NIF_TERM e1)
ERL_NIF_TERM enif_make_list2(ErlNifEnv* env, ERL_NIF_TERM e1, ERL_NIF_TERM
e2)
ERL_NIF_TERM enif_make_list3(ErlNifEnv* env, ERL_NIF_TERM e1, ERL_NIF_TERM
e2, ERL_NIF_TERM e3)
ERL_NIF_TERM enif_make_list4(ErlNifEnv* env, ERL_NIF_TERM e1, ...,
ERL_NIF_TERM e4)
ERL_NIF_TERM enif_make_list5(ErlNifEnv* env, ERL_NIF_TERM e1, ...,
ERL_NIF_TERM e5)
ERL_NIF_TERM enif_make_list6(ErlNifEnv* env, ERL_NIF_TERM e1, ...,
ERL_NIF_TERM e6)
ERL_NIF_TERM enif_make_list7(ErlNifEnv* env, ERL_NIF_TERM e1, ...,
ERL_NIF_TERM e7)
ERL_NIF_TERM enif_make_list8(ErlNifEnv* env, ERL_NIF_TERM e1, ...,
ERL_NIF_TERM e8)
ERL_NIF_TERM enif_make_list9(ErlNifEnv* env, ERL_NIF_TERM e1, ...,
ERL_NIF_TERM e9)
```

Creates an ordinary list term with length indicated by the function name. Prefer these functions (macros) over the variadic `enif_make_list` to get a compile-time error if the number of arguments does not match.

```
ERL_NIF_TERM enif_make_list_cell(ErlNifEnv* env, ERL_NIF_TERM head,
ERL_NIF_TERM tail)
```

Creates a list cell `[head | tail]`.

```
ERL_NIF_TERM enif_make_list_from_array(ErlNifEnv* env, const ERL_NIF_TERM
arr[], unsigned cnt)
```

Creates an ordinary list containing the elements of array `arr` of length `cnt`.

Returns an empty list if `cnt` is 0.

```
ERL_NIF_TERM enif_make_long(ErlNifEnv* env, long int i)
```

Creates an integer term from a `long int`.

`int enif_make_map_put(ErlNifEnv* env, ERL_NIF_TERM map_in, ERL_NIF_TERM key, ERL_NIF_TERM value, ERL_NIF_TERM* map_out)`

Makes a copy of map `map_in` and inserts `key` with `value`. If `key` already exists in `map_in`, the old associated value is replaced by `value`.

If successful, this function sets `*map_out` to the new map and returns `true`. Returns `false` if `map_in` is not a map.

The `map_in` term must belong to environment `env`.

`int enif_make_map_remove(ErlNifEnv* env, ERL_NIF_TERM map_in, ERL_NIF_TERM key, ERL_NIF_TERM* map_out)`

If map `map_in` contains `key`, this function makes a copy of `map_in` in `*map_out`, and removes `key` and the associated value. If map `map_in` does not contain `key`, `*map_out` is set to `map_in`.

Returns `true` on success, or `false` if `map_in` is not a map.

The `map_in` term must belong to environment `env`.

`int enif_make_map_update(ErlNifEnv* env, ERL_NIF_TERM map_in, ERL_NIF_TERM key, ERL_NIF_TERM new_value, ERL_NIF_TERM* map_out)`

Makes a copy of map `map_in` and replace the old associated value for `key` with `new_value`.

If successful, this function sets `*map_out` to the new map and returns `true`. Returns `false` if `map_in` is not a map or if it does not contain `key`.

The `map_in` term must belong to environment `env`.

`unsigned char *enif_make_new_binary(ErlNifEnv* env, size_t size, ERL_NIF_TERM* termp)`

Allocates a binary of size `size` bytes and creates an owning term. The binary data is mutable until the calling NIF returns. This is a quick way to create a new binary without having to use *`ErlNifBinary`*. The drawbacks are that the binary cannot be kept between NIF calls and it cannot be reallocated.

Returns a pointer to the raw binary data and sets `*termp` to the binary term.

`ERL_NIF_TERM enif_make_new_map(ErlNifEnv* env)`

Makes an empty map term.

`ERL_NIF_TERM enif_make_pid(ErlNifEnv* env, const ErlNifPid* pid)`

Makes a pid term from `*pid`.

`ERL_NIF_TERM enif_make_ref(ErlNifEnv* env)`

Creates a reference like *`erlang:make_ref/0`*.

`ERL_NIF_TERM enif_make_resource(ErlNifEnv* env, void* obj)`

Creates an opaque handle to a memory-managed resource object obtained by *`enif_alloc_resource`*. No ownership transfer is done, as the resource object still needs to be released by *`enif_release_resource`*. However, notice that the call to `enif_release_resource` can occur immediately after obtaining the term from `enif_make_resource`, in which case the resource object is deallocated when the term is garbage collected. For more details, see the *example of creating and returning a resource object* in the User's Guide.

Note:

Since ERTS 9.0 (OTP-20.0), resource terms have a defined behavior when compared and serialized through `term_to_binary` or passed between nodes.

- Two resource terms will compare equal iff they would yield the same resource object pointer when passed to *`enif_get_resource`*.
- A resoure term can be serialized with `term_to_binary` and later be fully recreated if the resource object is still alive when `binary_to_term` is called. A **stale** resource term will be returned from `binary_to_term` if the resource object has been deallocated. *`enif_get_resource`* will return false for stale resource terms.

  The same principles of serialization apply when passing resource terms in messages to remote nodes and back again. A resource term will act stale on all nodes except the node where its resource object is still alive in memory.

Before ERTS 9.0 (OTP-20.0), all resource terms did compare equal to each other and to empty binaries (<<>>). If serialized, they would be recreated as plain empty binaries.

`ERL_NIF_TERM enif_make_resource_binary(ErlNifEnv* env, void* obj, const void* data, size_t size)`

Creates a binary term that is memory-managed by a resource object `obj` obtained by *`enif_alloc_resource`*. The returned binary term consists of `size` bytes pointed to by `data`. This raw binary data must be kept readable and unchanged until the destructor of the resource is called. The binary data can be stored external to the resource object, in which case the destructor is responsible for releasing the data.

Several binary terms can be managed by the same resource object. The destructor is not called until the last binary is garbage collected. This can be useful to return different parts of a larger binary buffer.

As with *`enif_make_resource`*, no ownership transfer is done. The resource still needs to be released with *`enif_release_resource`*.

`int enif_make_reverse_list(ErlNifEnv* env, ERL_NIF_TERM list_in, ERL_NIF_TERM *list_out)`

Sets `*list_out` to the reverse list of the list `list_in` and returns `true`, or returns `false` if `list_in` is not a list.

This function is only to be used on short lists, as a copy is created of the list, which is not released until after the NIF returns.

The `list_in` term must belong to environment `env`.

`ERL_NIF_TERM enif_make_string(ErlNifEnv* env, const char* string, ErlNifCharEncoding encoding)`

Creates a list containing the characters of the `NULL`-terminated string `string` with encoding *encoding*.

`ERL_NIF_TERM enif_make_string_len(ErlNifEnv* env, const char* string, size_t len, ErlNifCharEncoding encoding)`

Creates a list containing the characters of the string `string` with length `len` and encoding *encoding*. `NULL` characters are treated as any other characters.

```
ERL_NIF_TERM enif_make_sub_binary(ErlNifEnv* env, ERL_NIF_TERM bin_term,
size_t pos, size_t size)
```

Makes a subbinary of binary `bin_term`, starting at zero-based position `pos` with a length of `size` bytes. `bin_term` must be a binary or bitstring. `pos+size` must be less or equal to the number of whole bytes in `bin_term`.

```
ERL_NIF_TERM enif_make_tuple(ErlNifEnv* env, unsigned cnt, ...)
```

Creates a tuple term of arity `cnt`. Expects `cnt` number of arguments (after `cnt`) of type `ERL_NIF_TERM` as the elements of the tuple.

```
ERL_NIF_TERM enif_make_tuple1(ErlNifEnv* env, ERL_NIF_TERM e1)
ERL_NIF_TERM enif_make_tuple2(ErlNifEnv* env, ERL_NIF_TERM e1, ERL_NIF_TERM
e2)
ERL_NIF_TERM enif_make_tuple3(ErlNifEnv* env, ERL_NIF_TERM e1, ERL_NIF_TERM
e2, ERL_NIF_TERM e3)
ERL_NIF_TERM enif_make_tuple4(ErlNifEnv* env, ERL_NIF_TERM e1, ...,
ERL_NIF_TERM e4)
ERL_NIF_TERM enif_make_tuple5(ErlNifEnv* env, ERL_NIF_TERM e1, ...,
ERL_NIF_TERM e5)
ERL_NIF_TERM enif_make_tuple6(ErlNifEnv* env, ERL_NIF_TERM e1, ...,
ERL_NIF_TERM e6)
ERL_NIF_TERM enif_make_tuple7(ErlNifEnv* env, ERL_NIF_TERM e1, ...,
ERL_NIF_TERM e7)
ERL_NIF_TERM enif_make_tuple8(ErlNifEnv* env, ERL_NIF_TERM e1, ...,
ERL_NIF_TERM e8)
ERL_NIF_TERM enif_make_tuple9(ErlNifEnv* env, ERL_NIF_TERM e1, ...,
ERL_NIF_TERM e9)
```

Creates a tuple term with length indicated by the function name. Prefer these functions (macros) over the variadic `enif_make_tuple` to get a compile-time error if the number of arguments does not match.

```
ERL_NIF_TERM enif_make_tuple_from_array(ErlNifEnv* env, const ERL_NIF_TERM
arr[], unsigned cnt)
```

Creates a tuple containing the elements of array `arr` of length `cnt`.

```
ERL_NIF_TERM enif_make_uint(ErlNifEnv* env, unsigned int i)
```

Creates an integer term from an `unsigned int`.

```
ERL_NIF_TERM enif_make_uint64(ErlNifEnv* env, ErlNifUInt64 i)
```

Creates an integer term from an unsigned 64-bit integer.

```
ERL_NIF_TERM enif_make_ulong(ErlNifEnv* env, unsigned long i)
```

Creates an integer term from an `unsigned long int`.

```
ERL_NIF_TERM enif_make_unique_integer(ErlNifEnv *env, ErlNifUniqueInteger
properties)
```

Returns a unique integer with the same properties as specified by *`erlang:unique_integer/1`*.

`env` is the environment to create the integer in.

`ERL_NIF_UNIQUE_POSITIVE` and `ERL_NIF_UNIQUE_MONOTONIC` can be passed as the second argument to change the properties of the integer returned. They can be combined by OR:ing the two values together.

See also *`ErlNifUniqueInteger`*.

`int enif_map_iterator_create(ErlNifEnv *env, ERL_NIF_TERM map, ErlNifMapIterator *iter, ErlNifMapIteratorEntry entry)`

Creates an iterator for the map `map` by initializing the structure pointed to by `iter`. Argument `entry` determines the start position of the iterator: `ERL_NIF_MAP_ITERATOR_FIRST` or `ERL_NIF_MAP_ITERATOR_LAST`.

Returns `true` on success, or false if `map` is not a map.

A map iterator is only useful during the lifetime of environment `env` that the `map` belongs to. The iterator must be destroyed by calling *`enif_map_iterator_destroy`*:

```
ERL_NIF_TERM key, value;
ErlNifMapIterator iter;
enif_map_iterator_create(env, my_map, &iter, ERL_NIF_MAP_ITERATOR_FIRST);

while (enif_map_iterator_get_pair(env, &iter, &key, &value)) {
    do_something(key,value);
    enif_map_iterator_next(env, &iter);
}
enif_map_iterator_destroy(env, &iter);
```

Note:

The key-value pairs of a map have no defined iteration order. The only guarantee is that the iteration order of a single map instance is preserved during the lifetime of the environment that the map belongs to.

`void enif_map_iterator_destroy(ErlNifEnv *env, ErlNifMapIterator *iter)`

Destroys a map iterator created by *`enif_map_iterator_create`*.

`int enif_map_iterator_get_pair(ErlNifEnv *env, ErlNifMapIterator *iter, ERL_NIF_TERM *key, ERL_NIF_TERM *value)`

Gets key and value terms at the current map iterator position.

On success, sets `*key` and `*value` and returns `true`. Returns `false` if the iterator is positioned at head (before first entry) or tail (beyond last entry).

`int enif_map_iterator_is_head(ErlNifEnv *env, ErlNifMapIterator *iter)`

Returns `true` if map iterator `iter` is positioned before the first entry.

`int enif_map_iterator_is_tail(ErlNifEnv *env, ErlNifMapIterator *iter)`

Returns `true` if map iterator `iter` is positioned after the last entry.

`int enif_map_iterator_next(ErlNifEnv *env, ErlNifMapIterator *iter)`

Increments map iterator to point to the next key-value entry.

Returns `true` if the iterator is now positioned at a valid key-value entry, or `false` if the iterator is positioned at the tail (beyond the last entry).

`int enif_map_iterator_prev(ErlNifEnv *env, ErlNifMapIterator *iter)`

Decrements map iterator to point to the previous key-value entry.

Returns `true` if the iterator is now positioned at a valid key-value entry, or `false` if the iterator is positioned at the head (before the first entry).

`int enif_monitor_process(ErlNifEnv* env, void* obj, const ErlNifPid* target_pid, ErlNifMonitor* mon)`

Starts monitoring a process from a resource. When a process is monitored, a process exit results in a call to the provided *`down`* callback associated with the resource type.

Argument `obj` is pointer to the resource to hold the monitor and `*target_pid` identifies the local process to be monitored.

If `mon` is not `NULL`, a successful call stores the identity of the monitor in the *`ErlNifMonitor`* struct pointed to by `mon`. This identifier is used to refer to the monitor for later removal with *`enif_demonitor_process`* or compare with *`enif_compare_monitors`*. A monitor is automatically removed when it triggers or when the resource is deallocated.

Returns `0` on success, < 0 if no `down` callback is provided, and > 0 if the process is no longer alive.

This function is only thread-safe when the emulator with SMP support is used. It can only be used in a non-SMP emulator from a NIF-calling thread.

`ErlNifTime enif_monotonic_time(ErlNifTimeUnit time_unit)`

Returns the current *Erlang monotonic time*. Notice that it is not uncommon with negative values.

`time_unit` is the time unit of the returned value.

Returns `ERL_NIF_TIME_ERROR` if called with an invalid time unit argument, or if called from a thread that is not a scheduler thread.

See also *`ErlNifTime`* and *`ErlNifTimeUnit`*.

`ErlNifMutex *enif_mutex_create(char *name)`

Same as *`erl_drv_mutex_create`*.

`void enif_mutex_destroy(ErlNifMutex *mtx)`

Same as *`erl_drv_mutex_destroy`*.

`void enif_mutex_lock(ErlNifMutex *mtx)`

Same as *`erl_drv_mutex_lock`*.

`int enif_mutex_trylock(ErlNifMutex *mtx)`

Same as *`erl_drv_mutex_trylock`*.

`void enif_mutex_unlock(ErlNifMutex *mtx)`

Same as *`erl_drv_mutex_unlock`*.

`ERL_NIF_TERM enif_now_time(ErlNifEnv *env)`

Returns an *erlang:now()* time stamp.

This function is deprecated.

`ErlNifResourceType *enif_open_resource_type(ErlNifEnv* env, const char* module_str, const char* name, ErlNifResourceDtor* dtor, ErlNifResourceFlags flags, ErlNifResourceFlags* tried)`

Creates or takes over a resource type identified by the string `name` and gives it the destructor function pointed to by *dtor*. Argument `flags` can have the following values:

`ERL_NIF_RT_CREATE`
: Creates a new resource type that does not already exist.

`ERL_NIF_RT_TAKEOVER`
: Opens an existing resource type and takes over ownership of all its instances. The supplied destructor `dtor` is called both for existing instances and new instances not yet created by the calling NIF library.

The two flag values can be combined with bitwise OR. The resource type name is local to the calling module. Argument `module_str` is not (yet) used and must be `NULL`. `dtor` can be `NULL` if no destructor is needed.

On success, the function returns a pointer to the resource type and `*tried` is set to either `ERL_NIF_RT_CREATE` or `ERL_NIF_RT_TAKEOVER` to indicate what was done. On failure, returns `NULL` and sets `*tried` to `flags`. It is allowed to set `tried` to `NULL`.

Notice that `enif_open_resource_type` is only allowed to be called in the two callbacks *load* and *upgrade*.

See also *enif_open_resource_type_x*.

`ErlNifResourceType *enif_open_resource_type_x(ErlNifEnv* env, const char* name, const ErlNifResourceTypeInit* init, ErlNifResourceFlags flags, ErlNifResourceFlags* tried)`

Same as *enif_open_resource_type* except it accepts additional callback functions for resource types that are used together with *enif_select* and *enif_monitor_process*.

Argument `init` is a pointer to an *ErlNifResourceTypeInit* structure that contains the function pointers for destructor, down and stop callbacks for the resource type.

`int enif_port_command(ErlNifEnv* env, const ErlNifPort* to_port, ErlNifEnv *msg_env, ERL_NIF_TERM msg)`

Works as *erlang:port_command/2*, except that it is always completely asynchronous.

`env`
: The environment of the calling process. Must not be `NULL`.

`*to_port`
: The port ID of the receiving port. The port ID is to refer to a port on the local node.

`msg_env`
: The environment of the message term. Can be a process-independent environment allocated with *enif_alloc_env* or `NULL`.

`msg`
: The message term to send. The same limitations apply as on the payload to *erlang:port_command/2*.

Using a `msg_env` of `NULL` is an optimization, which groups together calls to `enif_alloc_env`, `enif_make_copy`, `enif_port_command`, and `enif_free_env` into one call. This optimization is only useful when a majority of the terms are to be copied from `env` to `msg_env`.

Returns `true` if the command is successfully sent. Returns `false` if the command fails, for example:

- `*to_port` does not refer to a local port.
- The currently executing process (that is, the sender) is not alive.
- `msg` is invalid.

See also *enif_get_local_port*.

`void *enif_priv_data(ErlNifEnv* env)`

Returns the pointer to the private data that was set by *load* or *upgrade*.

`ERL_NIF_TERM enif_raise_exception(ErlNifEnv* env, ERL_NIF_TERM reason)`

Creates an error exception with the term `reason` to be returned from a NIF, and associates it with environment `env`. Once a NIF or any function it calls invokes `enif_raise_exception`, the runtime ensures that the exception it creates is raised when the NIF returns, even if the NIF attempts to return a non-exception term instead.

The return value from `enif_raise_exception` can only be used as the return value from the NIF that invoked it (directly or indirectly) or be passed to *enif_is_exception*, but not to any other NIF API function.

See also *enif_has_pending_exception* and *enif_make_badarg*.

`void *enif_realloc(void* ptr, size_t size)`

Reallocates memory allocated by *enif_alloc* to `size` bytes.

Returns `NULL` if the reallocation fails.

The returned pointer is suitably aligned for any built-in type that fit in the allocated memory.

`int enif_realloc_binary(ErlNifBinary* bin, size_t size)`

Changes the size of a binary `bin`. The source binary can be read-only, in which case it is left untouched and a mutable copy is allocated and assigned to `*bin`.

Returns `true` on success, or `false` if memory allocation failed.

`void enif_release_binary(ErlNifBinary* bin)`

Releases a binary obtained from *enif_alloc_binary*.

`void enif_release_resource(void* obj)`

Removes a reference to resource object `obj` obtained from *enif_alloc_resource*. The resource object is destructed when the last reference is removed. Each call to `enif_release_resource` must correspond to a previous call to `enif_alloc_resource` or *enif_keep_resource*. References made by *enif_make_resource* can only be removed by the garbage collector.

`ErlNifRWLock *enif_rwlock_create(char *name)`

Same as *erl_drv_rwlock_create*.

`void enif_rwlock_destroy(ErlNifRWLock *rwlck)`

Same as *erl_drv_rwlock_destroy*.

`void enif_rwlock_rlock(ErlNifRWLock *rwlck)`

Same as *erl_drv_rwlock_rlock*.

`void enif_rwlock_runlock(ErlNifRWLock *rwlck)`

Same as *erl_drv_rwlock_runlock*.

`void enif_rwlock_rwlock(ErlNifRWLock *rwlck)`

Same as *erl_drv_rwlock_rwlock*.

`void enif_rwlock_rwunlock(ErlNifRWLock *rwlck)`

Same as *erl_drv_rwlock_rwunlock*.

`int enif_rwlock_tryrlock(ErlNifRWLock *rwlck)`

Same as *erl_drv_rwlock_tryrlock*.

`int enif_rwlock_tryrwlock(ErlNifRWLock *rwlck)`

Same as *erl_drv_rwlock_tryrwlock*.

`ERL_NIF_TERM enif_schedule_nif(ErlNifEnv* env, const char* fun_name, int flags, ERL_NIF_TERM (*fp)(ErlNifEnv* env, int argc, const ERL_NIF_TERM argv[]), int argc, const ERL_NIF_TERM argv[])`

Schedules NIF `fp` to execute. This function allows an application to break up long-running work into multiple regular NIF calls or to schedule a *dirty NIF* to execute on a dirty scheduler thread.

`fun_name`

Provides a name for the NIF that is scheduled for execution. If it cannot be converted to an atom, `enif_schedule_nif` returns a `badarg` exception.

`flags`

Must be set to `0` for a regular NIF. If the emulator was built with dirty scheduler support enabled, `flags` can be set to either `ERL_NIF_DIRTY_JOB_CPU_BOUND` if the job is expected to be CPU-bound, or `ERL_NIF_DIRTY_JOB_IO_BOUND` for jobs that will be I/O-bound. If dirty scheduler threads are not available in the emulator, an attempt to schedule such a job results in a `notsup` exception.

`argc` and `argv`

Can either be the originals passed into the calling NIF, or can be values created by the calling NIF.

The calling NIF must use the return value of `enif_schedule_nif` as its own return value.

Be aware that `enif_schedule_nif`, as its name implies, only schedules the NIF for future execution. The calling NIF does not block waiting for the scheduled NIF to execute and return. This means that the calling NIF cannot expect to receive the scheduled NIF return value and use it for further operations.

`int enif_select(ErlNifEnv* env, ErlNifEvent event, enum ErlNifSelectFlags mode, void* obj, const ErlNifPid* pid, ERL_NIF_TERM ref)`

This function can be used to receive asynchronous notifications when OS-specific event objects become ready for either read or write operations.

Argument `event` identifies the event object. On Unix systems, the functions `select`/`poll` are used. The event object must be a socket, pipe or other file descriptor object that `select`/`poll` can use.

Argument `mode` describes the type of events to wait for. It can be `ERL_NIF_SELECT_READ`, `ERL_NIF_SELECT_WRITE` or a bitwise OR combination to wait for both. It can also be `ERL_NIF_SELECT_STOP` which is described further below. When a read or write event is triggerred, a notification message like this is sent to the process identified by `pid`:

```
{select, Obj, Ref, ready_input | ready_output}
```

`ready_input` or `ready_output` indicates if the event object is ready for reading or writing.

Argument `pid` may be `NULL` to indicate the calling process.

Argument `obj` is a resource object obtained from *`enif_alloc_resource`*. The purpose of the resource objects is as a container of the event object to manage its state and lifetime. A handle to the resource is received in the notification message as `Obj`.

Argument `ref` must be either a reference obtained from *`erlang:make_ref/0`* or the atom `undefined`. It will be passed as `Ref` in the notifications. If a selective `receive` statement is used to wait for the notification then a reference created just before the `receive` will exploit a runtime optimization that bypasses all earlier received messages in the queue.

The notifications are one-shot only. To receive further notifications of the same type (read or write), repeated calls to `enif_select` must be made after receiving each notification.

Use `ERL_NIF_SELECT_STOP` as `mode` in order to safely close an event object that has been passed to `enif_select`. The *`stop`* callback of the resource `obj` will be called when it is safe to close the event object. This safe way of closing event objects must be used even if all notifications have been received and no further calls to `enif_select` have been made.

The first call to `enif_select` for a specific OS `event` will establish a relation between the event object and the containing resource. All subsequent calls for an `event` must pass its containing resource as argument `obj`. The relation is dissolved when `enif_select` has been called with `mode` as `ERL_NIF_SELECT_STOP` and the corresponding `stop` callback has returned. A resource can contain several event objects but one event object can only be contained within one resource. A resource will not be destructed until all its contained relations have been dissolved.

Note:

Use *`enif_monitor_process`* together with `enif_select` to detect failing Erlang processes and prevent them from causing permanent leakage of resources and their contained OS event objects.

Returns a non-negative value on success where the following bits can be set:

`ERL_NIF_SELECT_STOP_CALLED`
: The stop callback was called directly by `enif_select`.

`ERL_NIF_SELECT_STOP_SCHEDULED`
: The stop callback was scheduled to run on some other thread or later by this thread.

Returns a negative value if the call failed where the follwing bits can be set:

`ERL_NIF_SELECT_INVALID_EVENT`
: Argument `event` is not a valid OS event object.

`ERL_NIF_SELECT_FAILED`
: The system call failed to add the event object to the poll set.

Note:

Use bitwise AND to test for specific bits in the return vaue. New significant bits may be added in future releases to give more detailed information for both failed and successful calls. Do NOT use equallity tests like `==`, as that may cause your application to stop working.

Example:

```
retval = enif_select(env, fd, ERL_NIF_SELECT_STOP, resource, ref);
if (retval < 0) {
    /* handle error */
}
/* Success! */
if (retval & ERL_NIF_SELECT_STOP_CALLED) {
    /* ... */
}
```

`ErlNifPid *enif_self(ErlNifEnv* caller_env, ErlNifPid* pid)`

Initializes the pid variable `*pid` to represent the calling process.

Returns `pid`.

`int enif_send(ErlNifEnv* env, ErlNifPid* to_pid, ErlNifEnv* msg_env, ERL_NIF_TERM msg)`

Sends a message to a process.

`env`
: The environment of the calling process. Must be `NULL` only if calling from a created thread.

`*to_pid`
: The pid of the receiving process. The pid is to refer to a process on the local node.

`msg_env`
: The environment of the message term. Must be a process-independent environment allocated with *`enif_alloc_env`* or NULL.

`msg`
: The message term to send.

Returns `true` if the message is successfully sent. Returns `false` if the send operation fails, that is:

- `*to_pid` does not refer to an alive local process.
- The currently executing process (that is, the sender) is not alive.

The message environment `msg_env` with all its terms (including `msg`) is invalidated by a successful call to `enif_send`. The environment is to either be freed with *`enif_free_env`* of cleared for reuse with *`enif_clear_env`*.

If `msg_env` is set to `NULL`, the `msg` term is copied and the original term and its environemt is still valid after the call.

This function is only thread-safe when the emulator with SMP support is used. It can only be used in a non-SMP emulator from a NIF-calling thread.

Note:

Passing `msg_env` as `NULL` is only supported as from ERTS 8.0 (Erlang/OTP 19).

`unsigned enif_sizeof_resource(void* obj)`

Gets the byte size of resource object `obj` obtained by *`enif_alloc_resource`*.

`int enif_snprintf(char *str, size_t size, const char *format, ...)`

Similar to `snprintf` but this format string also accepts `"%T"`, which formats Erlang terms.

`void enif_system_info(ErlNifSysInfo *sys_info_ptr, size_t size)`

Same as *`driver_system_info`*.

`int enif_term_to_binary(ErlNifEnv *env, ERL_NIF_TERM term, ErlNifBinary *bin)`

Allocates a new binary with *`enif_alloc_binary`* and stores the result of encoding `term` according to the Erlang external term format.

Returns `true` on success, or `false` if the allocation fails.

See also *`erlang:term_to_binary/1`* and *`enif_binary_to_term`*.

`int enif_thread_create(char *name,ErlNifTid *tid,void * (*func)(void *),void *args,ErlNifThreadOpts *opts)`

Same as *`erl_drv_thread_create`*.

`void enif_thread_exit(void *resp)`

Same as *`erl_drv_thread_exit`*.

`int enif_thread_join(ErlNifTid, void **respp)`

Same as *`erl_drv_thread_join`*.

`ErlNifThreadOpts *enif_thread_opts_create(char *name)`

Same as *`erl_drv_thread_opts_create`*.

`void enif_thread_opts_destroy(ErlNifThreadOpts *opts)`

Same as *`erl_drv_thread_opts_destroy`*.

`ErlNifTid enif_thread_self(void)`

Same as *`erl_drv_thread_self`*.

`int enif_thread_type(void)`

Determine the type of currently executing thread. A positive value indicates a scheduler thread while a negative value or zero indicates another type of thread. Currently the following specific types exist (which may be extended in the future):

`ERL_NIF_THR_UNDEFINED`

Undefined thread that is not a scheduler thread.

`ERL_NIF_THR_NORMAL_SCHEDULER`

A normal scheduler thread.

`ERL_NIF_THR_DIRTY_CPU_SCHEDULER`

A dirty CPU scheduler thread.

`ERL_NIF_THR_DIRTY_IO_SCHEDULER`

A dirty I/O scheduler thread.

`ErlNifTime enif_time_offset(ErlNifTimeUnit time_unit)`

Returns the current time offset between *Erlang monotonic time* and *Erlang system time* converted into the `time_unit` passed as argument.

`time_unit` is the time unit of the returned value.

Returns `ERL_NIF_TIME_ERROR` if called with an invalid time unit argument or if called from a thread that is not a scheduler thread.

See also *`ErlNifTime`* and *`ErlNifTimeUnit`*.

`void *enif_tsd_get(ErlNifTSDKey key)`

Same as *`erl_drv_tsd_get`*.

`int enif_tsd_key_create(char *name, ErlNifTSDKey *key)`

Same as *`erl_drv_tsd_key_create`*.

`void enif_tsd_key_destroy(ErlNifTSDKey key)`

Same as *`erl_drv_tsd_key_destroy`*.

`void enif_tsd_set(ErlNifTSDKey key, void *data)`

Same as *`erl_drv_tsd_set`*.

`int enif_whereis_pid(ErlNifEnv *env, ERL_NIF_TERM name, ErlNifPid *pid)`

Looks up a process by its registered name.

`env`
: The environment of the calling process. Must be `NULL` only if calling from a created thread.

`name`
: The name of a registered process, as an atom.

`*pid`
: The *`ErlNifPid`* in which the resolved process id is stored.

On success, sets `*pid` to the local process registered with `name` and returns `true`. If `name` is not a registered process, or is not an atom, `false` is returned and `*pid` is unchanged.

Works as *`erlang:whereis/1`*, but restricted to processes. See *`enif_whereis_port`* to resolve registered ports.

`int enif_whereis_port(ErlNifEnv *env, ERL_NIF_TERM name, ErlNifPort *port)`

Looks up a port by its registered name.

`env`
: The environment of the calling process. Must be `NULL` only if calling from a created thread.

`name`
: The name of a registered port, as an atom.

`*port`
: The *`ErlNifPort`* in which the resolved port id is stored.

On success, sets `*port` to the port registered with `name` and returns `true`. If `name` is not a registered port, or is not an atom, `false` is returned and `*port` is unchanged.

Works as *`erlang:whereis/1`*, but restricted to ports. See *`enif_whereis_pid`* to resolve registered processes.

See Also

`erlang:load_nif/2`

erl_tracer

Erlang module

This behavior module implements the back end of the Erlang tracing system. The functions in this module are called whenever a trace probe is triggered. Both the `enabled` and `trace` functions are called in the context of the entity that triggered the trace probe. This means that the overhead by having the tracing enabled is greatly effected by how much time is spent in these functions. So, do as little work as possible in these functions.

Note:

All functions in this behavior must be implemented as NIFs. This limitation can be removed in a future releases. An *example tracer module NIF* implementation is provided at the end of this page.

Warning:

Do not send messages or issue port commands to the `Tracee` in any of the callbacks. This is not allowed and can cause all sorts of strange behavior, including, but not limited to, infinite recursions.

Data Types

```
trace_tag_call() =
    call | return_to | return_from | exception_from
trace_tag_gc() =
    gc_minor_start | gc_minor_end | gc_major_start | gc_major_end
trace_tag_ports() =
    open |
    closed |
    link |
    unlink |
    getting_linked |
    getting_unlinked
trace_tag_procs() =
    spawn |
    spawned |
    exit |
    link |
    unlink |
    getting_linked |
    getting_unlinked |
    register |
    unregister
trace_tag_receive() = 'receive'
trace_tag_running_ports() =
    in | out | in_exiting | out_exiting | out_exited
trace_tag_running_procs() =
```

```
    in | out | in_exiting | out_exiting | out_exited
trace_tag_send() = send | send_to_non_existing_process
trace_tag() =
    trace_tag_send() |
    trace_tag_receive() |
    trace_tag_call() |
    trace_tag_procs() |
    trace_tag_ports() |
    trace_tag_running_procs() |
    trace_tag_running_ports() |
    trace_tag_gc()
```

The different trace tags that the tracer is called with. Each trace tag is described in detail in *`Module:trace/5`*.

```
tracee() = port() | pid() | undefined
```

The process or port that the trace belongs to.

```
trace_opts() =
    #{extra => term(),
      match_spec_result => term(),
      scheduler_id => integer() >= 0,
      timestamp =>
          timestamp | cpu_timestamp | monotonic | strict_monotonic}
```

The options for the tracee:

`timestamp`
: If set the tracer has been requested to include a time stamp.

`extra`
: If set the tracepoint has included additional data about the trace event. What the additional data is depends on which `TraceTag` has been triggered. The `extra` trace data corresponds to the fifth element in the trace tuples described in *erlang:trace/3*.

`match_spec_result`
: If set the tracer has been requested to include the output of a match specification that was run.

`scheduler_id`
: If set the scheduler id is to be included by the tracer.

```
tracer_state() = term()
```

The state specified when calling *`erlang:trace(PidPortSpec,true, [{tracer,Module,TracerState}])`*. The tracer state is an immutable value that is passed to `erl_tracer` callbacks and is to contain all the data that is needed to generate the trace event.

Callback Functions

The following functions are to be exported from an `erl_tracer` callback module:

`Module:enabled/3`
: Mandatory

`Module:trace/5`
: Mandatory

`Module:enabled_call/3`
: Optional

`Module:trace_call/5`
: Optional

Module:enabled_garbage_collection/3
Optional
Module:trace_garbage_collection/5
Optional
Module:enabled_ports/3
Optional
Module:trace_ports/5
Optional
Module:enabled_procs/3
Optional
Module:trace_procs/5
Optional
Module:enabled_receive/3
Optional
Module:trace_receive/5
Optional
Module:enabled_running_ports/3
Optional
Module:trace_running_ports/5
Optional
Module:enabled_running_procs/3
Optional
Module:trace_running_procs/5
Optional
Module:enabled_send/3
Optional
Module:trace_send/5
Optional

Exports

`Module:enabled(TraceTag, TracerState, Tracee) -> Result`

Types:

TraceTag = *trace_tag()* | trace_status
TracerState = term()
Tracee = *tracee()*
Result = trace | discard | remove

This callback is called whenever a tracepoint is triggered. It allows the tracer to decide whether a trace is to be generated or not. This check is made as early as possible to limit the amount of overhead associated with tracing. If `trace` is returned, the necessary trace data is created and the trace callback of the tracer is called. If `discard` is returned, this trace call is discarded and no call to trace is done.

`trace_status` is a special type of `TraceTag`, which is used to check if the tracer is still to be active. It is called in multiple scenarios, but most significantly it is used when tracing is started using this tracer. If `remove` is returned when the `trace_status` is checked, the tracer is removed from the tracee.

This function can be called multiple times per tracepoint, so it is important that it is both fast and without side effects.

`Module:enabled_call(TraceTag, TracerState, Tracee) -> Result`

Types:

TraceTag = *trace_tag_call()*

```
TracerState = term()
Tracee = tracee()
Result = trace | discard | remove
```

This callback is called whenever a tracepoint with trace flag `call | return_to` is triggered.

If `enabled_call/3` is undefined, `Module:enabled/3` is called instead.

`Module:enabled_garbage_collection(TraceTag, TracerState, Tracee) -> Result`

Types:

```
TraceTag =  trace_tag_gc()
TracerState = term()
Tracee = tracee()
Result = trace | discard | remove
```

This callback is called whenever a tracepoint with trace flag `garbage_collection` is triggered.

If `enabled_garbage_collection/3` is undefined, `Module:enabled/3` is called instead.

`Module:enabled_ports(TraceTag, TracerState, Tracee) -> Result`

Types:

```
TraceTag =  trace_tag_ports()
TracerState = term()
Tracee = tracee()
Result = trace | discard | remove
```

This callback is called whenever a tracepoint with trace flag `ports` is triggered.

If `enabled_ports/3` is undefined, `Module:enabled/3` is called instead.

`Module:enabled_procs(TraceTag, TracerState, Tracee) -> Result`

Types:

```
TraceTag =  trace_tag_procs()
TracerState = term()
Tracee = tracee()
Result = trace | discard | remove
```

This callback is called whenever a tracepoint with trace flag `procs` is triggered.

If `enabled_procs/3` is undefined, `Module:enabled/3` is called instead.

`Module:enabled_receive(TraceTag, TracerState, Tracee) -> Result`

Types:

```
TraceTag =  trace_tag_receive()
TracerState = term()
Tracee = tracee()
Result = trace | discard | remove
```

This callback is called whenever a tracepoint with trace flag `'receive'` is triggered.

If `enabled_receive/3` is undefined, `Module:enabled/3` is called instead.

`Module:enabled_running_ports(TraceTag, TracerState, Tracee) -> Result`

Types:

```
TraceTag =  trace_tag_running_ports()
TracerState = term()
Tracee = tracee()
Result = trace | discard | remove
```

This callback is called whenever a tracepoint with trace flag *`running_ports`* is triggered.

If `enabled_running_ports/3` is undefined, *`Module:enabled/3`* is called instead.

`Module:enabled_running_procs(TraceTag, TracerState, Tracee) -> Result`

Types:

```
TraceTag =  trace_tag_running_procs()
TracerState = term()
Tracee = tracee()
Result = trace | discard | remove
```

This callback is called whenever a tracepoint with trace flag *`running_procs`* | *`running`* is triggered.

If `enabled_running_procs/3` is undefined, *`Module:enabled/3`* is called instead.

`Module:enabled_send(TraceTag, TracerState, Tracee) -> Result`

Types:

```
TraceTag =  trace_tag_send()
TracerState = term()
Tracee = tracee()
Result = trace | discard | remove
```

This callback is called whenever a tracepoint with trace flag *`send`* is triggered.

If `enabled_send/3` is undefined, *`Module:enabled/3`* is called instead.

`Module:trace(TraceTag, TracerState, Tracee, TraceTerm, Opts) -> Result`

Types:

```
TraceTag =  trace_tag()
TracerState = term()
Tracee = tracee()
TraceTerm = term()
Opts = trace_opts()
Result = ok
```

This callback is called when a tracepoint is triggered and the *`Module:enabled/3`* callback returned `trace`. In it any side effects needed by the tracer are to be done. The tracepoint payload is located in the `TraceTerm`. The content of the `TraceTerm` depends on which `TraceTag` is triggered. `TraceTerm` corresponds to the fourth element in the trace tuples described in *`erlang:trace/3`*.

If the trace tuple has five elements, the fifth element will be sent as the `extra` value in the `Opts` maps.

`Module:trace(seq_trace, TracerState, Label, SeqTraceInfo, Opts) -> Result`

Types:

TracerState = term()
Label = term()
SeqTraceInfo = term()
Opts = *trace_opts()*
Result = ok

The `TraceTag` `seq_trace` is handled slightly differently. There is no `Tracee` for `seq_trace`, instead the `Label` associated with the `seq_trace` event is specified.

For more information on what `Label` and `SeqTraceInfo` can be, see *`seq_trace(3)`*.

`Module:trace_call(TraceTag, TracerState, Tracee, TraceTerm, Opts) -> Result`

Types:

TraceTag = *trace_tag_call()*
TracerState = term()
Tracee = *tracee()*
TraceTerm = term()
Opts = *trace_opts()*
Result = ok

This callback is called when a tracepoint is triggered and the *`Module:enabled_call/3`* callback returned `trace`.

If `trace_call/5` is undefined, *`Module:trace/5`* is called instead.

`Module:trace_garbage_collection(TraceTag, TracerState, Tracee, TraceTerm, Opts) -> Result`

Types:

TraceTag = *trace_tag_gc()*
TracerState = term()
Tracee = *tracee()*
TraceTerm = term()
Opts = *trace_opts()*
Result = ok

This callback is called when a tracepoint is triggered and the *`Module:enabled_garbage_collection/3`* callback returned `trace`.

If `trace_garbage_collection/5` is undefined, *`Module:trace/5`* is called instead.

`Module:trace_ports(TraceTag, TracerState, Tracee, TraceTerm, Opts) -> Result`

Types:

TraceTag = *trace_tag()*
TracerState = term()
Tracee = *tracee()*
TraceTerm = term()
Opts = *trace_opts()*
Result = ok

This callback is called when a tracepoint is triggered and the *`Module:enabled_ports/3`* callback returned `trace`.

If `trace_ports/5` is undefined, *`Module:trace/5`* is called instead.

`Module:trace_procs(TraceTag, TracerState, Tracee, TraceTerm, Opts) -> Result`

Types:

TraceTag = ***trace_tag()***
TracerState = term()
Tracee = ***tracee()***
TraceTerm = term()
Opts = ***trace_opts()***
Result = ok

This callback is called when a tracepoint is triggered and the *`Module:enabled_procs/3`* callback returned `trace`.

If `trace_procs/5` is undefined, *`Module:trace/5`* is called instead.

`Module:trace_receive(TraceTag, TracerState, Tracee, TraceTerm, Opts) -> Result`

Types:

TraceTag = ***trace_tag_receive()***
TracerState = term()
Tracee = ***tracee()***
TraceTerm = term()
Opts = ***trace_opts()***
Result = ok

This callback is called when a tracepoint is triggered and the *`Module:enabled_receive/3`* callback returned `trace`.

If `trace_receive/5` is undefined, *`Module:trace/5`* is called instead.

`Module:trace_running_ports(TraceTag, TracerState, Tracee, TraceTerm, Opts) -> Result`

Types:

TraceTag = ***trace_tag_running_ports()***
TracerState = term()
Tracee = ***tracee()***
TraceTerm = term()
Opts = ***trace_opts()***
Result = ok

This callback is called when a tracepoint is triggered and the *`Module:enabled_running_ports/3`* callback returned `trace`.

If `trace_running_ports/5` is undefined, *`Module:trace/5`* is called instead.

`Module:trace_running_procs(TraceTag, TracerState, Tracee, TraceTerm, Opts) -> Result`

Types:

TraceTag = ***trace_tag_running_procs()***

TracerState = term()
Tracee = *tracee()*
TraceTerm = term()
Opts = *trace_opts()*
Result = ok

This callback is called when a tracepoint is triggered and the *`Module:enabled_running_procs/3`* callback returned `trace`.

If `trace_running_procs/5` is undefined, *`Module:trace/5`* is called instead.

`Module:trace_send(TraceTag, TracerState, Tracee, TraceTerm, Opts) -> Result`

Types:

TraceTag = *trace_tag_send()*
TracerState = term()
Tracee = *tracee()*
TraceTerm = term()
Opts = *trace_opts()*
Result = ok

This callback is called when a tracepoint is triggered and the *`Module:enabled_send/3`* callback returned `trace`.

If `trace_send/5` is undefined, *`Module:trace/5`* is called instead.

Erl Tracer Module Example

In this example, a tracer module with a NIF back end sends a message for each `send` trace tag containing only the sender and receiver. Using this tracer module, a much more lightweight message tracer is used, which only records who sent messages to who.

The following is an example session using it on Linux:

```
$ gcc -I erts-8.0/include/ -fPIC -shared -o erl_msg_tracer.so erl_msg_tracer.c
$ erl
Erlang/OTP 19 [DEVELOPMENT] [erts-8.0] [source-ed2b56b] [64-bit] [smp:8:8] [async-threads:10] [hipe] [kernel

Eshell V8.0  (abort with ^G)
1> c(erl_msg_tracer), erl_msg_tracer:load().
ok
2> Tracer = spawn(fun F() -> receive M -> io:format("~p~n",[M]), F() end end).
<0.37.0>
3> erlang:trace(new, true, [send,{tracer, erl_msg_tracer, Tracer}]).
0
{trace,<0.39.0>,<0.27.0>}
4> {ok, D} = file:open("/tmp/tmp.data",[write]).
{trace,#Port<0.486>,<0.40.0>}
{trace,<0.40.0>,<0.21.0>}
{trace,#Port<0.487>,<0.4.0>}
{trace,#Port<0.488>,<0.4.0>}
{trace,#Port<0.489>,<0.4.0>}
{trace,#Port<0.490>,<0.4.0>}
{ok,<0.40.0>}
{trace,<0.41.0>,<0.27.0>}
5>
```

`erl_msg_tracer.erl`:

```
-module(erl_msg_tracer).

-export([enabled/3, trace/5, load/0]).

load() ->
    erlang:load_nif("erl_msg_tracer", []).

enabled(_, _, _) ->
    error.

trace(_, _, _, _, _) ->
    error.
```

`erl_msg_tracer.c`:

```
#include <erl_nif.h>

/* NIF interface declarations */
static int load(ErlNifEnv* env, void** priv_data, ERL_NIF_TERM load_info);
static int upgrade(ErlNifEnv* env, void** priv_data, void** old_priv_data, ERL_NIF_TERM load_info);
static void unload(ErlNifEnv* env, void* priv_data);

/* The NIFs: */
static ERL_NIF_TERM enabled(ErlNifEnv* env, int argc, const ERL_NIF_TERM argv[]);
static ERL_NIF_TERM trace(ErlNifEnv* env, int argc, const ERL_NIF_TERM argv[]);

static ErlNifFunc nif_funcs[] = {
    {"enabled", 3, enabled},
    {"trace", 5, trace}
};

ERL_NIF_INIT(erl_msg_tracer, nif_funcs, load, NULL, upgrade, unload)

static int load(ErlNifEnv* env, void** priv_data, ERL_NIF_TERM load_info)
{
    *priv_data = NULL;
    return 0;
}

static void unload(ErlNifEnv* env, void* priv_data)
{

}

static int upgrade(ErlNifEnv* env, void** priv_data, void** old_priv_data,
     ERL_NIF_TERM load_info)
{
    if (*old_priv_data != NULL || *priv_data != NULL) {
 return -1; /* Don't know how to do that */
    }
    if (load(env, priv_data, load_info)) {
 return -1;
    }
    return 0;
}

/*
 * argv[0]: TraceTag
 * argv[1]: TracerState
 * argv[2]: Tracee
 */
static ERL_NIF_TERM enabled(ErlNifEnv* env, int argc, const ERL_NIF_TERM argv[])
{
    ErlNifPid to_pid;
    if (enif_get_local_pid(env, argv[1], &to_pid))
        if (!enif_is_process_alive(env, &to_pid))
            if (enif_is_identical(enif_make_atom(env, "trace_status"), argv[0]))
                /* tracer is dead so we should remove this tracepoint */
                return enif_make_atom(env, "remove");
            else
                return enif_make_atom(env, "discard");

    /* Only generate trace for when tracer != tracee */
    if (enif_is_identical(argv[1], argv[2]))
        return enif_make_atom(env, "discard");

    /* Only trigger trace messages on 'send' */
    if (enif_is_identical(enif_make_atom(env, "send"), argv[0]))
        return enif_make_atom(env, "trace");
```

```
    /* Have to answer trace_status */
    if (enif_is_identical(enif_make_atom(env, "trace_status"), argv[0]))
        return enif_make_atom(env, "trace");

    return enif_make_atom(env, "discard");
}

/*
 * argv[0]: TraceTag, should only be 'send'
 * argv[1]: TracerState, process to send {Tracee, Recipient} to
 * argv[2]: Tracee
 * argv[3]: Message
 * argv[4]: Options, map containing Recipient
 */
static ERL_NIF_TERM trace(ErlNifEnv* env, int argc, const ERL_NIF_TERM argv[])
{
    ErlNifPid to_pid;
    ERL_NIF_TERM recipient, msg;

    if (enif_get_local_pid(env, argv[1], &to_pid)) {
      if (enif_get_map_value(env, argv[4], enif_make_atom(env, "extra"), &recipient)) {
        msg = enif_make_tuple3(env, enif_make_atom(env, "trace"), argv[2], recipient);
        enif_send(env, &to_pid, NULL, msg);
      }
    }

    return enif_make_atom(env, "ok");
}
```