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 \texttt{erlang:now/0}. \texttt{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.
1.3 Time and Time Correction in Erlang

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
1.3 Time and Time Correction in Erlang

- 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.
1.3 Time and Time Correction in Erlang

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.
1.3 Time and Time Correction in Erlang

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)`
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 smoother 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:

```erlang
{'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.
1.3 Time and Time Correction in Erlang

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:

```erlang
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) | '__' | '$$'
• TermConstruct = {{}} | {{ ConditionExpression, ... }} | [ ] | [ConditionExpression, ... ] | #() | #{term() => ConditionExpression, ... } | NonCompositeTerm | Constant
• NonCompositeTerm ::= term() (not list or tuple or map)
• Constant ::= { const, term() } | GuardFunction ::= BoolFunction | abs | element | hd | length | node | round | size | tl | trunc | '+' | '-' | '*' | 'div' | 'rem' | 'band' | 'bor' | 'bxor' | 'bnot' | 'bsl' | 'bsr' | '=>' | '=<' | '===' | '==' | '/=' | 'self' | get_tcw
• MatchBody ::= [ ActionTerm ]
• ActionTerm ::= ConditionExpression | ActionCall
• ActionCall ::= { ActionFunction } | { ActionFunction, ActionTerm, ... }
• ActionFunction ::= set_seq_token | get_seq_token | message | return_trace | exception_trace | process_dump | enable_trace | disable_trace | trace | display | caller | set_tcw | silent
A match specification used in \texttt{ets(3)} can be described in the following \textit{informal} grammar:
• MatchExpression ::= [ MatchFunction, ... ]
• MatchFunction ::= [ MatchHead, MatchConditions, MatchBody ]
• MatchHead ::= MatchVariable | '_-' | [ MatchHeadPart, ... ]
• MatchHeadPart ::= term() | MatchVariable | '__'
• MatchVariable ::= '$<number>'
• MatchConditions ::= [ MatchCondition, ... ] | [ ]
• MatchCondition ::= { GuardFunction } | { GuardFunction, ConditionExpression, ... }
• BoolFunction ::= is_atom | is_float | is_integer | is_list | is_number | is_pid | is_port | is_reference | is_tuple | is_map | is_binary | is_function | is_record | is_seq_trace | and' | 'or' | 'not' | 'xor' | 'andalso' | 'orelse'
• ConditionExpression ::= ExprMatchVariable | { GuardFunction } | { GuardFunction, ConditionExpression, ... } | TermConstruct
• ExprMatchVariable ::= MatchVariable (bound in the MatchHead) | '__' | '$$'
• TermConstruct = {{}} | {{ ConditionExpression, ... }} | [ ] | [ConditionExpression, ... ] | #() | #{term() => ConditionExpression, ... } | NonCompositeTerm | Constant
• NonCompositeTerm ::= term() (not list or tuple or map)
• Constant ::= { const, term() }
1.4 Match Specifications in Erlang

- GuardFunction ::= BoolFunction | \( \text{abs} \) | \( \text{element} \) | \( \text{hd} \) | \( \text{length} \) | \( \text{node} \) | \( \text{round} \) | \( \text{size} \) | \( \text{trunc} \) | '+' | '-' | '*' | '/' | '%' | '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:

- \( \text{is_atom} \), \( \text{is_float} \), \( \text{is_integer} \), \( \text{is_list} \), \( \text{is_number} \), \( \text{is_pid} \), \( \text{is_port} \), \( \text{is_reference} \), \( \text{is_tuple} \), \( \text{is_map} \), \( \text{is_binary} \), \( \text{is_function} \)

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

- \( \text{is_record} \)

  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:

- \( \text{is_seq_trace} \)

  Returns true if a sequential trace token is set for the current process, otherwise false.
1.4 Match Specifications in Erlang

**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.

**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.

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.
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.

<table>
<thead>
<tr>
<th>Context</th>
<th>Type</th>
<th>Match target</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ETS</td>
<td></td>
<td>{Key, Value1, Value2, ...}</td>
<td>A table object</td>
</tr>
<tr>
<td>Trace call</td>
<td></td>
<td>[Arg1, Arg2, ...]</td>
<td>Function arguments</td>
</tr>
<tr>
<td>Trace send</td>
<td></td>
<td>[Receiver, Message]</td>
<td>Receiving process/port and message term</td>
</tr>
<tr>
<td>Trace 'receive'</td>
<td></td>
<td>[Node, Sender, Message]</td>
<td>Sending node, process/port and message term</td>
</tr>
</tbody>
</table>

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 (1e8). 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:

<table>
<thead>
<tr>
<th>Expression</th>
<th>Variable Bindings</th>
<th>Result</th>
</tr>
</thead>
</table>

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 Match Specifications in Erlang

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 ActionTerms are executed as in an imperative language, that is, for their side effects. Functions with side effects are also allowed when tracing.

---

<table>
<thead>
<tr>
<th>MatchExpression</th>
<th>MatchHead part</th>
<th>MatchBody part</th>
</tr>
</thead>
<tbody>
<tr>
<td>[{'$1', '$2'}]</td>
<td>'$1' = a, '$2' = b</td>
<td>{a,b}</td>
</tr>
<tr>
<td>{const, {'$1', '$2'}}</td>
<td>Irrelevant</td>
<td>{'$1', '$2'}</td>
</tr>
<tr>
<td>a</td>
<td>Irrelevant</td>
<td>a</td>
</tr>
<tr>
<td>'$1'</td>
<td>'$1' = []</td>
<td>[]</td>
</tr>
<tr>
<td>['$1']</td>
<td>'$1' = []</td>
<td>[[]]</td>
</tr>
<tr>
<td>[[{a}]]</td>
<td>Irrelevant</td>
<td>[{a}]</td>
</tr>
<tr>
<td>42</td>
<td>Irrelevant</td>
<td>42</td>
</tr>
<tr>
<td>&quot;hello&quot;</td>
<td>Irrelevant</td>
<td>&quot;hello&quot;</td>
</tr>
<tr>
<td>$1</td>
<td>Irrelevant</td>
<td>49 (the ASCII value for character '1')</td>
</tr>
</tbody>
</table>

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

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

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

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

```erlang
[[{'_', '$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}]):

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

The above problem can also be solved as follows:

```erlang
[[{'$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]):

```erlang
[[{'$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:

```erlang
[[{'$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 \texttt{MatchVariable} or an \texttt{'_'.} To replace the whole parameter list with a single variable is a special case. In all other cases the \texttt{MatchHead} must be a \texttt{proper} list.

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

\begin{verbatim}
[{'_','-'),
 ['==','{get_tcw},{const, 1}'],,
 []]
\end{verbatim}

Generate a trace message only if there is a \texttt{seq_trace} token:

\begin{verbatim}
[{'_','-'),
 ['==','{is_seq_trace},{const, 1}'],,
 []]
\end{verbatim}

Remove the \texttt{'silent'} trace flag when the first argument is \texttt{'verbose'}, and add it when it is \texttt{'silent'}:

\begin{verbatim}
['$1','-'),
 ['==','{hd, '$1'},verbose]
 ['trace', [silent],[[]]],
 ['$1','-'),
 ['==','{hd, '$1'},silent]
 ['trace', [],[silent]]
\end{verbatim}

Add a \texttt{return_trace} message if the function is of arity 3:

\begin{verbatim}
['$1','-'),
 ['==','{length, '$1'},3]
 ['return_trace'],
 ['_','-'),[[],[]]]
\end{verbatim}

Generate a trace message only if the function is of arity 3 and the first argument is \texttt{'trace'}:

\begin{verbatim}
[['trace','$2','$3']
 ,[],
 ['_','-'),[[],[]]]
\end{verbatim}

1.4.8 ETS Examples

Match all objects in an ETS table, where the first element is the atom \texttt{'strider'} and the tuple arity is 3, and return the whole object:
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.
1.5 How to Interpret the Erlang Crash Dumps

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.
1.5 How to Interpret the Erlang Crash Dumps

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 obtained 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).
1.5 How to Interpret the Erlang Crash Dumps

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, duplicate_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.
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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.
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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:
1.6 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:

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
1.6 How to Implement an Alternative Carrier for the Erlang Distribution

- 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. Queueing 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:

```c
#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include <unistd.h>
#include <errno.h>
#include <sys/types.h>
#include <sys/stat.h>
#include <sys/socket.h>
#include <sys/un.h>
#include <fcntl.h>
#define HAVE_UIO_H
#include "erl_driver.h"

/* Interface routines */
static ErlDrvData uds_start(ErlDrvPort port, char *buff);
static void uds_stop(ErlDrvData handle);
static void uds_command(ErlDrvData handle, char *buff, int bufflen);
static void uds_input(ErlDrvData handle, ErlDrvEvent event);
static void uds_output(ErlDrvData handle, ErlDrvEvent event);
static void uds_finish(void);
static int uds_control(ErlDrvData handle, unsigned int command,
                       char* buf, int count, char** res, int res_size);

static ErlDrvEntry uds_driver_entry = {
    NULL,                            /* init, N/A */
    uds_start,                       /* start, called when port is opened */
    uds_stop,                        /* stop, called when port is closed */
    uds_command,                     /* output, called when erlang has sent */
    uds_input,                       /* ready_input, called when input descriptor ready */
    uds_output,                      /* ready_output, called when output descriptor ready */
    "uds_drv",                       /* char *driver_name, the argument to open_port */
    uds_finish,                      /* finish, called when unloaded */
    NULL,                            /* void * that is not used (BC) */
    uds_control,                     /* control, port_control callback */
    NULL,                            /* timeout, called on timeouts */
    NULL,                            /* outputv, vector output interface */
    NULL,                            /* ready async callback */
    NULL,                            /* flush callback */
    NULL,                            /* call callback */
    NULL,                            /* event callback */
    ERL_DRV_EXTENDED_MARKER,         /* Extended driver interface marker */
    ERL_DRV_EXTENDED_MAJOR_VERSION,  /* Major version number */
    ERL_DRV_EXTENDED_MINOR_VERSION,  /* Minor version number */
    ERL_DRV_FLAG_SOFT_BUSY,          /* Driver flags. Soft busy flag is required for distribution drivers */
    NULL,                            /* Reserved for internal use */
    NULL,                            /* process_exit callback */
};
```
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:

```c
typedef enum {
    portTypeUnknown,      /* An uninitialized port */
    portTypeListener,     /* A listening port/socket */
    portTypeAcceptor,     /* An intermediate stage when accepting
                           on a listen port */
    portTypeConnector,    /* An intermediate stage when connecting */
    portTypeCommand,      /* A connected open port in command mode */
    portTypeIntermediate, /* A connected open port in special
                           half active mode */
    portTypeData          /* A connected open port in data mode */
} 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:

```c
typedef unsigned char Byte;
typedef unsigned int Word;

typedef struct uds_data {
    int fd;                   /* File descriptor */
    ErlDrvPort port;          /* The port identifier */
    int lockfd;               /* The file descriptor for a lock file in case of listen sockets */
    Byte creation;            /* The creation serial derived from the lock file */
    PortType type;            /* Type of port */
    char *name;               /* Short name of socket for unlink */
    Word sent;                /* Bytes sent */
    Word received;            /* Bytes received */
    struct uds_data *partner; /* The partner in an accept/listen pair */
    struct uds_data *next;    /* Next structure in list */
    int buffer_size;          /* The allocated size of the input buffer */
    int buffer_pos;           /* Where the current header is in the input buffer */
    int header_pos;           /* Where the current header is in the input buffer */
    Byte *buffer;             /* The actual input buffer */
} 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.
Selected Parts of the Distribution Driver Implementation

The implementation 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) }
```
1.6 How to Implement an Alternative Carrier for the Erlang Distribution

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.

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

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:

```c
(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) {
```

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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

```c
(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) }
```

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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:

```c
( 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)         }/* Got a package */
(14)         if (ud->type == portTypeCommand) {
(15)             ibuf[-1] = 'R'; /* There is always room for a single byte
(16)                 opcode before the actual buffer
(17)                 (where the packet header was) */
(18)             driver_output(ud->port, ibuf - 1, res + 1);
(19)             driver_select(ud->port, (ErlDrvEvent) ud->fd, DO_READ,0);
(20)             return;
(21)         } else {
(22)             ibuf[-1] = DIST_MAGIC_RECV_TAG; /* XXX */
(23)             driver_output(ud->port, ibuf - 1, res + 1);
(24)             driver_select(ud->port, (ErlDrvEvent) ud->fd, DO_READ,1);
(25)         }
(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:
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:

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

    put_packet_length(header, bufflen);
    iov[0].iov_base = (char *) header;
    iov[0].iov_len = 4;
    iov[1].iov_base = buff;
    iov[1].iov_len = bufflen;
    eio.iov = iov;
    eio.binv = binv;
    eio.vsize = 2;
    eio.size = bufflen + 4;
    written = 0;
    if (driver_sizeq(ud->port) == 0) {
        if ((written = writenv(ud->fd, iov, 2)) == eio.size) {
            ud->sent += written;
            if (ud->type == portTypeCommand) {
                driver_output(ud->port, "Sok", 3);
            }
            return;
        } else if (written < 0) {
            // Handle error
        }
    } else if (written < 0) {
        // Handle error
    }
}
```
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:

```c
(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)         } else {
(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)         }
```
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:

```c
(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)    } else {
(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.
1.6 How to Implement an Alternative Carrier for the Erlang Distribution

**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:

```c
(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;
```
1.6 How to Implement an Alternative Carrier for the Erlang Distribution

```erlang
(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
```

1.7 The Abstract Format

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 $F_1, \ldots, F_k$, then $\text{Rep}(D) = \{\text{Rep}(F_1), \ldots, \text{Rep}(F_k)\}$.
• If $F$ is an attribute `-export([Fun_1/A_1, \ldots, Fun_k/A_k])$, then $\text{Rep}(F) = \{\text{attribute}, \text{LINE}, \text{export}, \{[\text{Fun_1}, \text{A_1}], \ldots, \{\text{Fun_k}, \text{A_k}\}\}\}$.
• If $F$ is an attribute `-import(Mod,[Fun_1/A_1, \ldots, Fun_k/A_k])$, then $\text{Rep}(F) = \{\text{attribute}, \text{LINE}, \text{import}, \{\text{Mod}, \{[\text{Fun_1}, \text{A_1}], \ldots, \{\text{Fun_k}, \text{A_k}\}\}\}\}$.
• If $F$ is an attribute `-module(Mod)$, then $\text{Rep}(F) = \{\text{attribute}, \text{LINE}, \text{module}, \text{Mod}\}$.
• If $F$ is an attribute `-file(File,Line)$, then $\text{Rep}(F) = \{\text{attribute}, \text{LINE}, \text{file}, \{\text{File}, \text{Line}\}\}$.
• If $F$ is a function declaration Name $Fc_1 ; \ldots ; Name~Fc_k$, where each $Fc_i$ is a function clause with a pattern sequence of the same length $\text{Arity}$, then $\text{Rep}(F) = \{\text{function}, \text{LINE}, \text{Name}, \text{Arity}, \{\text{Rep}(Fc_1), \ldots, \text{Rep}(Fc_k)\}\}$.
• If $F$ is a function specification `-Spec Name~Ft_1; \ldots; Ft_k$, where $\text{Spec}$ is either the atom $\text{spec}$ or the atom callback, and each $Ft_i$ is a possibly constrained function type with an argument sequence of the same length $\text{Arity}$, then $\text{Rep}(F) = \{\text{attribute}, \text{LINE}, \text{Spec}, \{\{\text{Name}, \text{Arity}\}, \{\text{Rep}(Fc_1), \ldots, \text{Rep}(Fc_k)\}\}\}$.
• If $F$ is a record declaration `-record(Name,{V_1, \ldots, V_k})$, where each $V_i$ is a record field, then $\text{Rep}(F) = \{\text{attribute}, \text{LINE}, \text{record}, \{\text{Name}, \text{Arity}, \{\text{Rep}(V_1), \ldots, \text{Rep}(V_k)\}\}\}$.
• If $F$ is a type declaration `-Type Name(V_1, \ldots, V_k) :: T$, where $\text{Type}$ is either the atom $\text{type}$ or the atom $\text{opaque}$, each $V_i$ is a variable, and $T$ is a type, then $\text{Rep}(F) = \{\text{attribute}, \text{LINE}, \text{Type}, \{\text{Name}, \text{Rep}(T), \{\text{Rep}(V_1), \ldots, \text{Rep}(V_k)\}\}\}$.
• If $F$ is a wild attribute `-A(T)$, then $\text{Rep}(F) = \{\text{attribute}, \text{LINE}, \text{A}, \text{T}\}$.

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

**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,LINE}`, denoting an end-of-stream encountered before a complete form had been parsed

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 $\text{Rep}(L) = \{\text{atom}, \text{LINE}, \text{L}\}$.
- If $L$ is a character literal, then $\text{Rep}(L) = \{\text{char}, \text{LINE}, \text{L}\}$.
- If $L$ is a float literal, then $\text{Rep}(L) = \{\text{float}, \text{LINE}, \text{L}\}$.
1.7 The Abstract Format

- If \( L \) is an integer literal, then \( \text{Rep}(L) = \{\text{integer}, \text{LINE}, L\} \).
- If \( L \) is a string literal consisting of the characters \( C_1, \ldots, C_k \), then \( \text{Rep}(L) = \{\text{string}, \text{LINE}, [C_1, \ldots, C_k]\} \).

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 \( P_1, \ldots, P_k \) is a sequence of patterns, then \( \text{Rep}(P_1, \ldots, P_k) = [\text{Rep}(P_1), \ldots, \text{Rep}(P_k)] \). 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 \( \text{Rep}(P) = \text{Rep}(L) \).
- If \( P \) is a bitstring pattern \( \ll P_1:Size_1/TSL_1, \ldots, P_k:Size_k/TSL_k \gg \), where each \( Size_i \) is an expression that can be evaluated to an integer, and each \( TSL_i \) is a type specifier list, then \( \text{Rep}(P) = \{\text{bin}, \text{LINE}, \{(\text{bin_element}, \text{LINE}, \text{Rep}(P_1), \text{Rep}(Size_1), \text{Rep}(TSL_1)), \ldots, \text{bin_element}, \text{LINE}, \text{Rep}(P_k), \text{Rep}(Size_k), \text{Rep}(TSL_k)\}\} \). For \( \text{Rep}(TSL) \), see below. An omitted \( Size_i \) is represented by \( \text{default} \). An omitted \( TSL_i \) is represented by \( \text{default} \).
- If \( P \) is a compound pattern \( P_1 = P_2 \), then \( \text{Rep}(P) = \{\text{match}, \text{LINE}, \text{Rep}(P_1), \text{Rep}(P_2)\} \).
- If \( P \) is a cons pattern \( [P_h | P_t] \), then \( \text{Rep}(P) = \{\text{cons}, \text{LINE}, \text{Rep}(P_h), \text{Rep}(P_t)\} \).
- If \( P \) is a map pattern \( \#(A_1, \ldots, A_k) \), where each \( A_i \) is an association \( P_i_1 := P_i_2 \), then \( \text{Rep}(P) = \{\text{map}, \text{LINE}, \{(\text{Rep}(A_1), \ldots, \text{Rep}(A_k)\}\} \). For \( \text{Rep}(A) \), see below.
- If \( P \) is a nil pattern \( [] \), then \( \text{Rep}(P) = \{\text{nil}, \text{LINE}\} \).
- If \( P \) is an operator pattern \( P_1 \text{ Op } P_2 \), where \( \text{Op} \) 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 \( \text{Rep}(P) = \{\text{op}, \text{LINE}, \text{Op}, \text{Rep}(P_1), \text{Rep}(P_2)\} \).
- If \( P \) is an operator pattern \( \text{Op } P_0 \), where \( \text{Op} \) is a unary operator (this is an occurrence of an expression that can be evaluated to a number at compile time), then \( \text{Rep}(P) = \{\text{op}, \text{LINE}, \text{Op}, \text{Rep}(P_0)\} \).
- If \( P \) is a parenthesized pattern \( (P_0) \), then \( \text{Rep}(P) = \text{Rep}(P_0) \), 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 \( \text{Rep}(P) = \{\text{record_index}, \text{LINE}, \text{Name}, \text{Rep}(Field)\} \).
- If \( P \) is a record pattern \#Name\{Field_1=P_1, \ldots, Field_k=P_k\}, where each \( Field_i \) is an atom or \( _\) (wildcard), then \( \text{Rep}(P) = \{\text{record}, \text{LINE}, \text{Name}, \{(\text{record_field}, \text{LINE}, \text{Rep}(Field_1), \text{Rep}(P_1)), \ldots, \text{record_field}, \text{LINE}, \text{Rep}(Field_k), \text{Rep}(P_k)\}\} \).
- If \( P \) is a tuple pattern \{P_1, \ldots, P_k\}, then \( \text{Rep}(P) = \{\text{tuple}, \text{LINE}, [\text{Rep}(P_1), \ldots, \text{Rep}(P_k)]\} \).
- If \( P \) is a universal pattern \( _\), then \( \text{Rep}(P) = \{\text{var}, \text{LINE}, '_\}' \).
- If \( P \) is a variable pattern \( V \), then \( \text{Rep}(P) = \{\text{var}, \text{LINE}, A\} \), 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 \( E_1, \ldots, E_k \), and \( \text{Rep}(B) = [\text{Rep}(E_1), \ldots, \text{Rep}(E_k)] \).

An expression \( E \) is one of the following:
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- If \( E \) is an atomic literal \( L \), then \( \text{Rep}(E) = \text{Rep}(L) \).
- If \( E \) is a bitstring comprehension \( \langle\langle E_0 \mid Q_1, \ldots, Q_k\rangle\rangle \), where each \( Q_i \) is a qualifier, then \( \text{Rep}(E) = \{bc, \text{LINE}, \text{Rep}(E_0), [\text{Rep}(Q_1), \ldots, \text{Rep}(Q_k)]\} \). For \( \text{Rep}(Q) \), see below.
- If \( E \) is a bitstring constructor \( \langle\langle E_1:\text{Size}_1/\text{TSL}_1, \ldots, E_k:\text{Size}_k/\text{TSL}_k\rangle\rangle \), where each \( \text{Size}_i \) is an expression and each \( \text{TSL}_i \) is a type specifier list, then \( \text{Rep}(E) = \{\text{bin}, \text{LINE}, \{\text{bin_element}, \text{LINE}, \text{Rep}(E_1), \text{Rep}(\text{Size}_1), \text{Rep}(\text{TSL}_1)\}, \ldots, \{\text{bin_element}, \text{LINE}, \text{Rep}(E_k), \text{Rep}(\text{Size}_k), \text{Rep}(\text{TSL}_k)\}\} \). For \( \text{Rep}(\text{TSL}) \), see below. An omitted \( \text{Size}_i \) is represented by default. An omitted \( \text{TSL}_i \) is represented by default.
- If \( E \) is a block expression \( \begin{array}{c} \text{begin} \ B \ \text{end} \end{array} \), where \( B \) is a body, then \( \text{Rep}(E) = \{\text{block}, \text{LINE}, \text{Rep}(B)\} \).
- If \( E \) is a case expression \( \begin{array}{c} \text{case} \ E_0 \ \text{of} \ Cc_1 ; \ldots ; Cc_k \ \text{end} \end{array} \), where \( E_0 \) is an expression and each \( Cc_i \) is a case clause, then \( \text{Rep}(E) = \{'\text{case}', \text{LINE}, \text{Rep}(E_0), \{\text{Rep}(Cc_1), \ldots, \text{Rep}(Cc_k)\}\} \).
- If \( E \) is a catch expression \( \begin{array}{c} \text{catch} \ E_0 \end{array} \), then \( \text{Rep}(E) = \{'\text{catch}', \text{LINE}, \text{Rep}(E_0)\} \).
- If \( E \) is a cons skeleton \( \langle\langle E_h \mid E_t\rangle\rangle \), then \( \text{Rep}(E) = \{\text{cons}, \text{LINE}, \text{Rep}(E_h), \text{Rep}(E_t)\} \).
- If \( E \) is a fun expression \( \begin{array}{c} \text{fun} \ Name/\text{Arity} \end{array} \), then \( \text{Rep}(E) = \{'\text{fun}', \text{LINE}, \{\text{function}, \text{Name}, \text{Arity}\}\} \).
- If \( E \) is a fun expression \( \begin{array}{c} \text{fun} \ Module:Name/\text{Arity} \end{array} \), then \( \text{Rep}(E) = \{'\text{fun}', \text{LINE}, \{\text{function}, \text{Rep}(Module), \text{Rep}(Name), \text{Rep}(\text{Arity})\}\} \). (Before Erlang/OTP R15: \( \text{Rep}(E) = \{'\text{fun}', \text{LINE}, \{\text{function}, \text{Name}, \text{Arity}\}\} \).
- If \( E \) is a fun expression \( \begin{array}{c} \text{fun} \ Fc_1 ; \ldots ; Name \ Fc_k \ \text{end} \end{array} \), where each \( Fc_i \) is a function clause, then \( \text{Rep}(E) = \{'\text{fun}', \text{LINE}, \{\text{clauses}, \{\text{Rep}(Fc_1), \ldots, \text{Rep}(Fc_k)\}\}\} \).
- If \( E \) is a fun expression \( \begin{array}{c} \text{fun} \ Name \ Fc_1 ; \ldots ; Name \ Fc_k \ \text{end} \end{array} \), where \( Name \) is a variable and each \( Fc_i \) is a function clause, then \( \text{Rep}(E) = \{'\text{name_fun}', \text{LINE}, \text{Name}, \{\text{Rep}(Fc_1), \ldots, \text{Rep}(Fc_k)\}\} \).
- If \( E \) is a function call \( \begin{array}{c} E_0(E_1, \ldots, E_k) \end{array} \), then \( \text{Rep}(E) = \{\text{call}, \text{LINE}, \text{Rep}(E_0), \{\text{Rep}(E_1), \ldots, \text{Rep}(E_k)\}\} \).
- If \( E \) is a function call \( \begin{array}{c} E_m:E_0(E_1, \ldots, E_k) \end{array} \), then \( \text{Rep}(E) = \{\text{call}, \text{LINE}, \{\text{remote}, \text{LINE}, \{\text{Rep}(E_m), \text{Rep}(E_0)\}, \{\text{Rep}(E_1), \ldots, \text{Rep}(E_k)\}\}\} \).
- If \( E \) is an if expression \( \begin{array}{c} \text{if} \ Ic_1 ; \ldots ; Ic_k \ \text{end} \end{array} \), where each \( Ic_i \) is an if clause, then \( \text{Rep}(E) = \{'\text{if}', \text{LINE}, \{\text{Rep}(Ic_1), \ldots, \text{Rep}(Ic_k)\}\} \).
- If \( E \) is a list comprehension \( \langle\langle E_0 \mid Q_1, \ldots, Q_k\rangle\rangle \), where each \( Q_i \) is a qualifier, then \( \text{Rep}(E) = \{\text{lc}, \text{LINE}, \{\text{Rep}(E_0), \{\text{Rep}(Q_1), \ldots, \text{Rep}(Q_k)\}\}\} \). For \( \text{Rep}(Q) \), see below.
- If \( E \) is a map creation \( \#(A_1, \ldots, A_k) \), where each \( A_i \) is an association \( E_i_1 => E_i_2 \) or \( E_i_1 := E_i_2 \), then \( \text{Rep}(E) = \{\text{map}, \text{LINE}, \{\text{Rep}(A_1), \ldots, \text{Rep}(A_k)\}\} \). For \( \text{Rep}(A) \), see below.
- If \( E \) is a map update \( E_0\#(A_1, \ldots, A_k) \), where each \( A_i \) is an association \( E_i_1 => E_i_2 \) or \( E_i_1 := E_i_2 \), then \( \text{Rep}(E) = \{\text{map}, \text{LINE}, \text{Rep}(E_0), \{\text{Rep}(A_1), \ldots, \text{Rep}(A_k)\}\} \). For \( \text{Rep}(A) \), see below.
- If \( E \) is a match operator expression \( \begin{array}{c} P = E_0 \end{array} \), where \( P \) is a pattern, then \( \text{Rep}(E) = \{\text{match}, \text{LINE}, \text{Rep}(P), \text{Rep}(E_0)\} \).
- If \( E \) is nil [], then \( \text{Rep}(E) = \{\text{nil}, \text{LINE}\} \).
- If \( E \) is an operator expression \( \begin{array}{c} E_1 \ \text{Op} \ E_2 \end{array} \), where \( \text{Op} \) is a binary operator other than match operator =, then \( \text{Rep}(E) = \{\text{op}, \text{LINE}, \text{Op}, \text{Rep}(E_1), \text{Rep}(E_2)\} \).
- If \( E \) is an operator expression \( \begin{array}{c} \text{Op} \ E_0 \end{array} \), where \( \text{Op} \) is a unary operator, then \( \text{Rep}(E) = \{\text{op}, \text{LINE}, \text{Op}, \text{Rep}(E_0)\} \).
- If \( E \) is a parenthesized expression \( \begin{array}{c} \text{E_0} \end{array} \), then \( \text{Rep}(E) = \text{Rep}(E_0) \), that is, parenthesized expressions cannot be distinguished from their bodies.
- If \( E \) is a receive expression \( \text{receive} \ Cc_1 ; \ldots ; Cc_k \ \text{end} \), where each \( Cc_i \) is a case clause, then \( \text{Rep}(E) = \{'\text{receive}', \text{LINE}, \{\text{Rep}(Cc_1), \ldots, \text{Rep}(Cc_k)\}\} \).
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- If $E$ is a receive expression $\text{receive } Cc_1 ; \ldots ; Cc_k \text{ after } E_0 \rightarrow B_t \text{ end}$, where each $Cc_i$ is a case clause, $E_0$ is an expression, and $B_t$ is a body, then $\text{Rep}(E) = \{\text{receive}', \text{LINE}, \text{[Rep}(Cc_1), \ldots, \text{Rep}(Cc_k)], \text{Rep}(E_0), \text{Rep}(B_t)\}.$

- If $E$ is a record creation $\#\text{Name}\{\text{Field}_1=E_1, \ldots, \text{Field}_k=E_k\}$, where each $\text{Field}_i$ is an atom or $\_\_\_$, then $\text{Rep}(E) = \{\text{record}, \text{LINE}, \text{Name}, \text{[\{record_field, LINE, \text{Rep}(\text{Field}_1), \text{Rep}(E_1)\}, \ldots, \text{\{record_field, LINE, \text{Rep}(\text{Field}_k), \text{Rep}(E_k)\}]\}}.$

- If $E$ is a record field access $E_0\#\text{Name}.\text{Field}$, where $\text{Field}$ is an atom, then $\text{Rep}(E) = \{\text{record_field, LINE, \text{Name}, \text{Rep}(\text{Field})}\}.$

- If $E$ is a record field index $\#\text{Name}.\text{Field}$, where $\text{Field}$ is an atom, then $\text{Rep}(E) = \{\text{record_index, LINE, \text{Name}, \text{Rep}(\text{Field})}\}.$

- If $E$ is a record update $E_0\#\text{Name}\{\text{Field}_1=E_1, \ldots, \text{Field}_k=E_k\}$, where each $\text{Field}_i$ is an atom, then $\text{Rep}(E) = \{\text{record}, \text{LINE, \text{Name, \text{Rep}(\text{Field}_0), \text{[\{record_field, LINE, \text{Rep}(\text{Field}_1), \text{Rep}(E_1)\}, \ldots, \{record_field, LIN}e, \text{Rep}(\text{Field}_k), \text{Rep}(E_k)\}]\}}.$

- If $E$ is a tuple skeleton $\{E_1, \ldots, E_k\}$, then $\text{Rep}(E) = \{\text{tuple, LINE, [Rep}(E_1), \ldots, \text{Rep}(E_k)\}$.

- If $E$ is a try expression $\text{try } B \text{ catch } Tc_1 ; \ldots ; Tc_k \text{ end}$, where $B$ is a body and each $Tc_i$ is a catch clause, then $\text{Rep}(E) = \{\text{try}', \text{LINE, Rep}(B), [], \text{[Rep}(Tc_1), \ldots, \text{Rep}(Tc_k)], []\}.$

- If $E$ is a try expression $\text{try } B \text{ of } Cc_1 ; \ldots ; Cc_k \text{ catch } Tc_1 ; \ldots ; Tc_n \text{ end}$, where $B$ is a body, each $Cc_i$ is a case clause, and each $Tc_j$ is a catch clause, then $\text{Rep}(E) = \{\text{try}', \text{LINE, Rep}(B), \text{[Rep}(Cc_1), \ldots, \text{Rep}(Cc_k)], \text{[Rep}(Tc_1), \ldots, \text{Rep}(Tc_n)], []\}.$

- If $E$ is a try expression $\text{try } B \text{ after } A \text{ end}$, where $B$ and $A$ are bodies, then $\text{Rep}(E) = \{\text{try}', \text{LINE, Rep}(B), [], [], \text{Rep}(A)\}.$

- If $E$ is a try expression $\text{try } B \text{ after } A \text{ end}$, where $B$ and $A$ are bodies, and each $Cc_i$ is a case clause, then $\text{Rep}(E) = \{\text{try}', \text{LINE, Rep}(B), \{Rep}(Cc_1), \ldots, \text{Rep}(Cc_k)], [], \text{Rep}(A)\}.$

- If $E$ is a try expression $\text{try } B \text{ catch } Tc_1 ; \ldots ; Tc_k \text{ after } A \text{ end}$, where $B$ and $A$ are bodies, and each $Tc_i$ is a catch clause, then $\text{Rep}(E) = \{\text{try}', \text{LINE, Rep}(B), [], \text{[Rep}(Tc_1), \ldots, \text{Rep}(Tc_k)], \text{Rep}(A)\}.$

- If $E$ is a try expression $\text{try } B \text{ catch } Tc_1 ; \ldots ; Tc_k \text{ after } A \text{ end}$, where $B$ and $A$ are bodies, each $Cc_i$ is a case clause, and each $Tc_j$ is a catch clause, then $\text{Rep}(E) = \{\text{try}', \text{LINE, Rep}(B), \{Rep}(Cc_1), \ldots, \text{Rep}(Cc_k)], \text{[Rep}(Tc_1), \ldots, \text{Rep}(Tc_n)], \text{Rep}(A)\}.$

- If $E$ is a variable $V$, then $\text{Rep}(E) = \{\text{var}', \text{LINE}, \text{A}\}$, 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 $\text{Rep}(Q) = \text{Rep}(E).$

- If $Q$ is a generator $P \leftarrow E$, where $P$ is a pattern and $E$ is an expression, then $\text{Rep}(Q) = \{\text{generate, LINE, Rep}(P), \text{Rep}(E)\}.$

- If $Q$ is a bitstring generator $P \leq E$, where $P$ is a pattern and $E$ is an expression, then $\text{Rep}(Q) = \{\text{b_generate, LINE, Rep}(P), \text{Rep}(E)\}.$

Bitstring Element Type Specifiers

A type specifier list TSL for a bitstring element is a sequence of type specifiers $TS_1 - \ldots - TS_k$, and $\text{Rep}(\text{TSL}) = \{\text{Rep}(TS_1), \ldots, \text{Rep}(TS_k)\}.$
• If TS is a type specifier $A$, where $A$ is an atom, then $\text{Rep}(\text{TS}) = A$.
• If TS is a type specifier $A:\text{Value}$, where $A$ is an atom and $\text{Value}$ is an integer, then $\text{Rep}(\text{TS}) = \{A, \text{Value}\}$.

Associations
An association $A$ is one of the following:
• If $A$ is an association $K \Rightarrow V$, then $\text{Rep}(A) = \{\text{map_field_assoc}, \text{LINE}, \text{Rep}(K), \text{Rep}(V)\}$.
• If $A$ is an association $K := V$, then $\text{Rep}(A) = \{\text{map_field_exact}, \text{LINE}, \text{Rep}(K), \text{Rep}(V)\}$.

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 $P \rightarrow B$, where $P$ is a pattern and $B$ is a body, then $\text{Rep}(C) = \{\text{clause}, \text{LINE}, [\text{Rep}(P)], [], \text{Rep}(B)\}$.
• If $C$ is a case clause $P \leftarrow B$, where $P$ is a pattern and $B$ is a body, then $\text{Rep}(C) = \{\text{map_field_assoc}, \text{LINE}, \text{Rep}(K), \text{Rep}(V)\}$.
• If $C$ is a catch clause $P \rightarrow B$, where $P$ is a pattern and $B$ is a body, then $\text{Rep}(C) = \{\text{clause}, \text{LINE}, [\text{Rep}(P)], [], \text{Rep}(B)\}$.
• If $C$ is a catch clause $P \leftarrow B$, where $P$ is a pattern and $B$ is a body, then $\text{Rep}(C) = \{\text{map_field_assoc}, \text{LINE}, \text{Rep}(K), \text{Rep}(V)\}$.

1.7.6 Guards
A guard sequence $Gs$ is a sequence of guards $G_1; \ldots; G_k$, and $\text{Rep}(Gs) = [\text{Rep}(G_1), \ldots, \text{Rep}(G_k)]$. If the guard sequence is empty, then $\text{Rep}(Gs) = [\]$.
A guard $G$ is a non-empty sequence of guard tests $Gt_1, \ldots, Gt_k$, and $\text{Rep}(G) = [\text{Rep}(Gt_1), \ldots, \text{Rep}(Gt_k)]$.
A guard test $Gt$ is one of the following:
• If $Gt$ is an atomic literal $L$, then $\text{Rep}(Gt) = \text{Rep}(L)$.
• If $Gt$ is a bitstring constructor $\ll Gt_1: \text{Size}_1/TSL_1, \ldots, Gt_k: \text{Size}_k/TSL_k \rr$, where each $\text{Size}_i$ is a guard test and each $\text{TSL}_i$ is a type specifier list, then $\text{Rep}(Gt) = \{\text{bin}, \text{LINE}, [(\text{bin_element}, \text{LINE}, \text{Rep}(Gt_1), \text{Rep}(\text{Size}_1), \text{Rep}(\text{TSL}_1)), \ldots, (\text{bin_element}, \text{LINE}, \text{Rep}(Gt_k), \text{Rep}(\text{Size}_k), \text{Rep}(\text{TSL}_k))\}]$. For $\text{Rep}(\text{TSL})$, see above. An omitted $\text{Size}_i$ is represented by default. An omitted $\text{TSL}_i$ is represented by default.
• If $Gt$ is a cons skeleton $[Gt_h | Gt_t]$, then $\text{Rep}(Gt) = \{\text{cons}, \text{LINE}, \text{Rep}(Gt_h), \text{Rep}(Gt_t)\}$.
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- 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 function type fun(), then Rep(T) = {type, LINE, 'fun', [type, LINE, any, Rep(T_0)]}.
- If T is a function 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}. 

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- 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 is_subtype(V, T) or 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.

<table>
<thead>
<tr>
<th>Key Sequence</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Home</td>
<td>Beginning of line</td>
</tr>
<tr>
<td>C-a</td>
<td>Beginning of line</td>
</tr>
<tr>
<td>C-b</td>
<td>Backward character</td>
</tr>
<tr>
<td>C-Left</td>
<td>Backward word</td>
</tr>
<tr>
<td>M-b</td>
<td>Backward word</td>
</tr>
<tr>
<td>C-d</td>
<td>Delete character</td>
</tr>
<tr>
<td>M-d</td>
<td>Delete word</td>
</tr>
<tr>
<td>End</td>
<td>End of line</td>
</tr>
</tbody>
</table>
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](http://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:

```c
/* 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`.

```c
/* 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.)

```c
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.)

```c
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;
    }
```

58 | Ericsson AB. All Rights Reserved.: Erlang Run-Time System Application (ERTS)
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.

```c
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:

```c
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.

```c
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.)

```c
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`:
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_dlld: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`.

```c
/* 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 = {
```
1.9 How to Implement a Driver

```c
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.)

```c
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.

```c
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.

```c
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)
```
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`.

```erlang
-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 `driver_select` function is called when we need to select on input or output.

```erlang
driver_select(data->port, (ErlDrvEvent)data->socket, DO_WRITE, 0);
    ei_x_free(&x);
}
```
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`.

```c
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.

```c
struct our_async_data {
    bool prev;
    vector<int> data;
    our_async_data(ErlDrvPort p, int command, const char* buf, int len);
};
```
1.9 How to Implement a Driver

```
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.

```erlang
-module(next_perm).
-export([next_perm/1, prev_perm/1, load/0, all_perm/1]).
load() ->
  case whereis(next_perm) of
  undefined ->
    case erl_dll: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).
pred_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 = pred_perm(L),
  all_perm(New, L, [New]).
all_perm(L, L, Acc) ->
  Acc;
all_perm(L, Orig, Acc) ->
  New = pred_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 either '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:

```erlang
{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.
```
1.10 Inet Configuration

{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 \textit{inet\_res(3)} to use TCP (Virtual Circuit) instead of UDP. Defaults to \texttt{false}.

\begin{verbatim}
{edns, Version}.
Version = false | 0
Sets the EDNS version that \textit{inet\_res(3)} will use. The only allowed version is zero. Defaults to \texttt{false}, which means not to use EDNS.
\end{verbatim}

\begin{verbatim}
{udp\_payload\_size, Size}.
N = integer()
Sets the allowed UDP payload size \textit{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.
\end{verbatim}

\begin{verbatim}
{udp, Module}.
Module = atom()
Tell Erlang to use another primitive UDP module than \textit{inet\_udp}.
\end{verbatim}

\begin{verbatim}
{tcp, Module}.
Module = atom()
Tell Erlang to use another primitive TCP module than \textit{inet\_tcp}.
\end{verbatim}

\begin{verbatim}
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.
\end{verbatim}

\section{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 \texttt{erl\_inetrc}, stored in directory \texttt{/cfg\_files}) can then look as follows (Unix):

\begin{verbatim}
%% -- 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}.
\end{verbatim}
1.11 External Term Format

%% 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:

<table>
<thead>
<tr>
<th>1</th>
<th>1</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>131</td>
<td>Tag</td>
<td>Data</td>
</tr>
</tbody>
</table>

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:

<table>
<thead>
<tr>
<th>1</th>
<th>1</th>
<th>4</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>131</td>
<td>80</td>
<td>UncompressedSize</td>
<td>Zlib-compressedData</td>
</tr>
</tbody>
</table>

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:

<table>
<thead>
<tr>
<th>1</th>
<th>Uncompressed Size</th>
</tr>
</thead>
</table>

72 | Ericsson AB. All Rights Reserved.: Erlang Run-Time System Application (ERTS)
As from ERTS 5.10 (OTP R16) support for UTF-8 encoded atoms has been introduced in the external format. However, only characters that can be encoded using Latin-1 (ISO-8859-1) are currently supported in atoms. The support for UTF-8 encoded atoms in the external format has been implemented to be able to support all Unicode characters in atoms in some future release. Until full Unicode support for atoms has been introduced, it is an error to pass atoms containing characters that cannot be encoded in Latin-1, and the behavior is undefined.

When distribution flag DFLAG_UTF8_ATOMS has been exchanged between both nodes in the distribution handshake, all atoms in the distribution header are encoded in UTF-8, otherwise in Latin-1. The two new tags ATOM_UTF8_EXT and SMALL_ATOM_UTF8_EXT are only used if the distribution flag DFLAG_UTF8_ATOMS has been exchanged between nodes, or if an atom containing characters that cannot be encoded in Latin-1 is encountered.

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:

<table>
<thead>
<tr>
<th>1</th>
<th>1</th>
<th>1</th>
<th>NumberOfAtomCacheRefs</th>
<th>2+1</th>
<th>N</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>131</td>
<td>68</td>
<td>NumberOfAtomCacheRefs</td>
<td>Flags</td>
<td>AtomCacheRefs</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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.

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

<table>
<thead>
<tr>
<th>1 bit</th>
<th>3 bits</th>
</tr>
</thead>
<tbody>
<tr>
<td>NewCacheEntryFlag</td>
<td>SegmentIndex</td>
</tr>
</tbody>
</table>

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:

<table>
<thead>
<tr>
<th>3 bits</th>
<th>1 bit</th>
</tr>
</thead>
<tbody>
<tr>
<td>CurrentlyUnused</td>
<td>LongAtoms</td>
</tr>
</tbody>
</table>

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:

<table>
<thead>
<tr>
<th>1</th>
<th>1</th>
<th>2</th>
<th>Length</th>
</tr>
</thead>
</table>
| 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 CachedAtomRefs 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:

<table>
<thead>
<tr>
<th>1</th>
</tr>
</thead>
</table>
### 1.11 External Term Format

#### Table 11.8: InternalSegmentIndex

| InternalSegmentIndex | 82 | AtomCacheReferenceIndex |

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 scanf 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 ATOM_EXT

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>Len</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>Len</td>
<td>AtomName</td>
</tr>
</tbody>
</table>

Table 11.13: 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.

### 1.11.8 REFERENCE_EXT

<table>
<thead>
<tr>
<th>1</th>
<th>N</th>
<th>4</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>101</td>
<td>Node</td>
<td>ID</td>
<td>Creation</td>
</tr>
</tbody>
</table>

Table 11.14: REFERENCE_EXT

Encodes a reference object (an object generated with erlang:make_ref/0). The Node term is an encoded atom, that is, ATOM_EXT, SMALL_ATOM_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.

### 1.11.9 PORT_EXT

<table>
<thead>
<tr>
<th>1</th>
<th>N</th>
<th>4</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>102</td>
<td>Node</td>
<td>ID</td>
<td>Creation</td>
</tr>
</tbody>
</table>

Table 11.15: 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.

### 1.11.10 PID_EXT

| 1 | N | 4 | 4 | 1 |

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1.11 External Term Format

Table 11.16: PID_EXT

<table>
<thead>
<tr>
<th>Node</th>
<th>ID</th>
<th>Serial</th>
<th>Creation</th>
</tr>
</thead>
</table>

Encodes a process identifier object (obtained from `erlang:spawn/3` or friends). The ID and Creation fields work 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.

1.11.11 SMALL_TUPLE_EXT

<table>
<thead>
<tr>
<th>1</th>
<th>1</th>
<th>N</th>
</tr>
</thead>
</table>

Table 11.17: SMALL_TUPLE_EXT

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

1.11.12 LARGE_TUPLE_EXT

<table>
<thead>
<tr>
<th>1</th>
<th>4</th>
<th>N</th>
</tr>
</thead>
</table>

Table 11.18: LARGE_TUPLE_EXT

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

1.11.13 MAP_EXT

<table>
<thead>
<tr>
<th>1</th>
<th>4</th>
<th>N</th>
</tr>
</thead>
</table>

Table 11.19: 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

1.11.14 NIL_EXT

| 1 |

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1.11 External Term Format

1.11.15 STRING_EXT

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>Len</th>
</tr>
</thead>
<tbody>
<tr>
<td>107</td>
<td>Length</td>
<td>Characters</td>
</tr>
</tbody>
</table>

Table 11.21: 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.

1.11.16 LIST_EXT

<table>
<thead>
<tr>
<th>1</th>
<th>4</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>108</td>
<td>Length</td>
<td>Elements</td>
</tr>
</tbody>
</table>

Table 11.22: 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]).

1.11.17 BINARY_EXT

<table>
<thead>
<tr>
<th>1</th>
<th>4</th>
<th>Len</th>
</tr>
</thead>
<tbody>
<tr>
<td>109</td>
<td>Len</td>
<td>Data</td>
</tr>
</tbody>
</table>

Table 11.23: 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).

1.11.18 SMALL_BIG_EXT

| 1 | 1 | 1 | n |

Table 11.24: SMALL_BIG_EXT

Binaries are encoded as small/big or big/small for 1, 2, or 4 byte integers.
1.11 External Term Format

### Table 11.24: SMALL_BIG_EXT

<table>
<thead>
<tr>
<th>110</th>
<th>n</th>
<th>Sign</th>
<th>d(0) ... d(n-1)</th>
</tr>
</thead>
</table>

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:

\[ B = 256^{(d_0 \times B^0 + d_1 \times B^1 + d_2 \times B^2 + \ldots + d(N-1) \times B^{(n-1)})} \]

#### 1.11.19 LARGE_BIG_EXT

<table>
<thead>
<tr>
<th>111</th>
<th>n</th>
<th>Sign</th>
<th>d(0) ... d(n-1)</th>
</tr>
</thead>
</table>

Table 11.25: LARGE_BIG_EXT

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

#### 1.11.20 NEW_REFERENCE_EXT

<table>
<thead>
<tr>
<th>114</th>
<th>Len</th>
<th>Node</th>
<th>Creation</th>
<th>ID ...</th>
</tr>
</thead>
</table>

Table 11.26: 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.

\( N' = 4 \times \text{Len} \).

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.

#### 1.11.21 SMALL_ATOM_EXT

<table>
<thead>
<tr>
<th>115</th>
<th>Len</th>
<th>AtomName</th>
</tr>
</thead>
</table>

Table 11.27: SMALL_ATOM_EXT
An atom is stored with a 1 byte unsigned length, followed by \texttt{Len} numbers of 8-bit Latin-1 characters that forms the \texttt{AtomName}. Longer atoms can be represented by \texttt{ATOM_EXT}.

**Note:**
\texttt{SMALL_ATOM_EXT} was introduced in ERTS 5.7.2 and require an exchange of distribution flag \texttt{DFLAG_SMALL_ATOM_TAGS} in the \textit{distribution handshake}.

### 1.11.22 FUN_EXT

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>4</th>
<th>N1</th>
<th>N2</th>
<th>N3</th>
<th>N4</th>
<th>N5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>117</td>
<td></td>
<td>NumFree</td>
<td>Pid</td>
<td>Module</td>
<td>Index</td>
<td>Uniq</td>
</tr>
</tbody>
</table>

Table 11.28: FUN_EXT

**Pid**
A process identifier as in \texttt{PID_EXT}. Represents the process in which the fun was created.

**Module**
Encoded as an atom, using \texttt{ATOM_EXT}, \texttt{SMALL_ATOM_EXT}, or \texttt{ATOM_CACHE_REF}. This is the module that the fun is implemented in.

**Index**
An integer encoded using \texttt{SMALL_INTEGER_EXT} or \texttt{INTEGER_EXT}. It is typically a small index into the module’s fun table.

**Uniq**
An integer encoded using \texttt{SMALL_INTEGER_EXT} or \texttt{INTEGER_EXT}. Uniq is the hash value of the parse for the fun.

**Free vars**
\texttt{NumFree} number of terms, each one encoded according to its type.

### 1.11.23 NEW_FUN_EXT

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>4</th>
<th>1</th>
<th>16</th>
<th>4</th>
<th>4</th>
<th>N1</th>
<th>N2</th>
<th>N3</th>
<th>N4</th>
<th>N5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>112</td>
<td></td>
<td>Size</td>
<td>Arity</td>
<td>Uniq</td>
<td>Index</td>
<td>NumFree</td>
<td>Module</td>
<td>OldIndex</td>
<td>OldUniq</td>
<td>Pid</td>
</tr>
</tbody>
</table>

Table 11.29: NEW_FUN_EXT

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

**Size**
The total number of bytes, including field \texttt{Size}.

---

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### 1.11.24 EXPORT_EXT

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>N1</th>
<th>N2</th>
<th>N3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>113</td>
<td>Module</td>
<td>Function</td>
<td>Arity</td>
</tr>
</tbody>
</table>

**Table 11.30: EXPORT_EXT**

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

*Module* and *Function* are atoms (encoded using ATOM_EXT, SMALL_ATOM_EXT, or ATOM_CACHE_REF).

*Arity* is an integer encoded using SMALL_INTEGER_EXT.

### 1.11.25 BIT_BINARY_EXT

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>4</th>
<th>1</th>
<th>Len</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>77</td>
<td>Len</td>
<td>Bits</td>
<td>Data</td>
</tr>
</tbody>
</table>

**Table 11.31: BIT_BINARY_EXT**
This term represents a bitstring whose length in bits does not have to be a multiple of 8. The \( \text{Len} \) field is an unsigned 4 byte integer (big-endian). The \( \text{Bits} \) 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.

### 1.11.26 NEW_FLOAT_EXT

<table>
<thead>
<tr>
<th>1</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>70</td>
<td>IEEE float</td>
</tr>
</tbody>
</table>

Table 11.32: 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.

### 1.11.27 ATOM_UTF8_EXT

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>Len</th>
</tr>
</thead>
<tbody>
<tr>
<td>118</td>
<td>Len</td>
<td>AtomName</td>
</tr>
</tbody>
</table>

Table 11.33: ATOM_UTF8_EXT

An atom is stored with a 2 byte unsigned length in big-endian order, followed by \( \text{Len} \) 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.

### 1.11.28 SMALL_ATOM_UTF8_EXT

<table>
<thead>
<tr>
<th>1</th>
<th>1</th>
<th>Len</th>
</tr>
</thead>
<tbody>
<tr>
<td>119</td>
<td>Len</td>
<td>AtomName</td>
</tr>
</tbody>
</table>

Table 11.34: SMALL_ATOM_UTF8_EXT

An atom is stored with a 1 byte unsigned length, followed by \( \text{Len} \) 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.

### 1.12 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)
1.12 Distribution Protocol

- Authentication (done by net_kernel(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.

1.12.1 EPMD Protocol

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

![EPMD Protocol Diagram]

Figure 12.1: Summary of EPMD Requests
1.12 Distribution Protocol

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

<table>
<thead>
<tr>
<th>2</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>Request</td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>1</th>
<th>1</th>
<th>2</th>
<th>2</th>
<th>2</th>
<th>Nlen</th>
<th>2</th>
<th>Elen</th>
</tr>
</thead>
<tbody>
<tr>
<td>120</td>
<td>PortNo</td>
<td>NodeType</td>
<td>Protocol</td>
<td>HighestVersion</td>
<td>LowestVersion</td>
<td>Nlen</td>
<td>NodeName</td>
<td>Elen</td>
<td>Extra</td>
</tr>
</tbody>
</table>

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 |

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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.

\[
\begin{array}{ll}
1 & N \\
122 & \text{NodeName}
\end{array}
\]

Table 12.4: PORT_PLEASE2_REQ (122)

where \( N = \text{Length} - 1 \).

\[
\begin{array}{ll}
1 & 1 \\
119 & \text{Result}
\end{array}
\]

Table 12.5: PORT2_RESP, Result = 0

If \( \text{Result} > 0 \), the packet only consists of \([119, \text{Result}]\).

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 \texttt{net_adm:names/1,2}. A TCP connection is opened to the EPMD and this request is sent.

\[
\begin{array}{cccccccccc}
\text{Result} & \text{PortNo} & \text{NodeType} & \text{NodeType} & \text{HighestVersion} & \text{LowestVersion} & \text{Nlen} & \text{Elen} & \text{Name} & \text{Helen}
\end{array}
\]

Table 12.6: PORT2_RESP, Result = 0

If \( \text{Result} > 0 \), the packet only consists of \([119, \text{Result}]\).

The EPMD closes the socket when it has sent the information.
1.12 Distribution Protocol

Table 12.7: NAMES_REQ (110)

The response for a NAMES_REQ is as follows:

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>EPMDPortNo</th>
<th>NodeInfo*</th>
</tr>
</thead>
</table>

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:

```erl
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.

Table 12.9: DUMP_REQ

The response for a DUMP_REQ is as follows:

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>EPMDPortNo</th>
<th>NodeInfo*</th>
</tr>
</thead>
</table>

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:

```erl
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.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>107</td>
</tr>
</tbody>
</table>

Table 12.11: KILL_REQ

The response for a KILL_REQ is as follows:

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>OKString</td>
</tr>
</tbody>
</table>

Table 12.12: KILL_RESP

where OKString is "OK".

STOP_REQ (Not Used)

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>n</td>
</tr>
<tr>
<td>115</td>
<td>NodeName</td>
</tr>
</tbody>
</table>

Table 12.13: STOP_REQ

where \( n = \text{Length} - 1 \).

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:

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>OKString</td>
</tr>
</tbody>
</table>

Table 12.14: STOP_RESP

where OKString is "STOPPED".

A negative response can look as follows:

<p>| |</p>
<table>
<thead>
<tr>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
</tr>
</tbody>
</table>
1.12 Distribution Protocol

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

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

<table>
<thead>
<tr>
<th>'s'</th>
<th>Status0</th>
<th>Status1</th>
<th>...</th>
<th>StatusN</th>
</tr>
</thead>
<tbody>
<tr>
<td>'s' is the message tag. 'Status0' ... 'StatusN' is the status as a string (not terminated).</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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:
1.12 Distribution Protocol

'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
recv_status
(if status was 'alive'
  send_status          ->
  recv_status)
  send_status          <-
  (ChB)
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:
```
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_BINARY,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.
1.12 Distribution Protocol

-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:

<table>
<thead>
<tr>
<th>4</th>
<th>d</th>
<th>n</th>
<th>m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>DistributionHeader</td>
<td>ControlMessage</td>
<td>Message</td>
</tr>
</tbody>
</table>

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:

<table>
<thead>
<tr>
<th>4</th>
<th>1</th>
<th>n</th>
<th>m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>Type</td>
<td>ControlMessage</td>
<td>Message</td>
</tr>
</tbody>
</table>

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)
**1.12 Distribution Protocol**

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**

\[(19, \text{FromPid}, \text{ToProc}, \text{Ref}),\] where \text{FromPid} = monitoring process and \text{ToProc} = monitored process pid or name (atom)

**DEMONITOR_P**

\[(20, \text{FromPid}, \text{ToProc}, \text{Ref}),\] where \text{FromPid} = monitoring process and \text{ToProc} = monitored process pid or name (atom)

We include \text{FromPid} just in case we want to trace this.

**MONITOR_P_EXIT**

\[(21, \text{FromProc}, \text{ToPid}, \text{Ref}, \text{Reason}),\] where \text{FromProc} = monitored process pid or name (atom), \text{ToPid} = monitoring process, and \text{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 an 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 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.

**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 \(1/\text{PartsPerSecond}\) 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:

```erlang
> 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:

```erlang
X = erlang:adler32(Data1),
Y = erlang:adler32(X,Data2).
```

assigns the same value to Y as this:

```erlang
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:

```erlang
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]
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.

```
> apply(erlang, atom_to_list, ['Erlang']).
"Erlang"
```

(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 (that is, characters from 128 through 255 are encoded in two bytes).

Note:

atom_to_binary(Atom, latin1) never fails, as the text representation of an atom can only contain characters from 0 through 255. In a future release, the text representation of atoms can be allowed to contain any Unicode character and atom_to_binary(Atom, latin1) then fails 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})).
   <<8,7,6,5,4>>
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. Only Unicode characters up to 255 are allowed.

Note:
binary_to_atom(Binary, utf8) fails if the binary contains Unicode characters > 255. In a future release, such Unicode characters can be allowed and binary_to_atom(Binary, utf8) does then not fail. 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).
** exception error: bad argument
   in function binary_to_atom/2
erlang

called as binary_to_atom(<<208,128>>,utf8)

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.
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:

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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]).
```

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(<1433:16,3:3>).
 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.

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 (funs 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 funs will be ignored. If such funs 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:

\[
X = \text{erlang:crc32(Data1)}, \\
Y = \text{erlang:crc32}(X,\text{Data2}).
\]

assigns the same value to Y as this:

\[
Y = \text{erlang:crc32}([\text{Data1},\text{Data2}]).
\]

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 |
http | http_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(),
    HttpMethod,
    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 HttpHeaders 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
> 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
> 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 {\text{'DOWN'}, MonitorRef, _, _, _} message, because of the monitor, will be placed in the caller message queue in the future. However, a {\text{'DOWN'}, MonitorRef, _, _, _} message can have been placed in the caller message queue before the call. It is therefore usually advisable to remove such a \text{'DOWN'} message from the message queue after monitoring has been stopped. 

\text{demonitor} \left( \text{MonitorRef}, \ [\text{flush}] \right) \text{ can be used instead of} \text{demonitor} \left( \text{MonitorRef} \right) \text{ if this cleanup is wanted.}

Note:

Before Erlang/OTP R11B (ERTS 5.5) \text{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 \text{'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 \text{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 \text{badarg}, for example if \text{MonitorRef} is a remote reference.

demonitor(MonitorRef, OptionList) -> boolean()

Types:

\text{MonitorRef} = \text{reference()}
\text{OptionList} = [\text{Option}]
\text{Option} = \text{flush} | \text{info}

The returned value is true unless \text{info} is part of \text{OptionList}.

demonitor(MonitorRef, []) is equivalent to \text{demonitor} \left( \text{MonitorRef} \right).

Options:

\text{flush}

Removes (one) \{_, MonitorRef, _, _, _\} message, if there is one, from the caller message queue after monitoring has been stopped.

Calling \text{demonitor} \left( \text{MonitorRef}, \ [\text{flush}] \right) \text{ is equivalent to the following, but more efficient:}

\begin{verbatim}
demonitor(MonitorRef),
receive
    {_, MonitorRef, _, _, _} ->
        true
    after 0 ->
        true
end
\end{verbatim}

\text{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:

\[
\text{erlang:external_size(, [])}
\]

\[
\text{erlang:external_size(Term, Options) -> integer() >= 0}
\]

Types:
- \(\text{Term} = \text{term()}\)
- \(\text{Options} = \{\{\text{minor_version}, \text{Version} :: \text{integer()} >= 0\}\}\)

Calculates, without doing the encoding, the maximum byte size for a term encoded in the Erlang external term format. The following condition applies always:

\[
> \text{Size1} = \text{byte_size(term_to_binary(, ))},
> \text{Size2} = \text{erlang:external_size(, )},
> \text{true} = \text{Size1 <= Size2}.
\]

Option \(\{\text{minor_version}, \text{Version}\}\) specifies how floats are encoded. For a detailed description, see `term_to_binary/2`.

\[
\text{float(Number)} -> \text{float()}
\]

Types:
- \(\text{Number} = \text{number()}\)

Returns a float by converting \(\text{Number}\) to a float, for example:

\[
> \text{float(55)}.
55.0
\]

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.

\[
\text{float_to_binary(Float)} -> \text{binary()}
\]

Types:
- \(\text{Float} = \text{float()}\)

The same as `float_to_binary(Float, [{scientific, 20}])`.  

120 | Ericsson AB. All Rights Reserved.: Erlang Run-Time System Application (ERTS)
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:

```erlang
> 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:

```erlang
> float_to_list(7.12, [{decimals, 4}]).
"7.1200"
> float_to_list(7.12, [{decimals, 4}, compact]).
"7.12"
```
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}
  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}`.

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:

```erlang
> 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:

```erlang
> put(key1, merry),
put(key2, lambs),
put({any, [valid, term]}, {are, playing}),
{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:

\[
\begin{align*}
&> \text{put(dog, \{animal,1\})}, \\
& \quad \text{put(cow, \{animal,2\})}, \\
& \quad \text{put(lamb, \{animal,3\})}, \\
& \quad \text{get_keys}. \\
& \quad [\text{dog}, \text{cow}, \text{lamb}]
\end{align*}
\]

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:

\[
\begin{align*}
&> \text{put(mary, \{1, 2\})}, \\
& \quad \text{put(had, \{1, 2\})}, \\
& \quad \text{put(a, \{1, 2\})}, \\
& \quad \text{put(little, \{1, 2\})}, \\
& \quad \text{put(dog, \{1, 3\})}, \\
& \quad \text{put(lamb, \{1, 2\})}, \\
& \quad \text{get_keys(\{1, 2\})}. \\
& \quad [\text{mary}, \text{had}, \text{a}, \text{little}, \text{lamb}]
\end{align*}
\]

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) of the last exception 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 \[].

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(GroupName, Pid) -> true`

Types:

- **GroupName** = **Pid** = `pid()`

Sets the group leader of `Pid` to `GroupName`. 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).
```

```
o_prompt% echo $?
17
```

### `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).

string()
   An Erlang crash dump is produced with Status as slogan. Then the runtime system exits with status code 1. Note that only code points in the range 0-255 may be used and the string will be truncated if longer than 200 characters.

abort
   The runtime system aborts producing a core dump, if that is enabled in the 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.

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.

erlang:hash(Term, Range) -> integer() >= 1

Types:
   Term = term()
   Range = integer() >= 1

Returns a hash value for Term within the range 1..Range. The maximum range is 1..2^27-1.

Warning:
This BIF is deprecated, as the hash value can differ on different architectures. The hash values for integer terms > 2^27 and large binaries are poor. The BIF is retained for backward compatibility reasons (it can have been used to hash records into a file), but all new code is to use one of the BIFs \erlang:phash/2\ or \erlang:phash2/1,2\ instead.

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 awakened 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).
```
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]).
<1,2,3,1,2,3,4,5,6>>
```

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.
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.

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.
String can only contain ISO-latin-1 characters (that is, numbers < 256) as the implementation does not allow Unicode characters equal to or above 256 in atoms. 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.

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:

```erlang
> 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_tuple(List) -> tuple()

Types:

- List = [term()]

Returns a tuple corresponding to List, for example

```erlang
> 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

Note:
Before Erlang/OTP R14B, NIFs were an experimental feature. Versions before Erlang/OTP R14B can have
different and possibly incompatible NIF semantics and interfaces. For example, in Erlang/OTP R13B03 the return
value on failure was {error,Reason,Text}.

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 | reload | upgrade
  The corresponding library callback was unsuccessful.

  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.

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 = #{}
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 \( \{ \text{error, Errors} \} \) is returned, where \( \text{Errors} \) is a list of natural language descriptions of what was wrong with the match specification.

If Type is \( \text{table} \), the object to match against is to be a tuple. The function then returns \( \{ \text{ok}, \text{Result}, [\text{Warnings}] \} \), where \( \text{Result} \) is what would have been the result in a real \( \text{ets:select/2} \) call, or \( \text{false} \) if the match specification does not match the object tuple.

If Type is \( \text{trace} \), the object to match against is to be a list. The function returns \( \{ \text{ok}, \text{Result, Flags, Warnings} \} \), where \( \text{Result} \) is one of the following:

- \( \text{true} \) if a trace message is to be emitted
- \( \text{false} \) if a trace message is not to be emitted
- The message term to be appended to the trace message

\( \text{Flags} \) is a list containing all the trace flags to be enabled, currently this is only \( \text{return_trace} \).

This is a useful debugging and test tool, especially when writing complicated match specifications. See also \( \text{ets:test_ms/2} \).

\[
\text{max}(\text{Term1}, \text{Term2}) \rightarrow \text{Maximum}
\]

Types:

\[
\begin{align*}
\text{Term1} = \text{Term2} = \text{Maximum} & = \text{term()} \\
\end{align*}
\]

Returns the largest of \( \text{Term1} \) and \( \text{Term2} \). If the terms are equal, \( \text{Term1} \) is returned.

\[
\text{erlang:md5}(\text{Data}) \rightarrow \text{Digest}
\]

Types:

\[
\begin{align*}
\text{Data} & = \text{iodata()} \\
\text{Digest} & = \text{binary()}
\end{align*}
\]

Computes an MD5 message digest from \( \text{Data} \), where the length of the digest is 128 bits (16 bytes). \( \text{Data} \) is a binary or a list of small integers and binaries.

For more information about MD5, see [RFC 1321 - The MD5 Message-Digest Algorithm](https://tools.ietf.org/html/rfc1321).

**Warning:**

The MD5 Message-Digest Algorithm is not considered safe for code-signing or software-integrity purposes.

\[
\text{erlang:md5_final}(\text{Context}) \rightarrow \text{Digest}
\]

Types:

\[
\begin{align*}
\text{Context} = \text{Digest} & = \text{binary()}
\end{align*}
\]

Finishes the update of an MD5 \( \text{Context} \) and returns the computed MD5 message digest.

\[
\text{erlang:md5_init()} \rightarrow \text{Context}
\]

Types:

\[
\text{Context} = \text{binary()}
\]

Creates an MD5 context, to be used in the following calls to \( \text{md5_update/2} \).
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.

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.

\[
\begin{align*}
total &= processes + system \\
processes &= processes\_used + Processes\_NotUsed \\
system &= atom + binary + code + ets + OtherSystem \\
atom &= atom\_used + Atom\_NotUsed \\
RealTotal &= processes + RealSystem \\
RealSystem &= system + MissedSystem
\end{align*}
\]

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 prerreservation 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, , , 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:

\[
\{'DOWN', \text{MonitorRef}, \text{Type}, \text{Object}, \text{Info}\}
\]

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 Types and Items 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: \[ \text{node()} = \text{nodes(this)} \], \[ \text{nodes(connected)} = \text{nodes([visible, hidden])} \], and \[ \text{nodes()} = \text{nodes(\text{visible})} \].

\[ \text{now()} \rightarrow \text{Timestamp} \]

Types:
- \[ \text{Timestamp} = \text{timestamp()} \]
- \[ \text{timestamp()} = \{\text{MegaSecs} :: \text{integer()} \geq 0, \text{Secs} :: \text{integer()} \geq 0, \text{MicroSecs} :: \text{integer()} \geq 0\} \]

**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 Don't* describes what to use instead of \texttt{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 \texttt{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.

\[ \text{open_port(PortName, PortSettings)} \rightarrow \text{port()} \]

Types:
- \[ \text{PortName} = \{\text{spawn, Command :: string()} | \text{binary()}\} | \{\text{spawn_driver, Command :: string()} | \text{binary()}\} | \{\text{spawn_executable, FileName :: file:name()}\} | \]

*erlang*
{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 specified 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.

efile
   No more available file descriptors (for the OS process that the Erlang emulator runs in).

enfile
   Full file table (for the entire OS).

eaccess
   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 $2^{32}$.

This BIF can be used instead of the old deprecated BIF `erlang:hash/2`, as it calculates better hashes for all data types, but consider using `phash2/1, 2` instead.

```
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.
```

**Warning:**

This BIF is intended for debugging and is not to be used in application programs.

```
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.
- If `Operation` does not fit in a 32-bit integer.
- If the port driver does not support synchronous control operations.
- 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 Items:
• registered_name (if the port has a registered name)
• id
• connected
• links
• name
• input
• output

For more information about the different Items, 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:
- \( \text{Port} = \text{port()} | \text{atom()} \)
- \( \text{Index} = \text{integer()} \geq 0 \)

Index is the internal index of the port. This index can be used to separate ports.
If the port identified by \( \text{Port} \) is not open, \( \text{undefined} \) 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 \( \text{port_info/2} \) returns \( \text{undefined} \).
Failure: \text{badarg} if \( \text{Port} \) is not a local port identifier, or an atom.

erlang:port_info(Port, Item :: input) ->
{input, Bytes} | undefined

Types:
- \( \text{Port} = \text{port()} | \text{atom()} \)
- \( \text{Bytes} = \text{integer()} \geq 0 \)

Bytes is the total number of bytes read from the port.
If the port identified by \( \text{Port} \) is not open, \( \text{undefined} \) 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 \( \text{port_info/2} \) returns \( \text{undefined} \).
Failure: \text{badarg} if \( \text{Port} \) is not a local port identifier, or an atom.

erlang:port_info(Port, Item :: links) -> {links, Pids} | undefined

Types:
- \( \text{Port} = \text{port()} | \text{atom()} \)
- \( \text{Pids} = [\text{pid()}] \)

Pids is a list of the process identifiers of the processes that the port is linked to.
If the port identified by \( \text{Port} \) is not open, \( \text{undefined} \) 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 \( \text{port_info/2} \) returns \( \text{undefined} \).
Failure: \text{badarg} if \( \text{Port} \) is not a local port identifier, or an atom.

erlang:port_info(Port, Item :: locking) ->
{locking, Locking} | undefined

Types:
- \( \text{Port} = \text{port()} | \text{atom()} \)
- \( \text{Locking} = \text{false} | \text{port_level} | \text{driver_level} \)

Locking is one of the following:
- \text{false} (emulator without SMP support)
- \text{port_level} (port-specific locking)
- \text{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 \texttt{Port} is not open, \texttt{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 \texttt{port_info/2} returns \texttt{undefined}.

Failure: \texttt{badarg} if \texttt{Port} is not a local port identifier, or an atom.

\begin{verbatim}
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 \texttt{open_port}((\texttt{spawn} | \texttt{spawn_executable}, Command), Options). If the port is not the result of spawning an OS process, the value is \texttt{undefined}.

If the port identified by \texttt{Port} is not open, \texttt{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 \texttt{port_info/2} returns \texttt{undefined}.

Failure: \texttt{badarg} if \texttt{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 \texttt{port_command/2}, \texttt{port_command/3}, or \texttt{Port ! (Owner, \{command, Data\}}.

If the port identified by \texttt{Port} is not open, \texttt{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 \texttt{port_info/2} returns \texttt{undefined}.

Failure: \texttt{badarg} if \texttt{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 \texttt{parallelism} of \texttt{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 \texttt{Port} is not open, \texttt{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 \texttt{port_info/2} returns \texttt{undefined}.

**Failure:** \texttt{badarg} if \texttt{Port} is not a local port identifier, or an atom.

\begin{verbatim}
erlang:port_info(Port, Item :: registered_name) ->
    \{registered_name, RegisteredName\} |
    [] |
    undefined
\end{verbatim}

**Types:**
- \texttt{Port} = \texttt{port()} \texttt{atom()}
- \texttt{RegisteredName} = \texttt{atom()}

\texttt{RegisteredName} is the registered name of the port. If the port has no registered name, \texttt{[]} is returned.

If the port identified by \texttt{Port} is not open, \texttt{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 \texttt{port_info/2} returns \texttt{undefined}.

**Failure:** \texttt{badarg} if \texttt{Port} is not a local port identifier, or an atom.

\begin{verbatim}
erlang:port_to_list(Port) -> string()
\end{verbatim}

**Types:**
- \texttt{Port} = \texttt{port()}

Returns a string corresponding to the text representation of the port identifier \texttt{Port}.

**Warning:**

This BIF is intended for debugging. It is not to be used in application programs.

\begin{verbatim}
erlang:ports() -> [port()]
\end{verbatim}

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.

\begin{verbatim}
pre_loaded() -> [module()]
\end{verbatim}

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 \texttt{init} must be preloaded.

\begin{verbatim}
erlang:process_display(Pid, Type) -> true
\end{verbatim}

**Types:**
- \texttt{Pid} = \texttt{pid()}
- \texttt{Type} = \texttt{backtrace}

Writes information about the local process \texttt{Pid} on standard error. The only allowed value for the atom \texttt{Type} is \texttt{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` in `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, 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 have 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.

```erlang
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.

```erlang
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.

```erlang
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} |
  {min_heap_size, MinHeapSize :: integer() >= 0} |
  {message_queue_data, MQD :: message_queue_data()} |
  {monitored_by, Pids :: [pid()]} |
  {monitors, Monitors ::
    [{process | port,
      Pid ::
        pid() | port() |
          {RegName :: atom(), Node :: node()}}]} |
  {priority, Level :: priority_level()} |
  {reductions, Number :: integer() >= 0} |
  {registered_name, [] | (Atom :: atom())} |
Returns a list containing InfoTuples with miscellaneous information about the process identified by Pid, or undefined if the process is not alive.

The order of the InfoTuples is undefined and all InfoTuples are not mandatory. The InfoTuples part of the result can be changed without prior notice.

The InfoTuples 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 InfoTuples, 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()} |} |
Returns information about the process identified by Pid, as specified by Item orItemList. 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.

IfItemList is specified, the result is InfoTupleList. The InfoTuples inInfoTupleList are included with the corresponding Items in the same order as the Items were included inItemList. Valid Items can be included multiple times inItemList.
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 InfoTuples with corresponding Items:

{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 currently referred to by this process. This InfoTuple can be changed or removed without prior notice.

{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.

{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 Items.

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:

```erlang
> 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:

```erlang
> 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
erlang:raise(Class, Reason, Stacktrace) -> no_return()
```

**Types:**
- **Class** = `error` | `exit` | `throw`
- **Reason** = term()
- **Stacktrace** = `raise_stacktrace()`
  ```erlang
  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 function 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
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
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 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.

erlang: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:

```erlang
> 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:

```erlang
> 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()) |
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()) |
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
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 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()

Retruns 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()]

Retruns 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()]

Retruns 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()

Retruns 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 fullsweepered 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()` =
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**

```
split_binary(Bin, Pos) -> {binary(), binary()}
```

Types:

- **Bin** = binary()
- **Pos** = integer() \( \geq 0 \)

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:

```
> Bin = list_to_binary("0123456789").
<<"0123456789">>
> byte_size(Bin).
10
> {B1, B2} = split_binary(Bin, 3).
{{"012"},<<"3456789">>}
> byte_size(B1).
3
> byte_size(B2).
7
```

**erlang:start_timer**

```
erlang:start_timer(Time, Dest, Msg) -> TimerRef
```

Types:

- **Time** = integer() \( \geq 0 \)
- **Dest** = pid() | atom()
- **Msg** = term()


 Starts a timer. The same as calling erlang:start_timer(Time, Dest, Msg, []).

**erlang:start_timer**

```
erlang:start_timer(Time, Dest, Msg, Options) -> TimerRef
```

Types:
erlang

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 \[\text{erlang:system_info(start_time)}, \text{erlang:system_info(end_time)}\]. If a relative time is specified, the Time value is not allowed to be negative.

If Dest is a \text{pid()}\, it must be a \text{pid()} of a process created on the current runtime system instance. This process has either terminated or not. If Dest is an \text{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 \text{pid()}, the timer is automatically canceled if the process referred to by the \text{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 \text{atom()}.

See also \text{erlang:send_after/4}, \text{erlang:cancel_timer/2}, and \text{erlang:read_timer/2}.

Failure: \text{badarg} if the arguments do not satisfy the requirements specified here.

\text{statistics(Item :: active_tasks)} -> \{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 scheduler. That is, the number of processes and ports that are ready to run, or are currently running. The element location in the list corresponds to the scheduler and its run queue. The first element corresponds to scheduler number 1 and so on. The information is not gathered atomically. That is, the result is not necessarily a consistent snapshot of the state, but instead quite efficiently gathered.

See also \text{statistics(total_active_tasks)}, \text{statistics(run_queue_lengths)}, and \text{statistics(total_run_queue_lengths)}.

\text{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 =
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
> 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:

```erlang
define statistics(M) -> erlang:statistics(microstate_accounting()).
define statistics(M) ->
  lists:map(fun({counters => Cnt} = M) ->
    MsCnt = maps:map(fun({K, PerfCount}) ->
      erlang:convert_time_unit(PerfCount, perf_counter, 1000)
    end, Cnt),
    lists:map(fun({counters => MsCnt}) ->
      end, erlang:statistics(MsCnt))
  end, M).
```

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_Types:**
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_States 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_States 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.

go_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 \texttt{msacc(3)} can be used to more easily analyse these statistics. Returns \texttt{undefined} if system flag \texttt{microstate\_accounting} is turned off.

The list of thread information is unsorted and can appear in different order between calls.

\textbf{Note:}

The threads and states are subject to change without any prior notice.

\begin{verbatim}
Statistics(Item :: reductions) ->
  {Total_Reductions, Reductions_Since_Last_Call}

Types:
  Total_Reductions = Reductions_Since_Last_Call = integer() \geq 0

Returns information about reductions, for example:

> statistics(reductions).
{2046,11}
\end{verbatim}

\textbf{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 \texttt{statistics(exact\_reductions)}.

\begin{verbatim}
statistics(Item :: run\_queue) -> integer() \geq 0

Returns the total length of the run-queues. That is, the number of processes and ports that are ready to run on all available run-queues. 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 \texttt{statistics(total\_run\_queue\_lengths)}, especially when a large amount of schedulers is used.

statistics(Item :: run\_queue\_lengths) -> [RunQueueLenght]

Types:
  RunQueueLenght = integer() \geq 0

Returns a list where each element represents the amount of processes and ports ready to run for each run queue. The element location in the list corresponds to the run queue of a scheduler. The first element corresponds to the run queue of scheduler number 1 and so on. The information is \textbf{not} gathered atomically. That is, the result is not necessarily a consistent snapshot of the state, but instead quite efficiently gathered.

See also \texttt{statistics(total\_run\_queue\_lengths)}, \texttt{statistics(active\_tasks)}, and \texttt{statistics(total\_active\_tasks)}.

statistics(Item :: runtime) ->
  {Total_Run_Time, Time_Since_Last_Call}

Types:
\end{verbatim}
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.

Example:

```erlang
> statistics(runtime).
{1690,1620}
```

```erlang
statistics(Item :: scheduler_wall_time) ->
    [{SchedulerId, ActiveTime, TotalTime}] | undefined

Types:
    SchedulerId = integer() >= 1
    ActiveTime = TotalTime = integer() >= 0

Returns a list of tuples with \(\{\text{SchedulerId}, \text{ActiveTime}, \text{TotalTime}\}\), where \(\text{SchedulerId}\) is an integer ID of the scheduler, \(\text{ActiveTime}\) is the duration the scheduler has been busy, and \(\text{TotalTime}\) is the total time duration since \(\text{scheduler_wall_time}\) activation. The time unit is undefined and can be subject to change between releases, OSs, and system restarts. \(\text{scheduler_wall_time}\) is only to be used to calculate relative values for scheduler-utilization. \(\text{ActiveTime}\) can never exceed \(\text{TotalTime}\).

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 \(\text{scheduler_wall_time}\) is turned off.

The list of scheduler information is unsorted and can appear in different order between calls.

Using \(\text{scheduler_wall_time}\) to calculate scheduler-utilization:

```erlang
> 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:

```erlang
> 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],
```
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)), A/T.
0.9769136803764825
```

Note:

scheduler_wall_time is by default disabled. To enable it, use
erlang:system_flag(scheduler_wall_time, true).

**statistics(Item :: total_active_tasks) -> ActiveTasks**

Types:

```
ActiveTasks = integer() >= 0
```

Returns the total amount of active processes and ports in the system. That is, the number of processes and ports that are ready to run, or are currently running. The information is not gathered atomically. That is, the result is not necessarily a consistent snapshot of the state, but instead quite efficiently gathered.

See also `statistics(active_tasks)`, `statistics(run_queue_lengths)`, and `statistics(total_run_queue_lengths)`.

**statistics(Item :: total_run_queue_lengths) -> TotalRunQueueLenghts**

Types:

```
TotalRunQueueLenghts = integer() >= 0
```

Returns the total length of the run queues. That is, the number of processes and ports that are ready to run on all available run queues. The information is not gathered atomically. That is, the result is not necessarily a consistent snapshot of the state, but much more efficiently gathered compared to `statistics(run_queue)`.

See also `statistics(run_queue_lengths)`, `statistics(total_active_tasks)`, and `statistics(active_tasks)`.

**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.
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)`.

```
<table>
<thead>
<tr>
<th>Flag :: dirty_cpuSchedulersOnline</th>
</tr>
</thead>
<tbody>
<tr>
<td>DirtyCPUSchedulersOnline</td>
</tr>
<tr>
<td>OldDirtyCPUSchedulersOnline</td>
</tr>
</tbody>
</table>
```

Types:

```
DirtyCPUSchedulersOnline = OldDirtyCPUSchedulersOnline = integer() >= 1
```

Sets the number of dirty CPU schedulers online. Range is $1 \leq \text{DirtyCPUSchedulersOnline} \leq N$, 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.

Note:
The dirty schedulers functionality is experimental. Enable support for dirty schedulers when building OTP to try out the functionality.

For more information, see `erlang:system_info(dirty_cpu_schedulers)` and `erlang:system_info(dirty_cpu_schedulers_online)`.

```
<table>
<thead>
<tr>
<th>Flag :: fullsweep_after</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
</tr>
<tr>
<td>OldNumber</td>
</tr>
</tbody>
</table>
```

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.

```
<table>
<thead>
<tr>
<th>Flag :: microstate_accounting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Action</td>
</tr>
</tbody>
</table>
```

Sets system flag microstate_accounting. Action is a string indicating an action to be taken. Possible actions are `on` and `off`.

Returns the old value of the flag.

In low-memory systems (especially without virtual memory), setting the value to `off` can help to conserve memory.

This value can also be set through (OS) environment variable ERL_MOSTSTATE_ACCOUNTING.
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, OldState}

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, OldState}

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_vheap_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, OldState}

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 after 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, OldState}

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 |
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 LevelEntries of a list must contain the same LevelTag, except on the top level where both node and processor LevelTags 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 LevelTags 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 CpuTopoogyy. 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, +hmaxx 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).

min_heap_size

Returns {min_heap_size, MinHeapSize}, where MinHeapSize is the current system-wide minimum heap size for spawned processes.

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_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 :: 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_cpuSchedulers) ->
    integer() >= 0
erlang:system_info(Item :: dirty_cpuSchedulersOnline) ->
    integer() >= 0
erlang:system_info(Item :: dirty_ioschedulers) ->
    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:
allocated_areas, allocator, alloc_util_allocators, allocator_sizes

See above.

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).
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 +zdngc to erl(1). For more information, see the documentation of the command-line flag.

dirty_cpuSchedulers

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).

Notice that the dirty schedulers functionality is experimental. Enable support for dirty schedulers when building OTP to try out the functionality.

See also erlang:system_flag(dirty_cpuSchedulers_online, DirtyCPUSchedulersOnline), erlang:system_info(dirty_cpuSchedulers_online), erlang:system_info(dirty_cpuSchedulers), erlang:system_info(schedulers_online), erlang:system_info(schedulers), and erlang:system_flag(schedulers_online, SchedulersOnline).

dirty_cpuSchedulers_online

Returns the number of dirty CPU scheduler online. The return value satisfies 1 <= DirtyCPUSchedulersOnline <= N, where N is the smallest of the return values of erlang:system_info(dirty_cpuSchedulers) 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).

Notice that the dirty schedulers functionality is experimental. Enable support for dirty schedulers when building OTP to try out the functionality.

For more information, see erlang:system_info(dirty_cpuSchedulers), erlang:system_info(dirty_cpuSchedulers_online), erlang:system_info(schedulers_online), and erlang:system_flag(dirty_cpuSchedulers_online, DirtyCPUSchedulersOnline).

dirty_ioSchedulers

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).
Notice that the dirty schedulers functionality is experimental. Enable support for dirty schedulers when building OTP to try out the functionality.

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.
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.

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)`.

Returns a list of Pids when multi-scheduling is blocked, otherwise the empty list is returned. The Pids 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)`.

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>".

Returns a list of Pids when normal multi-scheduling is blocked (that is, all normal schedulers but one is blocked), otherwise the empty list is returned. The Pids 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(normal_multi_scheduling_blockers)`
- and `erlang:system_info(schedulers)`.

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.

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 Keys as first element, and Values 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 Functions 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 Keys as first element, and Values 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 function 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 Functions 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 \(1 \leq \text{SchedulerId} \leq \text{erlang:system_info(schedulers_online)}\).

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.

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 \texttt{Version} are 0 and 1.

As from Erlang/OTP 17.0, \{(minor_version, 1)\} is 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, \texttt{binary_to_term/1} can decode this representation.

\{(minor_version, 0)\} means that floats are encoded using a textual representation. This option is useful to ensure that releases before Erlang/OTP R11B-4 can decode resulting binary.

See also \texttt{binary_to_term/1}.

\texttt{throw(Any) \rightarrow no_return()}

\textbf{Types:}

\begin{itemize}
  \item \texttt{Any = term()}
\end{itemize}

A non-local return from a function. If evaluated within a \texttt{catch}, \texttt{catch} returns value \texttt{Any}. Example:

\begin{verbatim}
> catch throw({hello, there}).
{hello,there}
\end{verbatim}

\textbf{Failure: nocatch} if not evaluated within a catch.

\texttt{time() \rightarrow Time}

\textbf{Types:}

\begin{itemize}
  \item \texttt{Time = calendar:time()}
\end{itemize}

Returns the current time as \texttt{(Hour, Minute, Second)}.

The time zone and Daylight Saving Time correction depend on the underlying OS. Example:

\begin{verbatim}
> time().
(9,42,44)
\end{verbatim}

\texttt{erlang:time_offset() \rightarrow integer()}

Returns the current time offset between \textit{Erlang monotonic time} and \textit{Erlang system time} in \texttt{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 \textit{time warp mode} used.

\textbf{Note:}

A change in time offset can be observed at slightly different points in time by different processes.

If the runtime system is in \textit{multi-time warp mode}, the time offset is changed when the runtime system detects that the \textit{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:

\[
\text{timestamp}() \rightarrow \\
\text{ErlangSystemTime} = \text{erlang:system_time(microsecond)}, \\
\text{MegaSecs} = \text{ErlangSystemTime} \div 1000000000000, \\
\text{Secs} = \text{ErlangSystemTime} \div 1000000 - \text{MegaSecs} \times 1000000, \\
\text{MicroSecs} = \text{ErlangSystemTime} \mod 1000000, \\
\{\text{MegaSecs}, \text{Secs}, \text{MicroSecs}\}.
\]

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 \texttt{call} and \texttt{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 \texttt{(return\_trace)} match specification action instead.

Message tags: \texttt{return\_to}.

\texttt{procs}

Traces process-related events.

Message tags: \texttt{spawn, spawned, exit, register, unregister, link, unlink, getting\_linked, and getting\_unlinked}.

\texttt{ports}

Traces port-related events.

Message tags: \texttt{open, closed, register, unregister, getting\_linked, and getting\_unlinked}.

\texttt{running}

Traces scheduling of processes.

Message tags: \texttt{in and out}.

\texttt{exiting}

Traces scheduling of exiting processes.

Message tags: \texttt{in\_exiting, out\_exiting, and out\_exited}.

\texttt{running\_procs}

Traces scheduling of processes just like \texttt{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: \texttt{in and out}.

\texttt{running\_ports}

Traces scheduling of ports.

Message tags: \texttt{in and out}.

\texttt{garbage\_collection}

Traces garbage collections of processes.

Message tags: \texttt{gc\_minor\_start, gc\_max\_heap\_size, and gc\_minor\_end}.

\texttt{timestamp}

Includes a time stamp in all trace messages. The time stamp (Ts) has the same form as returned by \texttt{erlang:now()}.

\texttt{cpu\_timestamp}

A global trace flag for the Erlang node that makes all trace time stamps using flag \texttt{timestamp} to be in CPU time, not wall clock time. That is, \texttt{cpu\_timestamp} is not used if \texttt{monotonic\_timestamp} or \texttt{strict\_monotonic\_timestamp} is enabled. Only allowed with \texttt{PidPortSpec=\texttt{all}. If the host machine OS does not support high-resolution CPU time measurements, \texttt{trace/3} exits with \texttt{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 a 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_onSpawn

Makes any process created by a traced process inherit its trace flags, including flag set_on_spawn.

set_onFirstSpawn

Makes the first process created by a traced process inherit its trace flags, excluding flag set_on_first_spawn.

set_onLink

Makes any process linked by a traced process inherit its trace flags, including flag set_on_link.

set_onFirstLink

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.

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.
The total size of binaries allowed in the virtual heap in the process before doing a garbage collection.

The total size of unique off-heap binaries referenced from the process old heap.

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()} |

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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 Items 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 Items 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

\[\text{trace_pattern_mfa()} = \{\text{atom()}, \text{atom()}, \text{arity()} | \_\} \mid \text{on_load}\]

\[\text{trace_match_spec()} =
\quad \{[[\text{term()}] | \_ | \text{match_variable()}, [\text{term()}], [\text{term()}]]\}\]

\[\text{match_variable()} = \text{atom()}\]

Approximation of \$1\mid\$2\mid\$3\mid...

The same as \text{erlang:trace_pattern(Event, MatchSpec, [])} retained for backward compatibility.

\text{erlang:trace_pattern(MFA :: \text{send}, MatchSpec, FlagList :: [])} \rightarrow
\quad \text{integer()} \geq 0

Types:
\[\text{MatchSpec} = (\text{MatchSpecList} :: \text{trace_match_spec()}) \mid \text{boolean()}\]

\[\text{trace_match_spec()} =
\quad \{[[\text{term()}] | \_ | \text{match_variable()}, [\text{term()}], [\text{term()}]]\}\]

\[\text{match_variable()} = \text{atom()}\]

Approximation of \$1\mid\$2\mid\$3\mid...

Sets trace pattern for \text{message sending}. Must be combined with \text{erlang:trace/3} to set the \text{send} trace flag for one or more processes. By default all messages sent from \text{send} traced processes are traced. To limit traced send events based on the message content, the sender and/or the receiver, use \text{erlang:trace_pattern/3}.

Argument \text{MatchSpec} can take the following forms:

\text{MatchSpecList}

A list of match specifications. The matching is done on the list \{\text{Receiver, Msg}\}. \text{Receiver} is the process or port identity of the receiver and \text{Msg} is the message term. The pid of the sending process can be accessed with the guard function \text{self}/0. An empty list is the same as \text{true}. For more information, see section \text{Match Specifications in Erlang} in the User's Guide.

\text{true}

Enables tracing for all sent messages (from \text{send} traced processes). Any match specification is removed. \text{This is the default}.

\text{false}

Disables tracing for all sent messages. Any match specification is removed.

Argument \text{FlagList} must be [] for \text{send} tracing.

The return value is always \text{1}.

Examples:

Only trace messages to a specific process \text{Pid}:

\begin{verbatim}
> \text{erlang:trace_pattern(send, \{[[\text{Pid}, \_],[],[],[]], []\}).}
1
\end{verbatim}

Only trace messages matching \{\text{reply, }\_\}:

\begin{verbatim}
> \text{erlang:trace_pattern(send, \{[[\_], \{\text{reply,}\_\}],[],[]], []\}).}
1
\end{verbatim}
Only trace messages sent to the sender itself:

```erlang
> erlang:trace_pattern(send, [[['$1', '_']], ['='=','$1',{self}]], []).
1
```

Only trace messages sent to other nodes:

```erlang
> 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
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()`

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:

```erl
> erlang:trace_pattern('receive', [[{'_','_'),[{_,[]},[],[]]],[]]).
1
```

Only trace messages matching 
{reply, _}:

```erl
> erlang:trace_pattern('receive', [[{'_','_'),[{reply, '_'}],[],[]]],[]).
1
```

Only trace messages from other nodes:

```erl
> 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.

```erl
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.
Modifers:
  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 \( X = \text{erlang:unique_integer([monotonic])} \) and \( Y = \text{erlang:unique_integer([monotonic])} \) 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 \texttt{monotonic} modifier unless you really need strictly monotonically increasing values.

All valid \texttt{Modifiers} can be combined. Repeated (valid) \texttt{Modifiers} in the \texttt{ModifierList} are ignored.

Note:

The set of integers returned by \texttt{erlang:unique_integer/1} using different sets of \texttt{Modifiers} will overlap. For example, by calling \texttt{unique_integer([monotonic])}, and \texttt{unique_integer([positive, monotonic])} repeatedly, you will eventually see some integers that are returned by both calls.

Failures:

\texttt{badarg} if \texttt{ModifierList} is not a proper list.
\texttt{badarg} if \texttt{Modifier} is not a valid modifier.

\texttt{erlang:universaltime() -> DateTime}

Types:

\[
\text{DateTime} = \text{calendar:datetime()}
\]

Returns the current date and time according to Universal Time Coordinated (UTC) in the form \({\{\text{Year, Month, Day}\}, \{\text{Hour, Minute, Second}\}}\) if supported by the underlying OS. Otherwise \texttt{erlang:universaltime()} is equivalent to \texttt{erlang:localtime()}. Example:

\[
> \text{erlang:universaltime().}
\]

\[
{{1996,11,6},{14,18,43}}
\]

\texttt{erlang:universaltime_to_localtime(Universaltime) -> Localtime}

Types:
Localtime = Universaltime = \textit{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:

\begin{verbatim}
> erlang:universaltime_to_localtime([\{1996,11,6\},\{14,18,43\}]).
\{\{1996,11,7\},\{15,18,43\}\}
\end{verbatim}

Failure: \texttt{badarg} if Universaltime denotes an invalid date and time.

\texttt{unlink(Id) -> true}

Types:
\begin{verbatim}
Id = pid() \mid port()
\end{verbatim}

Removes the link, if there is one, between the calling process and the process or port referred to by \texttt{Id}.

Returns \texttt{true} and does not fail, even if there is no link to \texttt{Id}, or if \texttt{Id} does not exist.

Once \texttt{unlink(Id)} has returned, it is guaranteed that the link between the caller and the entity referred to by \texttt{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 \texttt{Id} calling \texttt{exit/2}. Therefore, it can be appropriate to clean up the message queue when trapping exits after the call to \texttt{unlink(Id)}, as follows:

\begin{verbatim}
unlink(Id),
receive
  \{'EXIT', Id, _\} ->
  true
after 0 ->
  true
end
\end{verbatim}

\textbf{Note:}

Before Erlang/OTP R11B (ERTS 5.5) \texttt{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.

\texttt{unregister(RegName) -> true}

Types:
\begin{verbatim}
RegName = atom()
\end{verbatim}

Removes the registered name \texttt{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.

\[\text{whereis(RegName)} \rightarrow \text{pid()} | \text{port()} | \text{undefined}\]

Types:
- \(\text{RegName} = \text{atom()}\)

Returns the process identifier or port identifier with the registered name \(\text{RegName}\). Returns \text{undefined} if the name is not registered. Example:

> whereis(db).
<0.43.0>

\[\text{erlang:yield()} \rightarrow \text{true}\]

Voluntarily lets other processes (if any) get a chance to execute. Using this function is similar to \text{receive after 1} \rightarrow \text{ok end}, except that \text{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.
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"]]}
```

prograde

The name of the program which started Erlang:
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()
```

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
% erl -noshell -eval 'R = 16#1F+16#A0, io:format("~.16B~n", [R])' \n-s erlang halt
```

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
% erl -run foo -run foo bar -run foo bar baz 1 2
```

This starts the Erlang runtime system and evaluates the following functions:

```erl
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
% erl -s foo -s foo bar -s foo bar baz 1 2
```

This starts the Erlang runtime system and evaluates the following functions:
The functions are executed sequentially in an initialization process, which then terminates normally and passes control to the user. This means that a \texttt{-s} call that does not return blocks further processing; to avoid this, use some variant of \texttt{spawn} in such cases.

Because of the limited length of atoms, it is recommended to use \texttt{-run} instead.

### Example

```erlang
% 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

\textit{erl_prim_loader(3), heart(3)}
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:

- **badarg**
  - Bad argument.
- **data_error**
  - The data contains errors.
- **stream_error**
  - Inconsistent stream state.
- **einval**
  - Bad value or wrong function called.
- **{need_dictionary,Adler32}**
  - See `inflate/2`.

**Data Types**

- **zstream() = port()**
  - A zlib stream, see `open/0`.
- **zlevel() = none | default | best_compression | best_speed | 0..9**
- **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.

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:

```erlang
crc = lists:foldl(fun(Data, Crc0) ->
  zlib:adler32(Z, Crc0, Data),
  end, zlib:adler32(Z,<<>>, Datas)
```

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 oriolists, 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.

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.

crc32(Z, Data) -> CRC
Types:
  Z = zstream()
  Data = iodata()
  CRC = integer()
Calculates the CRC checksum for Data.

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)
```

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.

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 = none | sync | full | finish  
  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:

```erlang
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.

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) -> Size
Types:
  Z = zstream()
  Size = integer() >= 0

Gets the size of the intermediate buffer.

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.

inflatede(Z, Data) -> Decompressed
Types:
    Z = zstream()
    Data = iodata()
    Decompressed = iolist()
Decompresses as much data as possible. It can introduce some output latency (reading input without producing any output).
If a preset dictionary is needed at this point (see inflatedSetDictionary/2). inflate/2 throws a {need_dictionary,Adler} exception, where Adler is the Adler-32 checksum of the dictionary chosen by the compressor.

inflatedeChunk(Z) -> Decompressed | {more, Decompressed}
Types:
    Z = zstream()
    Decompressed = iolist()
Reads the next chunk of uncompressed data, initialized by inflatedeChunk/2.
This function is to be repeatedly called, while it returns {more, Decompressed}.

inflatedeChunk(Z, Data) -> Decompressed | {more, Decompressed}
Types:
    Z = zstream()
    Data = iodata()
    Decompressed = iolist()
Like inflate/2, but decompresses no more data than will fit in the buffer configured through setBufSize/2. 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 inflatedeChunk/1 is to be used to read it.
This function can introduce some output latency (reading input without producing any output).
If a preset dictionary is needed at this point (see inflatedSetDictionary/2), this function throws a {need_dictionary,Adler} exception, where Adler is the Adler-32 checksum of the dictionary chosen by the compressor.
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).

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 immediately after a call of inflate/2 if this call threw a {need_dictionary, Adler} exception. The dictionary chosen by the compressor can be determined from the Adler value thrown by the call to inflate/2. The compressor and decompressor must use the same dictionary (see deflateSetDictionary/2).
Example:

```erlang
erp{zlib:inflate(Z, Compressed) of
    case catch zlib:inflate(Z, Compressed) of
        {'EXIT',{{need_dictionary,DictID},_}} ->
            zlib:inflateSetDictionary(Z, Dict),
            Uncompressed = zlib:inflate(Z, []);
        Uncompressed ->
            Uncompressed
    end.

open() -> zstream()
Opens a zlib stream.

setBufSize(Z, Size) -> ok
Types:
    Z = zstream()
    Size = integer() >= 0
Sets the intermediate buffer size.

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
*./*/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 \texttt{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.
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 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.

-env Variable Value
Sets the host OS environment variable Variable to the value Value for the Erlang runtime system. Example:

```erb
% 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.

-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
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.

-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.

Note:
The runtime system with SMP support is not available on all supported platforms. 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.

\[ +c \; \text{true} \mid \text{false} \]

Enables or disables \textit{time correction}:

- \text{true}
  - Enables time correction. This is the default if time correction is supported on the specific platform.
- \text{false}
  - Disables time correction.

For backward compatibility, the boolean value can be omitted. This is interpreted as \[ +c \; \text{false} \].

\[ +C \; \text{no\_time\_warp} \mid \text{single\_time\_warp} \mid \text{multi\_time\_warp} \]

Sets \textit{time warp mode}:

- \text{no\_time\_warp}
  - \textit{No time warp mode} (the default)
- \text{single\_time\_warp}
  - \textit{Single time warp mode}
- \text{multi\_time\_warp}
  - \textit{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 \texttt{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.

\[ +e \; \text{Number} \]

Sets the maximum number of ETS tables.

\[ +ec \]

Forces option \textit{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 \textit{Unicode Filenames} in the STDLIB User's Guide. Notice that this value also applies to command-line parameters and environment variables (see section \textit{Unicode in Enviroment 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 \texttt{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.
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.

Memory allocator-specific flags. For more information, see erts_alloc(3).

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.

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

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.

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 :SchedulersOnline 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. **This option is experimental** and is supported only if the emulator was configured and built with support for dirty schedulers enabled (it is disabled by default).

+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. **This option is experimental** and is supported only if the emulator was configured and built with support for dirty schedulers enabled (it is disabled by default).

+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. **This option is experimental** and is supported only if the emulator was configured and built with support for dirty schedulers enabled (it is disabled by default).
+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 BindTypes:

- **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.

- **nnrs**
  - 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>`
• \(<\text{ThreadIds}\> = T\langle\text{IdList}\> | t\langle\text{IdList}\>
• \(<\text{CoreIds}\> = C\langle\text{IdList}\> | c\langle\text{IdList}\>
• \(<\text{ProcessorIds}\> = P\langle\text{IdList}\> | p\langle\text{IdList}\>
• \(<\text{NodeIds}\> = N\langle\text{IdList}\> | n\langle\text{IdList}\>
• \(<\text{IdDefs}\> = <\text{LogicalIds}\><\text{ThreadIds}\><\text{CoreIds}\><\text{ProcessorIds}\><\text{NodeIds}\> | <\text{LogicalIds}\><\text{ThreadIds}\><\text{CoreIds}\><\text{NodeIds}\><\text{ProcessorIds}\>
• \text{CpuTopology} = <\text{IdDefs}\>:<\text{IdDefs}\> | <\text{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 \(<\text{IdRange}\>\)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:

• \(<\text{LogicalIds}\><\text{ThreadIds}\><\text{CoreIds}\><\text{ProcessorIds}\><\text{NodeIds}\>, that is, thread is part of a core that is part of a processor, which is part of a NUMA node.
• \(<\text{LogicalIds}\><\text{ThreadIds}\><\text{CoreIds}\><\text{NodeIds}\><\text{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 \(<\text{ProcessorIds}\>\) is omitted, its default position is before \(<\text{NodeIds}\>\). That is, the default is processor external NUMA nodes.

If a list of identifiers is used in an \(<\text{IdDefs}\>\):

• \(<\text{LogicalIds}\>\) must be a list of identifiers.
• At least one other identifier type besides \(<\text{LogicalIds}\>\) 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:

```erlang
% 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:
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 L0-1,3-2c0-3p0N0:L7,4,5c0-3p1N1
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}}]]]]}
```

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 \texttt{erlang:system_info(port_parallelism)}. The default can be overridden on port creation by passing option \texttt{parallelism} to \texttt{erlang:open_port/2}.

+sss size

Suggested stack size, in kilowords, for scheduler threads. Valid range is 4-8192 kilowords. The default stack size is OS-dependent.

+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.

\textbf{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.

\textbf{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 by a SIGALRM signal.

If the variable is not set or set to 0 seconds (ERL_CRASH_DUMP_SECONDS=0), the runtime system does not even attempt to write the crash dump file. It only terminates.

If the variable is set to negative value, such as ERL_CRASH_DUMP_SECONDS=-1, the runtime system waits indefinitely for the crash dump file to be written.

This variable is used with heart(3) if heart is running:

ERL_CRASH_DUMP_SECONDS=0

Suppresses the writing a crash dump file entirely, thus rebooting the runtime system immediately. This is the same as not setting the environment variable.

ERL_CRASH_DUMP_SECONDS=-1

Setting the environment variable to a negative value causes the termination of the runtime system to wait until the crash dump file has been completely written.

ERL_CRASH_DUMP_SECONDS=S

Waits for S seconds to complete the crash dump file and then terminates the runtime system.

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.

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 \texttt{erlc} program provides a common way to run all compilers in the Erlang system. Depending on the extension of each input file, \texttt{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

\texttt{erlc flags file1.ext file2.ext...}

Compiles one or more files. The files must include the extension, for example, \texttt{.erl} for Erlang source code, or \texttt{.yrl} for Yecc source code. \texttt{Erlc} uses the extension to invoke the correct compiler.

Generally Useful Flags

The following flags are supported:

- \texttt{-I <Directory>}
  Instructs the compiler to search for include files in the \texttt{Directory}. When encountering an \texttt{-include} or \texttt{-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 \texttt{-I}; the directory specified last is searched first

- \texttt{-o <Directory>}
  The directory where the compiler is to place the output files. Defaults to the current working directory.

- \texttt{-D<Name>}
  Defines a macro.

- \texttt{-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.

- \texttt{-W<Error>}
  Makes all warnings into errors.

- \texttt{-W<Number>}
  Sets warning level to \texttt{Number}. Defaults to 1. To turn off warnings, use \texttt{-W0}.

- \texttt{-W}
  Same as \texttt{-W1}. Default.

- \texttt{-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.

Exports

script-name script-arg1 script-arg2...
escript escript-flags script-name script-arg1 script-arg2...
escript runs a script written in Erlang.
Example:

```erlang
$ 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:

```erlang
$ 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
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:

-include_lib("kernel/include/file.hrl").

-modes(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]
    | {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
main(_Args) ->
    io:format(erlang:system_info(smp_support)).
".

ok
ok
ok
ok
ok
ok
ok
ok
ok
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:

```erlang
> {ok, SourceCode} = file:read_file("demo.erl").
{ok,<<"%% demo.erl
-module(demo).
-export([main/1]).

%% Demo
main(_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,
       152,61,107,0,0,0,118,0,...>>}],
     <<70,79,82,49,0,0,2,228,66,69,65,77,65,116,65,111,109,0,0,0,
       83,0,0,...>>,
     {"demo.erl",
       {file_info,118,regular,read_write,
        {{2010,3,2},{0,59,22}},
        {{2010,3,2},{0,59,22}},
        {54,1,0,0,0,0,0,0},
        <<"%% demo.erl
-module(demo).
-export([main/1]).

%% Demo
main(_Arg)...>>}
```
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:

```erlang
> 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, <<80,75,3,4,20,0,0,8,0,118,7,98,60,105,
               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 after the command is issued in the shell, 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.
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()` (e.g., `-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:

`-stopaction` `[[<erlang shell command>]]`

Defines the `StopAction`, the command given to the Erlang shell when the service is stopped. Default is none.

`-onfail` `[[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.

{-sname | -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 cosmetic 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 \texttt{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 \texttt{start\_disabled} and the sequence \texttt{enable}, \texttt{start}, and \texttt{disable} is that all other \texttt{erlsrv} commands are locked out during the sequence of operations in \texttt{start\_disable}, making the operation atomic from an \texttt{erlsrv} user's point of view.

\texttt{erlsrv remove <service-name>}

Removes the service completely with all its registered options. It is stopped before it is removed.

\texttt{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.

\texttt{erlsrv help}

Displays a brief help text.

\section*{Environment}

The environment of an Erlang machine started as a service contains two special variables:

\begin{description}
\item[ERLSRV\_SERVICE\_NAME] The name of the service that started the machine.
\item[ERLSRV\_EXECUTABLE] The full path to the \texttt{erlsrv.exe}, which can be used to manipulate the service. This comes in handy when defining a heart command for your service.
\end{description}

A command file for restarting a service looks as follows:

\begin{verbatim}
@echo off
%ERLSRV\_EXECUTABLE% stop %ERLSRV\_SERVICE\_NAME%
%ERLSRV\_EXECUTABLE% start %ERLSRV\_SERVICE\_NAME%
\end{verbatim}

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).

\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 \texttt{SetConsoleCtrlHandler} to register a control handler that returns \texttt{true} in answer to the \texttt{CTRL\_LOGOFF\_EVENT} and \texttt{CTRL\_SHUTDOWN\_EVENT} events. Other applications only forward \texttt{WM\_ENDSESSION} and \texttt{WM\_QUERYENDSESSION} to the default window procedure.

A brief example in C of how to set the console control handler:

\begin{verbatim}
#include <windows.h>
/*
 ** A console control handler that ignores the log off events,
 */
\end{verbatim}
// 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)`
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 `erlsvr` during emulator restart. Locate the (possibly customized) `start_erl` program so that it is not overwritten during upgrade.

• The default options of the `erlsvr` program are not sufficient for release handling. The machine started by `erlsvr` is be specified as the `start_erl` program and the arguments are to contain `++` followed by the desired options.

See Also

`erlsvr(1), release_handler(3)`
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:

```plaintext
===== <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.

**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 opened 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)`
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**

```plaintext
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)`
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**

Rewrite driver callback `control` to use return type `ErlDrvSSizeT` instead of `int`.
Rewrite driver callback `call` to use return type `ErlDrvSSizeT` instead of `int`.

**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:**

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.
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
**Erl_drv_driver**

```c

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**

```c

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

```c
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

```c
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_rwlock, erl_drv_rwlock_rwlock, erl_drv_rwlock_rwlock, erl_drv_rwlock_rwlock, and erl_drv_rwlock_rwlock.

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:

<table>
<thead>
<tr>
<th>Enum</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ERL_DRV_SEC</td>
<td>Seconds</td>
</tr>
<tr>
<td>ERL_DRV_MSEC</td>
<td>Milliseconds</td>
</tr>
<tr>
<td>ERL_DRV_USEC</td>
<td>Microseconds</td>
</tr>
<tr>
<td>ERL_DRV_NSEC</td>
<td>Nanoseconds</td>
</tr>
</tbody>
</table>

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:

```c
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 only thread-safe when the emulator with SMP support is used.

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 only thread-safe when the emulator with SMP support is used.

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 only thread-safe when the emulator with SMP support is used.

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 ErlDrvMonitors. 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 only thread-safe when the emulator with SMP support is used.

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.

```c
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`.

```c
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`.

```c
long driver_pdl_dec_refc(ErlDrvPDL pdl)
```

Decrement 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.

```c
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.

```c
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.

```c
void driver_pdl_lock(ErlDrvPDL pdl)
```

Locks the port data lock passed as argument (pdl).
This function is thread-safe.

```c
void driver_pdl_unlock(ErlDrvPDL pdl)
```

Unlocks the port data lock passed as argument (`pdl`).
This function is thread-safe.

```c
SysIOVec *driver_peekq(ErlDrvPort port, int *vlen)
```

Retrieves the driver queue as a pointer to an array of `SysIOVecs`. 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.

```c
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.

```c
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.

```c
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`.

```c
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 only thread-safe when the emulator with SMP support is used.

**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.

```c
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`.

```c
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.

```c
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.

\[
\text{ErlDrvTime erl_drv_convert_time_unit(ErlDrvTime val, ErlDrvTimeUnit from, ErlDrvTimeUnit to)}
\]

Converts the \(\text{val}\) value of time unit \(\text{from}\) to the corresponding value of time unit \(\text{to}\). The result is rounded using the floor function.

\[
\begin{align*}
\text{val} & \quad \text{Value to convert time unit for.} \\
\text{from} & \quad \text{Time unit of } \text{val}. \\
\text{to} & \quad \text{Time unit of returned value.}
\end{align*}
\]

Returns \text{ERL_DRV_TIME_ERROR} if called with an invalid time unit argument.

See also \text{ErlDrvTime} and \text{ErlDrvTimeUnit}.

\[
\text{int erl_drv_equal_tids(ErlDrvTid tid1, ErlDrvTid tid2)}
\]

Compares two thread identifiers, \(\text{tid1}\) and \(\text{tid2}\), for equality.

Returns 0 if they are not equal, and a value not equal to 0 if they are equal.

\[
\begin{align*}
\text{Note:} \\
\text{A thread identifier can be reused very quickly after a thread has terminated. Therefore, if a thread corresponding to one of the involved thread identifiers has terminated since the thread identifier was saved, the result of \text{erl_drv_equal_tids} does possibly not give the expected result.}
\end{align*}
\]

This function is thread-safe.

\[
\text{int erl_drv_getenv(const char *key, char *value, size_t *value_size)}
\]

Retrieves the value of an environment variable.

\[
\begin{align*}
\text{key} & \quad \text{A NULL-terminated string containing the name of the environment variable.}
\end{align*}
\]
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.

```c
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.

```c
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.

```c
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.

```c
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.
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 \texttt{erl_drv_send_term} functions can be used for sending to any process on the local node.

**Note:**
Parameter \texttt{port} is not an ordinary port handle, but a port handle converted using \texttt{driver_mk_port}.

Parameter \texttt{term} points to an array of \texttt{ErlDrvTermData} with \texttt{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 \texttt{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 \texttt{ERL_DRV_TUPLE} term.)
- A map must be specified with the number of key-value pairs \texttt{N}. The key-value pairs must precede the \texttt{ERL_DRV_MAP} in this order: \texttt{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 \texttt{ERL_DRV_LIST}.

The special term \texttt{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.

<table>
<thead>
<tr>
<th>Term type</th>
<th>Arguments</th>
</tr>
</thead>
<tbody>
<tr>
<td>ERL_DRV_NIL</td>
<td>\texttt{ErlDrvTermData \ atom (from driver_mk_atom(char *string))}</td>
</tr>
<tr>
<td>ERL_DRV_ATOM</td>
<td>\texttt{ErlDrvSInt integer}</td>
</tr>
<tr>
<td>ERL_DRV_UINT</td>
<td>\texttt{ErlDrvUInt integer}</td>
</tr>
<tr>
<td>ERL_DRV_UINT64</td>
<td>\texttt{ErlDrvUInt64 *integer_ptr}</td>
</tr>
<tr>
<td>ERL_DRV_BUN2BINARY</td>
<td>char *bufl, ErlDrvUInt len, ErlDrvUInt offset</td>
</tr>
<tr>
<td>ERL_DRV_STRING</td>
<td>char *strl, int len</td>
</tr>
<tr>
<td>ERL_DRV_TUPLE</td>
<td>\texttt{int sz}</td>
</tr>
<tr>
<td>ERL_DRV_LIST</td>
<td>\texttt{int sz}</td>
</tr>
<tr>
<td>ERL_DRV_PID</td>
<td>\texttt{ErlDrvTermData pid (from driver_connected(ErlDrvPort port))}</td>
</tr>
<tr>
<td>ERL_DRV_STRING_CONS</td>
<td>\texttt{char *strl, int len}</td>
</tr>
<tr>
<td>ERL_DRV_FLOAT</td>
<td>double *dbll</td>
</tr>
<tr>
<td>ERL_DRV_EXT2TERM</td>
<td>char *bufl, ErlDrvUInt len</td>
</tr>
<tr>
<td>ERL_DRV_MAP</td>
<td>\texttt{int sz}</td>
</tr>
</tbody>
</table>

The unsigned integer data type \texttt{ErlDrvUInt} and the signed integer data type \texttt{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 \texttt{int} arguments in the list above.

The unsigned integer data type \texttt{ErlDrvUInt64} and the signed integer data type \texttt{ErlDrvSInt64} are always 64 bits wide. They were introduced in ERTS 5.7.4.

To build the tuple \{(\texttt{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_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.

```c
void erl_drv_rwlock_rwlock(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.

```c
int erl_drv_rwlock_rwlock(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.

```c
int erl_drv_rwlock_rwlock(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.

```c
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`. 
erl_driver

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.
nname 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 \texttt{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. \texttt{key} is a thread-specific data key. \texttt{data} is a pointer to data to associate with \texttt{key} in the calling thread.

\begin{quote}
\textbf{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.
\end{quote}

This function is thread-safe.

char *erl_errno_id(int error)
Returns the atom name of the Erlang error, given the error number in \texttt{error}. The error atoms are \texttt{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 \texttt{de} previously added with \texttt{add_driver_entry}. Driver entries added by the \texttt{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 \texttt{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 \texttt{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 \texttt{Port ! \{Owner, \{command, Data\}\}} or \texttt{port_command/2,3}. If the \texttt{ERL_DRV_FLAG_SOFT_BUSY} has been set in the \texttt{driver_entry}, data can be forced into the driver through \texttt{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 \texttt{erl_drv_busy_msgq_limits}.

void set_port_control_flags(ErlDrvPort port, int flags)
Sets flags for how the \texttt{control} driver entry function will return data to the port owner process. (The \texttt{control} function is called from \texttt{erlang:port_control/3}.) Currently there are only two meaningful values for \texttt{flags}: 0 means that data is returned in a list, and \texttt{PORT_CONTROL_FLAG_BINARY} means data is returned as a binary from \texttt{control}.

\section*{See Also}
\texttt{driver_entry(3), erlang(3), erl_ddll(3), section How to Implement an Alternative Carrier for the Erlang Distribution} in the User's Guide
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 preemptive 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(drivernname). (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:
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.

```c
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).

```c
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.

```c
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`.

```c
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`.

```c
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 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 mbzd.

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: li_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

+M Mamcbf <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.

+M Rmcbf <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.

+M Sco 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.

+M Scrfsd <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}).

+M Scrpm 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 ui 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>.
erts_alloc

+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 maximum 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>mbcs <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>mmbc <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>mmbc <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. 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<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<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 -instrin 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(allocation) 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)
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:

```c
/* 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:

```erlang
-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.

A loaded NIF library is tied to the Erlang module code version that loaded it. If the module is upgraded with a new version, the new Erlang code need to load its own NIF library (or maybe choose not to). The new code version can, however, choose to load the 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, each Erlang module code can keep its own private data. This private data can be set when the NIF library is loaded and then retrieved by calling `enif_priv_data`.

A NIF library cannot be loaded explicitly. A library is automatically unloaded when the module code that it belongs to is purged by the code server.

Functionality
All functions that a NIF library needs to do with Erlang are performed through the 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 on the same node, 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.

```erlang
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.

**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`, `reload`, and `upgrade` are all 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()`

**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

Noteworthy:

The dirty NIF functionality described here is experimental. Dirty NIF support is available only when the emulator is configured with dirty schedulers enabled. This feature is disabled by default. The Erlang runtime without SMP support does not support dirty schedulers even when the dirty scheduler support is 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 `+SDbcpu`, and `+SDbio`.

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 because 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, reload, 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*, *reload*, *upgrade* and *unload* are pointers to functions. One of *load*, *reload*, or *upgrade* is called to initialize the library. *unload* is called to release the library. All are described individually below.

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 that 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.

*upgrade* works as *load*, except that *old_priv_data* already contains the value set by the last call to *load* or *reload* 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. Notice that unload is not called for a replaced library as a consequence of reload.

int (*reload)(ErlNifEnv* env, void** priv_data, ERL_NIF_TERM load_info)

Note:

The reload mechanism is deprecated. It was only intended as a development feature. Do not use it as an upgrade method for live production systems. It can be removed in future releases. Ensure to pass reload as NULL to ERL_NIF_INIT to disable it when not used.

reload is called when the NIF library is loaded and a previously loaded library already exists for this module code.

Works as load, except that *priv_data already contains the value set by the previous call to load or reload.

The library fails to load if reload returns anything other than 0 or if reload is NULL.

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_TERMS 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.

The dirty NIF functionality described here is experimental. You have to enable support for dirty schedulers when building OTP to try out the functionality.

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.
ErlNifPid
A process identifier (pid). In contrast to pid terms (instances of ERL_NIF_TERM), ErlNifPids 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), ErlNifPorts 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.

ErlNifResourceDtor

typedef void ErlNifResourceDtor(ErlNifEnv* env, void* obj);

The function prototype of a resource destructor function.

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.

Exports

void *enif_alloc(size_t size)
Allocates memory of size bytes.
Returns NULL if the allocation fails.

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.

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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 =/=).

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_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.

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 enode or if size was < 1.

The written string is always NULL-terminated, unless buffer size is < 1.

```c
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.

```c
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.

```c
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.

```c
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.

```c
int enif_getenv(const char* key, char* value, size_t *value_size)
```

Same as erl_drv_getenv.

```c
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 ERL_NIF_TERM to which reason points to the value of the exception's 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.

```c
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_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)
Returns 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.
erl_nif

The map_in term must belong to environment env.

```c
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.

```c
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.

```c
ERL_NIF_TERM enif_make_new_map(ErlNifEnv* env)
```

Makes an empty map term.

```c
ERL_NIF_TERM enif_make_pid(ErlNifEnv* env, const ErlNifPid* pid)
```

Makes a pid term from *pid.

```c
ERL_NIF_TERM enif_make_ref(ErlNifEnv* env)
```

Creates a reference like erlang:make_ref/0.

```c
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.
Notice that the only defined behavior of using a resource term in an Erlang program is to store it and send it between processes on the same node. Other operations, such as matching or term_to_binary, have unpredictable (but harmless) results.

```c
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.

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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 e2, ERL_NIF_TERM e3, ERL_NIF_TERM e4)
ERL_NIF_TERM enif_make_tuple5(ErlNifEnv* env, ERL_NIF_TERM e1, ERL_NIF_TERM e2, ERL_NIF_TERM e3, ERL_NIF_TERM e4, ERL_NIF_TERM e5)
ERL_NIF_TERM enif_make_tuple6(ErlNifEnv* env, ERL_NIF_TERM e1, ERL_NIF_TERM e2, ERL_NIF_TERM e3, ERL_NIF_TERM e4, ERL_NIF_TERM e5, ERL_NIF_TERM e6)
ERL_NIF_TERM enif_make_tuple7(ErlNifEnv* env, ERL_NIF_TERM e1, ERL_NIF_TERM e2, ERL_NIF_TERM e3, ERL_NIF_TERM e4, ERL_NIF_TERM e5, ERL_NIF_TERM e6, ERL_NIF_TERM e7)
ERL_NIF_TERM enif_make_tuple8(ErlNifEnv* env, ERL_NIF_TERM e1, ERL_NIF_TERM e2, ERL_NIF_TERM e3, ERL_NIF_TERM e4, ERL_NIF_TERM e5, ERL_NIF_TERM e6, ERL_NIF_TERM e7, ERL_NIF_TERM e8)
ERL_NIF_TERM enif_make_tuple9(ErlNifEnv* env, ERL_NIF_TERM e1, ERL_NIF_TERM e2, ERL_NIF_TERM e3, ERL_NIF_TERM e4, ERL_NIF_TERM e5, ERL_NIF_TERM e6, ERL_NIF_TERM e7, ERL_NIF_TERM e8, 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).

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 three callbacks load, reload, and upgrade.

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.

```c
void *enif_priv_data(ErlNifEnv* env)
```

Returns the pointer to the private data that was set by load, reload, or upgrade.

Was previously named enif_get_data.

```c
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.

```c
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.

```c
void enif_release_binary(ErlNifBinary* bin)
```

Releases a binary obtained from enif_alloc_binary.

```c
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.

```c
ErlNifRWLock *enif_rwlock_create(char *name)
```

Same as erl_drv_rwlock_create.

```c
void enif_rwlock_destroy(ErlNifRWLock *rwlck)
```

Same as erl_drv_rwlock_destroy.

```c
void enif_rwlock_rlock(ErlNifRWLock *rwlck)
```

Same as erl_drv_rwlock_rlock.

```c
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_rwlock(ErlNifRWLock *rwlck)
Same as erl_drv_rwlock_rwlock.

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.
The dirty NIF functionality described here is experimental. You have to enable support for dirty schedulers when building OTP to try out the functionality.

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 the experimental 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 badarg 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.

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.

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*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 environment 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):

<table>
<thead>
<tr>
<th>Type Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ERL_NIF_THR_UNDEFINED</td>
<td>Undefined thread that is not a scheduler thread.</td>
</tr>
<tr>
<td>ERL_NIF_THR_NORMAL_SCHEDULER</td>
<td>A normal scheduler thread.</td>
</tr>
<tr>
<td>ERL_NIF_THR_DIRTY_CPU_SCHEDULER</td>
<td>A dirty CPU scheduler thread.</td>
</tr>
<tr>
<td>ERL_NIF_THR_DIRTY_IO_SCHEDULER</td>
<td>A dirty I/O scheduler thread.</td>
</tr>
</tbody>
</table>

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.

See Also

erlang:load_nif/2
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.

### 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 | outExited`
- `trace_tag_running_procs()` =

### 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.
in | out | in_exiting | out_exiting | outExited

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:

```erlang
% erl_msg_tracer.erl

c(resolver), resolver: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]).
ok
4> {ok, D} = file:open("/tmp/tmp.data",[write]).
{trace,#Port<0.486>,<0.40.0>}
{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>}
```

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ok
4> {ok, D} = file:open("/tmp/tmp.data",[write]).
{trace,#Port<0.486>,<0.40.0>}
{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>}
```

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:
-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))
            /* 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 {argv[2], argv[4]} to
 * argv[2]: Tracee
 * argv[3]: Recipient
 * argv[4]: Options, ignored
 */
static ERL_NIF_TERM trace(ErlNifEnv* env, int argc, const ERL_NIF_TERM argv[])
{
    ErlNifPid to_pid;
    if (enif_get_local_pid(env, argv[1], &to.pid)) {
        ERL_NIF_TERM msg = enif_make_tuple3(env, enif_make_atom(env, "trace"), argv[2], argv[4]);
        enif_send(env, &to_pid, NULL, msg);
    }

    return enif_make_atom(env, "ok");
}