eChronos Manual: Kochab Variant

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Introduction

This document provides the information that system designers and application developers require to successfully create reliable and efficient embedded applications with eChronos.

The Concepts chapter presents the fundamental ideas and functionalities realized by the RTOS and how developers can harness them to successfully construct systems.

The API Reference chapter documents the details of the run-time programming interface that applications use to interact with the RTOS.

The Configuration Reference chapter details the interface to the build-time configuration of the RTOS that system designers use to tailor the RTOS to their applications.

Throughout this document, *eChronos RTOS* or *the RTOS* will refer specifically to the *Kochab* variant of eChronos.

Concepts

This chapter introduces the concepts that form the foundation of the RTOS. Many of these concepts would be familiar to readers who have experience in other real-time operating systems. However, this chapter does cover aspects that are specific to the RTOS and significant for constructing correct systems.

In addition to this documentation, RTOS training can provide a more hands-on, practical introduction to the RTOS.

Overview

The eChronos RTOS facilitates the rapid development of reliable, high-performance embedded applications. It allows developers to focus on the application logic by wrapping the complexities of low-level platform and system code in a comprehensive, easy-to-use operating-system API. Since each application configures the RTOS to its specific requirements, this document refers to the combination of RTOS and application code simply as the *system*.

In terms of its functionality, the RTOS is a task-based operating system that multiplexes the available CPU time between tasks according to a preemptive scheduling algorithm based on task priorities. Since it is preemptive, tasks execute on the CPU until they either voluntarily relinquish the CPU by calling a blocking RTOS API function, or are preempted by a higher-priority task being made runnable by an interrupt. The RTOS API (see API Reference) gives tasks access to the objects that the RTOS provides. They include Interrupt Service Routines, Signals, Time and Timers, Mutexes, and Semaphores.

A distinctive feature of the RTOS is that these objects, including tasks, are defined and configured at build time (see Configuration Reference), not at run time. This configuration defines, for example, the tasks and mutexes that exist in a system at

compile and run time. Static system configuration like this is typical for small embedded systems. It avoids the need for dynamic memory allocation and permits a much higher degree of code optimization. The Configuration Reference chapter describes the available configuration options for each type of object in the RTOS.

Startup

The RTOS does not start automatically when a system boots. Instead, the system is expected to start normally, as per the platform's conventions and C runtime environment. The C runtime environment invokes the canonical `main` function without any involvement of the RTOS. This allows the user to customize how the system is initialized before starting the RTOS.

The RTOS provides a `start` API that needs to be called to initialize the RTOS and begin its execution. The `start` API never returns. All tasks are automatically started by the RTOS.

There is no API to shut down or stop the RTOS once it has started.

Error Handling

There are some rare cases in which the RTOS may detect a fatal error state. Fatal errors include, for example, the fact that the timer component is unable to process a timer tick before another tick occurs. How such error states are handled best depends to a large degree on the application and system requirements. Therefore, the RTOS allows applications to customize the response to error states.

When the RTOS detects an error state, it calls the application-provided function `fatal_error`. The application can implement its preferred strategy to deal with error states this way, where typical approaches are to log the error state and reset the system. The RTOS supplies a single `ErrorId` parameter to the application's `fatal_error` function that indicates the kind of error that occurred.

The RTOS relies on `fatal_error` to not return, so it must stop the system and prevent the RTOS and application from continuing to execute. This also means that the `fatal_error` function must not use any RTOS APIs.

Assertions

A particular instance of error states is when an assertion in the RTOS implementation fails. There two kinds of such assertions: API assertions and internal assertions. Both kinds are optional and can be enabled or disabled in the system configuration (see Error Handling Configuration).

API assertions check a wide range of (but not all) requirements and preconditions that the RTOS API has regarding application run-time behavior. For example, the `mutex_lock` API implementation can assert that the mutex ID that the application provides identifies a valid mutex. All such assertions cover requirements and preconditions that are clearly documented. It is good practice for applications to enable these assertions via the `api_asserts` configuration item for debugging and test builds. It is recommended to disable them in release builds to avoid the code-size and execution-time costs they incur.

Internal assertions check a (relatively small) range of internal assumptions of the RTOS implementation that are not related to the application behavior. These implementation-specific sanity checks are irrelevant to applications and primarily intended for testing and debugging the RTOS implementation itself. Applications are free to enable them via the `internal_asserts` configuration item. However, they provide no tangible benefit to applications and they do incur code-size and execution-time overhead.

Tasks

As the core mechanism of the RTOS, tasks are the basic building blocks for structuring complex systems. Tasks provide independent control flows that can, on the one hand, be easily understood, implemented, and maintained. On the other hand, they interact with each other via the RTOS APIs to form a complete application and provide its full functionality.

Task and System Structure

In general, a CPU executes a stream of instructions that modify internal state (registers and memory) and control external devices. The challenge for an application developer is to work out which instructions should be executed to obtain the desired application behavior.

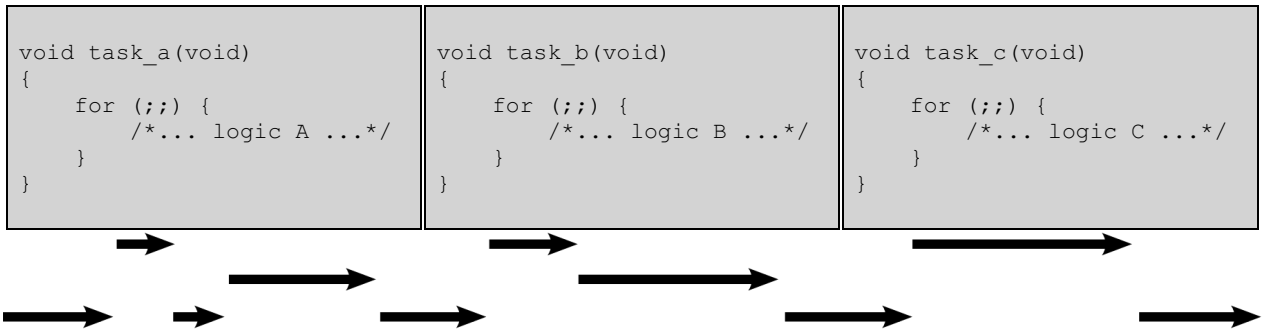
For systems with simple requirements this can be easily achieved with a single big-loop design. However as the inherent complexity of requirements increases, a single big-loop becomes too complicated to effectively develop, reason about, or debug.

The diagram below shows an example of this big-loop design. As more demands are placed on the system, the code in the *logic* part of the code becomes too complicated.

There are multiple ways that a system designer could start to address this complexity. The overarching design principle is separation of concerns, where logic that addresses different aspects of the system are separated in some manner to make the complexity more manageable. One approach to decomposing a system is to structure the functionality so that rather than a single large loop, there are multiple smaller loops, each performing a cohesive set of actions.

The RTOS implements this abstraction by providing tasks. Each task in the system executes its own loop, and the RTOS provides the underlying mechanism for switching the CPU from one task to another.

The diagram below shows three tasks, A, B and C, each with their own loop. The logic for each of these should be simpler than the case where this logic is mixed in a single big loop. The arrows show how each task executes independently on the underlying CPU. The end of each arrow represents the point in time where the RTOS switches the CPU from running one task to running a different task.



Task Names

Each task in the system has a unique name chosen and configured by the system designer. The name is an ASCII string[1] and should describe the functionality of the

task (also see the `tasks/task/name` configuration item).

Within the RTOS and the application implementation, task names translate to constants of type `TaskId`. Each task has a unique `TaskId` which is assigned automatically by the RTOS configuration tool. The RTOS configuration tool generates a symbolic macro of the form `TASK_ID_<name>`. Application code should use this symbolic macro rather than directly using integer values to refer to tasks.

Task Functions

Each task in the system is configured with a function that serves as the entry point into the implementation of the given task's functionality. The RTOS sets up each task such that when it is started, it begins its execution with this function. Task functions are configured statically together with the other task properties (also see `tasks/task/function`).

For the RTOS to correctly call a task's function, it must have the type signature `void fn(void)`. That is, it shall have no arguments because the RTOS does not supply any arguments to task functions. Furthermore, it is an implementation error for a task function to return. The effect of a task function returning is generally undefined, but it may result in a fatal error state (see Error Handling).

Although it is a less common system design, multiple tasks may share the same task function because they run on separate stacks. However, such a setup requires particular care with regard to concurrent access to shared data structures and resources.

Task Stacks

Each task in the system has its own unique stack. Stacks are created and set up by the RTOS configuration and runtime environment, so a system designer's main concern with stacks is choosing an appropriate size.

Stacks are used for several purposes while an application runs:

- The primary user of a stack is the task code itself as it holds variables and return addresses during function calls.
- Additionally, when the RTOS performs a task switch away from a task, it saves that task's context (such as its register values) on its stack.
- Furthermore, Interrupt Service Routines use the stack of the task they interrupt.

The size of each stack is chosen by the system designer and configured statically and individually for each task (see the `tasks/task/stack_size` configuration item in the Task Configuration Section). This size needs to be chosen carefully to ensure that there is sufficient space on the stack for all the kinds of stack usage listed above.

The effect of a stack overflow, when a task, the RTOS, or one or more ISRs require more than the available stack space, is generally undefined. On some target platforms, the RTOS may support available hardware or software mechanisms to detect stack overflows.

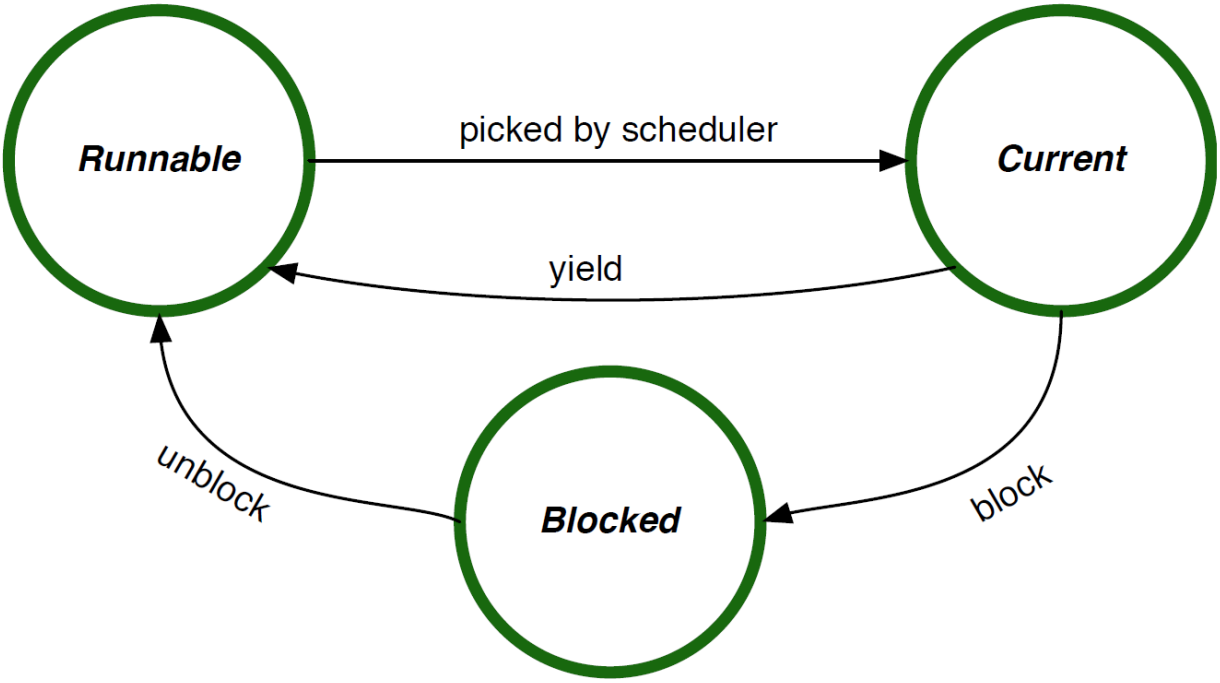
Task Switching

The task that is actively executing on the CPU is known as the current task (also see the `task_current` API). To multiplex multiple tasks on a single CPU, the RTOS implements a context switching mechanism for changing the current task. The task's context refers to all the state associated with the task but for which the underlying hardware can support only one copy at a time. Specifically, the processor only supports a single program counter, stack pointer, and register state. During a context switch, the RTOS saves the current task's state on the task's stack and then restores the state for the new current task.

The Preemption section provides more details on context switches, what can lead to them, and how to control them, which is an important aspect of constructing correct system behavior.

Task States

An RTOS task can be in one of three primary states: current, runnable, or blocked. Tasks within a system do no usually operate in isolation; they interact with other tasks, devices, and the external environment. When interacting with another entity, the RTOS provides mechanisms so that the task can wait until the other entity is ready, rather than the task needing to constantly poll the other entity. When a task is waiting, it moves into the blocked state. There are a number of RTOS operations that cause a task to block, such as waiting for a signal, locking a mutex, or sleeping. When a task is in the blocked state, it is no longer current, so the RTOS must choose another runnable task to become the current task. The blocked task unblocks and becomes runnable when the entity it is waiting on is ready, e.g., when a signal is delivered, a mutex is available, or a sleep duration has completed.



It is possible for the overall system to arrive in a state where all tasks are in the blocked state[2]. In this situation, there is no current task and the system enters an idle mode. When the system is in idle mode, interrupts may still occur and interrupt handlers are still processed. Tasks may become runnable again when an interrupt handler unblocks a task via an interrupt event (see Interrupt Events). If the platform supports it, the RTOS places the hardware into a low-power state while the system is idle.

When there is more than one task in the runnable state, the RTOS must use the scheduling algorithm to determine the task that becomes current. The scheduling algorithm is described in the Scheduling Algorithm section.

Scheduling Algorithm

The scheduling algorithm is an important component of the RTOS because it determines which one of the runnable tasks is selected for active execution. For this purpose, the RTOS uses a *strict priority with inheritance* algorithm.

Each task in the system is assigned a priority (which is a positive, integral value, with higher values meaning higher priority). Priorities must be unique, that is, no two tasks may have the same priority.

The general rule of this scheduling algorithm is to pick the task with the highest effective priority from the set of runnable tasks.

The algorithm is *strict* in the sense that a task is never permitted to be the current task when one or more higher priority ones are runnable. The RTOS achieves this by triggering task preemption whenever necessary (see Preemption).

Priority Inheritance

Normally, a task's effective priority is the priority it has been explicitly assigned, however in some cases a task may be assigned a different priority based on *priority inheritance*.

When a task in the system is not runnable (i.e.: it is blocked), it may be blocked waiting for a specific task, or alternatively, it may be blocked waiting on an external event or no specific task. To reduce the occurrence of priority inversion, the scheduler implements priority inheritance for the case where a task is blocked on another specific task. A task's effective priority is the higher one of:

1. the task's own explicitly assigned priority, or
2. the highest of the effective priorities of all tasks that are blocked on the task.

Consider three tasks, A, B and C with priorities 20, 10, and 5. If task A is blocked on task C, then C's effective priority is 20, rather than 5. In this case, assuming C is runnable, it would be selected. It is important to note that this inheritance relationship is transitive, so if C blocked on a task D with priority 1, then D's effective priority would be 20.

Preemption

The RTOS is *preemptive*, which means that Task Switching can be triggered in either of two ways:

1. voluntarily, by RTOS code the current task chooses to execute causing the current task to become blocked (see Task States), or
2. involuntarily (as far as the current task is concerned), by the RTOS due to an ISR (see Interrupt Service Routines) changing the set of runnable tasks.

The second case is known as *task preemption*, or just *preemption*.

When an interrupt occurs, first the ISR runs. Then, depending on the platform and RTOS variant, the RTOS may either:

1. resume the currently executing task, provided the ISR could not have possibly changed the set of runnable tasks, or
2. use the Scheduling Algorithm to determine the next task to run, which may or may

not be the currently executing task.

Note that at this point, the only reason why the scheduler would choose a different task to run is that the ISR changed the set of runnable tasks via an interrupt event (see Interrupt Events).

Finally, the RTOS performs a task switch to the new task chosen by the scheduler if it differs from the current one. Otherwise, it resumes the current task.

Signals

The signal mechanism is a flexible feature that helps tasks to interact with each other. Signals are typically used for event notifications. For example, a driver task can use a signal to notify a handler task whenever new data is available for processing. Typically, the driver task would send a signal every time new data becomes available while the handler task would repeatedly wait to receive the signal and then process the data.

The signal mechanism typically blocks the handler task while it waits, and makes the task runnable again when it receives the exact signal it is waiting for. Interrupt service routines can also send signals to a task via the interrupt event mechanism described in the Interrupt Events section.

Each task is associated with a set of pending signals. When the system starts, this set is empty for all tasks, so there are no signals to receive for any task. *Sending* a signal to a task effectively adds the given signal to the task's pending signal set. Similarly, *receiving* a signal removes the given signal from the task's pending signal set (which, of course, requires the signal to be pending in the first place).

Tasks use signals via the following main APIs:

- `signal_send` sends a signal to another task, adding it to that task's pending signal set.
- `signal_peek` checks whether a signal is currently pending for the calling task, i.e., whether the specified signal is in the task's pending signal set. `signal_peek` only performs the check without modifying the task's pending signals or blocking the task.
- `signal_poll` checks for and receives a signal, i.e., if the given signal is in the calling task's pending signal set, it removes it.

- `signal_wait` waits to receive a given signal, i.e., it blocks the calling task if necessary until the signal is pending and then receives it.

The above API functions also exist in versions that send or receive multiple signals in a single call. When a task receives multiple signals, it is its responsibility to process each of those signals according to their semantics.

The RTOS does not predefine which signals exist in a system or what their meanings or semantics are. System designers and applications are entirely free to define signals and to attach meaning to them. They do so via the system configuration (see Signal Configuration).

The main property of each signal is its name, a so-called *label*, and applications always refer to signals via their names/labels. For this purpose, the RTOS defines the constants `SIGNAL_ID_<label>` and `SIGNAL_SET_<label>` for each signal. They refer to individual signals by their names and they can be used to construct signal sets from individual signals. Although signals and signal sets are internally represented as numbers, applications neither need nor should make assumptions about those numeric values of signals.

Interrupt Service Routines

By default, the CPU executes code in *normal*, non-interrupted context and all RTOS tasks run in this context. However, in response to interrupts, the CPU transitions into the interrupt context and executes a previously registered interrupt service routine (ISR). When an ISR completes, the CPU returns to the normal context and continues to execute the previously interrupted code path. The exact details of interrupt handling and how ISRs interact with the normal flow of execution heavily depend on the target platform.

RTOS tasks always execute in the normal context which can be interrupted by a hardware interrupt. This allows the system to respond to hardware events with low latency.

It is the responsibility of the application to implement ISRs that adequately handle the interrupts that can occur. The RTOS itself is generally not involved in handling interrupts, and leaves interrupt handling to applications. Depending on the RTOS variant and target platform, the RTOS may or may not provide minimal wrappers that allow ISRs to be plain C functions.

ISRs may only use a very small subset of the RTOS API which consists mainly of

raising Interrupt Events. To prevent inconsistencies from arising in the RTOS and system state, the majority of the RTOS API is not accessible to ISRs. Therefore, applications are recommended to clearly differentiate between code executed in ISRs and task code. Sharing code between the two modes of execution creates the risk of the shared code using RTOS APIs not available to ISRs.

Stack Considerations

ISRs execute on the stack of the current task. For this reason, each ISR should minimize its stack usage. As the ISR may interrupt any task, each task must have a large enough stack to accommodate both its own usage and the maximum stack usage of any ISR. On platforms that support and use nested interrupts, there needs to be sufficient stack space to accommodate a task's state plus all nestable ISRs.

Data Consistency

As the system may interrupt a task at any time, it is important that the ISR modifies any data structures that it may share with tasks in a safe manner. For example, if an ISR and a task both have code that increments a value (e.g., `i++`), it is possible for one of the increments to be lost. Code such as `i++` is implemented with three separate instructions: read from memory, increment value, and write to memory. If an interrupt happens between the read and write instructions, any changes to the variable that the ISR makes would be lost when the task's write instruction is executed.

One approach to solve this issue is to use instructions that can modify a memory location in a single operation.

Disabling and Enabling Interrupts

Another option to ensure data consistency is to disable interrupts when updating shared data structures as in the following example:

```
interrupt_disable();
i++;
interrupt_enable();
```

Tasks may freely disable and enable interrupts to block ISRs from interrupting tasks. However, to ensure that RTOS APIs behave correctly, they must always be called with interrupts enabled. Calling an RTOS API with interrupts disabled is an implementation error.

Another side effect of this approach is that it increases the latency between a hardware interrupt occurring and the corresponding ISR being executed. When and for how long a task disables interrupts can heavily influence the timing of ISR processing

and task activation. Therefore, this aspect of application design and implementation requires particular care.

The RTOS itself ensures that ISRs execute with a low latency, and so the RTOS avoids disabling interrupts whenever possible. As a result, an interrupt may occur during the execution of an RTOS API function, which means that the RTOS state may not be consistent when an ISR executes. For this reason the ISRs must not call the regular RTOS APIs. If an ISR were to call any regular RTOS function, it would corrupt RTOS state, and cause incorrect system behavior.

Of course, it is necessary for ISRs to interact with tasks. To achieve this, Interrupt Events provide links between ISRs and tasks.

Interrupt Events

Interrupt events provide the bridge between tasks and interrupt service routines. The system can be configured with a number of interrupt events. Each interrupt event is associated with a `TaskId` and `SignalSet`[3]. The `TaskId` and `SignalSet` association is usually done when the system is configured. A task may choose to update this association at run-time using the `interrupt_event_task_set` API.

An interrupt service routine can call the `interrupt_event_raise` API to raise one of the interrupt events configured in the system. The `interrupt_event_raise` API is carefully implemented using an atomic instruction to avoid any possible data races. When an interrupt event is raised, it causes the associated signal set to be sent to the task associated with the interrupt event. This provides a safe and efficient mechanism for interrupt service routines to interact with tasks.

Time and Timers

It is not surprising that time is an important aspect of most real-time systems. The RTOS provides a number of important interfaces for keeping track of time. The RTOS tracks overall execution of the system, and additionally provides timer objects that allow tasks to schedule certain actions to happen after a specific duration of time.

Ticks

All of the time-based interfaces in the RTOS are based around a tick concept. The RTOS does not keep track of physical or wall-clock time; instead it counts only ticks,

so time and durations are expressed only in ticks in the RTOS API. How much absolute physical time a tick represents is left to the system design.

The RTOS depends on the system to generate ticks, provide a suitable system tick driver, and inform the RTOS of each tick. The system designer should ensure that the RTOS `timer_tick` API is called for each tick. The `timer_tick` API is safe to call from an interrupt service routine.

When a system tick is processed, the `timer_current_ticks` API value is incremented by one. This allows tasks to keep track of the amount of time that the system has been running for, or shorter durations as they choose.

Timers

Timers trigger certain actions, such as sending a signal, at a configurable time (expressed in ticks). The Timer Configuration defines which timers exist in a system and what their properties are.

The main property of a timer is its tick value, which says how many ticks in the future the timer will expire. When a system tick is processed, any enabled timer objects are decremented[4] by one. When a timer is decremented to zero, the timer is said to expire. The exact behavior that occurs when a timer expires depends on the configuration of the timer object.

- A timer object may be configured as a watchdog. When a watchdog timer expires, it causes a fatal error to occur (see Error Handling).
- Alternatively, a timer may be configured to send, when it expires, a configurable set of signals to a configurable task. If the timer is periodic, it automatically starts counting down again.
- Alternatively, a timer may be a one-shot timer, in which case it is disabled upon expiring, so it does not start counting down again.

Timing Considerations

As timers are based on ticks, it is important to understand some of the limitations that this imposes.

Firstly, the best possible timing resolution is limited by the tick period. If we assume a 40Hz tick (25ms period), then a desired period of 30ms must either be rounded down to 25ms or up to 50ms.

From a practical point of view this means that if the `timer_current_ticks` variable reads as 10, the actual elapsed time could be anywhere between 250ms and 300ms (more generally elapsed time is in the range `timer_current_ticks * tick_period` to `(timer_current_ticks + 2) * tick_period`). To see how this can happen, consider the case where `timer_current_ticks` is 10. If a task is scheduled and then the next tick occurs (which indicates 275ms of real-time has elapsed), the tick is not processed until the newly scheduled task yields (or blocks). Since the task can execute for up to 25ms, it is possible for the elapsed time to reach (just under) 300ms, with the `timer_current_ticks` still reading as 10 (250ms). Another consequence of this is that actual length of the time between two ticks being processed can be anywhere from zero to 2 times the tick period (e.g.: 0ms to 50ms in the current example). If we continue the previous example and the task blocks at after executing for about 25ms, then the pending tick (which is now just under 25ms overdue) is processed. Immediately after the pending tick is processed, the new tick happens, and may be processed immediately (if, for example, the RTOS is idle).

It is useful to consider the impact on actual timer objects. First, assume a periodic timer, which is set up with a period of 10 ticks. Using the same 25ms tick period as above, the time between consecutive timer expiries can range between 225ms and 275ms. Only over long periods of time, the average time between consecutive expiries approaches the nominal 250ms value. A similar level of imprecision is evident in a one-shot timer. A 10-tick one-shot timer expires between 225ms and 275ms after it is set. When a timer is required to expire after at least 250ms but not before then, it needs to be set to 11 ticks.

Note that the above latency considerations also apply to the value of the `timer_current_ticks` and `sleep` APIs.

Mutexes

Mutexes provide a mechanism for controlling mutual exclusion among tasks. Mutual exclusion can be used, for example, to ensure that only a single task operates on a data structure, device, or some other shared resource at any point in time.

Assume, for example, a system with a hardware block for CRC calculation. Such a CRC engine might have two registers, `input`, and `result`, which are used to sequentially feed data to it and to retrieve the resulting CRC, respectively. It could be represented by the following type and object for memory-mapped hardware access:

```
struct crc_engine {
    unsigned char input;
```

```
    unsigned char result;
};

struct crc_engine crc;
```

Its functionality could be made available to tasks by the following function:

```
unsigned char
crc_calculate(const unsigned char *const src,
              const unsigned char length) {
    unsigned char idx;
    for (idx = 0; idx != length; idx += 1) {
        crc.input = src[idx];
    }
    return crc.result;
}
```

However, since the RTOS is preemptive, a task switch can occur at any time inside the function. Therefore, one task might start using the CRC engine while another, interrupted task has not yet completed its own use of it. This would lead to an overlap of input values and therefore incorrect CRC results.

Mutexes can help to prevent such consistency issues. Used correctly, a mutex ensures that only a single task at a time can execute code paths like the above.

At any given time, a mutex is in exactly one of two possible states: available or acquired. Initially, each mutex is available. Only after a task A acquires it via the `mutex_lock` or `mutex_try_lock` APIs, the mutex is in the acquired state. After task A has finished manipulating the shared resources, it uses the `mutex_unlock` API to put the mutex back into the available state. This allows other tasks to acquire it:

```
unsigned char
crc_calculate(const unsigned char *const src,
              const unsigned char length) {
    unsigned char idx, result;
    mutex_lock(RTOS_MUTEX_ID_CRC);
    for (idx = 0; idx != length; idx += 1) {
        crc.input = src[idx];
    }
    result = crc.result;
    mutex_unlock(RTOS_MUTEX_ID_CRC);
    return result;
}
```

The API guarantees that only a single task in the system can hold a mutex at a given time. In other words, it is guaranteed that when any number of tasks attempt to acquire a mutex, only one of them succeeds. When a task A has already acquired a mutex and another task B uses `mutex_lock` on the same mutex, the API blocks task B. Only when task A releases the mutex, task B unblocks, acquires the mutex, and returns from its call to `mutex_lock`.

It is an implementation error for a task to call `mutex_lock` on a mutex it has already acquired. It is also an implementation error to call `mutex_unlock` on a mutex not acquired by the calling task (i.e., if the mutex is either not acquired by any task or acquired by a different task).

The `mutex_try_lock` API allows a task to avoid being blocked by always returning immediately. If the mutex is already acquired by another task, the API returns immediately, indicating that the calling task has not acquired the mutex.

The system designer defines at configuration time which mutexes are available in a system. The main property of a mutex is its name, such as `CRC` in the example above. Therefore, the implementation refers to a mutex via its symbolic name `MUTEX_ID_<name>` that has the type `MutexId`. Applications must not make any assumptions about or rely on the numeric values that the configuration tool assigns to such symbolic names.

As with any other objects that are not interrupt events, mutexes and their related APIs can not be used by interrupt service routines.

Semaphores

Semaphores provide a signaling mechanism. Conceptually, a semaphore is an integral value with two operations: *post* and *wait*. Post is sometimes called *V*, *signal*, or *up*. Wait is sometimes called *P* or *down*. The post operation increments the underlying value, whereas the wait operation decrements the underlying value, if (and only if) the current value of the semaphore is greater than zero. The wait operation blocks the calling task until the semaphore value can be successfully decremented.

Unlike Mutexes, a semaphore has no concept of a task that holds the semaphore. On RTOS variants using priority-based scheduling with priority inheritance, a consequence of this is that when a task waits on a semaphore, no task will inherit the waiting task's priority. Please see Scheduling Algorithm for more details on the scheduling algorithm in use by this variant.

The post operation is made available through the `sem_post` API. The wait operation is made available through the `sem_wait` API. Additionally, the `sem_try_wait` API allows a task to attempt to decrement a semaphore without blocking.

API Reference

This chapter describes the runtime application programming interface (APIs) provided by the RTOS.

Correct API Usage

The RTOS API design and implementation leave room for the application to use it incorrectly. For example, there are generally no safeguards in the RTOS itself against the application supplying invalid task-ID values to API functions. To achieve correct system behavior, it is the application's responsibility to use the RTOS API under the conditions and requirements documented here.

The RTOS implementation is able to detect some case of the application using the RTOS API incorrectly. This feature needs to be enabled in the system configuration (see `api_asserts`). When enabled, the RTOS checks some but not all cases of the API being used incorrectly. If it detects such a case, it calls the `fatal_error` function.

Types

The RTOS defines a number of *types* that are used in the API. Most types are implemented as unsigned integers (e.g: `uint8_t`). Unfortunately, the C language performs type checking only on the underlying types, but ignores any type definitions (`typedef`s). It is recommended that a suitable static analysis or lint tool is used to ensure that application code is using the correct types when calling APIs.

Constant Definitions

The RTOS defines a number of pre-processor macros as constants. Ideally these would be made available as typed static constant variables, however some compilers do not always generate optimal code for that case, so a pre-processor macro is used instead.

Functions vs. Macros

Some compilers do not support function inlining. For performance or code space considerations, some APIs described in this chapter are implemented as function-like macros. This is an implementation detail and the use of all APIs must conform to the formal function definitions provided in this chapter.

start

```
void start(void);
```

The `start` API initializes the RTOS, makes all tasks runnable and then, based on the scheduling algorithm, chooses and starts executing the current task. This function must be called from the system's main function. This function does not return.

Error Handling API

ErrorId

An instance of this type refers to a specific RTOS error state. When the RTOS detects an error state, it passes a value of type `ErrorId` to the `fatal_error` function, which the application needs to implement. The RTOS implementation defines constants that identify all potential error states and the corresponding `ErrorId` values. The names of these constants follow the pattern `ERROR_ID_<error-state>`.

Task API

TaskId

Instances of this type identify specific tasks. The underlying type is an unsigned integer of a size large enough to represent all tasks[5]. The `TaskId` should generally be treated as an opaque value. Arithmetic operations should not be used on a `TaskId`.

The application may assume that a `TaskId` is in the range `TASK_ID_ZERO` through `TASK_ID_MAX`. For example, if a per-task data structure is required, it is valid to use a fixed size array and index the array by using the `TaskId`. For iterating over such an array, it is valid use to increment an instance of `TaskId`, however care must be taken to ensure the resulting value is in range. `TaskId` instances can be tested for equality, however other logical operations (e.g., comparison) should not be used. For all tasks in the system, the configuration tool creates a constant with the name `TASK_ID_<name>` that should be used in preference to raw values.

TASK_ID_ZERO

This constant has the type `TaskId` and represents the task with the numerically lowest task ID in the system. This can be used in cases where application code wishes to iterate over all tasks in the system.

TASK_ID_MAX

This constant has the type `TaskId` and represents the task with the numerically highest task ID in the system. This can be used in cases where application code wishes to iterate over all tasks in the system.

TASK_ID_<name>

These constants have the type `TaskId`. A constant is created for each task in the system, where `<name>` is the upper-case conversion of the task's name (see Task Names).

task_current

```
TaskId task_current(void);
```

This function returns the task ID for the current task.

Signal API

SignalSet

A `SignalSet` holds multiple distinct signals (the maximum supported signals depends on the `signalset_size` configuration parameter). The underlying type is an unsigned integer of the appropriate size.

SignalId

A `SignalId` is an alias for the `SignalSet` type, but represents the special case where the set contains exactly one signal (i.e., it is a singleton set).

To test whether a signal set contains a signal, use the bitwise *and* operator. For example, `SIGNAL_SET_ALL & SIGNAL_ID_<label>` always evaluates to `SIGNAL_ID_<label>` for all signals. To construct a signal set from multiple signals, use the bitwise *or* operator. For example, `SIGNAL_SET_EMPTY | SIGNAL_ID_<label>` always evaluates to `SIGNAL_ID_<label>` for all signals.

SIGNAL_SET_EMPTY

`SIGNAL_SET_EMPTY` has the type `SignalSet` and represents an empty set.

SIGNAL_SET_ALL

`SIGNAL_SET_ALL` has the type `SignalSet` and represents set containing all signals in the system.

SIGNAL_ID_<label> and SIGNAL_SET_<label>

`SIGNAL_ID_<label>` has the type `SignalId`. `SIGNAL_SET_<label>` has the type `SignalSet`. Constants of this form are automatically generated for each signal label. The `<label>` portion of the name is an upper-case conversion the signal label.

signal_wait_set

```
SignalSet signal_wait_set(SignalSet requested_set);
```

This API makes a task wait for and receive a set of signals. If none of the signals in `requested_set` is pending, the calling task blocks until at least one of them is pending. When the API returns, it returns all of the task's pending signals that are in `requested_set` and atomically removes them from the pending signal set. The returned signal set is guaranteed to not be empty and to only contain signals in the requested set. Immediately after the API returns, it is guaranteed that none of the signals in `requested_set` are pending any more.

signal_wait

```
void signal_wait(SignalId requested_signal);
```

This API behaves exactly as `signal_wait_set` for the singleton signal set `requested_signal`. Since its only valid return value would be equivalent to `requested_signal`, it does not return a value.

signal_poll_set

```
SignalSet signal_poll_set(SignalSet requested_set);
```

This API receives a set of signals without waiting for them to become pending. When the API returns, it returns all the task's pending signals that are in `requested_set` and atomically removes them from the pending signal set. The returned signal set is guaranteed to only contain signals in the requested set. Immediately after the API returns, it is guaranteed that none of the signals in `requested_set` are pending any more. If none of the requested signals are pending, the API returns `SIGNAL_SET_EMPTY`.

signal_poll

```
bool signal_poll(SignalId requested_signal);
```

This API behaves exactly as `signal_poll_set` for the singleton signal set `requested_signal`. It returns true if the requested signal is pending and false otherwise.

signal_peek_set

```
SignalSet signal_peek_set(SignalSet requested_set);
```

This API checks if a set of signals is currently pending without modifying the pending signals. When the API returns, it returns all the task's pending signals that are in `requested_set`. The returned signal set is guaranteed to only contain signals in the requested set. When the API returns, it is guaranteed that all of the signals in the returned signal set are pending. If none of the requested signals are pending, the API returns `SIGNAL_SET_EMPTY`.

signal_peek

```
bool signal_peek(SignalId requested_signal);
```

This API behaves exactly as `signal_peek_set` for the singleton signal set `requested_signal`. It returns true if the requested signal is pending and false otherwise.

signal_send_set

```
void signal_send_set(TaskId destination, SignalSet send_set);
```

This API adds the signal set `send_set` to the pending signal set of the task with the ID

`destination`. After this API returns, it is guaranteed that the destination task can successfully use the peek, poll, or wait APIs to check for and/or receive the signals in `send_set`.

signal_send

```
void signal_send(TaskId task, SignalId signal);
```

This API behaves exactly as `signal_send_set` for the singleton signal set `signal`.

Interrupt Event API

InterruptEventId

Instances of this type refer to specific interrupt events. The underlying type is an unsigned integer of a size large enough to represent all interrupt events[6].

Also refer to the Platform Interrupt Event API section.

INTERRUPT_EVENT_ID_<name>

These constants of type `InterruptEventId` are automatically generated at build time for each interrupt event in the system. Note that `<name>` is the upper-case conversion of the interrupt event's name configured through `interrupt_events/interrupt_event/name`. Applications should treat the numeric values of these constants as opaque values and use them in preference to raw numeric values to refer to interrupt events.

Platform Interrupt Event API

interrupt_event_raise

```
void interrupt_event_raise(InterruptEventId event);
```

The `interrupt_event_raise` API raises the specified interrupt event. This API must be called only from an interrupt service routine (not a task). Raising an interrupt event causes the signal set associated with the interrupt event to be sent to the task associated with the interrupt event. This and `timer_tick` are the only RTOS API functions that an interrupt service routine may call.

interrupt_event_task_set

```
void interrupt_event_task_set(InterruptEventId interrupt_event_id, TaskId task_id);
```

This function configures at run time which task is signaled when the specified interrupt event is raised. In some application scenarios, the static configuration via `interrupt_events/interrupt_event/task` is sufficient and does not need to be modified at run time. In those cases, this function does not need to be called. In other scenarios, it an interrupt event may need to be signaled to a dynamically changing set of tasks. In those cases, this function allows the application to update this configuration setting at run time.

Sleep API

sleep

```
void sleep(TicksRelative ticks);
```

The `sleep` API blocks the current task for the specified number of timer ticks. After `ticks` timer ticks, the task becomes runnable again. Note that that does not immediately make it the current task again. See the Time and Timers section for further information on timing and scheduling considerations.

Timer API

TimerId

A `TimerId` refers to a specific timer. The underlying type is an unsigned integer of a size large enough to represent all timers[7]. The `TimerId` value should be treated as an opaque value. For all timers in the system, the configuration tool creates a constant with the name `TIMER_ID_<name>` that should be used in preference to raw values.

TicksAbsolute

The `TicksAbsolute` type is used to represent an absolute number of ticks. It is a 32-bit unsigned integer that has a large enough range to represent the total number of ticks since system boot. For a 40Hz (25ms period) tick, this can handle over 1,200 days worth of ticks.

TicksRelative

The `TicksRelative` type is used to represent a number of ticks relative to a point in time. It is a 16-bit unsigned integer. Assuming a 40Hz tick this provides range for up to 27 minutes' worth of ticks.

TIMER_ID_<name>

`TIMER_ID_<name>` has the type `TimerId`. A constant is created for each timer in the system. Note that *name* is the upper-case conversion of the timer's name.

timer_current_ticks

```
TicksAbsolute timer_current_ticks;
```

The value of this variable is the current global tick count in the system. It directly reflects how many times the `timer_tick` API has been called since the system startup.

timer_tick

```
void timer_tick(void);
```

This API is to be called to register a system tick with the RTOS. It is usually triggered by a periodic, external event, such as an interrupt generated by a hardware timer. It is safe to call this API directly from an interrupt service routine.

Note that the RTOS timer functionality directly depends on this API being called regularly. The registered tick remains pending until the RTOS processes the tick (see Timing Considerations).

timer_enable

```
void timer_enable(TimerId timer);
```

This API is called to start a timer. The timer starts counting down from its configured reload value. If the timer's reload value is zero, then the timer expires immediately (and performs its configured expiry behavior).

timer_disable

```
void timer_disable(TimerId timer);
```

This API stops a timer. The configured expiry action does not occur if the timer is disabled before it has expired. Disabling a timer does not simply pause the timer; if the timer is reenabled (with the `timer_enable` API), it starts counting from the

configured reload value.

timer_oneshot

```
void timer_oneshot(TimerId timer, TicksRelative timeout);
```

This API starts a timer in a one-shot manner. When the timer expires, it does not automatically restart. The timer expires after `timeout` number of ticks.

timer_check_overflow

```
bool timer_check_overflow(TimerId timer);
```

This API returns true if a timer has overflowed. A timer overflows if the signal it sends on expiry would be lost. For example, if a task is expecting to receive signals from a periodic timer and does not receive them quickly enough, the timer is marked as having overflowed. Calling the `timer_check_overflow` API clears the overflow mark if set.

The calling task may be subject to an unpredictable amount of delay between calling this function and evaluating its return value, in the case that the task is preempted.

timer_remaining

```
TicksRelative timer_remaining(TimerId timer);
```

This API returns the number of ticks remaining before the specified timer expires.

The calling task may be subject to an unpredictable amount of delay between calling this function and evaluating its return value, in the case that the task is preempted.

timer_reload_set

```
void timer_reload_set(TimerId timer, TicksRelative reload_value);
```

This API configures a timer's reload value. The `reload` value is used to initialize the timer when it is enabled (or when it restarts in the case of a periodic timer).

timer_signal_set

```
void timer_signal_set(TimerId timer, TaskId task, SignalSet sigset);
```

This API configures the timer so that on expiry it sends the set of signals `sigset` to the specified task.

timer_error_set

```
void timer_error_set(TimerId timer, ErrorId error);
```

This API configures the timer so that on expiry it causes a fatal error to occur. The specified `error` code is passed to the configured `fatal_error` function.

Mutex API

MutexId

An instance of this type refers to a specific mutex. The underlying type is an unsigned integer of a size large enough to represent all mutexes[8].

MUTEX_ID_<name>

These constants of type `MutexId` exist for all mutexes defined in the system configuration. `<name>` is the upper-case conversion of the mutex's name.

Applications shall use the symbolic names `MUTEX_ID_<name>` to refer to mutexes wherever possible. Applications shall not rely on the numeric value of a mutex ID. Across two different RTOS and applications builds, the ID for the same mutex may have different numeric values.

MUTEX_ID_ZERO and MUTEX_ID_MAX

The IDs of all mutexes are guaranteed to be a contiguous integer range between `MUTEX_ID_ZERO` and `MUTEX_ID_MAX`, inclusive. Applications may iterate over all mutexes via `for (id = MUTEX_ID_ZERO; id <= MUTEX_ID_MAX; id += 1)`. Also, they may associate information with mutexes, for example as follows:

```
unsigned int mutex_lock_count[1 + MUTEX_ID_MAX - MUTEX_ID_ZERO];
#define mutex_lock_and_count(ID)\
do {\
    mutex_lock(ID);\
    mutex_lock_count[(ID) - MUTEX_ID_ZERO] += 1;\
} while (0)
```

mutex_lock

```
void mutex_lock(MutexId mutex);
```

This API acquires the specified mutex. It returns only after it has acquired the mutex, which may be either immediately or after another task has released the mutex. A task

must release a mutex before acquiring it again.

If the mutex is in the *available* state, it transitions into the *acquired* state and the API returns immediately.

If the mutex is in the *acquired* state, the mutex state does not change, but the calling task blocks and a task switch occurs. After the task unblocks and becomes the current task again, it attempts to acquire the mutex again in the same fashion until successful.

This API is guaranteed to return only after the calling task has transitioned successfully the mutex from the *available* into the *acquired* state.

This implies that a task cannot successfully acquire the same mutex twice without releasing it in between. Attempting to do so effectively blocks the calling task indefinitely.

mutex_lock_timeout

```
bool mutex_lock_timeout(MutexId mutex, TicksRelative timeout);
```

This function waits a maximum *timeout* number of ticks to acquire the specified mutex.

Its behaviour matches that of `mutex_lock`, except that the maximum amount of time that the calling task can be blocked is bounded by the *timeout* number of ticks given. For more information, see Time and Timers.

If `mutex_lock_timeout` successfully acquires the mutex, it returns true. Otherwise, it returns false.

The system designer must not use this function to attempt to acquire a mutex previously acquired by the same task without releasing it in between.

mutex_try_lock

```
bool mutex_try_lock(MutexId mutex);
```

This API attempts to acquire the specified mutex. It returns true if it successfully acquired the mutex and false if the mutex is already acquired by another task.

If the mutex is in the *available* state, it transitions into the *acquired* state and the API returns true immediately.

If the mutex is in the *acquired* state, the mutex state does not change and the API returns false immediately.

This API does not cause a task switch.

mutex_unlock

```
void mutex_unlock(MutexId mutex);
```

This API releases the specified mutex so that other tasks can acquire it. A task should not release a mutex that it has not previously acquired.

This API transitions a mutex into the *available* state, unblocks all blocked tasks that have called `mutex_lock` while it was in the *acquired* state, and returns.

This API may cause a task switch.

mutex_holder_is_current

```
bool mutex_holder_is_current(MutexId mutex);
```

This API returns whether the current task is the holder of the specified mutex at the time the API is called.

Semaphores

SemId

Instances of this type refer to specific semaphores. The type is an unsigned integer of a size large enough to represent all semaphores[9].

SEM_ID_<name>

These constants of type `SemId` exist for all semaphores defined in the system configuration. `<name>` is the upper-case conversion of the semaphore's name.

Applications shall use the symbolic names `SEM_ID_<name>` to refer to semaphores wherever possible. Applications shall not rely on the numeric value of a semaphore ID. Across two different RTOS and applications builds, the ID for the same semaphore may have different numeric values.

SEM_ID_ZERO and SEM_ID_MAX

The IDs of all semaphores are guaranteed to be a contiguous integer range between `SEM_ID_ZERO` and `SEM_ID_MAX`, inclusive. Applications may iterate over all semaphores

via `for (id = SEM_ID_ZERO; id <= SEM_ID_MAX; id += 1)`.

SemValue

This type represents a semaphore's current and, optionally, maximum value (see `sem_max_init`). The bit width of the `SemValue` type depends on the configuration item `semaphore_value_size`.

sem_max_init

```
void sem_max_init(SemId sem, SemValue max);
```

This function is only available if the `semaphore_enable_max` configuration item is true. It initializes the specified semaphore with the given maximum value, which must be non-zero. The application must call it once and only once per semaphore, and must do so before using the `sem_post` API with the semaphore. The maximum value of a semaphore influences the behavior of the `sem_post` API.

sem_post

```
void sem_post(SemId sem);
```

This function increments the semaphore value by one. Additionally, it makes all tasks runnable that have called `sem_wait` and are currently blocked on the semaphore.

If the configuration item `semaphore_enable_max` is true, the following applies:

- Before an application calls `sem_post` for a semaphore, it must call `sem_max_init` once and only once for that semaphore.
- Calling `sem_post` when the semaphore value is equal to the semaphore maximum is considered a fatal error. In that case, the RTOS implementation calls the `fatal_error` function (see Error Handling).

One of the tasks made runnable may preempt the calling task, depending on the Scheduling Algorithm.

sem_wait

```
void sem_wait(SemId sem);
```

This function waits until the semaphore value of *sem* is greater than zero and then decrements the semaphore value.

If the semaphore value of *sem* is zero, `sem_wait` blocks the calling task. When another task makes it runnable again via the `sem_post` function, `sem_wait` checks the semaphore value again in the same manner. If the semaphore value is greater than zero, `sem_wait` decrements the semaphore value by one and returns.

Thus, `sem_wait` returns immediately if the semaphore value is initially greater than zero. If the semaphore value is initially 0, however, the calling task may be blocked for an unbounded amount of time. The semaphore implementation itself does not guarantee progress if there are multiple tasks waiting on the semaphore. Which waiting task gets to decrement the semaphore value and return from `sem_wait` depends entirely on the Scheduling Algorithm.

`sem_wait_timeout`

```
bool sem_wait_timeout(SemId sem, TicksRelative timeout);
```

This function waits a maximum *timeout* number of ticks until the semaphore value of *sem* is greater than zero, in which case it will decrement the semaphore value and return true.

If the *timeout* number of ticks elapses before the semaphore value can be decremented, then `sem_wait_timeout` will return false. The system designer should ensure that the RTOS `timer_tick` API is called for each tick. For more information, see Time and Timers.

The behavior of `sem_wait_timeout` matches that of `sem_wait`, except that the maximum amount of time that the calling task can be blocked is bounded by the *timeout* number of ticks given.

`sem_try_wait`

```
bool sem_try_wait(SemId sem);
```

This function attempts to decrement the semaphore value of the specified semaphore without blocking the calling task.

If the semaphore value is positive, it is decremented and `sem_try_wait` returns true. Otherwise, the function returns false and the semaphore value is not modified. This function does not cause a context switch.

Configuration Reference

This chapter provides a description of the available configuration items for the RTOS. The RTOS is configured via the configuration tool called `prj`[10].

Types

Configuration items have one of a number of different types.

- Boolean values are either true or false.
- Integers are numbers of arbitrary size specified in standard base-10 notation.
- C identifiers are strings that are valid identifiers in the C language (and generally refer to a function or variable that is available in the final system).
- Identifiers are strings used to name the different RTOS objects. Identifiers must be lower-case string consisting of ASCII letters, digits and the underscore symbol. Identifiers must start with a lower-case ASCII letter.

Notation

Since the system configuration is specified in XML format, the configuration items form a hierarchy of elements. For example, the list of tasks contains an entry for each task where in each entry several task-specific items are nested.

For clarity, this document refers to each item through a notation similar to XPath. For example, the *name* property of a task in the tasks component would be referred to as *tasks/task/name*. It reflects not only the name of the property itself but also its location within the hierarchy of an entire system definition.

RTOS Configuration

prefix

In some cases the RTOS APIs may conflict with existing symbol or pre-processor macro names used in a system. Therefore, the RTOS gives system designers the option to prefix all RTOS APIs to help avoid name-space conflicts. The prefix must be an all lower-case, legal C identifier. This is an optional configuration item that defaults to the empty string, i.e., no prefix.

The following examples are based on `prefix` having the value `rtos`.

- functions and variables: lower-case version of `prefix` plus an underscore, so `start` becomes `rtos_start` and `task_current` becomes `rtos_task_current`.
- types: CamelCase version of `prefix`, so `TaskId` becomes `RtosTaskId`.
- constants: upper-case version of `prefix` plus an underscore, so `TASK_ID_ZERO` becomes `RTOS_TASK_ID_ZERO`.

Error Handling Configuration

api_asserts

This configuration item is a boolean with a default of false. When true, the RTOS checks the arguments passed to API functions at runtime for consistency. For example, it checks whether the value of the `MutexId` argument of the `mutex_lock` API identifies a valid mutex. If the check passes, the check has no effect on the behavior of the API. If the check fails, the RTOS calls the `fatal_error` function.

internal_asserts

This configuration item is a boolean with a default of false. When true, the RTOS checks internal implementation state for consistency at runtime. For example, it checks whether the `TaskId` instance identifying the current task is a valid task ID. If the check passes, the check has no effect on the behavior of the RTOS. If the check fails, the RTOS calls the `fatal_error` function.

fatal_error

This configuration item is an optional C identifier with no default. It must be the name of a C function which the application implements and the RTOS calls when a fatal error state occurs. See Section Error Handling for more information.

Task Configuration

tasks

This configuration is a list of `task` configuration objects. The configuration must include at least one task because a system without tasks cannot run application functionality.

tasks/task/name

This configuration item specifies the task's name (also see Task Names). Each task must have a unique name. The name must be of an identifier type. This is a mandatory configuration item with no default.

tasks/task/function

This configuration item specifies the task's function (also see Task Functions). It must be the name of a function that the application implements so that it is available at link time. This is a mandatory configuration item with no default.

tasks/task/stack_size

This configuration item specifies the task's stack size in bytes (also see Task Stacks). It is a mandatory configuration item with no default.

Signal Configuration

signalset_size

This specifies the size of signal sets in bits. It should be 8, 16 or 32. This is an optional configuration item that defaults to 8.

signal_labels

The `signal_labels` configuration is an optional list of signal configuration objects that defaults to an empty list.

signal_labels/signal_label/name

This configuration specifies the name of the signal label. Signal label names must be unique. The name must be of an identifier type. This configuration is mandatory.

Interrupt Event Configuration

interrupt_events

The `interrupt_events` configuration is a list of interrupt event configuration objects.

interrupt_events/interrupt_event/name

This configuration item specifies the interrupt event's name. Each interrupt event must have a unique name. The name must be of an identifier type. This is a mandatory configuration item with no default.

interrupt_events/interrupt_event/task

This configuration item specifies the task to which a signal set is sent when the interrupt event is raised. This configuration item is optional. If no task is set, raising the interrupt event causes a fatal error. If the system designer does not set the task in the static configuration, it can be set at runtime using the `interrupt_event_task_set` API.

interrupt_events/interrupt_event/sig_set

This configuration item specifies the signal set that is sent to the interrupt event's associated task. A signal set is a list of one or more specified signal labels. This configuration item is optional and defaults to the empty set.

Timer Configuration

timers

The `timers` configuration is a list of `timer` configuration objects.

timers/timer/name

This configuration item specifies the timer's name. Each timer must have a unique name. The name must be of an identifier type. This is a mandatory configuration item

with no default.

timers/timer/enabled

This boolean configuration item determines whether the timer is enabled when the system starts. If it is true, the timer commences countdown on the very first tick. This is an optional configuration item that defaults to false. A timer can be enabled at runtime using the `timer_enable` API.

timers/timer/reload

This configuration item specifies the timer's reload value. The reload value is used to initialize the timer each time it is enabled. The value is specified as a relative number of ticks. The value must be presentable as a `TicksRelative` type. This is an optional configuration item that defaults to zero.

timers/timer/task

This configuration item specifies the task to which a signal set is sent when the timer expires. This configuration item is optional. If no task is set when the timer expires, a fatal error occurs. If the system designer does not set the task in the static configuration, it can be set at runtime using the `timer_signal_set` API.

timers/timer/sig_set

This configuration item specifies the signal set that is sent to the timer's associated task. A signal set is a list of one or more specified signal labels. This configuration item is optional and defaults to the empty set.

timers/timer/error

This configuration item specifies the error code that is passed to the `fatal_error` function when the timer expires. This configuration item is optional and defaults to zero. This should not be set if a task is specified.

Mutex Configuration

mutexes

The `mutexes` configuration is a list of `mutex` configuration objects. See the Mutex Configuration section for details on configuring each mutex.

mutexes/mutex/name

This configuration item specifies the mutex's name. Each mutex must have a unique name. The name must be of an identifier type. This is a mandatory configuration item with no default.

Semaphore Configuration

semaphore_value_size

This optional integer configuration item specifies the width of the `SemValue` type in bits. Valid values are 8, 16, and 32, with 8 being the default.

semaphore_enable_max

This boolean value controls whether semaphores have a maximum value or not. When set to true, the `sem_max_init` function is available and the `sem_post` function enforces the maximum value. This is an optional configuration item that defaults to false.

semaphores

This configuration item is a list of `semaphores/semaphore` configuration objects.

semaphores/semaphore

This configuration item is a dictionary of values defining the properties of a single semaphore.

semaphores/semaphore/name

This configuration item specifies the name of a semaphore. Each semaphore must have a unique name. The name must be of an identifier type. This is a mandatory configuration item with no default.

---

1. There are some additional restrictions on valid names. See the Configuration Reference section for more details.↩
2. In a system designed to operate with low power consumption, it is desirable for this to be the case most of the time.↩
3. See the Signals section for more details.↩
4. The actual implementation does not decrement each timer, although it is an

accurate description of the logical behavior.↩

5. This is normally a `uint8_t`.↩
6. This is normally a `uint8_t`.↩
7. This is normally a `uint8_t`.↩
8. This is normally a `uint8_t`.↩
9. This is normally a `uint8_t`.↩
10. See `prj` manual for more details.↩