User Guide

General MCU RT_Thread Usage Guide

Introduction

This document mainly introduces the use of RT_Thread system in National Technology general MCU, which is applicable to N32G45x, N32G4FR, N32WB452, N32G43x, N32L40x, N32L43x series chips. This document uses N32G45x as an example to introduce the related usage instructions of RT_Thread system.

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1 RT_Thread

1.1 Overview

RT-Thread, the full name is Real Time-Thread, as the name suggests, it is an embedded real-time multi-threaded operating system, one of the basic attributes is to support multi-tasking, allowing multiple tasks to run concurrently does not mean that the processor is actually executing multiple tasks at the same time. In fact, a processor core can only run one task at a time, because the execution time of each task is very short, Tasks are switched very quickly through the task scheduler (the scheduler decides the task to be executed at the moment according to the priority), gives the illusion that multiple tasks are running at the same time. In the RT-Thread system, tasks are implemented by threads, and the thread scheduler in RT-Thread is the above-mentioned task scheduler.

RT-Thread is mainly written in C language, which is easy to understand and easy to transplant. It applies the object-oriented design method to the real-time system design, which makes the code style elegant, the structure clear, the system modularized and the tailorability very good. For resource-constrained microcontroller (MCU) systems, the NANO version that only requires 3KB Flash and 1.2KB RAM memory resources can be tailored through easy-to-use tools (NANO is a minimalist version of the kernel officially released by RT-Thread in July 2017); For resource-rich IoT devices, RT-Thread can use online software package management tools, and cooperate with system configuration tools to achieve intuitive and fast modular tailoring, seamlessly import rich software function packages to realize complex functions such as Android-like graphical interface, touch and slide effects, and intelligent voice interaction effects.

Compared with the Linux operating system, RT-Thread has the advantages of small size, low cost, low power consumption, and fast startup. In addition, RT-Thread also has the characteristics of high real-time performance and small resource consumption, which is very suitable for various resource constraints (such as cost, power consumption constraints, etc.). Although a 32-bit MCU is its main operating platform, in fact many application processors with MMUs, ARM9, ARM11 and even Cortex-A series-level CPUs are also suitable for RT-Thread in specific applications.

1.2 RT-Thread architecture

In recent years, the concept of Internet of Things (IoT) has been widely popularized, the Internet of Things market has developed rapidly, and the networking of embedded devices has become the general trend. The terminal networking has greatly increased the software complexity, and the traditional RTOS kernel has become more and more difficult to meet the needs of the market. In this case, the concept of the Internet of Things Operating System (IoT OS) came into being. IoT operating system refers to the operating system kernel (which can be RTOS, Linux, etc.), including relatively complete middleware components such as file systems and graphics libraries, and a software platform with low power consumption, security, communication protocol support and cloud connectivity, RT-Thread is an IoT OS.

One of the main differences between RT-Thread and many other RTOSs such as FreeRTOS and uC/OS is that it is not only a real-time kernel, but also has rich middle-layer components, as shown in Figure 1-1.

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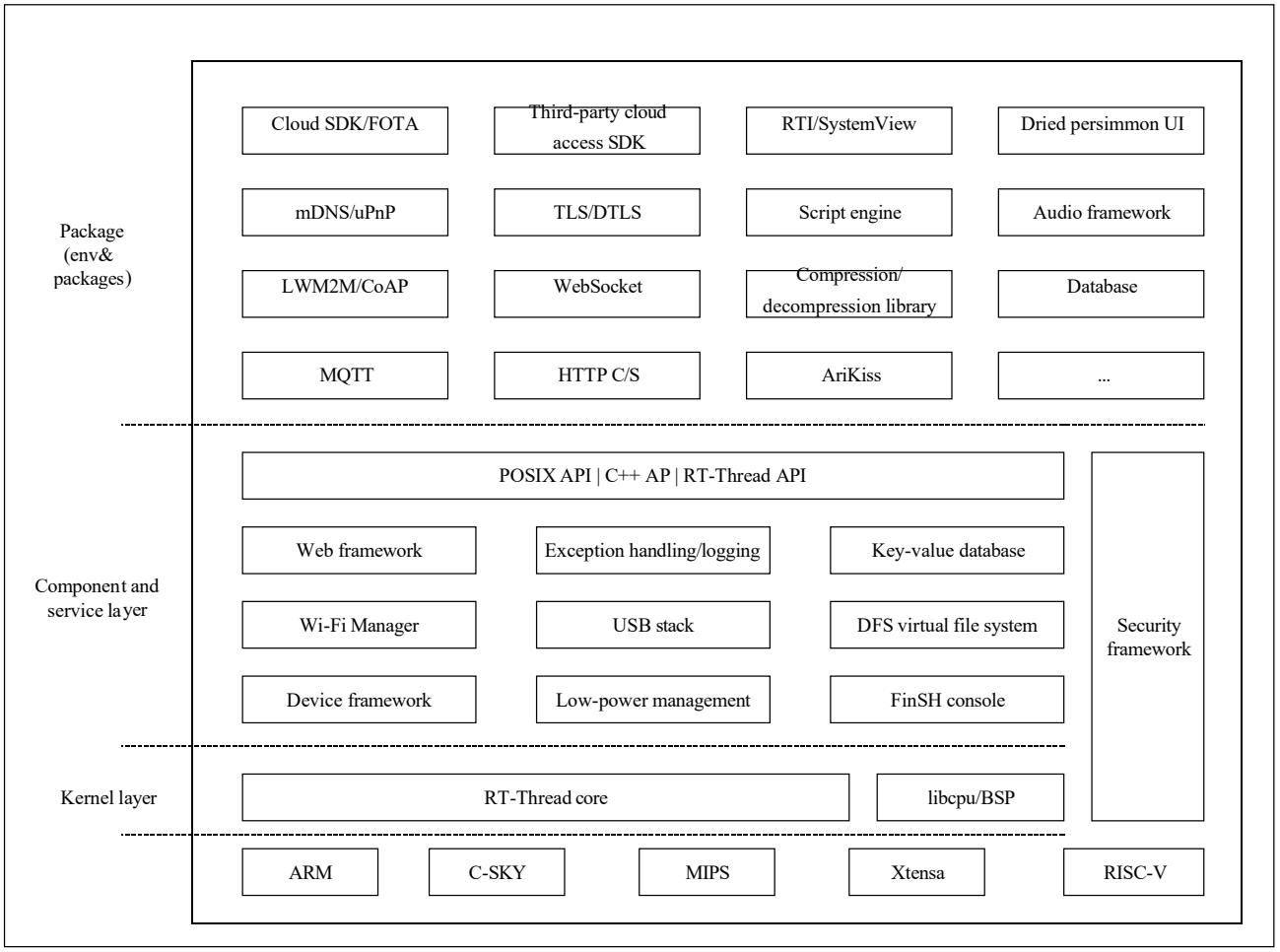
Figure 1-1 RT_Thread software framework diagram



It specifically includes the following parts:

- Kernel layer: RT-Thread kernel is the core part of RT-Thread, including the realization of objects in the kernel system, such as multithreading and its scheduling, semaphores, mailboxes, message queues, memory management, timers, etc.; libcpu/BSP (chip porting related files/board support package) is closely related to hardware and consists of peripheral drivers and CPU porting.
- Component and service layer: components are upper-layer software based on RT-Thread kernel, such as virtual file system, FinSH command line interface, network framework, device framework, etc. Modular design is adopted to achieve high cohesion within components and low coupling between components.
- RT-Thread software package: running on the RT-Thread IoT operating system platform, general software components for different application fields, consisting of description information, source code or library files. RT-Thread provides an open software package platform, where official or developer-provided software packages are stored. This platform provides developers with many choices of reusable software packages, which is also an important part of the RT-Thread ecosystem. The ecosystem of software packages is crucial to the choice of an operating system, because these software packages are highly reusable and highly modular, which greatly facilitates application developers to create the system they want in the shortest time. The number of software packages that RT-Thread has supported has reached 60+, for example:
  - IoT-related software packages: Paho MQTT, WebClient, mongoose, WebTerminal, etc.

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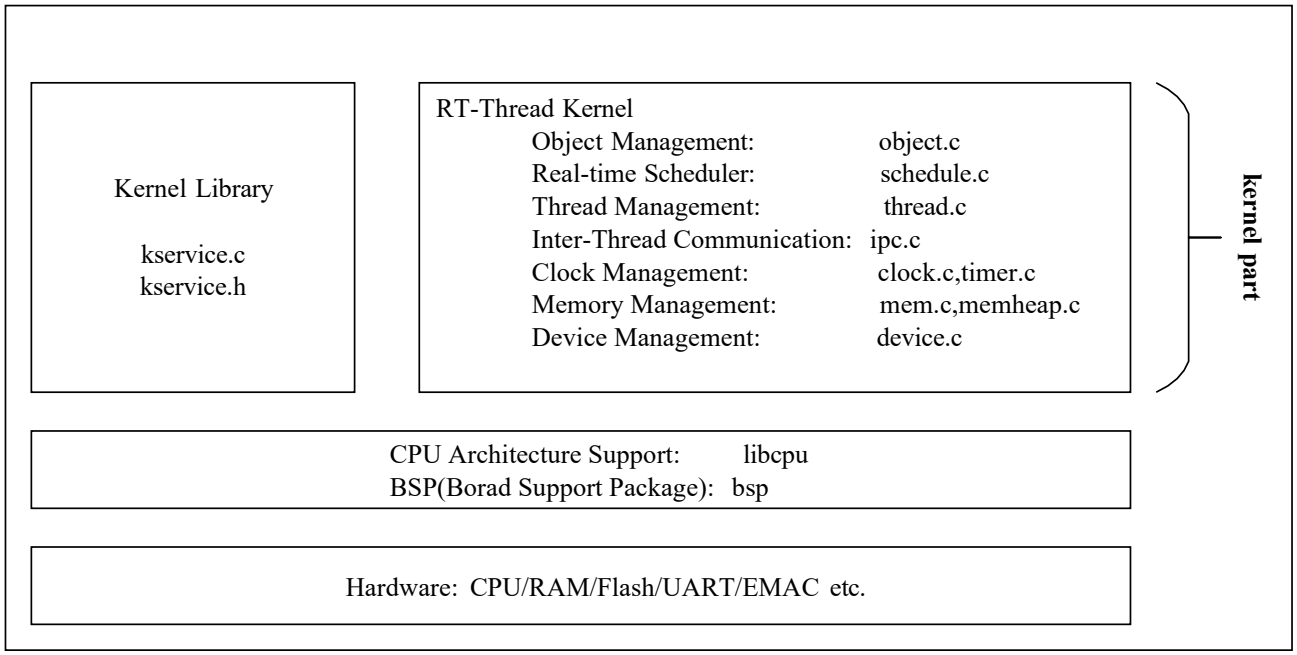
- Scripting language related packages: currently support JerryScript, MicroPython
- Multimedia related software packages: Openmv, mupdf
- Tool package: CmBacktrace, EasyFlash, EasyLogger, SystemView
- System-related software packages: RTGUI, Persimmon UI, lwext4, partition, SQLite, etc.
- Peripheral library and driver software package: RealTek RTL8710BN SDK

1.3 RT_Thread kernel

The kernel is the most basic and most important part of the operating system. Figure 1-2 is the RT-Thread kernel architecture diagram. The kernel is above the hardware layer, and the kernel part includes the kernel library and real-time kernel implementation.

Figure 1-2 RT_Thread kernel and underlying structure



The kernel library is a small set of C library-like function implementation subsets that ensure that the kernel can run independently. It provides implementations of functions like "strcpy", "memcpy", "printf", "scanf", etc.The RT-Thread kernel library only provides a small part of the C library function implementation used by the kernel. In order to avoid the same name as the standard C library, the rt_ prefix will be added before these functions.

The implementation of real-time kernel includes: object management, thread management and scheduler, inter-thread communication management, clock management and memory management, etc. The minimum resource occupancy of the kernel is 3KB ROM and 1.2KB RAM.

1.4 RT_Thread thread management

In our daily life, when we want to complete a big task, we usually decompose it into many simple and easy-to-solve small problems. The small problems are solved one by one, and the big problems are solved accordingly. In a multithreaded operating system, developers are also required to decompose a complex application into multiple small, schedulable, serialized program units, when the tasks are properly divided and executed correctly, this design

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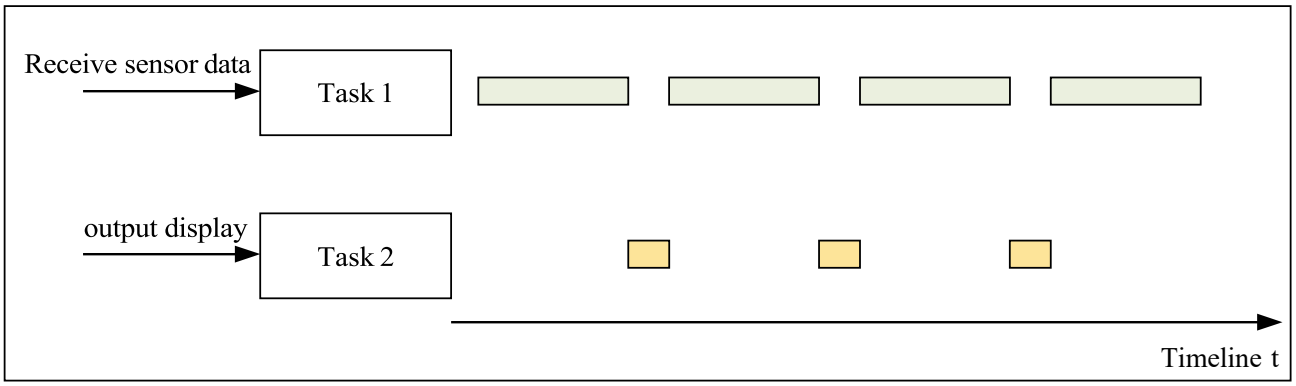
enables the system to meet the performance and time requirements of a real-time system, for example, let the embedded system perform such a task,the system collects data through sensors and displays the data through the display screen. In a multi-threaded real-time system, this task can be decomposed into two sub-tasks, as shown in Figure 1-3, a subtask continuously reads sensor data and writes the data to shared memory, another subtask periodically reads data from shared memory and outputs sensor data to the display.

Figure 1-3 Switching execution of sensor data receiving task and display task



In RT-Thread, the program entity corresponding to the above sub-tasks is the thread, the thread is the carrier for realizing the task, it is the most basic scheduling unit in RT-Thread, it describes the running environment of a task execution, it also describes the priority level of this task. Important tasks can be set to a relatively high priority, non-important tasks can be set to a lower priority, and different tasks can also be set to the same priority and run in turn.

When a thread is running, it will think that it is running in a way of exclusive CPU, and the running environment of the thread execution is called context, specifically, various variables and data, including all register variables, stack, memory information, etc.

1.5 RT_Thread clock management

The clock management of RT-Thread is based on the clock tick. The clock tick refers to the length of the interval between two interrupts of the periodic hardware timer. This periodic hardware timer is called the system clock. The clock tick (OS Tick) is the smallest clock unit in the RT-Thread operating system. The system tick is generally defined as a 32-bit unsigned integer, which is provided to the application for all time-related services, such as thread delay, thread time slice rotation scheduling and timer timeout, etc., the number of clock ticks counted from the start of the system is called the system time. The clock beat is derived from the periodic interrupt of the timer, and an interrupt represents an OS Tick. The length of the OS Tick can be adjusted according to the definition of RT_TICK_PER_SECOND, which is equal to 1/RT_TICK_PER_SECOND seconds. A clock with higher precision will cause the timer to be checked frequently in the system.

1.6 RT_Thread interrupt management

The interrupt management function of RT-Thread is mainly to manage interrupt devices, interrupt service routines, interrupt nesting, maintenance of interrupt stack, on-site protection and recovery during thread switching, etc.

When the CPU is processing internal data, an emergency occurs in the outside world, requiring the CPU to suspend the current work and turn to process this asynchronous event. After processing, return to the original interrupted address and continue the original work. This process is called interruption. The system that realizes this function is

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called the interrupt system, and the request source that applies for the CPU interrupt is called the interrupt source. When multiple interrupt sources request interrupts from the CPU at the same time, there is a problem of interrupt priority. Usually, according to the priority level of the interrupt source, the interrupt request source with the most urgent event will be processed first, that is, the interrupt request with the highest level will be responded first.

When an interrupt occurs, the CPU will execute in the following order:

1) Save the current processor state information
2) Load exception or interrupt handler function into PC register
3) Transfer control to the handler and start execution
4) Restores processor state information when handler function execution completes
5) Return to the previous program execution point from an exception or interrupt

Interrupts allow the CPU to process events as they occur, rather than having the CPU continually query whether a corresponding event has occurred.

1.7 RT_Thread memory management

Static memory pool interface: memory pool is a memory allocation method used to allocate a large number of small memory blocks of the same size. It can greatly speed up the speed of memory allocation and release, and can try to avoid memory fragmentation. When the memory pool is empty, the allocated thread can be blocked (either return immediately, or wait for a period of time to return, which is determined by the timeout parameter). When other threads release memory blocks to this memory pool, the blocked thread will be woken up.

Dynamic memory heap interface: Dynamic memory management is a real heap memory management module, which can allocate memory blocks of any size according to the needs of users when the current resources are satisfied. When the user no longer needs to use these memory blocks, they can be released back to the heap for allocation by other applications. In order to meet different needs, RT-Thread system provides two different sets of dynamic memory management algorithms, namely small heap memory management algorithm and SLAB memory management algorithm.

- The small heap memory management module is mainly used for systems with less system resources and is generally used for systems with less than 2MB memory space.
- The SLAB memory management module mainly provides a fast algorithm that approximates the multi-memory pool management algorithm when the system resources are relatively abundant.

The two memory management modules can only choose one of them or not use the dynamic heap memory manager at all when the system is running. The API interfaces provided by these two management modules are exactly the same.

In addition to the above, RT-Thread also has a management mechanism for multiple memory heaps, namely memheap memory management. The memheap method is suitable for the situation where there are multiple memory heaps in the system. It can "paste" multiple memories together to form a large memory heap, which is very convenient for users to use.

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2 RT_Thread application

2.1 Thread creation example

Real-time applications using RTOS can be structured as a set of independent threads. Each thread executes in its own context without accidentally relying on other threads in the system or the RTOS scheduler itself. At any point in time, only one thread in the application can execute, and the RTOS scheduler is responsible for determining which thread that thread should be.

Below is an example on thread creation.

led0_thread: this thread toggles LED0 every 500 ms
Create thread:
/* led0_thread definition */ rt_thread_init(&led0_thread, "led0", led0_thread_entry, RT_NULL, (rt_uint8_t*)&led0_stack[0], sizeof(led0_stack), 3, 5); /* Start led0_thread*/ rt_thread_startup(&led0_thread);

2.2 Semaphore example

A semaphore is a lightweight kernel object used to solve the synchronization problem between threads. A thread can acquire or release it to achieve synchronization or mutual exclusion.

The schematic diagram of semaphore work is shown in Figure 2-1. Each semaphore object has a semaphore value and a thread waiting queue, the value of the semaphore corresponds to the number of instances and resources of the semaphore object. If the semaphore value is 5, it means that there are 5 semaphore instances (resources) that can be used. When the number of semaphore instances is zero, the thread that applies for the semaphore will be suspended on the waiting queue of the semaphore, waiting for available semaphore instances (resources).

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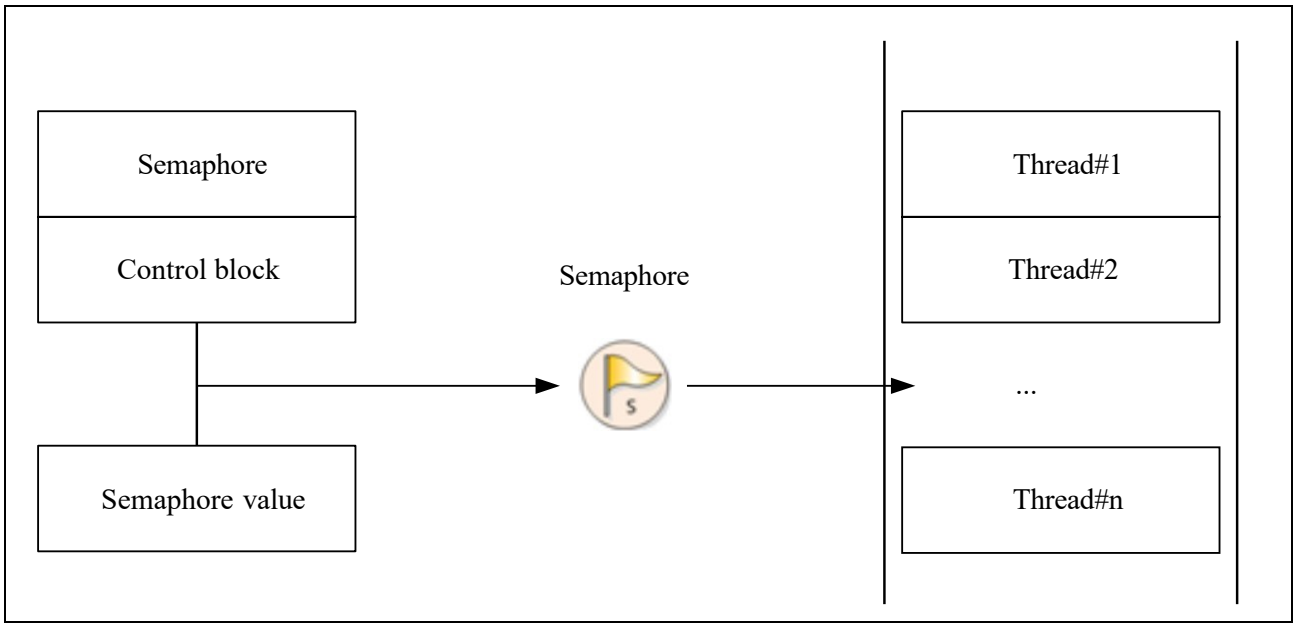
Figure 2-1 Schematic diagram of semaphore work



Semaphore:

```
/* Create the binary semaphore */
rt_sem_init(&key_sem,
            "keysem",
            0,
            RT_IPC_FLAG_FIFO);

/* Get the semaphore*/
rt_sem_take(&key_sem,
            RT_WAITING_FOREVER);

/* Relase the semaphore*/
rt_sem_release(&key_sem);
```

2.3 Mutex example

The difference between a mutex and a semaphore is that the thread that owns the mutex has ownership of the mutex, and the mutex supports recursive access and prevents thread priority flipping; and a mutex can only be released by the holding thread, while a semaphore can be released by any thread.

There are only two states of a mutex, unlocked or locked (two state values). When a thread holds it, the mutex is locked, and the thread takes ownership of it. Instead, when the thread releases it, the mutex is unlocked, losing ownership of it. When a thread holds a mutex, other threads will not be able to unlock it or hold it, and the thread holding the mutex can also acquire the lock again without being suspended, as shown in Figure 2-2 Show. This feature is very different from the general binary semaphore: in the semaphore, because there is no instance, the thread recursively holds will actively suspend (eventually form a deadlock).

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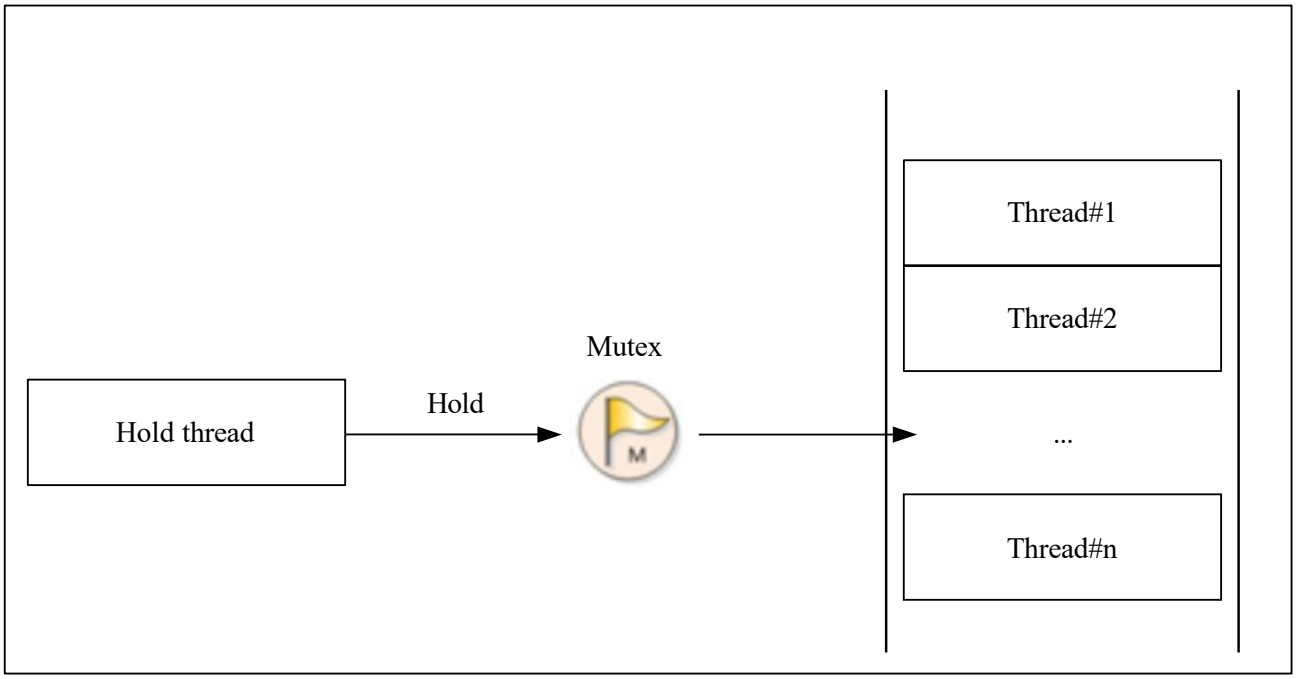
Figure 2-2 Mutex working diagram



Another potential problem caused by using semaphores is thread priority inversion. The so-called priority inversion, that is, when a high-priority thread tries to access a shared resource through the semaphore mechanism, if the semaphore is already held by a low-priority thread, and this low-priority thread may be used by other threads during the running process. Some medium-priority threads are preempted, thus causing high-priority threads to be blocked by many lower-priority threads, making it difficult to guarantee real-time performance. As shown in Figure 2-3: There are three threads with priority A, B and C, priority A > B > C. Threads A and B are in a suspended state, waiting for an event to be triggered, and thread C is running. At this time, thread C starts to use a shared resource M. During use, the event that thread A is waiting for arrives, and thread A turns to the ready state, because it has a higher priority than thread C, so it is executed immediately. But when thread A wants to use shared resource M, because it is being used by thread C, thread A is suspended and switched to thread C to run. If the event that thread B is waiting for arrives at this time, thread B turns to the ready state. Since thread B has a higher priority than thread C, thread B starts running, and thread C does not start running until it finishes running. Thread A can execute only after thread C releases shared resource M. In this case, the priority inversion: thread B runs before thread A. This does not guarantee the response time of high-priority threads.

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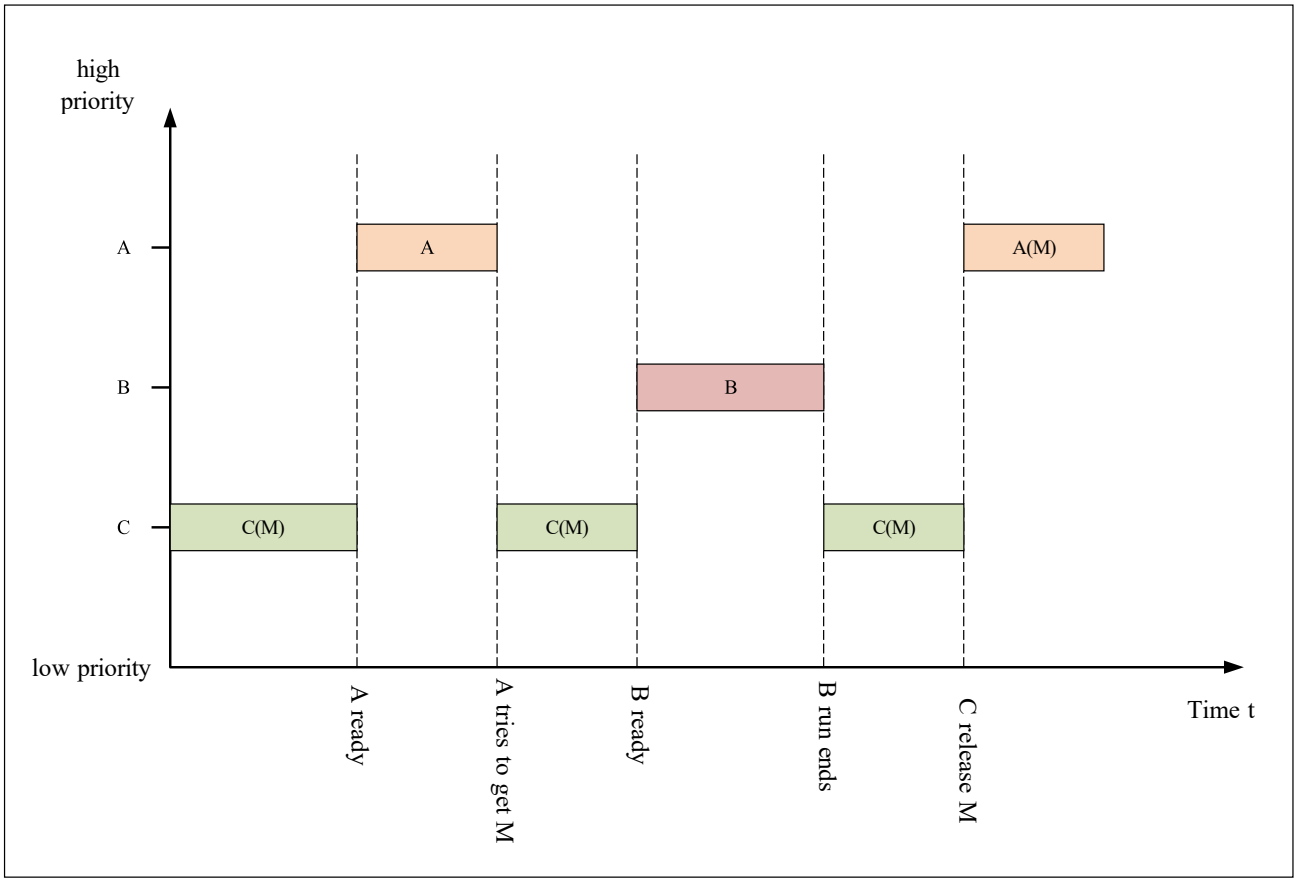
Figure 2-3 Priority inversion (M is a semaphore)



In the RT-Thread operating system, the mutex can solve the priority inversion problem and implement the priority inheritance algorithm. Priority inheritance solves the problem caused by priority inversion by raising the priority of thread C to the priority level of thread A during the period when thread A is suspended while trying to acquire a shared resource. This prevents C (and indirectly A) from being preempted by B, as shown in Figure 2-4. Priority inheritance refers to raising the priority of a low-priority thread that occupies a resource to make it equal to the priority of the thread with the highest priority among all threads waiting for the resource, then execute, and when the low-priority thread releases the resource, the priority returns to the initial setting. Thus, threads with inherited priorities avoid preemption of system resources by any intermediate-priority thread.

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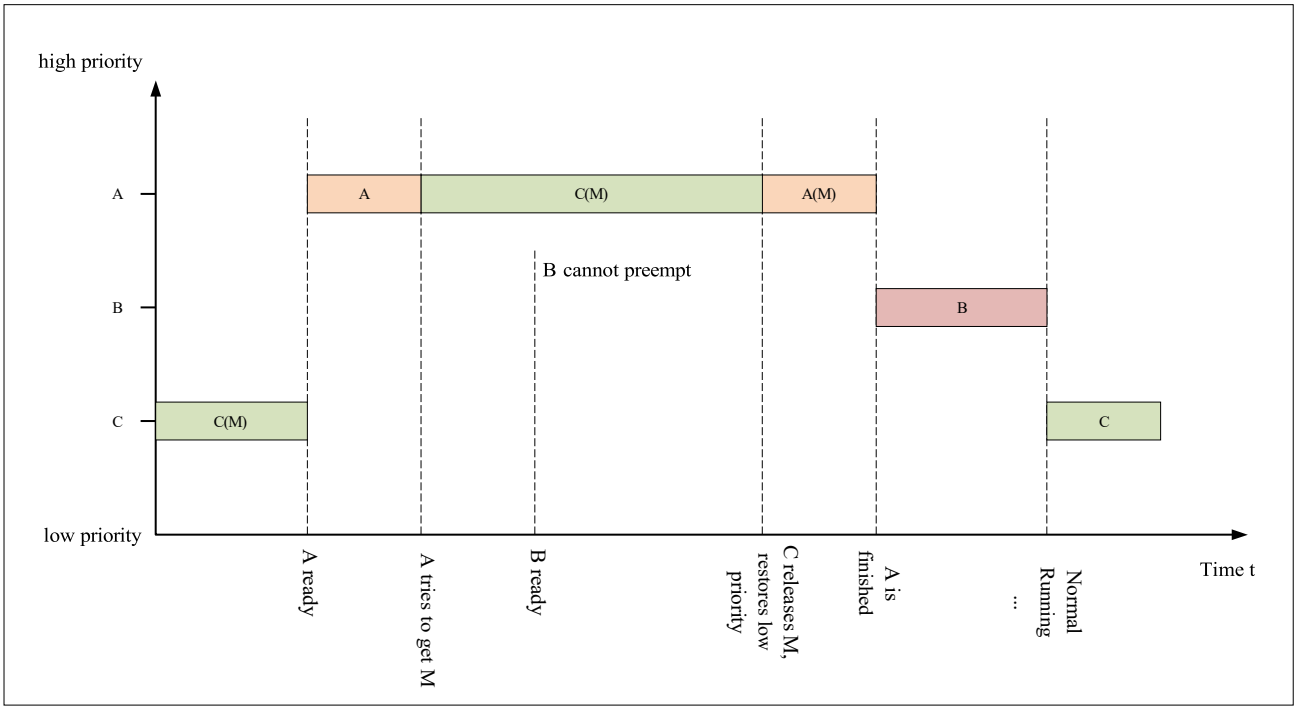
Figure 2-4 Priority inheritance (M is a mutex)



Note: After obtaining the mutex, please release the mutex as soon as possible, and in the process of holding the mutex, you must not change the priority of the thread holding the mutex.

Mutex

```
/* Create the mutex */
rt_mutex_init(&static_mutex,
              "smutex",
              RT_IPC_FLAG_FIFO);

/* Get the mutex */
rt_mutex_take(&static_mutex,
              10);

/* Relase the mutex */
rt_mutex_detach(&static_mutex);
```

2.4 Message queue example

The message queue can receive messages of variable length from threads or interrupt service routines, and buffer the messages in its own memory space. Other threads can also read the corresponding messages from the message queue, and when the message queue is empty, the reading thread can be suspended. When a new message arrives, the suspended thread will be woken up to receive and process the message. A message queue is an asynchronous communication method.

As shown in Figure 2-5, a thread or interrupt service routine can place one or more messages into a message queue. Likewise, one or more threads can get messages from the message queue. When multiple messages are sent to the message queue, the message that enters the message queue first is usually passed to the thread first, that is, the thread

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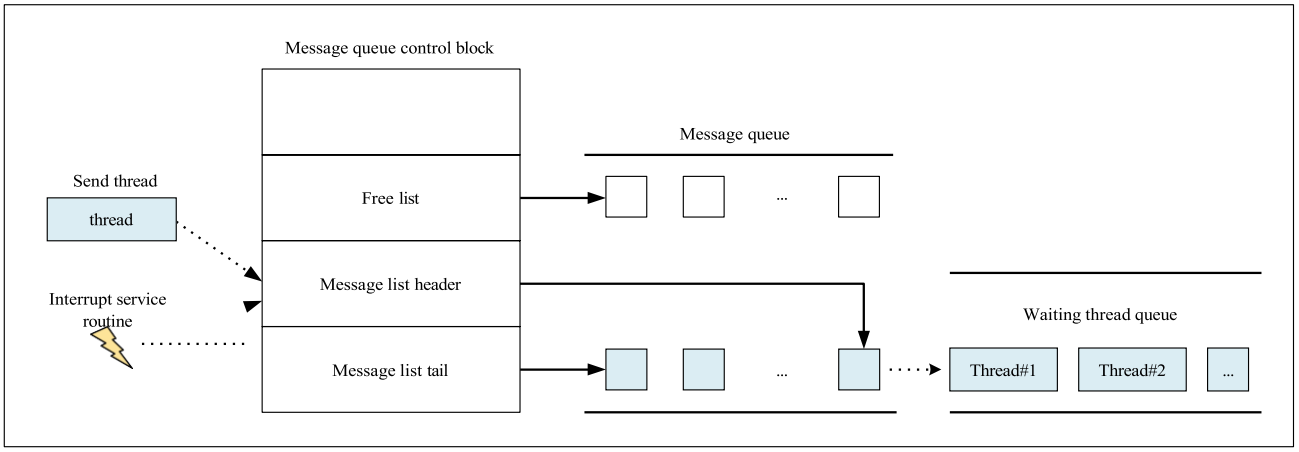
gets the message that enters the message queue first, that is, the first-in-first-out principle (FIFO).

Figure 2-5 Schematic diagram of message queue work



The message queue object of the RT-Thread operating system consists of multiple elements. When a message queue is created, it is assigned a message queue control block: message queue name, memory buffer, message size, and queue length. At the same time, each message queue object contains multiple message boxes, and each message box can store a message; the first and last message boxes in the message queue are called the message list header and the message list tail respectively, corresponding to msg_queue_head and msg_queue_tail in the message queue control block; some message boxes may be empty, and they form a linked list of free message boxes through msg_queue_free. The total number of message boxes in all message queues is the length of the message queue, which can be specified when the message queue is created.

Message queue

```
/* Create the message queue*/
rt_mq_init(&mq,
           "mqt",
            &msg_pool[0],
            128- sizeof(void*),
            sizeof(msg_pool),
            RT_IPC_FLAG_FIFO);

/* Send the message queue*/
rt_mq_send(&mq,
            &key_info[0],
            sizeof(key_info));

/* Receive the message queue*/
rt_mq_recv(&mq,
            &buf[0],
            sizeof(buf),
            RT_WAITING_FOREVER);
```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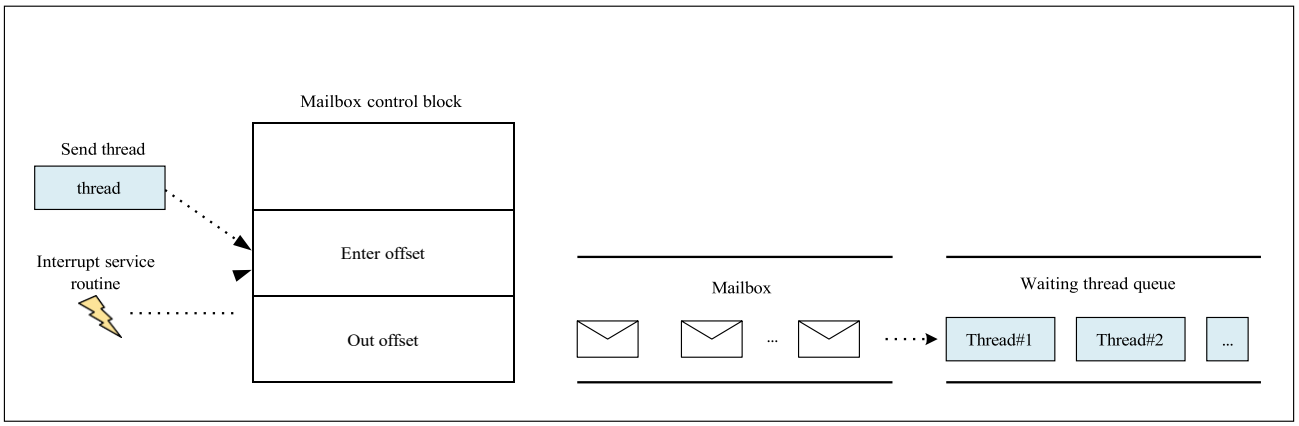
2.5 Mailbox example

The mailbox of the RT-Thread operating system is used for inter-thread communication, which is characterized by low overhead and high efficiency. Each message in the mailbox can only hold a fixed 4-byte content (for a 32-bit processing system, the size of the pointer is 4 bytes, so a message can hold exactly one pointer). A typical mailbox is also called exchanging messages, as shown in Figure 2-6, the thread or interrupt service routine sends a 4-byte message to mailbox from which one or more threads can receive and process it.

Figure 2-6 Schematic diagram of mailbox work



Mailbox

```
/* Create the mailbox*/
rt_mb_init(&mb,
           "mbt",
           &mb_pool[0],
           sizeof(mb_pool)/4,
           RT_IPC_FLAG_FIFO);

/* Send the mailbox*/
rt_mb_send(&mb,
           (rt_uint32_t )&key_info[0]);

/* Receive the mailbox*/
rt_mb_recv(&mb,
           (rt_uint32_t*)&str,
           RT_WAITING_FOREVER);
```

2.6 Event example

The event set is mainly used for synchronization between threads. Unlike the semaphore, it is characterized in that it can achieve one-to-many and many-to-many synchronization. That is, the relationship between a thread and multiple events can be set as: any one event wakes up the thread, or several events arrive before waking up the thread for subsequent processing; similarly, an event can also be multiple threads synchronizing multiple events. This collection of multiple events can be represented by a 32-bit unsigned integer variable, each bit of the variable

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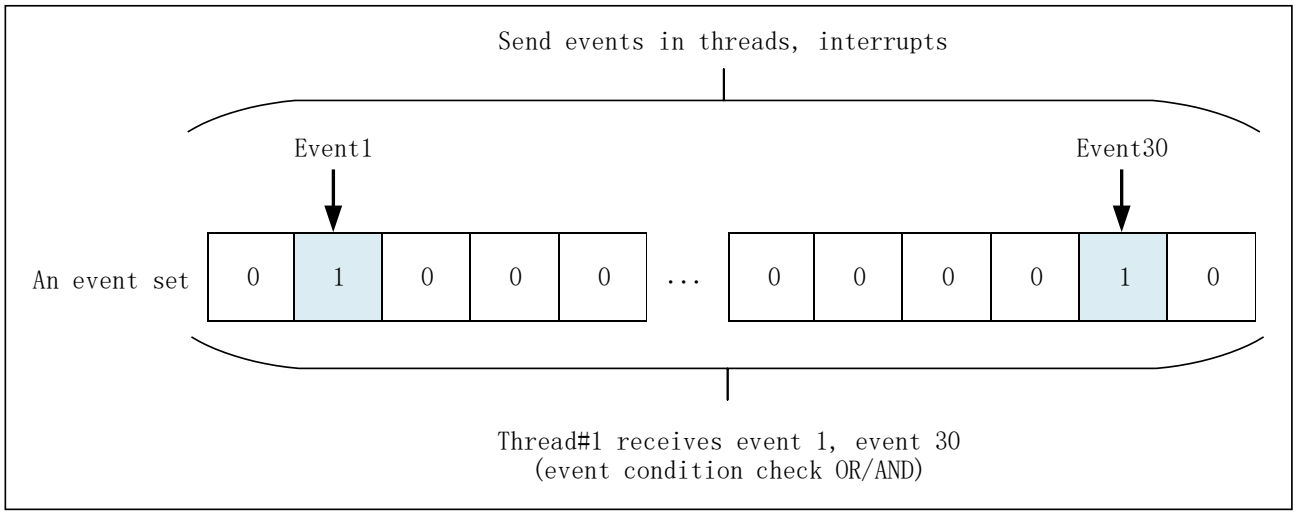
represents an event, and the thread associates one or more events through "logical AND" or "logical OR" to form event combination. The "logical OR" of events is also called independent synchronization, which means that the thread is synchronized with any one of the events; the "logical AND" of events is also called associative synchronization, which means that the thread is synchronized with several events.

The event set defined by RT-Thread has the following characteristics:

- Events are only related to threads, and events are independent of each other: each thread can have 32 event flags, which are recorded by a 32-bit unsigned integer, and each bit represents an event
- Events are only used for synchronization and do not provide data transfer function
- There is no queueing of events, that is, sending the same event to the thread multiple times (if the thread has not had time to read it away), the effect is equivalent to sending it only once. In RT-Thread, each thread has an event information flag, which has three attributes, namely RT_EVENT_FLAG_AND (logical AND), RT_EVENT_FLAG_OR (logical or) and RT_EVENT_FLAG_CLEAR (clear flag). When a thread waits for event synchronization, it can judge whether the currently received event satisfies the synchronization condition through 32 event flags and this event information flag.

Figure 2-7 Schematic diagram of event work



As shown in Figure 2-7, bits 1 and 30 are set in the event flag of thread #1, if the event information flag bit is set to logical AND, it means that thread #1 will only be triggered to wake up after both event 1 and event 30 have occurred, if the event information flag bit is set to logical OR, the occurrence of either event 1 or event 30 will trigger the wakeup of thread #1. If the information flag also sets the clear flag bit, then when thread #1 wakes up, it will actively clear event 1 and event 30 to zero, otherwise the event flag will still exist (ie set to 1).

Event

```
/* Create the event*/
rt_event_init( &event,
               "event",
               RT_IPC_FLAG_FIFO);

/* Send the event */
rt_event_send( &event,
```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```
                    (1 << 0)) ;

/* Receive the event s*/
rt_event_recv( &event,
                    ((1 << 0) | (1 << 1)),
                     RT_EVENT_FLAG_AND | RT_EVENT_FLAG_CLEAR,
                     10,
                     &evt);
```


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3 Supplementary instructions

There are many different CPU architectures in the embedded world, such as Cortex-M, ARM920T, MIPS32, RISC-V, etc. In order to enable RT-Thread to run on chips with different CPU architectures, RT-Thread provides a libcpu abstraction layer to adapt to different CPU architectures. The libcpu layer provides a unified interface to the kernel, including global interrupt switches, thread stack initialization, context switching, etc.

The libcpu abstraction layer of RT-Thread provides a unified set of CPU architecture porting interfaces downwards. This part of the interface includes the global interrupt switch function, thread context switch function, clock beat configuration and interrupt function, Cache and so on. The following table shows the interfaces and variables that need to be implemented for CPU architecture porting.

Table 3-1 libcpu porting related API

Functions and variables	Describe
rt_base_t rt_hw_interrupt_disable(void);	Turn off global interrupt
void rt_hw_interrupt_enable(rt_base_t level);	Turn on global interrupt
rt_uint8_t *rt_hw_stack_init(void *tentry, void *parameter, rt_uint8_t *stack_addr, void *texit);	The initialization of the thread stack, the kernel will call this function in thread creation and thread initialization
void rt_hw_context_switch_to(rt_uint32 to);	Context switching without source thread, invoked when the scheduler starts the first thread, and in signal
void rt_hw_context_switch(rt_uint32 from,rt_uint32 to);	Switch from from thread to to thread for switching between threads
void rt_hw_context_switch_interrupt(rt_uint32 from, rt_uint32 to);	Switch from the from thread to the to thread, which is used when switching in the interrupt
rt_uint32_t rt_thread_switch_interrupt_flag;	Indicates the flag that needs to be switched in the interrupt
rt_uint32_t rt_interrupt_from_thread, rt_interrupt_to_thread;	Used to save the from and to threads when the thread switches contexts

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4 Version history

Version	Date	Changes
V1.0	2021.01.08	Initial version

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