# FreeRTOS - Tasks

Tasks are jobs will be done in an application. These special jobs are managed by scheduler with task's stack, priority.

#arm #stm32 #rtos

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# 1. A Task

A task will do a specific functionality, such as toggling an LED, reading an input. The task function usually is in infinite loop, it means a task will continuously run and never returns.

The Task Function is declared as:

```
void taskFunctionName(void* argument) {
    for(;;) {
        // do things over and over
    }
}
```

In freeRTOS, every task has its own stack that stores TCB (Task Control Block) and other stack-related operations while the task is being executed. It also stores processor context before a context switch (switching to other task). Stack size must be sufficient to accommodate all local variables and processor context.

# 2. Startup

1. Main Application sets up the System Clock and necessary Peripherals
2. FreeRTOS is started by the `osKernelStart()` function in the `main.c` file from CMSIS_OS APIs:
    1. This calls to the `vTaskStartScheduler()` function from FreeRTOS APIs
    2. `vTaskStartScheduler()` creates an IDLE task using `xTaskCreate()`, then disables all interrupts by calling `portDISABLE_INTERRUPTS()` to be sure that no tick will happened before or during the call to `xPortStartScheduler()` function from FreeRTOS API
    3. `xPortStartScheduler()` configures the lowest priority level for `SysTick` and `PendSV` interrupts, then it starts the timer that generates the SysTick, enables FPU if presented (e.g. in CortexM4) and starts the first task using the `prvPortStartFirstTask()` function
    4. `prvPortStartFirstTask()` function (usually written in assembler) locates the stack and set `MSP` (used by the OS) to the start of the stack, then enables all interrupts. After this, it triggers software interrupt `SVC 0`
    5. As the result of SVC interrupt, `vPortSVCHandler()` is called
    6. `vPortSVCHandler()` restores the context, loads TCB (Task Block Control) of the first task (the highest priority one) from the Ready list and starts executing this task

# 3. The `IDLE` Task

The Idle task is created automatically when the scheduler is started:

- It is the `portTASK_FUNCTION()` function in the `task.c` file
- It performs the following operations (in endless loop):
    1. Check for deleted tasks to clean the memory
    2. Call `taskYIELD()` if not using preemption `configUSE_PREEMPTION = 0`
    3. Call `taskYIELD()` if there is another task waiting and `configIDLE_SHOULD_YIELD = 1` to not waste time
    4. Executes `vApplicationIdleHook()` if `configUSE_IDLE_HOOK = 1`
    5. Perform low power entrance if `configUSE_TICKLESS_IDLE != 0`

**The default task**

When using STM32CubeIDE to add FreeRTOS to project, there is a *default task* which is marked as *can be modified, not be removed*. This not the IDLE task mentioned above. User can configure it as a normal task, or even remove it in the main source code.

# 4. Task Lists

| Task List | Description |
|---|---|
| `ReadyTasksList[]` | Prioritized ready tasks lists separate for each task priority up to `configMAX_PRIORITIES` |
| `TasksWaitingTermination` | List of tasks which have been deleted but their memory pools are not freed yet. |
| `SuspendedTaskList` | List of tasks currently suspended |
| `PendingReadyTaskList` | Lists of tasks that have been read while the scheduler was suspended |
| `DelayedTaskList` | List of delayed tasks |
| `OverflowDelayedTaskList` | List of delayed tasks which have overflowed the current tick count |

There is no dedicated list for task in Running mode (as there is only one task in this state at the moment), but the currently run task ID is stored in variable `pxCurrentTCB`.

# 5. Task Functions

A task will do a specific functionality, such as toggling an LED, reading an input. The task function usually is in infinite loop, it means a task will continuously run and never returns. The Task Function is declared as:

```
void taskFunctionName(void* argument) {
    // do something first
    for(;;) {
        // do things over and over
    }
}
```

In freeRTOS, every task has its own stack that stores TCB (Task Control Block) and other stack-related operations while the task is being executed. It also stores processor context before a context switch (switching to other task). Stack size must be sufficient to accommodate all local variables and processor context.

A Task is created by calling `osThreadNew()` which indeed calls to:

- `xTaskCreateStatic()` if `configSUPPORT_STATIC_ALLOCATION == 1`, or calls to
- `xTaskCreate()` if `configSUPPORT_DYNAMIC_ALLOCATION == 1`.

The argument passed to the Task Function is declared as a `void*` pointer. This help to pass any type of data into the function handler.

# 6. Task states

**Ready**

> Task is ready to be executed but is not currently executing because a different task with equal or higher priority is running

**Running**

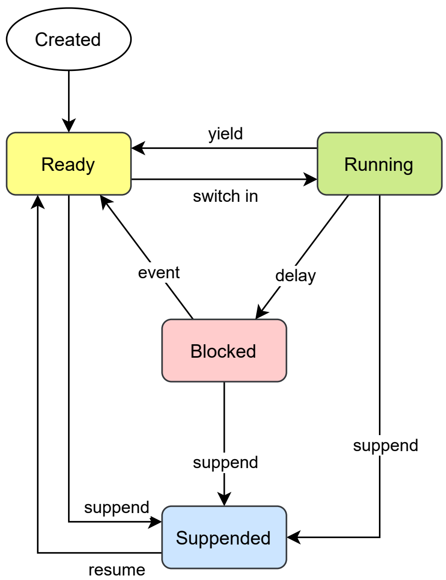
> Task is actually running (only one can be in this state at the moment)

**Blocked**

> Task is waiting for either a temporal or an external event

**Suspended**

> Task not available for scheduling, but still being kept in memory

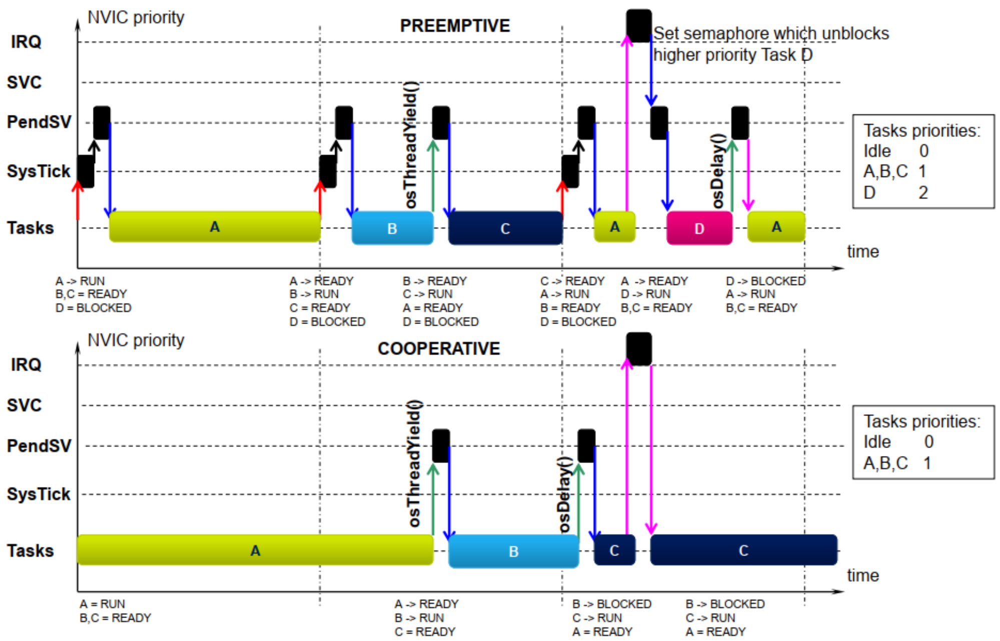



*Task states*

# 7. Task priorities

- Each task is assigned a priority from `tskIDLE_PRIORITY` /* defined in task.h */ to `MAX_PRIORITIES – 1` /* defined in FreeRTOSConfig.h */.
- The order of execution of tasks depends on this priority. The scheduler activates the task that has the highest priority of all tasks in the READY state.
- A Task with higher priority can preempt the running task if `configUSE_PREEMPTION = 1` /* defined in FreeRTOSConfig.h */

| Priority name | Value | Comment |
|---|---|---|
| osPriorityIdle | -3 | priority: idle (lowest) |
| osPriorityLow | -2 | priority: low |
| osPriorityBelowNormal | -1 | priority: below normal |
| osPriorityNormal | 0 | priority: normal (default) |
| osPriorityAboveNormal | 1 | priority: above normal |
| osPriorityHigh | 2 | priority: high |
| osPriorityRealtime | 3 | priority: realtime (highest) |
| osPriorityError | 0x84 | system cannot determine priority or thread has illegal priority |




*Task priority and execution order*

# 8. Task context switching

The process of saving the context of a task that is being suspended and restoring the context of a task being resumed is called context switching.

There are two 2 triggers that cause context switching:

1. **SysTick interrupt** This interrupt is used as a periodical signal to check if system needs to switch to another task.
    - The interrupt causes `xPortSysTickHandler()` run
    - `xPortSysTickHandler()` will:
        - blocks all interrupts (as its own priority is the lowest one) using `portDISABLE_INTERRUPTS()`
        - activates the PendSV bit to trigger `xPortPendSVHandler()` :
            - calls to `vTaskSwitchContext()` function which selects the highest priority task in the READY List using the macro `taskSELECT_HIGHEST_PRIORITY_TASK()`
        - unblocks all interrupts using `portENABLE_INTERRUPT()`
2. **Task yield** When a task has done its work, it can trigger a context switching by send a yield by calling to `portYIELD()` which will set the PendSV bit to trigger `xPortPendSVHandler()` and start the scheduler (see above sequence).

    Here are some cases that a task yield is called:

    - The idle task is done its internal task, it calls to `taskYIELD()`
    - When a task is in the block state, such as it has a delay or delayUntil function call, using `portYIELD_WITHIN_API()`
    - When an interrupt unblocks a task using `portYIELD_FROM_ISR()`

# 9. Lab 0: Tasks

Star a new project with FreeRTOS included in STM32CubeIDE. Refer to the Lab: Overview.

At this time, tasks will be added manually in code, without using the code generation in CubeMX. This project can be targeted on any MCU which has enough RAM to hold FreeRTOS.

Here are the settings needed for the lab:

1. HAL Timebase is assigned to a general timer, let FreeRTOS use the SysTick
2. UART1 is enabled for printing debug information, note the pinout.
3. Select CMSIS_OS version 2, and use default FreeRTOS settings

## 9.1. Enable UART redirection

It is useful to print out debug information, and to make it easier, UART redirection will be used. In this lab, it can be implemented in a minimal method by overriding the low-level `_write` function in the main file. Inside this function, a blocking call will be used to make sure all data is written in multi-thread. The correct method of synchronization will be discussed later.

main.c

```
int _write(int file, char *ptr, int len) {
    // block write to UART if it is not ready
    while(HAL_UART_GetState(&huart1) != HAL_UART_STATE_READY);

    HAL_StatusTypeDef hstatus;
    hstatus = HAL_UART_Transmit(&huart1, (uint8_t*) ptr, len,
                                HAL_MAX_DELAY);
    if (hstatus == HAL_OK) {
        return len;
    } else {
        return 0;
    }
}
```

## 9.2. Add 2 Tasks

Define two tasks in the main file. At this moment, two tasks will have the same priority as `osPriorityNormal` level. There is a `delay` param will be sent to the Task Function.

main.c

```
osThreadId_t Task1_Handle;
const osThreadAttr_t Task1_attributes = {
  .name = "Task1",
  .stack_size = 128 * 4,
  .priority = (osPriority_t) osPriorityNormal,
};
uint32_t Task1_delay = 500;

osThreadId_t Task2_Handle;
const osThreadAttr_t Task2_attributes = {
  .name = "Task2",
  .stack_size = 128 * 4,
  .priority = (osPriority_t) osPriorityNormal,
};
uint32_t Task2_delay = 1000;
```

These two tasks will print out a sequence of number by using the same task `CounterTask()` which gets delay time from its task function's parameter:

**HAL_Delay()**

At the beginning of this lab, `HAL_Delay()` function is used to simulate a heavy work which is consuming CPU. Scheduler will never put these tasks to the Blocked state.

```
static void CounterTask(void *argument) {
  char* name = pcTaskGetName(NULL); // the current active task
  uint32_t delay = *((uint32_t*)argument);
  uint8_t counter = 0;
  printf("%s: delay=%lu\r\n", name, delay);
  // main loop
  for(;;) {
    printf("%s: counter = %u\r\n", name, counter++);
    HAL_Delay(delay);
  }
}
```

In the main function, create two tasks using the `CounterTask()` function with different delay params. Note that the pointer pointing to the `int` param is converted to a `void*` pointer.

```
int main(void) {
    // Hardware init
    HAL_Init();
    SystemClock_Config();
    MX_GPIO_Init();
    MX_USART1_UART_Init();

    // FreeRTOS Init
    osKernelInitialize();

    // Add Tasks
    Task1_Handle = osThreadNew(CounterTask, (void*)&Task1_delay,
&Task1_attributes);
    Task2_Handle = osThreadNew(CounterTask, (void*)&Task2_delay,
&Task2_attributes);

    //Start scheduler
    osKernelStart();
}
```

## 9.3. Build and Run

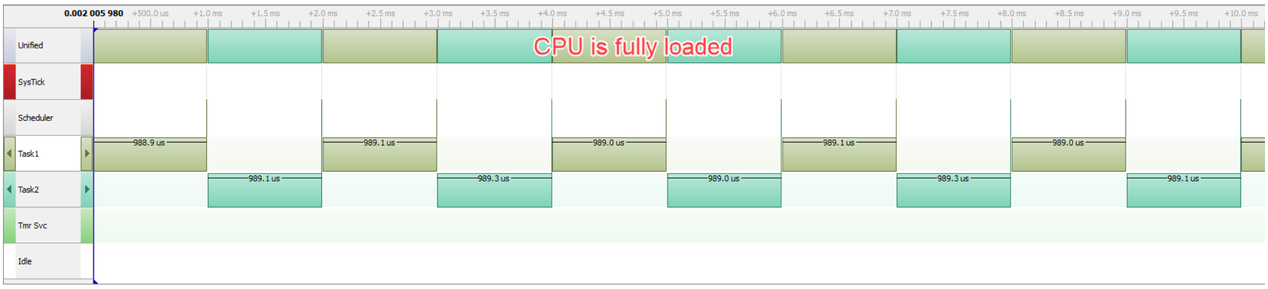
Compile the project and connect the UART1 to PC, and check the result:

- At startup, tasks print out their name and delay to confirm the attributes and params
- Both tasks run and print their counter value
- Task 1 has a smaller delay (500 ms) so it prints out faster than Task 2

```
FreeRTOS Tasks
Task2: delay=1000
Task2: counter = 0
Task1: delay=500
Task1: counter = 0
Task1: counter = 1
Task2: counter = 1
Task1: counter = 2
Task1: counter = 3
Task2: counter = 2
Task1: counter = 4
Task1: counter = 5
Task2: counter = 3
Task1: counter = 6
```

*Two tasks are printing*

Note that, because two tasks have the same priority, they will be switched at every SysTick interruption (about 1 ms). Both tasks use `HAL_Delay()` which in fact consume




*Two tasks have the same priority*

## 9.4. Change Priority

Let change one of two task to use `osPriorityHigh` priority, and see how system works after that modification.

The result is only high priority task can run because higher priory are requesting to use CPU all the time.

```
const osThreadAttr_t Task1_attributes
= {
.name = "Task1",
.stack_size = 128 * 4,
.priority = (osPriority_t)
osPriorityHigh,
}
```

```
const osThreadAttr_t Task2_attributes
= {
.name = "Task2",
.stack_size = 128 * 4,
.priority = (osPriority_t)
osPriorityHigh,
}
```

```
FreeRTOS Tasks
Task1: delay=500
Task1: counter = 0
Task1: counter = 1
Task1: counter = 2
Task1: counter = 3
Task1: counter = 4
```

*Only Task 1 with High Priority is running*

```
FreeRTOS Tasks
Task2: delay=1000
Task2: counter = 0
Task2: counter = 1
Task2: counter = 2
Task2: counter = 3
Task2: counter = 4
```

*Only Task 2 with High Priority is running*

**Change priority in runtime**

There are two functions to get and set task priority in runtime:

- The function `osThreadGetPriority()` calls `uxTaskPriorityGet()` or `uxTaskPriorityGetFromISR()` defined in `tasks.c` file
- The function `osThreadSetPriority()` calls `vTaskPrioritySet()` defined in `tasks.c` file. After setting new priority, this function also trigger the task scheduler to re-arrange tasks in the scheduled lists.

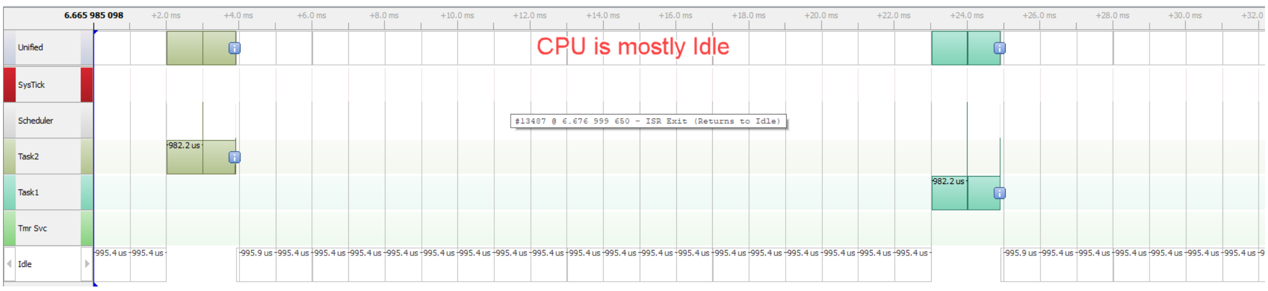
Two these functions must be enabled in **Include definitions** settings of FreeRTOS.

## 9.5. Use OS Delay

Keep one task in high priority, how to run both tasks? The key of RTOS scheduler is whenever a task is not working, it can be moved to block state and other task, even in lower priority, can run.

```
static void CounterTask(void *argument) {
  char* name = pcTaskGetName(NULL); // the current active task
  uint32_t delay = *((uint32_t*)argument);
  uint8_t counter = 0;
  printf("%s: delay=%lu\r\n", name, delay);
  // main loop
  for(;;) {
    printf("%s: counter = %u\r\n", name, counter++);
    osDelay(delay); // 1 tick = 1 ms
  }
}
```

Here is the CPU load while using `osDelay()` . CPU is only busy when it prints out on UART, and move to IDLE state in which CPU does nothing and waits for SysTick interruption. This is much effective way to lower power consumption.




*CPU is in Idle when both tasks are in delay*

There are some more functions related to delay:

- `osDelayUntil()` which calls to `vTaskDelayUntil()`
- `osAbortDelay()` which calls to `xTaskAbortDelay()`

The function `osDelay()` calls to `vTaskDelay()` function defined in `tasks.c` file to do below actions:

1. Calls `vTaskSuspendAll()` to pause the scheduler without disabling interrupts. RTOS tick will be held pending until the scheduler has been resumed.
2. Remove task from event list (running tasks) and move it to delayed list with given delay value using the function `prvAddCurrentTaskToDelayedList()`
3. Resume the scheduler using `xTaskResumeAll()` function
4. Trigger `PendSV` interrupt (using `portYIELD_WITHIN_API()` macro) to switch the context

# 10. Other Tasks functions

**Suspend and Resume**

A task can be put into Suspended State by calling to `osThreadSuspend()` which calls to `vTaskSuspend()` function. To resume a task, call to `osThreadResume()` function which actually calls to either `vTaskResume()` or `xTaskResumeFromISR()` function.

**Terminate a task**

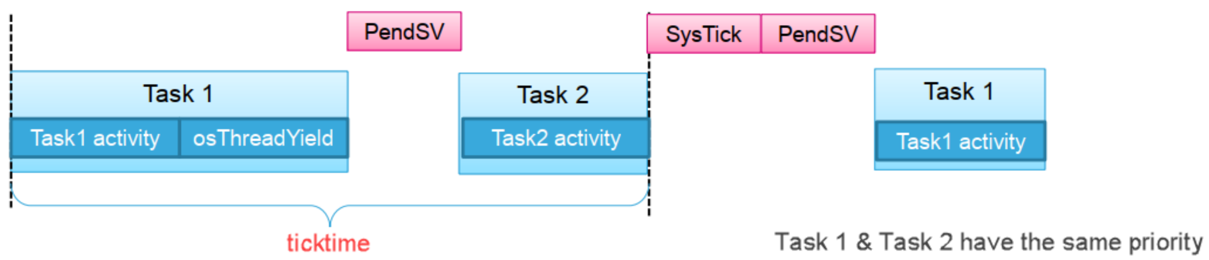
Call to `osThreadTerminate()` function which indeed calls to `vTaskDelete()` defined in `task.c` file:

1. Remove the task from the ready list using `uxListRemove()` and removes the task from waiting on an event tasks list.
2. In case the task is deleting itself, this function will switch execution to the next task calling function by calling `portYIELD_WITHIN_API()`

Memory allocated by the task code is not automatically freed and should be freed before the task is deleted. TCB and its original stack are freed by the IDLE Task.

**Task Yield**

When a task has done its job, and don't want to wait for a SysTick interruption, it can yield to scheduler to trigger context switching.




*Task 1 yield*