Task Management

(slides are based on Prof. Dr. Jian-Jia Chen and http://www.freertos.org)

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Outline

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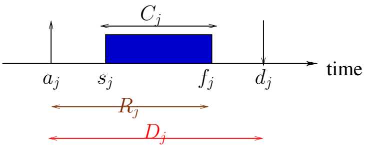
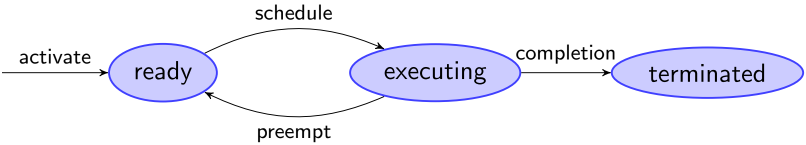
Timing parameters of a job J_j

- Arrival time (a_j) or release time (r_j) is the time at which the job becomes ready for execution
- Computation (execution) time (C_j) is the time necessary to the processor for executing the job without interruption.
- Absolute deadline (d_j) is the time at which the job should be completed.
- Relative deadline (D_j) is the time length between the arrival time and the absolute deadline.
- Start time (s_j) is the time at which the job starts its execution.
- Finishing time (f_j) is the time at which the job finishes its execution.
- Response time (R_j) is the time length at which the job finishes its execution after its arrival, which is $f_j - a_j$.



State of Jobs

- A job is either running or not running:



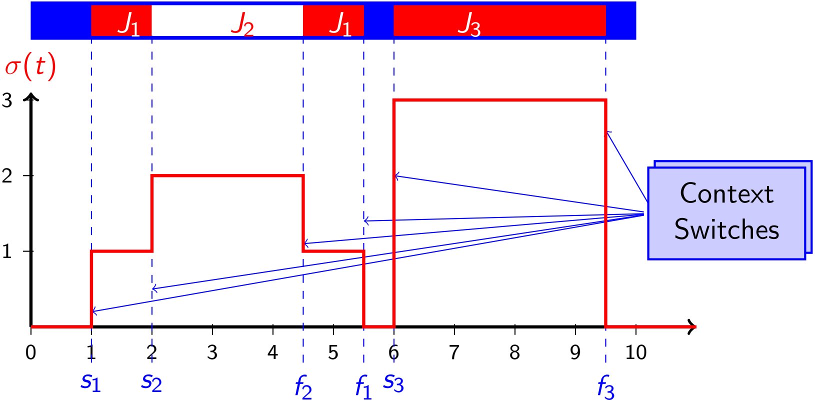
- All the jobs that are ready for executions are put into a ready queue
- A "scheduler" decides which job in the ready queue obtains the privilege of the computing resources to run

Schedules for a set of jobs $\{J_1, J_2, \ldots, J_N\}$

- A schedule is an assignment of jobs to the processor, such that each job is executed until completion.
- A schedule can be defined as an integer step function $\sigma : \mathbb{R} \rightarrow \mathbb{N}$, where $\sigma(t) = j$ denotes job J_j is executed at time t, and $\sigma(t) = 0$ denotes the system is idle at time t.
- If $\sigma(t)$ changes its value at some time t, then the processor performs a context switch at time t.
- Non-preemptive scheduling: there is only one interval with $\sigma(t) = j$ for every J_j, where t is covered by the interval.
- Preemptive scheduling: there could be more than one interval with $\sigma(t) = j$.

Scheduling Concept: Preemptive

Schedule: $\sigma : \mathbb{R} \to \mathbb{N}$ function of processor time to jobs



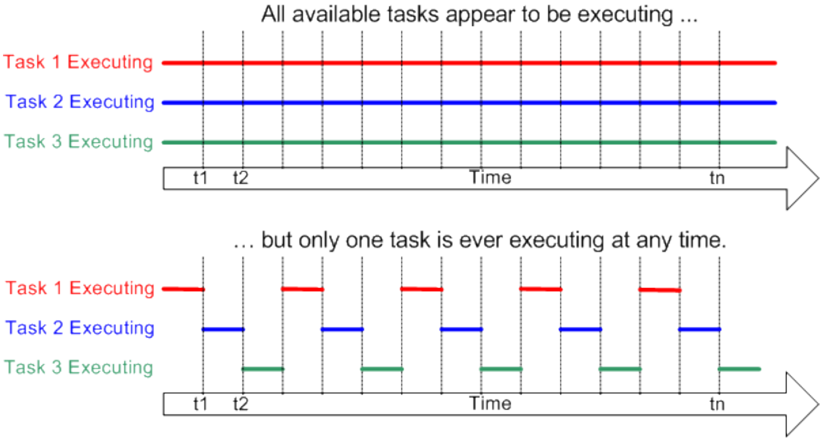
Recurrent Tasks

- When jobs (usually with the same computation requirement) are released recurrently, these jobs can be modeled by a recurrent task
- Periodic Task τ_i:
  - A job is released exactly and periodically by a period T_i
  - A phase ϕ_i indicates when the first job is released
  - A relative deadline D_i for each job from task τ_i
  - (ϕ_i, C_i, T_i, D_i) is the specification of periodic task τ_i, where C_i is the worst-case execution time.
- Sporadic Task τ_i:
  - T_i is the minimal time between any two consecutive job releases
  - A relative deadline D_i for each job from task τ_i
  - (C_i, T_i, D_i) is the specification of sporadic task τ_i, where C_i is the worst-case execution time.

Multi-Tasking

- The execution entities (tasks, processes, threads, etc.) are competing from each other for shared resources
  - In FreeRTOS, we will only use "tasks" for the rest of the whole course.
- Scheduling decision policy is needed
  - When to schedule an entity?
  - Which entity to schedule?
  - How to schedule entities?

Multi-Tasking



[http://www.freertos.org]

Outline

Introduction

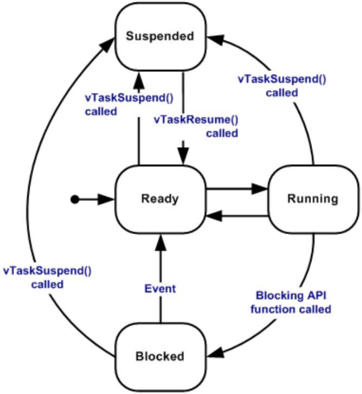
Preliminaries: FreeRTOS Start Up

Task creation and Management

FreeRTOS Scheduling

Task States

- Ready: A task that is able to execute is not currently running due to its lower priority
- Running: When a task is actually executing
- Blocked: Waiting for either a temporal or external event (Always has a timeout)
- Suspended: No timeout period allowed



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Data Types in FreeRTOS

Macro or typedef	Actual type
portCHAR	char
portSHORT	short
portLONG	long
portTickType	Used to store the tick count and specify block times
portBASE_TYPE	Used to represent the most efficient data type for the architecture

- Signed or unsigned **char** types should be always specified
- Plain **int** types should never be used

Variables and Functions Naming

- Variables: prefixes
  - 'c': for char
  - 's': for short
  - 'l': for long
  - 'x': for portBASE_TYPE and any others
  - 'u': for unsigned
  - 'p': pointer
  - combinations are possible
- Functions: prefixes
  - by the returning data type
  - 'v': for void
- Common macros:
  - pdTRUE is 1, pdFALSE is 0
  - pdPASS is 1, pdFAIL is 0

Macro prefixes

Prefix	Location
port (e.g., portMAX_DELAY)	portable.h
task (e.g., taskENTER_CRITICAL())	task.h
pd (e.g., pdTRUE)	projdefs.h
config (e.g., configUSE_PREEMPTION)	FreeRTOSConfig.h
err (e.g., errQUEUE_FULL)	projdefs.h

Configurations: FreeRTOSConfig.h

Some important fields/features:

- configUSE_PREEMPTION: This is set to 1 if the preemptive kernel is desired.
- configUSE_IDLE_HOOK: An idle task hook will execute a function during each cycle of the idle task.
- configUSE_TICK_HOOK: A tick hook function will execute on each RTOS tick interrupt if this value is set to 1.
- configTICK_RATE_HZ: This is the frequency at which the RTOS tick will operate.
- configMAX_PRIORITIES: The total number of priority levels that can be assigned when prioritizing a task.
- configUSE_COUNTING_SEMAPHORES: This is set to 1 if counting semaphores are required.
- configUSE_MUTEXES: This is set to 1 if mutexes are needed. Priority inheritance will then be enforced.
- etc...

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Structure of the Task

```c
void vATaskFunction( void *pvParameters )
    {
        for( ;; )
        {
            -- Task application code here. --
        }

        /* Tasks must not attempt to return from their implementing function or otherwise exit. If it is necessary for a task to exit then have the task call vTaskDelete( NULL ) to ensure its exit is clean. */
        vTaskDelete( NULL );
    }
```

Create A Task

```
portBASE_TYPE xTaskCreate( pdTASK_CODE pvTaskCode,
const signed portCHAR * const pcName,
unsigned portSHORT usStackDepth,
void *pvParameters,
unsigned portBASE_TYPE uxPriority,
xTaskHandle *pxCreatedTask
);
```

- calls xTaskGenericCreate((pvTaskCode), (pcName), (usStackDepth), (pvParameters), (uxPriority), (pxCreatedTask), (NULL), (NULL))
- pvTaskCode: A function that performs the computation of the task
- pcName: Name of the task used for debugging
- usStackDepth: Stack size of the process (task)
- pvParameters: Parameters passed to the process (task)
- uxPriority: Priority level indexed from 0 (lowest) to configMAX_PRIORITIES-1(highest)
- pxCreatedTask: Handler when creating a task

Create A Task (cont.)

- return value of xTaskCreate()
  - pdTRUE: the task is created successfully
  - errCOULD_NOT_ALLOCATE_REQUIRED_MEMORY: insufficient heap memory available for FreeRTOS to allocate enough RAM to hold the task data structures and stack
- All the related information of a task is stored in a task control block (TCB) so that the operating systems can use it for operating on a task.

Top of Stack	pointer to the last item place on the stack for the task
Task State	list item used to place the TCB in ready and blocked queues
Event List	list item used to place the TCB in the event lists
Priority	task priority (0=lowest)
Stack Start	pointer to the start of the process stack
Others	other information

Example - Task to be Crated

```c
/* Task to be created. */
void vTaskCode( void * pvParameters )
{
    /* The parameter value is expected to be 1 as 1 is passed in the pvParameters value in the call to xTaskCreate() below. */

    configASSERT( ( ( uint32_t ) pvParameters ) == 1 );

    for( ;; )
    {
        /* Task code goes here. */
    }
}
```

Example - Function to Create a Task

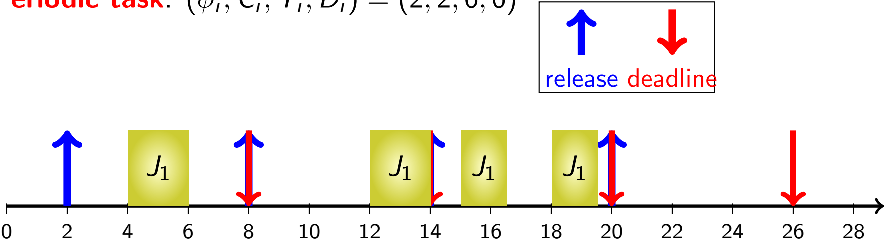
```c
/* Function that creates a task. */
void vOtherFunction( void )
{
portBASE TYPE xReturned;
xTaskHandle xHandle = NULL;
 /* Create the task, storing the handle. */
 xReturned = xTaskCreate(
  vTaskCode,       /* Function that implements the task. */
  "NAME",          /* Text name for the task. */
  1000,       /* Stack size in words, not bytes. */
  ( void * ) 1,    /* Parameter passed into the task. (if not, pass NULL) */
  1, /* Priority at which the task is created. */
  &xHandle);      /* Used to pass out the created handle of the task. (if not, pass NULL) */
```

Example - Function to Create a Task (cont.)

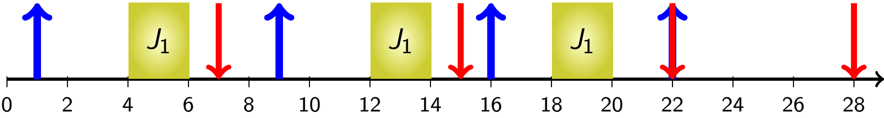
```
if( xReturned == pdPASS )
{
  /* The task was created.  Use the handle of the task to delete the task. */
  vTaskDelete( xHandle );
}
}
```

Examples of Recurrent Task Models

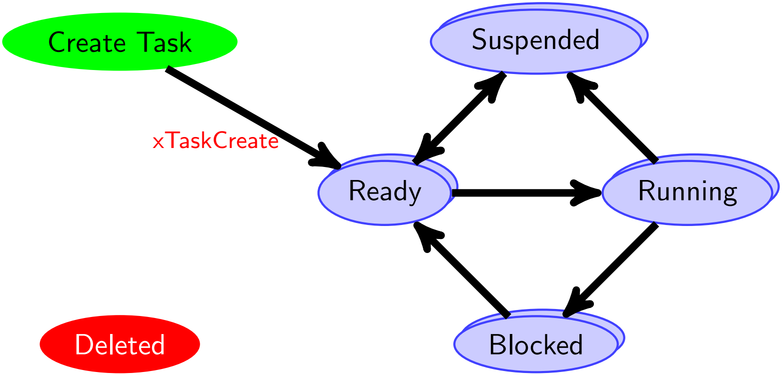
Periodic task: $(\phi_i, C_i, T_i, D_i) = (2, 2, 6, 6)$



Sporadic task: $(C_i, T_i, D_i) = (2, 6, 6)$



States of A Task



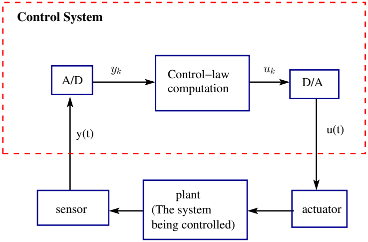
Example: Sporadic Control System

Pseudo-code for this system

while (true)

- start := get the system tick;
- perform analog-to-digital conversion to get y;
- compute control output u;
- output u and do digital-to-analog conversion;
- end := get the system tick;
- $sleepTime := T - (end - start)$;
- sleep $sleepTime$;

end while



void vTaskDelay(portTickType xTicksToDelay)

Delay a task for a given number of ticks. The actual time that the task remains blocked depends on the tick rate. The constant portTICK_RATE_MS can be used to calculate real time from the tick rate - with the resolution of one tick period.

- xTicksToDelay: The amount of time, in tick periods, that the calling task should block.
- INCLUDE_vTaskDelay must be defined as 1 for this function to be available.
- vTaskDelay() specifies a time at which the task wishes to unblock relative to the time at which vTaskDelay() is called.

Example: Periodic Control System

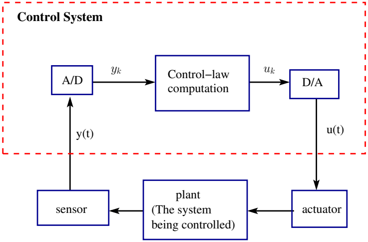
Pseudo-code for this system

set timer to interrupt periodically with period T;

at each timer interrupt
do

- perform analog-to-digital conversion to get y;
- compute control output u;
- output u and do digital-to-analog conversion;

od



void vTaskDelayUntil(portTickType *pxPreviousWakeTime, portTickType xTimeIncrement)

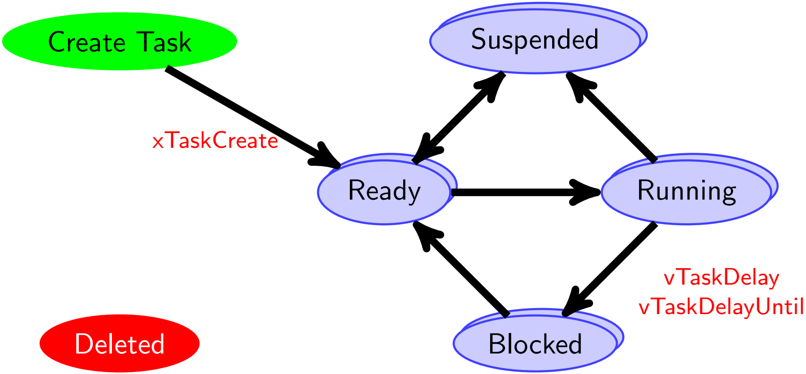
Delay a task until a specified time. This function can be used by periodic tasks to ensure a constant execution frequency (period).

- INCLUDE_vTaskDelayUntil must be defined as 1 for this function to be available.
- It differs from vTaskDelay ():
  - vTaskDelay () will cause a task to block for the specified number of ticks from the time vTaskDelay () is called.
  - It is therefore difficult to use vTaskDelay () by itself to generate a fixed execution frequency as the time between a task starting to execute and that task calling vTaskDelay () may not be fixed

An Example for vTaskDelayUntil

```
void vTaskFunction( void * pvParameters )
{
  portTickType xLastWakeTime;
  const portTickType xFrequency = 10;
  xLastWakeTime = xTaskGetTickCount ();
  for( ;; )
  {
    //do something
    vTaskDelayUntil( &xLastWakeTime, xFrequency );
  }
}
```

States of A Task



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vTaskStartScheduler()

```c
int main( void ){
  xTaskCreate(hello, "Task 1", 1000, NULL, 1, NULL );

  vTaskStartScheduler();

  for( ;; );
}
```

vTaskStartScheduler()

- Starts the real-time kernel tick processing.
- After calling, the kernel has control over which tasks are executed and when.
- This function does not return until an executing task calls vTaskEndScheduler ().
- At least one task should be created via a call to xTaskCreate () before calling vTaskStartScheduler ().
- An idle task is created automatically when the function is called.
    - It has a priority of zero (tskIDLE_PRIORITY).

Idle Task

- The processor requires something to execute, unless it is halt
- An idle task is a dummy procedure
- We can add a hook function vApplicationIdleHook() to an idle task
  - e.g., to measure the amount of processing capacity
  - e.g., to place the processor to the low-power mode
  - vApplicationIdleHook() must not, under any circumstances, call a function that might block. This will result in a scenario that no task is available to enter the Running state
- The idle task is also responsible for cleaning up the kernel resources used by a deleted task. It should be done in a reasonable amount of time.
- The idle task can be configured to be preempted
  - only at ticks (#define configIDLE_SHOULD_YIELD 0) or
  - at any time (#define configIDLE_SHOULD_YIELD 1)