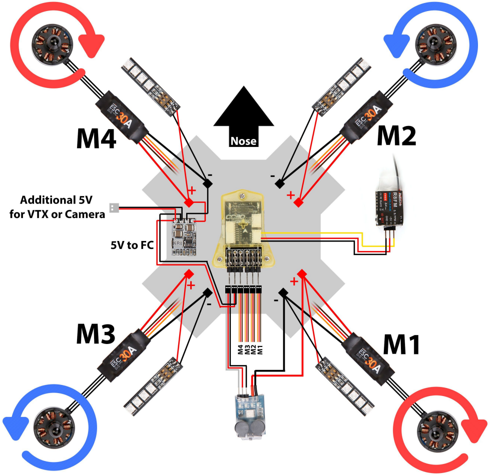
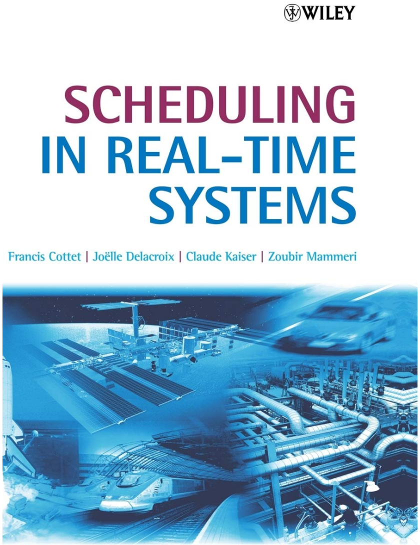


Scheduling of Dependent Tasks

Kizito NKURIKIYEYEZU, Ph.D.

Readings

- Read Chapter 3 of Cottet et al. (2002). Scheduling in Real-Time Systems.
- Topics
  - Task precedence relationships
  - Sharing critical resources
  - Mutual exclusion
  - Priority inversion
  - Deadlock



[1] Readings are based on Cottet, F., Delacroix, J., Mammeri, Z., & Kaiser, C. (2002). Scheduling in Real-Time Systems. Wiley.

Introduction

- The previous lecture assumed tasks were independent, i.e., there was no relationship between them
- This is too simplistic and does not reflect reality
- In most real-world application, inter-task cooperation and inter-task dependencies are a must
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- This is too simplistic and does not reflect reality
- In most real-world application, inter-task cooperation and inter-task dependencies are a must
  - some tasks must respect the processing order
  - mutual exclusion to protect shared resources
  - precedence constraints that correspond to synchronization or communication among tasks

Tasks with Precedence Relationships

- precedence constraint between two tasks τ_i and τ_j is denoted as $\tau_i \rightarrow \tau_j$ if the execution of task τ_i precedes that of task τ_j.
- In this case, task τ_j must await the completion of task τ_i before it can execute

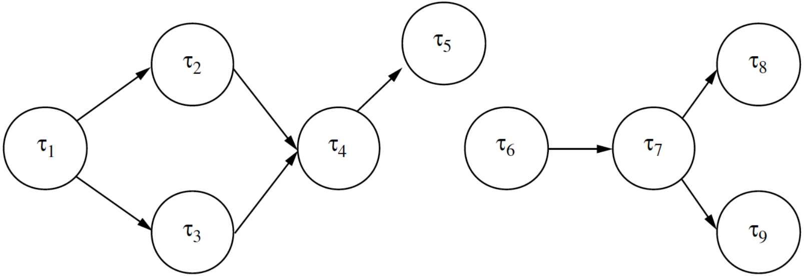

FIG 1. Example of two precedence graphs related to a set of nine tasks
The relationships is described through a graph where the nodes represent tasks and the arrows express the precedence constraint between two nodes.

Tasks with Precedence Relationships

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- Fig. 2 shows an example of a generalized precedence relationship where the rate of communicating task are not equal.

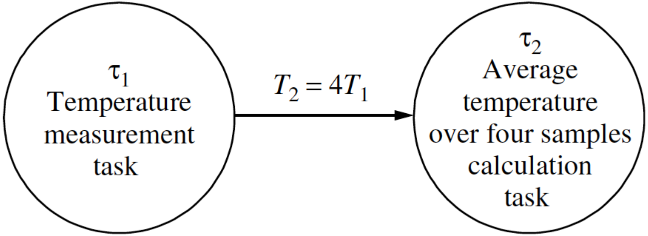

FIG 2. Example of a generalized precedence relationship between two tasks with different perio

Tasks with Precedence Relationships

Let's consider an example of in which τ_i has to communicate its results to task τ_j

- τ_i and τ_j have to be scheduled in a way that the execution of the k^{th} instance of task τ_i precedes the the execution of the k^{th} instance of the task τ_j. Thus, these task have the same rate, i.e., $T_i = T_j$

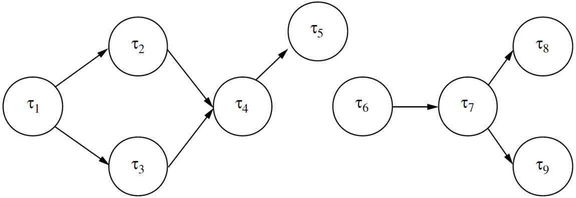

FIG 3. Example of two precedence graphs related to a set of nine tasks.
Note that tasks τ_1 to τ_5 have the same period and tasks τ_6 to τ_9 also have the same period.

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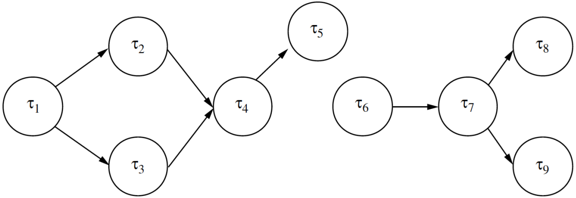
- $T_i \neq T_j$, then tasks will run at the lowest rate sooner or later; consequently, the task with the shortest period will miss its deadline[1].



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if $\tau_i \rightarrow \tau_j$, then the task parameters must be in accordance with the following rules[2]:

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Example

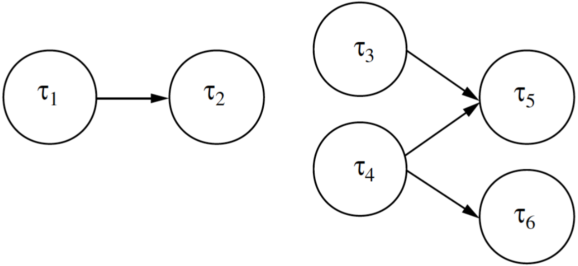

FIG 4. Precedence graphs of a set of six tasks

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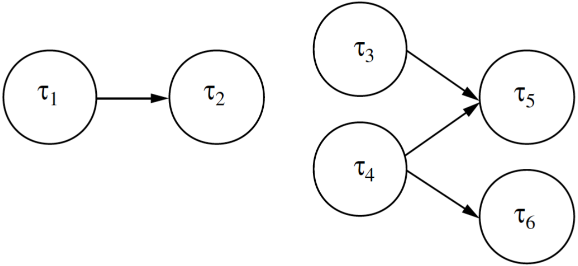

FIG 4. Precedence graphs of a set of six tasks

TAB 1. Example of priority mapping taking care of precedence constraints and using the RM scheduling algorithm

Task	τ_1	τ_2	τ_3	τ_4	τ_5	τ_6
Priority	6	5	4	3	2	1

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  - $priority_i \geq priority_j$ in accordance with the DM scheduling algorithm

Precedence constraints and the EDF algorithm

review—the earliest deadline first (EDF) algorithm assigns priority to tasks according to their absolute deadline: the task with the earliest deadline will be executed as the highest priority.

- with the EDF algorithm, the modification of task parameters relies on the deadline d.
- Rules for modifying release times and deadlines of tasks are based on the following observations[3], [4]:
  1. To get $\tau_i \rightarrow \tau_j$, the release time r_j^* of task τ_j must be greater than or equal to its initial value or to the new release times τ_i^* of its immediate predecessors τ_i increased by their execution times C_i

$$r_i^* \geq max((r_i^* + C_i), r_j) \quad (1)$$

[3] Blazewicz J. (1997), Scheduling dependent tasks with different arrival times to meet deadlines, in Beilner H. and Gelenbe E. (eds) Modeling and Performance Evaluation of Computer Systems, North Holland, Amsterdam, pp. 57–65

[4] Chetto H., Silly M. and Bouchentouf T.(1990). Dynamic scheduling of real-time tasks under

Constraints and the EDF algorithm

2. If we have to get $\tau_i \rightarrow \tau_j$, the deadline d_i^* of task τ_i has to be replaced by the minimum between its initial value d_i by the new dealine d_j^* of the immediate successors τ_j decreased by their execution times C_j :

$$d_i^* \geq min((d_j^* - C_j), d_i) \quad (2)$$

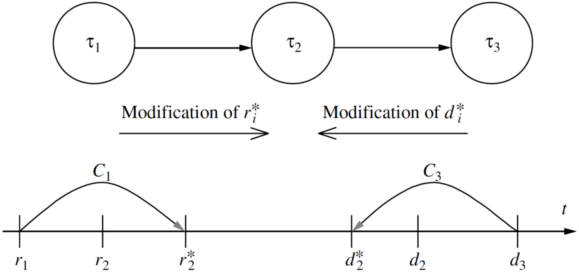

FIG 5. Modifications of task parameters in the case of EDF scheduling
The modifications begin with the tasks that have no predecessors for modifying their release times and with those with no successors for changing their deadlines. **Please see example on page 54.**

Tasks Sharing Critical Resources

Resource Sharing

- example of shared resource—data structures (e.g., queue), variables, main memory area, file, set of registers, I/O unit, etc.

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- In FreeRTOS, The taskENTER_CRITICAL() and taskEXIT_CRITICAL() provide a basic critical section implementation that works by simply disabling interrupts, either globally, or up to a specific interrupt priority level.

```

taskENTER_CRITICAL();
/* access to some exclusive resource*/
taskEXIT_CRITICAL();
```

LISTING 5: Mutual exclusion by disabling interrupts in FreeRTOS

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Resource Sharing

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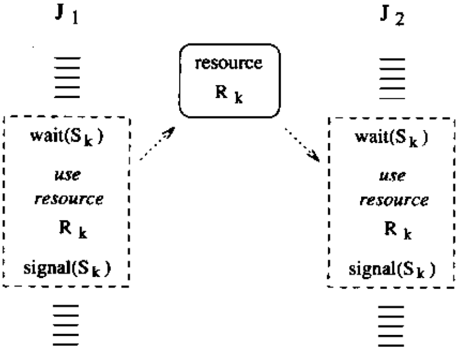

FIG 6. Two tasks sharing one resource

Resource Sharing

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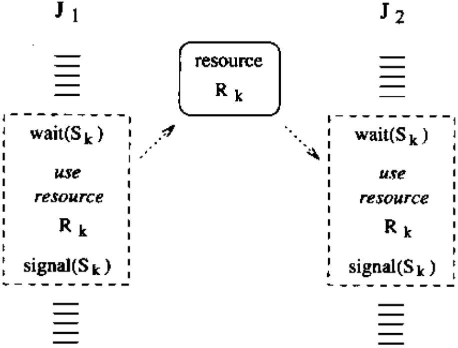
- Task J_1 is activated first and use the resource R (i.e, enters the critical section)



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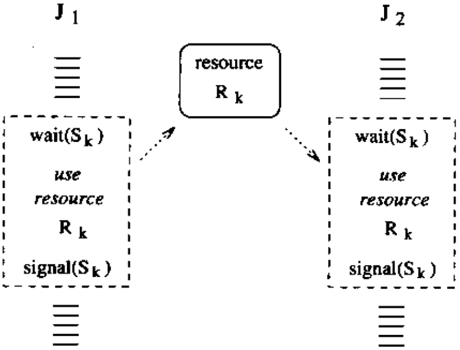

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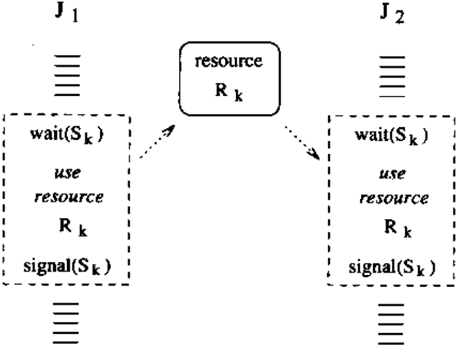

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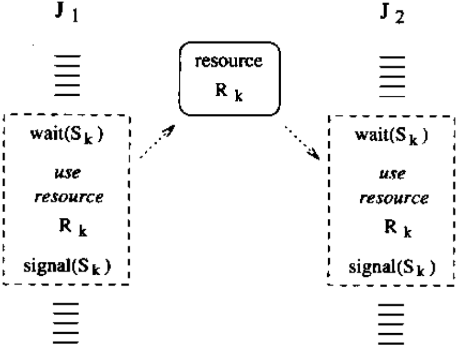
- This may lead to an uncontrolled blocking time for task J_2—which should normally run first since it has higher priority



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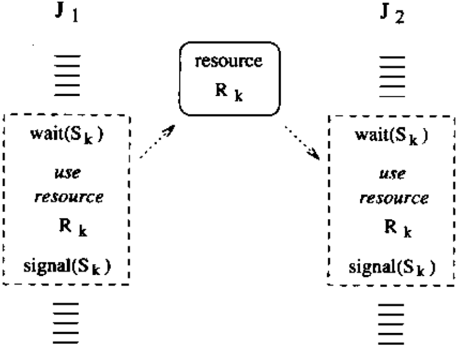
- How do we solve this?



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```
SemaphoreHandle_t xMutex
int main( void){
  xMutex = xSemaphoreCreateMutex()
  if(xMutex != NULL ){
    // Create tasks that use the mutex
  }
```

```c
void vTask1( void *pvParameters ){
  while(true){
     ...
     xSemaphoreTake(xMutex,portMAX_DELAY);
     /* access to exclusive resource */
     xSemaphoreGive(xMutex)
     ...
  }
}
void vTask2( void *pvParameters ){
  while(true){
     ...
     xSemaphoreTake(xMutex,portMAX_DELAY);
     /* access to exclusive resource */
     xSemaphoreGive(xMutex)
     ...
  }
}
```

Priority inversion

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- Priority inversion, contravenes the scheduling specification and can induce deadline missing

Priority inversion

Consider a task set composed of four tasks τ_1, τ_2,τ_3,τ_4 having decreasing priorities (i.e., τ_1 has the highest priority and τ_4 the lowest) and where Tasks τ_2 and τ_4 share a critical resource R_1, the access of which is mutually exclusive

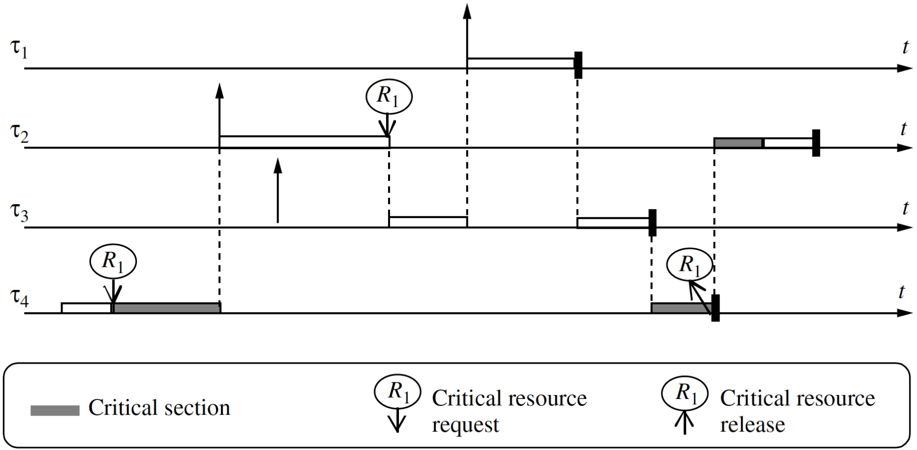

FIG 7. Example of priority inversion phenomenon

Priority inversion

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- The highest priority task able to execute is task τ_3, So task τ_3, gets the processor and runs.
- During this execution, the highest priority task τ_1 awakes. As a consequence task τ_3 is suspended and the processor is allocated to task τ_1.

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  - When there is priority inversion, the blocking time of each task cannot be bounded—this can lead to uncontrolled response time of each task.

Why this course?

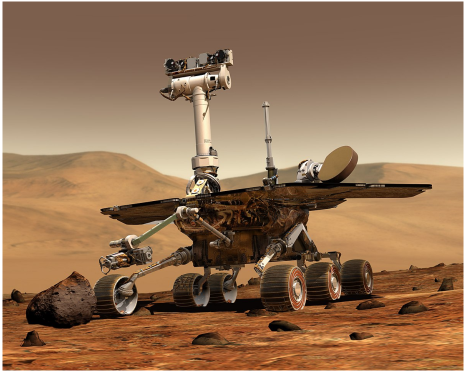

FIG 8. Artist's conception of NASA's Mars Exploration Rover on Mars. It's mission almost failed due priority inversion.

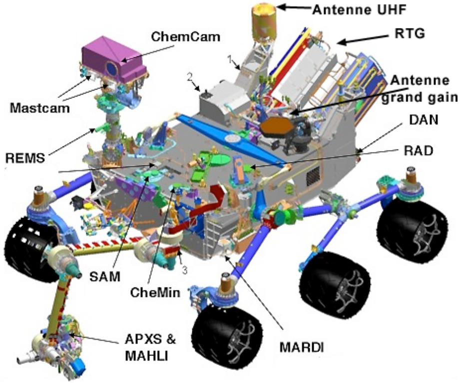

FIG 9. Instrumentation of the Mars Rover

[2] http://www.cs.cornell.edu/courses/cs614/1999sp/papers/pathfinder.html

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Solutions to Priority Inversion

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  - can lead to chain blocking[13]

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Deadlock phenomenon

summary—a situation in which two or more tasks are blocked indefinitely because each task is waiting for a resource acquired by another blocked task (Fig. 10).

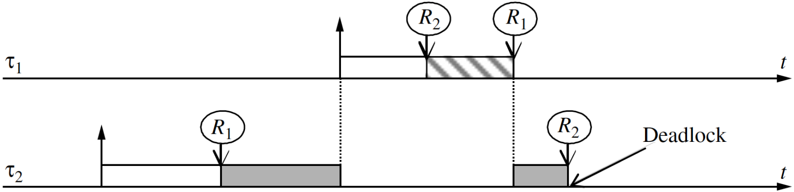

FIG 10. Example of the deadlock phenomenon

- Two tasks τ_1 and τ_1 use two critical resources R_1 and R_2.
- τ_1 and τ_2 access R_1 and R_2 in reverse order. Moreover, the priority of task τ_1 is greater than that of task τ_2.
- Now, suppose that task τ_2 executes first and locks resource R_1.

Deadlock phenomenon

- During the critical section of task τ_2 using resource R_1, task τ_1 awakes and preempts task τ_2 before it can lock the second resource R_2.

Deadlock phenomenon

- During the critical section of task τ_2 using resource R_1, task τ_1 awakes and preempts task τ_2 before it can lock the second resource R_2.
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- The final result is that task τ_2 is in possession of resource R_1 but is waiting for resource R_2 and task τ_1 is in possession of resource R_2 but is waiting for resource R_1.
- Neither task τ_1 nor task τ_2 will release the resource until its pending request is satisfied.

The end