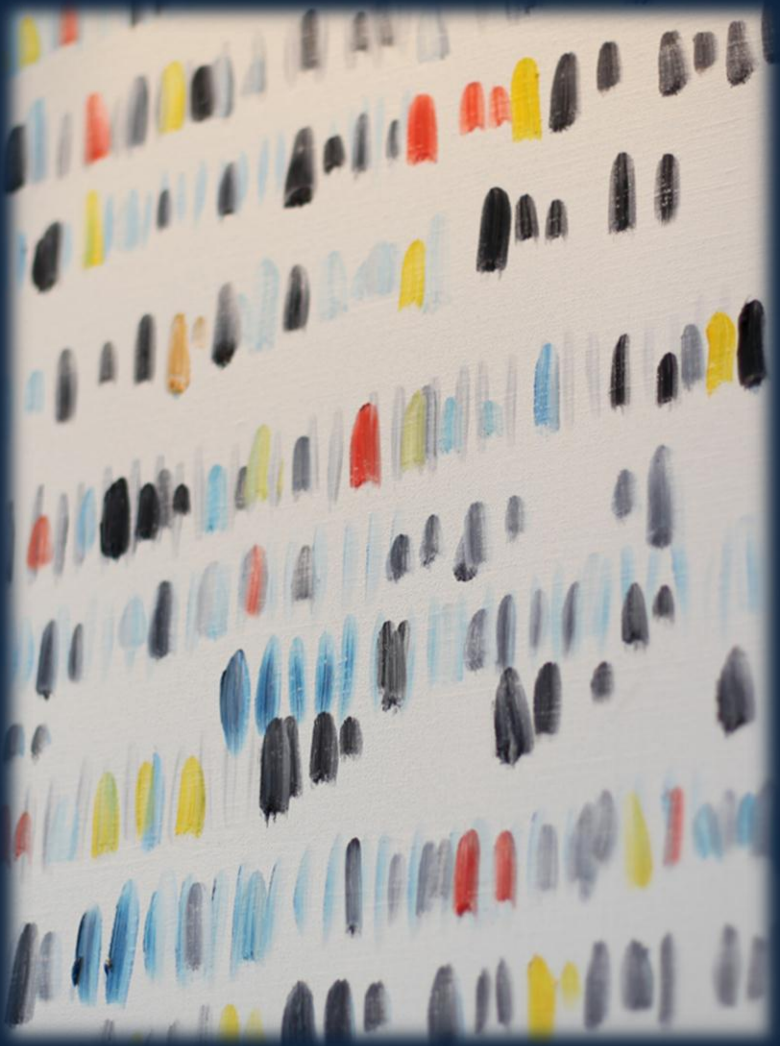


Scheduling

Jin-Soo Kim (*jinsookim@skku.edu*)
Computer Systems Laboratory
Sungkyunkwan University
http://csl.skku.edu

Basic Scheduling

Non-preemptive Scheduling

- The running task voluntarily yields the CPU
- Force everybody to cooperate

```
Thread ping ()
{
   while (1) {
      printf (“ping\n”);
      yield();
   }
}
```

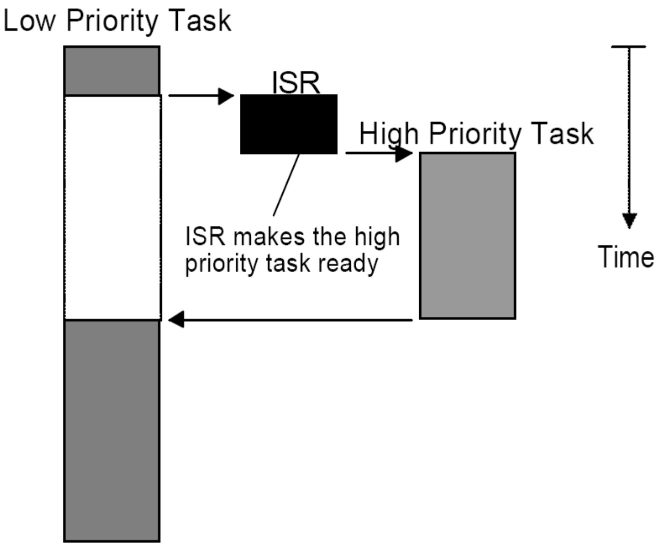
```
Thread pong ()
{
   while (1) {
      printf (“pong\n”);
      yield();
   }
}
```

Preemptive Scheduling

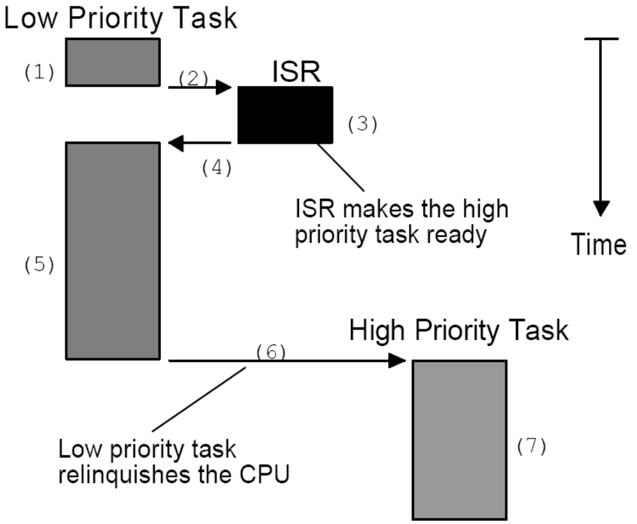
- The scheduler can interrupt a task and force a context switch
- Need to regain control of processor asynchronously → periodic timer interrupt
- At each timer interrupt, the scheduler gains control and context switches as appropriate
- Timer tick vs. quantum (or timeslice)

Comparison

Preemptive:
Always runs the highest available task.



Cooperative (Non-preemptive):
Context switches only occur if a task blocks, or explicitly relinquishes CPU control



Starvation

- A situation where a task is prevented from making progress because another task has the resource it requires
- A poor scheduling policy can cause starvation
- Synchronization can also cause starvation

Priority Scheduling (1)

- Choose task with highest priority to run next
- Round-robin or FIFO within the same priority
- Can be either preemptive or non-preemptive
- Priority is dynamically adjusted
  - Static priority vs. dynamic priority

Priority Scheduling (2)

- Starvation problem
  - If there is an endless supply of high priority tasks, no low priority task will ever run
- Aging
  - Increase priority as a function of wait time
  - Decrease priority as a function of CPU time

UNIX Schedulers

- Priority-based
  - Static priority + dynamic priority
- Preemptive
- Time-shared
- Aging
- Priority boost for I/O-bound tasks

- Priority vs. quantum?

Real-Time Scheduling

Real-Time Systems

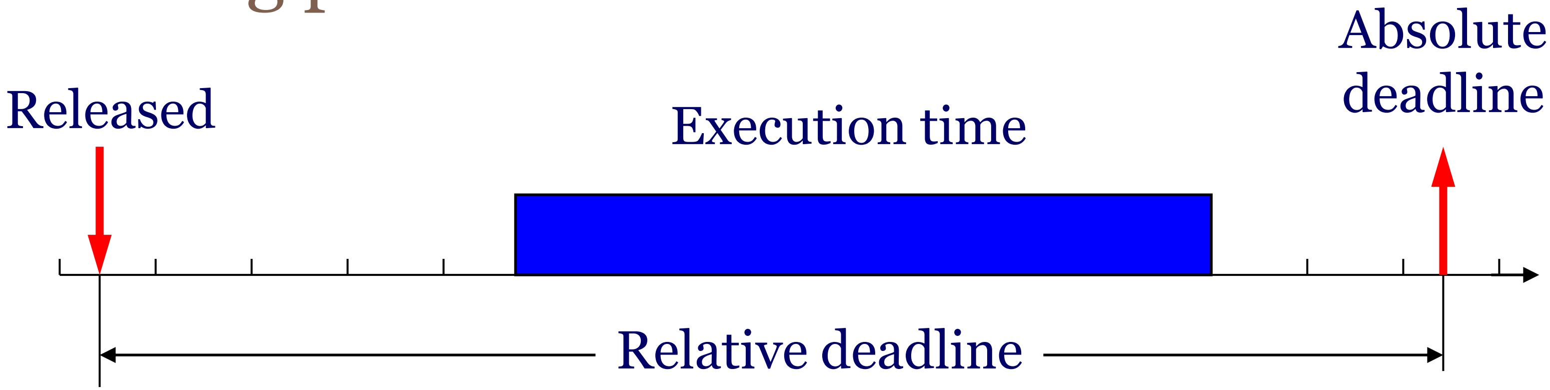
- Perform a computation to conform to external timing constraints
- Deadline frequency: periodic vs. aperiodic
- Deadline type:
  - Hard: failure to meet deadline causes system failure
  - Soft: failure to meet deadline causes degraded response (best effort, statistical guarantees)

Periodic vs. Aperiodic Tasks

- Periodic task: executes on (almost) every period
- Aperiodic task: executes on demand
- Analyzing aperiodic task sets is harder
  - Must consider worst-case combinations of task activations

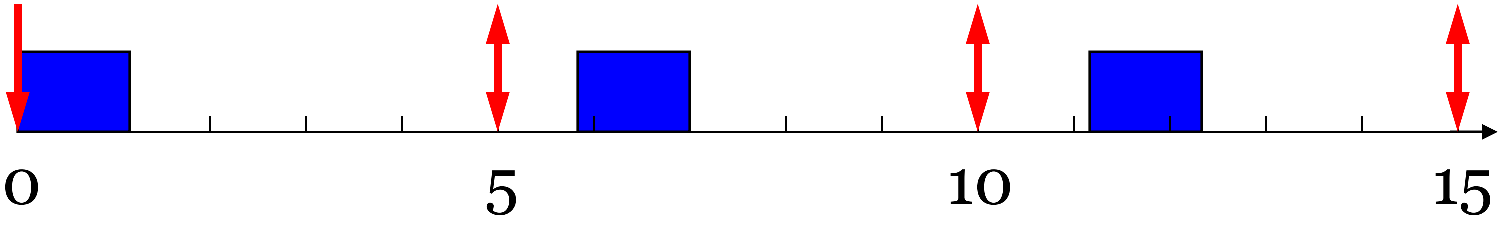
Real-Time Workload

- Job (unit of work)
  - A computation, a file read, a message transmission, etc.
- Attributes
  - Resources required to make progress
  - Timing parameters



Real-Time Task

- Task: a sequence of similar jobs
- Periodic task (p, e)
  - Its jobs repeat regularly
  - Period p = inter-release time ($0 < p$)
  - Execution time e = maximum execution time ($0 < e < p$)
  - Utilization $U = e/p$

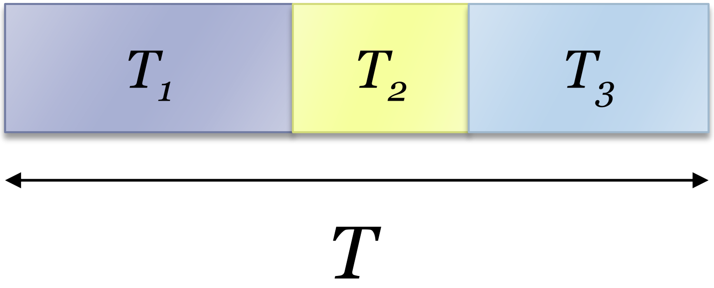


Real-Time Scheduling

- Schedulability
  - Property indicating whether a real-time system (a set of real-time tasks) can meet their deadlines
- Real-time scheduling
  - Determines the order of real-time task executions
  - Static-priority scheduling: RM
  - Dynamic-priority scheduling: EDF

Simple Feasibility Test

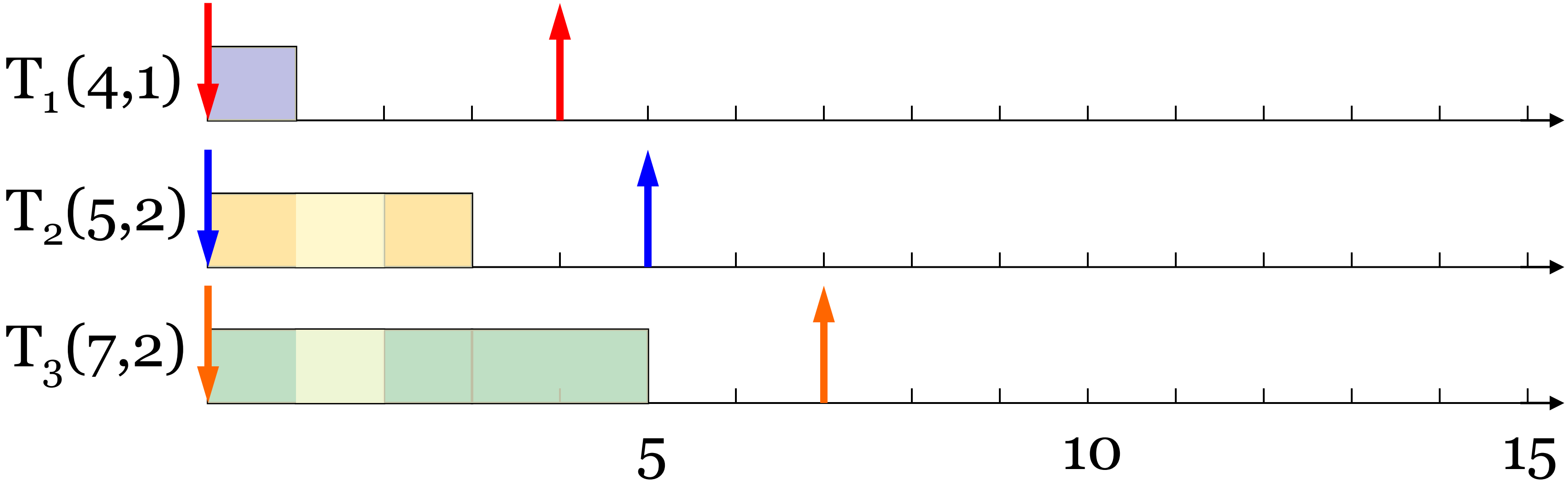
- Assume:
  - No resource conflicts
  - Constant process execution times



- Require:
  - $T \geq \sum_i T_i$
  - Can't use more than 100% of the CPU

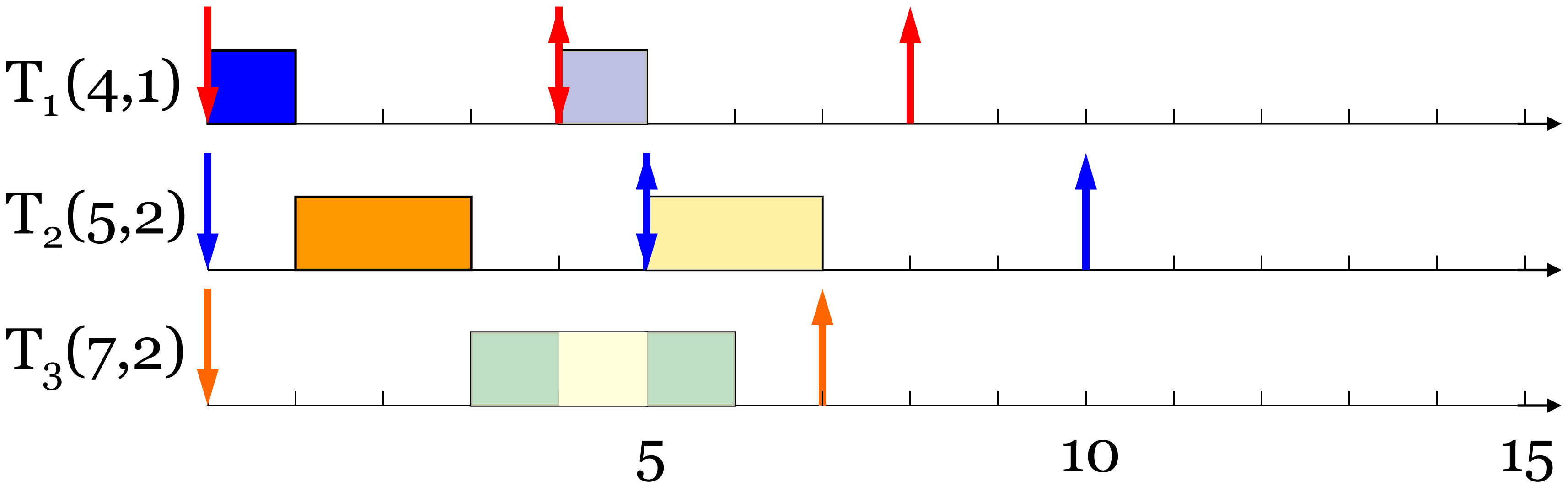
RM

- Rate Monotonic
  - Optimal static-priority scheduling
  - Assigns priority according to period
  - A task with a shorter period has a higher priority



RM

- Rate Monotonic
  - Executes a job with the shortest period



RM

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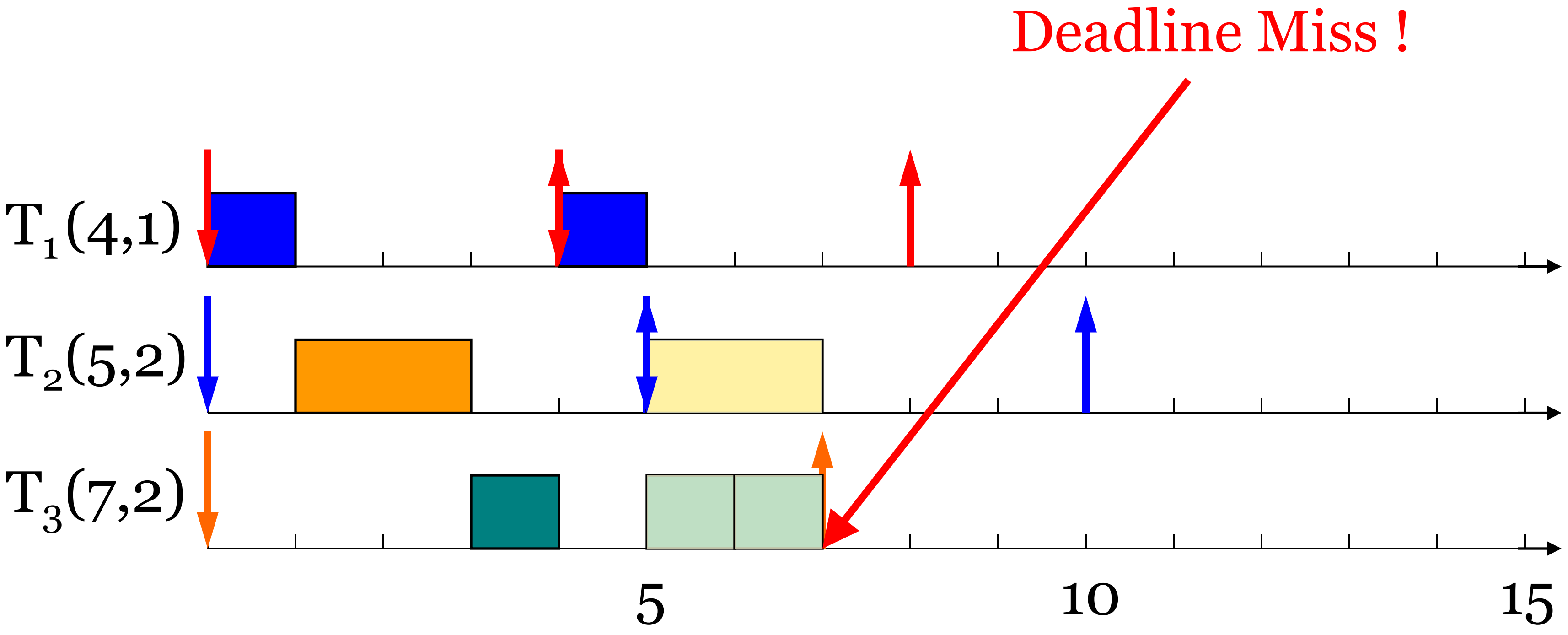


RM

- Utilization bound
  - Real-time system is schedulable under RM if

$$\sum U_i \le n(2^{1/n} - 1)$$

  - Example: $T_1(4,1)$, $T_2(5,1)$, $T_3(10,1)$

$$\sum U_i = 1/4 + 1/5 + 1/10 = 0.55$$

$$3(2^{1/3} - 1) \approx 0.78$$

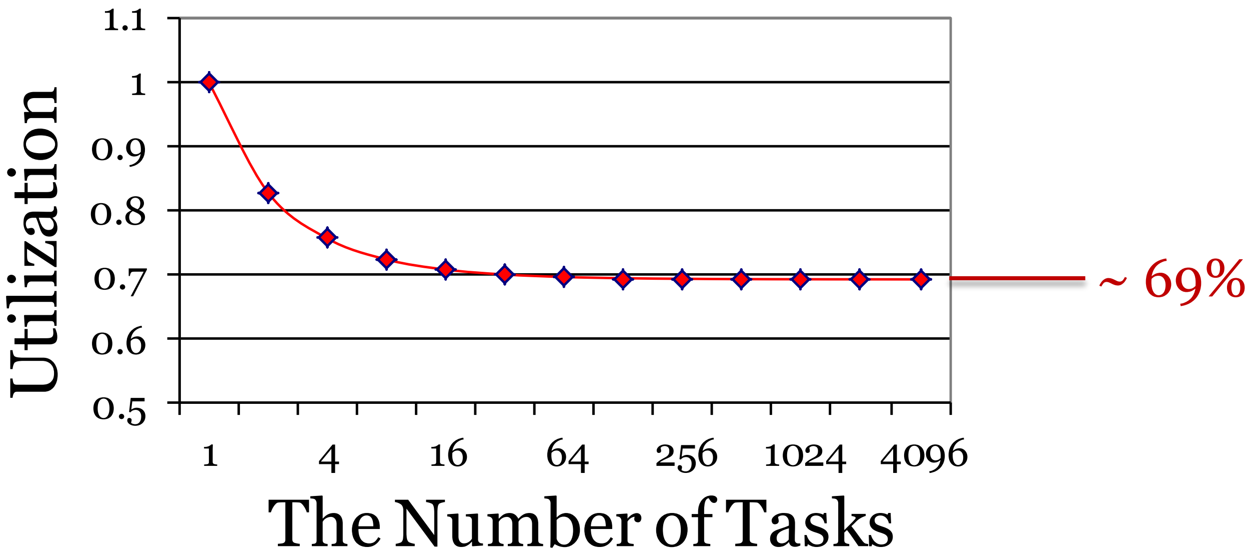
Thus, $\{T_1, T_2, T_3\}$ is schedulable under RM.

RM

- Utilization bound (cont'd)

$$\sum U_i \le n(2^{1/n} - 1)$$

RM Utilization Bounds

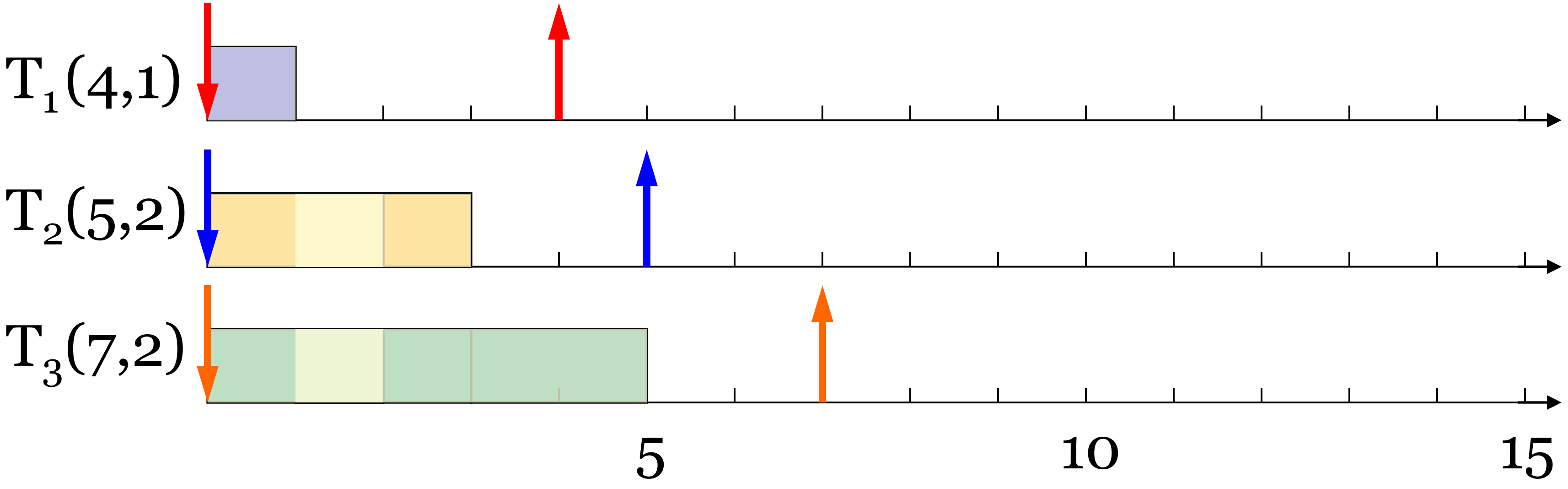


RM

- As the number of tasks approaches infinity, the maximum utilization approaches 69%
- RM cannot use 100% of CPU, even with zero context switch overhead
- Must keep idle cycles available to handle worst-case scenario
- However, RM guarantees all tasks will always meet their deadlines

EDF

- Earliest Deadline First
  - Optimal dynamic priority scheduling
  - Task with a shorter deadline has higher priority
  - Executes a job with the earliest deadline



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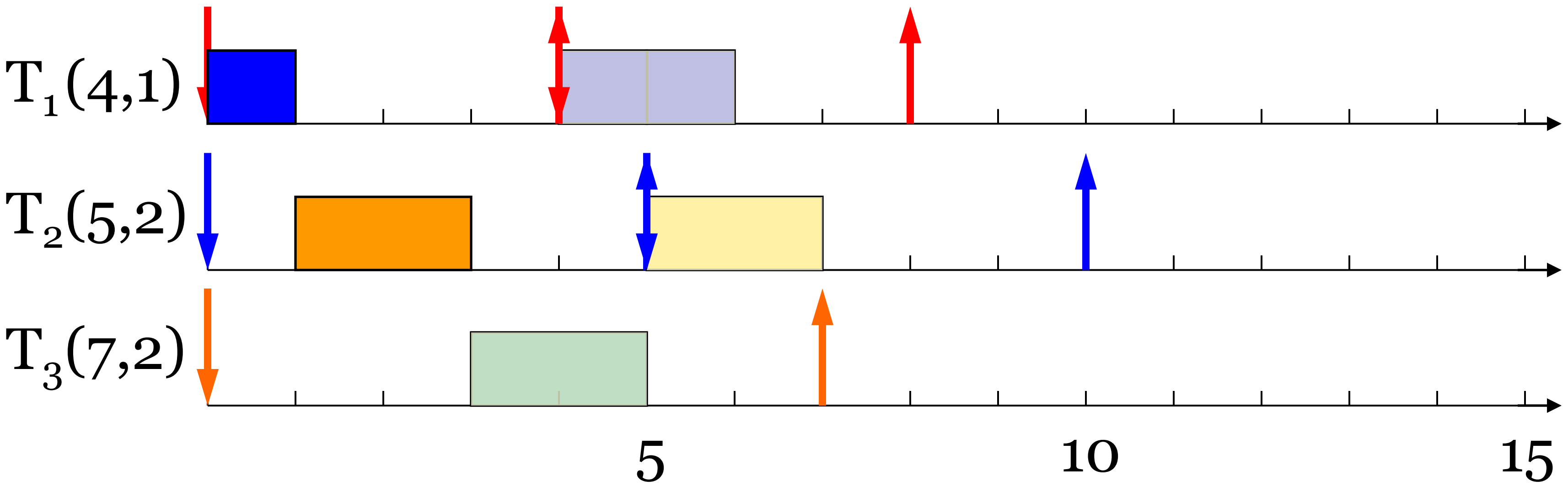

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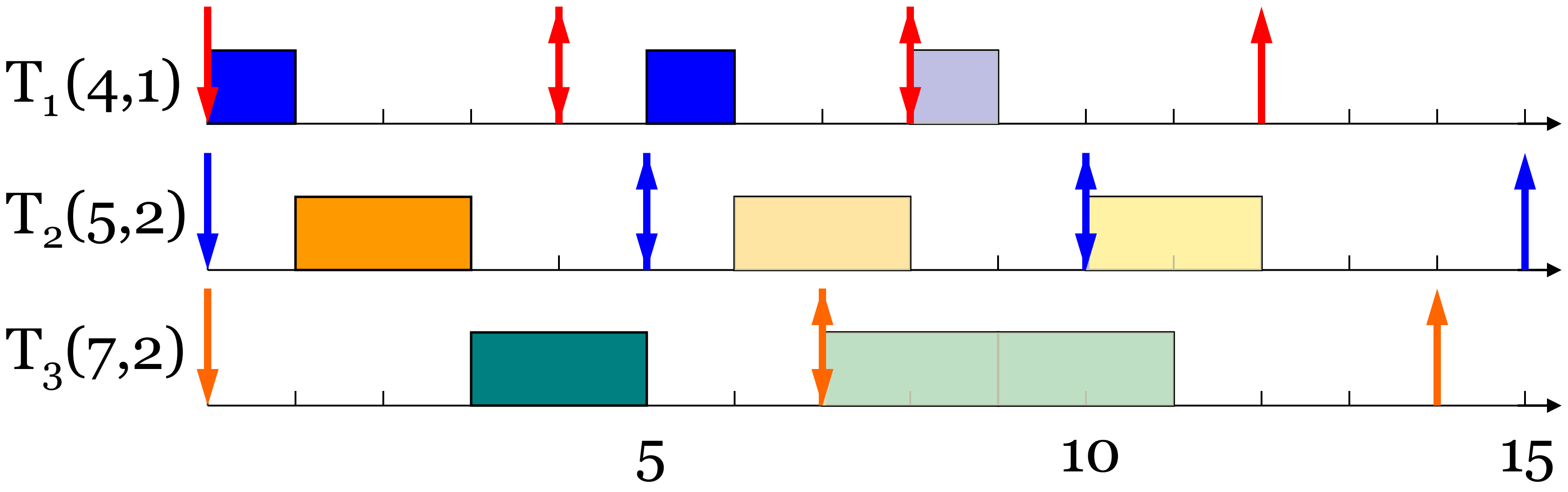

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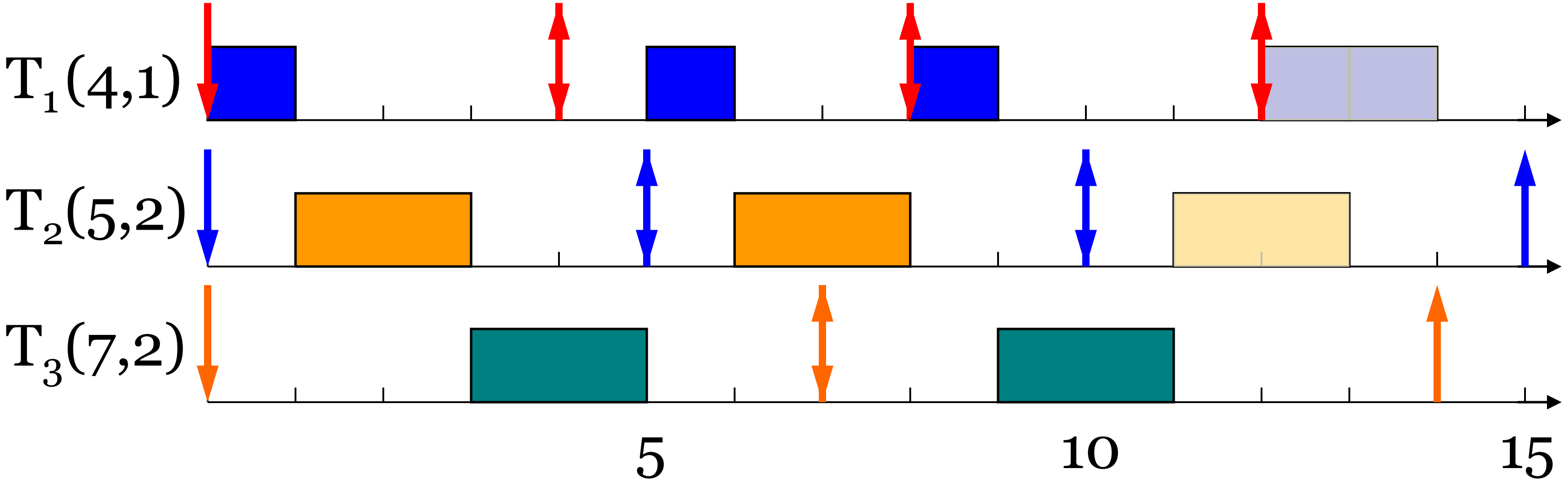
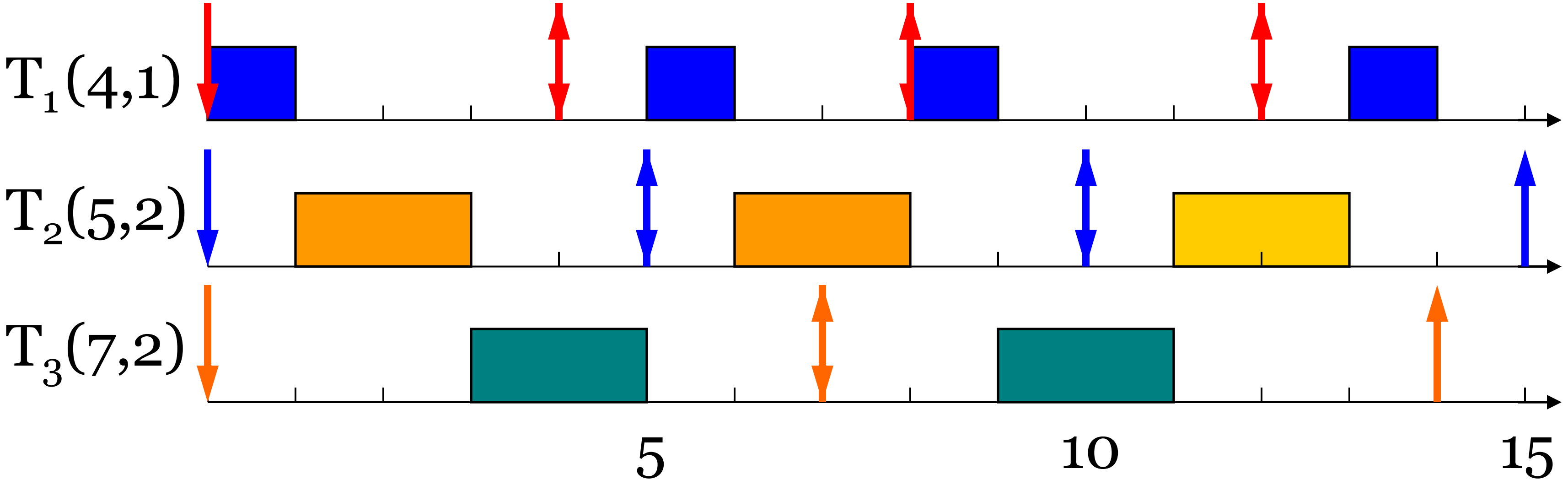


EDF

- Optimal scheduling algorithm
  - If there is a schedule for a set of real-time tasks, EDF can schedule it



EDF

- Utilization bound
  - Real-time system is schedulable under EDF if and only if

$$\sum U_i \leq 1$$

(cf) Liu & Layland, "Scheduling algorithms for multi-programming in a hard-real-time environment," *Journal of ACM*, 1973.

RM vs. EDF (1)

- Rate Monotonic
  - Simpler implementation, even in systems without explicit support for timing constraints
  - Predictability for the highest priority tasks
- EDF
  - Full processor utilization
  - Implementation complexity and runtime overhead due to dynamic priority management
  - Misbehavior during overload conditions

RM vs. EDF (2)

- Assumptions
  - All tasks are periodic and fully preemptible
  - All tasks are released at the beginning of period and have a deadline equal to their period
  - All tasks are independent
  - All tasks have a fixed computation time
  - No task may voluntarily suspend itself
  - All overheads are assumed to be 0
  - There is just one processor