Real-Time Systems

Lecture 5

Fixed Priority Scheduling

- Fixed-priority online scheduling
- Rate-Monotonic scheduling
  - The CPU utilization bound
- Deadline-Monotonic and arbitrary priorities
  – Worst-Case Response-Time analysis

Last lecture (4)

<u>Task scheduling basics</u>

- The concept of temporal complexity
- Definition of schedule and scheduling algorithm
- Some basic scheduling techniques (EDD, EDF, BB)
- The static cyclic scheduling technique

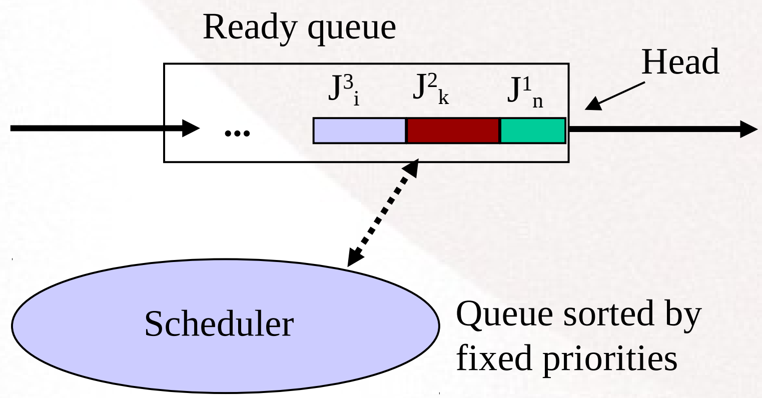
Online scheduling with fixed priorities

The schedule is **built** while the system is **operating normally** (online) and is based in a **static criterium** (priority)

The **ready queue** is sorted by **decreasing priorities**. Executes first the task with highest priority.

If the system is preemptive, whenever a task job **arrives** to the ready queue, if it has **higher priority** than the one currently executing, it **starts executing** while the latter one is moved to the ready queue

Complexity: **O(n)**



Online scheduling with fixed priorities

- **Pros**
  - Scales
  - Changes on the task set are immediately taken into account by the scheduler
  - Sporadic tasks are easily accommodated
  - Deterministic behavior on overloads
    - Tasks are affected by priority level (lower priority are the first ones)
- **Cons**
  - More complex implementation
  - Requires a kernel with support to fixed priorities
  - Higher execution overhead (scheduler + dispatcher)
  - Overloads (e.g. due to programming errors or unpredicted events) at higher priority tasks may **block** the execution of **lower priority** ones

Online scheduling with fixed priorities

Priority assignment to tasks

- Inversely proportional to period (***RM – Rate Monotonic***)

  Optimal among fixed priority scheduling criteria

- Inversely proportional to *deadline* (***DM – Deadline Monotonic***)

  Optimal if D<=T

- **Proportional** to the **task importance**
  Typically reduces the schedulability – **not optimal**

Online scheduling with fixed priorities

Schedulability tests

As the schedule is built online it is fundamental to know a *priori if* a given task set is schedulable (i.e., its temporal requirements are met)

There are two types of schedulability tests:

- Based on **CPU utilization rate**
- Based on **response time**

RM Scheduling

<u>**Schedulability tests for RM based on task utilization**</u>

(with preemption, *n independent tasks,* D=T)

- Liu&Layland's (1973) **Least Upper Bound**

$$U(n)=\sum_{i=1}^{n}\frac{C_i}{T_i}\leqslant n\left(2^{\frac{1}{n}}-1\right)$$ **=> One activation per period guaranteed**

- Bini&Buttazzo&Buttazzo's (2001) **Hyperbolic Bound**

$$\prod_{i=1}^{n}\left(\frac{C_i}{T_i}+1\right)\leqslant 2$$ **=> One activation per period guaranteed**

RM Scheduling

Interpretation of the Liu&Layland test

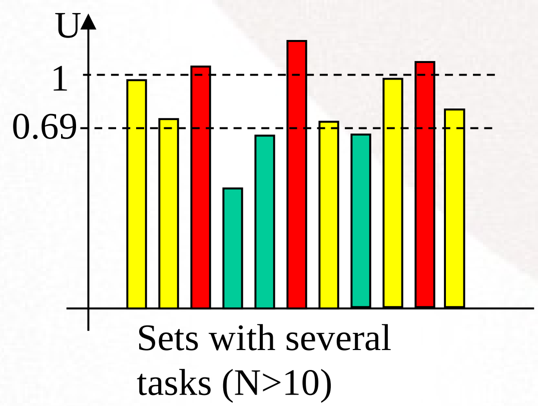
U(n) > 1 ⇒ task set not schedulable (*overload*) – **necessary condition**

U(n) ≤ Bound ⇒ task set is schedulable – **sufficient condition**

1 ≥ U(n) > Bound ⇒ test is indeterminate

Liu&Layland

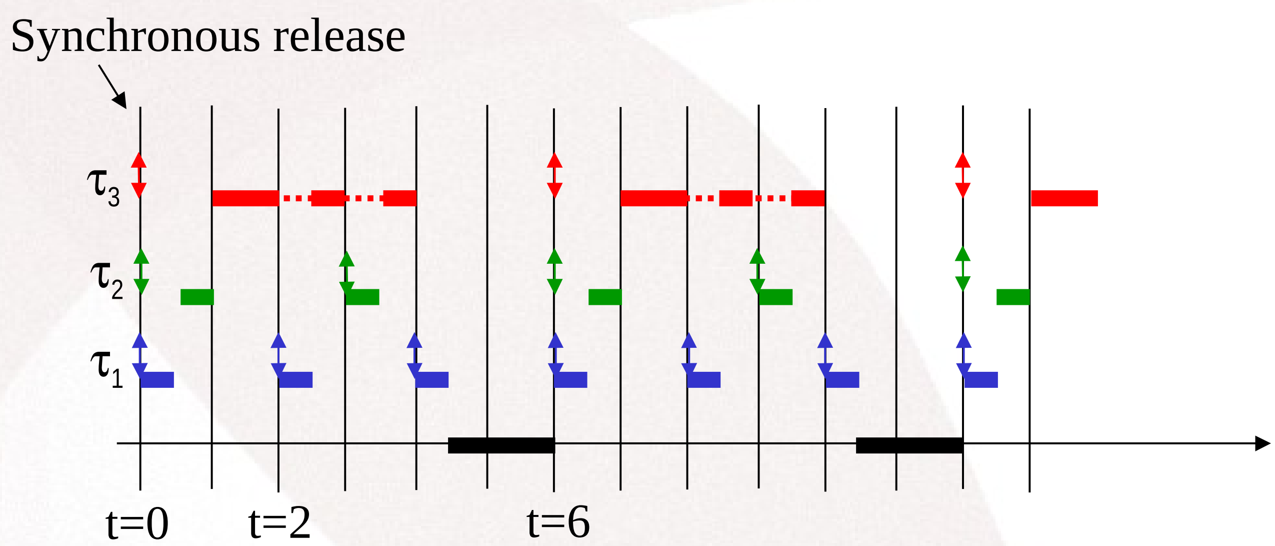
U(1) ≤ 1
U(2) ≤ 0.83
U(3) ≤ 0.78
...
U(∞) ≤ ln(2) ≈ 0.69



RM Scheduling – example 1

Task properties

τ_i	T_i	C_i
1	2	0.5
2	3	0.5
3	6	2



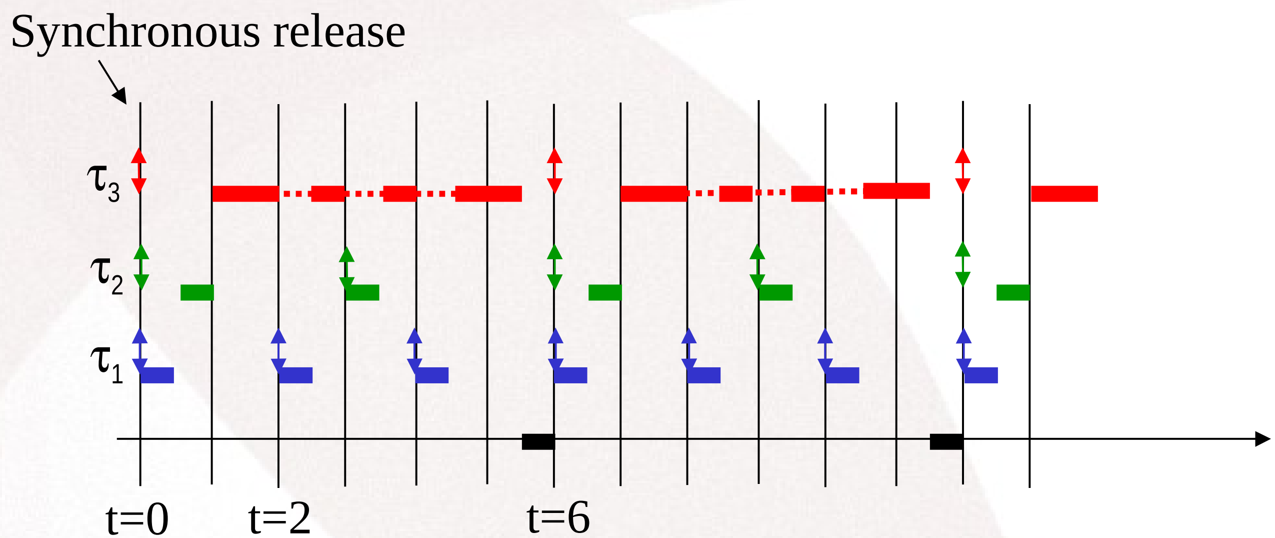
U = 0.5/2 + 0.5/3 + 2/6

U = **0.75 < 0.78** $\Rightarrow$ **1 activation per period is guaranteed**

RM Scheduling – example 2

Task properties

τ_i	T_i	C_i
1	2	0.5
2	3	0.5
3	6	**3**

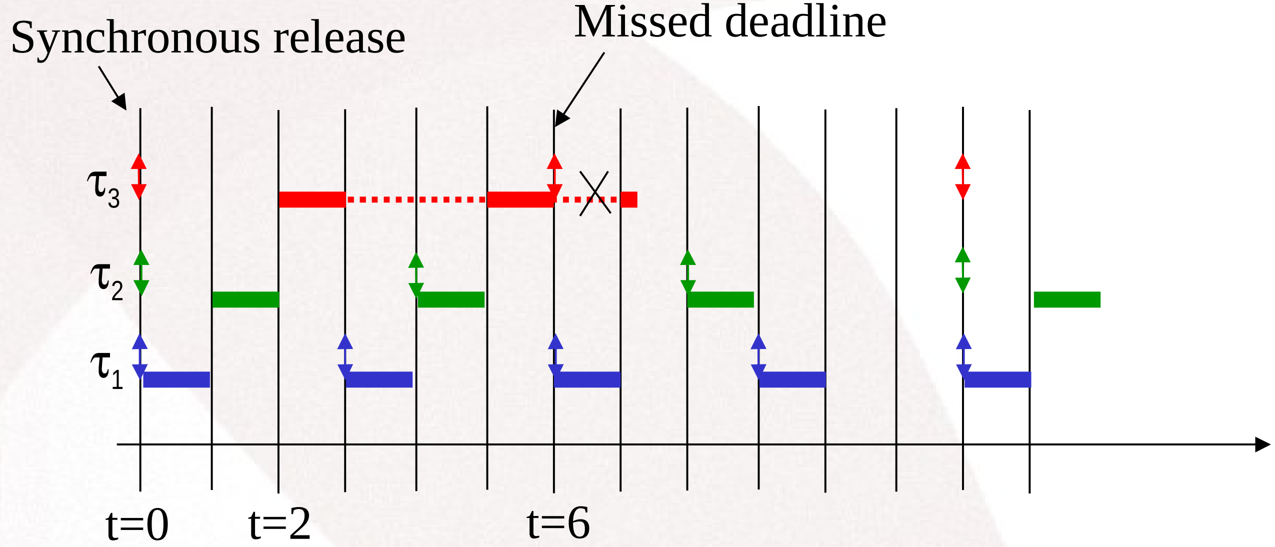


U = 0.5/2 + 0.5/3 + 3/6 = **0.92 > 0.78** $\Rightarrow$ **1 activation per period is not guaranteed. However it is feasible**

RM Scheduling – example 3

Task properties

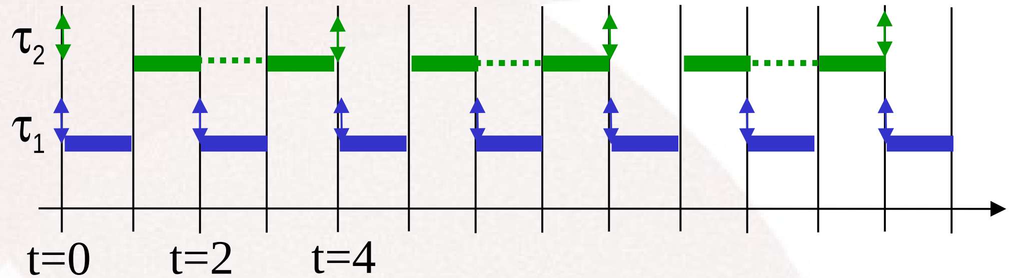
τ_i	T_i	C_i
1	**3**	**1**
2	**4**	**1**
3	6	**2.1**



U = 1/3 + 1/4 + 2.1/6 = **0.93 > 0.78** => **1 activation per period not guaranteed, with deadline miss by τ_3**

RM Scheduling – particular case

U = 1/2 + 2/4 = **1**



Harmonic periods

Schedulable iif **U(n) ≤1**

DM Scheduling

Scheulability tests for DM

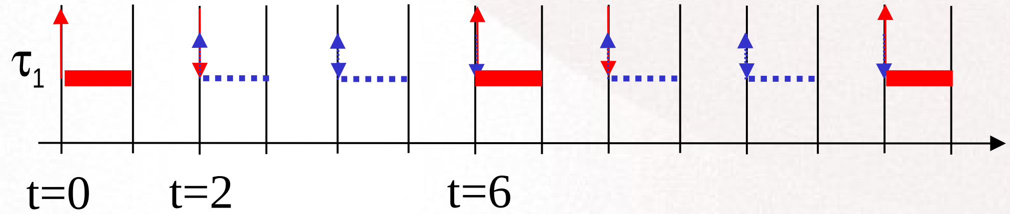
In some cases tasks may have **large periods** (low frequency) but require a **short response time**. In these cases we assign a deadline shorter than the period, and the **scheduling criteria is the deadline.**

In these cases we can also use utilization-based tests.

The adaptation is simple, but the test is **very pessimistic**.

$$U'(n)=\sum_{i=1}^{n}\frac{C_i}{D_i}\leqslant n\left(2^{\frac{1}{n}}-1\right)$$

τ_1 (C_1=1,T_1=6,D_1=2)



Response-time analysis

For **arbitrary fixed priorities**, including RM, DM e others, the **response time analysis** allow to obtain an **exact test** (i.e., necessary and sufficient condition) in the following conditions: preemption, synchronous release, independent tasks and $D \leq T$)

Worst-case response time (WCRT) = maximum time interval between arrival and finish instants. $\mathbf{Rwc_i = max_k(f_{i,k} - a_{i,k})}$

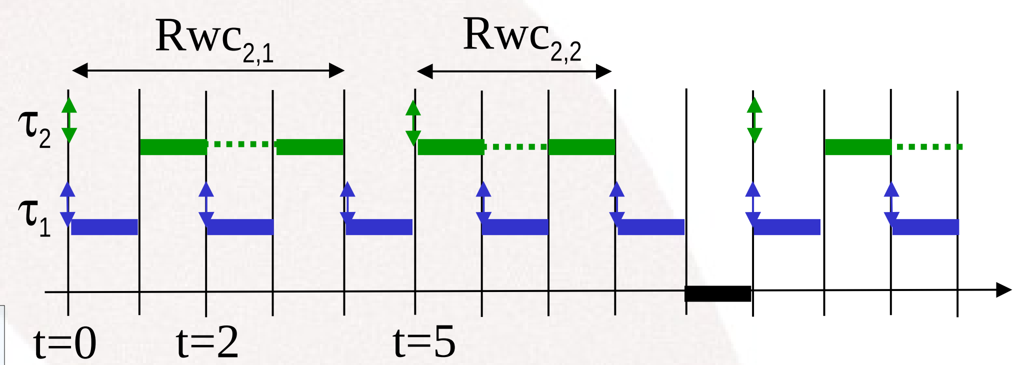
Schedulability test based on the WCRT

Compute $Rwc_i \ \forall_i$

$\forall_{i,}\ \mathbf{Rwc_i \leq D_i} \quad \Leftrightarrow$ **Task set is schedulable**

Response-time analysis

The WCRT of a give task occurs when the task is activated at the same time as all other high-priority tasks (**critical instant**)



Computing Rwc_i

$$\forall_i R_{wc_i} = I_i + C_i$$

$$I_i = \sum_{k \in hp(i)} \left\lceil \frac{R_{wc_i}}{T_k} \right\rceil * C_k$$

Number of times that higher priority task k is activated in the Rwc_i time interval

I_i – interference caused by the execution of higher priority tasks

Response-time analysis

The equation is solved iteratively. Stop conditions are:

- **A deadline is violated** ($Rwc_i > D_i$)
- **Convergence** (two successive iterations yield the same result)
  - $Rwc_i(m+1) = Rwc_i(m)$

$$R_{wc_i}(0) = \sum_{k \in hp(i)} C_k + C_i$$

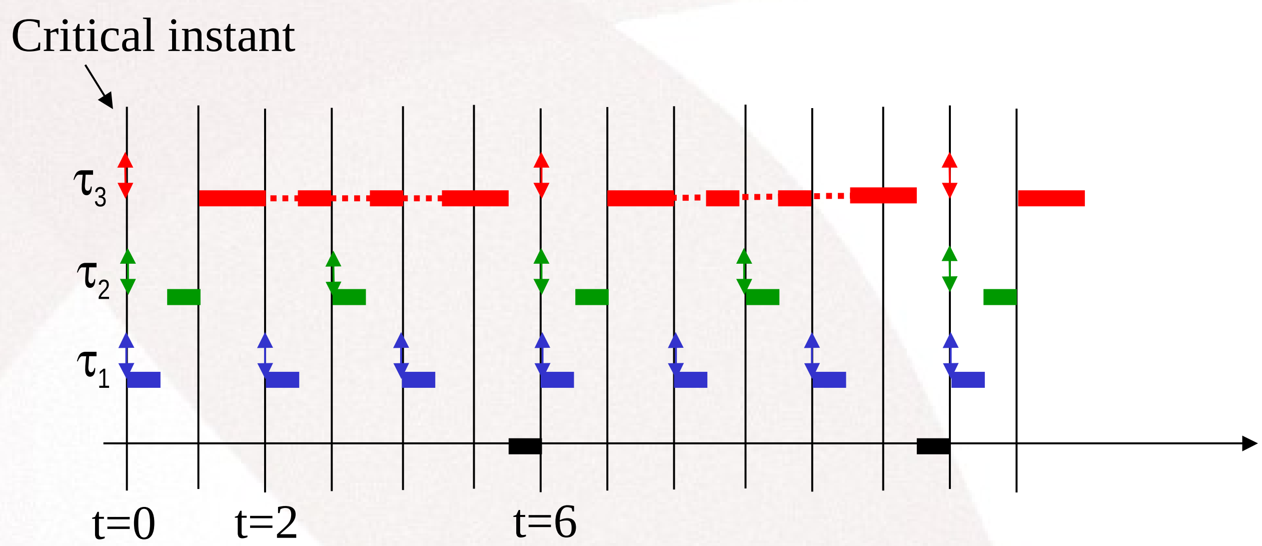
......

$$R_{wc_i}(m+1) = \sum_{k \in hp(i)} \left\lceil \frac{R_{wc_i}(m)}{T_k} \right\rceil * C_k + C_i$$

Response-time analysis

Task properties

τ_i	T_i	C_i
1	2	0.5
2	3	0.5
3	6	**3**



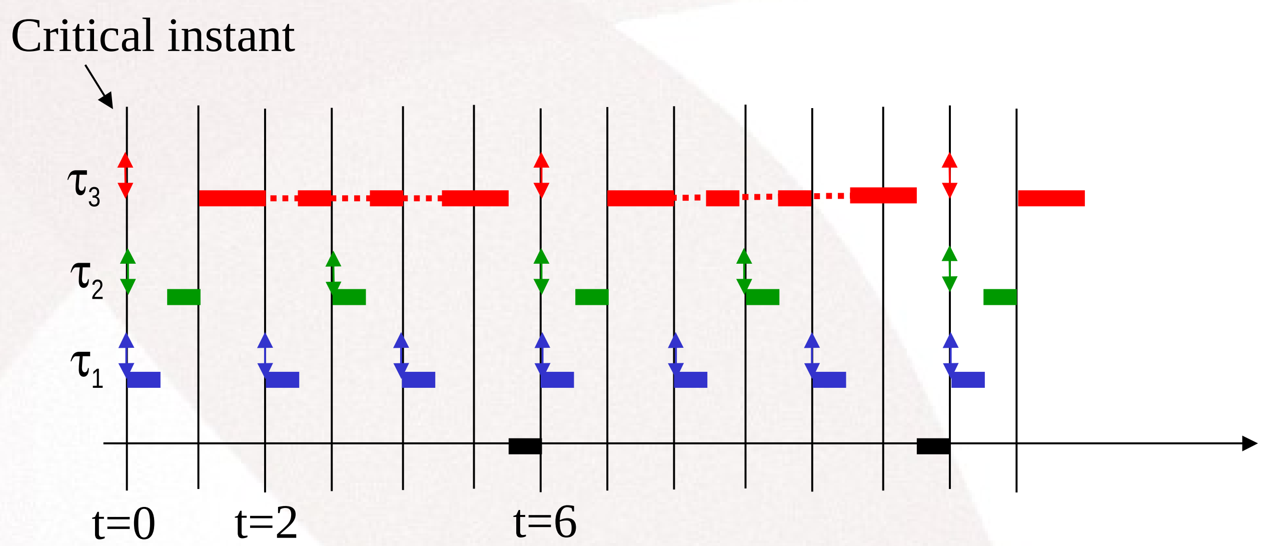
Rwc_1: ?

Rwc_2: ?

Response-time analysis

Task properties

τ_i	T_i	C_i
1	2	0.5
2	3	0.5
3	6	**3**



Rwc_1: $\mathbf{Rwc_1(0) = C_1 = 0.5}$

Rwc_2: $\mathbf{Rwc_2(0) = C_1 + C_2 = 1}$

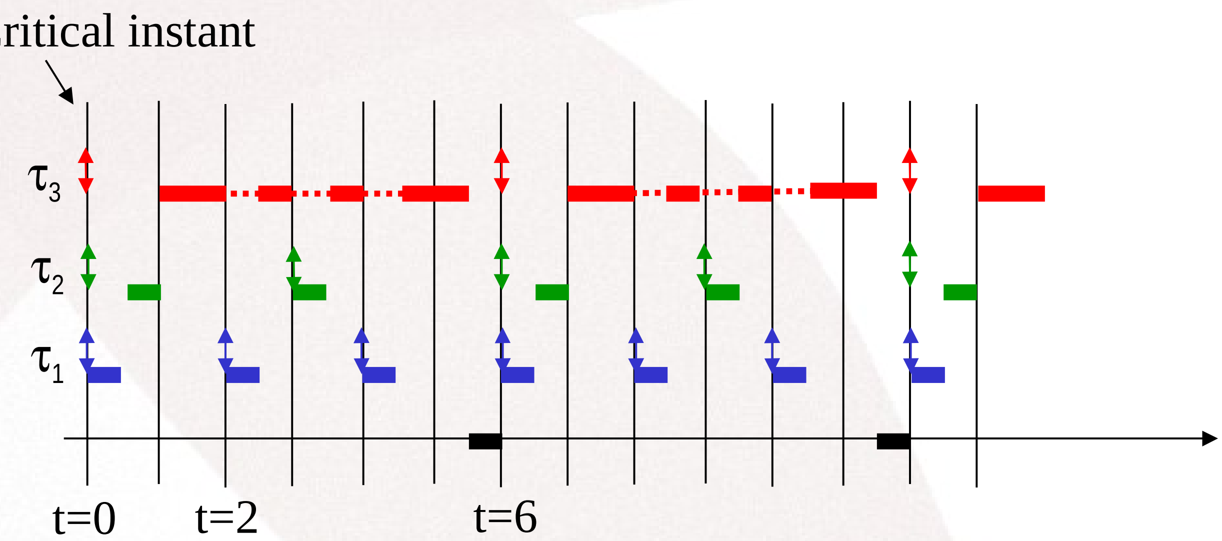
$\mathbf{Rwc_2(1) = \lceil Rwc_2(0)/T_1 \rceil * C_1 + C_2 = 1}$

$\mathbf{Rwc_2 = 1}$

Response-time analysis

Task properties

τ_i	T_i	C_i
1	2	0.5
2	3	0.5
3	6	**3**

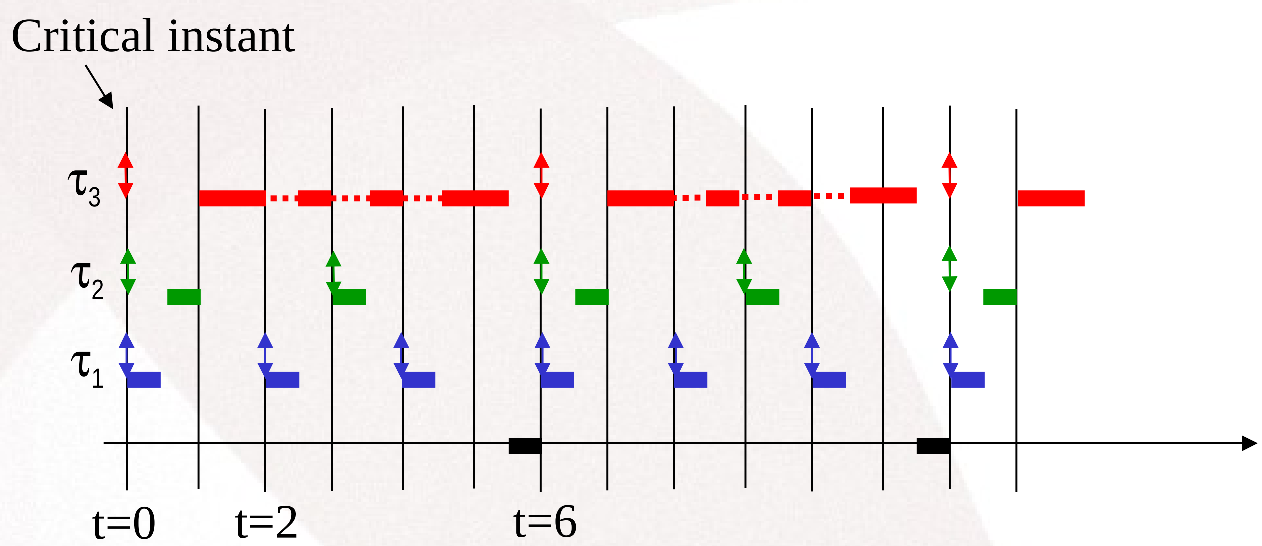


Rwc_3: ?

Response-time analysis

Task properties

τ_i	T_i	C_i
1	2	0.5
2	3	0.5
3	6	**3**



Rwc$_3$:

$$\mathbf{Rwc_3(0) = C_1+C_2+C_3 = 4}$$

$$\mathbf{Rwc_3(1) = \lceil Rwc_3(0)/T_1 \rceil * C_1 + \lceil Rwc_3(0)/T_2 \rceil * C_2 + C_3 = 5}$$

$$\mathbf{Rwc_3(2) = \lceil Rwc_3(1)/T_1 \rceil * C_1 + \lceil Rwc_3(1)/T_2 \rceil * C_2 + C_3 = 5.5}$$

$$\mathbf{Rwc_3(3) = \lceil Rwc_3(2)/T_1 \rceil * C_1 + \lceil Rwc_3(2)/T_2 \rceil * C_2 + C_3 = 5.5}$$

$$\mathbf{Rwc_3 = 5.5}$$

Restrictions to the schedulability tests previously presented

The previous schedulability tests must be modified in the following cases:

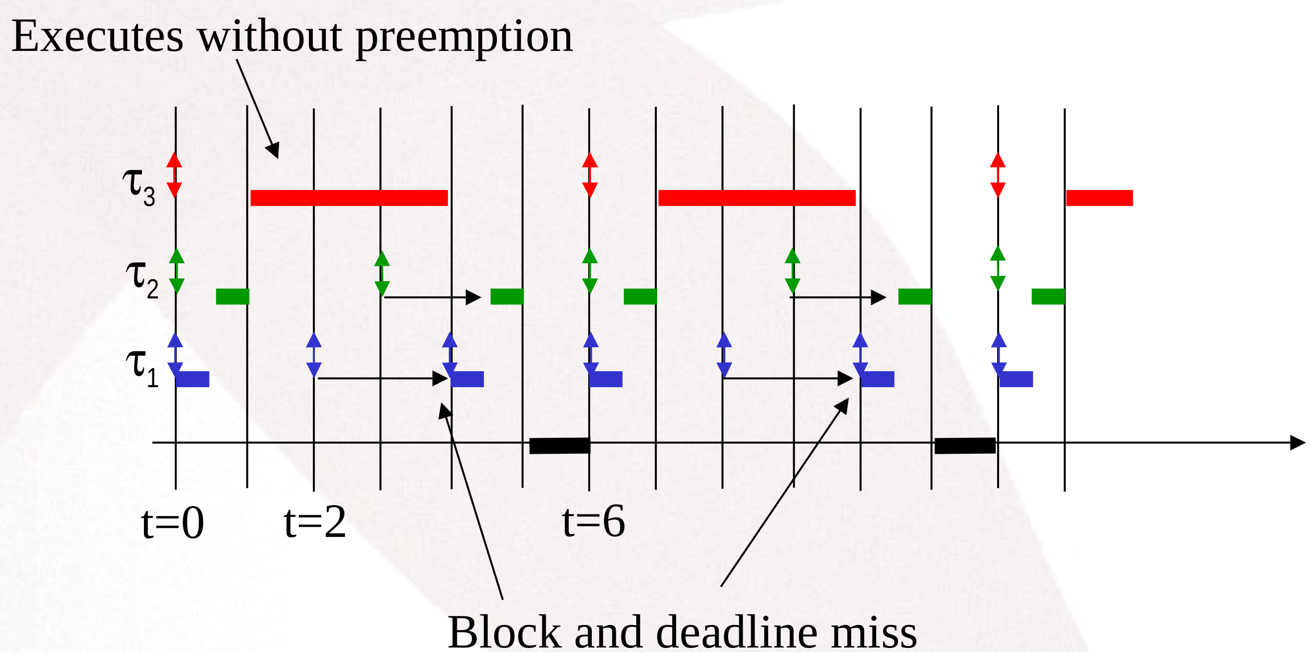
- **Non-preemption**
- **Tasks not independent**
  - **Share mutually exclusive resources**
  - **Have precedence constraints**

- It is also necessary to **take into account** the **overhead** of the kernel, because the scheduler, dispatcher and interrupts **consume CPU time**

Impact of non-preemption

Task properties

τ_i	T_i	C_i
1	2	0.5
2	3	0.5
3	6	**3**



Summary of 5

- **On-line** scheduling with **fixed-priorities**
- The **Rate Monotonic** scheduling policy – schedulabilty analysis based on utilization
- The **Deadline Monotonic** and arbitrary deadlines scheduling policies
- Response-time analysis