TAG DER INFORMATIK

DAY OF COMPUTER SCIENCE 2025

Thursday, 5 June

```
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    "Location": "Computer Science Center (E2)",
    "_info": "Get ice cream and party wristbands!"
}

$ PARTY.JSON < {
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    "Location": "Das LIEBIG, Liebigstr. 19",
    "_info": "Wristband required!"
}
```

More info at www.tdi.ac

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12.24196

Introduction to Embedded Systems

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Summer Semester 2025

Part 4

Real-Time Systems

Content

1. Real-Time Requirements
2. Real-Time Operating Systems – Example OSEK
3. Scheduling
4. Deadlocks & Priority Inversion
5. Priority Ceiling & Inheritance

Real-Time Requirements

Real time ~~=~~ fast~~?~~

- Computation is correct
- Computation is finished in time

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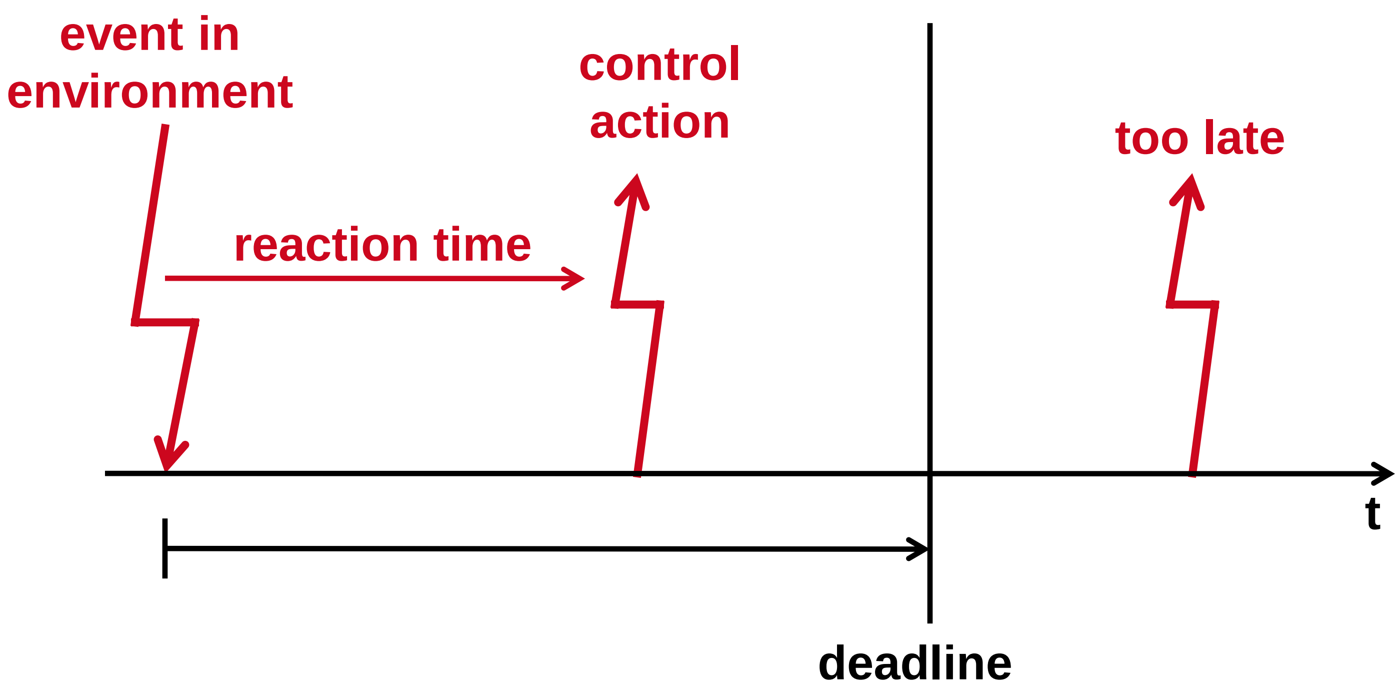
Real-Time Requirements

For embedded systems:

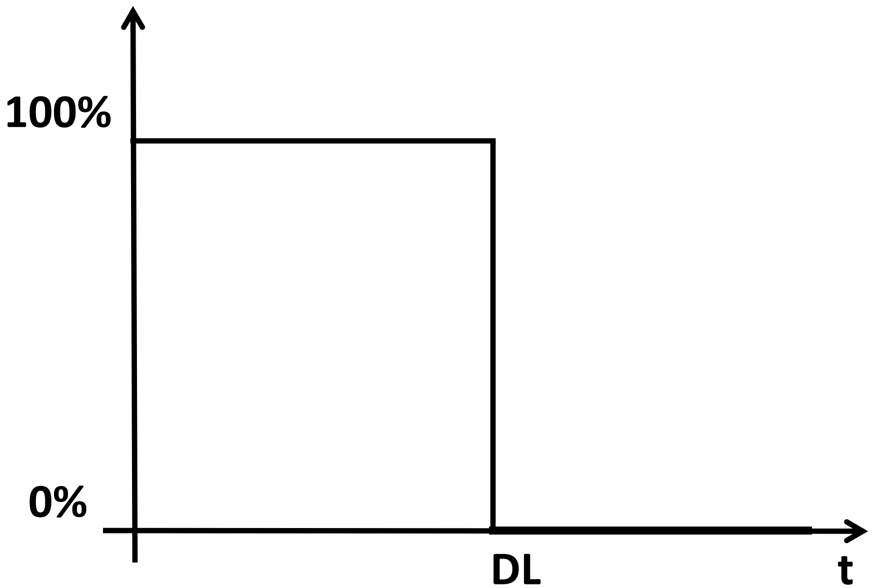
Physical environment does not wait for control actions!



Real-Time Requirements

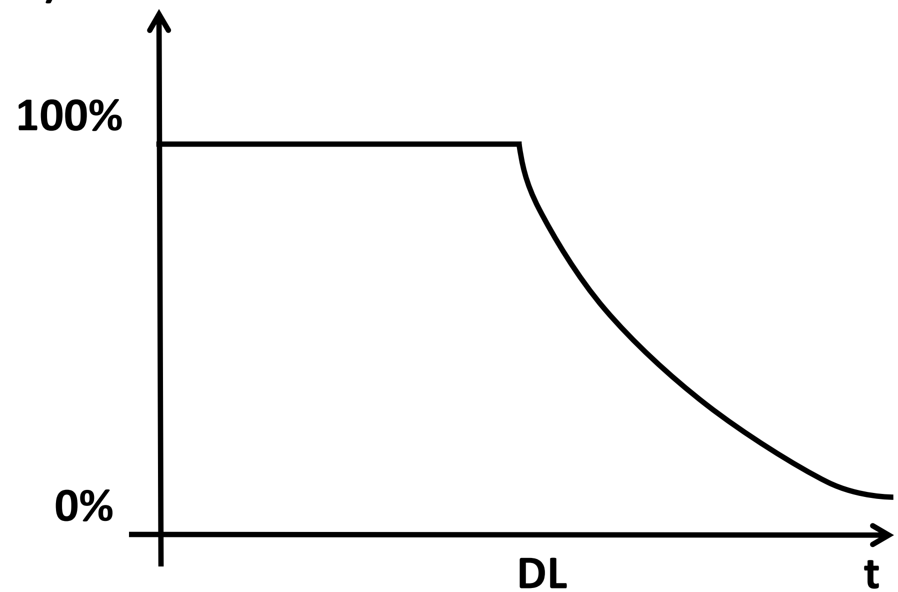
Hard vs. soft real-time requirements

Hard:



Soft:

a)

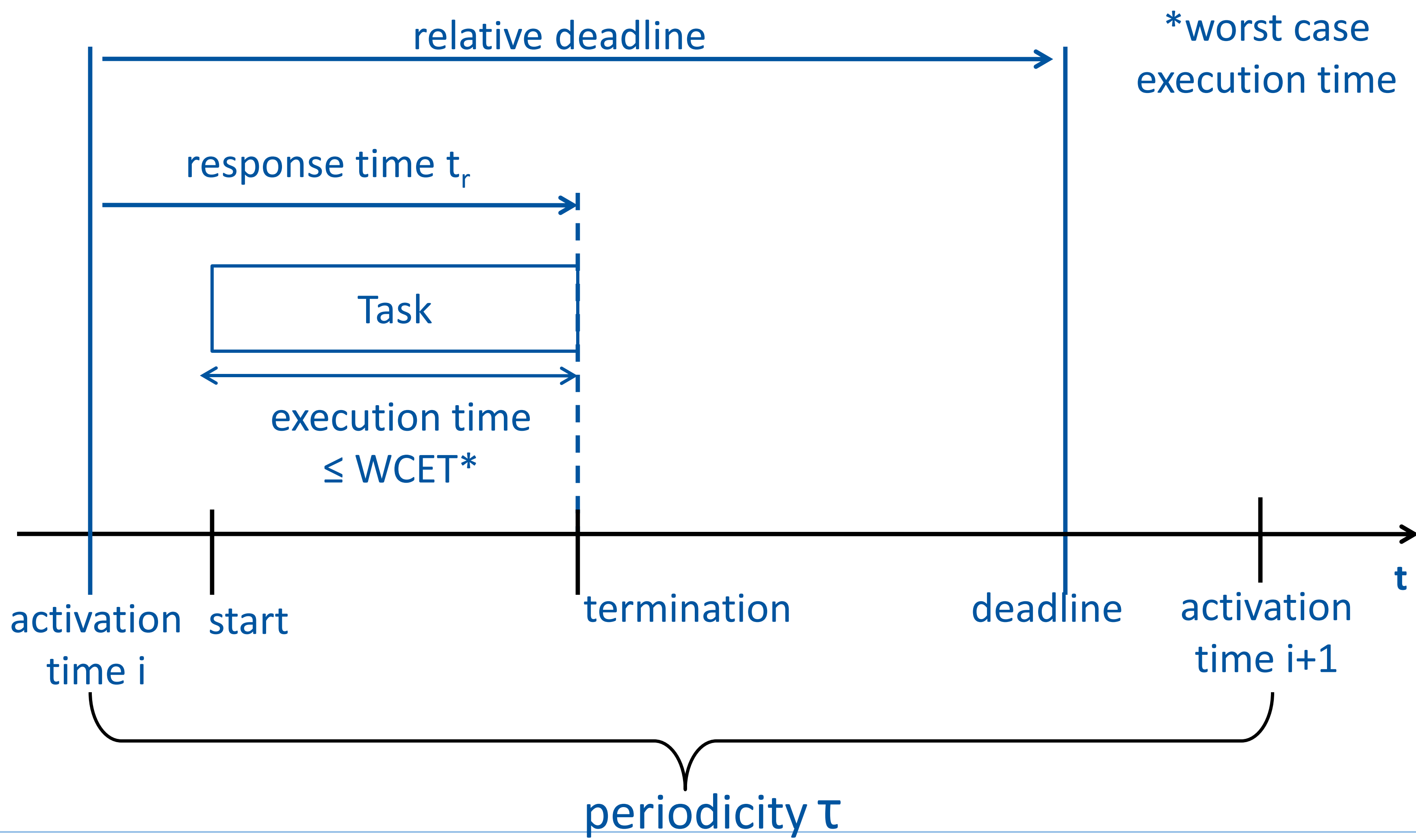


b) statistically a sufficient number of reactions in time.

How to Fulfill Real-Time Requirements?

- Polling
- Main loop and interrupts
- Real-time operating system

Real-Time Requirement Parameters for Multitasking OS



OSEK: History

1993: Start of project

„Offene Systeme und deren Schnittstellen für Elektronik im Kraftfahrzeug“

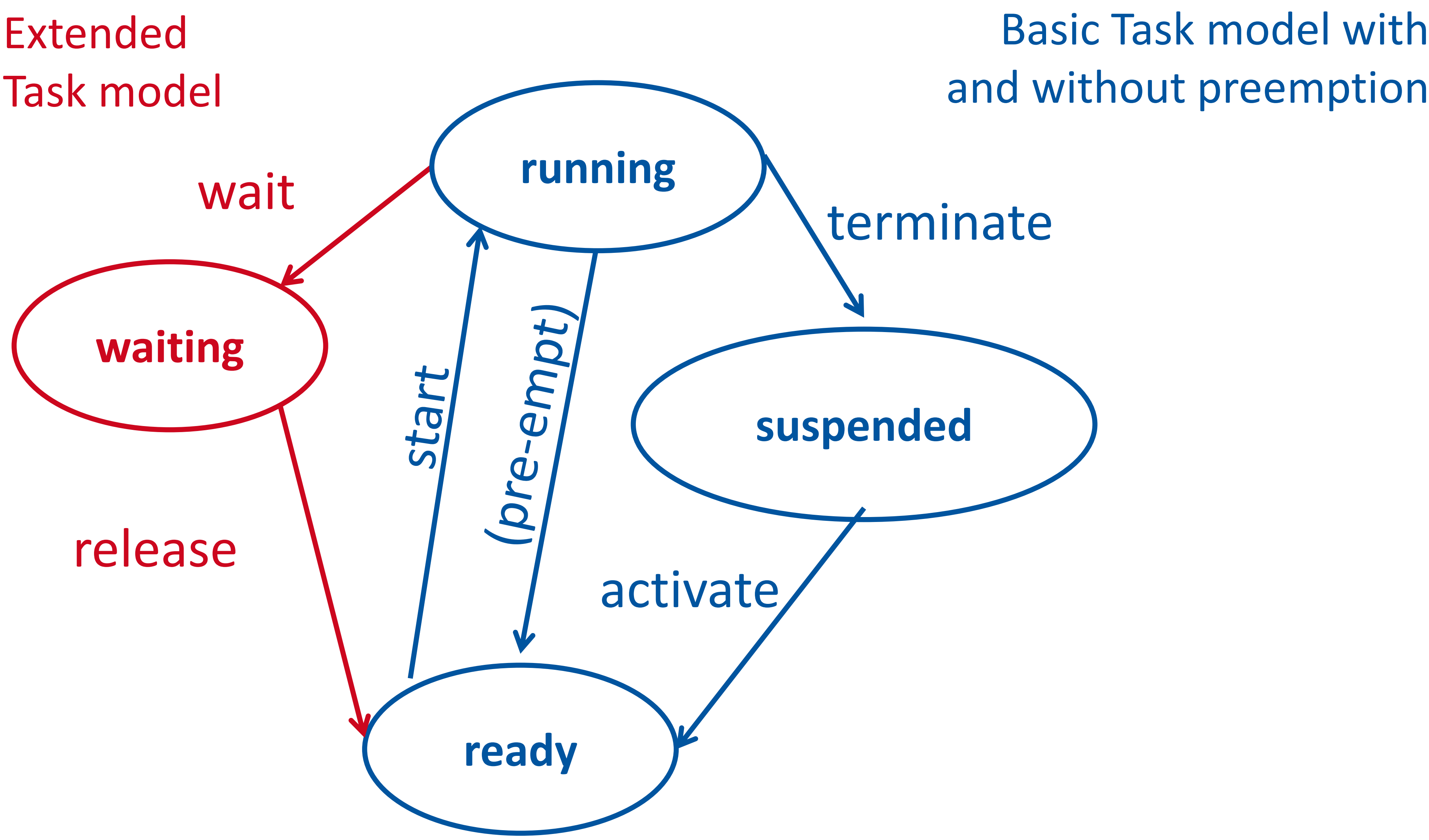
(Coordinator: Prof. Kiencke, University of Karlsruhe)

1994: PSA and Renault joinedwith French initiative

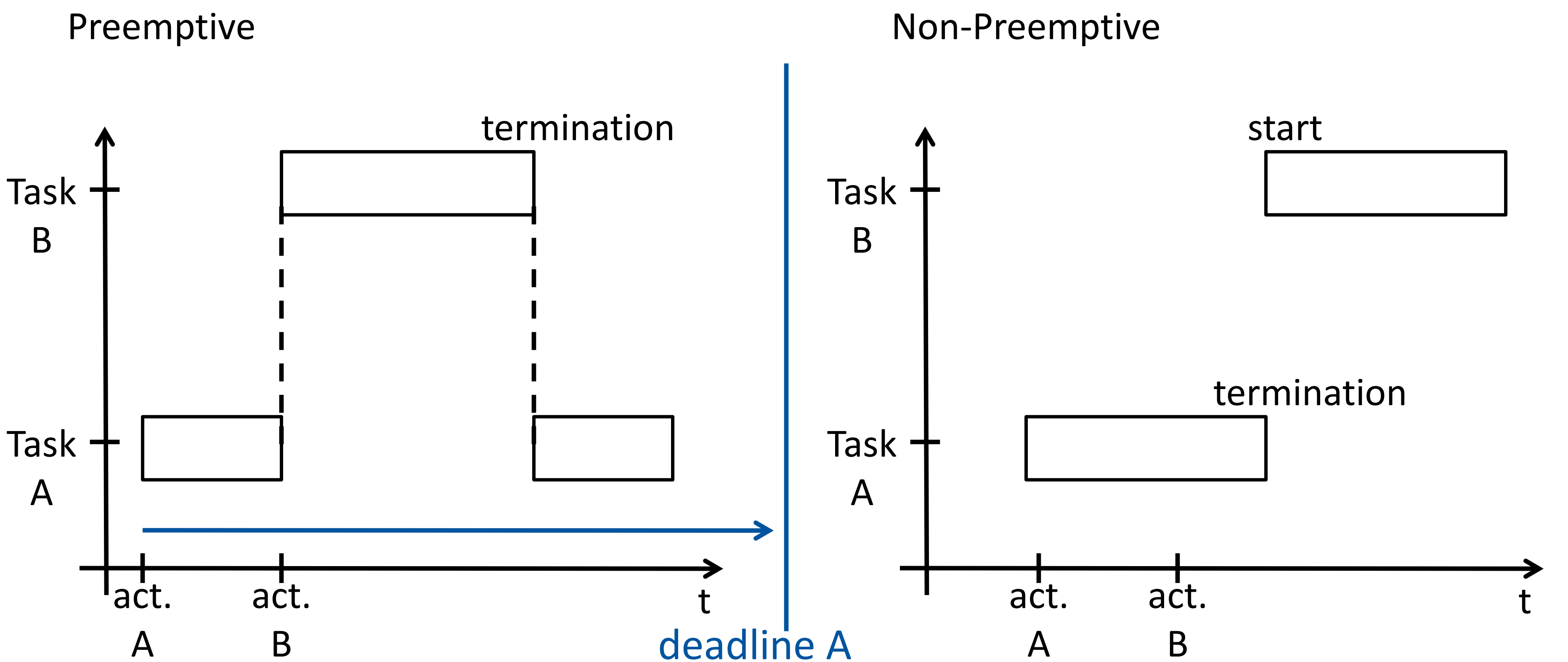
„VehicleDistributed Executive“ (VDX) → OSEK/VDX

Today: ISO standard

OSEK: Task Model

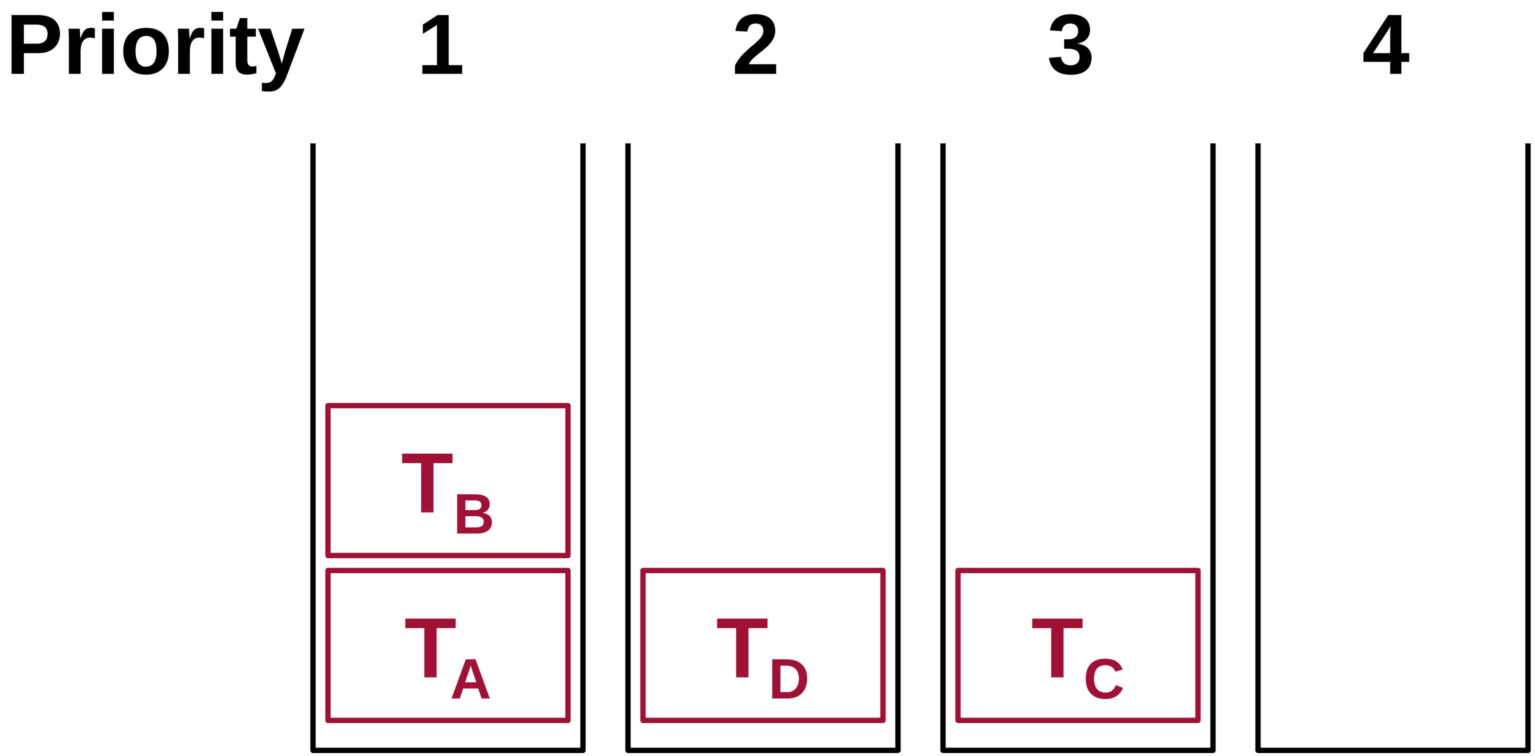


OSEK: Cooperative Scheduling – Pre-emption

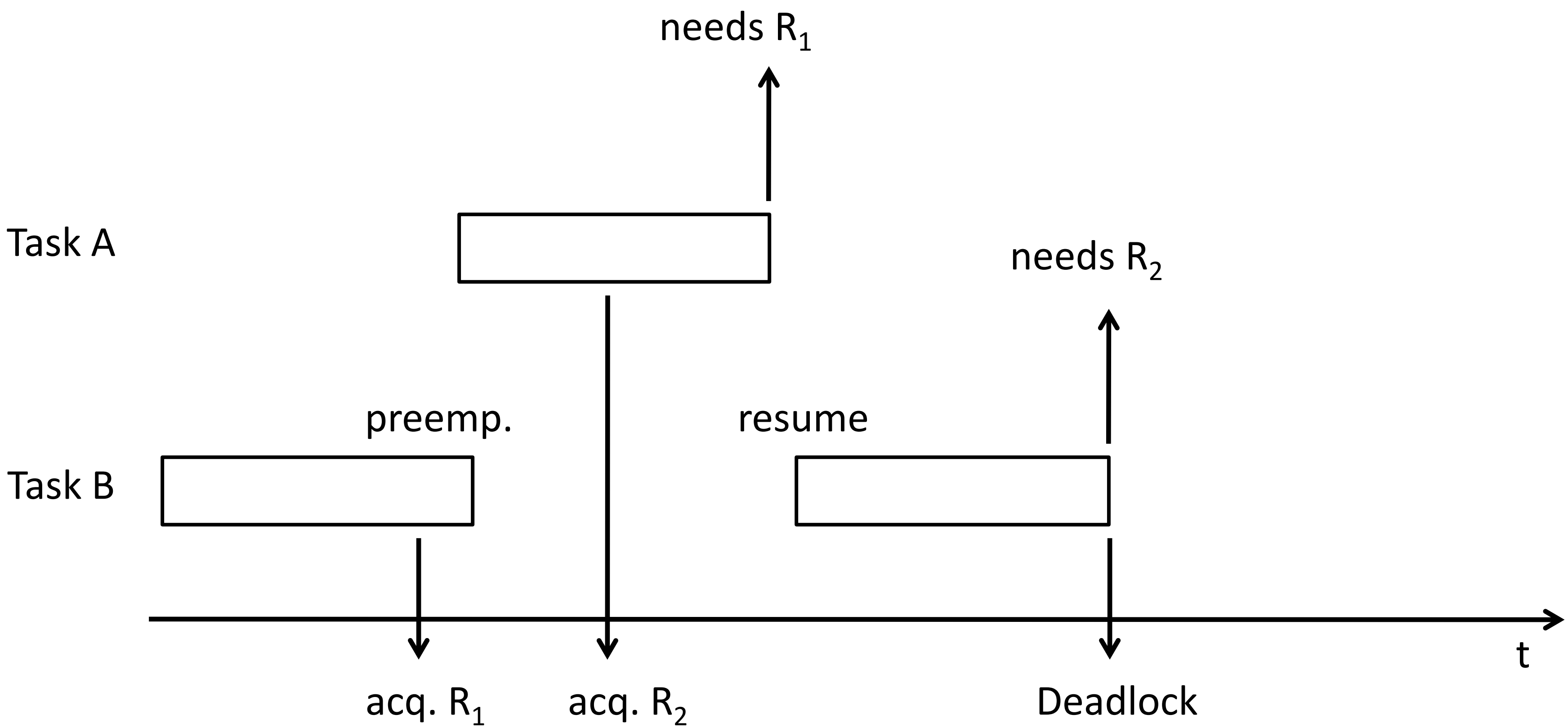


- Context swapping takes time
- Low priority task can starve

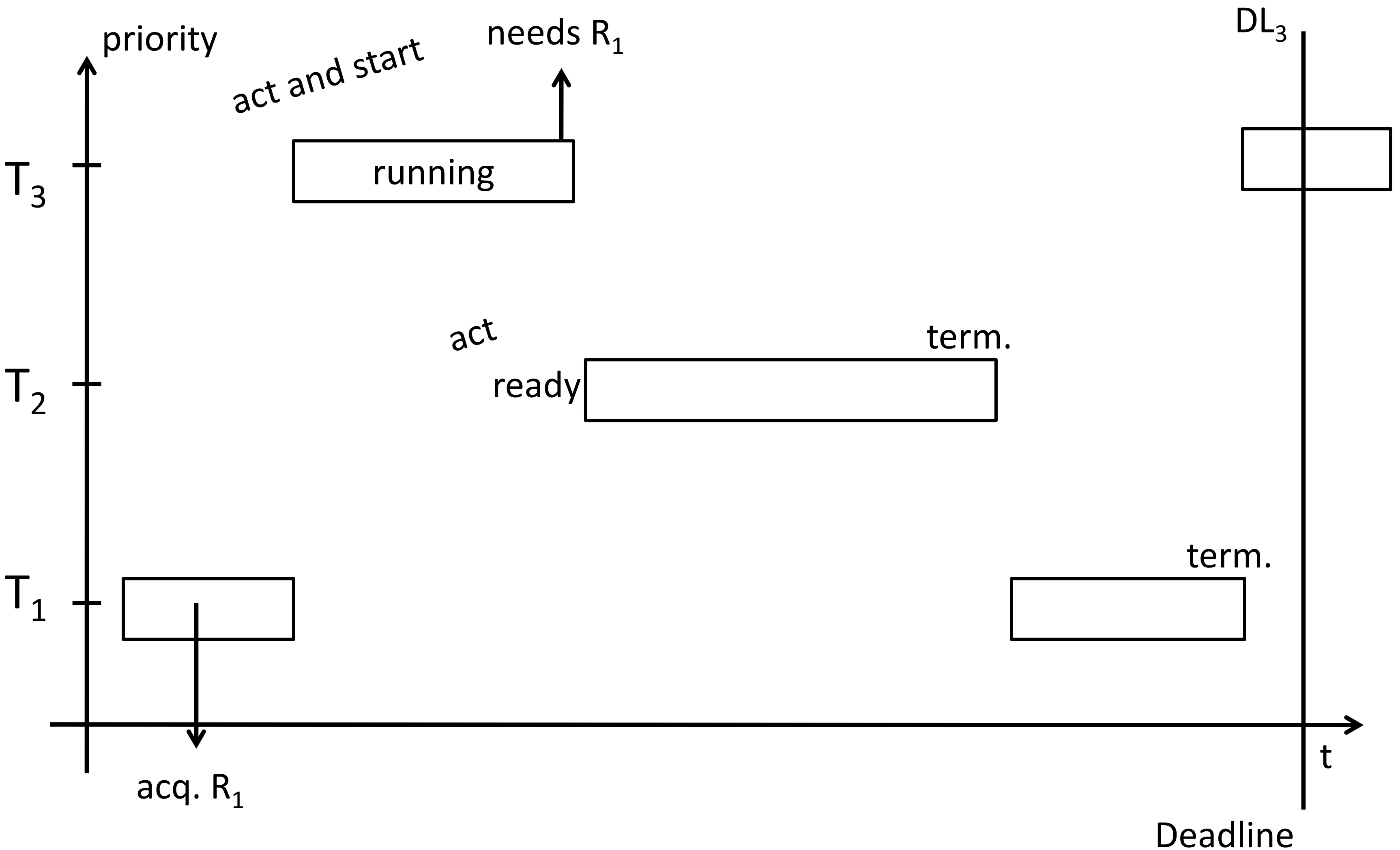
OSEK: Priority Queues



Problem: Deadlock



Problem: Priority Inversion



Example for Priority Inversion: Mars Pathfinder Project

Elements:

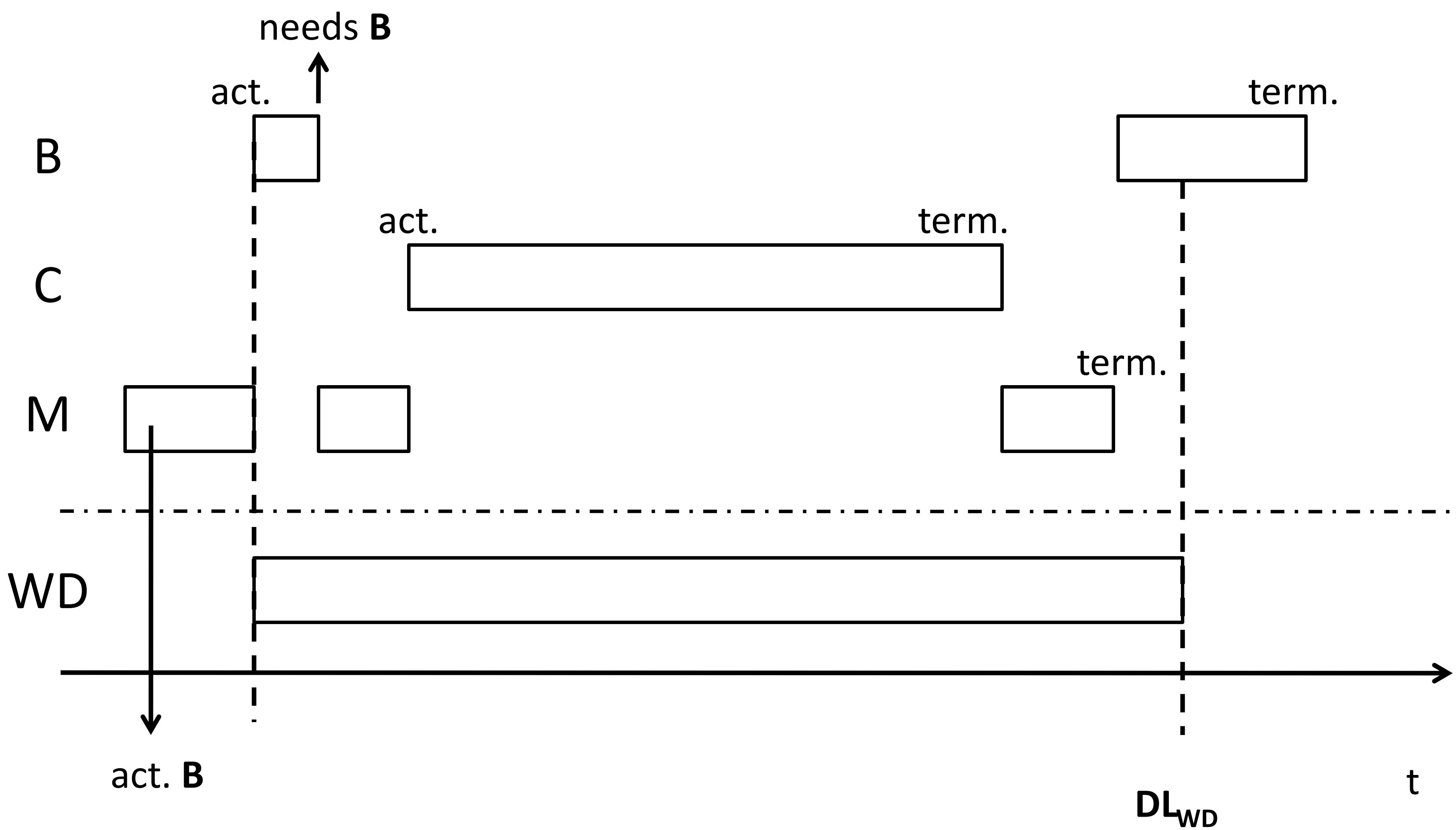
- One resource:
  - **B:** Information bus
- Three tasks:

B:	Bus management	needs **B**	highest priority
C:	Communication	does not need **B**	medium priority
M:	Metrological data gathering	needs **B**	lowest priority

- Watchdog timer WD, reset by bus management

Example for Priority Inversion: Mars Pathfinder Project

Problem:

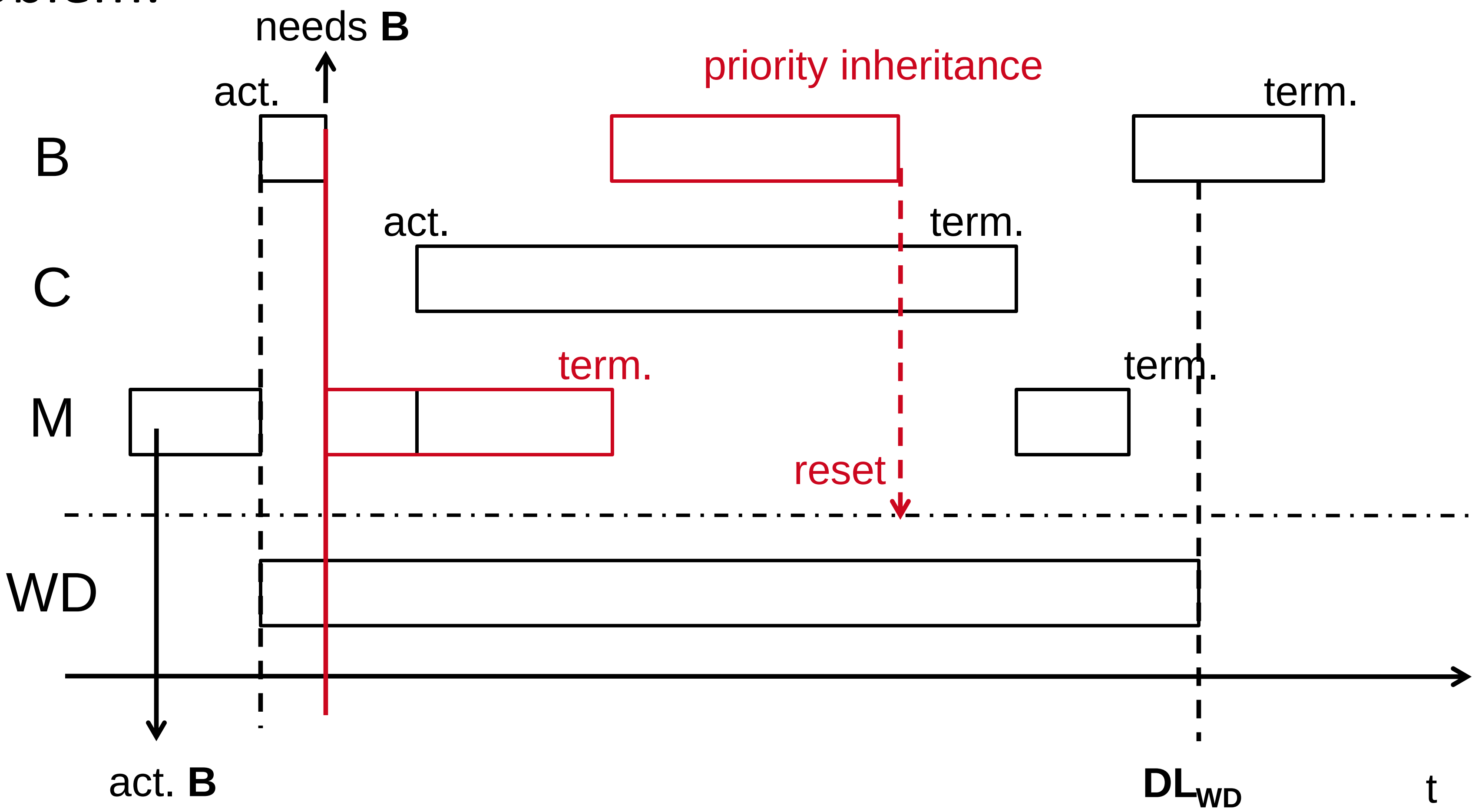


Priority Inheritance Protocol

- Task A (high priority) needs a resource R
- Task B (low priority) currently holds R
- As soon as A starts waiting for R
  - B inherits A’s priority
  - B cannot be preempted by an intermediate priority
  - No priority inversion possible
- Complex:
  - Current holder of a resource must be determined
  - Holder’s priority must be changeable while running

Example for Priority Inversion: Mars Pathfinder Project

Problem:



Priority Ceiling Protocol

- **Ceiling priorities** are assigned to the resources
- A resources priority is the highest priority of all tasks that may use it
- A task is upgraded to the resource's priority as soon as the task holds it.
- Can be calculated during design time
- Not optimal: T2 is upgraded to R_1's priority even if T4 is inactive

high T5

T4 $\rightarrow R_1$ ← Ceiling priority of R_1

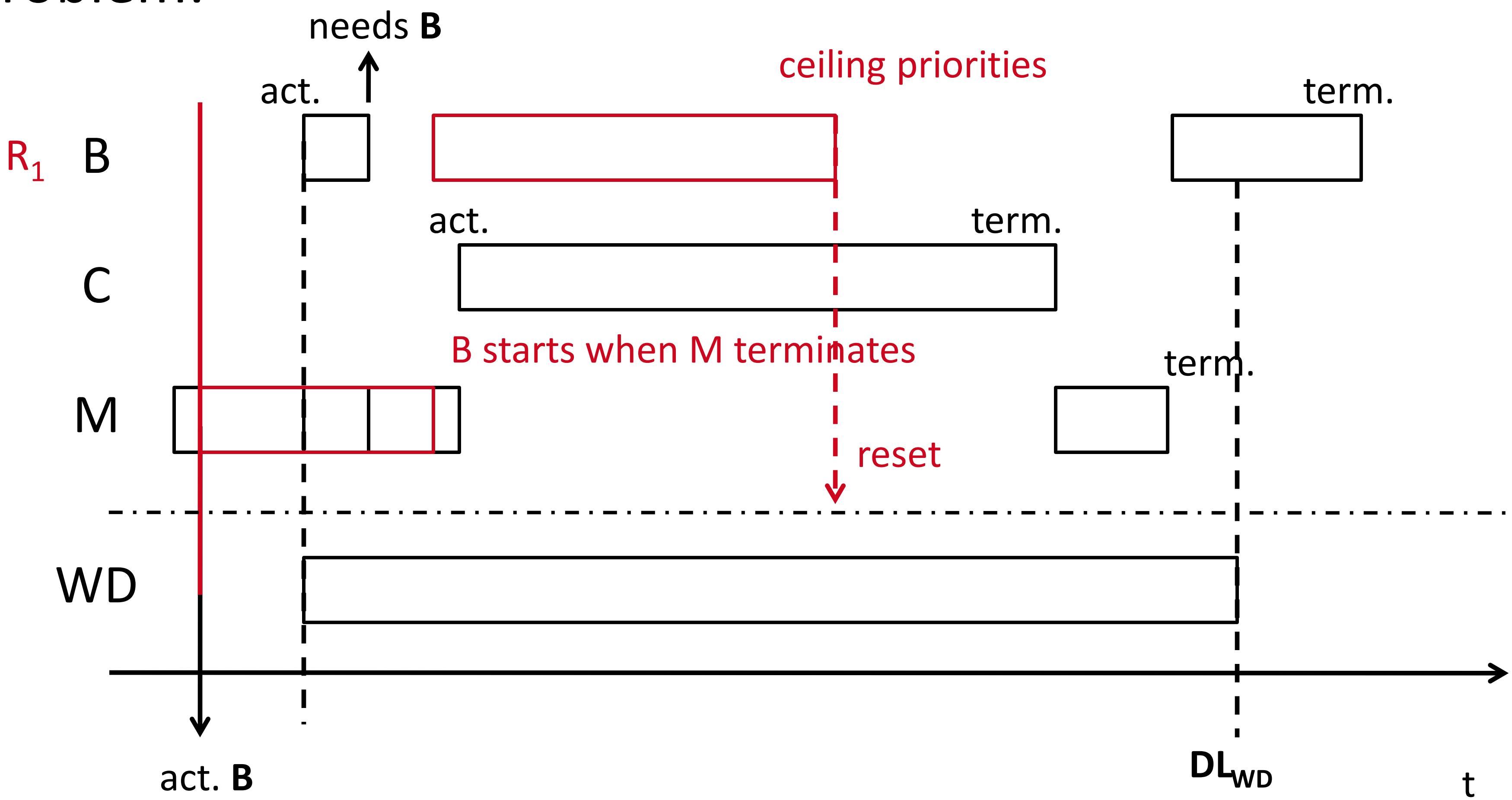
T3

T2 $\rightarrow R_1$

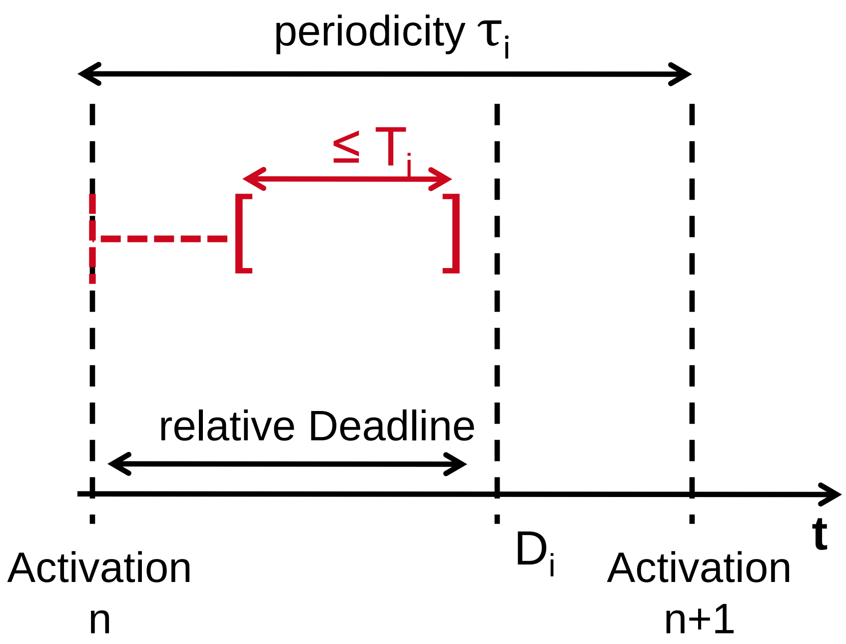
low T1

Example for Priority Inversion: Mars Pathfinder Project

Problem:



Reminder: Task parameters



A Task is characterized by
$\mathbf{T}_i = (\tau_i, T_i, D_i)$
$i=1,2,\ldots \rightarrow$ Task System

Definitions

Schedule:

Mapping of an execution sequence to a task system

Feasibility:

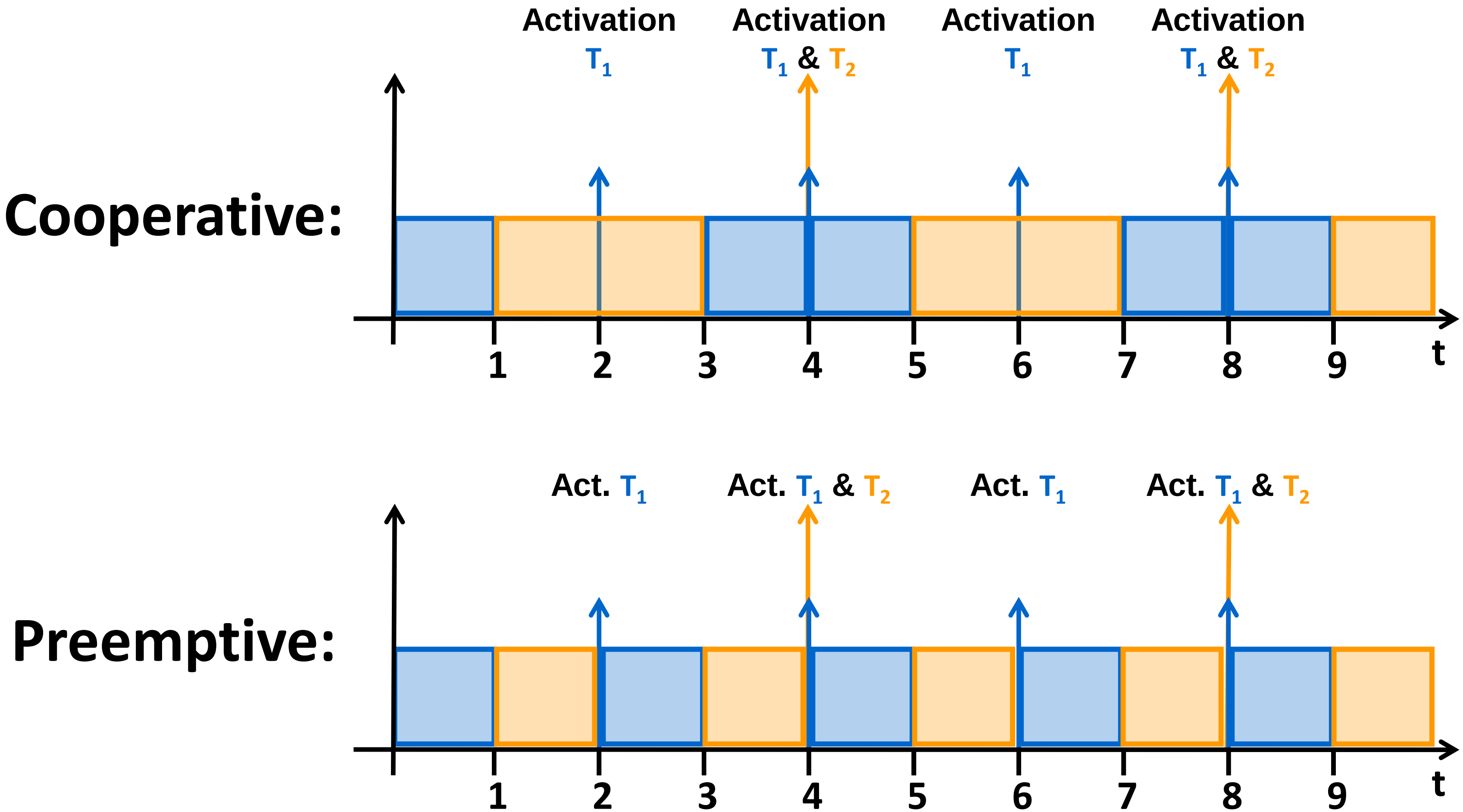
A schedule is feasible, if no deadline is violated.

Schedulability:

A task system is schedulable, if a feasible schedule exists.

Example 1 - Cooperative vs. Preemptive Scheduling

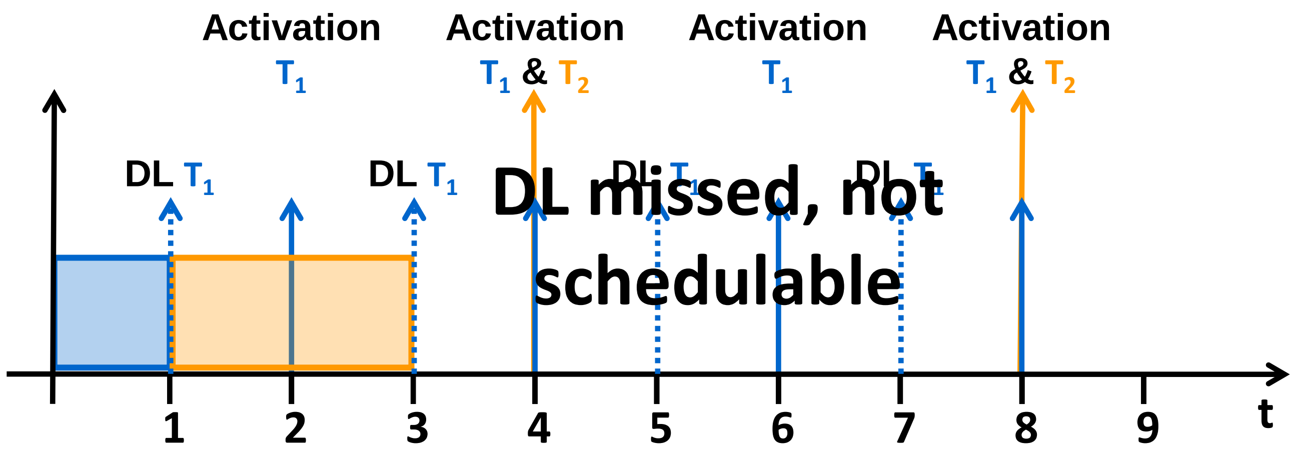
$T_1 = (2, 1, 2)$, $T_2 = (4, 2, 4)$



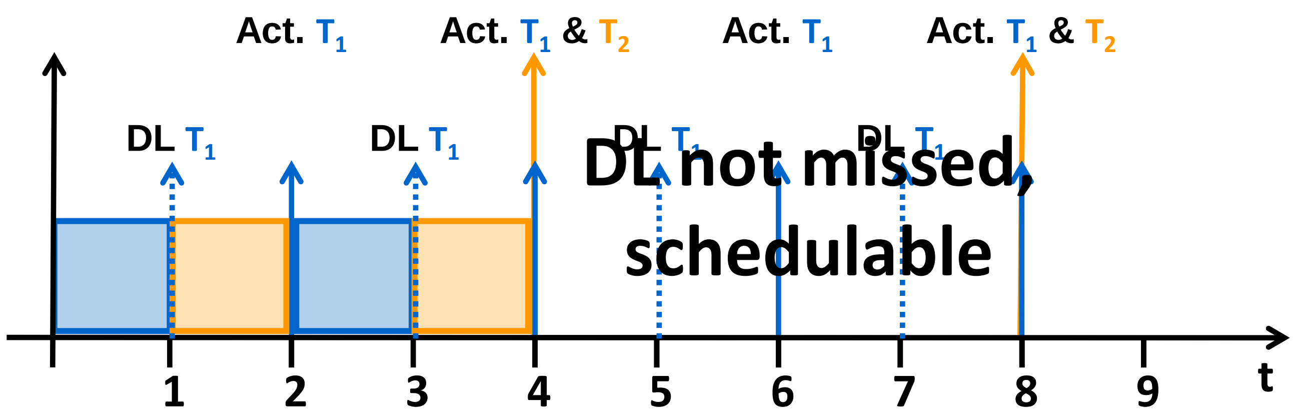
Example 2 - Cooperative vs. Preemptive Scheduling

$T_1 = (2, 1, 1)$, $T_2 = (4, 2, 4)$

Cooperative:



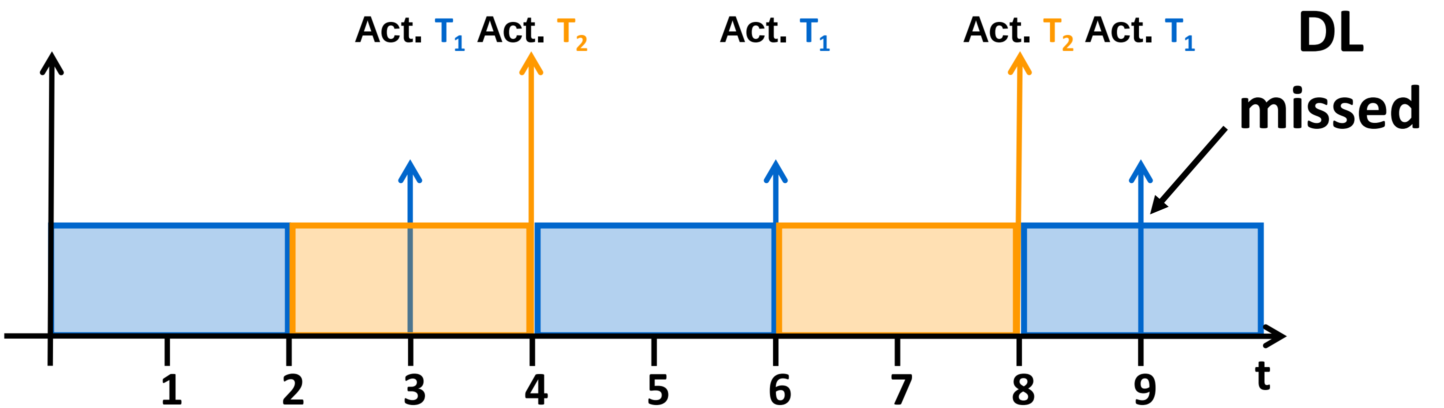
Preemptive:



Example 3 – Cooperative vs. Preemptive Scheduling

$T_1 = (3, 2, 3)$, $T_2 = (4, 2, 4)$

Preemptive:



Not schedulable using preemption
→ scheduling impossible

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Utilization

What was the problem in example 3?

→ CPU Utilization *U*

$$U = \sum_{i=1}^{m} \frac{T_i}{\tau_i}$$

Example 3: $U = \frac{2}{3} + \frac{2}{4} = \frac{14}{12} > 1$

U > 1 => Task system is not schedulable.

U ≤ 1 necessary condition for schedulability.

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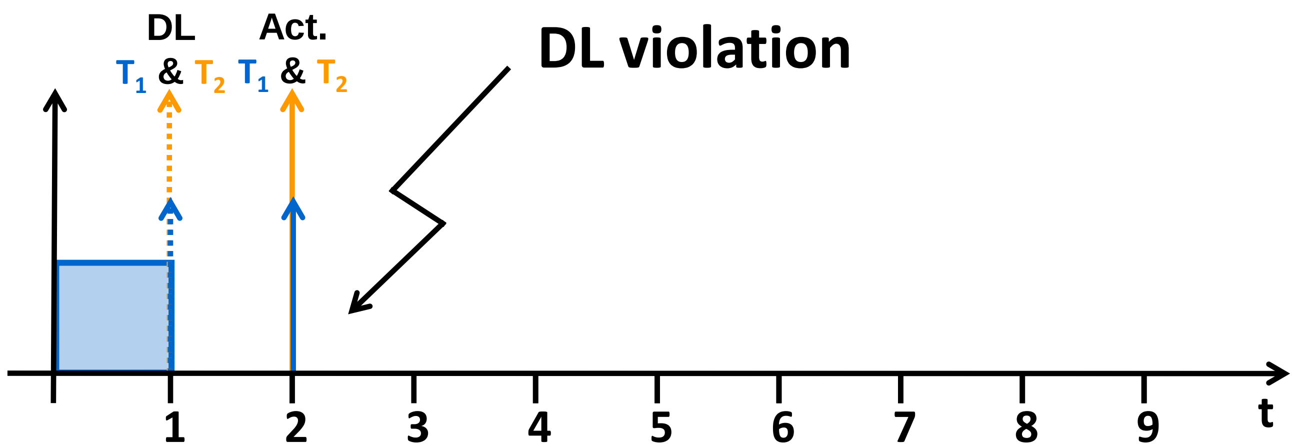
Questions

1. Is every task system with $U \leq 1$ schedulable?
   Or: Is $U \leq 1$ a sufficient condition for schedulability?
2. Is there an algorithm which generates a feasible schedule for every schedulable task system? (i.e. an „optimal“ algorithm)

Example 4 - Utilization

T_1 = (2, 1, 1), T_2 = (2, 1, 1)

$$U = \frac{1}{2} + \frac{1}{2} = 1$$



Earliest Deadline First Scheduling

Liu, Layland 1973

Execute the task with smallest D first.

Rate Monotonic Scheduling

$$\text{Rate} = \frac{1}{\tau}$$

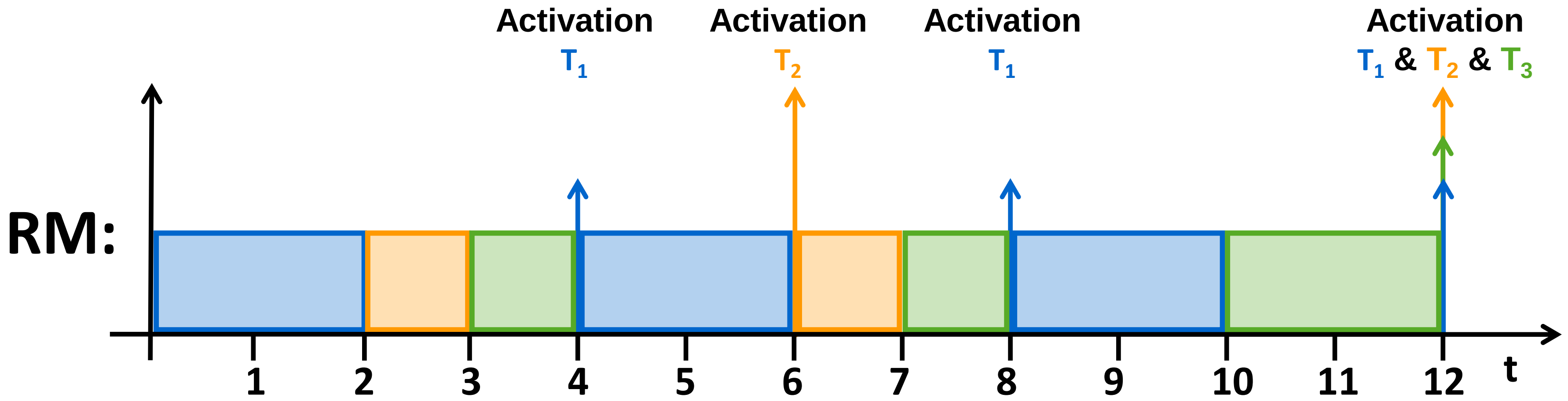
$$\text{Prio}(T_1) > \text{Prio}(T_2) > \cdots > \text{Prio}(T_m) \iff$$

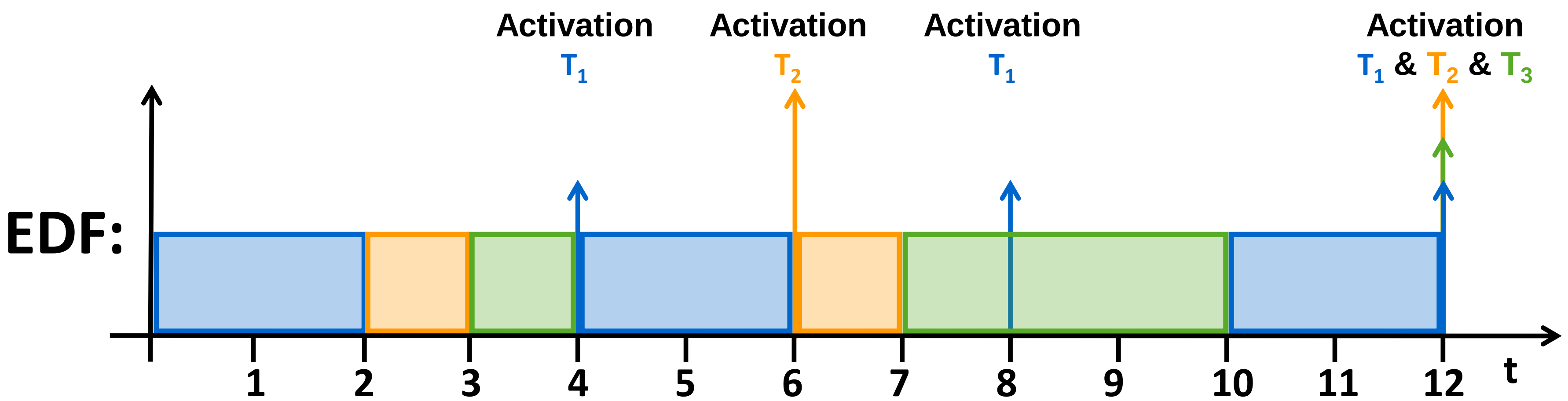
$$\frac{1}{\tau_1} > \frac{1}{\tau_2} > \cdots > \frac{1}{\tau_m}$$

A task system is RM-schedulable, if a feasible RM-schedule exists.

Example 5 – RM vs. EDF

$T_1 = (4, 2, 4)$, $T_2 = (6, 1, 6)$, $T_3 = (12, 4, 12)$ U=1 $\text{Prio}(T_1) > \text{Prio}(T_2) > \text{Prio}(T_3)$





Example 6 – RM vs. EDF

$T_1 = (4, 2, 4)$, $T_2 = (5, 2, 5)$, $T_3 = (10, 1, 10)$ U=1 $\mathrm{Prio}(T_1) > \mathrm{Prio}(T_2) > \mathrm{Prio}(T_3)$