Lecture 13:
Real-Time Scheduling

CS 3281

Slides adapted from UNC Real-Time Systems Group

Motivation – Cyber-Physical Systems

Surgical Robotics

Industrial Internet of Things (IIoT)

Power and Utilities

Satellites

Autonomous Vehicles

Drones & DoD Systems

Real-Time Systems

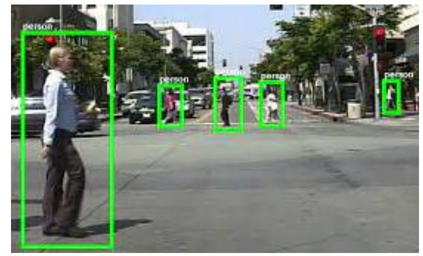
Enterprise Systems

Servers, desktops, web browsing, emails, etc.

“Real Fast” Systems

Interactive processing, i.e., video games

Soft Real-Time System



Pedestrian Detection

Hard Real-Time System

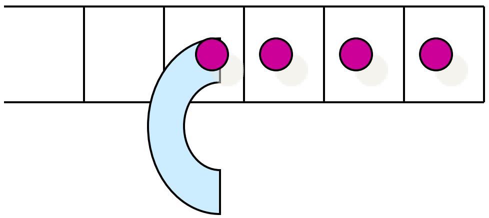
Arc-Flash Relays: ~2ms to break circuit

Degree of Timing Requirements

Interaction with the physical world requires keeping time with the real world.
Many CPS, especially safety- and mission-critical systems have strict timing requirements.

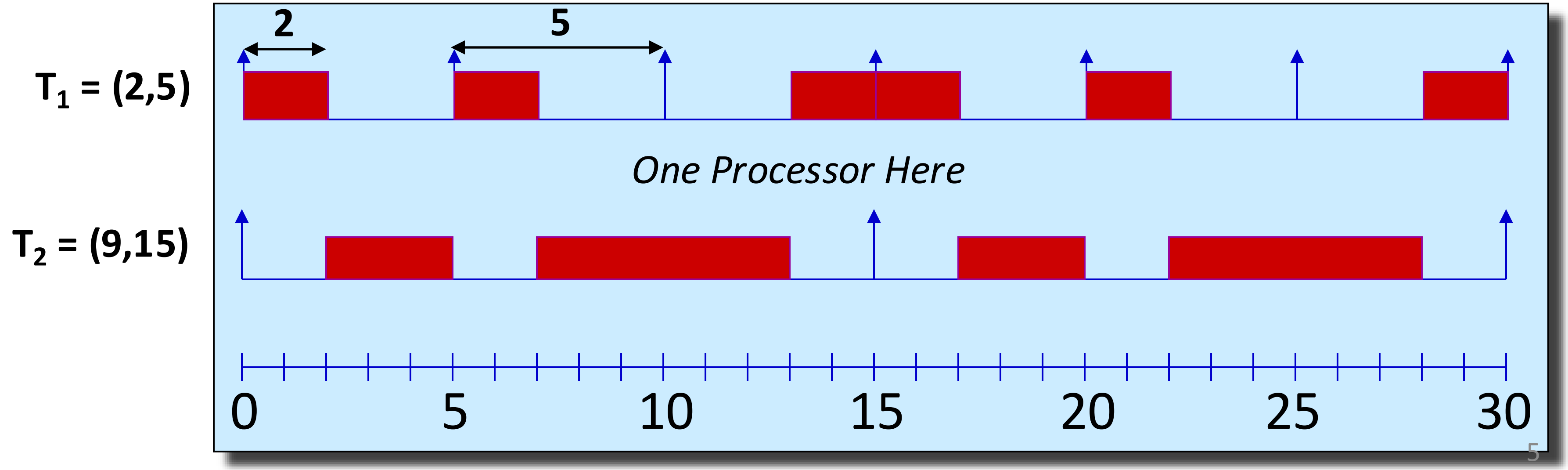
What is a Real-Time System?

- A system with a dual notion of correctness:
  - *Logical* correctness ("it does the right thing");
  - *Temporal* correctness ("it does it on time").
- A system wherein *predictability* is as important as *performance.*
- Real-time systems are designed based on worst case, rather than average case
- **A simple example:** A robot arm picking up objects from a conveyor belt.



Periodic Task Systems

- Set τ of periodic tasks scheduled on M cores:



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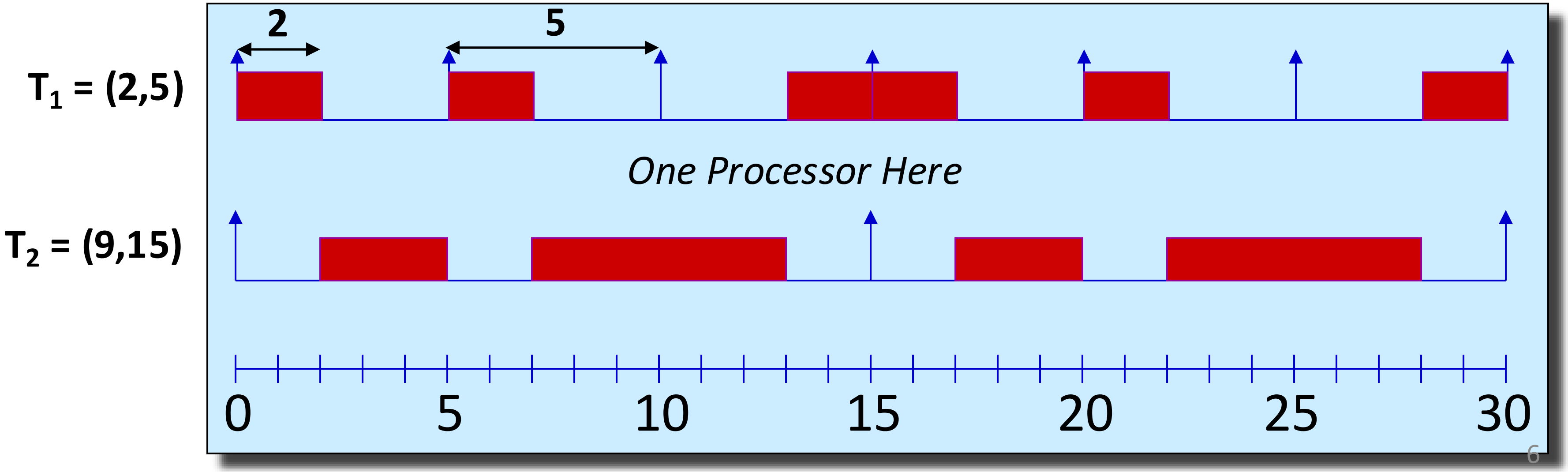
  - Task $T_i = (e_i,p_i)$ releases a *job* with exec. cost e_i every p_i time units.
    - Ti's *utilization* (or *weight*) is $u_i = e_i/p_i$.
    - *Total utilization* is $U(\tau) = \sum_{T_i} e_i/p_i$.



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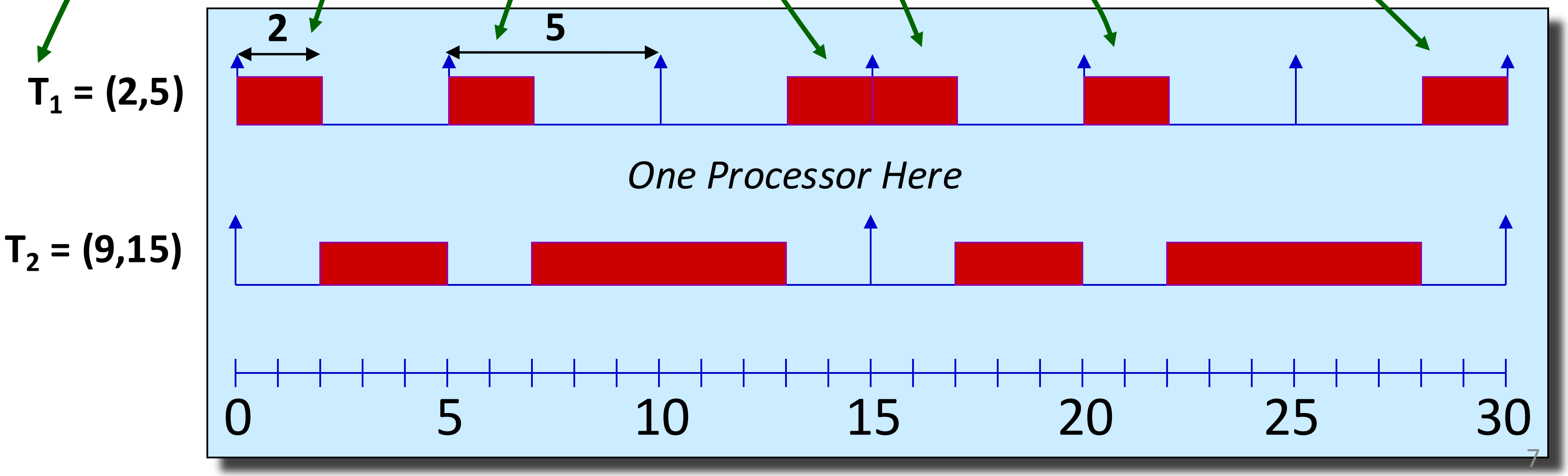

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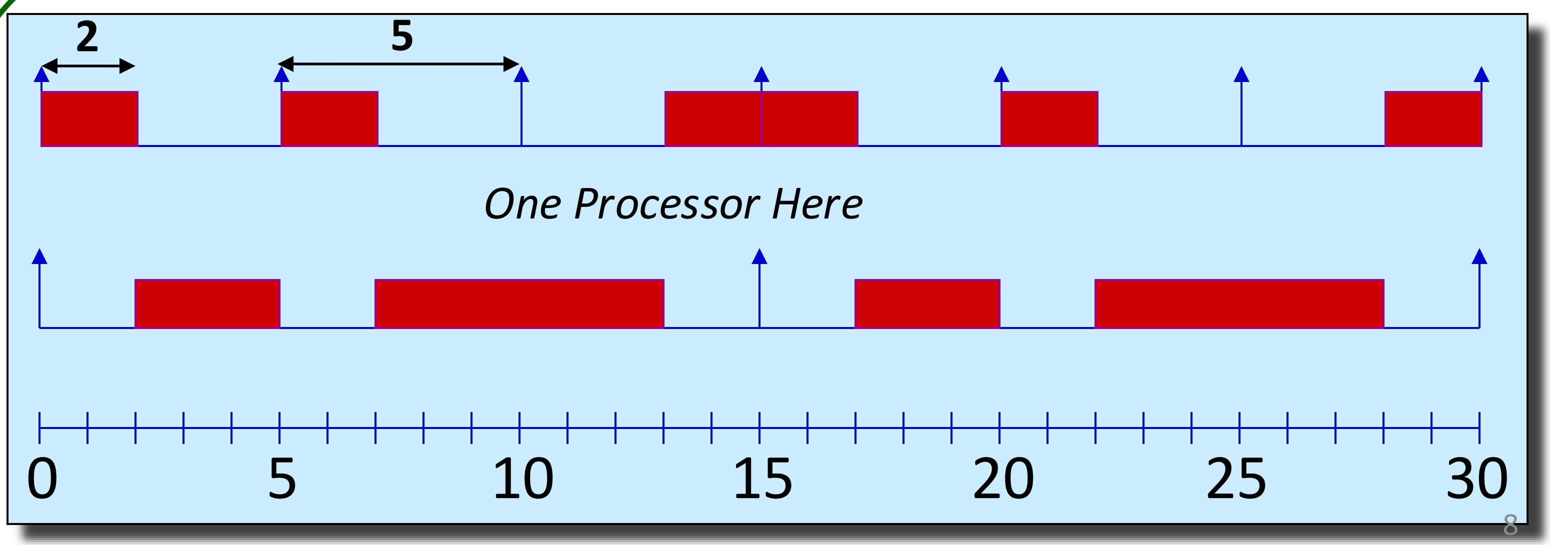
T_1 = (2,5)

2/5

T_2 = (9,15)



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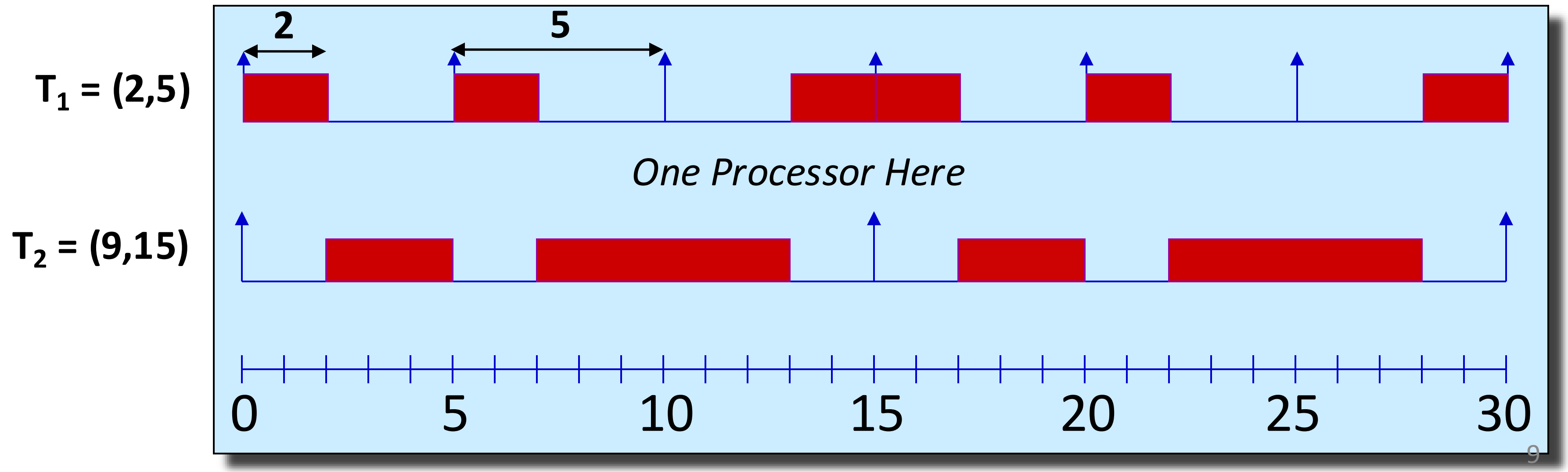
  - Each job of T_i has a *deadline* at the next job release of T_i.



Periodic Task Systems

- Set τ of **periodic tasks** scheduled on **M cores**:
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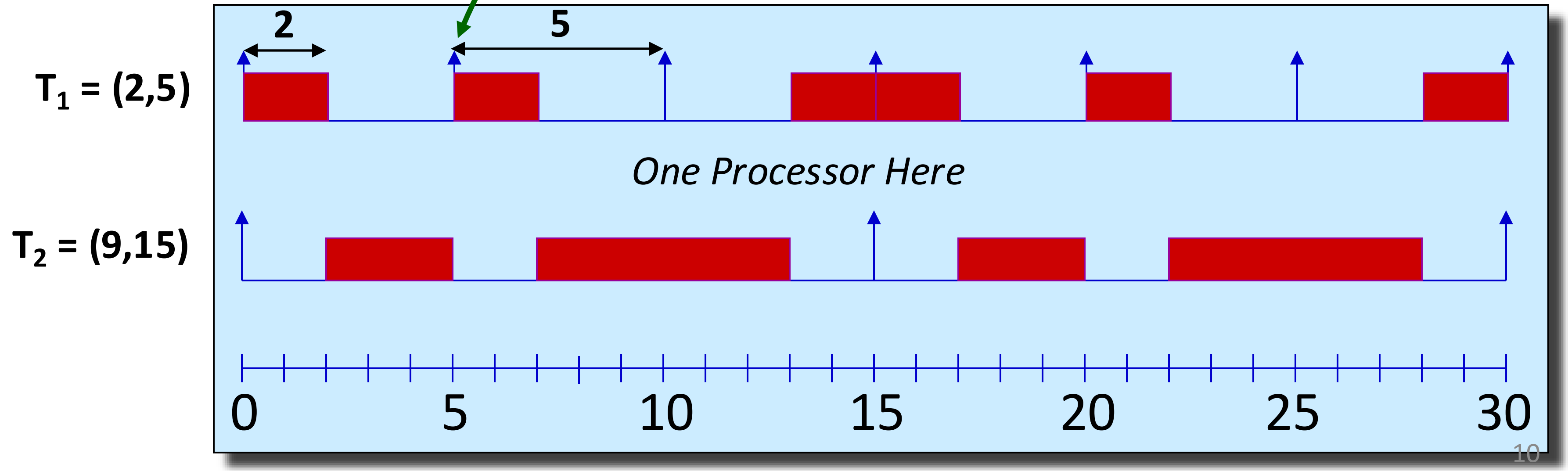

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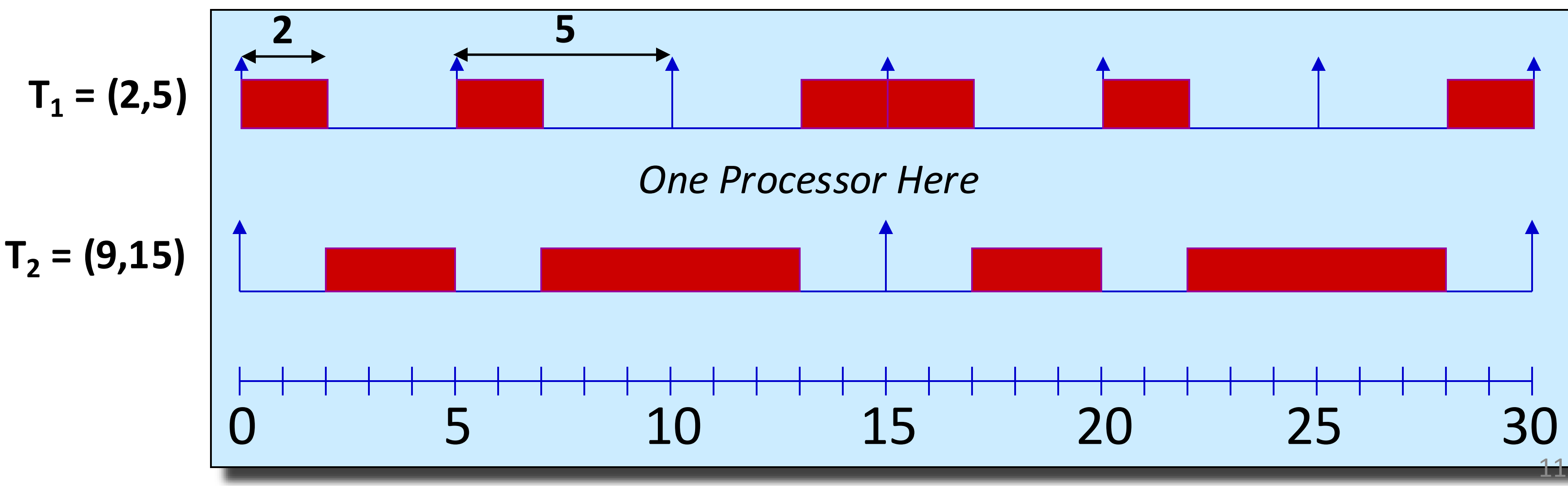
This is an example of an earliest-deadline-first (EDF) schedule.



Scheduling vs. Schedulability

- W.r.t. scheduling, we actually care about <u>*two*</u> kinds of algorithms:

Utilization loss occurs when a test requires utilizations to be restricted to get a "yes" answer.

deadlines higher priority

– **Schedulabi test**.

no timing requirement will be violated if τ is scheduled with EDF

τ → Test for EDF → yes / no

a timing requirement will (or may) be violated …

Optimality and Feasibility

- A schedule is **feasible** if all timing constraints are met
- A task set τ is **schedulable** using scheduling algorithm A if A produces a feasible schedule for τ
- A scheduling algorithm is **optimal** if it provides a feasible schedule for a schedulable task set

Static-Priority Scheduling

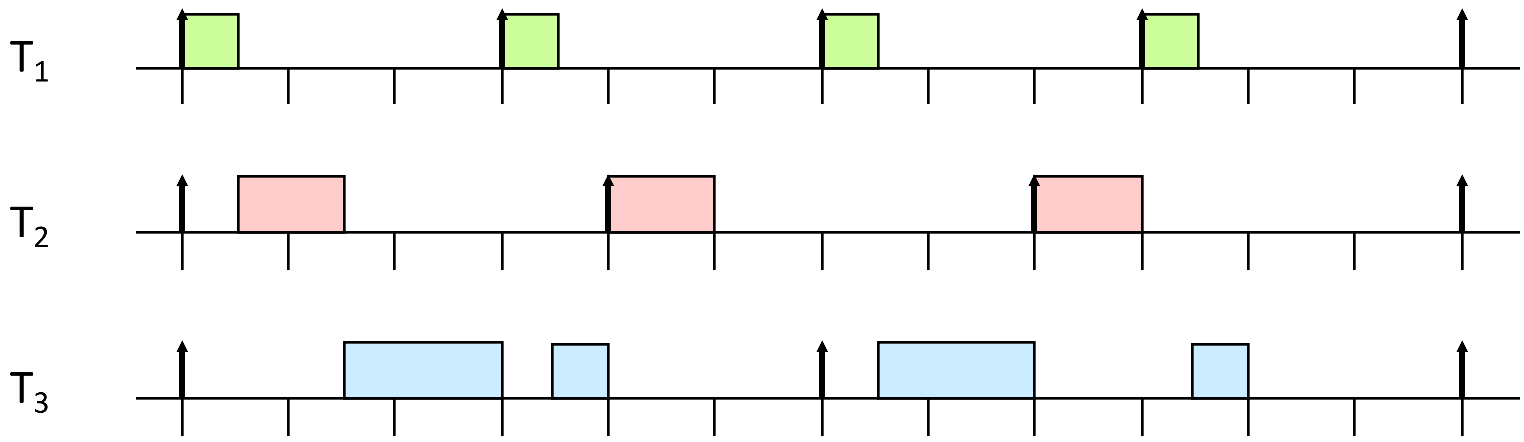
- Under fixed-priority scheduling, different jobs of a task are assigned the same priority.
- We will assume that tasks are indexed in decreasing priority order, i.e., T_i has higher priority than T_k if $i < k$.
- The ready task with the highest priority is always scheduled.

Rate-Monotonic Scheduling

(Liu and Layland)

Priority Definition: Tasks with smaller periods have higher priority.

Example Schedule: Three tasks, $T_1 = (0.5, 3)$, $T_2 = (1, 4)$, $T_3 = (2, 6)$.

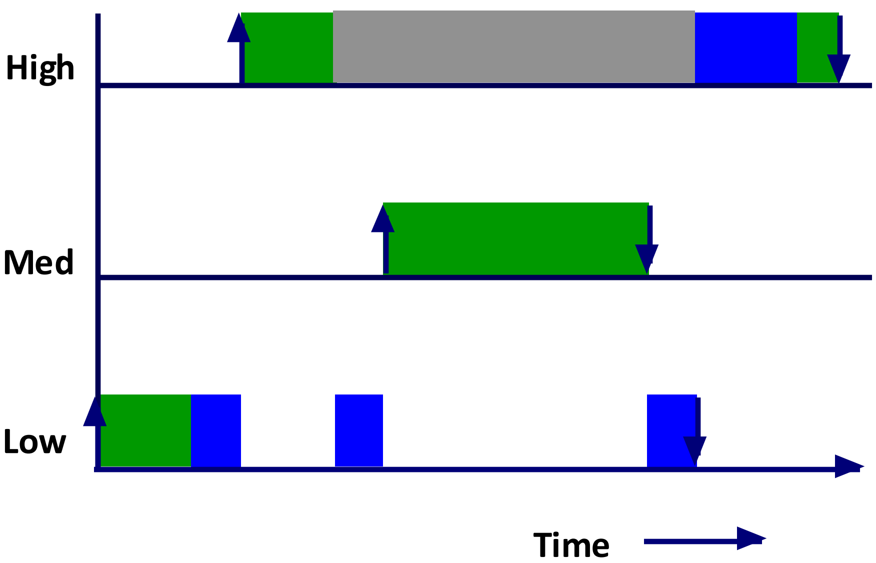


RT Synchronization 101

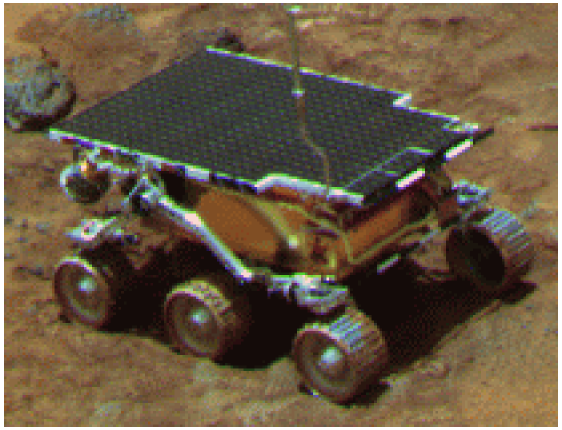
Priority Inversions

So far we've assumed all jobs are independent.
A *priority inversion* occurs when a high-priority job is blocked by a low-priority one.

This is bad because HP jobs usually have more stringent timing constraints.



Critical Section **Priority Inversion** **Computation Outside of CS's**



Mars Pathfinder infamously had a priority inversion when deployed and it almost caused a mission failure. A patch was sent remotely patched to fix.

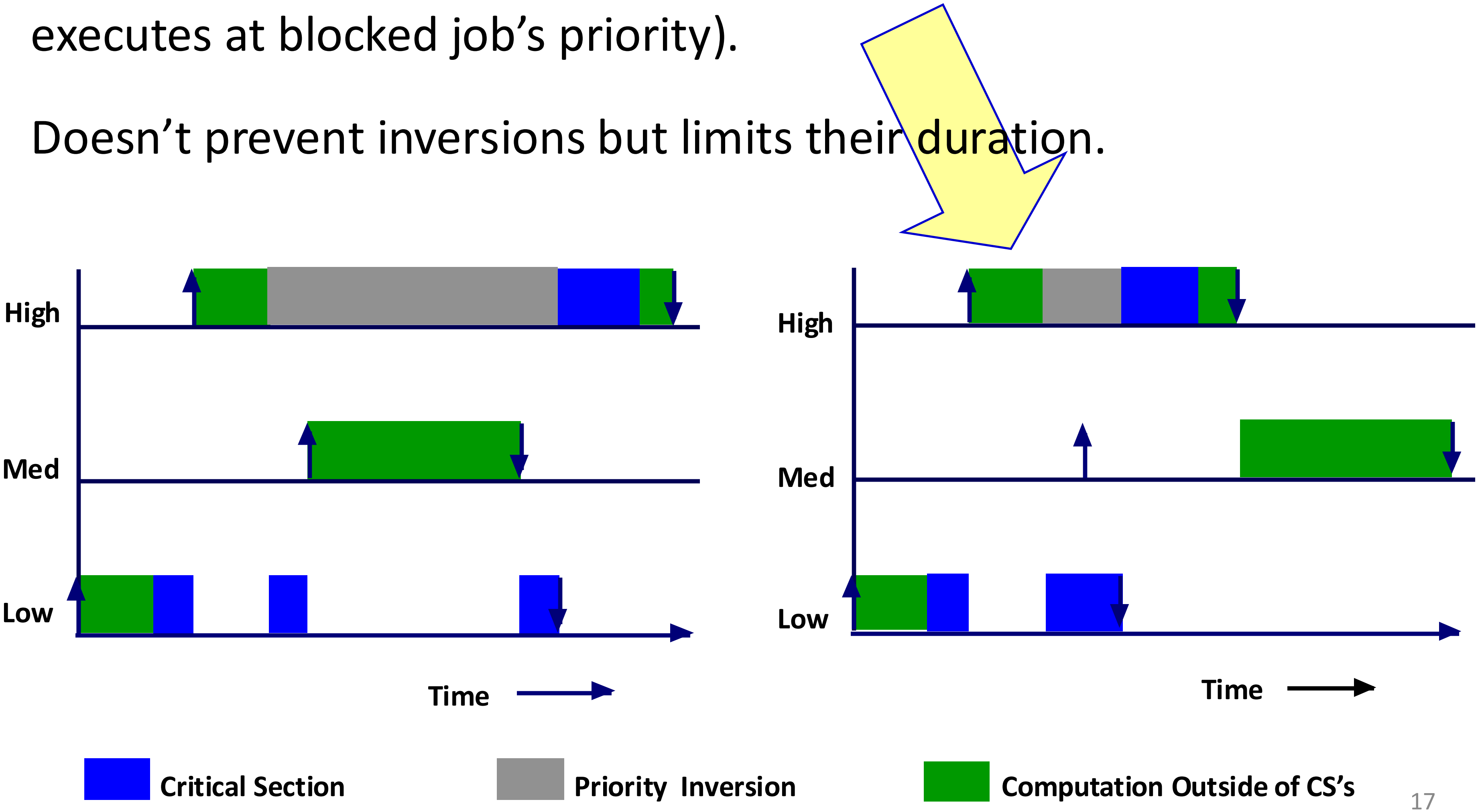
https://www.rapitasystems.com/blog/what-really-happened-software-mars-pathfinder-spacecraft

RT Synchronization 101

Priority Inheritance

A Common Solution: Use ***priority inheritance*** (blocking job executes at blocked job's priority).

Doesn't prevent inversions but limits their duration.



Scheduler Classes

- Linux has different algorithms for scheduling different types of processes
  - Called scheduler classes
- Each class implements a different but "pluggable" algorithm for scheduling
  - Within a class, you can set the policy
- RT class: `SCHED_FIFO`, `SCHED_RR`

- Non-RT class: `SCHED_OTHER` (CFS)

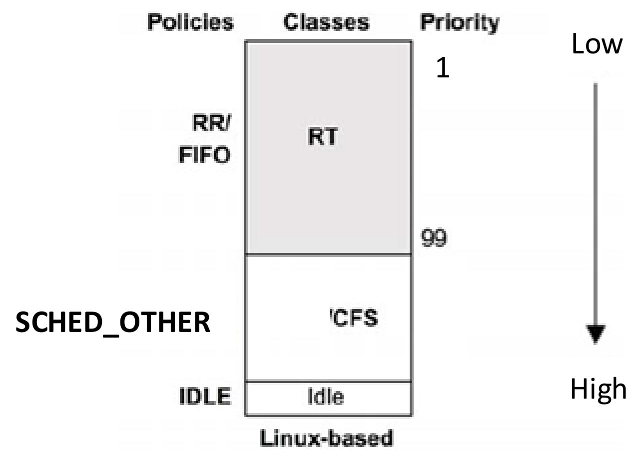


Figure from, "*Systems Performance: Enterprise and the Cloud*" by Brendan Gregg

Exercise

Consider two processes, T1 and T2, where $p1 = 50$, $e1 = 25$, $p2 = 75$, $e2 = 30$.

Illustrate the scheduling of these two processes using

- earliest-deadline-first (EDF) scheduling
- rate-monotonic scheduling

Exercise

Let A, B, and C be three tasks. A has the highest priority and C has the lowest priority. A and C use a shared resource protected by a mutex.

Suppose a scheduler makes decisions about scheduling tasks based on their priorities. That is, the scheduler runs, among tasks, the one with the highest priority. Such a task runs to completion or blocks for any reason.

- What are the completion times of A, B, C before applying the priority inheritance?
- What are the completion times of A, B, C after applying the priority inheritance?

Summary

- Real-time systems differ from general-purpose ones in that there exist timing requirements
- Common in cyber-physical and safety-critical systems, such as avionics, automotive, and other embedded devices.
- Timing requirements inform how scheduling should be handled
- Many classes of real-time scheduling algorithms
- Analysis complements the scheduling implementation to prove temporal correctness