K22 - Operating Systems: Design Principles and Internals

Fall 2025 @dit

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Lecture 13

References: Similar OS courses @Columbia, @Stanford, @UC San Diego, @Brown, @di (previous years); and textbooks: Operating Systems: Three Easy Pieces, Operating Systems: Principles and Practice, Operating System Concepts, Linux Kernel Development, Understanding the Linux Kernel

```c
/*
 * test_k22tree.c
 *
 * Υλοποίηση του userspace προγράμματος που:
 *  1. Κάνει iterative doubling μέχρι να χωρέσει όλο το δέντρο διεργασιών
 *  2. Καλεί το k22tree syscall
 *  3. Τυπώνει το αποτέλεσμα σε δενδρική μορφή (pre-order DFS)
 *  4. Χρησιμοποιεί stack για να υπολογίσει depth
 *
 * Τα σχόλια είναι αναλυτικά και γραμμένα ώστε να φαίνεται ξεκάθαρα
 * ότι η εργασία έγινε από εμένα.
 */

#include <stdio.h>
#include <unistd.h>
#include <sys/syscall.h>

#include <linux/k22info.h>

#ifndef __NR_k22tree
#define __NR_k22tree 467
#endif
```

Programming assignment #1

> Reasons for teams that got zero?

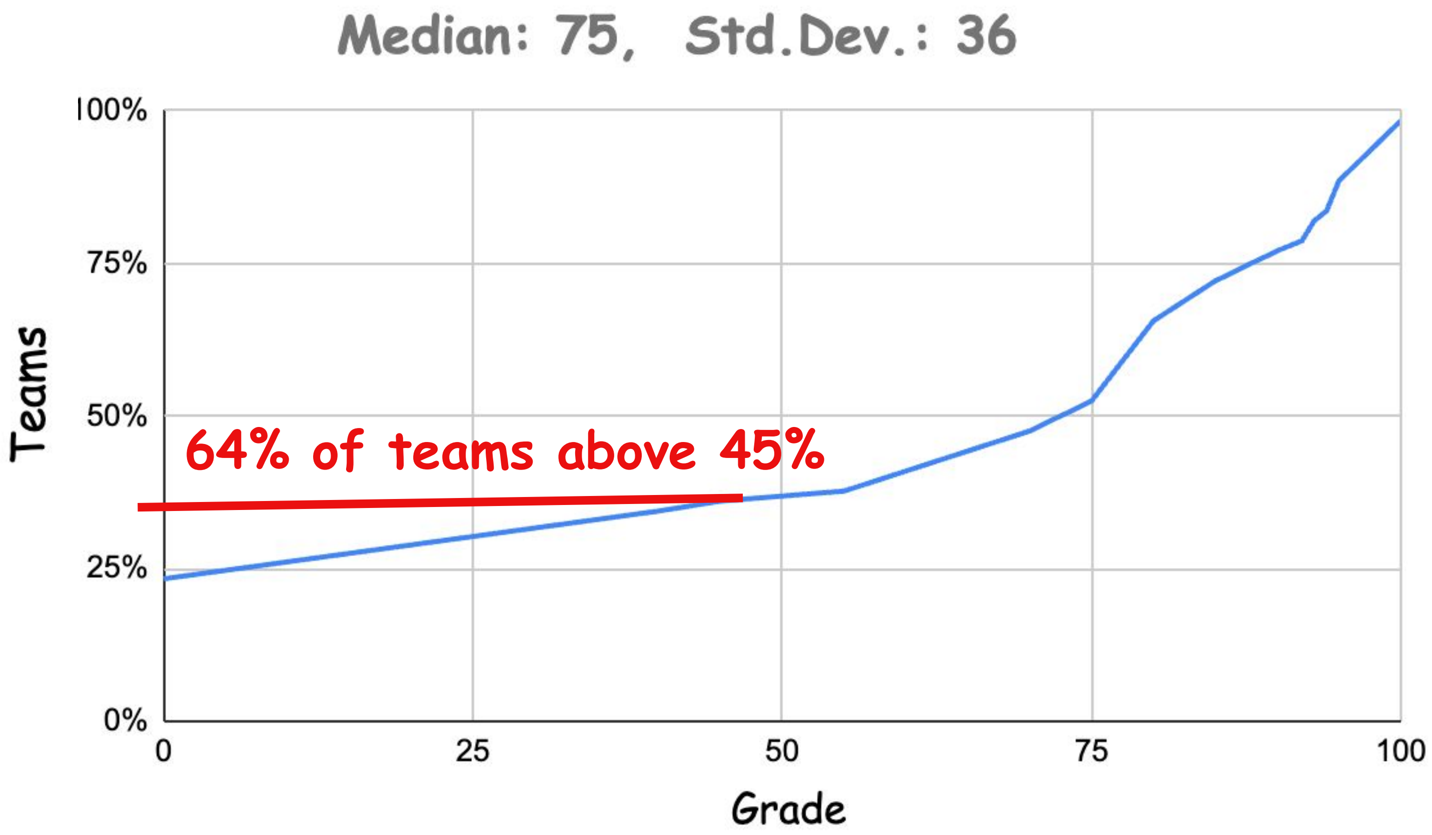
- **Correctness is not incremental**
  > The mentality "*my code is correct to an extend*" stops in K22.

- **If you cannot use a linter or git to produce/apply a patch**
  > You are not ready for this course

- **If you superficially ctrl-c/ctrl-v whatever LLMs produce**
  > You are not ready for this school

- **Finally:** Recursion is not for the kernel <- Let LLMs know about it

Programming assignment #1



Programming assignment #1

- Honest assessment of what's coming next

- **Programming assignment #2 is announced**
  - This is no toy system call
  - It will be painful; so, start working on it now!
  - Teams w/ < 55-60% in #1 => Reconsider taking K22
  - You are welcome to stay with us

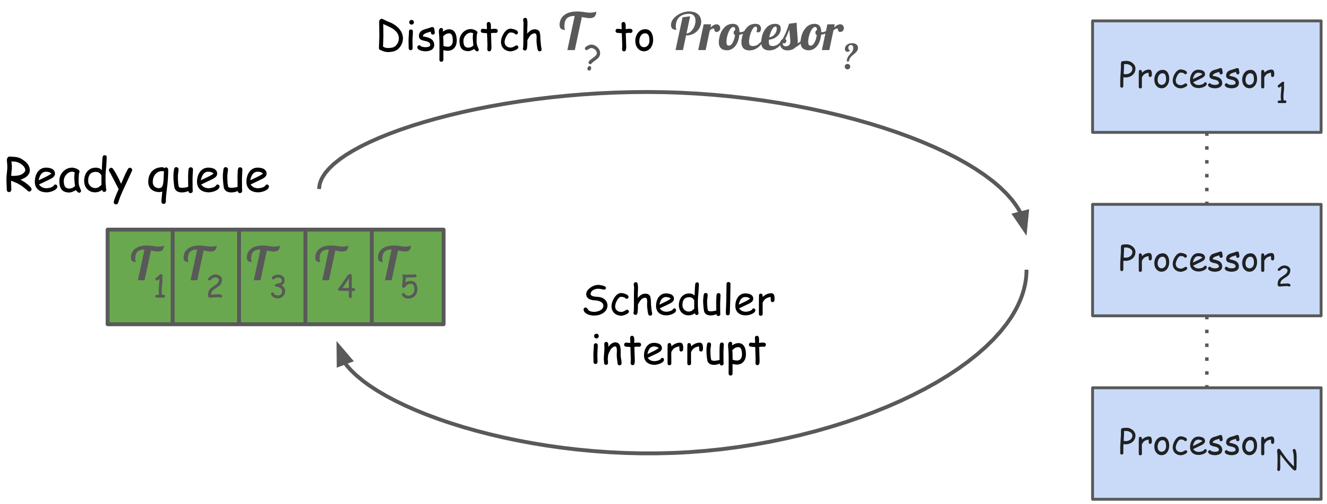
Overview

- We'll start from hardware and follow a question-oriented approach
  - ~~Intro [Q: What is an OS?]~~
  - ~~Events [Q: When does the OS run?]~~
  - ~~Runtime [Q: How does a program look like in memory?]~~
  - ~~Processes [Q: What is a process?]~~
  - ~~IPC [Q: How do processes communicate?]~~
  - ~~Threads [Q: What is a thread?]~~
  - ~~Synchronization [Q: What goes wrong w/o synchronization?]~~
  - **Time Management [Q: What is scheduling?]**
  - Memory Management [Q: What is virtual memory?]
  - Files [Q: What is a file descriptor?]
  - Storage Management [Q: How do we allocate disk space to files?]

* Basic (H/W & S/W)
* Abstractions
* Primitives
* **Mechanisms**

The scheduling problem

> Given k tasks ready to run in a system with N available processors, which task should be dispatched to which processor at any given point in time?



The scheduling problem

> Given k tasks ready to run in a system with N available processors, which task should be dispatched to which processor at any given point in time?

> **Quantitative goals**

- Minimize avg. completion time of all jobs
- Minimize the avg. response time of all jobs (latency)
- Maximize #jobs completed per unit of time (throughput)

The scheduling problem

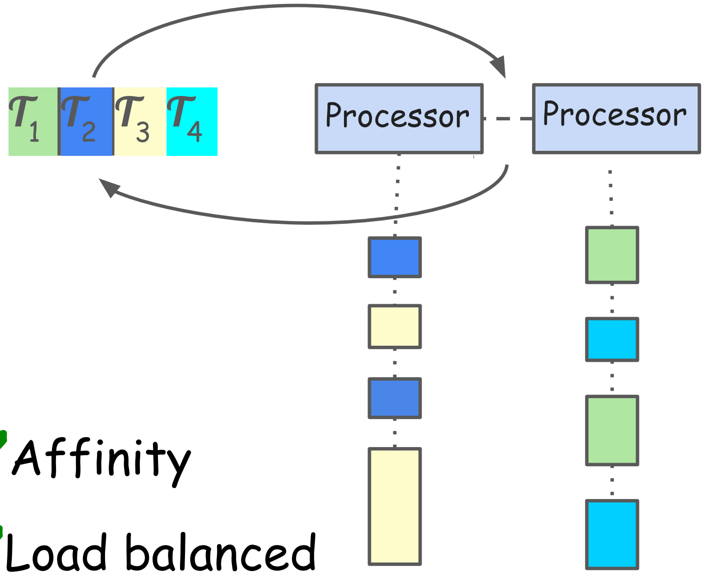
> Given k tasks ready to run in a system with N available processors, which task should be dispatched to which processor at any given point in time?

> **Qualitative goals**

- Jobs receive a similar share of available processors' time
- Upper bound on the maximum latency of jobs
- Uniform load across all available processors

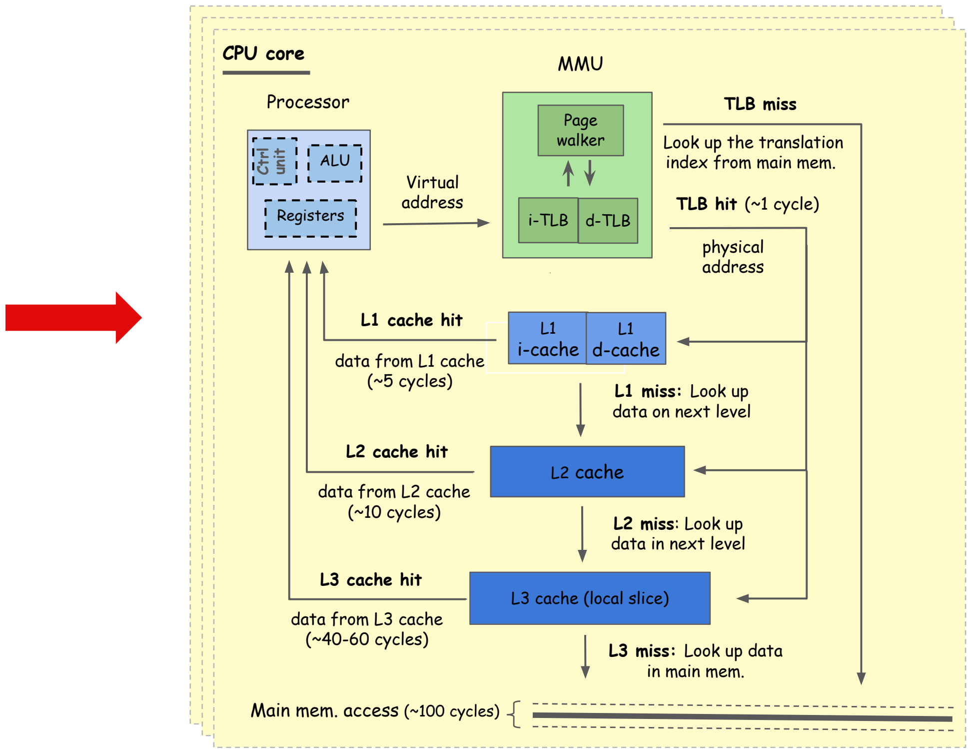
SMP load balancing and processor affinity

Processor affinity?



✔Affinity

✔Load balanced



Workloads and scheduling requirements

Real time workloads: Hard real time and soft real time

- Hard real time
  - Their tasks must finish within specific deadlines
  - Example: Pacemakers, Airbag deployment systems, Autopilots
  - Sched. goals: **Zero miss rate; Guarantees every time**
  - Sched. algorithms: Earliest Deadline First (EDF)
- Soft real time
  - Their tasks must receive priority over lower-priority tasks
  - Example: Video Streaming / Multimedia applications
  - Sched. goals: **Bounded latency**
  - Sched. algorithms: Priority-based scheduling

Workloads and scheduling requirements

CPU- vs I/O-bound workloads

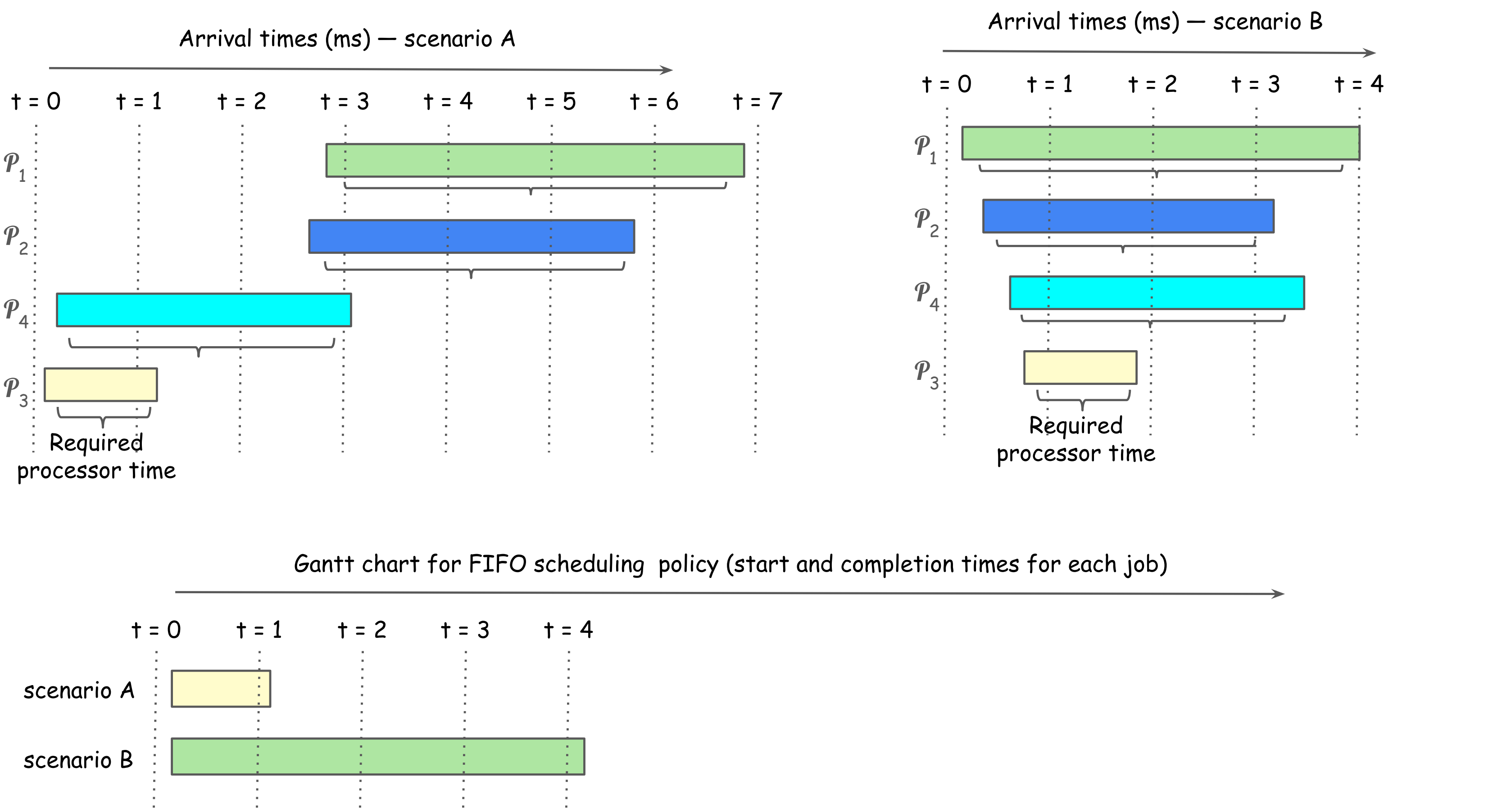
- CPU-bound
  - Their tasks spend most time doing intensive computation
  - Rarely yield voluntarily and rarely need to perform I/O
  - Example: Scientific simulations / computations
  - Sched. goals: **Balanced processor time / avoid starvation**
  - Sched. algorithms: RR with large quanta

Workloads and scheduling requirements

CPU- vs I/O-bound workloads

- I/O-bound workloads
  - Their tasks spend most of their time waiting for I/O
  - Short processor bursts and then block again
  - Example: Downloading a file / fetching data from disk
  - Sched. goals: Minimize I/O device idle periods by promptly allocating the processor for the brief time needed to initiate I/O requests (usually via DMA)
  - Sched. algorithms: Priority-based favoring I/O-bound tasks

First in First Out scheduling policy (SCHED_FIFO)



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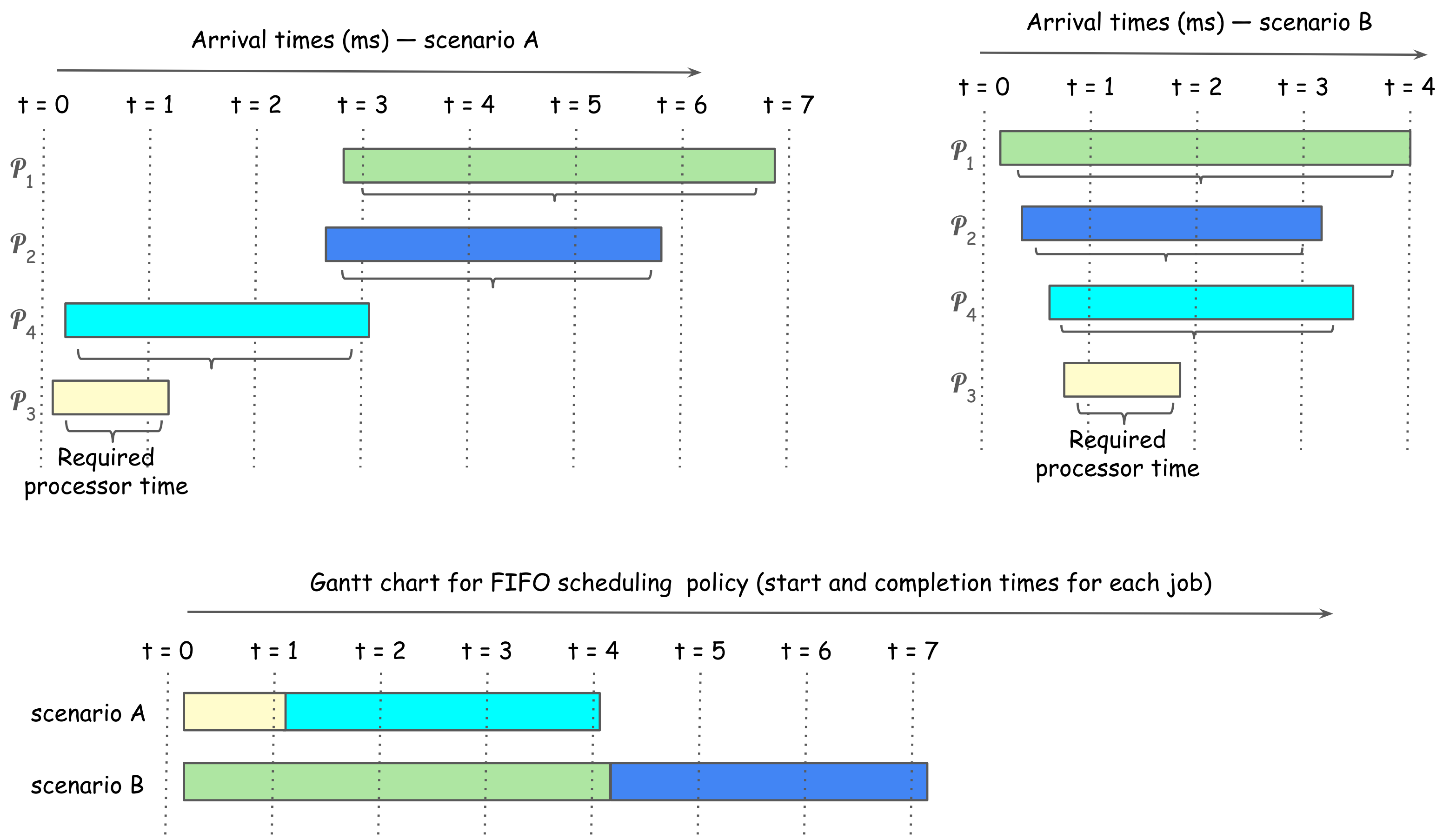

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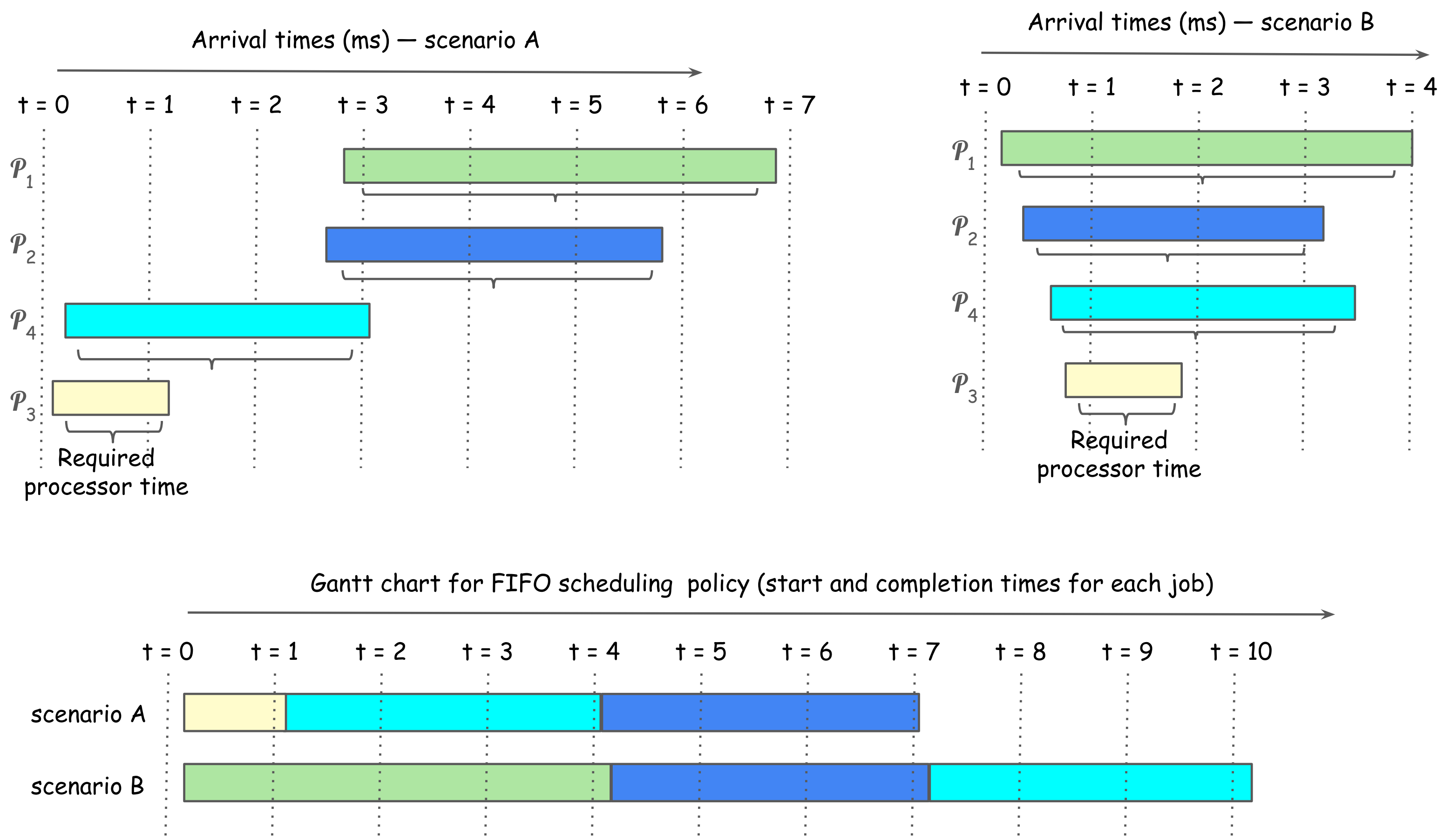

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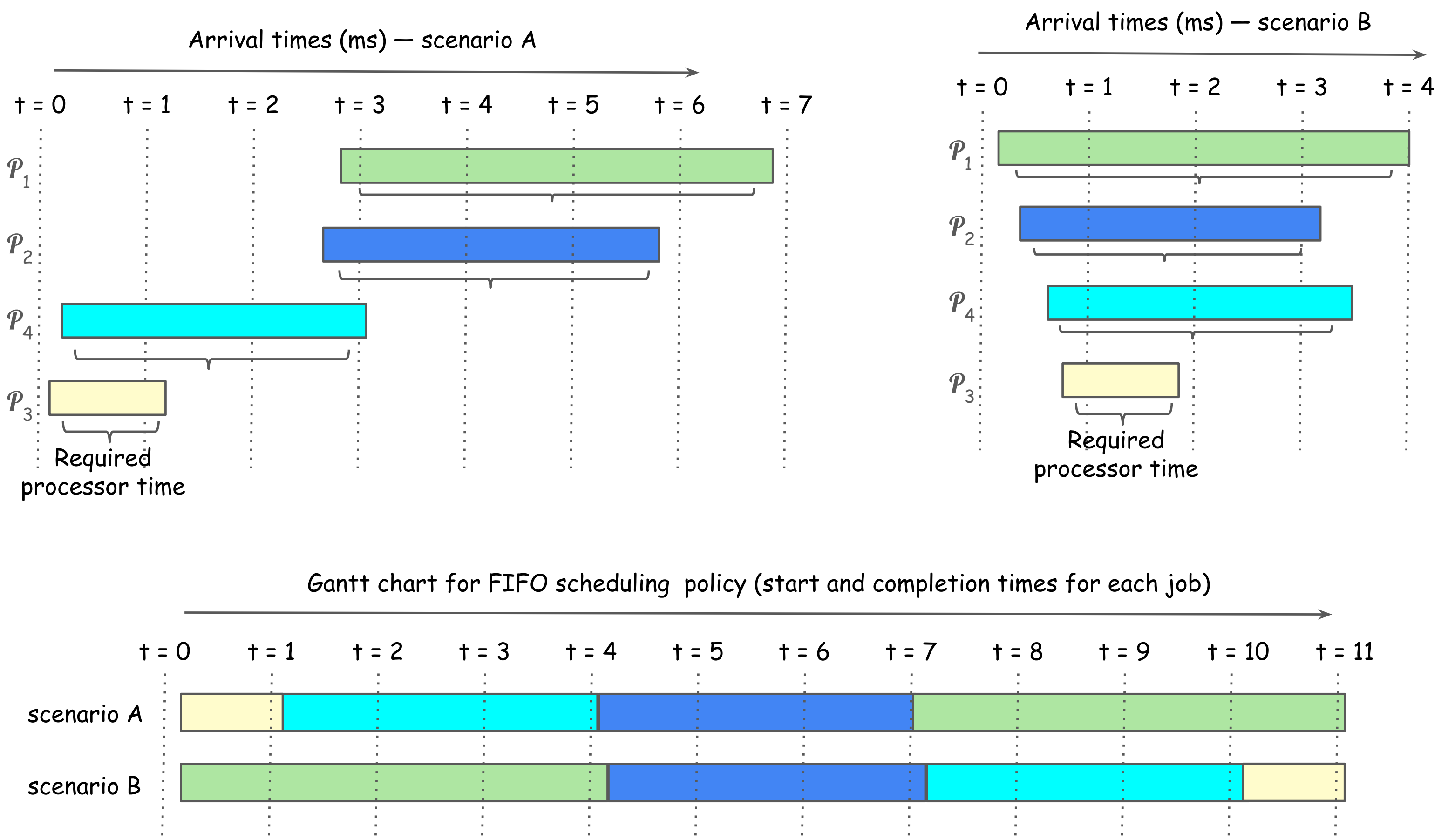
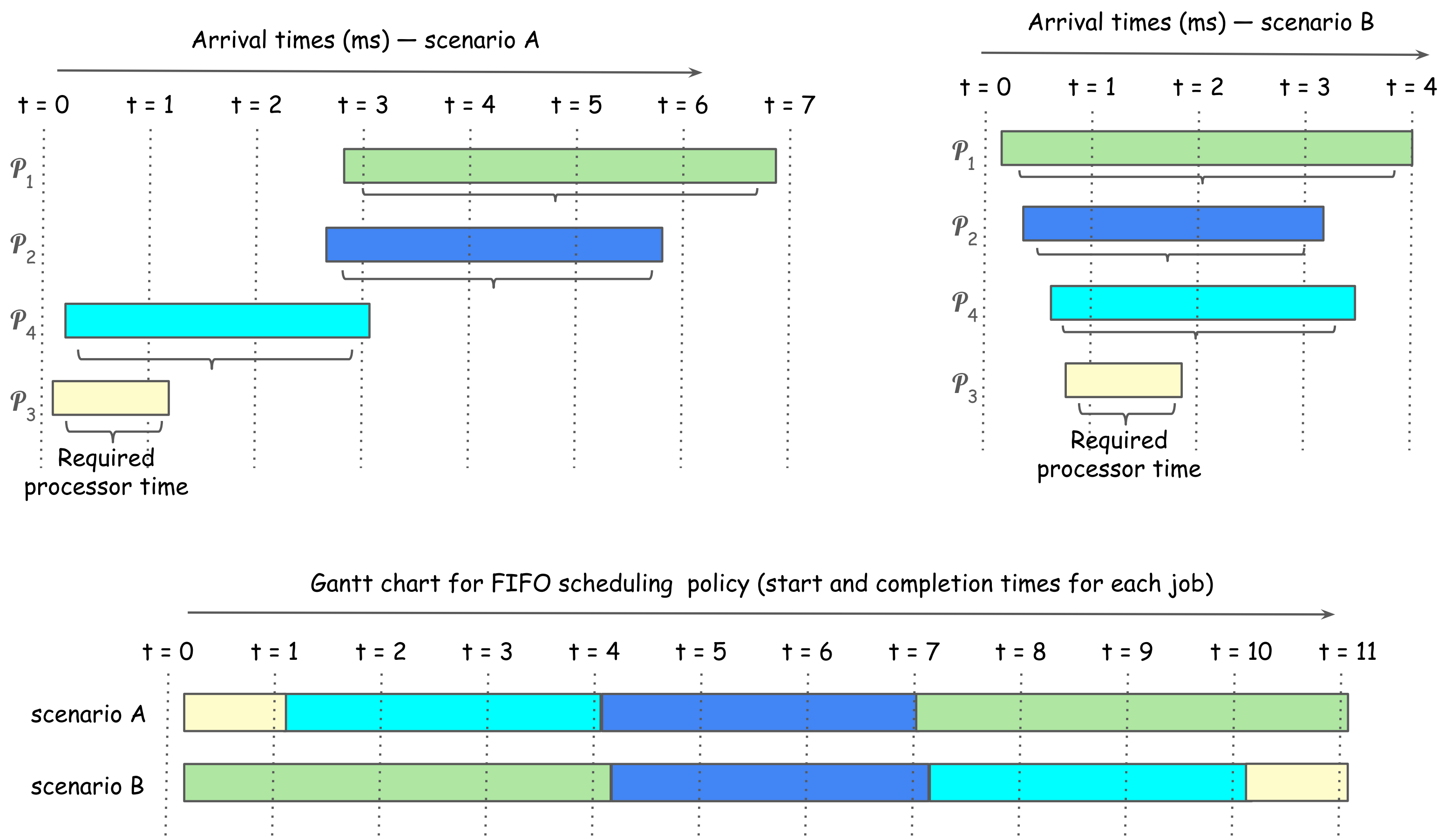
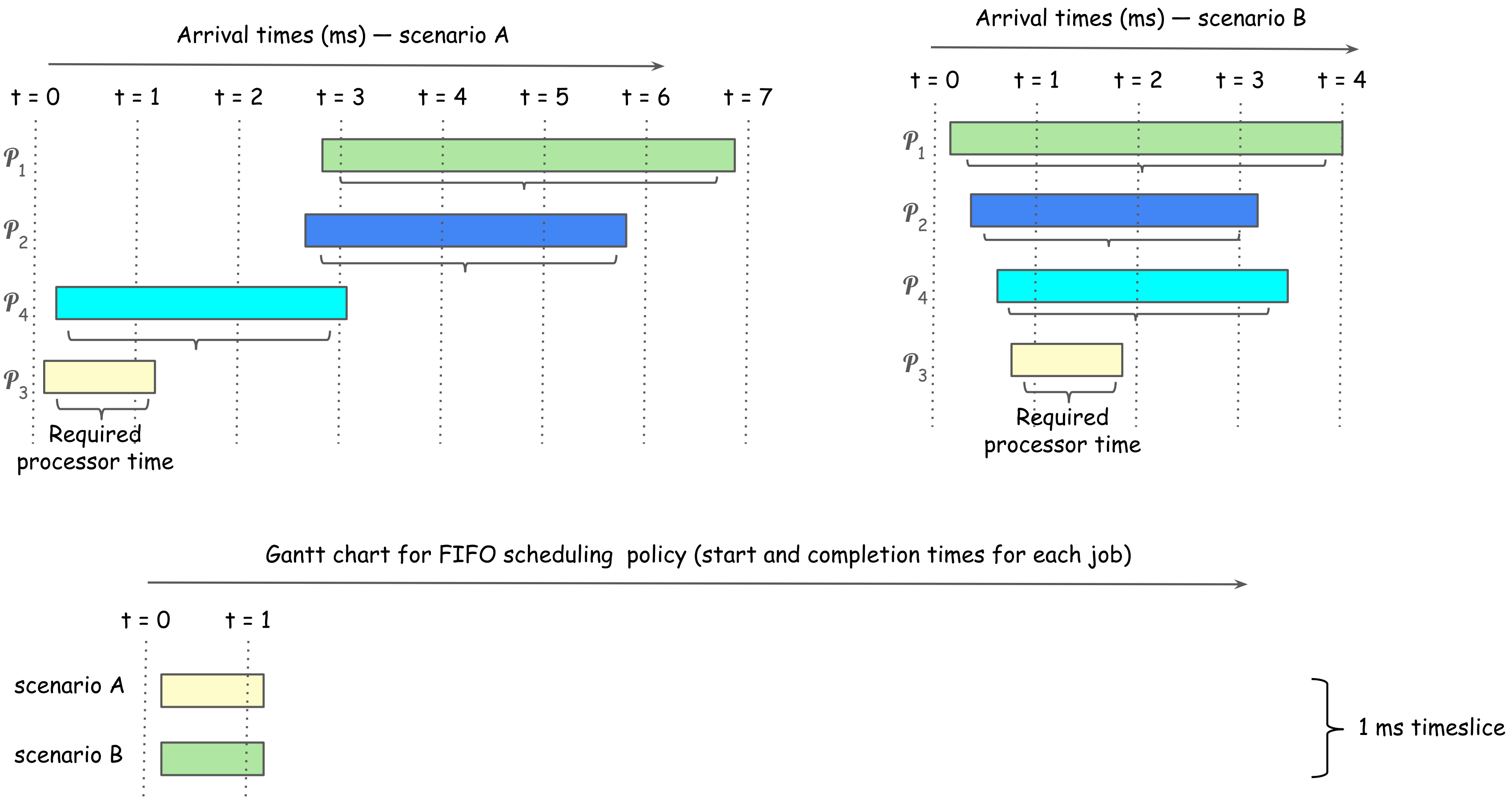


SCHED_FIFO: Avg.completion and response time?



Round Robin scheduling policy (SCHED_RR)



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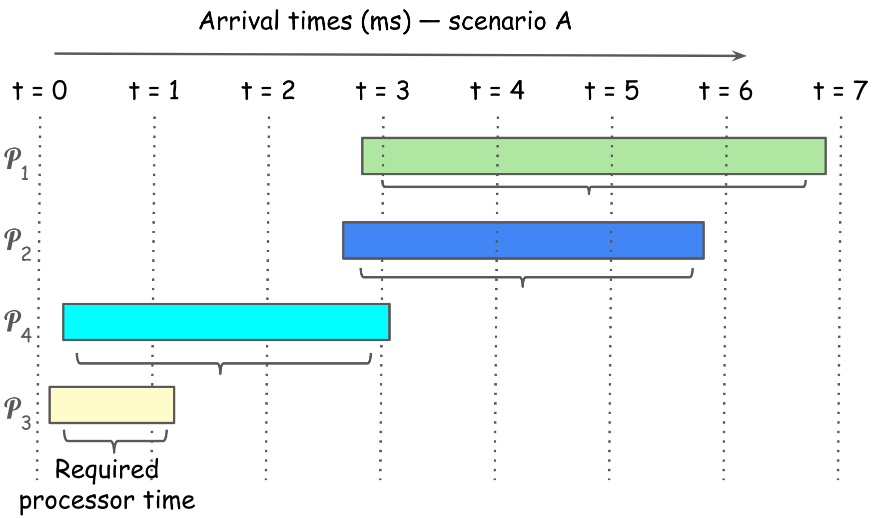

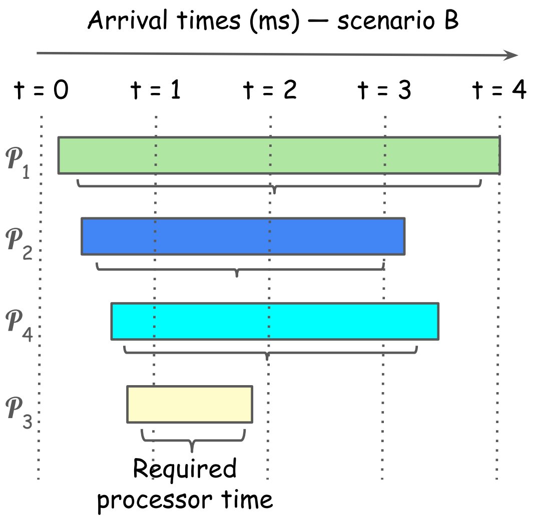

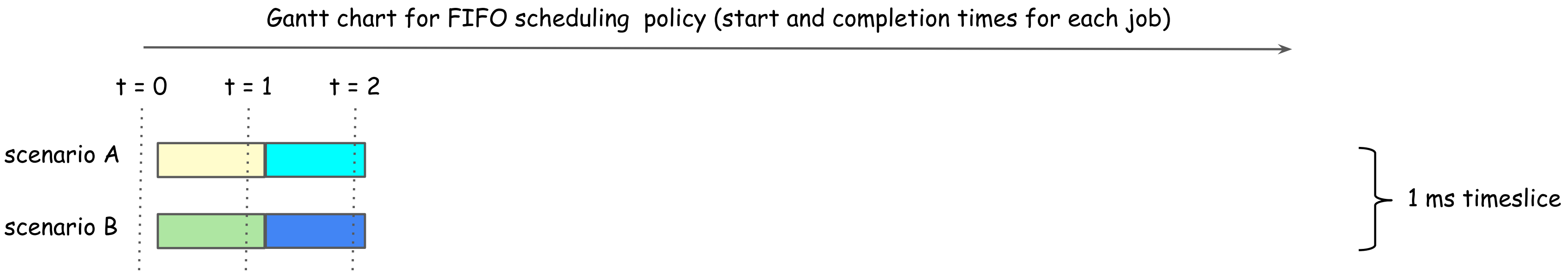

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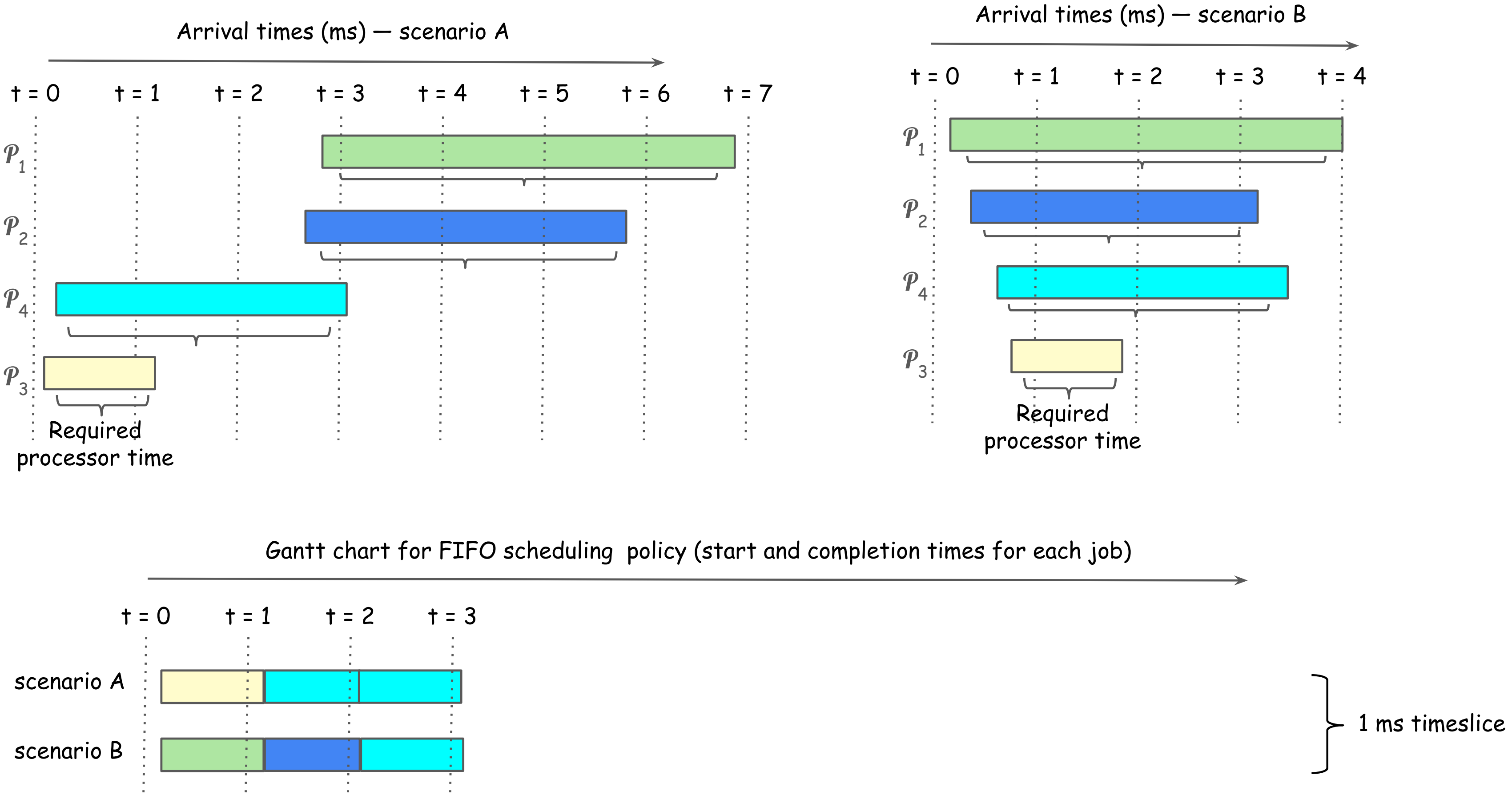

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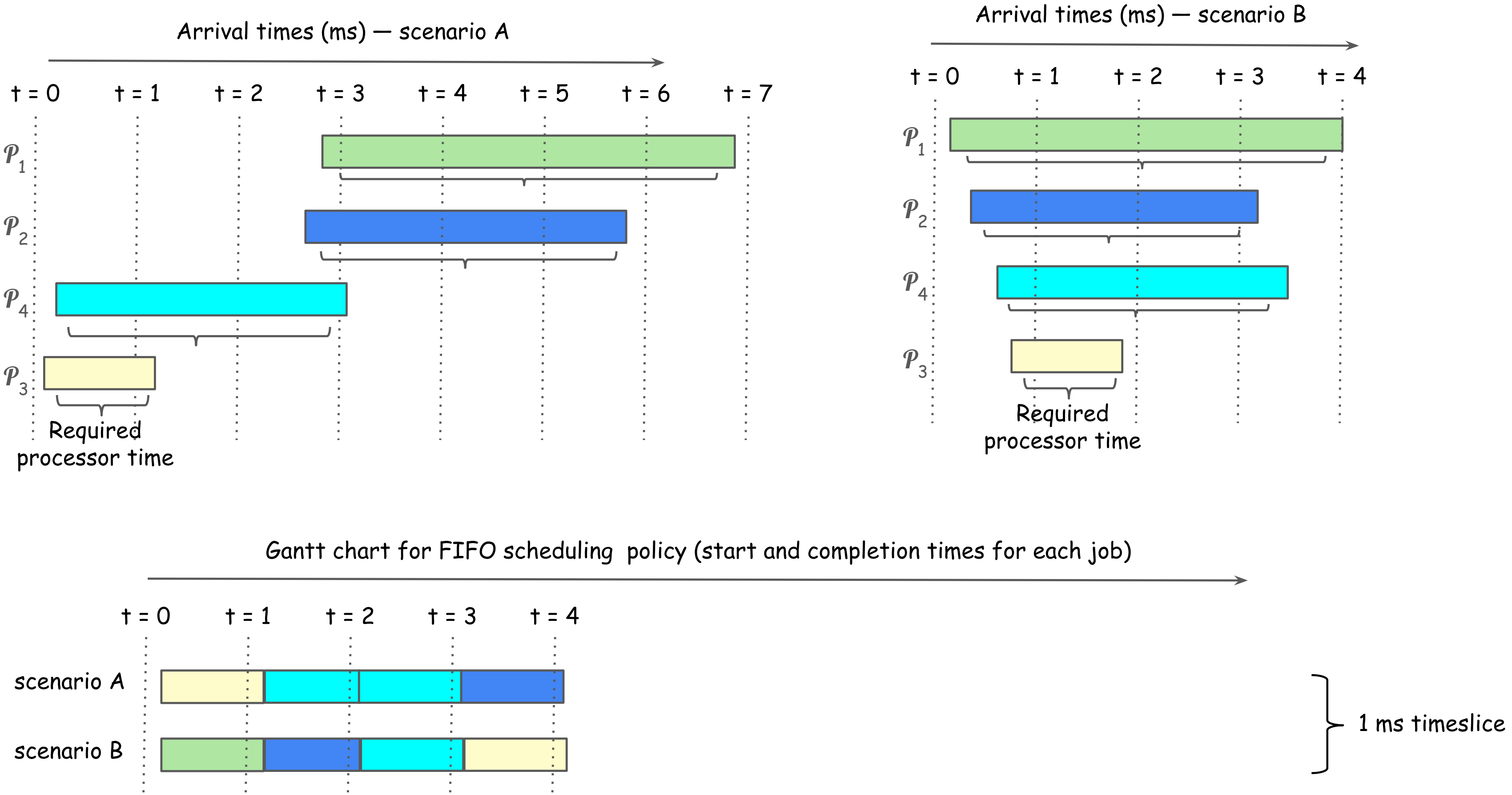

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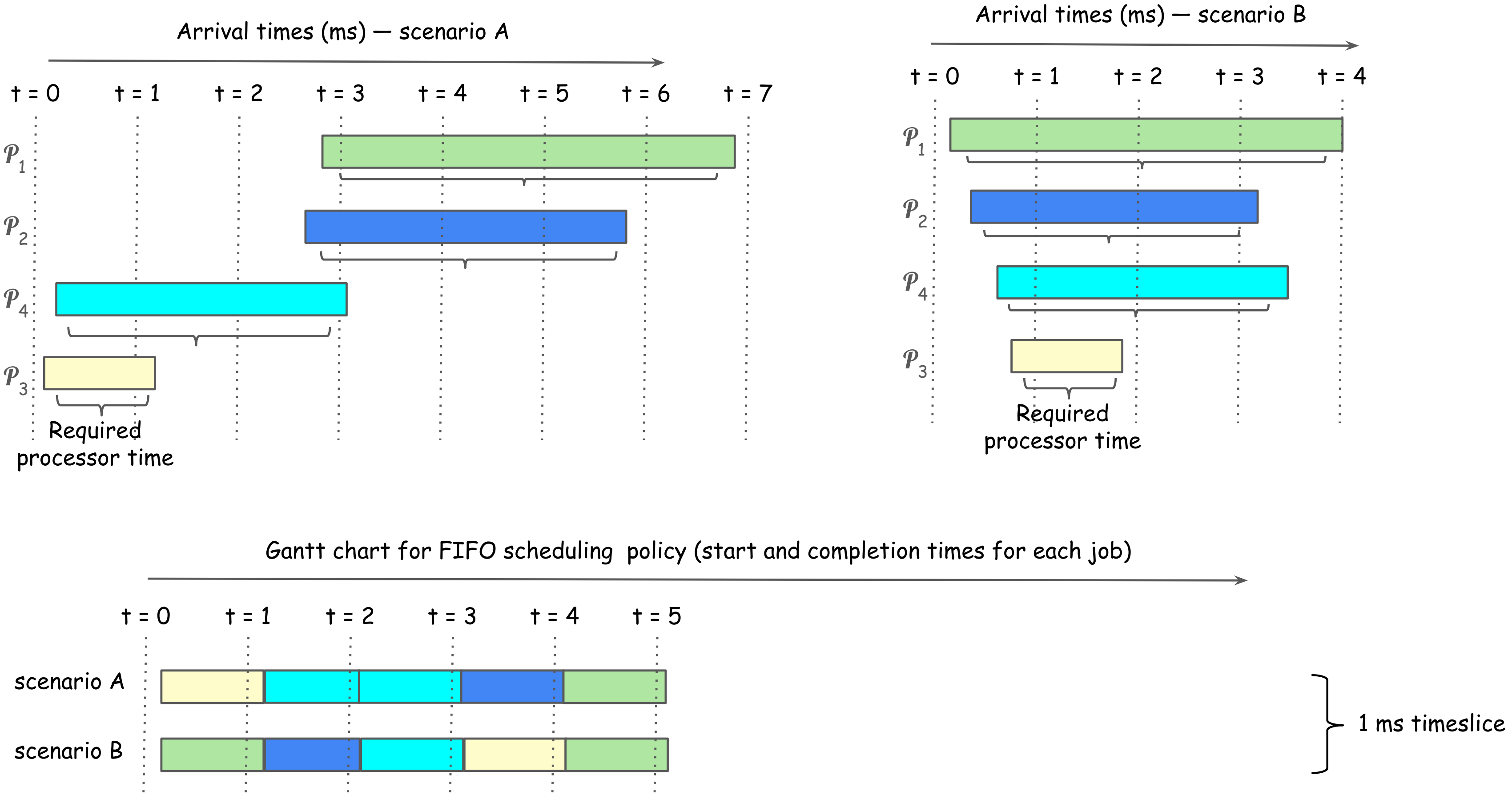

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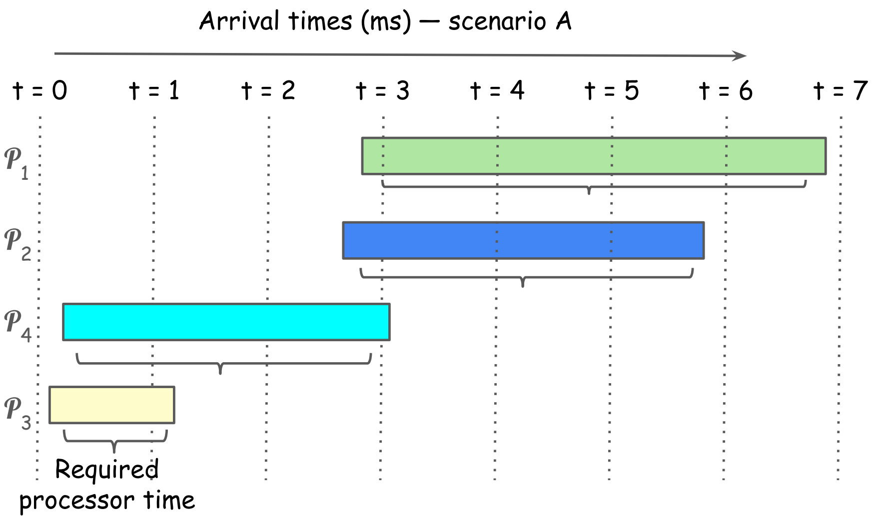

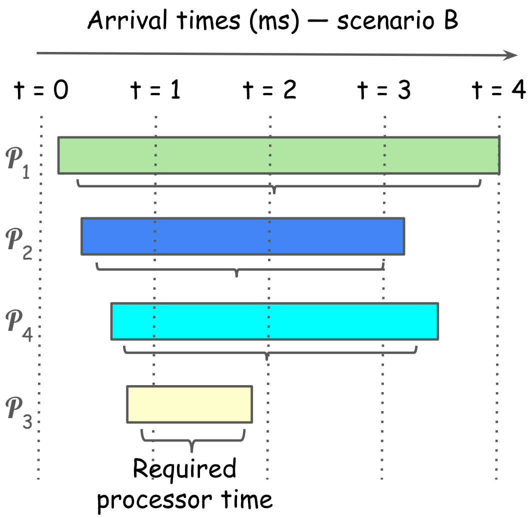

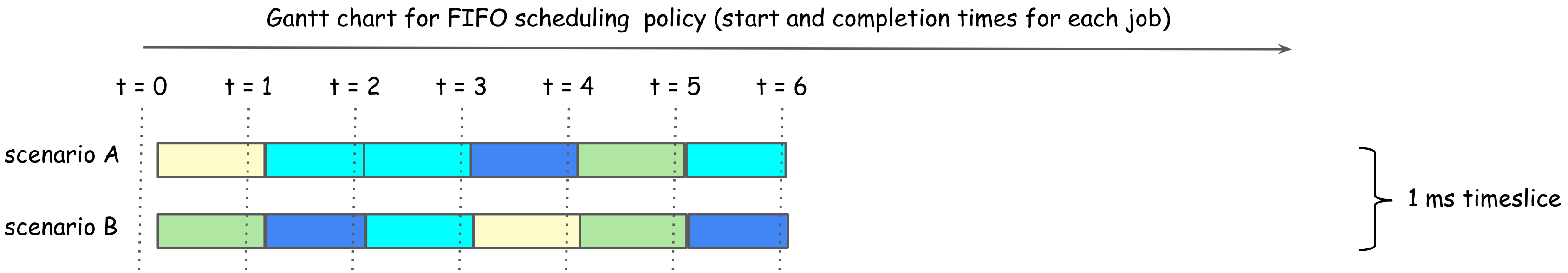

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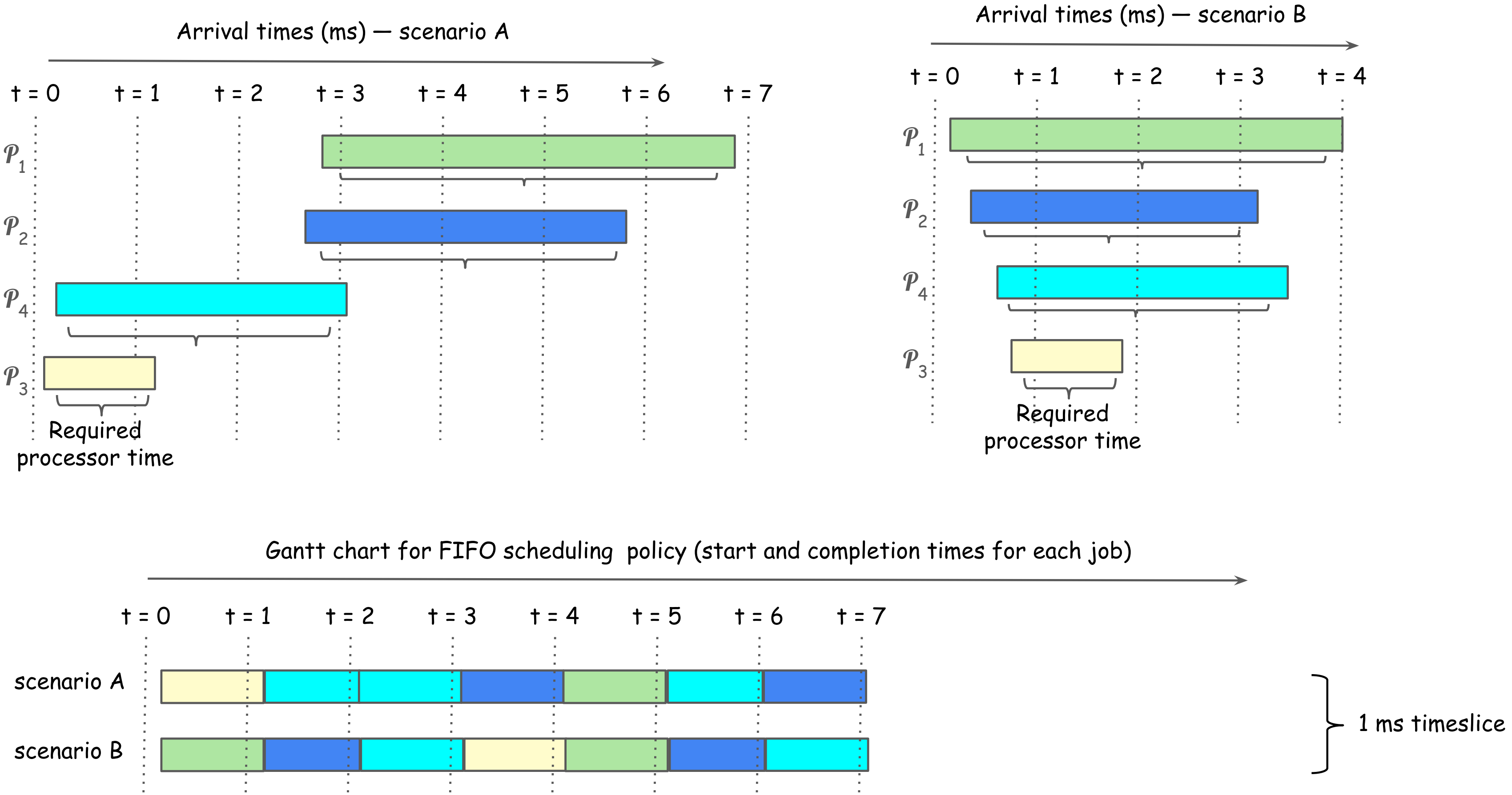

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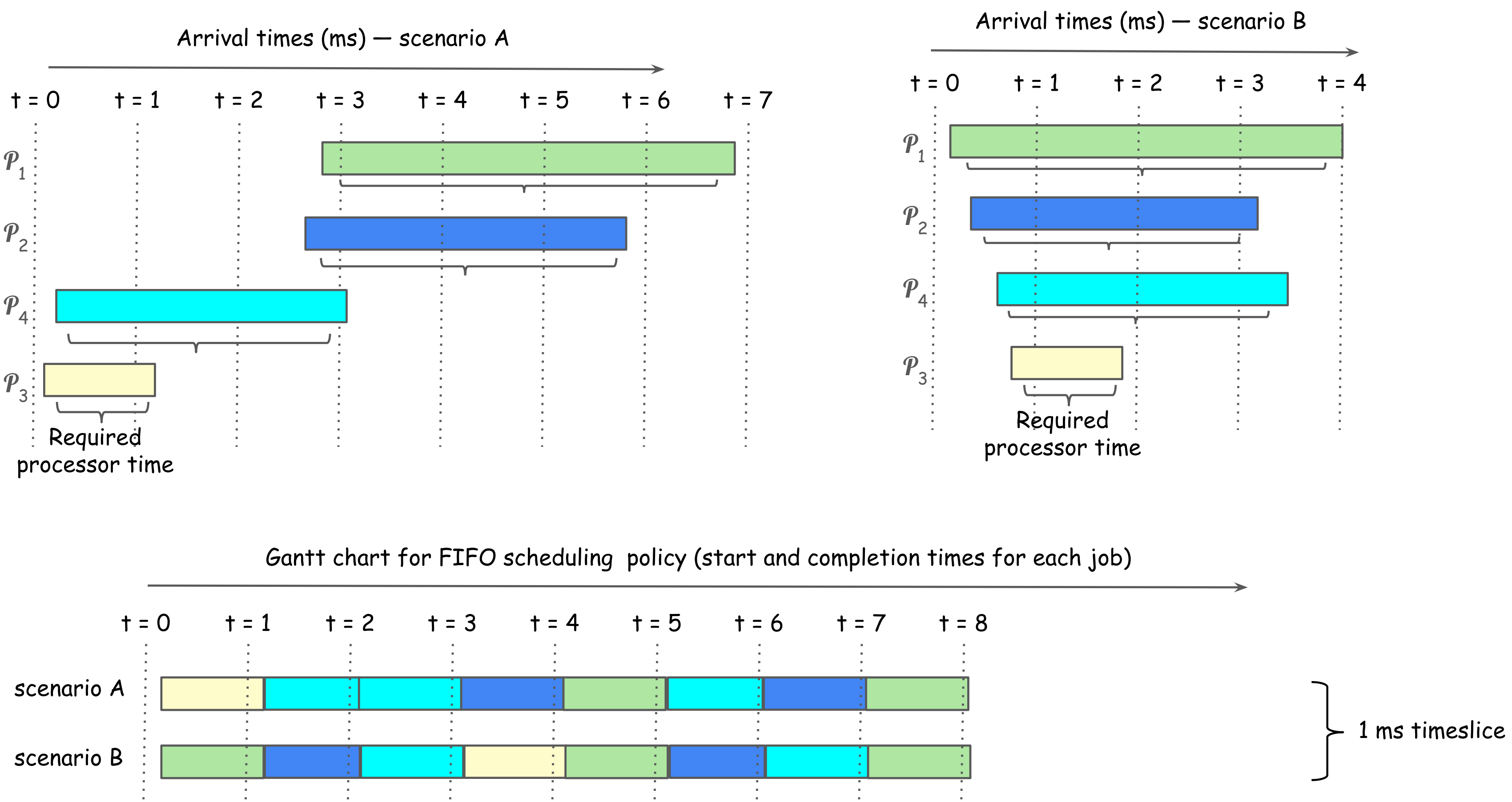

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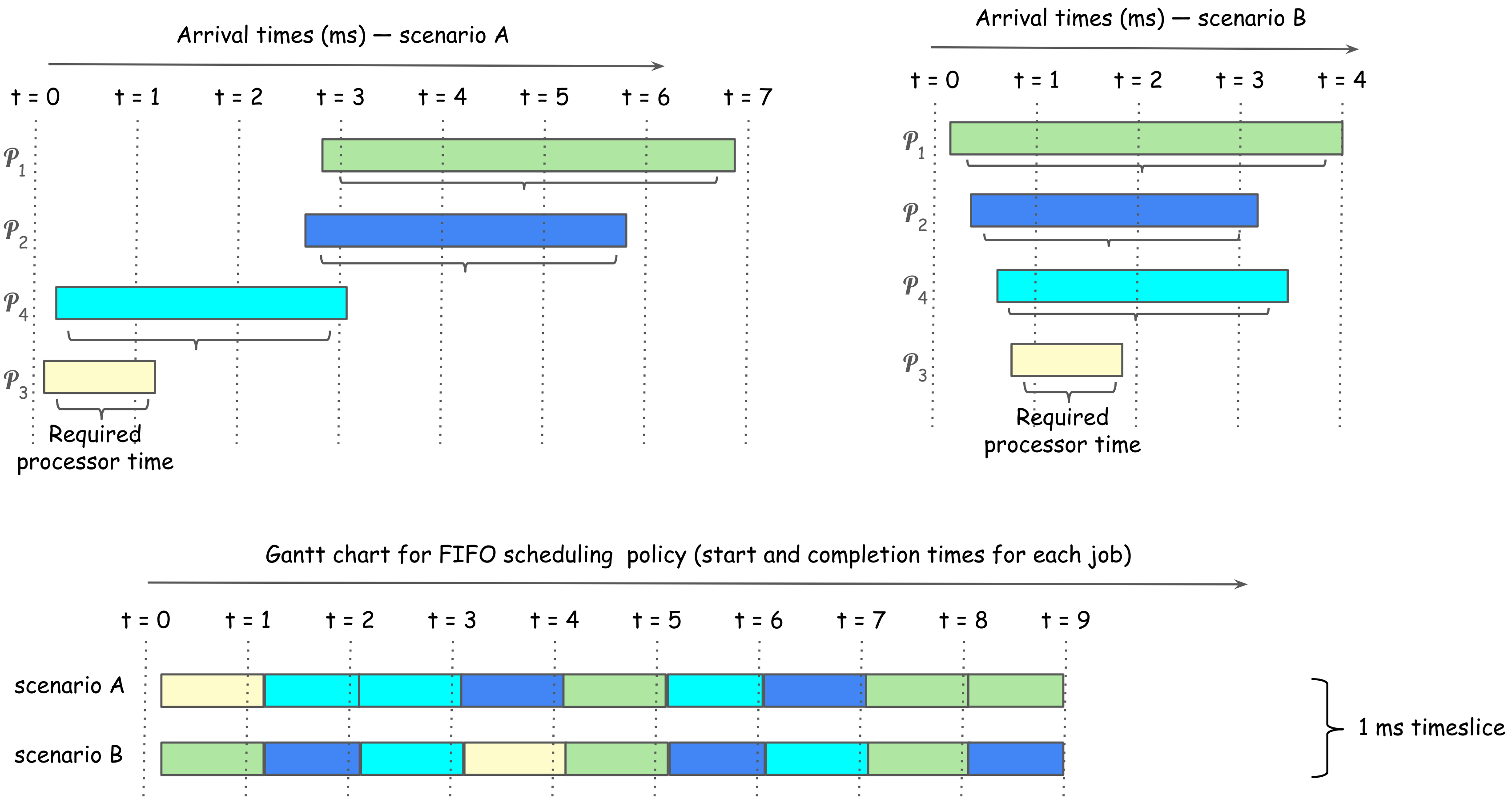

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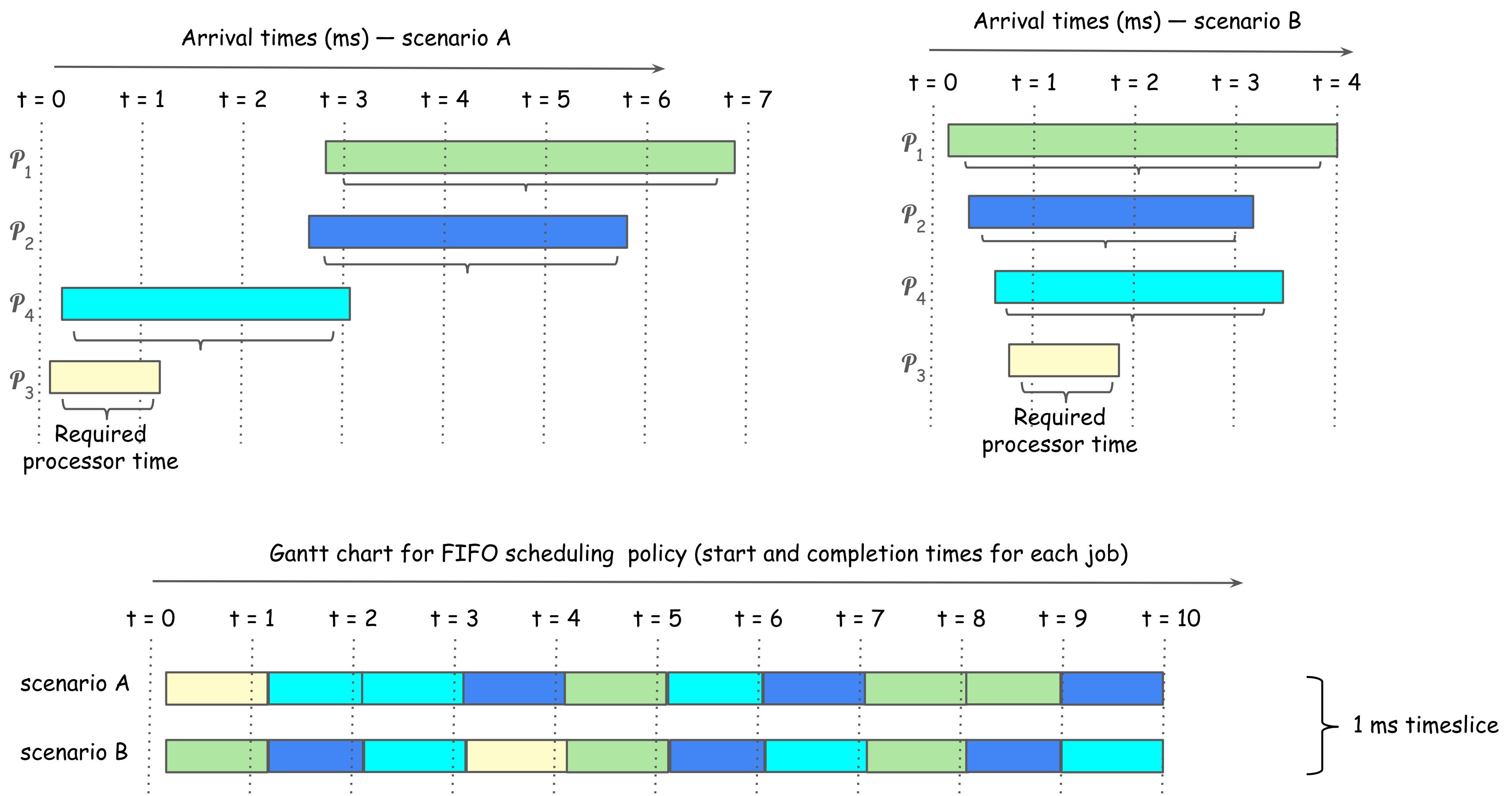

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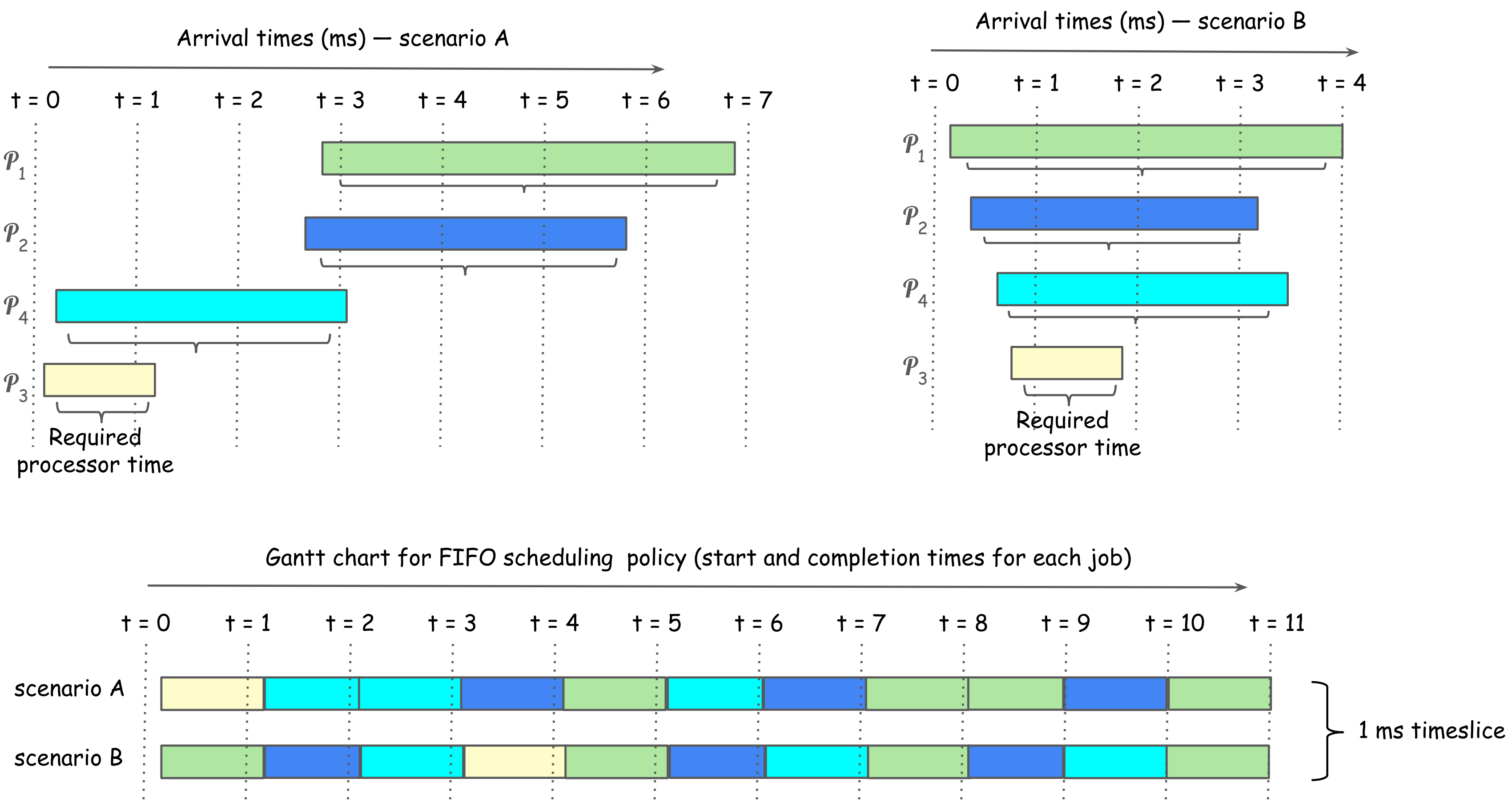
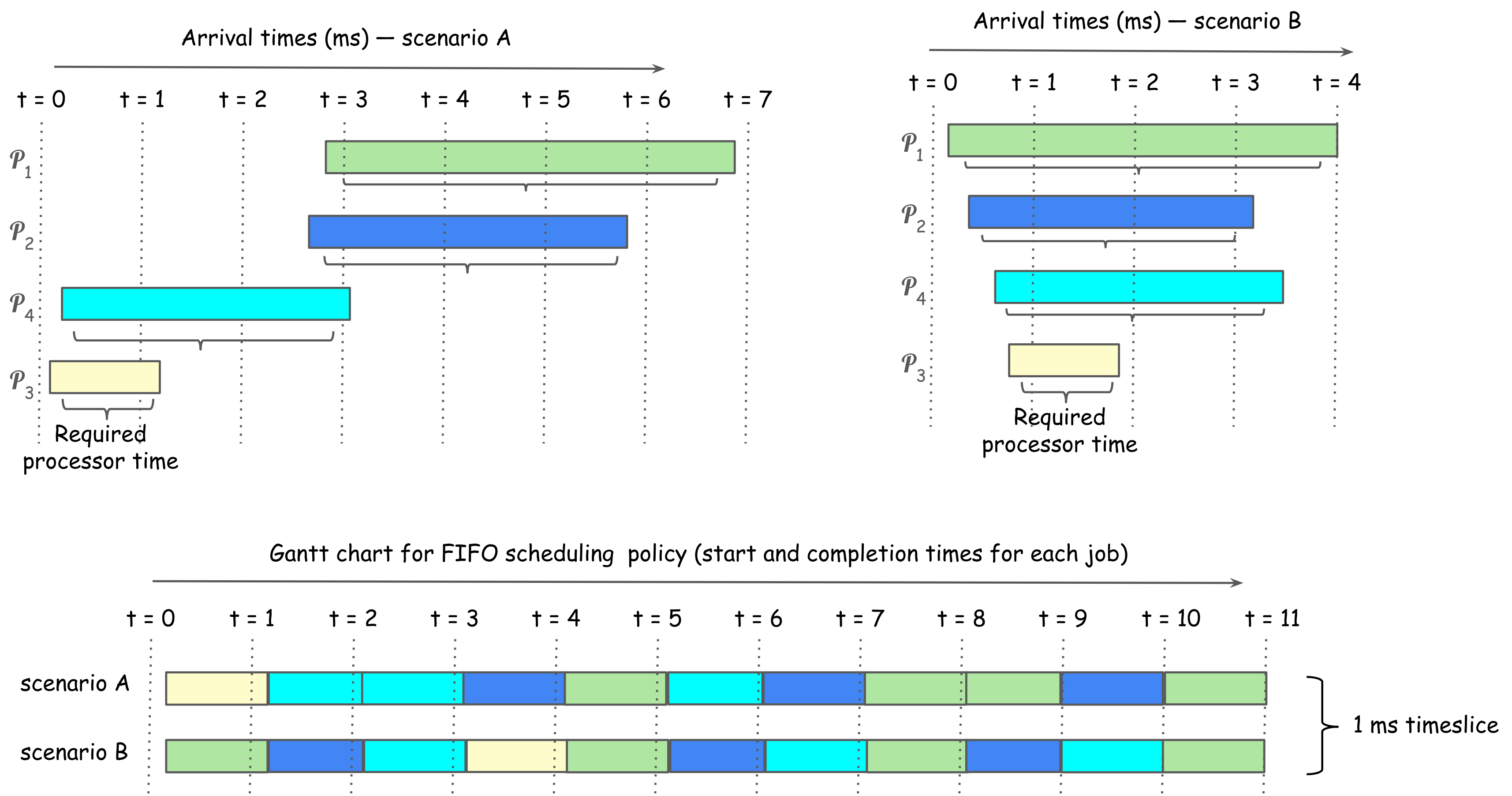
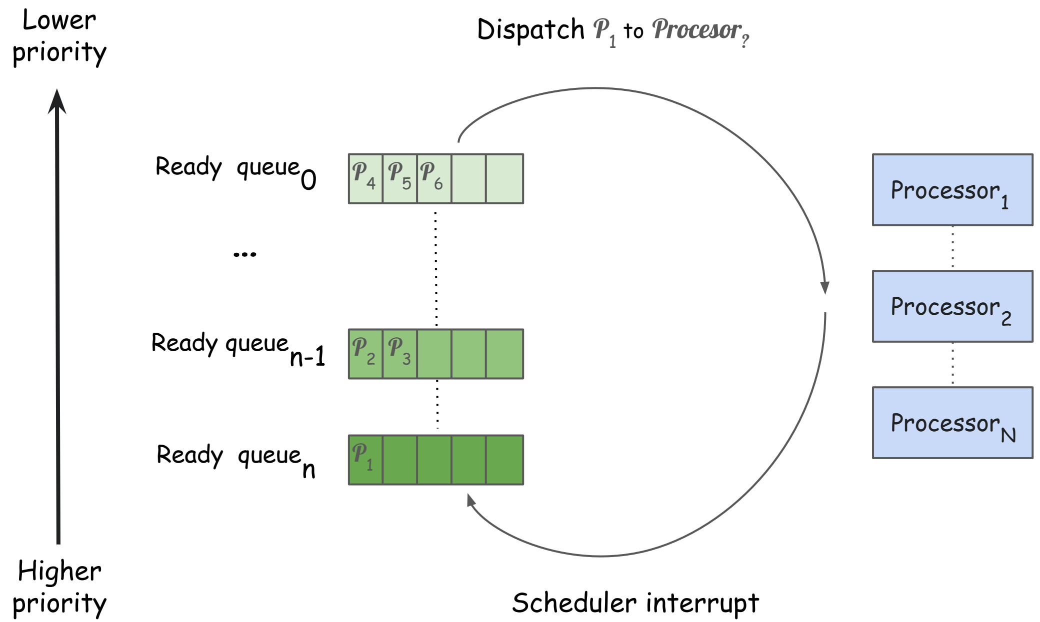


SCHED_RR: Avg.completion and response time?



Hierarchical priority-based scheduling



Ready for your first bug in the outer universe

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Mars Rover: software and hardware

- Works Real-Time Operating System (RTOS)

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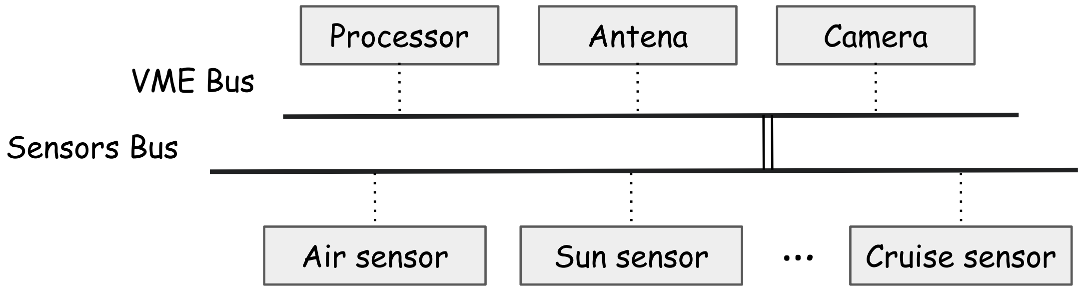
- Tasks must meet strict timing constraints
- Preemptive with priority-based scheduling
- Scheduler ticks at 8 Hz (i.e., every 125ms)

Mars Rover: software and hardware

- **Works Real-Time Operating System (RTOS)**
  - Tasks must meet strict timing constraints
  - Preemptive with priority-based scheduling
  - Scheduler ticks at 8 Hz (i.e., every 125ms)
- **Hardware overview**



Mars Rover: software and hardware

> Works Real-Time Operating System (RTOS)

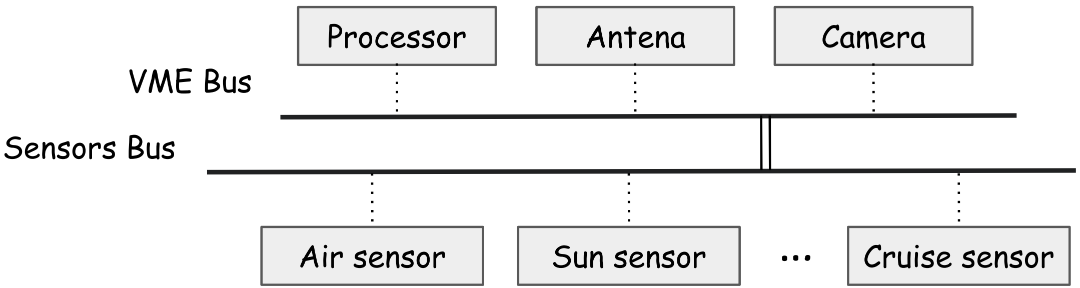
- Tasks must meet strict timing constraints
- Preemptive with priority-based scheduling
- Scheduler ticks at 8 Hz (i.e., every 125ms)

> Hardware overview

- Data from sensor bus to the VMA bus (to antenna)
- Processor signal from VMA bus to sensor bus (cruise)

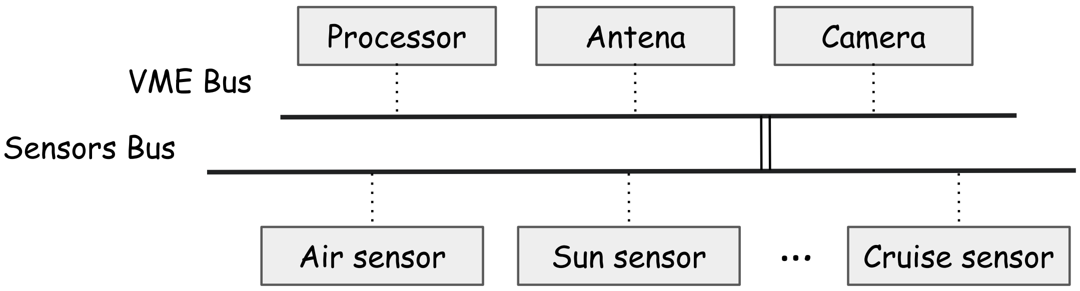
Mars Rover: software and hardware

- Synchronization



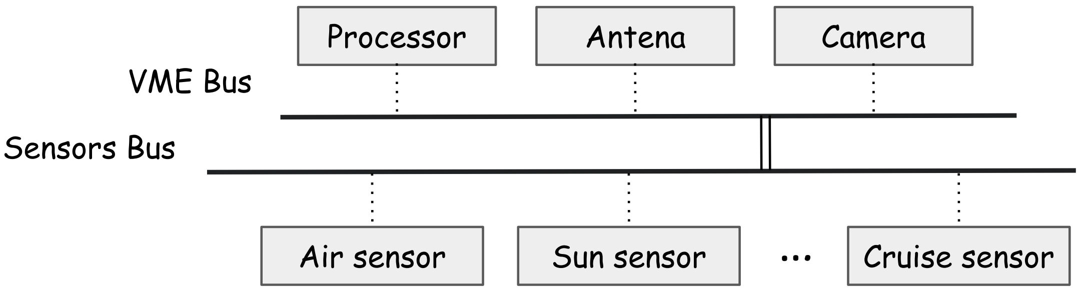
Mars Rover: software and hardware

- **Synchronization**
  - sched_tsk: Decides who transmits data next



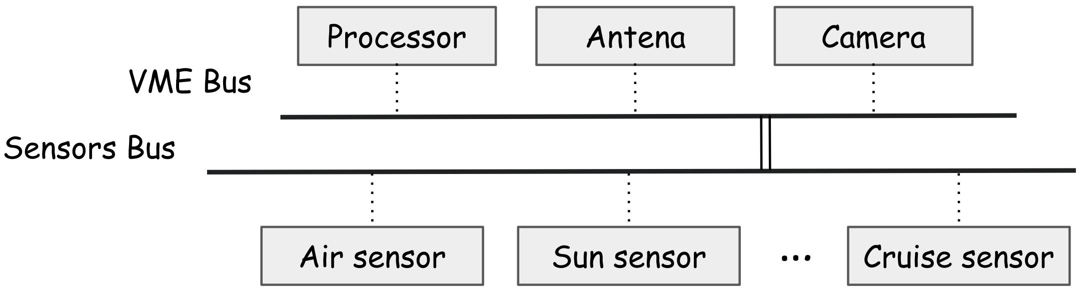
Mars Rover: software and hardware

- **Synchronization**
  - sched_tsk: Decides who transmits data next
  - dist_tsk: Decides who receives data next



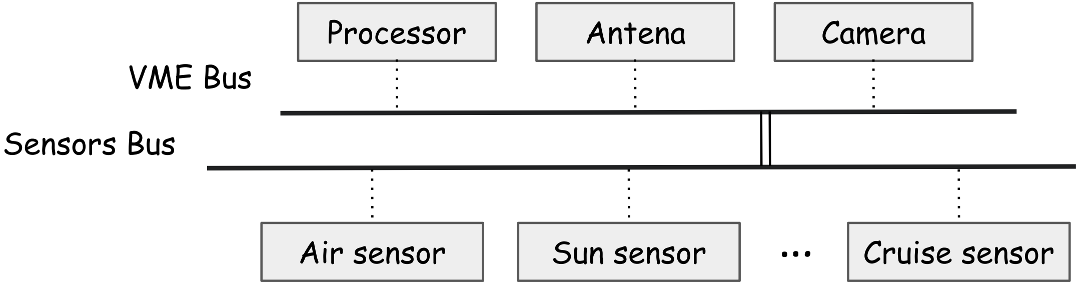
Mars Rover: software and hardware

- **Synchronization**
  - sched_tsk: Decides who transmits data next
  - dist_tsk: Decides who receives data next
  - comm_tsk: Uses the antenna to transmit data to Earth



Mars Rover: software and hardware

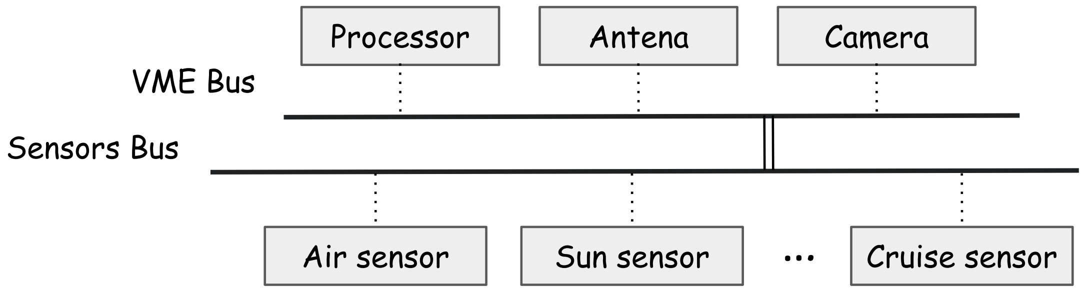
- **Synchronization**
  - sched_tsk: Decides who transmits data next
  - dist_tsk: Decides who receives data next
  - comm_tsk: Uses the antenna to transmit data to Earth
  - asi_tsk: Uses the air sensor for scientific computations



Mars Rover: software and hardware

> **Synchronization**
- sched_tsk: Decides who transmits data next
- dist_tsk: Decides who receives data next
- comm_tsk: Uses the antenna to transmit data to Earth
- asi_tsk: Uses the air sensor for scientific computations

Priorities: sched_tsk > dist_tsk (high) > comm_tsk (medium) > asi_tsk (low)



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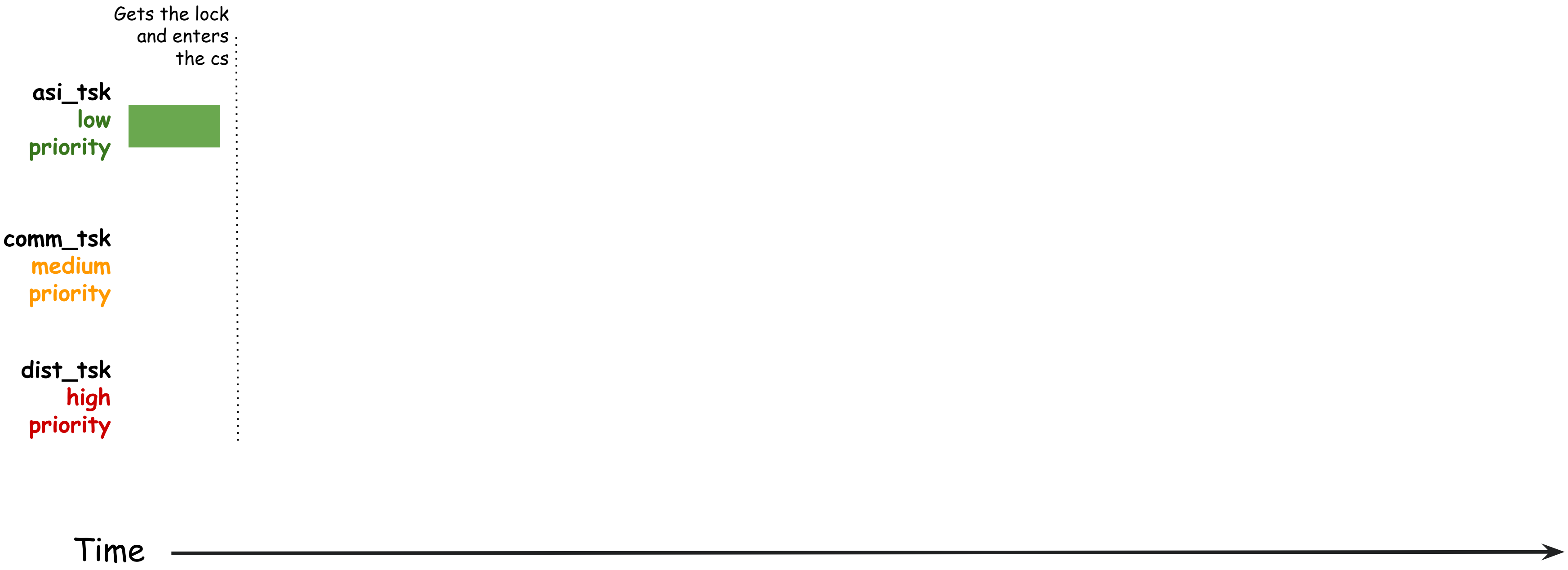

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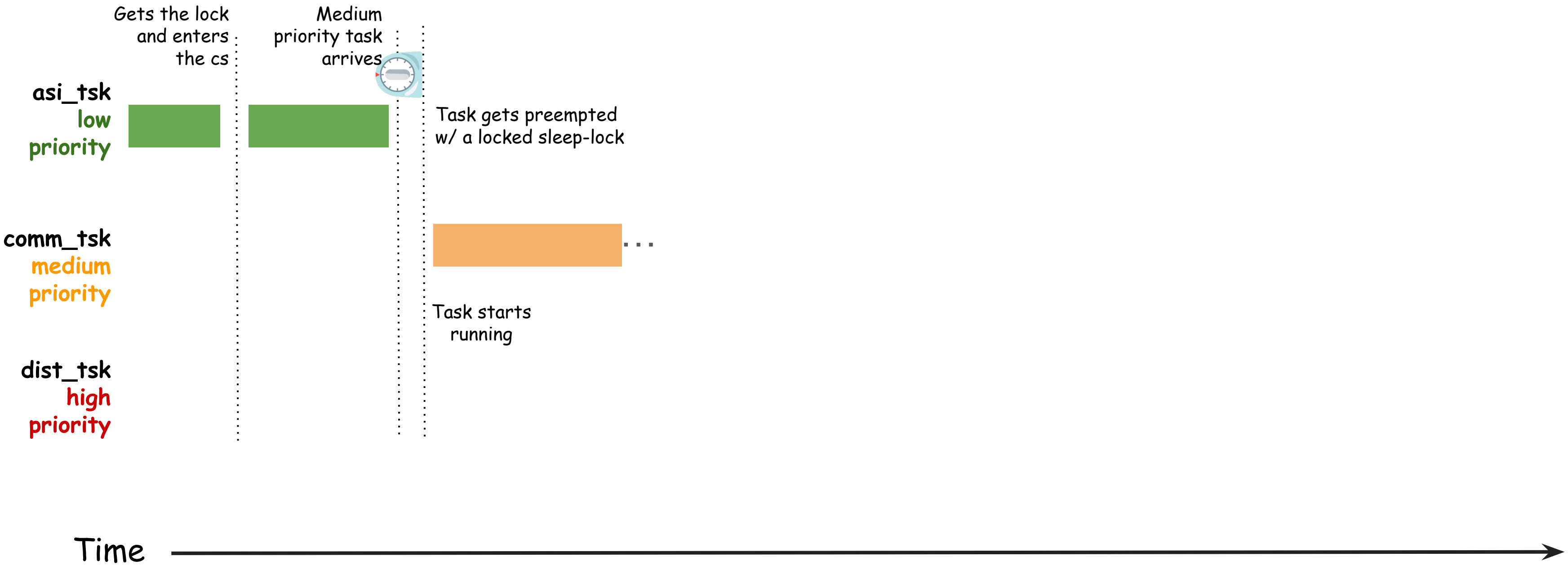

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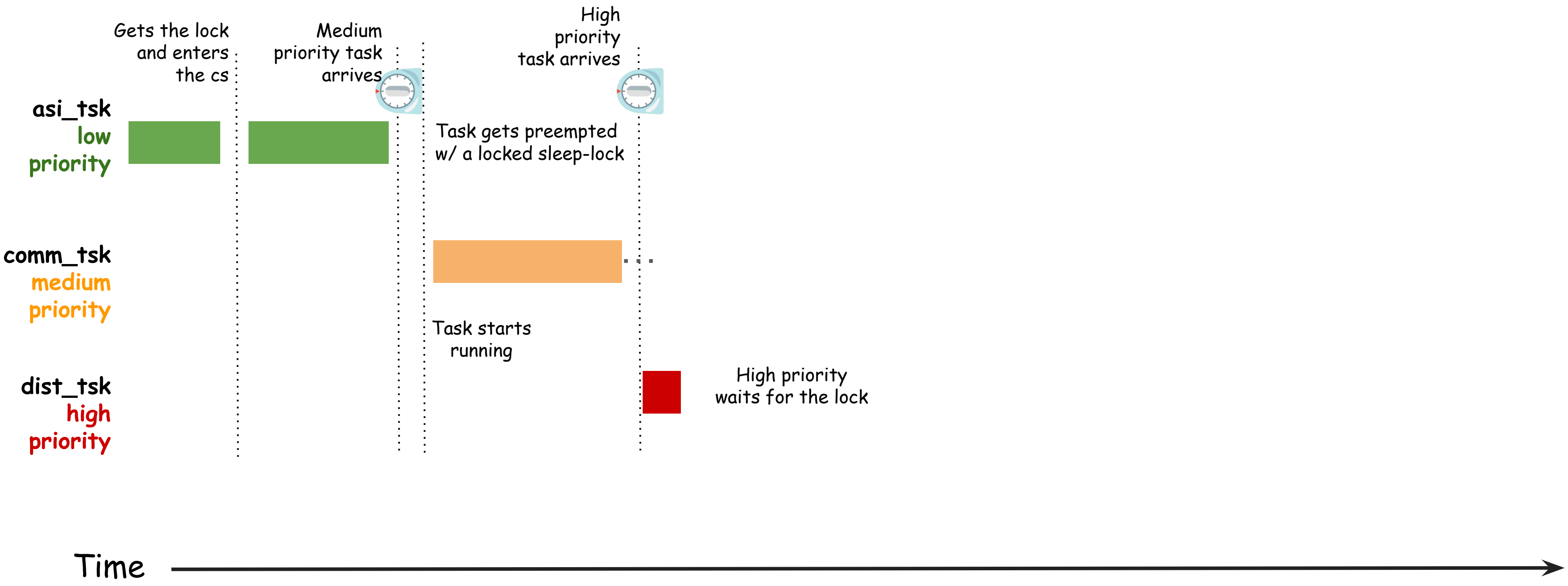

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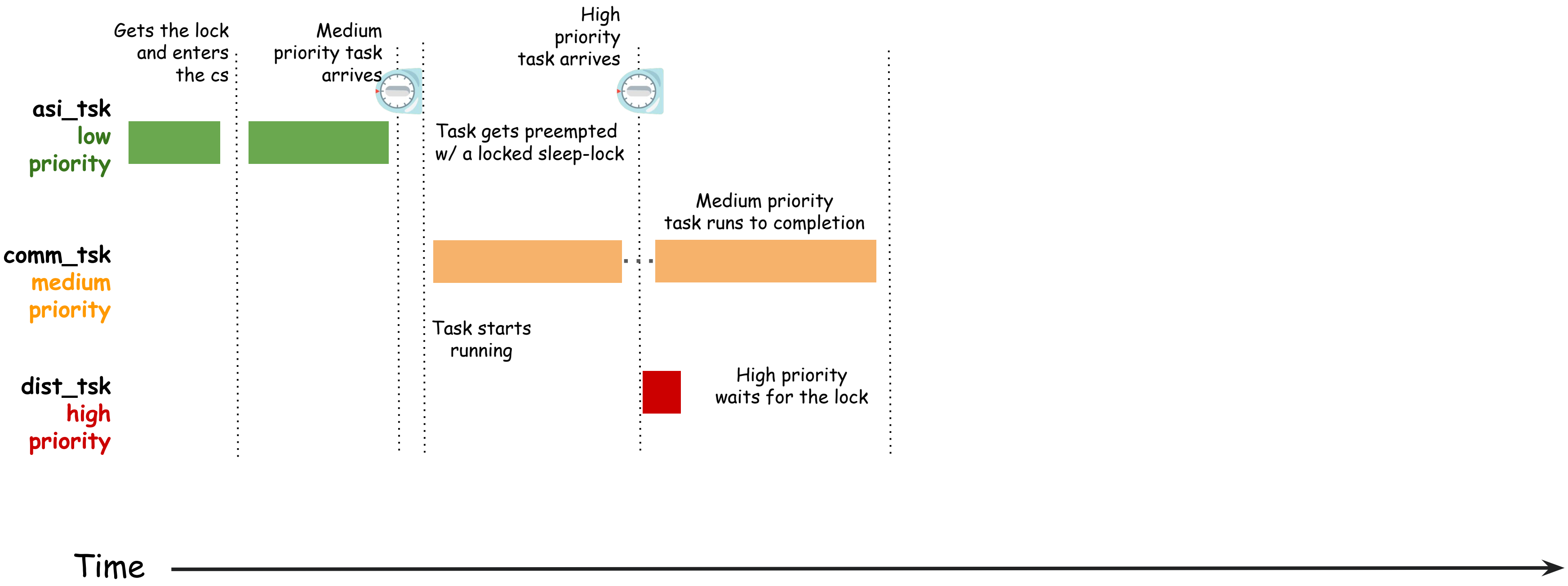

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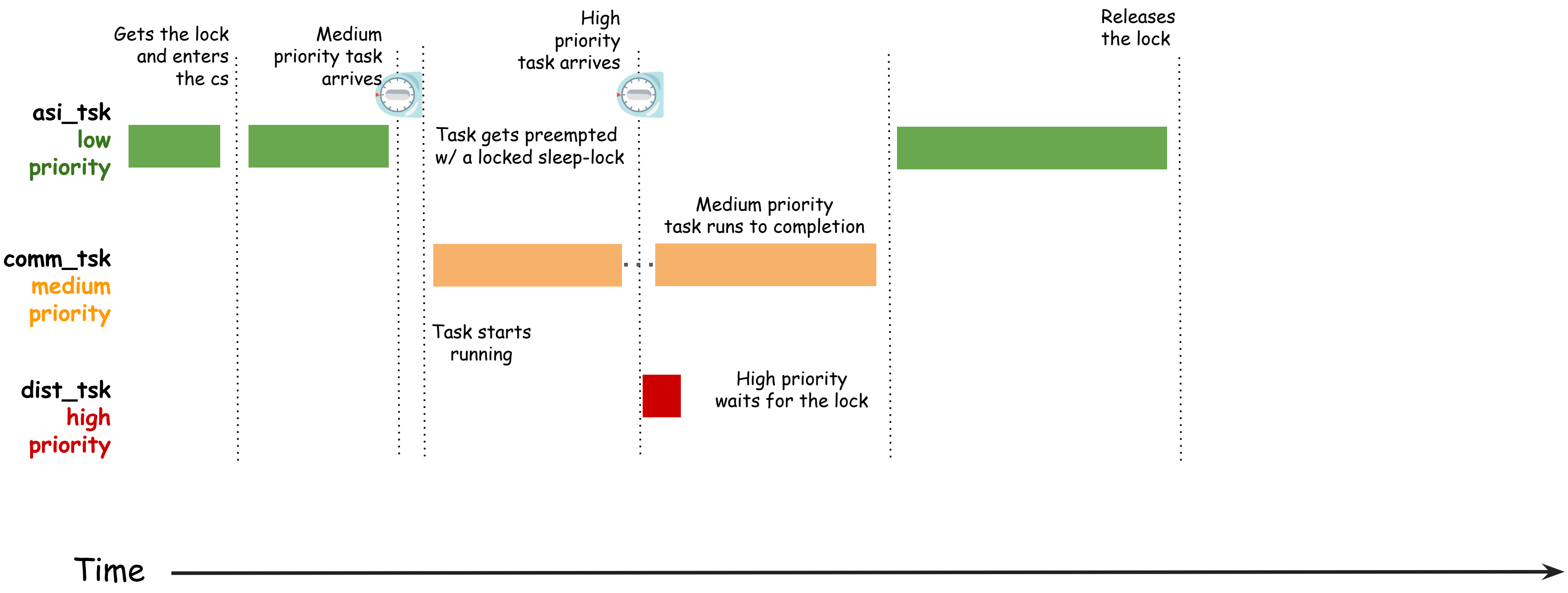

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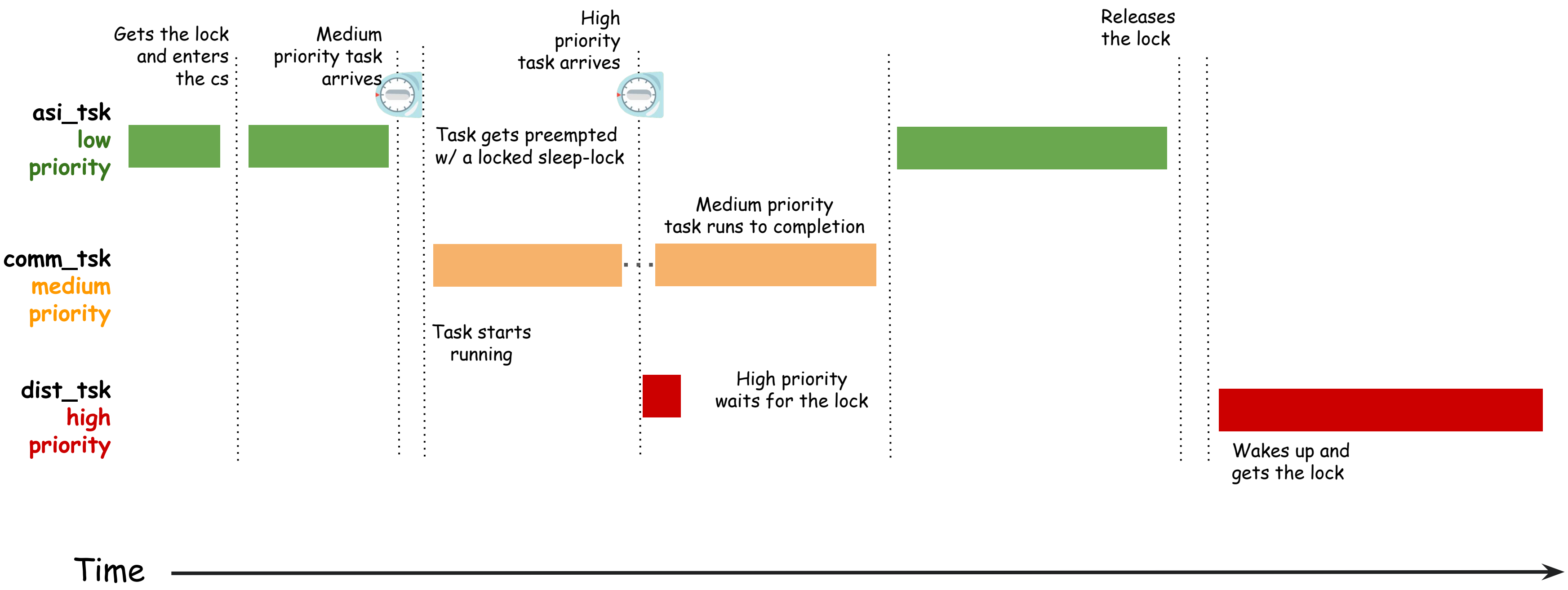

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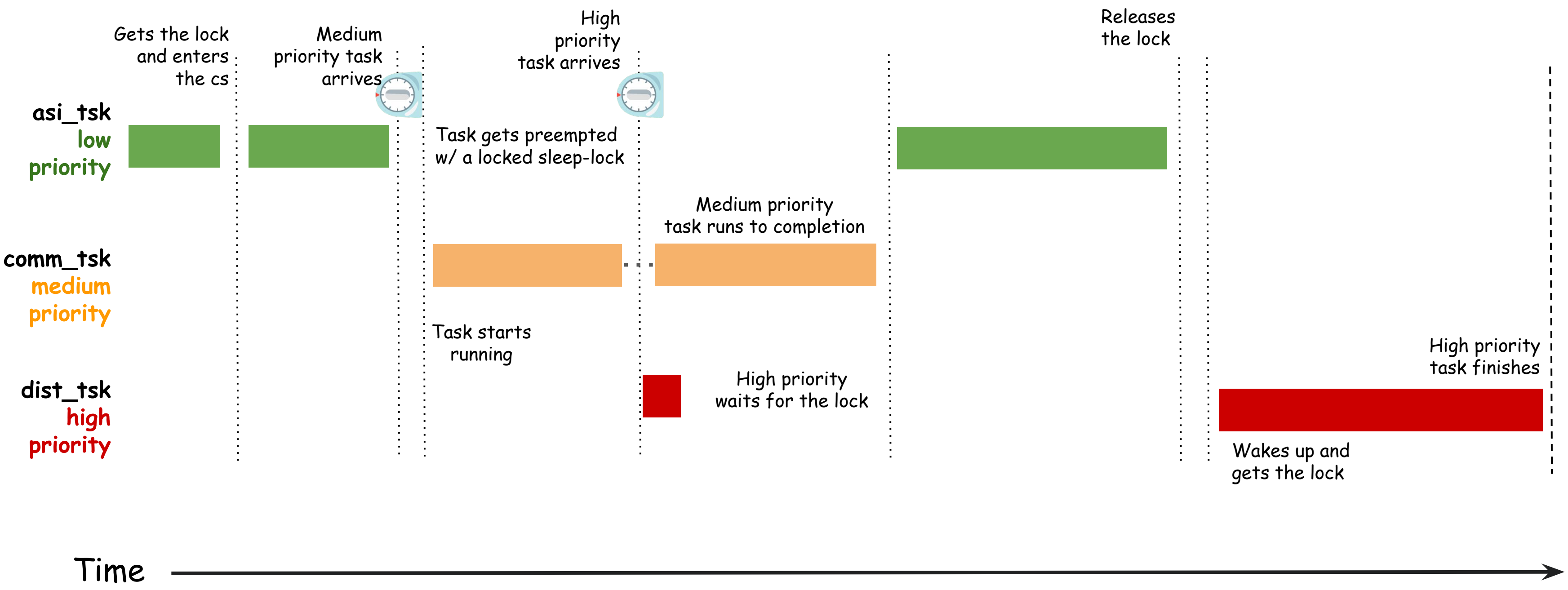

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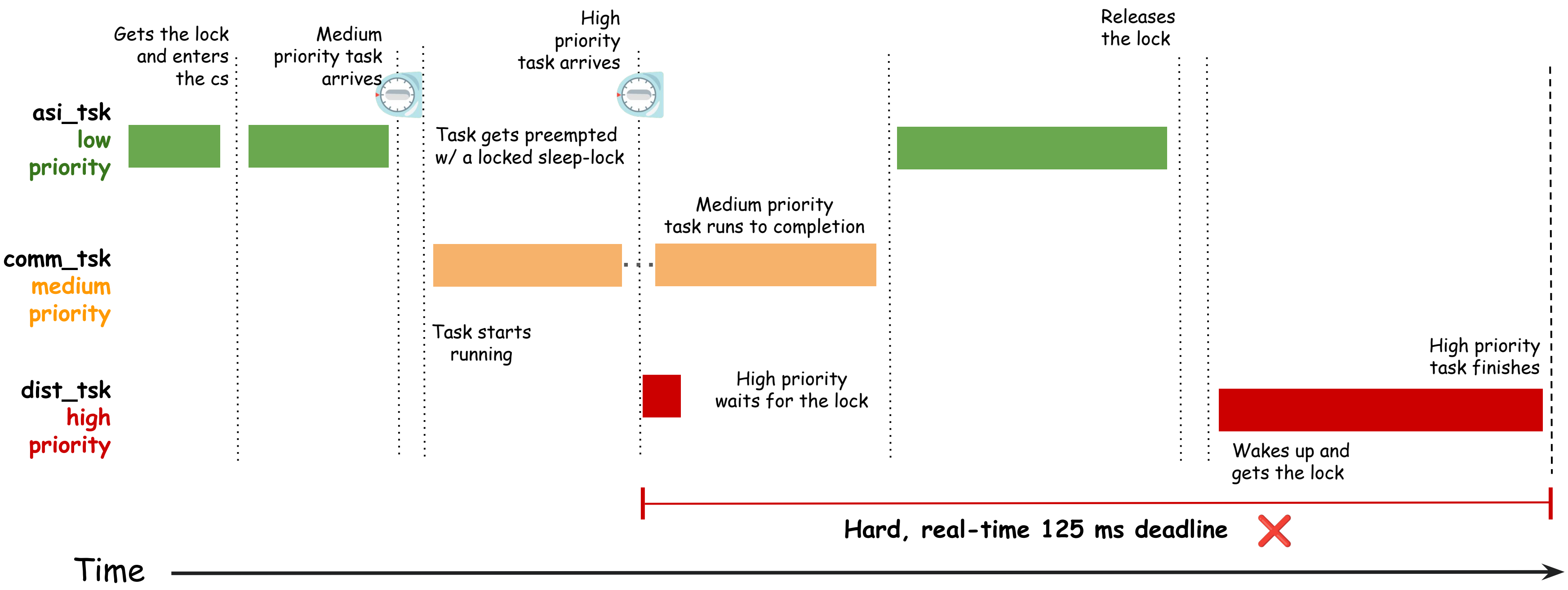
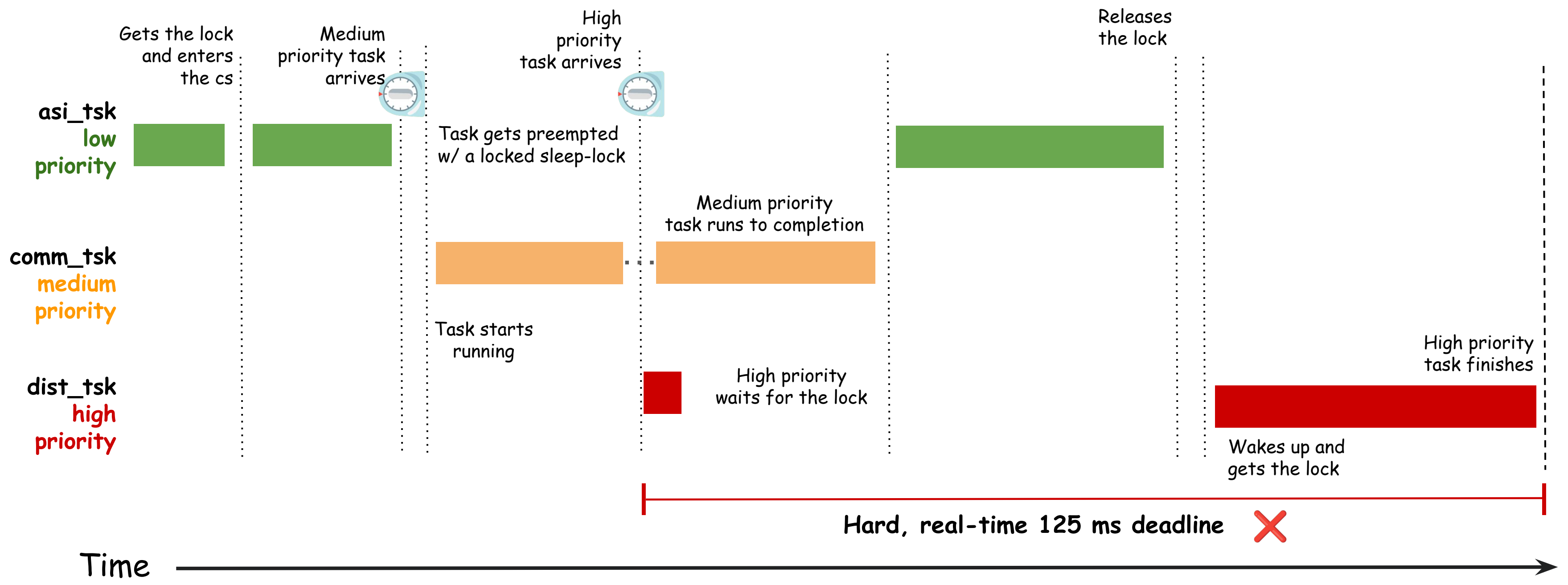
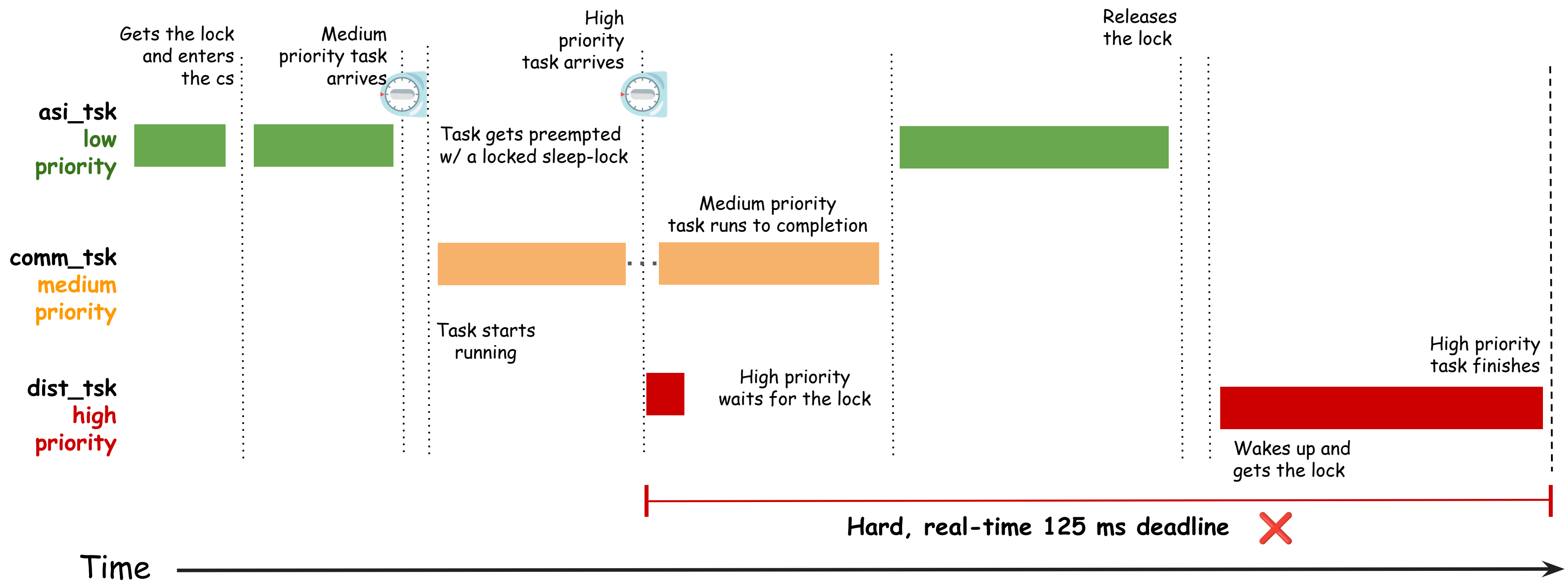


Classic example of priority inversion bug



Solution?



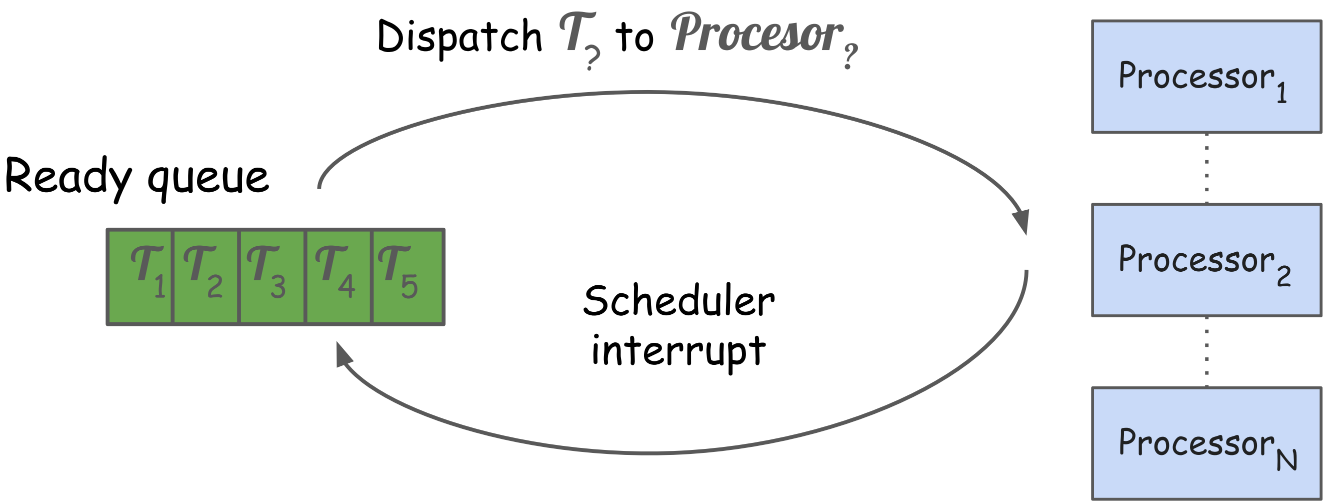
Gets the lock and enters the cs
Medium priority task arrives
High priority task arrives
Releases the lock
asi_tsk
low priority
Task gets preempted w/ a locked sleep-lock
Medium priority task runs to completion
comm_tsk
medium priority
Task starts running
High priority task finishes
dist_tsk
high priority
High priority waits for the lock
Wakes up and gets the lock
Hard, real-time 125 ms deadline
Time

The Linux scheduler

Precedence Order	Scheduler class	Implemented policies	Usecase	POSIX compliance
1	stop_sched_class	Run Linux kernel-internal tasks	Only used internally by the kernel; preempts anything running in the local processor	No
2	dl_sched_class	SCHED_DEADLINE	Hard real-time tasks whose execution deadlines must be met	No
3	rt_sched_class	SCHED_FIFO, SCHED_RR	Soft real-time tasks (e.g., audio daemon) with priorities [1–99]	Yes
4	cfs_sched_class, eevdf_sched_class	SCHED_NORMAL, SCHED_BATCH, SCHED_IDLE	User tasks with "nice" values in the range [-20–19]	Partially Yes
5	idle_sched_class	Run the Linux kernel "idle" task	Runs when the local processor is idle, and has no other task to run	No

Unicore scheduling

> Given k tasks ready to run in a system with N available processors, which task should be dispatched to which processor at any given point in time?



Multicore scheduling