

# Lecture 4

# CPU Scheduling

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Spring 2024

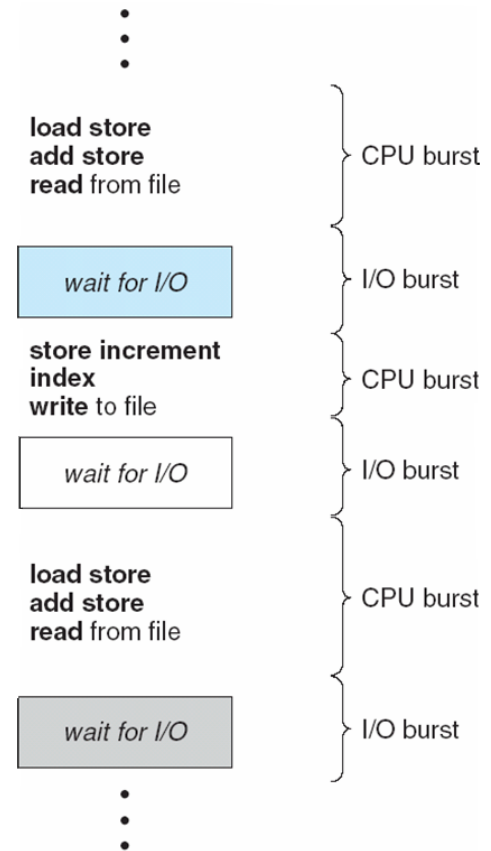
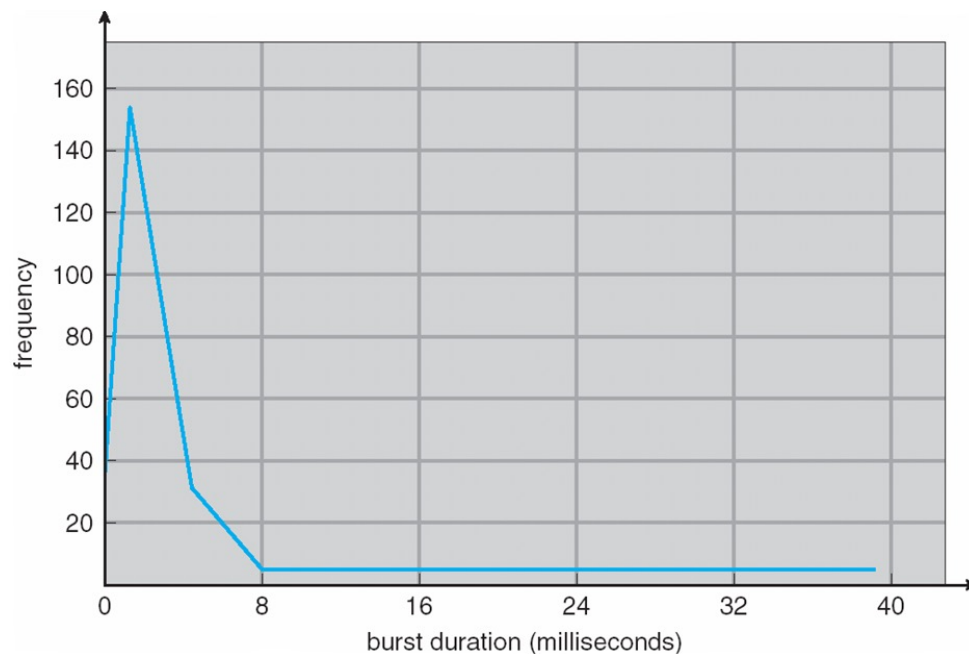
# CPU Scheduling

- Scheduling is important when multiple processes wish to run on a single CPU
  - CPU scheduler decides which process to run next
- Two types of processes
  - CPU bound and I/O bound

CPU-bound Process	I/O-bound process
Spends most of its running time on the CPU, i.e., <b>user-time</b> > <b>sys-time</b>	Spends most of its running time on I/O, i.e., <b>sys-time</b> > <b>user-time</b>
<u>Examples</u> - AI course assignments.	<u>Examples</u> - <b>/bin/l</b> s, networking programs.

# CPU Burst

- Process execution consists of a *cycle* of CPU execution and I/O wait
- **CPU burst** distribution



# CPU Scheduler

- CPU scheduler selects one of the processes that are ready to execute and allocates the CPU to it
- CPU scheduling decisions may take place when a process:
  - 1. Switches from running to waiting state
  - 2. Switches from running to ready state
  - 3. Switches from waiting to ready
  - 4. Terminates
- A scheduling algorithm takes place **only** under circumstances 1 and 4 is **non-preemptive**
- All other scheduling algorithms are **preemptive**

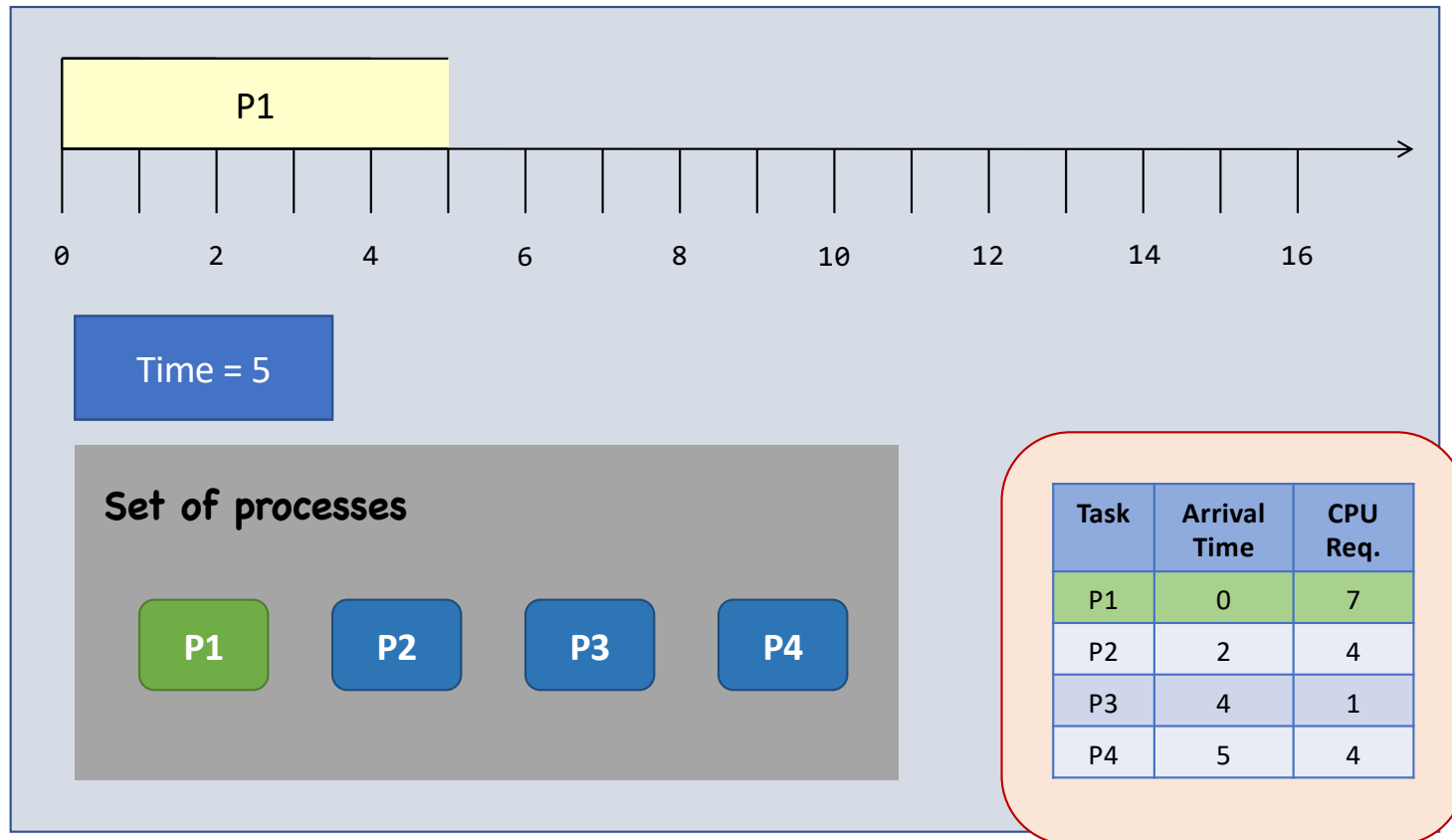
# Scheduling Algorithm Optimization Criteria

- Given a set of processes, with
  - **Arrival time:** the time they arrive in the CPU ready queue (from waiting state or from new state)
  - **CPU requirement:** their expected CPU burst time
- Minimize average turnaround time
  - **Turnaround time:** The time between the arrival of the task and the time it is blocked or terminated.
- Minimize average waiting time
  - **Waiting time:** The accumulated time that a task has waited in the ready queue.
- Reduce the number of context switches

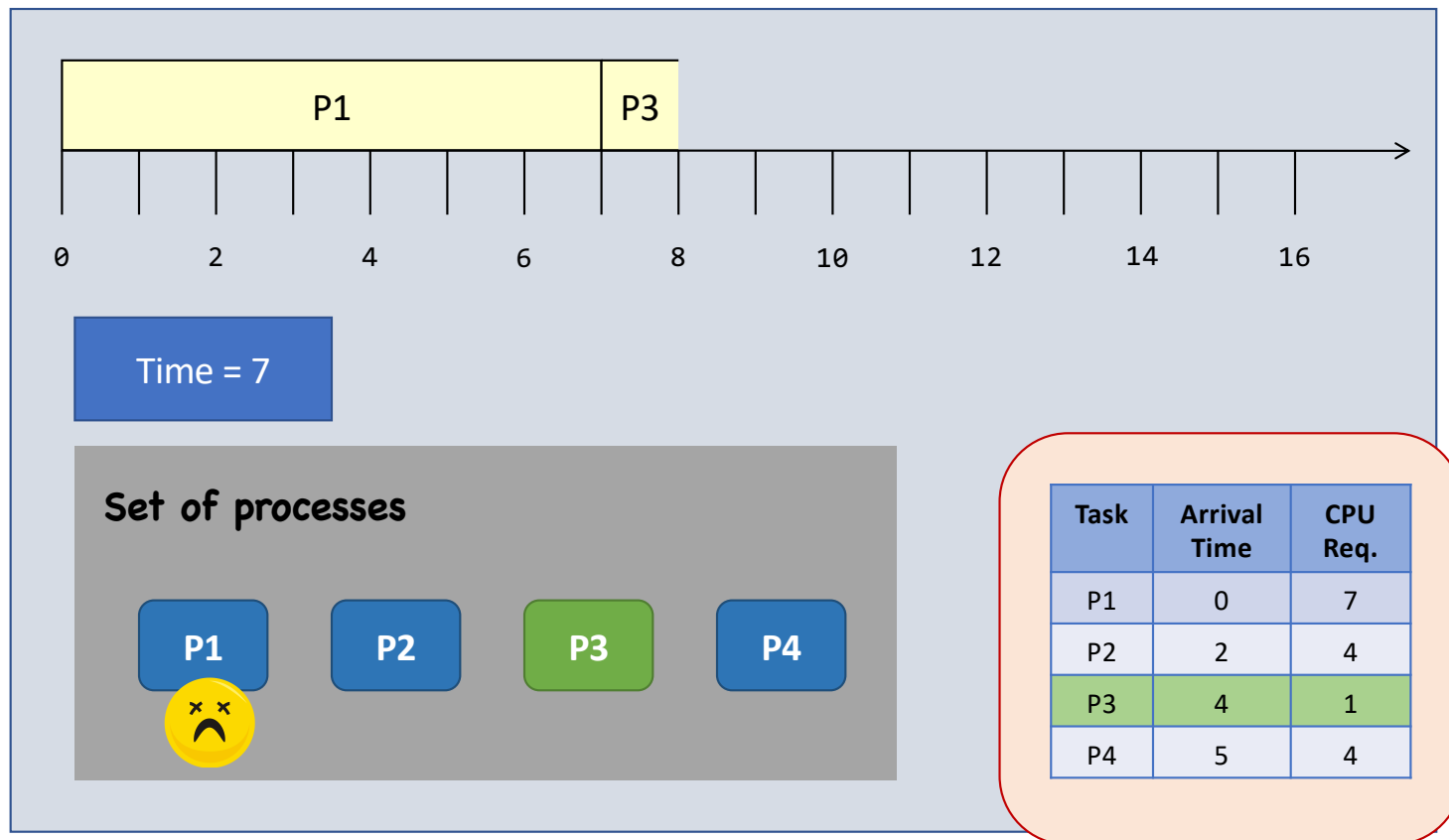
# Different Algorithms

- Shortest-job-first (SJF)
- Round-robin (RR)
- Priority scheduling

# Non-preemptive SJF



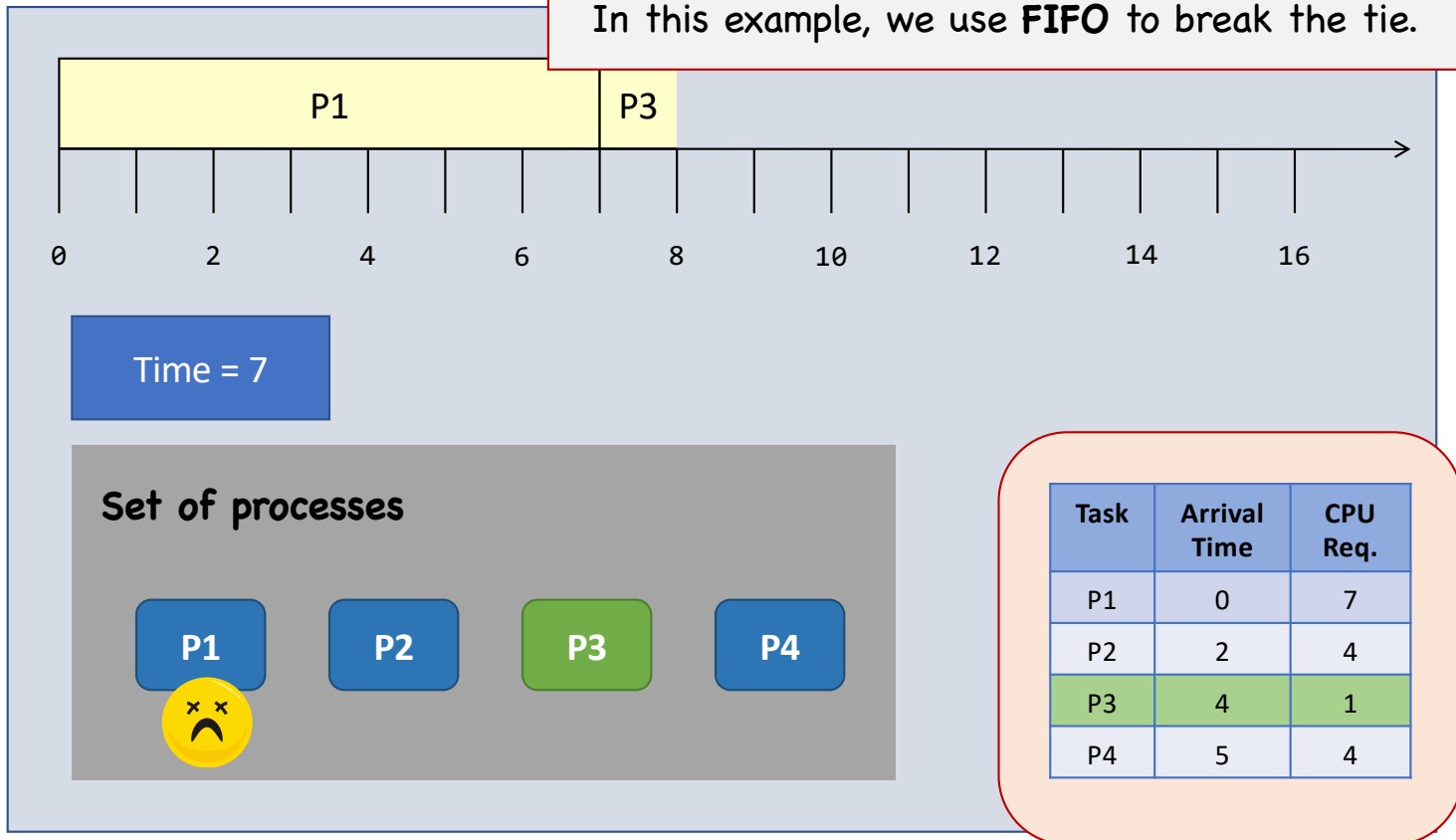
# Non-preemptive SJF



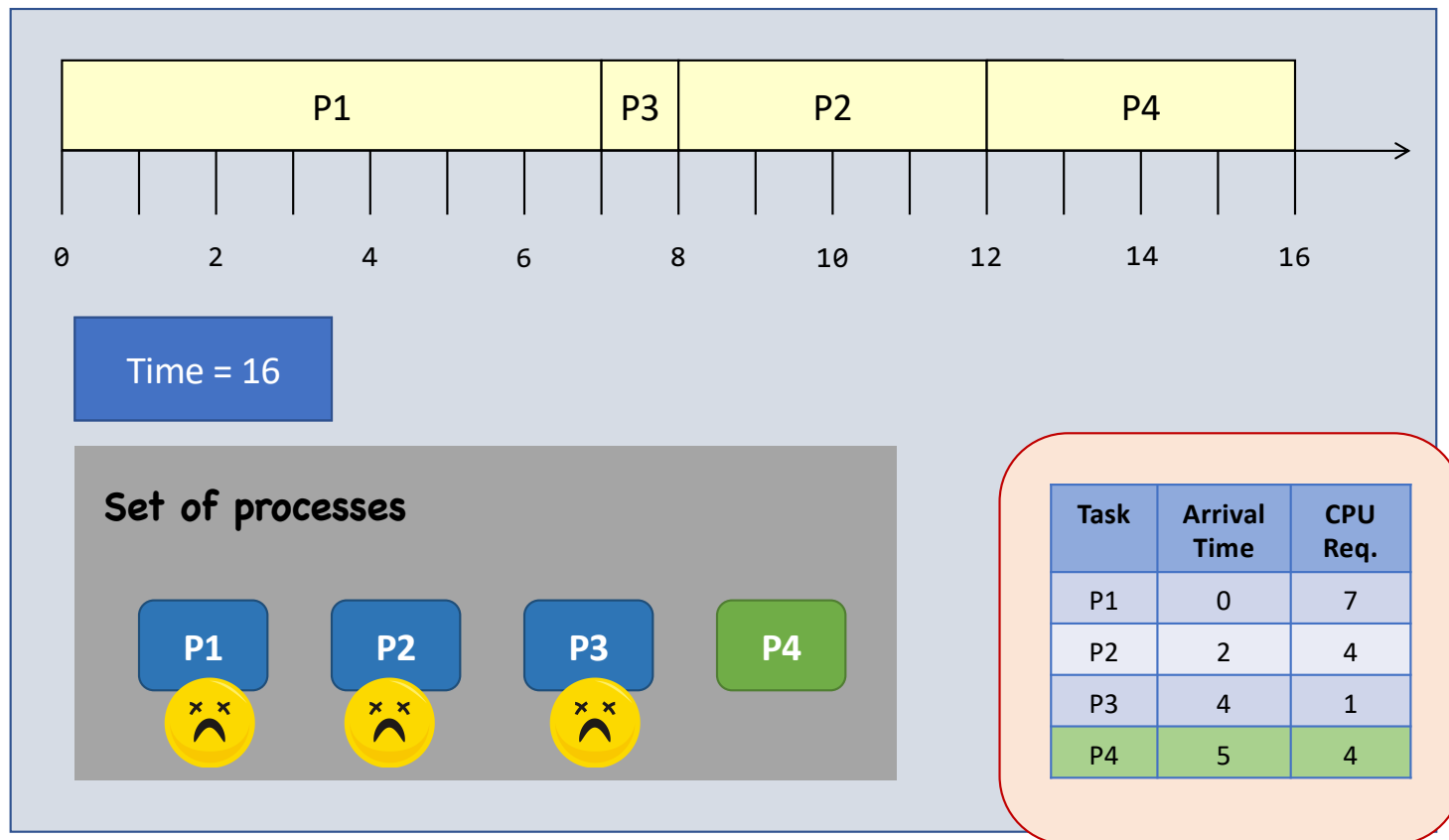


# Non-preemptive SJF

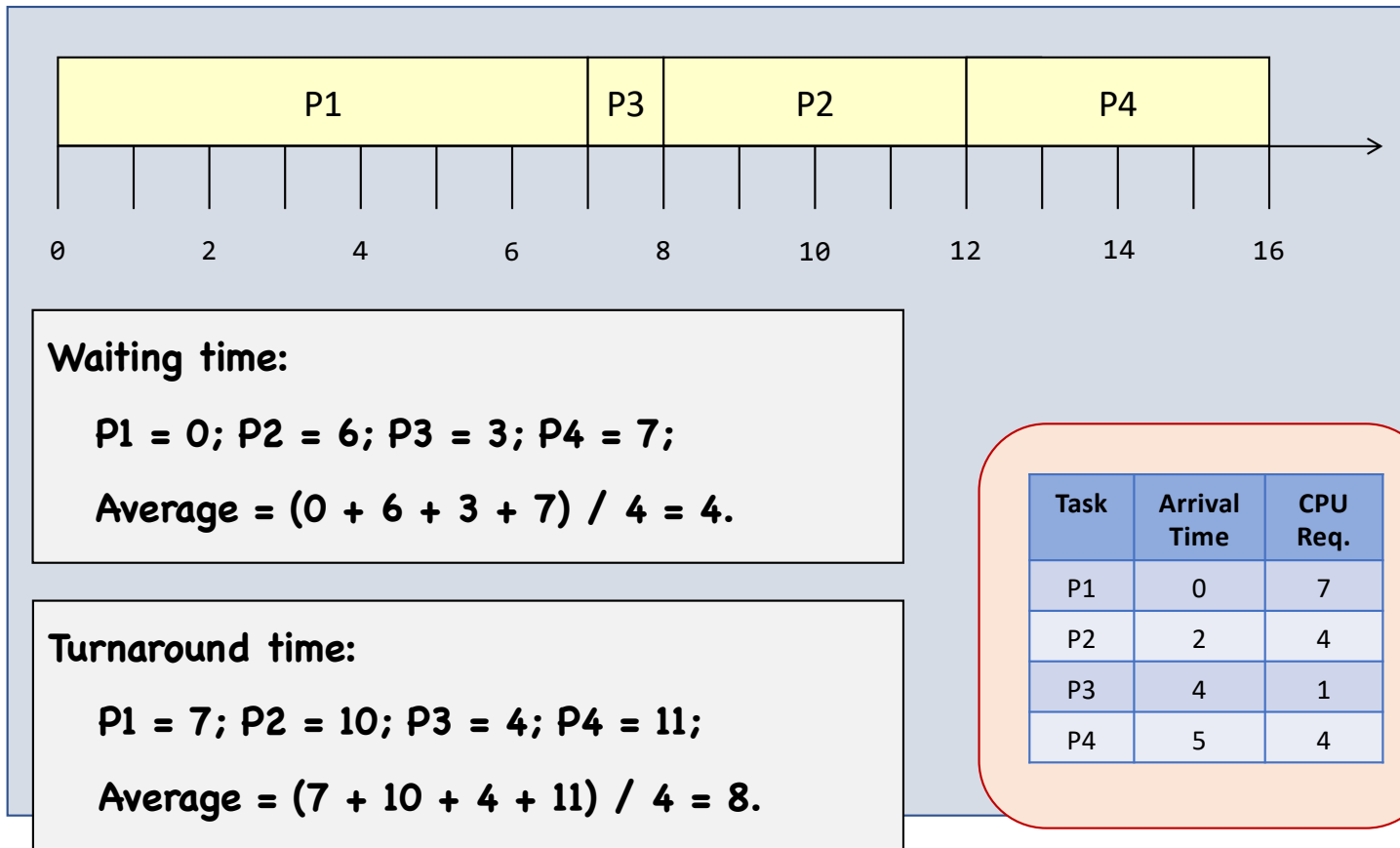
In this example, we use **FIFO** to break the tie.



# Non-preemptive SJF



# Non-preemptive SJF



# Preemptive SJF

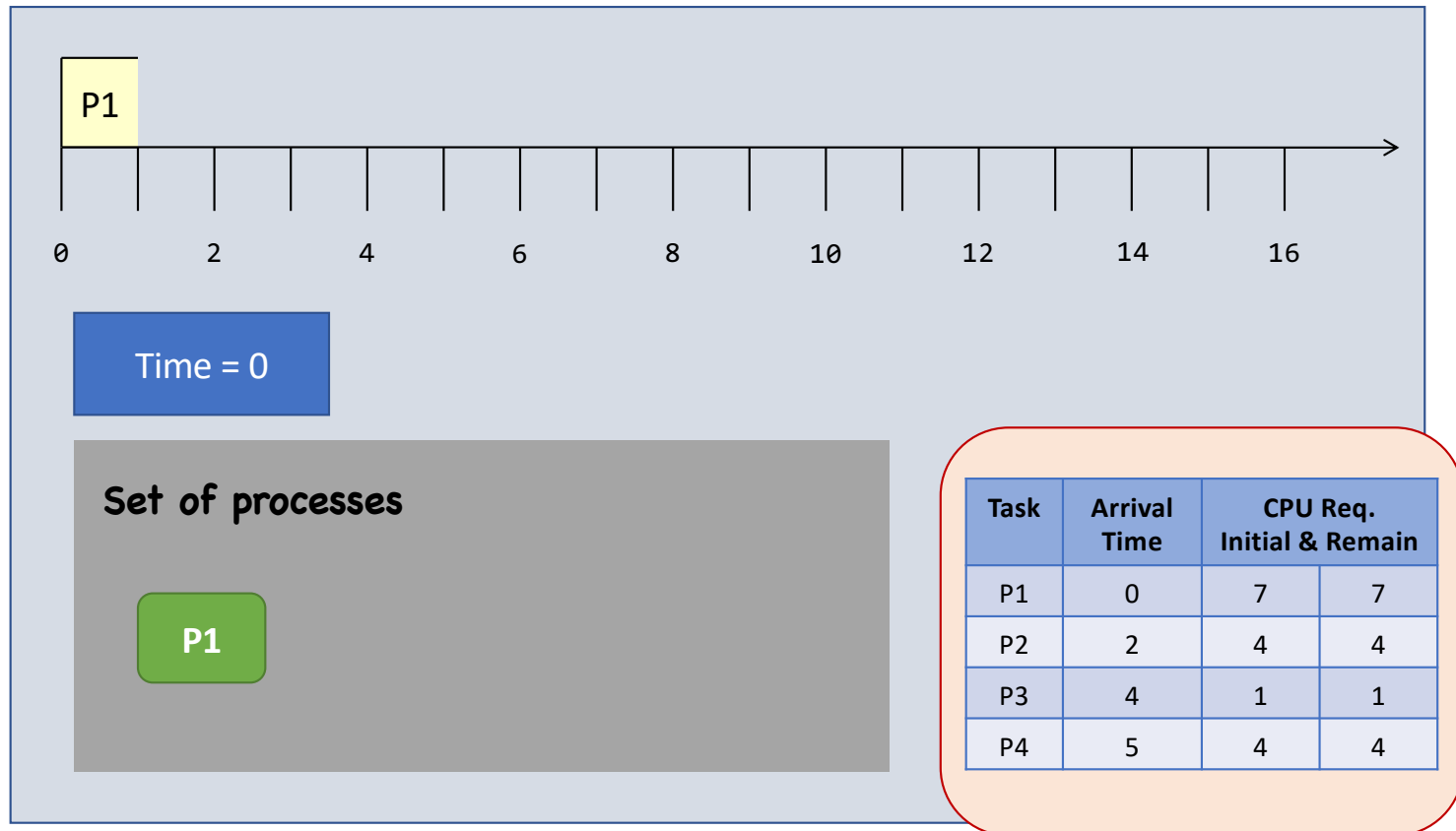


Whenever a new process arrives in the ready queue (either from waiting or from new state), the scheduler steps in and selects the next task based on **their remaining CPU requirements**.

Task	Arrival Time	CPU Req.	
		Initial	Remain
P1	0	7	7
P2	2	4	4
P3	4	1	1
P4	5	4	4

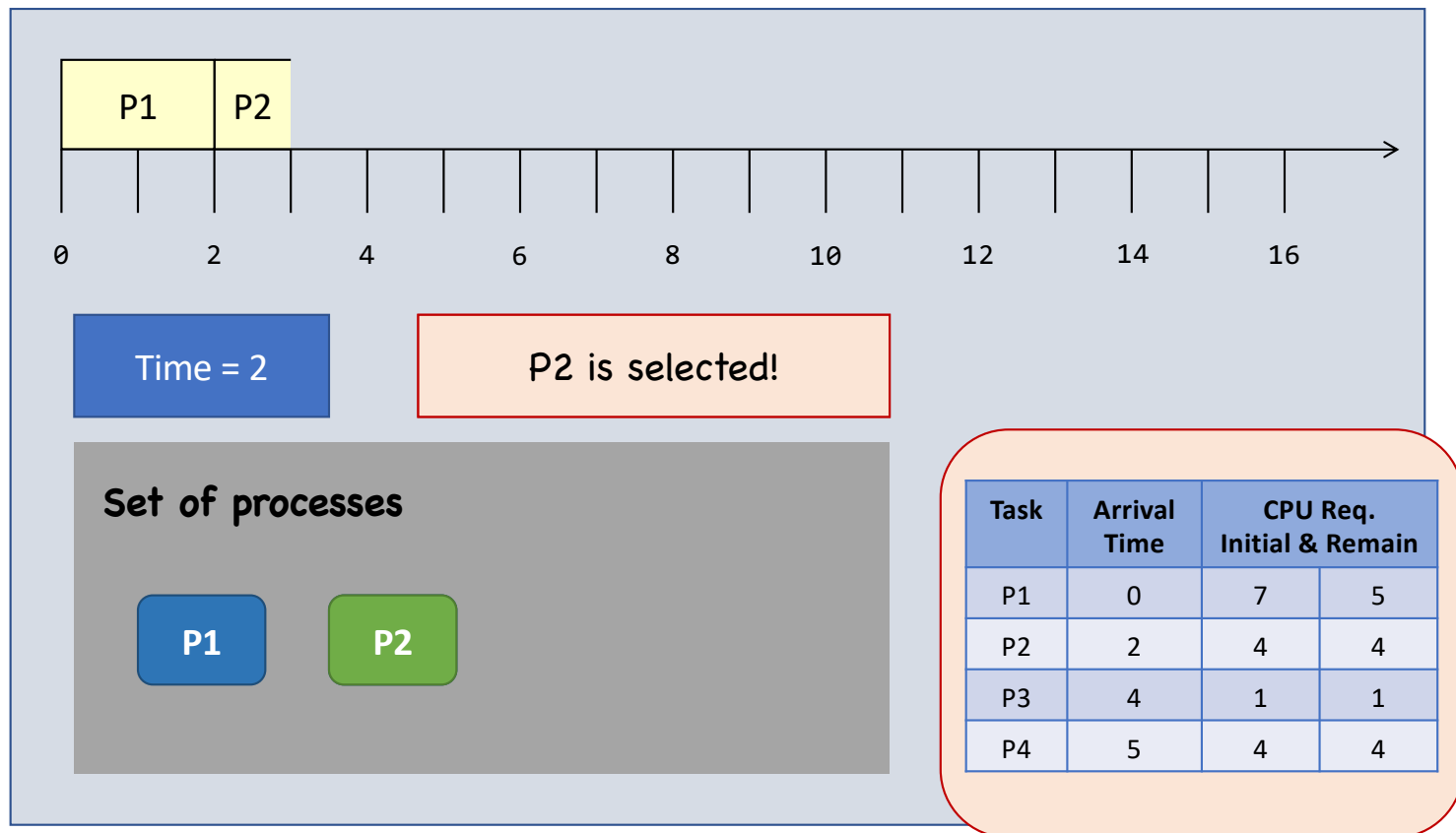
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# Preemptive SJF



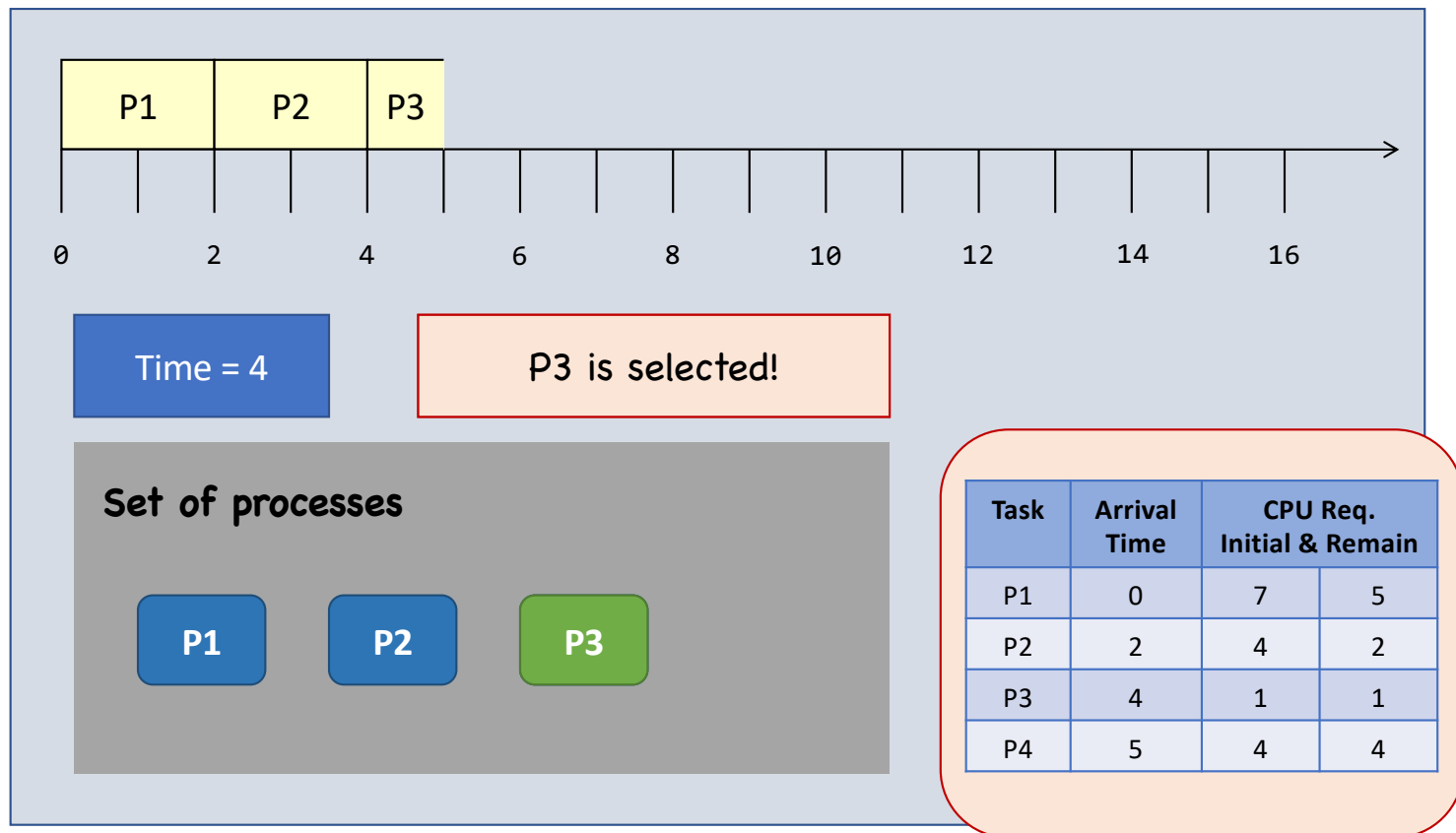
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# Preemptive SJF



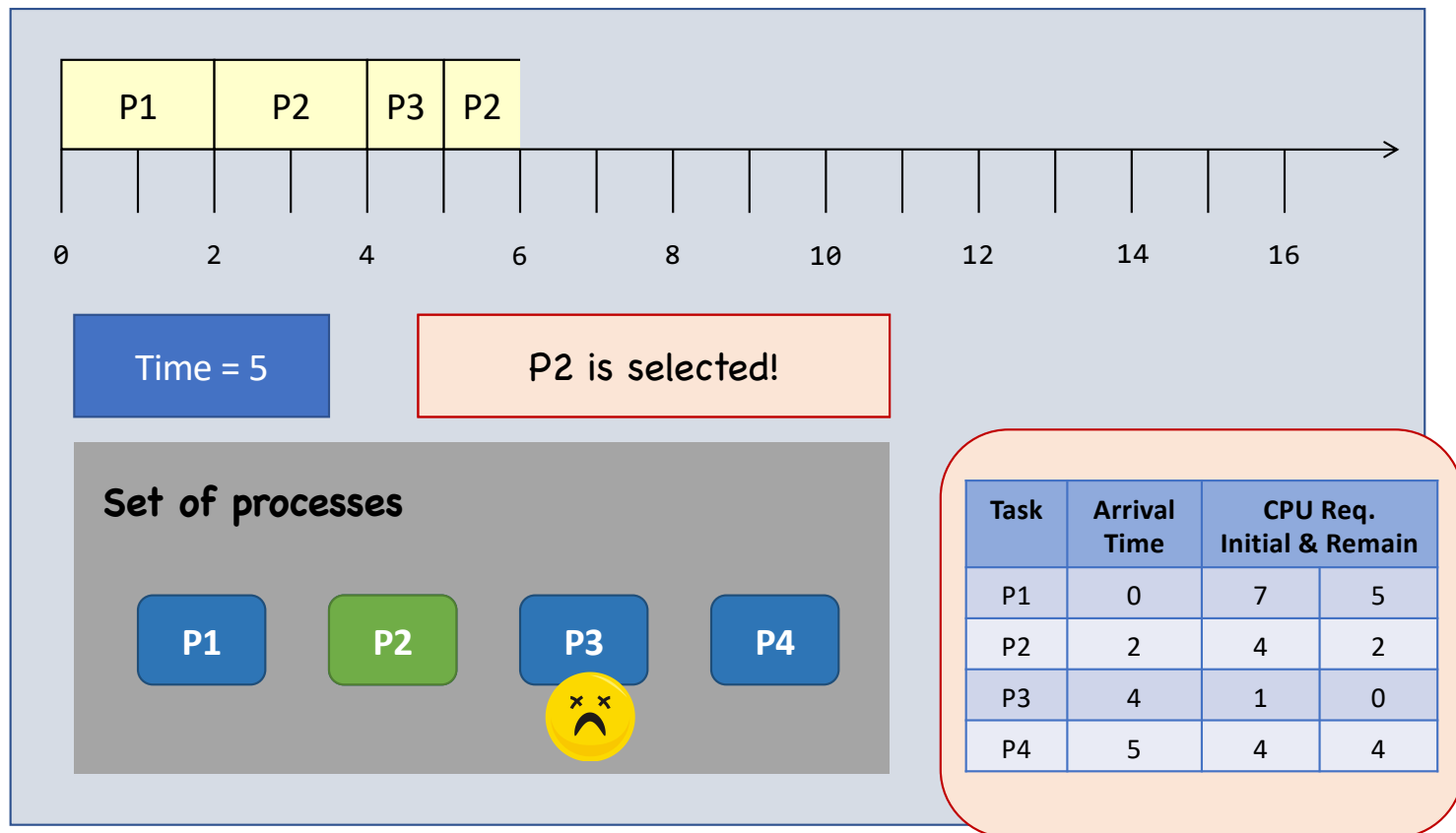
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# Preemptive SJF



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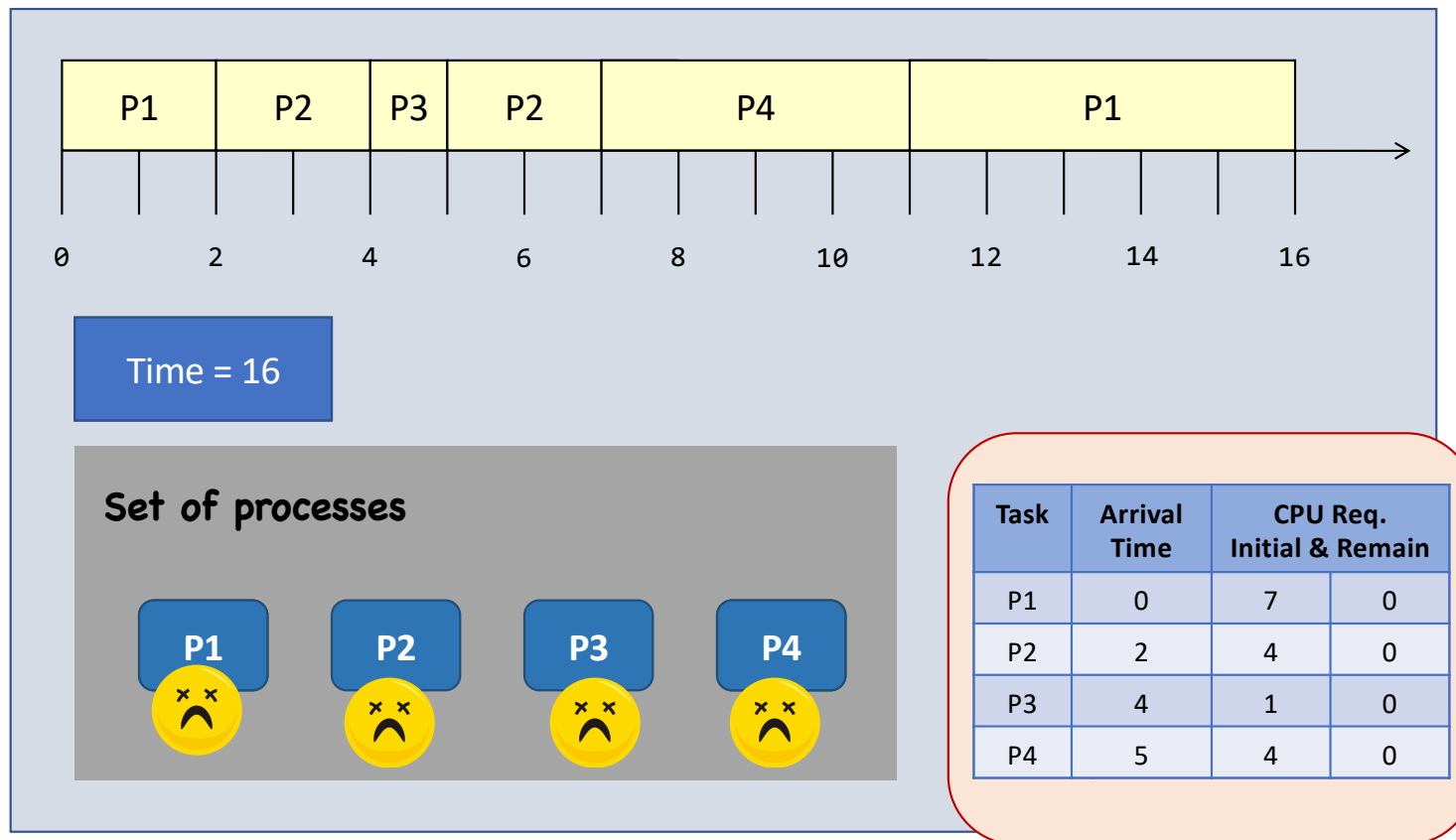
# Preemptive SJF



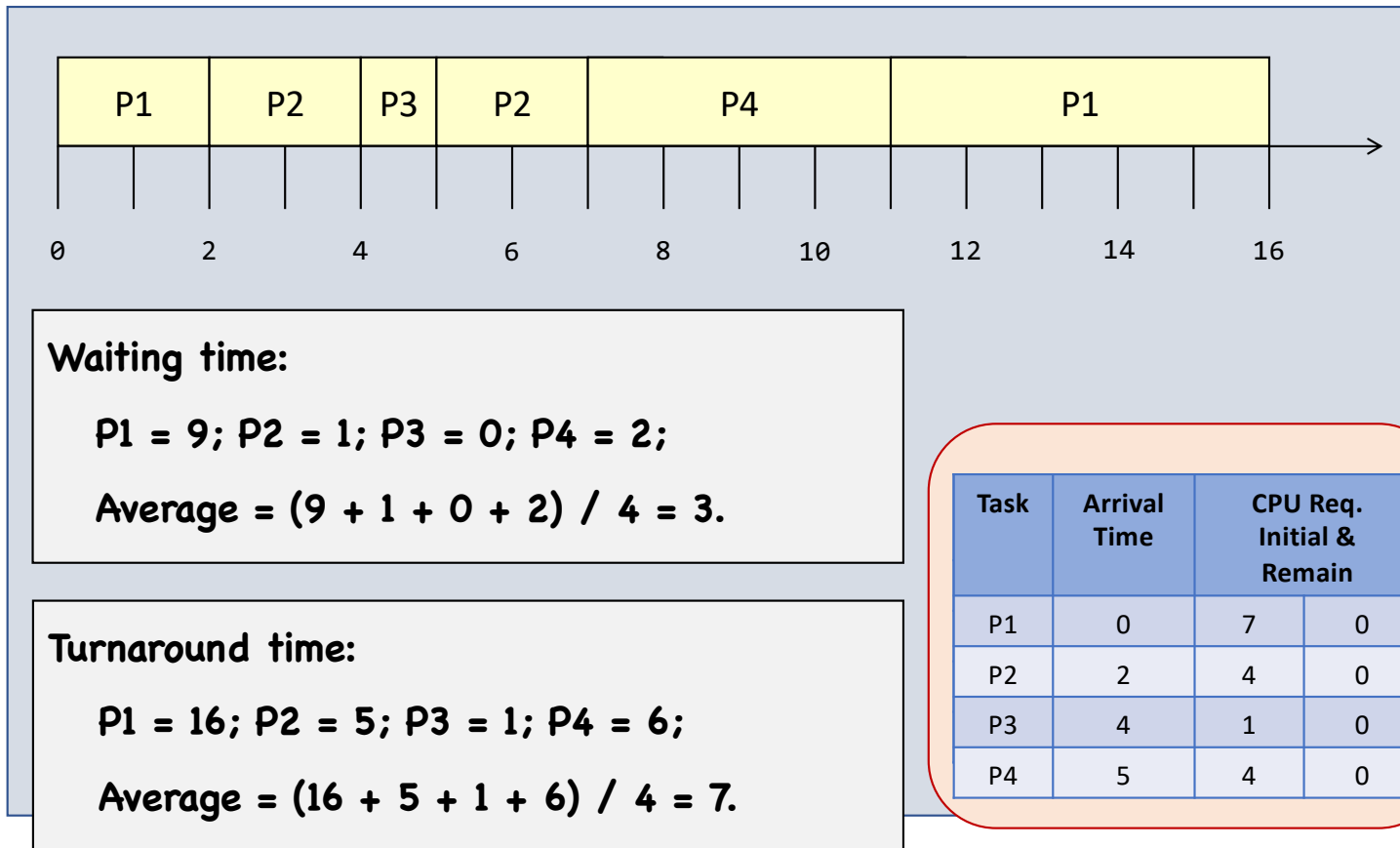


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# Preemptive SJF




# Preemptive SJF



# SJF: Preemptive or Not?

	Non-preemptive SJF	Preemptive SJF
Average waiting time	4	3 (smallest)
Average turnaround time	8	7 (smallest)
# of context switching	3	5 (largest)

The waiting time and the turnaround time decrease at the expense of the increased number of context switches.



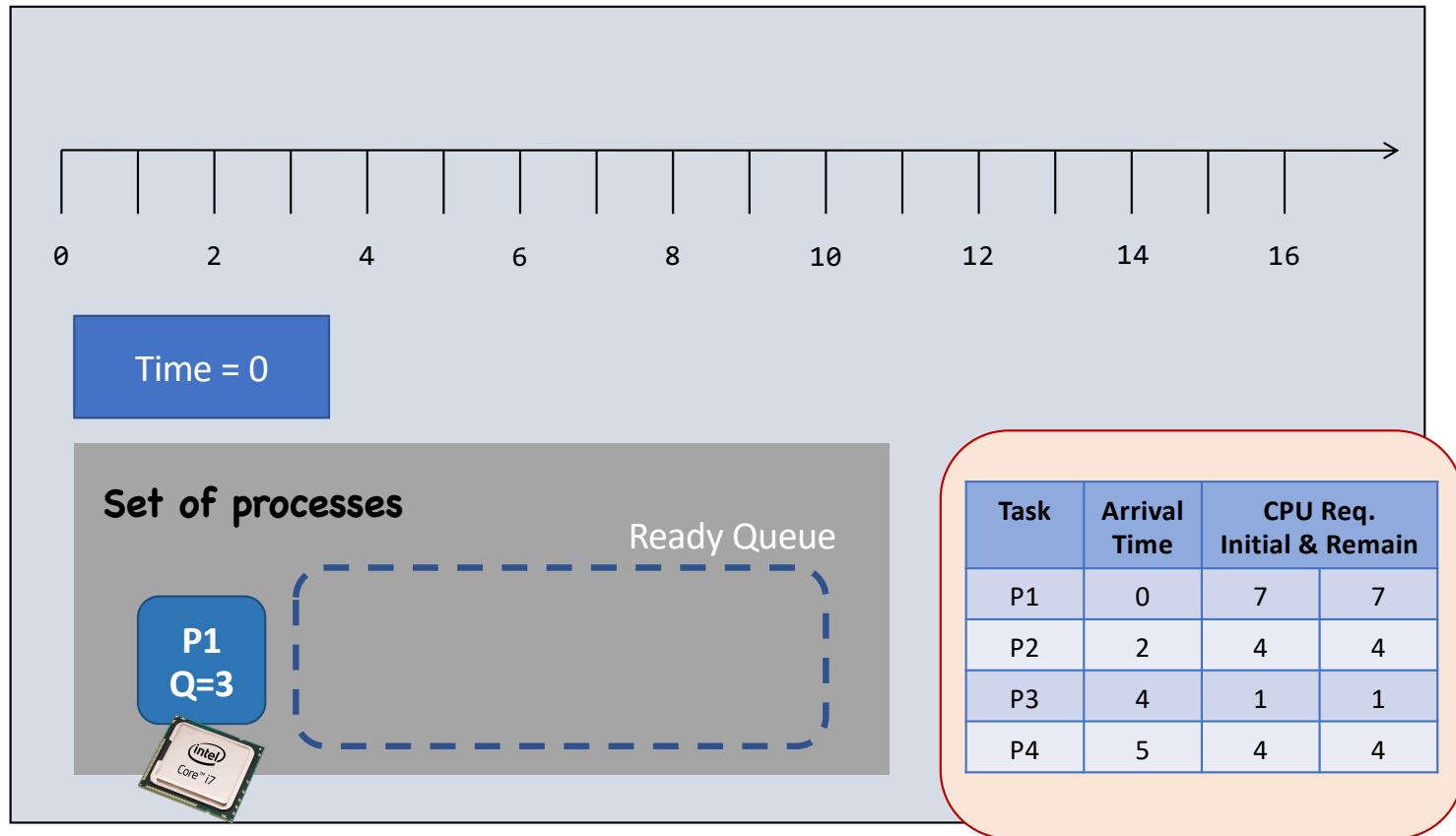
Task	Arrival Time	CPU Req.
P1	0	7
P2	2	4
P3	4	1
P4	5	4

# Round Robin (RR)

- Round-Robin (RR) scheduling is preemptive.
  - Every process is given a **quantum** (the amount of time allowed to execute).
  - Whenever the quantum of a process is used up (i.e., 0), the process is preempted, placed at the end of the queue, with its quantum re-charged
  - Then, the scheduler steps in and it chooses the next process which has a non-zero quantum to run.
  - Processes are therefore running one-by-one as a circular queue
- New processes are added to the tail of the ready queue
  - New process's arrival won't trigger a new selection decision

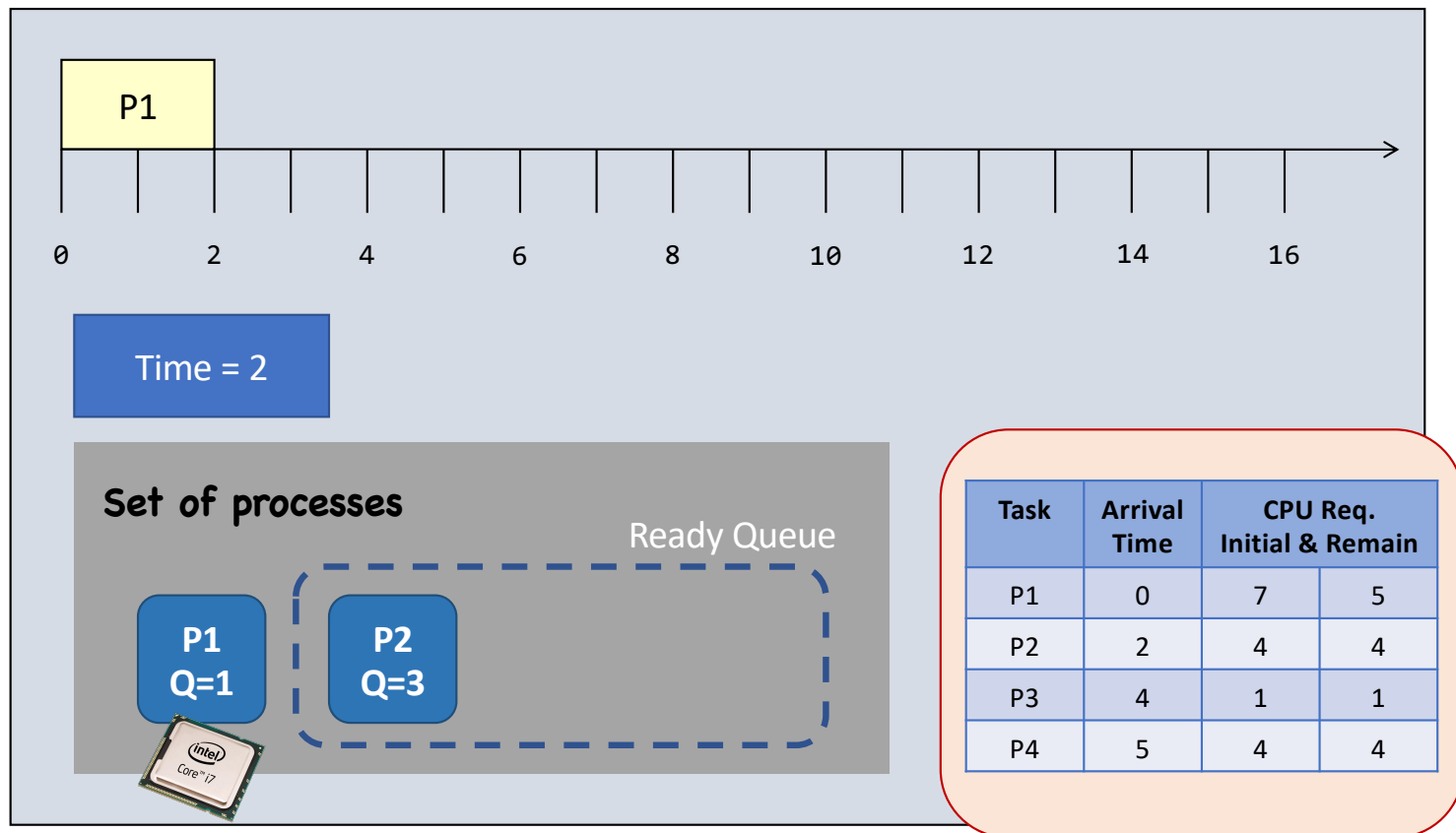
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# Round Robin (Quantum = 3)



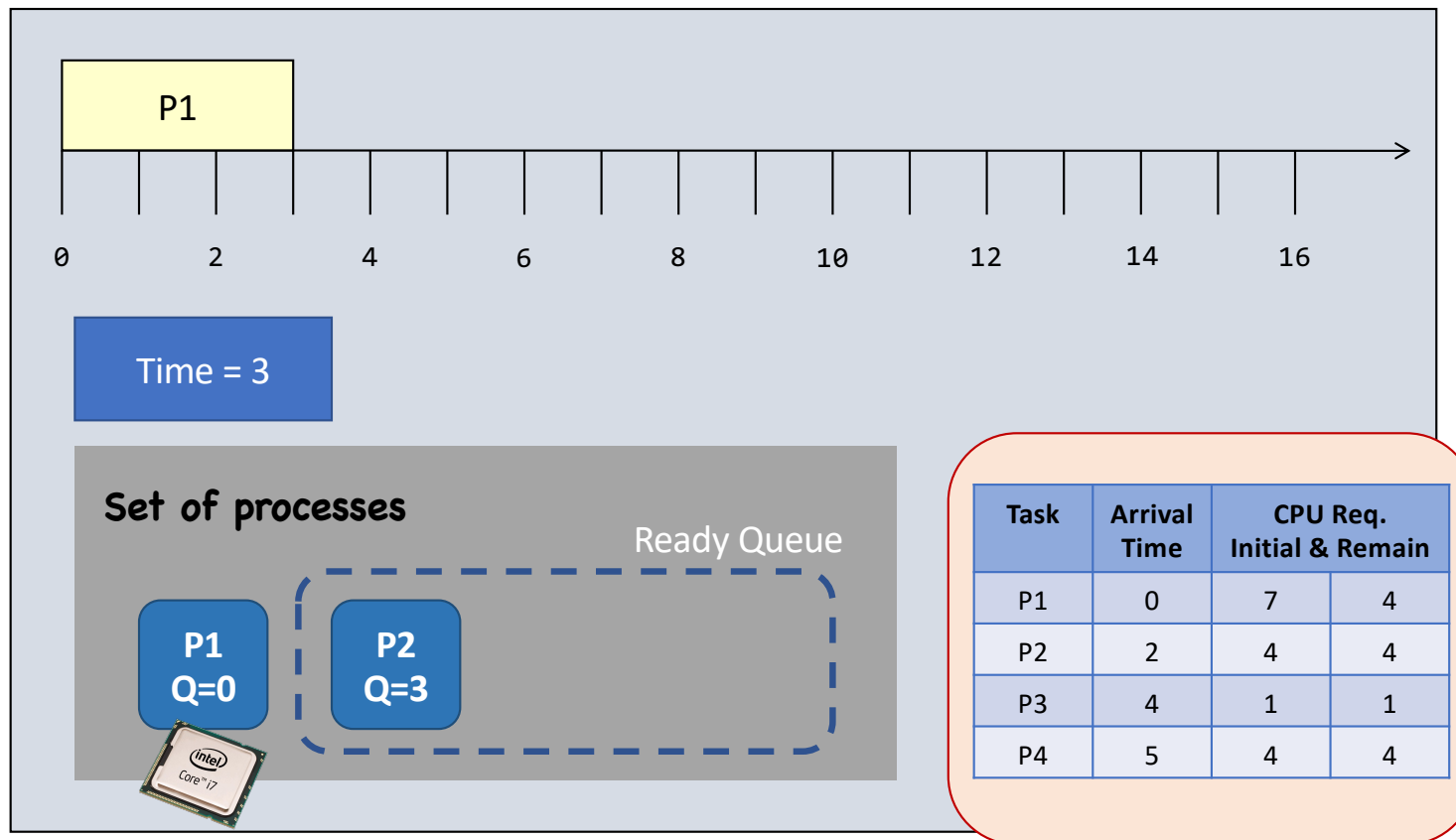
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# Round Robin (Quantum = 3)



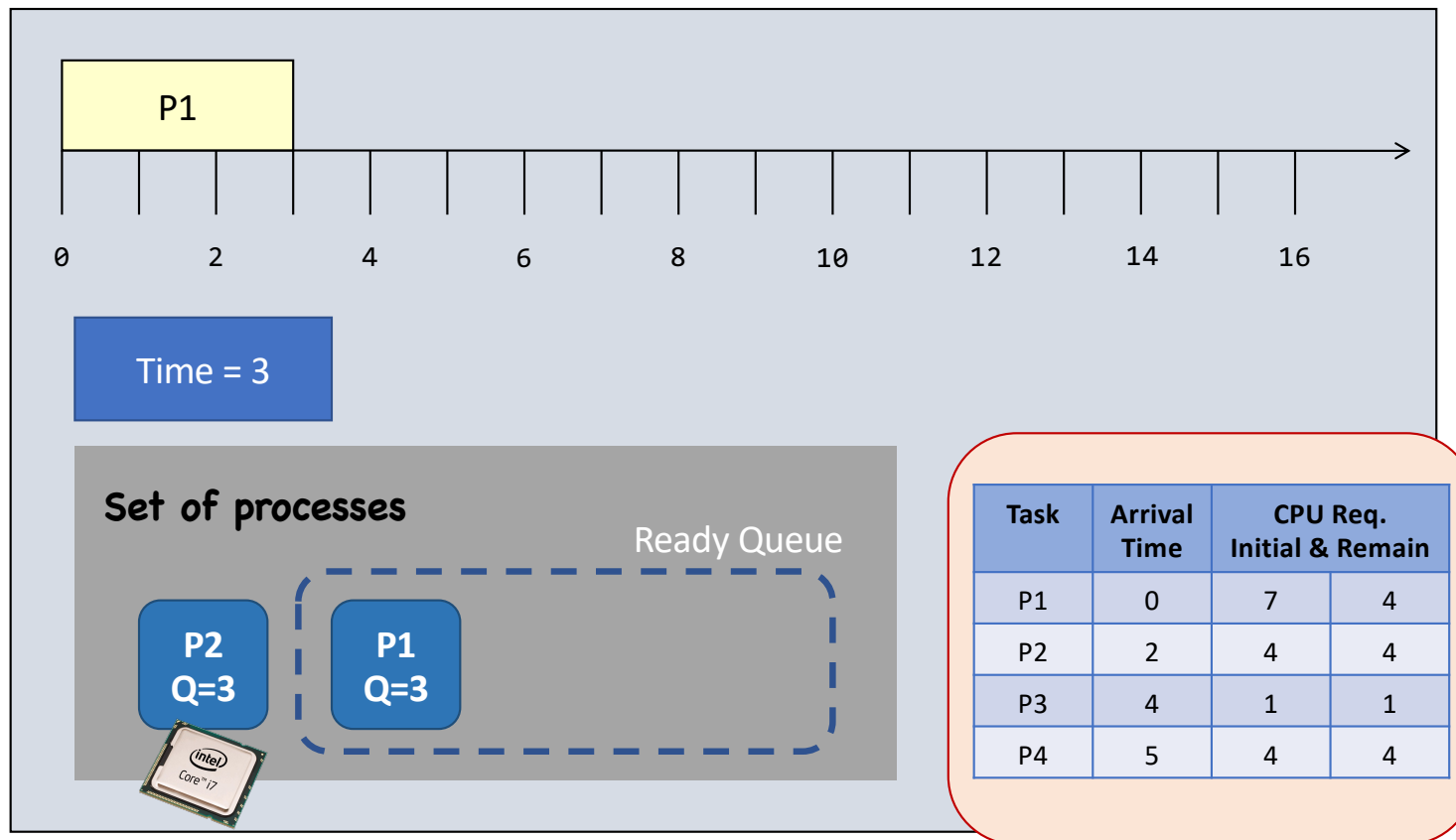
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# Round Robin (Quantum = 3)



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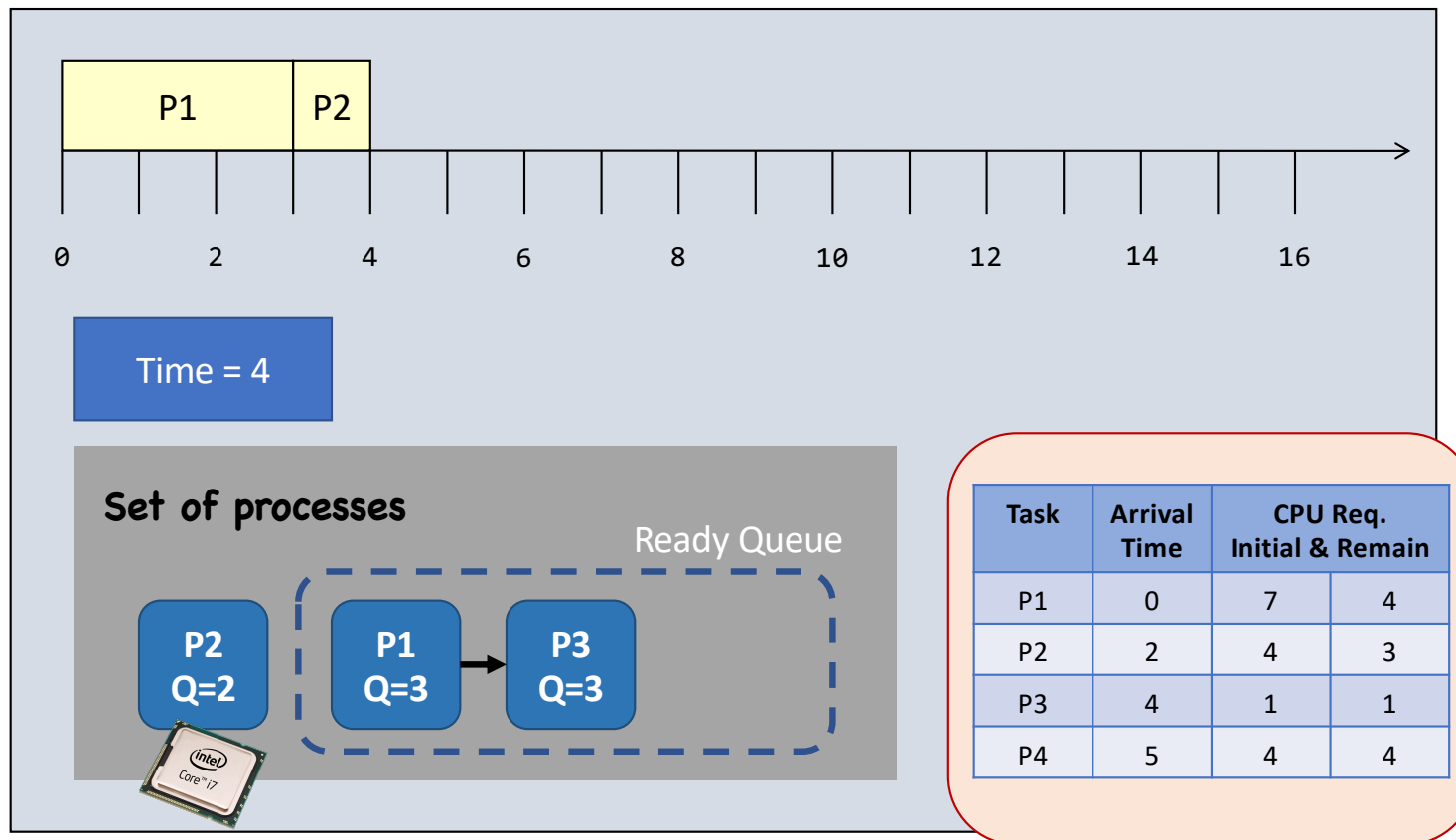
# Round Robin (Quantum = 3)





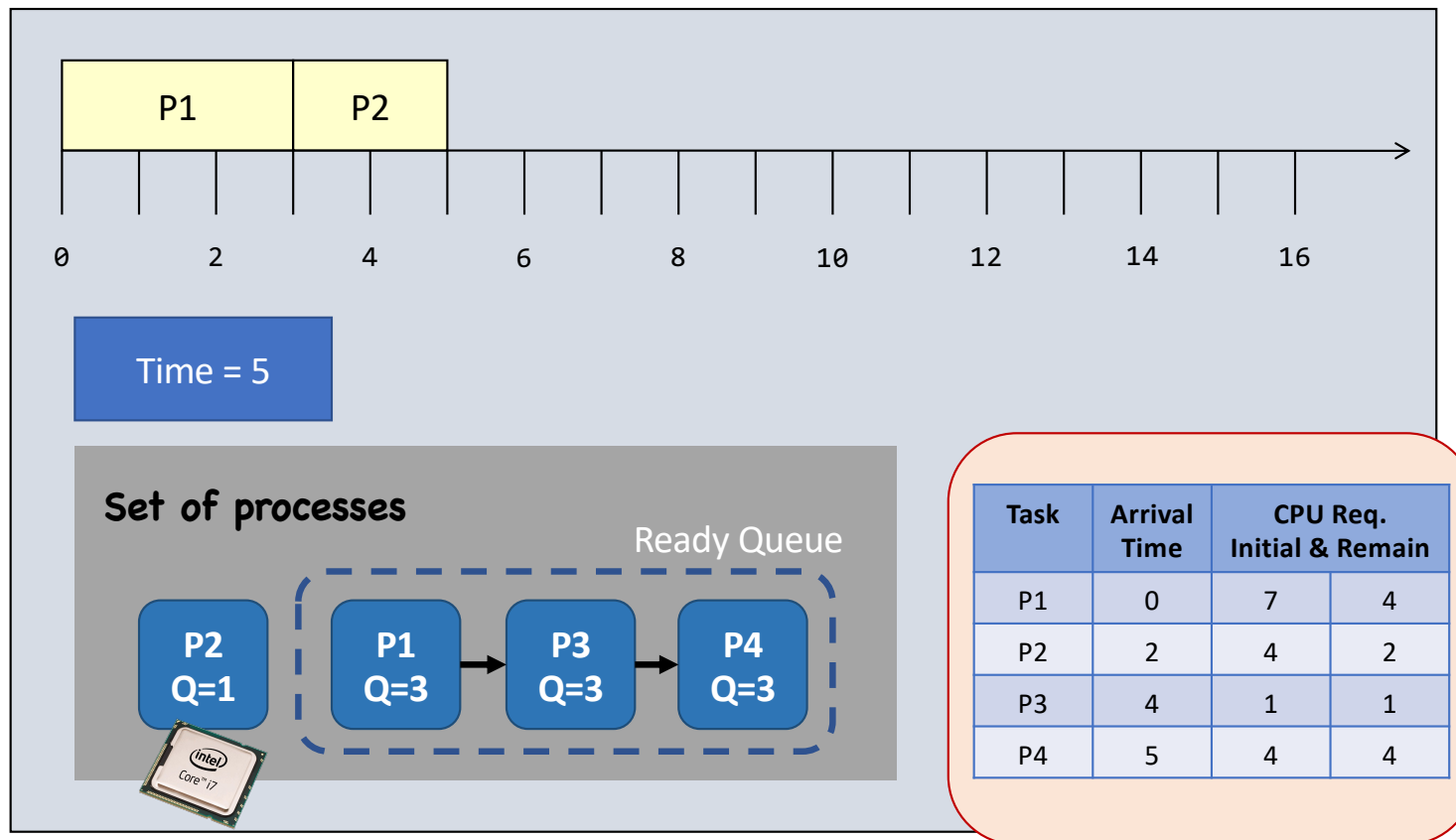
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# Round Robin (Quantum = 3)



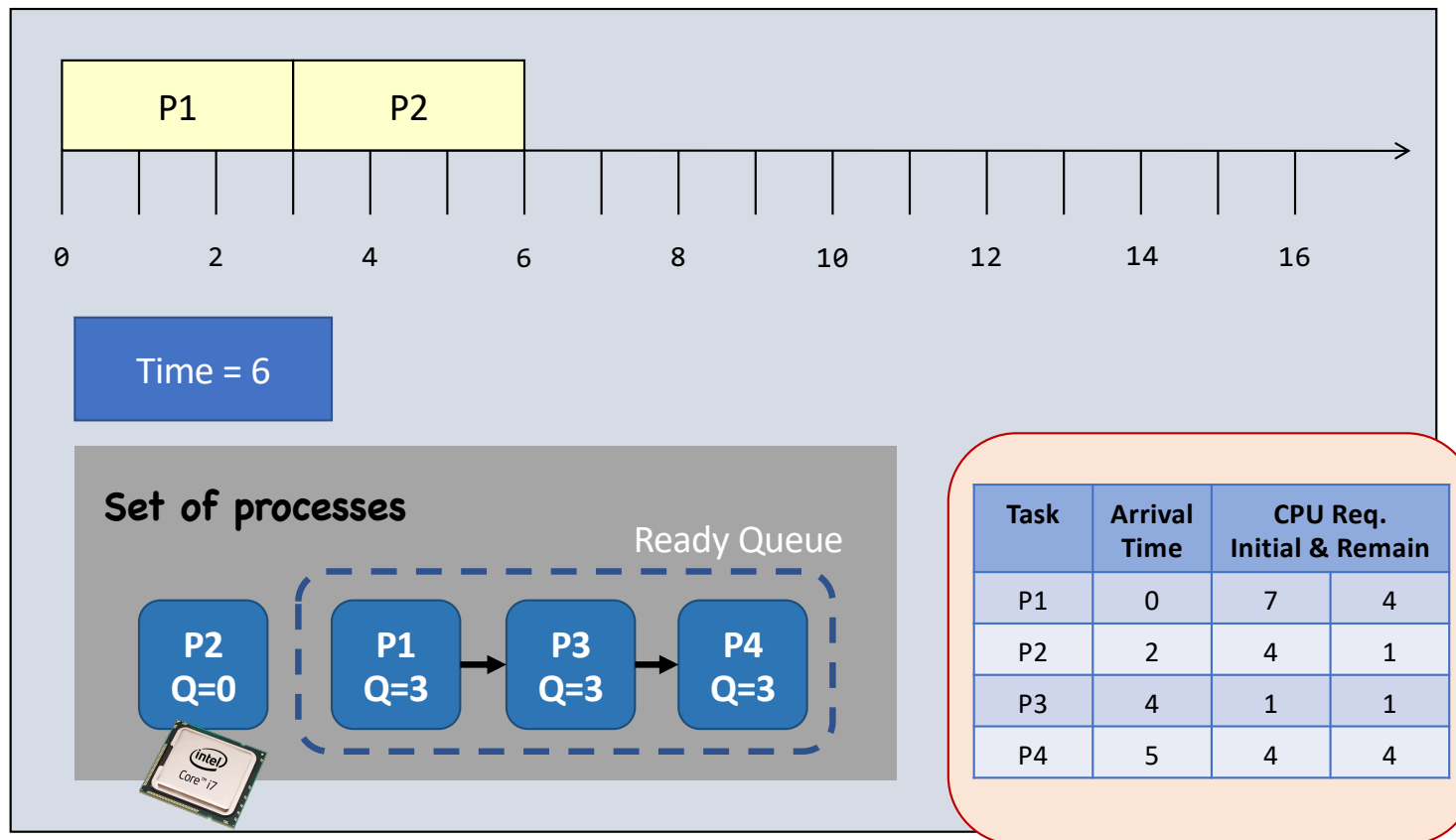
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# Round Robin (Quantum = 3)



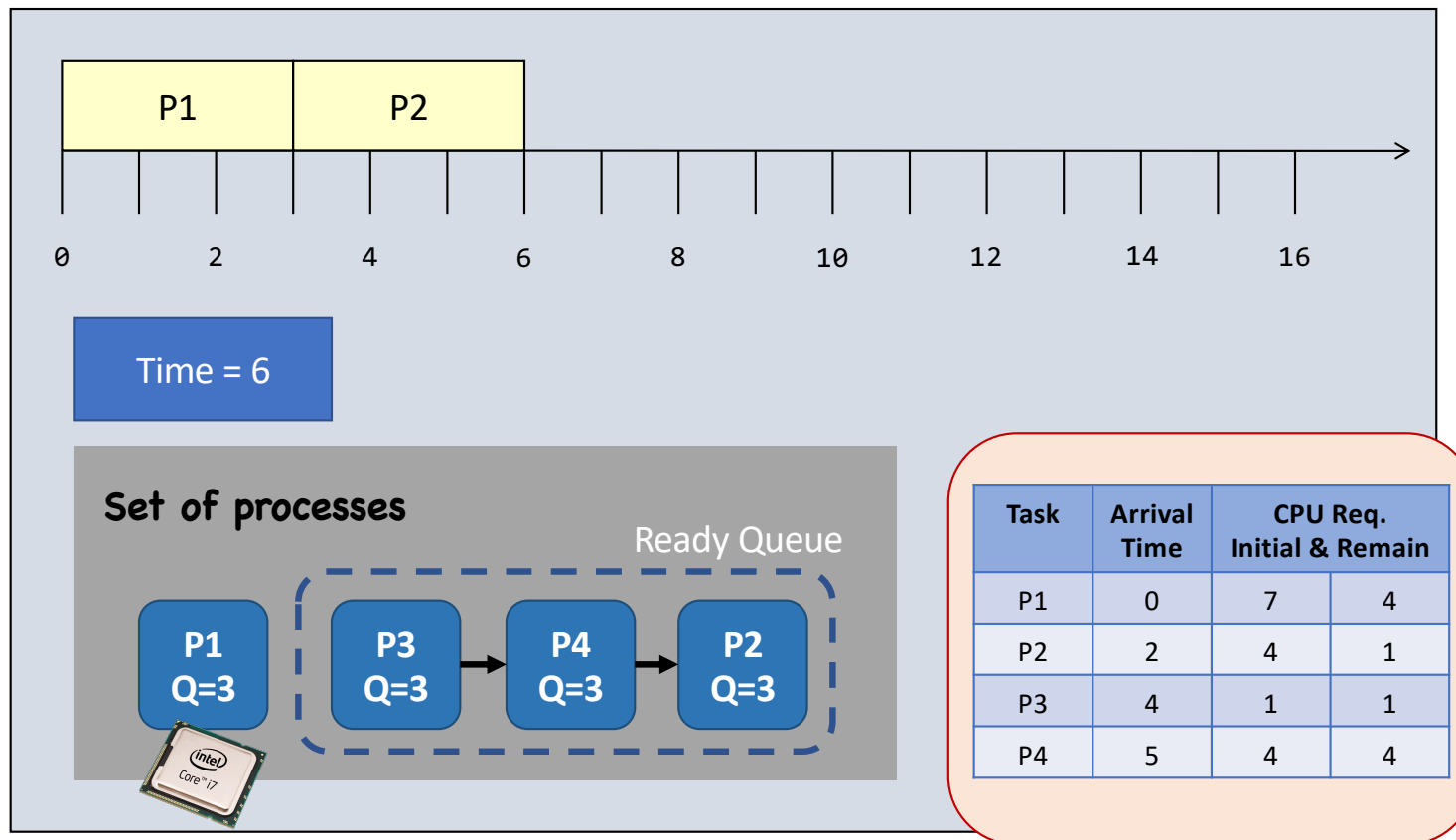
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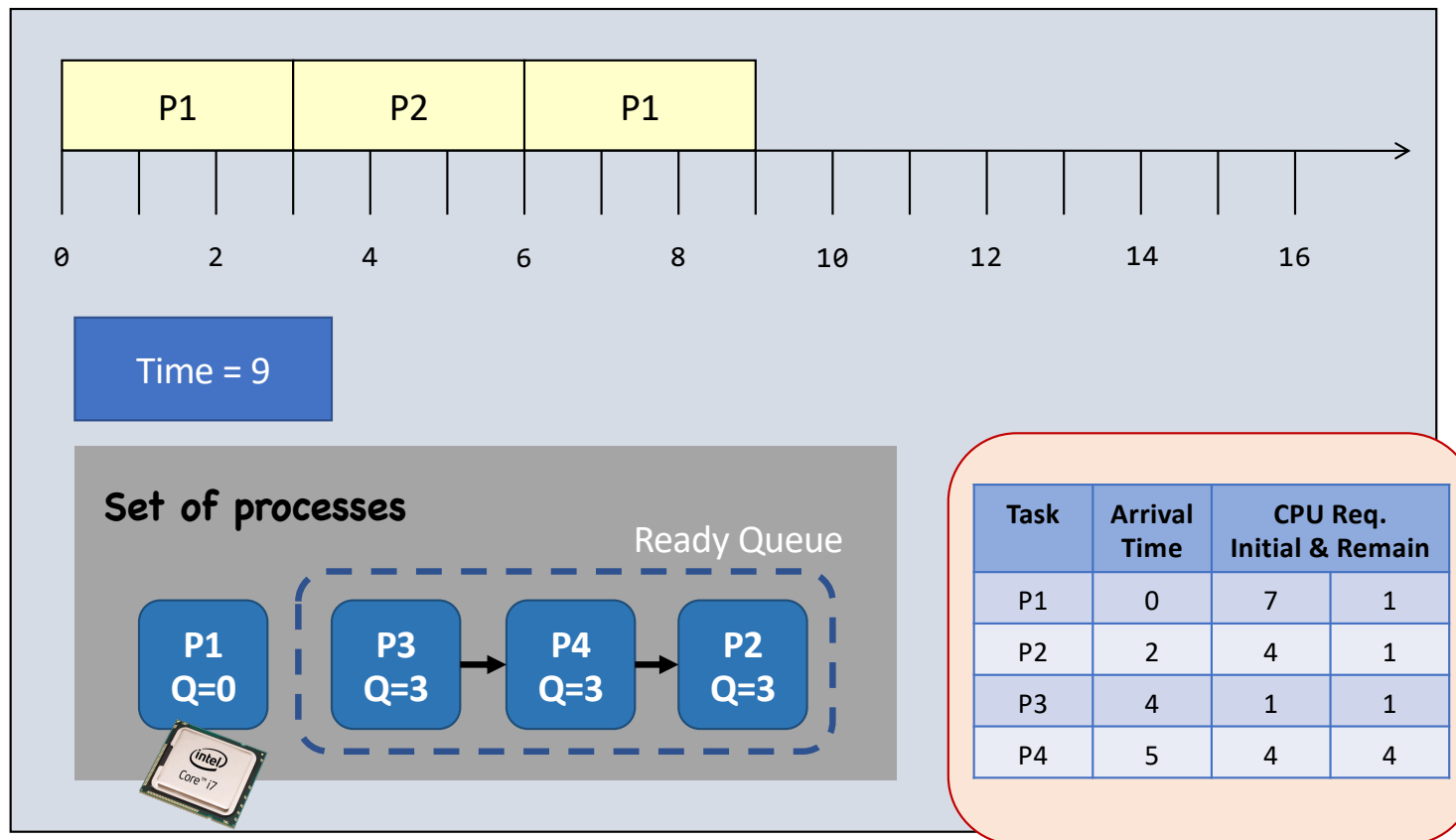
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# Round Robin (Quantum = 3)



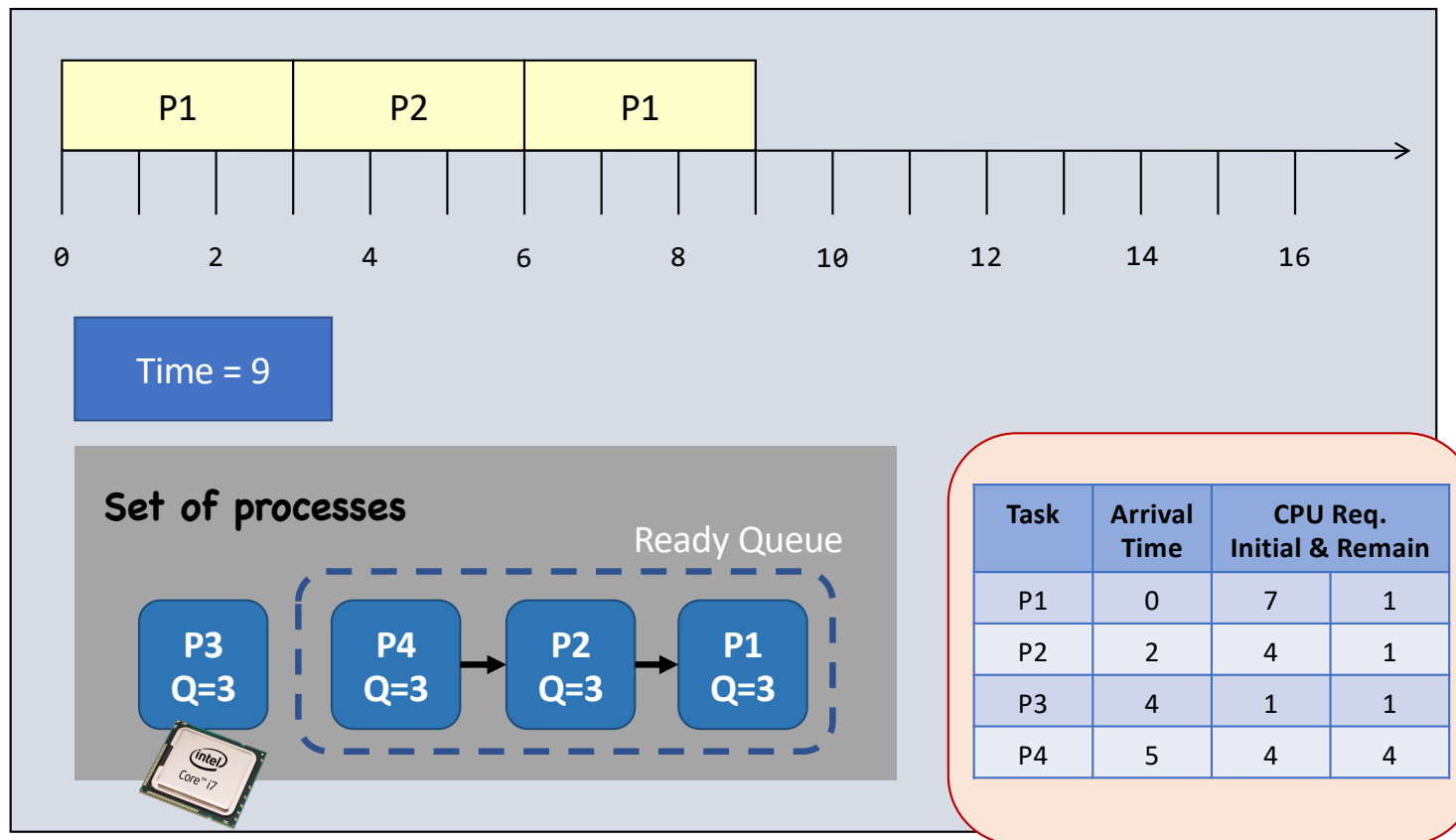
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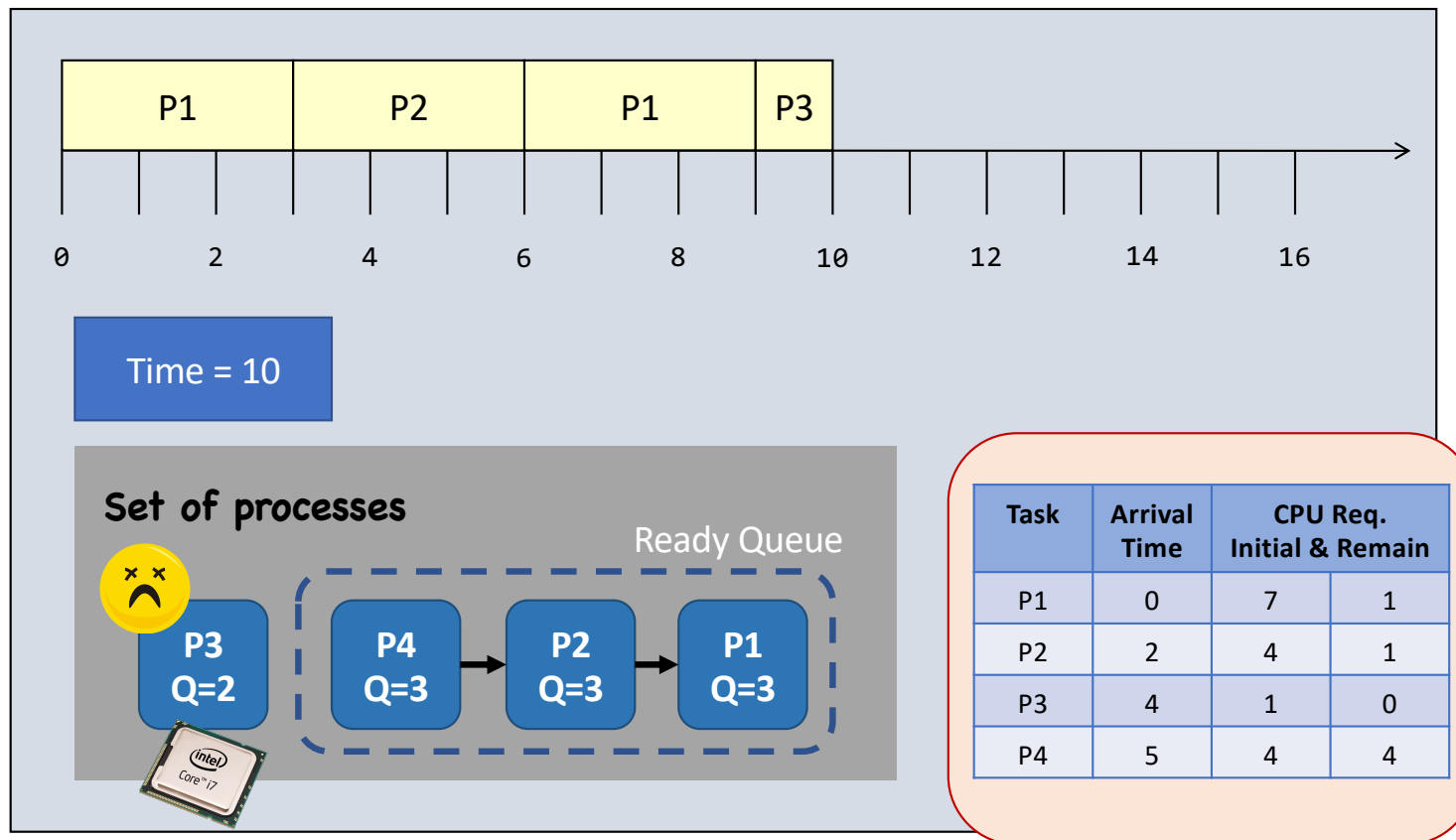
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# Round Robin (Quantum = 3)



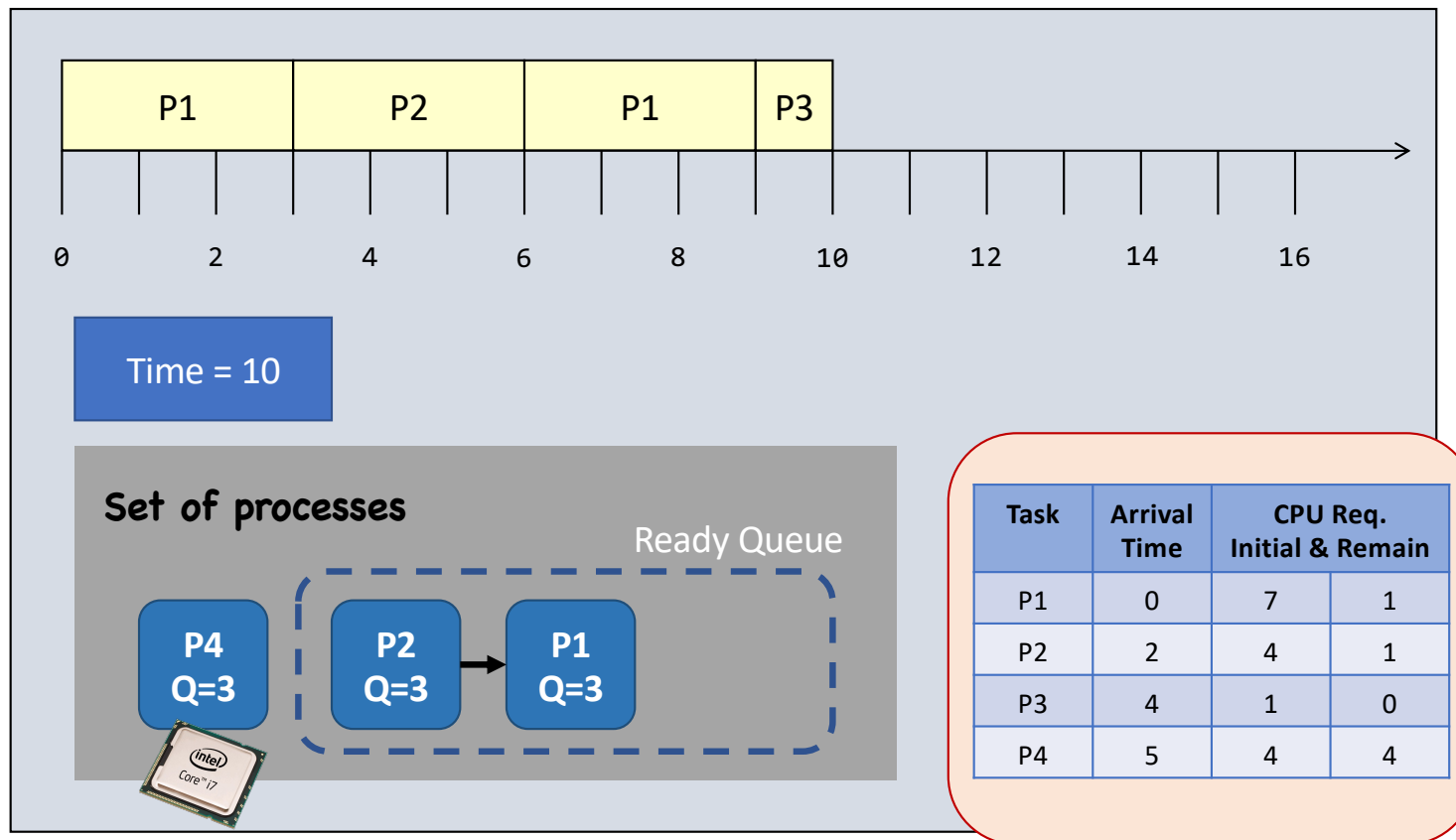
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# Round Robin (Quantum = 3)



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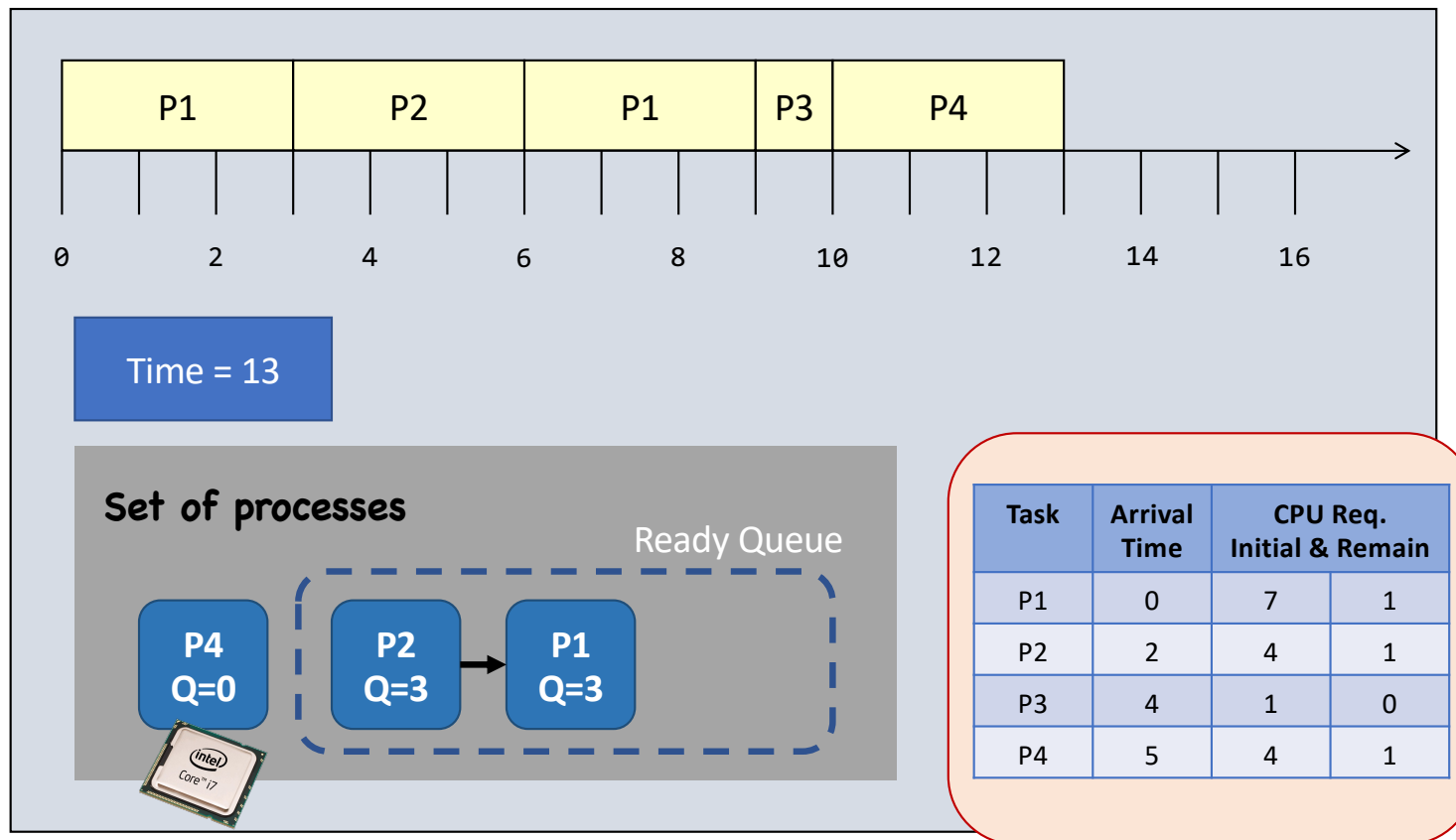
# Round Robin (Quantum = 3)





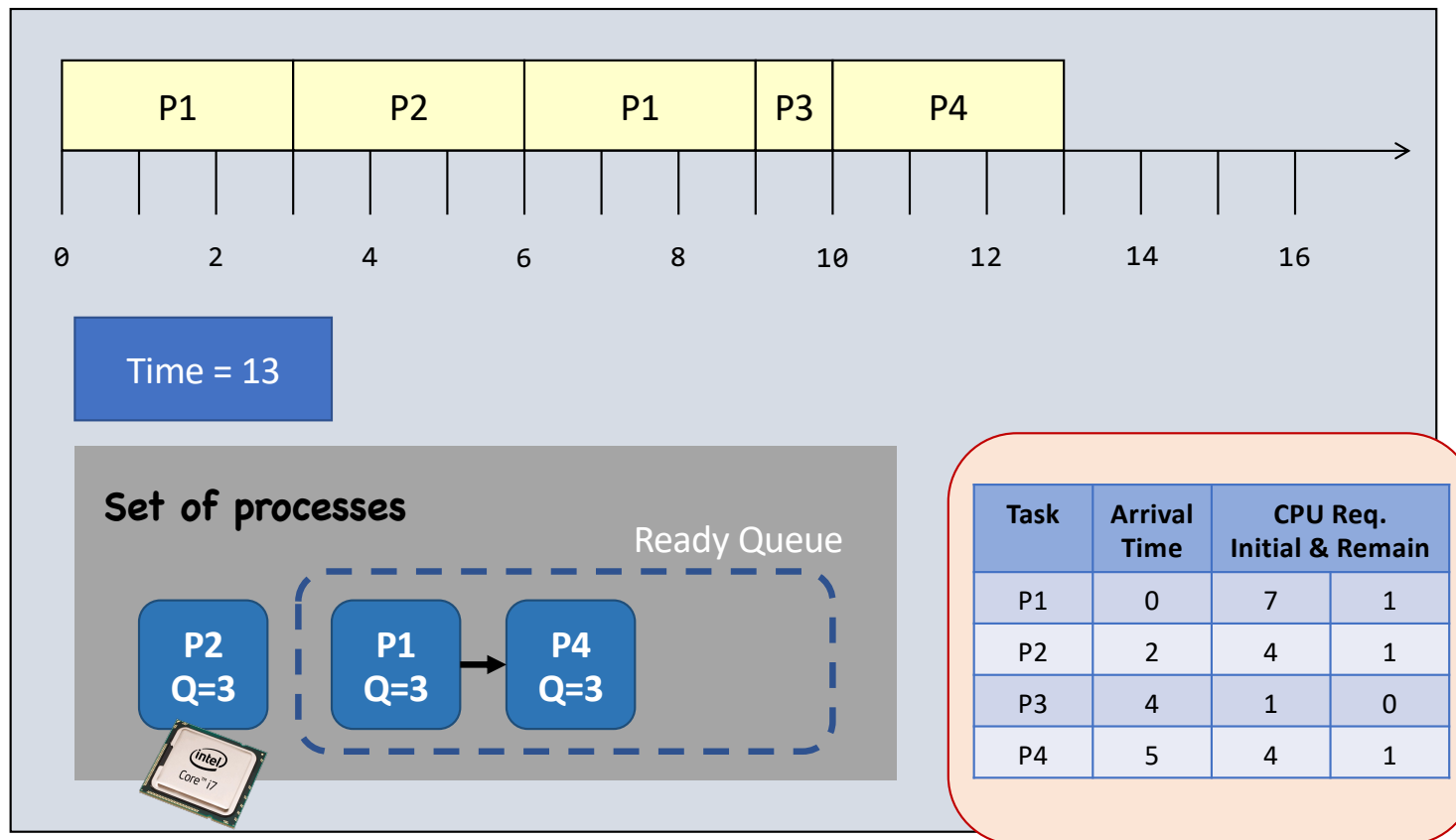
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# Round Robin (Quantum = 3)



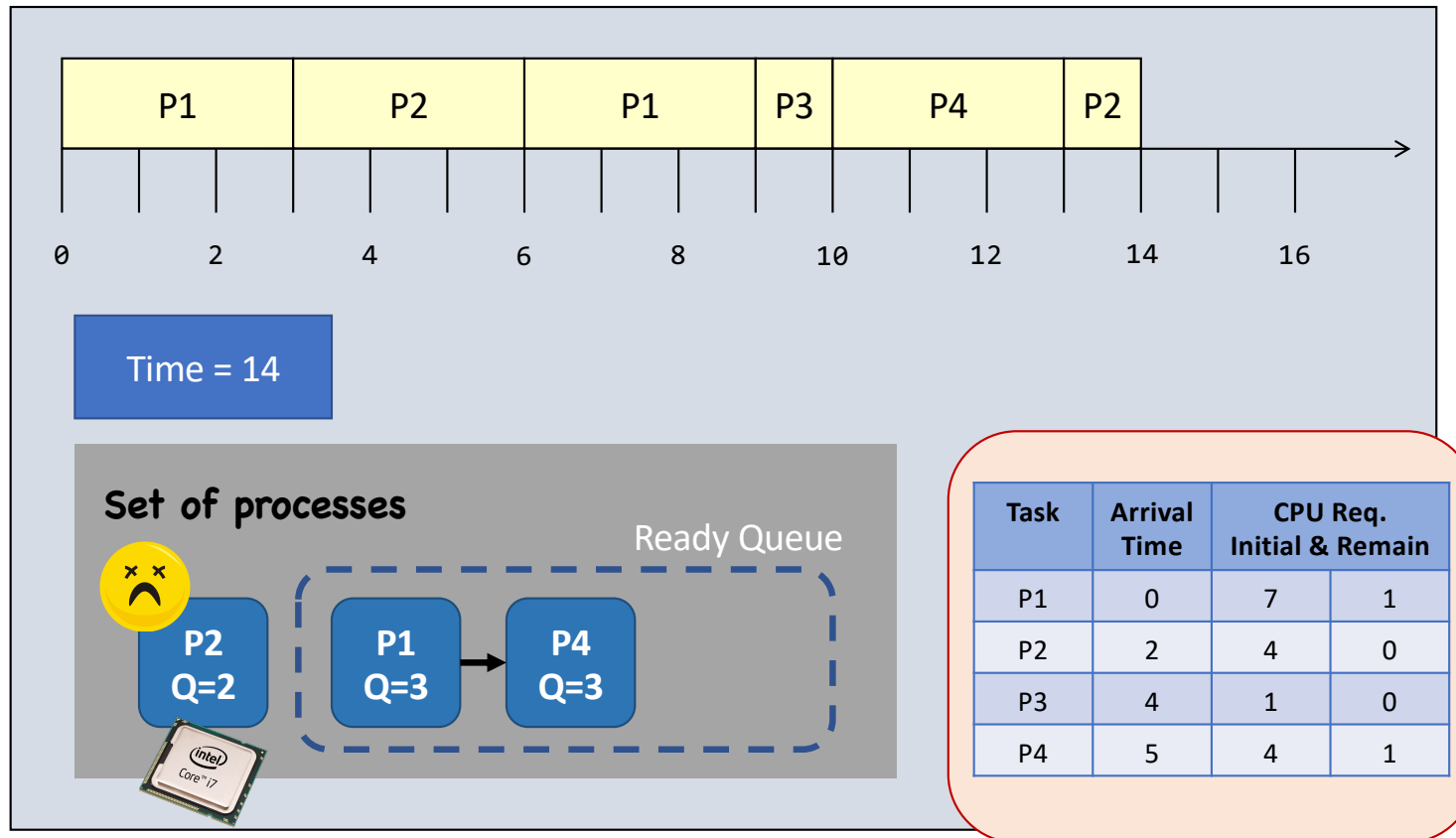
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# Round Robin (Quantum = 3)



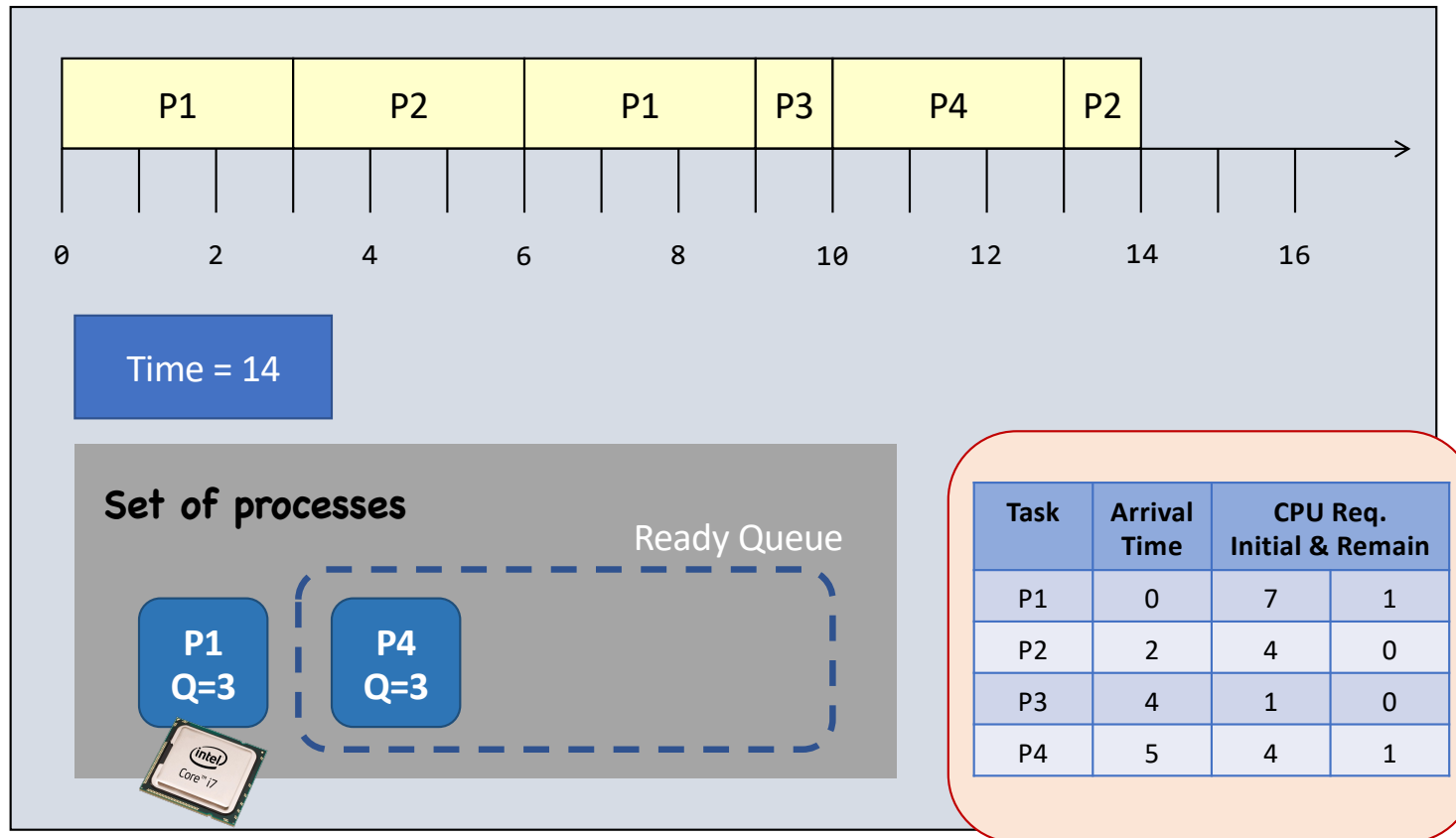
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# Round Robin (Quantum = 3)



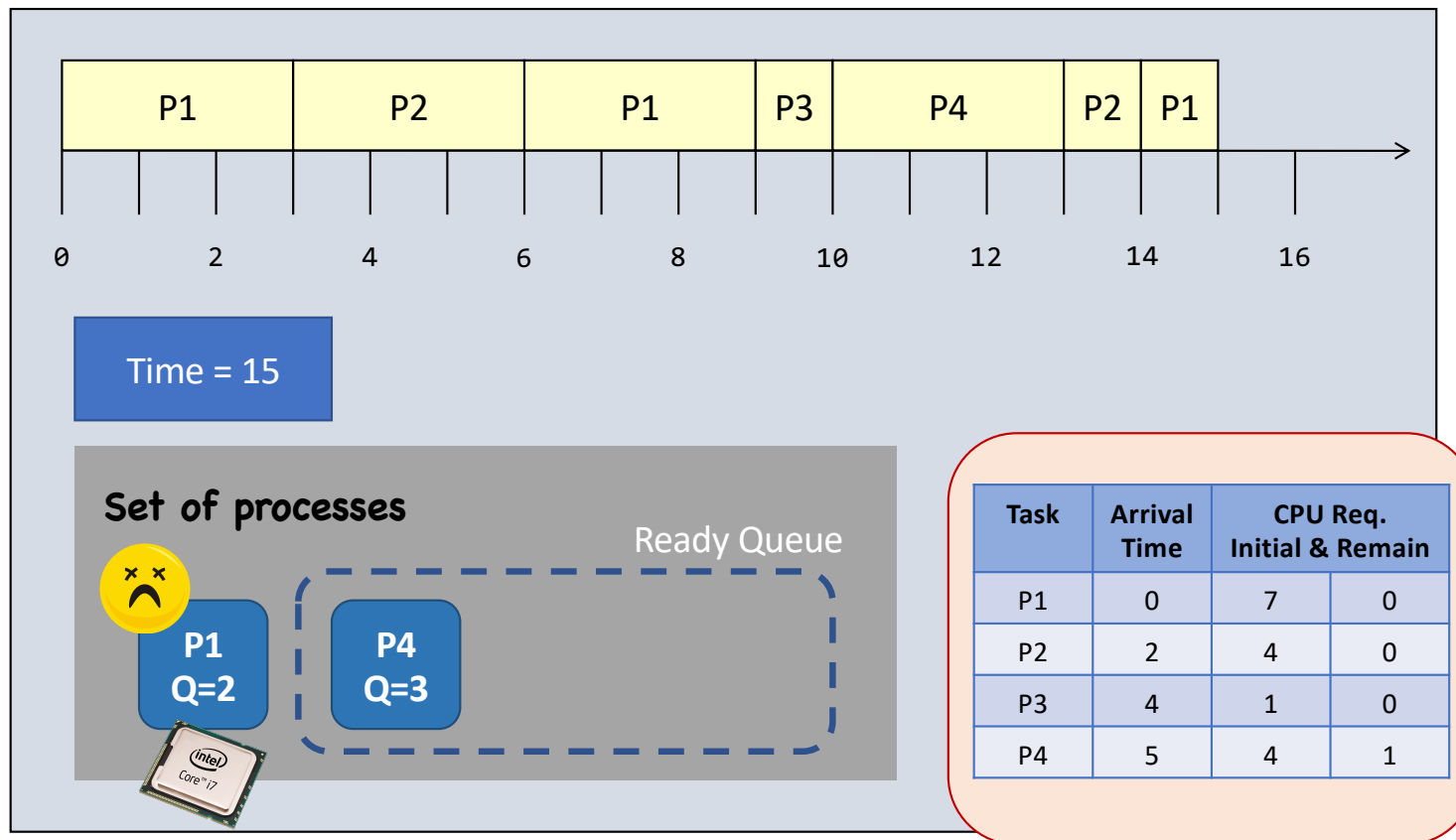
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# Round Robin (Quantum = 3)



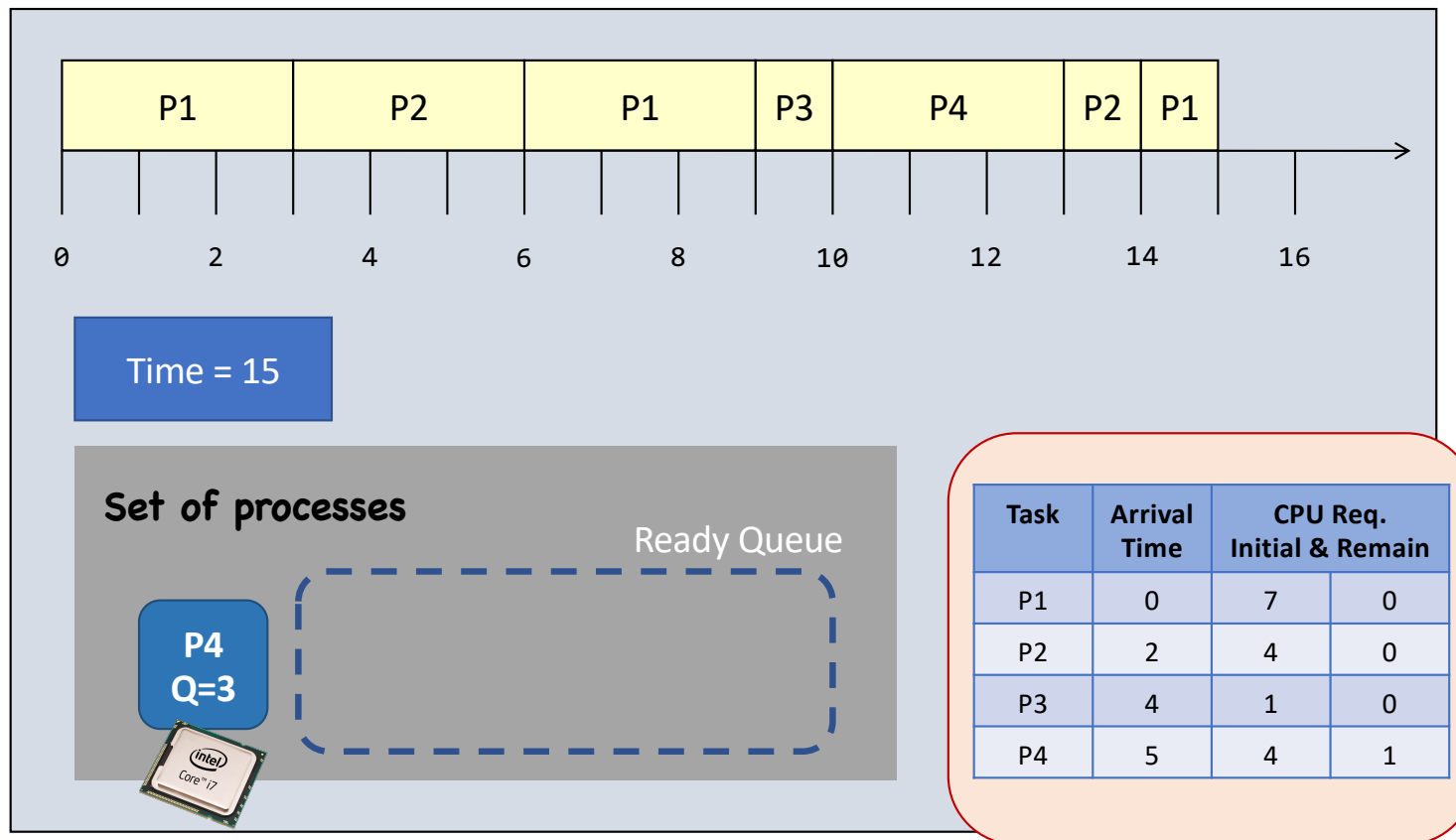
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# Round Robin (Quantum = 3)



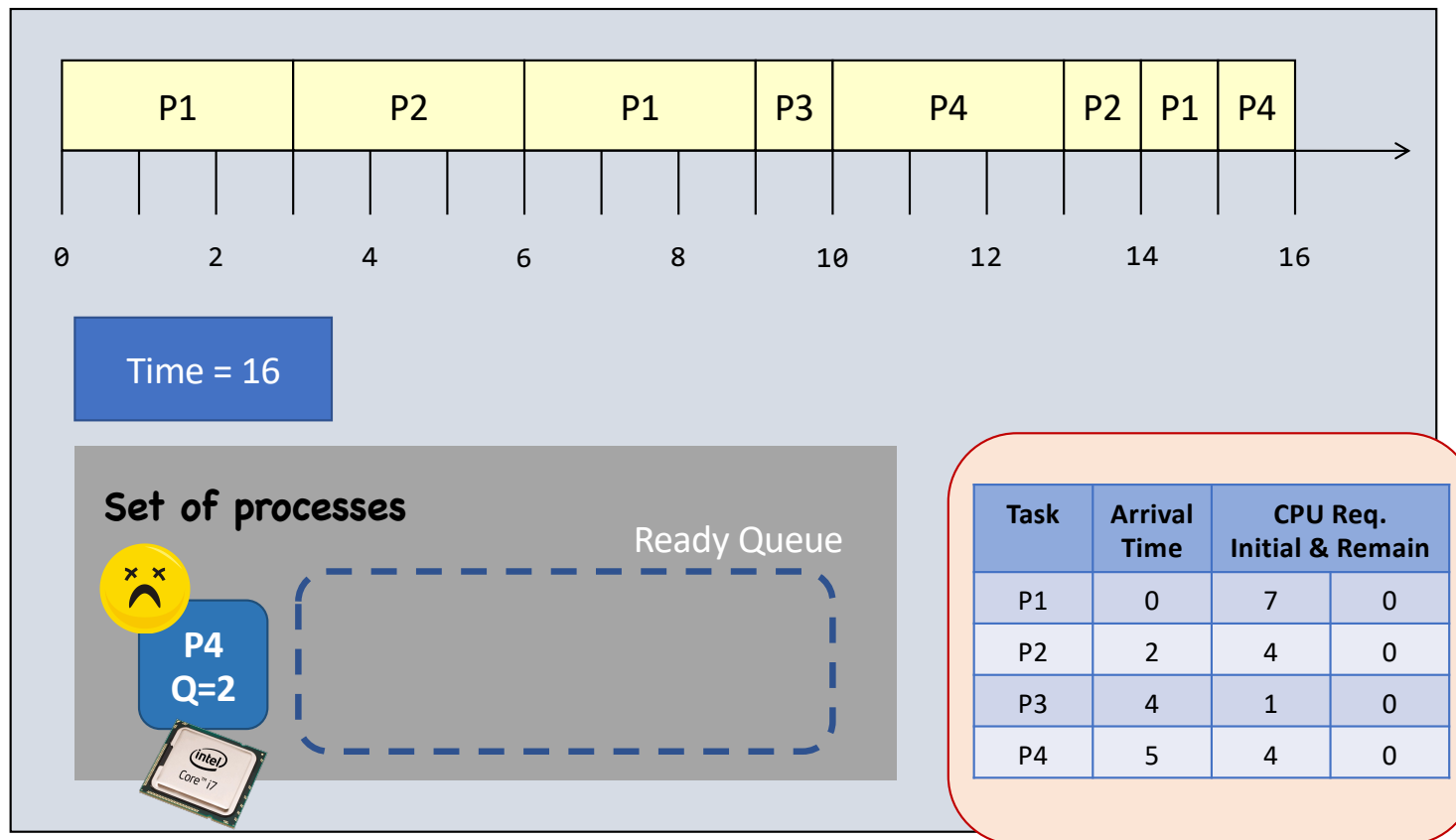
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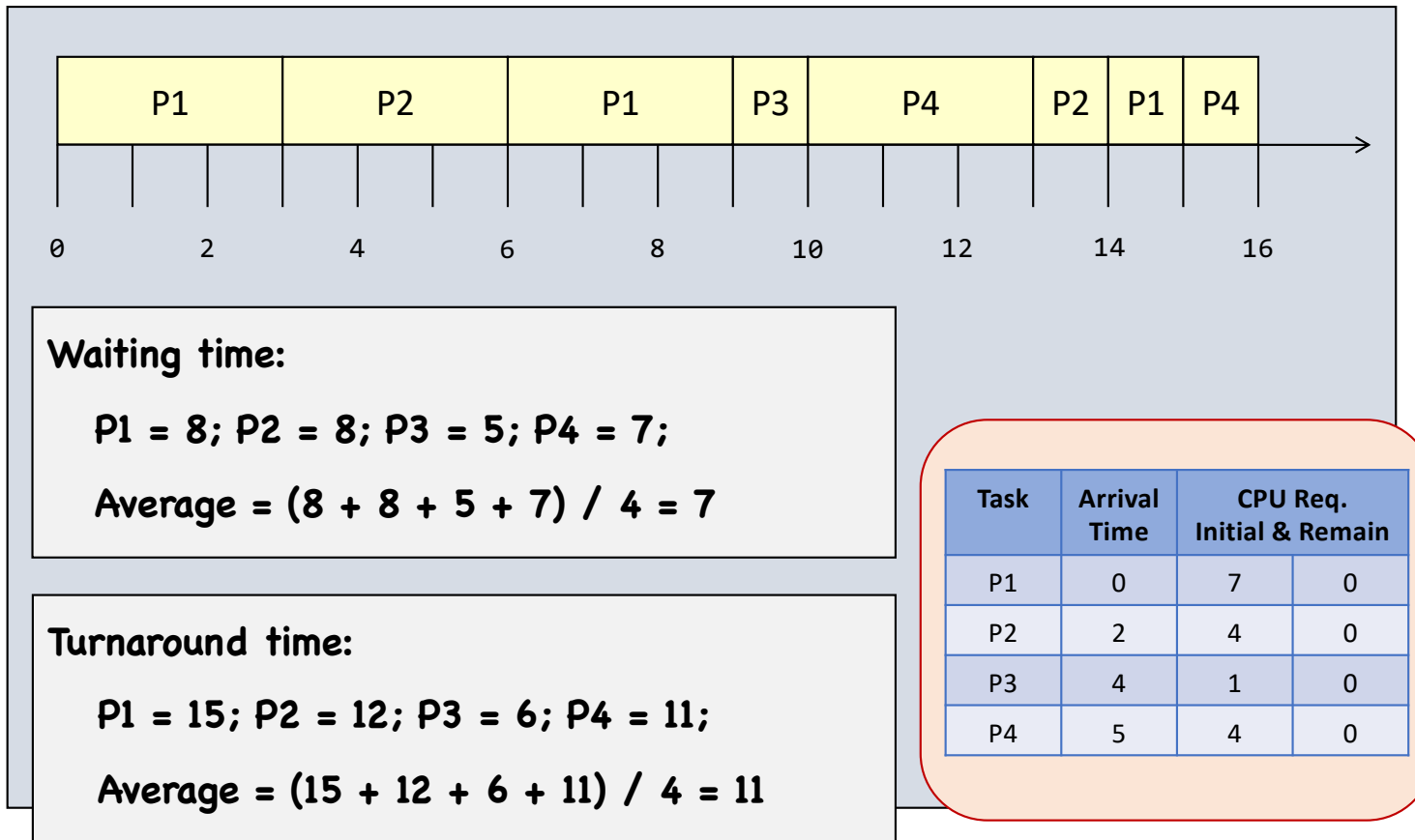
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# Round Robin (Quantum = 3)



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# Round Robin (Quantum = 3)





# RR v.s. SJF

	Non-preemptive SJF	Preemptive SJF	RR
Average waiting time	4	3	7 (largest)
Average turnaround time	8	7	11 (largest)
# of context switching	3	5	7 (largest)



So, the RR algorithm gets all the bad! Why do we still need it?

**The responsiveness of the processes** is great under the RR algorithm. E.g., you won't feel a job is "frozen" because every job gets the CPU from time to time!

# Priority Scheduling

- A priority number (integer) is associated with each process
- The CPU is allocated to the process with the highest priority (smallest integer  $\equiv$  highest priority)
  - Nonpreemptive: newly arrived process simply put into the queue
  - Preemptive: if the priority of the newly arrived process is higher than priority of the currently running process---preempt the CPU
- Static priority and dynamic priority
  - static priority: fixed priority throughout its lifetime
  - dynamic priority: priority changes over time
- SJF is a priority scheduling where priority is the next CPU burst time

# Priority Scheduling (Cont'd)

- Problem  $\equiv$  **Starvation** – low priority processes may never execute
  - Rumors has it that when they shut down the IBM 7094 at MIT in 1973, they found a low priority process that had been submitted in 1967 and had not yet been run.
- Solution  $\equiv$  **Aging** – as time progresses increase the priority of the process
  - Example: priority range from 127 (low) to 0 (high)
  - Increase priority of a waiting process by 1 every 15 minutes
  - 32 hours to reach priority 0 from 127

# Linux Scheduling

- Before Linux kernel version 2.5, traditional UNIX scheduling, not adequately support SMP
- Linux kernel version 2.5, O(1) scheduler
  - Constant scheduling time regardless number of tasks
  - Better support for SMP
  - Poor response time for interactive processes
- After Linux kernel version 2.6.23, CFS-completely fair scheduler
  - Default scheduler now

# Completely Fair Scheduler

- Scheduling class
  - Standard Linux kernel implements two scheduling classes
  - (1) Default scheduling class: CFS
  - (2) Real-time scheduling class
- Varying length scheduling quantum
  - Traditional UNIX scheduling uses 90ms fixed scheduling quantum
  - CFS assigns a proportion of CPU processing time to each task
- Nice value
  - -20 to +19, default nice is 0
  - Lower nice value indicates a higher relative priority
  - Higher value is “being nice”
  - Task with lower nice value receives higher proportion of CPU time

# Completely Fair Scheduler (Cont'd)

- Virtual run time
  - Each task has a per-task variable **vruntime**
  - Decay factor
    - Lower priority has higher rate of decay
    - $\text{nice} = 0$  virtual run time is identical to actual physical run time
    - A task with  $\text{nice} > 0$  runs for 200 milliseconds, its **vruntime** will be higher than 200 milliseconds
    - A task with  $\text{nice} < 0$  runs for 200 milliseconds, its **vruntime** will be lower than 200 milliseconds
- Lower virtual run time, higher priority
  - To decide which task to run next, scheduler chooses the task that has the smallest **vruntime** value
  - Higher priority can preempt lower priority

# Completely Fair Scheduler (Cont'd)

- Example: Two tasks have the same nice value
- One task is I/O bound and the other is CPU bound
- **vruntime** of I/O bound will be shorter than **vruntime** of CPU bound
- I/O bound task will eventually have higher priority and preempt CPU-bound tasks whenever it is ready to run

**Thank you!**

