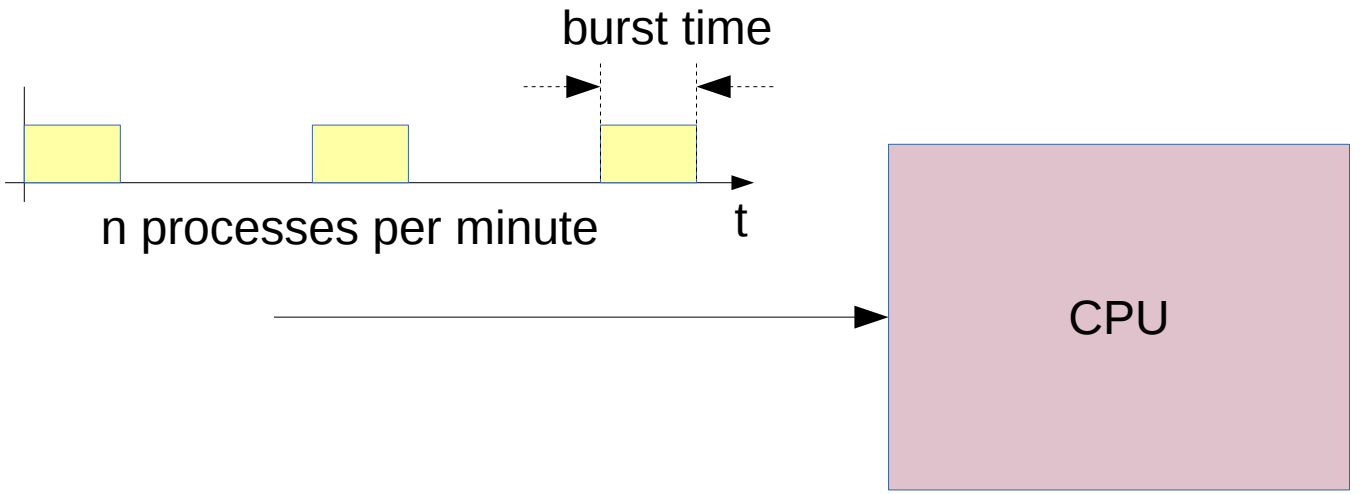
CPU Utilization (1)



$$CPU\ Utilization = \frac{Burst\ Time}{Period\ Time}$$

Example:
Processes arrive at a rate of 12 processes per minute. The average burst time is 4 seconds. Determine the average CPU utilization (in percentage).

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CPU Utilization (2)

- In Linux, *top* or *uptime* shows the “load average” on a system.
- Three numbers: System load average over the last 1min, 5min, 15min.
- The number is the number of processes in either a *runnable* or *uninterruptable* (e.g. waiting for some I/O) state.
- Interpretation
  - 100% utilization on a single core CPU -> 1.0
  - 100% utilization on a quad core CPU -> 4.0

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Goals of Process Scheduling

- Maximize CPU utilization
- Fair CPU allocation
- Minimize Turnaround Time
- Minimize Waiting Time
- Maximize the number of processes that complete execution per time unit (“throughput”)

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Process Scheduling Times

- **Arrival Time**
  The time at which the process arrives in the ready queue.
- **Completion Time**
  The time at which a process is completed.
- **Burst Time**
  CPU time that a process requires for its execution.
- **Turnaround Time**
  = Completion Time – Arrival Time
- **Waiting Time**
  The amount of time a process has been waiting in the ready queue.

Two Types of Scheduling Algorithms

- **Non-preemptive Scheduling**
  A process holds the CPU until it terminates or it switches from running to waiting state.
- **Preemptive Scheduling**
  A running process can be taken away from the CPU in favor of other processes.

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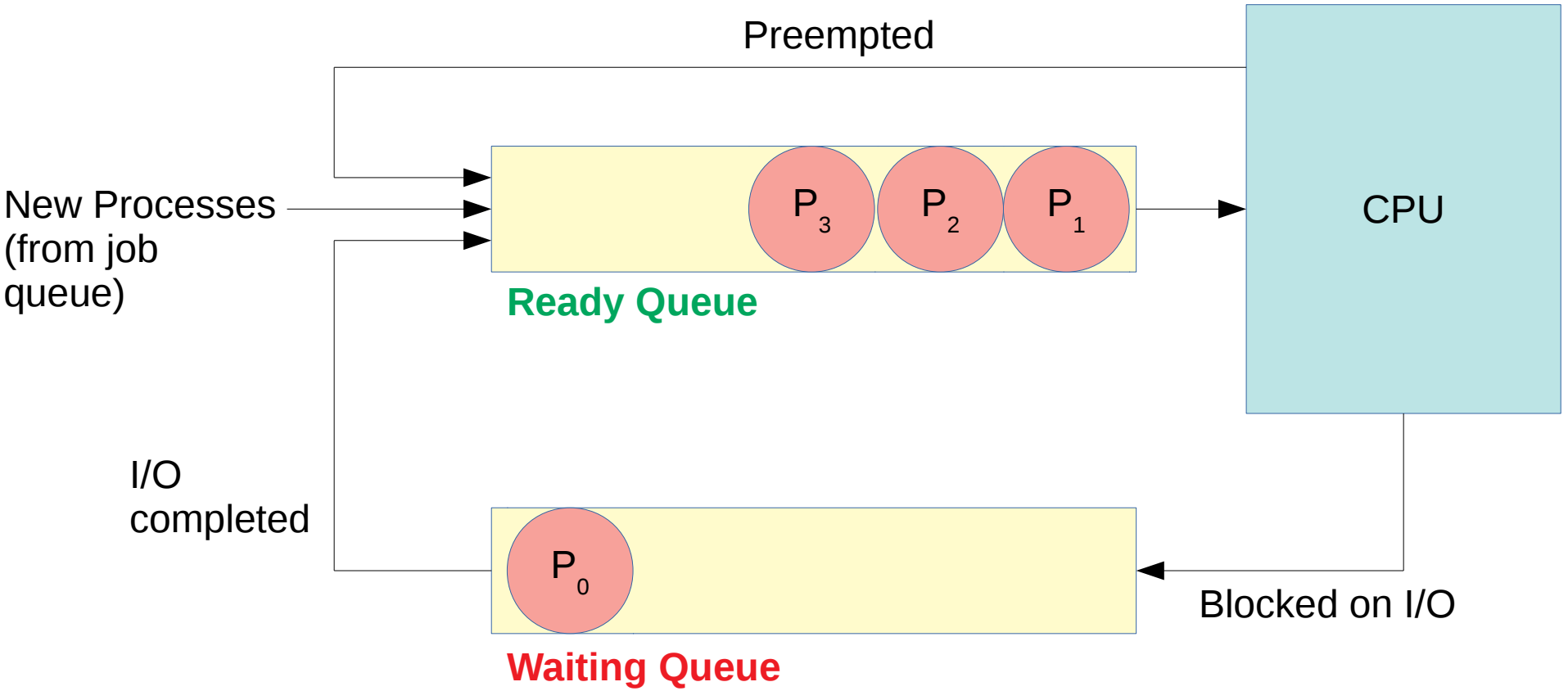
Scheduling Queues (simplified)



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Scheduling Algorithms

- First Come First Serve
- Shortest Job First
- Shortest Remaining Time First
- Round Robin Scheduling
- Priority Based Scheduling
- Highest Response Ratio Next
- Multilevel Queue Scheduling
- Multilevel Feedback Queue Scheduling

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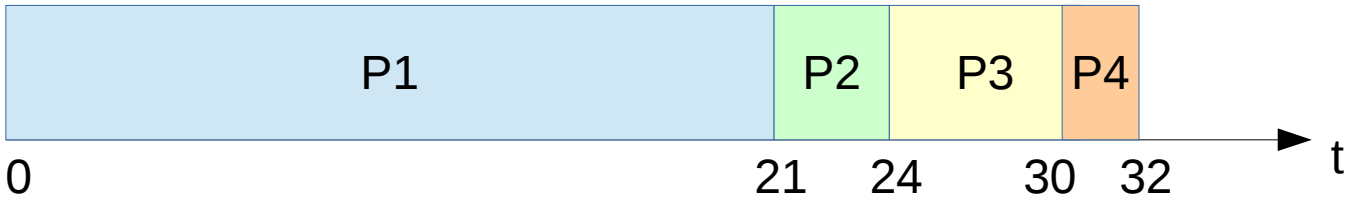
First Come First Serve (FCFS) (1)

Process	Burst Time
P1	21
P2	3
P3	6
P4	2

Assumption: Arrival Time of all processes is 0



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First Come First Serve (FCFS) (2)

- FIFO (First-In-First-Out) queue structure
- Simple to implement
- Non-preemptive
- Does not consider priority
- Low throughput possible due to *convoy effect* (Long processes will delay execution of short processes)
- No starvation (assuming that every process will eventually complete)

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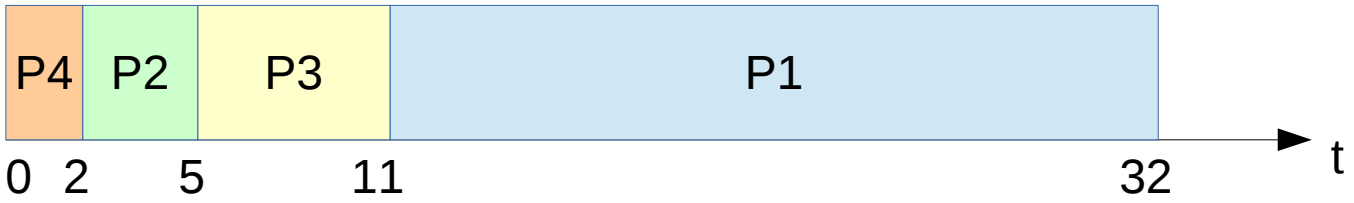
Shortest Job First (SJF) (1)

Process	Burst Time
P1	21
P2	3
P3	6
P4	2

Assumption: Arrival Time of all processes is 0



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Shortest Job First (SJF) (2)

- Always selects the process with the smallest burst time for execution first.
- A process' priority is the inverse of its predicted CPU burst time.
- The burst time of each process must be known in advance.
- Risk of starvation.

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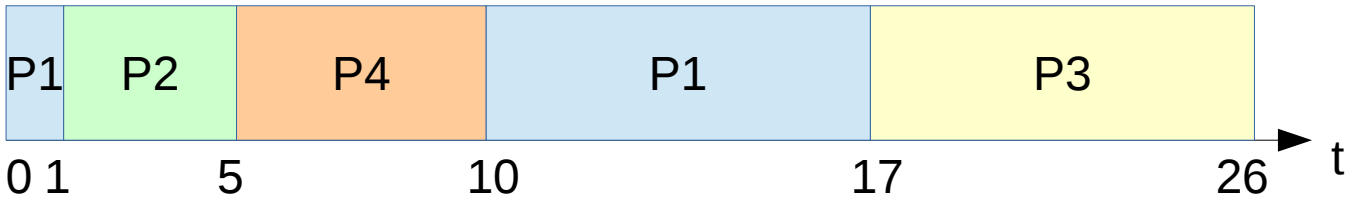
Shortest Remaining Time First (SRTF) (1)

Process	Burst Time	Arrival Time
P1	8	0
P2	4	1
P3	9	2
P4	5	3



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Shortest Remaining Time First (SRTF) (2)

- Whenever a process with a shorter burst time arrives, the currently executed process is preempted.
- Overhead due to context switching
- Starvation is possible (if short processes are continually added)

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Highest Response Ratio Next (HRRN)

- Similar to SJN with a small modification
- Decision which job is next is based on the highest *response ratio*.

$$response\,ratio = 1 + \frac{waiting\,time}{estimated\,run\,time}$$

- Jobs that have spent a relatively long waiting time will be preferred
- Mitigates the problem of starvation

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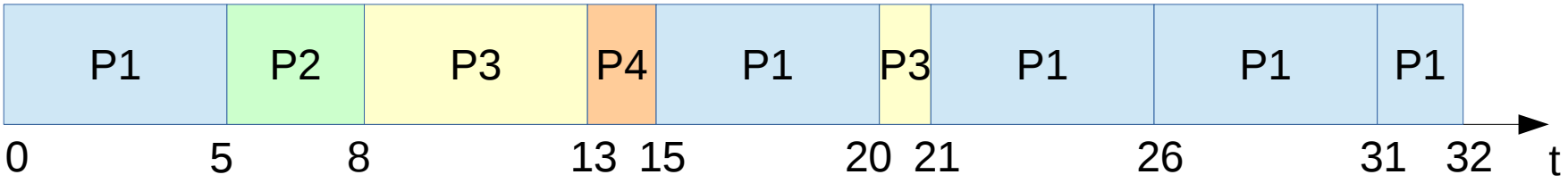
Round Robin Scheduling (RR) (1)

Process	Burst Time
P1	21
P2	3
P3	6
P4	2

Quantum: 5

Assumption: Arrival Time of all processes is 0



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Round Robing Scheduling (RR) (2)

- Assigns a fixed time quantum per process and cycles through all processes
- Process is rescheduled if it does not complete within the quantum
- No starvation
- Overhead due to context switching, especially with small time quanta
  - Quantum should be significantly higher than context switch time, e.g. 100 ms when context switch time is < 10 µs

Priority Based Scheduling (1)

Process	Burst Time	Priority
P1	21	2
P2	3	1
P3	6	4
P4	2	3

Assumption: Arrival Time of all processes is 0

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Priority Based Scheduling (2)

- Process with the highest priority is executed first
- Processes with the same priority require a second scheduling algorithm, e.g. FCFS
- Risk of starvation in preemptive priority scheduling

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Multilevel Queue Scheduling (1)

- Processes are classified into different groups each of which has its own scheduling requirements.
- Ready queue consists of multiple separate queues each of which has its own scheduling algorithm.
- Additional scheduling is required among the queues (e.g. preemptive priority scheduling)

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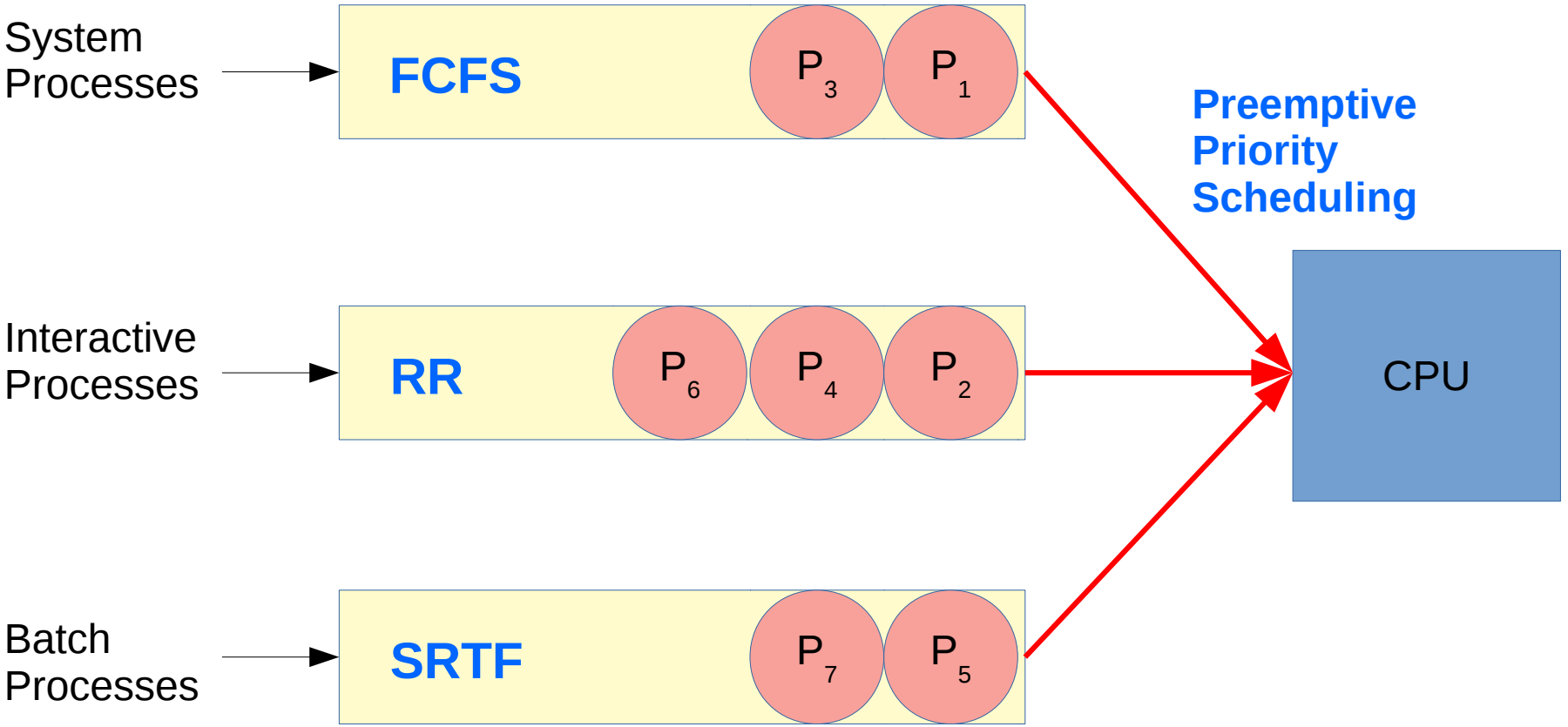
Multilevel Queue Scheduling (Example)



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Multilevel Feedback Queue Scheduling

- Enhanced variant of Multilevel Queue Scheduling
- Allows processes to move between the queues based on their spent CPU time
- Processes in high priority queues that spend too much CPU time may be moved to a lower priority queue
- Processes that have been waiting too long in a lower priority queue may be moved to a higher priority queue
- Most general scheduler, but also most complex to implement

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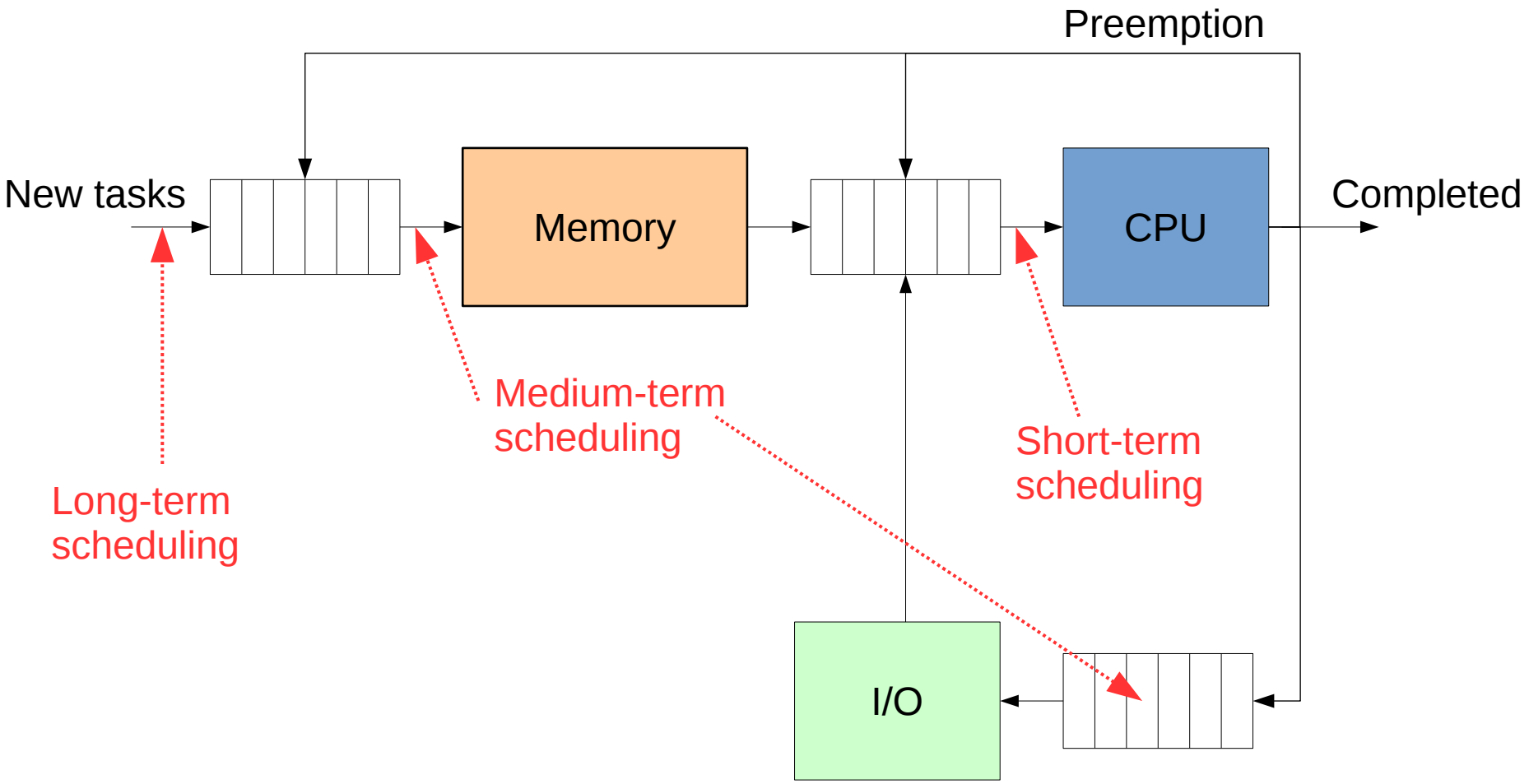
Scheduling Strategies in the OS



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Lab Exercises (1)

- Implement simulations of the following scheduling algorithms in C
  - First Come First Serve (FCFS)
  - Shortest Remaining Time First (SRTF)
  - Round Robin Scheduling (RR)
- The Linux kernel uses the Completely Fair Scheduler (CFS) as its default process scheduler. Investigate and explain the underlying concept

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Lab Exercises (2)

- What concept does Linux provide from a user's perspective to run processes with different priorities?
- Set up a scenario in which processes with higher priority are granted more CPU time than others.
- What mechanisms does Linux provide to prevent users from depriving other users of CPU time?

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Real-time Operating Systems (RTOS)

- Guarantees a certain behavior within predictable (well-defined) time constraints.
- OS-internal actions must be finished
- Two groups of RTOS
  - Hard
    - Deadlines must always be met
    - Example: Collision avoidance systems in aircrafts
  - Soft
    - Occasionally missed deadlines do not pose critical risks
    - Example: Decoders for media streaming

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Earliest Deadline First (EDF)

- Process with the earliest deadline gets dispatched to the CPU
- Algorithm requires a system clock (absolute time)
- Algorithm is preemptive
- All deadlines can be met, as long as sufficient computing resources are available
- Disadvantages
  - In overload scenarios, deadlines will be missed unpredictably
  - Difficult to implement in hardware

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Exercises

- Develop the timing diagram for EDF scheduling of two processes P_1, P_2, and P_3 with the following parameters:

Process	Arrival Time	Burst Time	Deadline
P1	0	4	20
P2	1	5	15
P3	2	6	16

- Rate-Monontonic Scheduling (RMS) is a fixed-priority real-time scheduling algorithm that is usually preferred over EDF.
  - What are its advantages over EDF?
  - How does it work?

Questions for Review

- What is the difference between a process and a program?
- What are the steps that are necessary to perform a context switch?
- Explain the five-state process model.
- What are the goals of process scheduling?
- What is a major disadvantage of SJF and SRTF?
- Why should the time quantum in RR scheduling be significantly higher than the time required to perform a context switch?
- Explain the principle of how a Multilevel Feedback Queue Scheduler works.
- What is the definition of an RTOS?
- What happens in EDF scheduling when the CPU load exceeds 100%?

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