Scheduling

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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”)

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.

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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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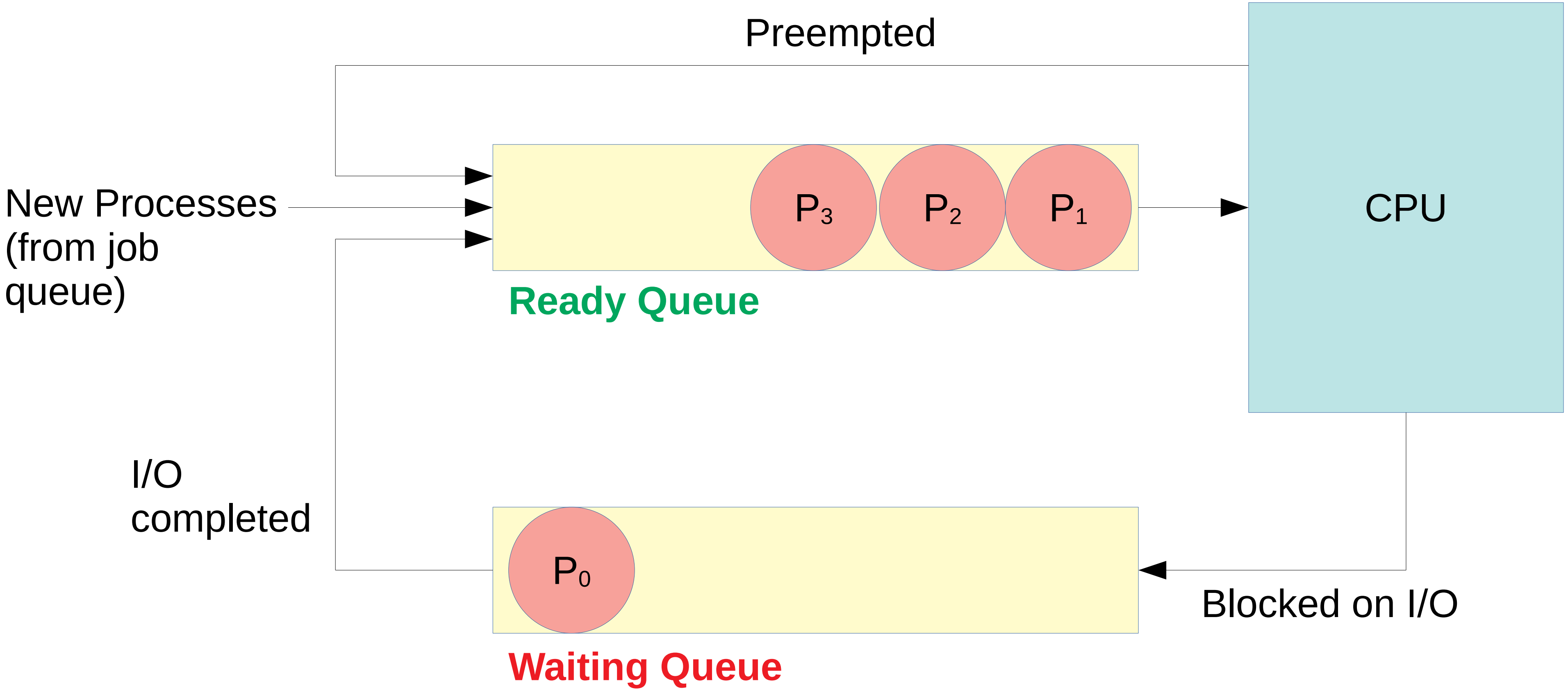
Scheduling Queues (simplified)



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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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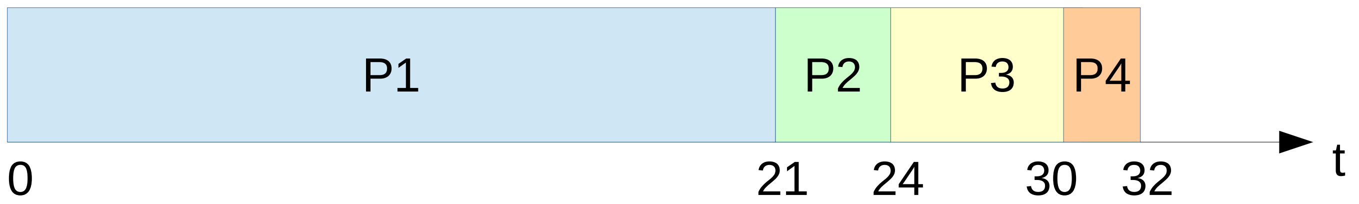
First Come First Serve (FCFS) (1)

Process	Burst Time	Arrival Time
P1	21	0.0
P2	3	0.1
P3	6	0.2
P4	2	0.3



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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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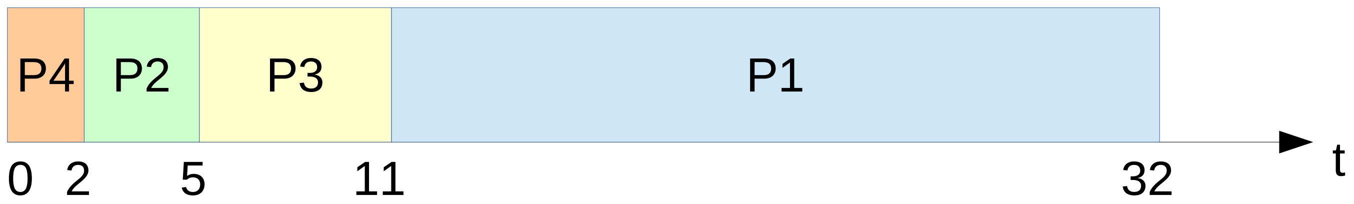
Shortest Job First (SJF) (1)

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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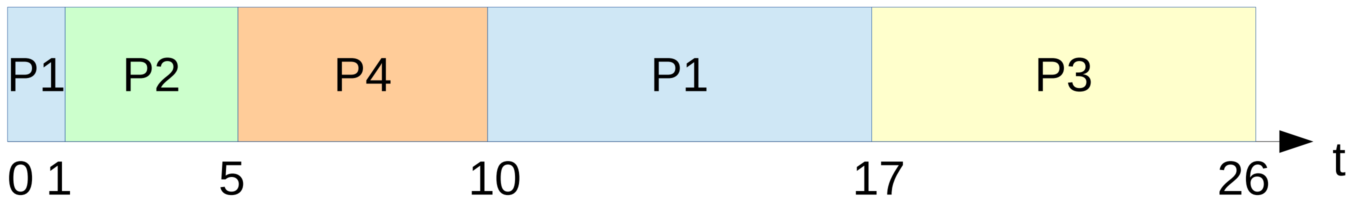
Shortest Remaining Time First (SRTF) (1)

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)

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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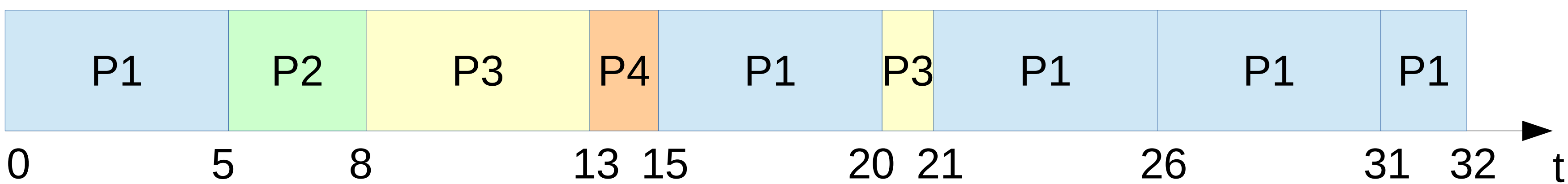
Round Robin Scheduling (RR) (1)

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

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Exercise

- Determine the average waiting time for the previous examples of the following scheduling algorithms:
  - First Come First Serve (FCFS)
  - Shortest Job First (SJF)
  - Shortest Remaining Time First (SRTF)
  - Round Robin (RR)

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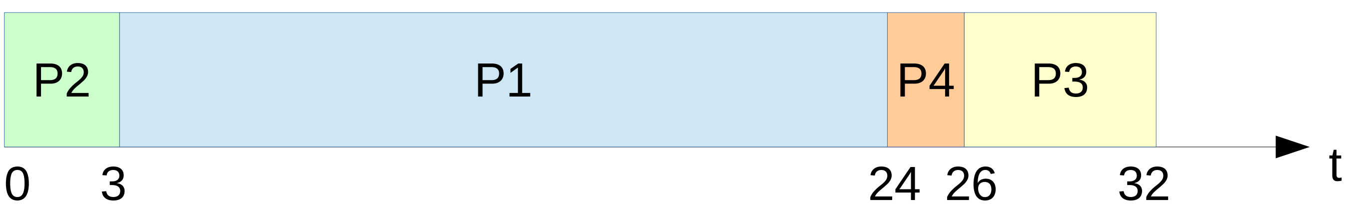
Priority Based Scheduling (1)

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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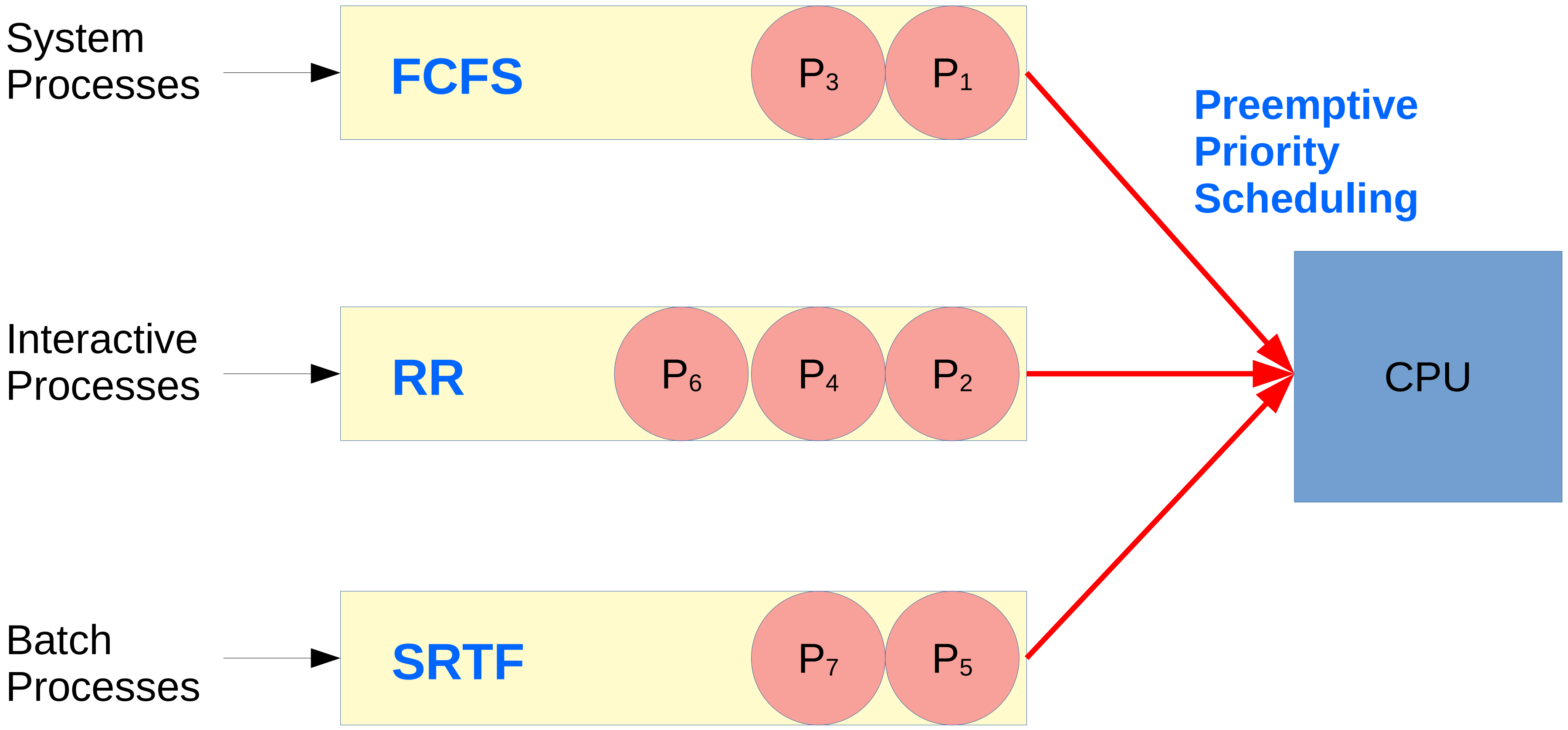
Multilevel Queue Scheduling (Example)



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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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Lab Exercise

- Implement simulations of the following scheduling algorithms in C
  - First Come First Serve (FCFS)
  - Shortest Remaining Time First (SRTF)
  - Round Robin Scheduling (RR)

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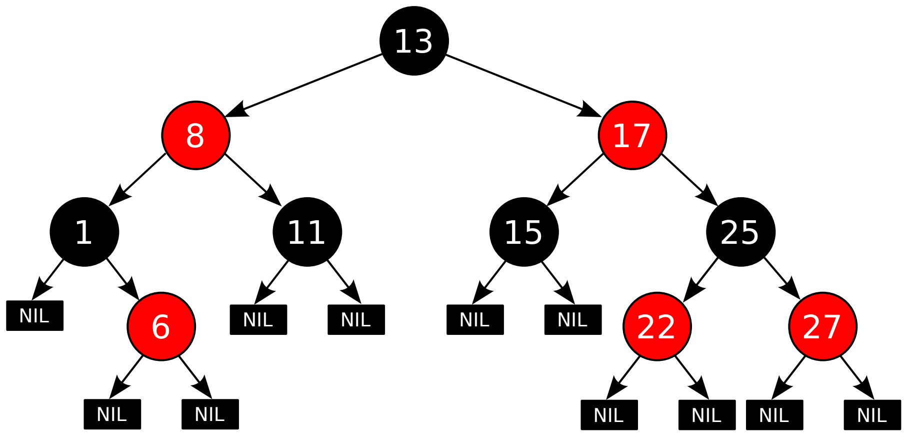
Completely Fair Scheduler (CFS) (1)

- Presently used by the Linux Kernel (since 2.6.23, October 2007)
- Developed by Ingo Molnár
- Idea: Ideal Fairness
  - Every Process receives 1/n CPU time
  - Sleeping processes “earn” CPU time, i.e. they are given a boost when they wake up



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- CFS uses a red-black tree instead of queues as its underlying data structure
- CFS uses nanoseconds granularity accounting

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Completely Fair Scheduler (CFS) (2)

- Each process has a virtual runtime (*vruntime*)

$$vruntime = \frac{runtime}{weight}$$

actual time already spent on the CPU

weight (is dependent on the process' priority/niceness) See also */kernel/sched/sched.h* → *prio_to_weight*)

- The higher the weight, the lower the impact of the actual runtime. → Slower increase of virtual runtime for processes with higher priority.
- CFS always chooses the process with the lowest virtual runtime.

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Completely Fair Scheduler (CFS) (3)

- Some related files and tools
  - */proc/stat*
  - */sys/kernel/debug/sched_features*
  - *proc/sys/kernel/sched_**
  - *taskset*
  - *trace-cmd*
  - *kernelshark*
- More technical details on CFS
  - https://www.kernel.org/doc/html/latest/scheduler/sched-design-CFS.html
  - https://doc.opensuse.org/documentation/leap/tuning/html/book-sle-tuning/cha-tuning-taskscheduler.html

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Lab Exercise

- 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 (or the operating system itself) of CPU time?

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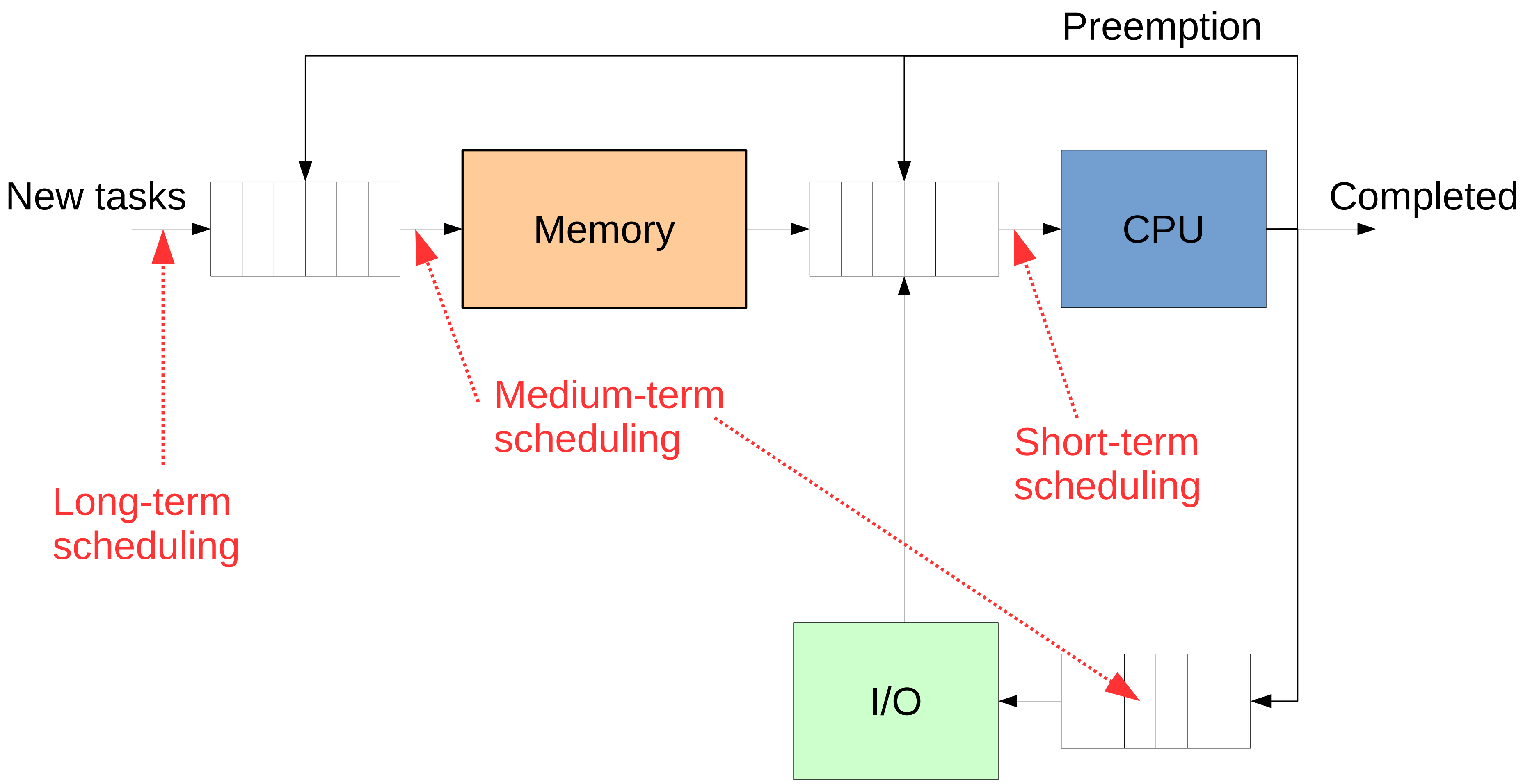
Scheduling Strategies in the OS



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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

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 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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