

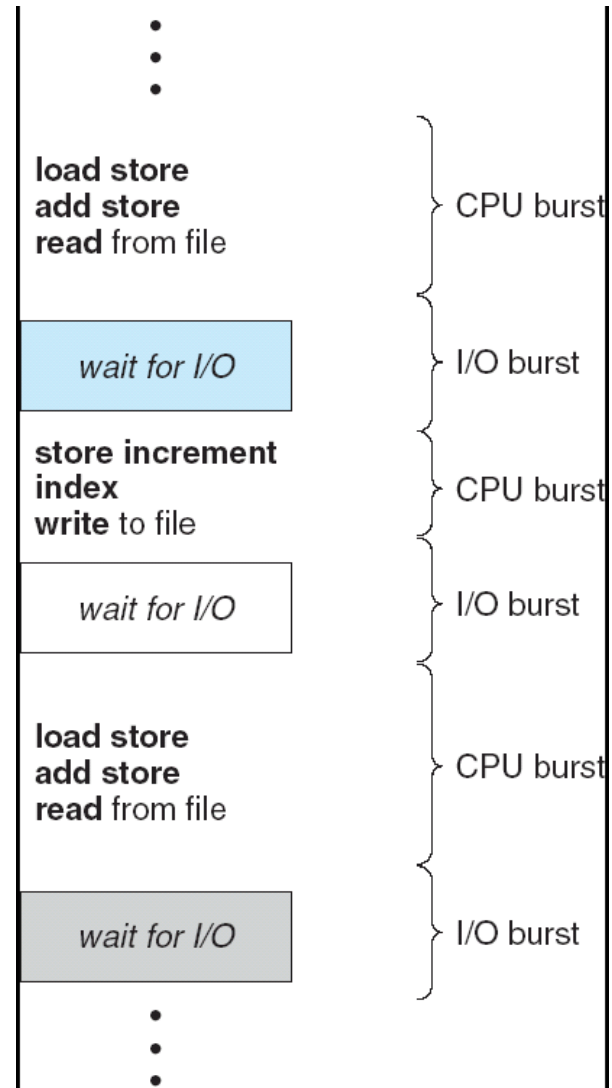
Part 3: Process Scheduling

- Basic Concepts
- Scheduling Criteria
- Scheduling Algorithms

Basic Concepts

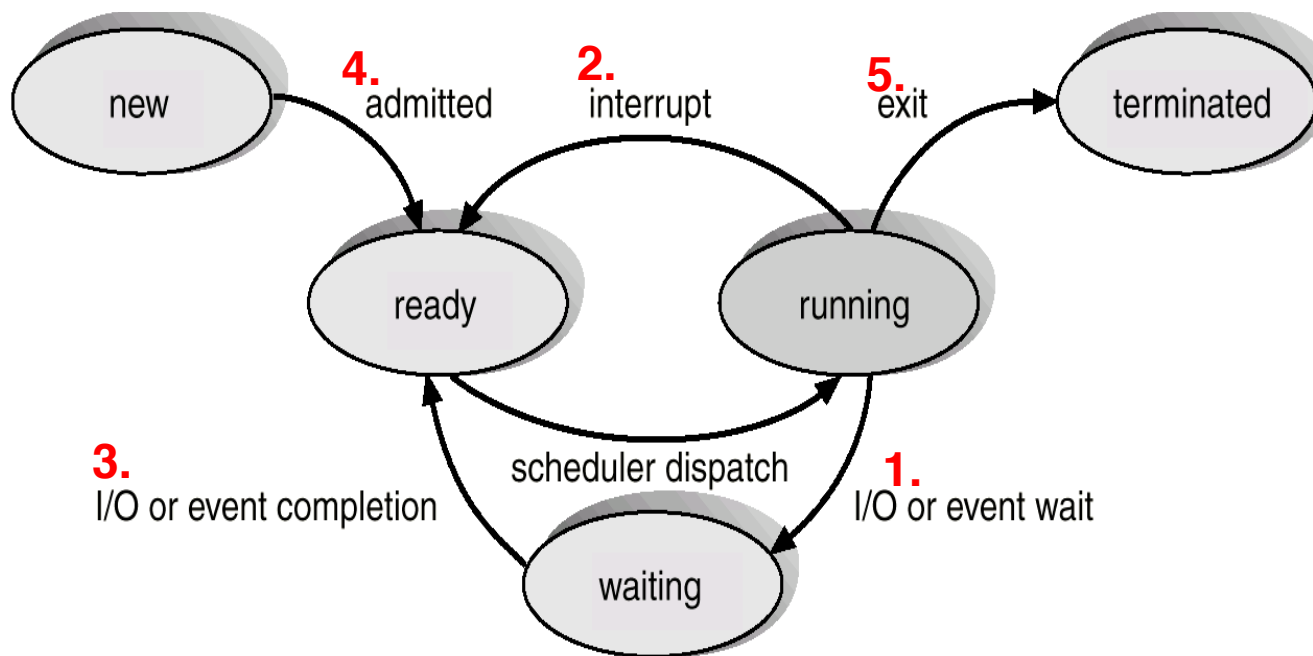
- **CPU–I/O Bursts:** Process execution alternates between CPU executions and I/O operations
 - **CPU burst:** Duration of one CPU execution cycle
 - **I/O burst:** Duration of one I/O operation (wait time)
- **CPU scheduling objective:** Keep the CPU busy as much as possible (i.e., using multiprogramming)
- For simplicity, we focus on the concepts of **short-term (ready queue) scheduler on a single CPU**

Alternating Sequence of CPU And I/O Bursts



CPU Scheduler (Short-Term)

- **Goal:** Select one of the processes in the ready queue, and allocate it to the CPU
- Scheduler may run whenever a process changes state



In which case(s) does CPU scheduling have to occur in order to keep the CPU busy?

Answer:
Only 1 and 5

Types of CPU Schedulers

- 1. Nonpreemptive** means that once the CPU has been allocated to a process, the process keeps the CPU until it **voluntarily releases the CPU** either by terminating or requesting I/O/event wait
 - Scheduling is nonpreemptive if it happens **only** for transitions 1 and 5
- 2. Preemptive** means that the CPU can be taken away from a running process **at any time** by the scheduler
 - Scheduling is preemptive if it **also** happens for transitions 2, 3, 4 or any other time instant

Scheduling Objectives

System-wide Objectives:

- 1. Max. CPU Utilization:** Keep the CPU as busy as possible
 - Percentage of time during which there is some process in the “**running**” state
- 2. Max. Throughput:** Number of processes that complete their execution per unit of time
 - Number of “**exit**” transitions per unit of time

Scheduling Objectives (Cont.)

Individual Process Objectives:

- 1. Min. Turnaround Time:** Amount of time to execute a particular process, i.e., from the time of creation to the time of termination
 - Time elapsed between “**admitted**” and “**exit**” **transitions** for a process
 - Average over all processes is denoted as **average turnaround time**

Scheduling Objectives (Cont.)

- 2. Min. Waiting Time:** Amount of time a process has been waiting in the “ready” state
- We do not consider time in “waiting” state; why?
 - Turnaround time components: CPU burst (running), I/O burst (waiting) and waiting time (ready)
 - If all processes have a single CPU burst (no I/O), then waiting time = turnaround time – CPU burst
- 3. Min. Response Time:** Time from a request submission (“admitted” transition) until the first response is produced

Scheduling Algorithms

1. First-Come, First-Served (FCFS)
2. Shortest Job First (SJF)
3. Priority-based Scheduling
4. Round Robin (RR)
5. Multilevel Queue Scheduling

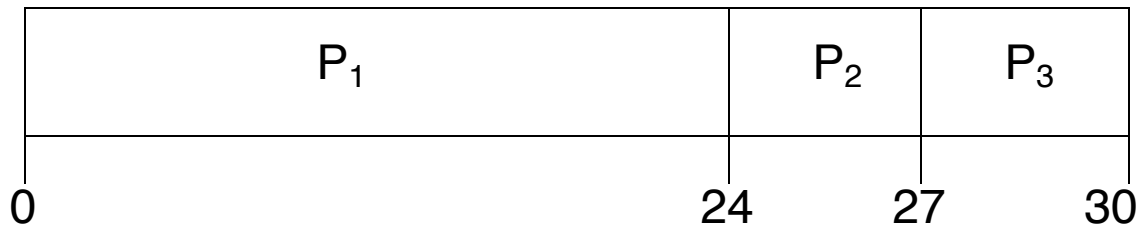
We assume a single CPU burst for each process, and focus on the average waiting time

First-Come, First-Served (FCFS) Scheduling

- **Example:**

<u>Process</u>	<u>CPU Burst Length</u>
P_1	24
P_2	3
P_3	3

- Suppose that processes arrive in the order P_1 , P_2 , P_3 , all at time 0
- **The Gantt Chart for the schedule is:**



- Waiting time for $P_1 = 0$; $P_2 = 24$; $P_3 = 27$
- Average waiting time: $(0 + 24 + 27)/3 = 17$

FCFS Scheduling (Cont.)

- Suppose that the processes arrive in the order P_2 , P_3 , P_1 , again all at time 0
- The Gantt chart for the schedule is:



- Waiting time for $P_1 = 6$; $P_2 = 0$; $P_3 = 3$
- Average waiting time: $(6 + 0 + 3)/3 = 3$
 - Much better than the previous case

FCFS Scheduling: Properties

- Is FCFS preemptive or nonpreemptive?
 - Nonpreemptive, because processes have to voluntarily release the CPU once allocated
- Main problem with FCFS is the **convoy effect**
 - Short processes suffer increased waiting times due to an earlier arrived long process
 - *We saw this effect in the previous example - P1 increased the waiting times of P2 and P3

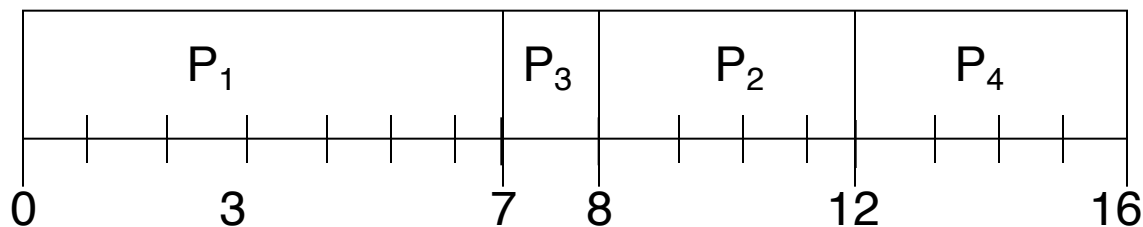
Shortest-Job-First (SJF) Scheduling

- Prioritize processes based on their CPU burst lengths
 - Shorter burst implies higher priority
 - Intuitive way to handle the convoy effect of FCFS
- Two schemes:
 1. **Nonpreemptive**: Once CPU is given to a process, it cannot be preempted until it completes its CPU burst
 2. **Preemptive (also known as Shortest Remaining-Time First or SRTF)**: If a newly created process has CPU burst length less than the remaining CPU burst of currently running process, then preemption will occur
- SJF/SRTF is optimal for minimizing average waiting time

Example of Nonpreemptive SJF

<u>Process</u>	<u>Arrival Time</u>	<u>Burst Time</u>
P_1	0.0	7 ✓
P_2	2.0	4 ✓
P_3	4.0	1 ✓
P_4	5.0	4 ✓

- SJF (Nonpreemptive) Gantt Chart:**

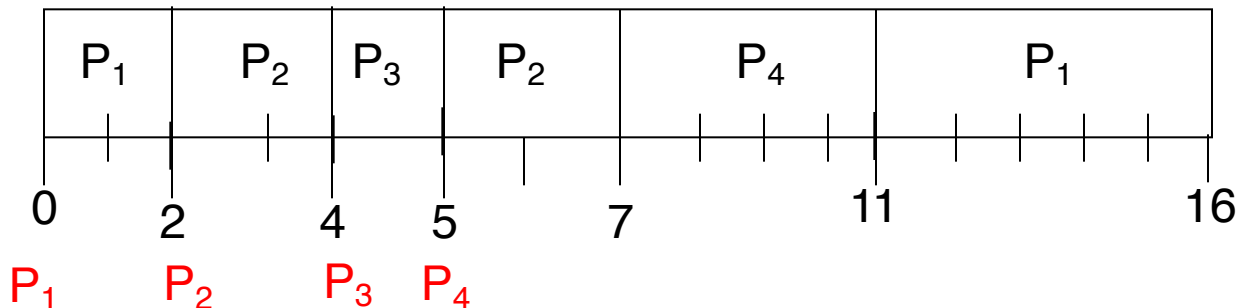


- Average waiting time = $(0 + 6 + 3 + 7)/4 = 4$

Example of Preemptive SJF (SRTF)

<u>Process</u>	<u>Arrival Time</u>	<u>Burst Time</u>
P_1	0.0	7 \rightarrow 5 \rightarrow 0
P_2	2.0	4 \rightarrow 2 \rightarrow 0
P_3	4.0	1 \rightarrow 0
P_4	5.0	4 \rightarrow 0

• SJF (Preemptive) Gantt Chart:



- Average waiting time = $(9 + 1 + 0 + 2)/4 = 3$

Priority-based Scheduling

- A **priority number (integer)** is associated with each process
- **CPU is allocated to the process with the highest priority**
 - Usually, smallest integer \equiv highest priority
 - **Two schemes:** Preemptive and nonpreemptive
 - FCFS \equiv Priority based on arrival order
 - SJF \equiv Priority based on CPU burst length
- **Problem of Starvation:** Lower priority processes may never execute in a heavily loaded system
 - **Solution is Aging:** As time progresses, slowly increase the priority of processes that are not able to execute

Round Robin (RR) Scheduling

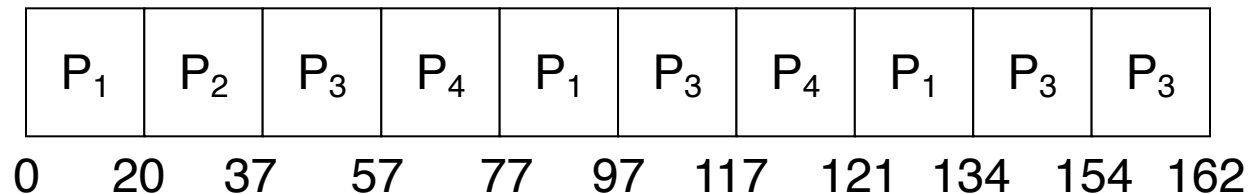
- **Fixed time quantum for scheduling (q):** A Process is allocated CPU for q time units, preempted thereafter and inserted at the end of the ready queue
 - Processes are **scheduled cyclically** based on q
 - Usually **q is small**, around 10-100 milliseconds
- **Performance:**
 - *n processes in ready queue \Rightarrow waiting time no more than $(n-1)q$ time units*
 - **Large $q \Rightarrow$ Degenerates to FCFS**
 - **Small $q \Rightarrow$ Many context switches; high overhead**

Example: RR with Time Quantum = 20

<u>Process</u>	<u>Burst Time</u>
P_1	53 → 33
P_2	17 → 0
P_3	68 → 48
P_4	24 → 4

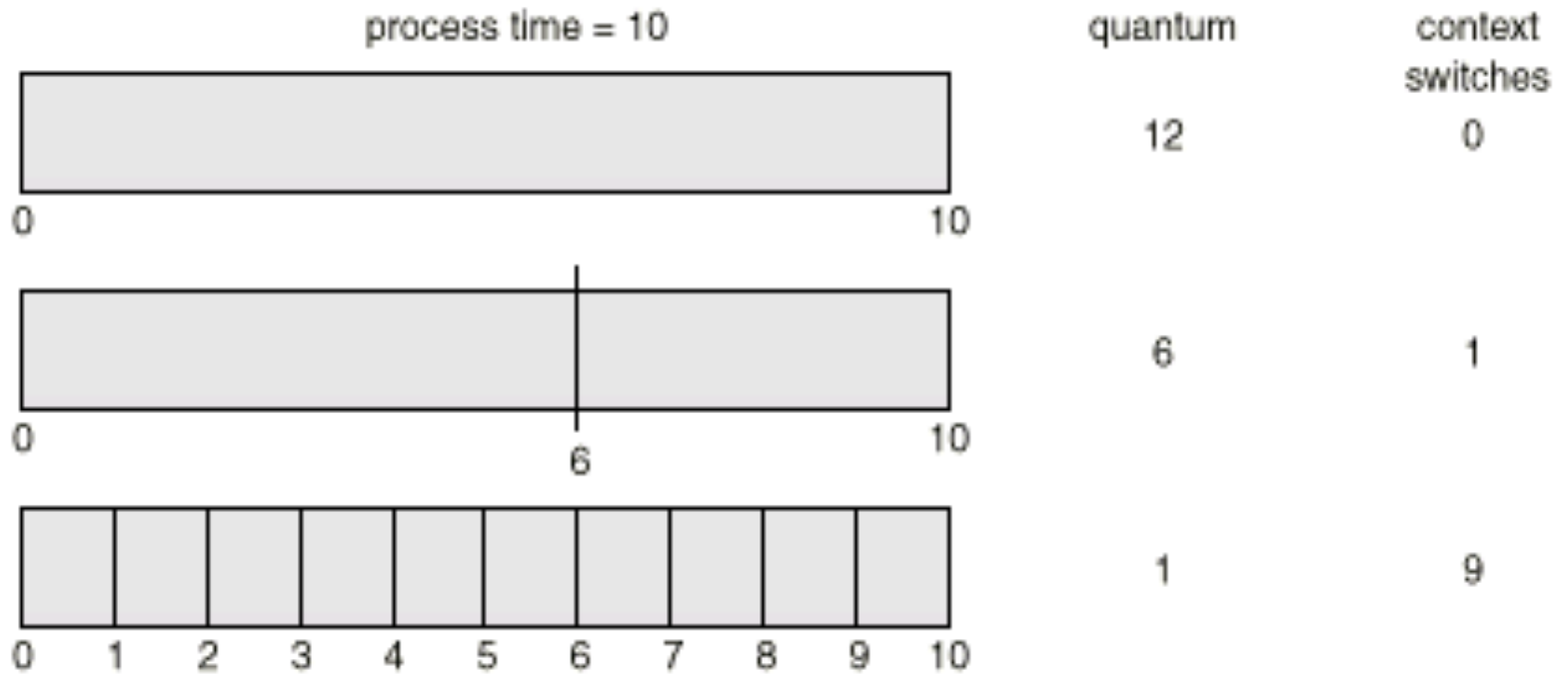
- All processes come at time 0 in the order of P_1 , P_2 , P_3 , P_4

- **RR Scheduling Gantt Chart:**

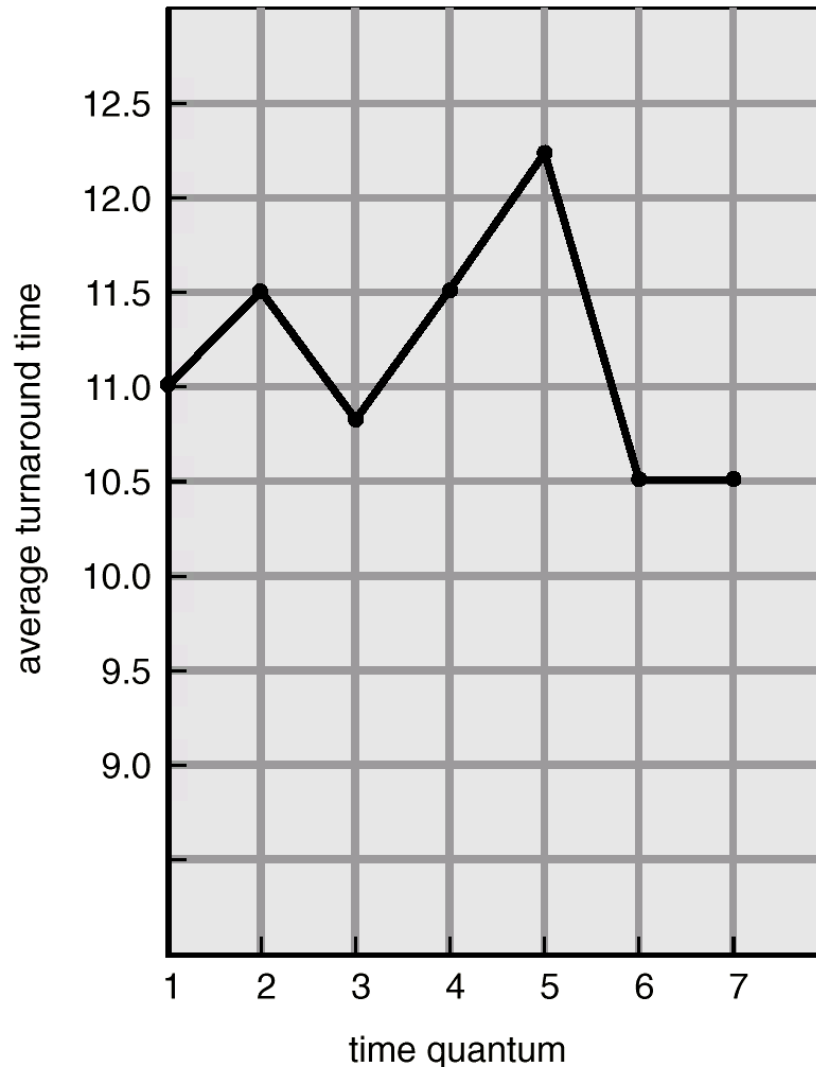


- Typically, higher average waiting/turnaround time than SJF, but better *response time*

Smaller Time Quantum Increases Context Switches



Turnaround Time Varies With Time Quantum



process	time
P_1	6
P_2	3
P_3	1
P_4	7

Assume arrival order is P_1 , P_2 , P_3 , P_4 all at time 0

- No well-defined relationship between average turnaround time and quantum size
- Average turnaround time remains fixed once quantum size is larger than maximum CPU burst length

Multilevel Queue Scheduling

- Different processes have different requirements
 - Foreground processes like those handling I/O need to be interactive (**RR is preferred**)
 - Background processes need NOT be interactive; scheduling overhead can be low (**FCFS**)
- **Solution: Multi-level Queue Scheduling**
 - Ready queue is partitioned into several queues
 - Each queue has its **own scheduling algorithm**
 - **How to schedule among the queues?**

Multilevel Queue Scheduling (Cont.)

- Two schemes for inter-queue scheduling
 - Fixed priority scheduling
 - *Queues served in priority order (e.g., foreground before background)
 - *Starvation for lower priority queues
 - Time-slice based scheduling
 - *Each queue gets a fixed time quantum on the CPU (e.g., 80ms for foreground, 20ms for background)