Chapter 5a: CPU Scheduling

Outline

- Basic Concepts

- Scheduling Criteria

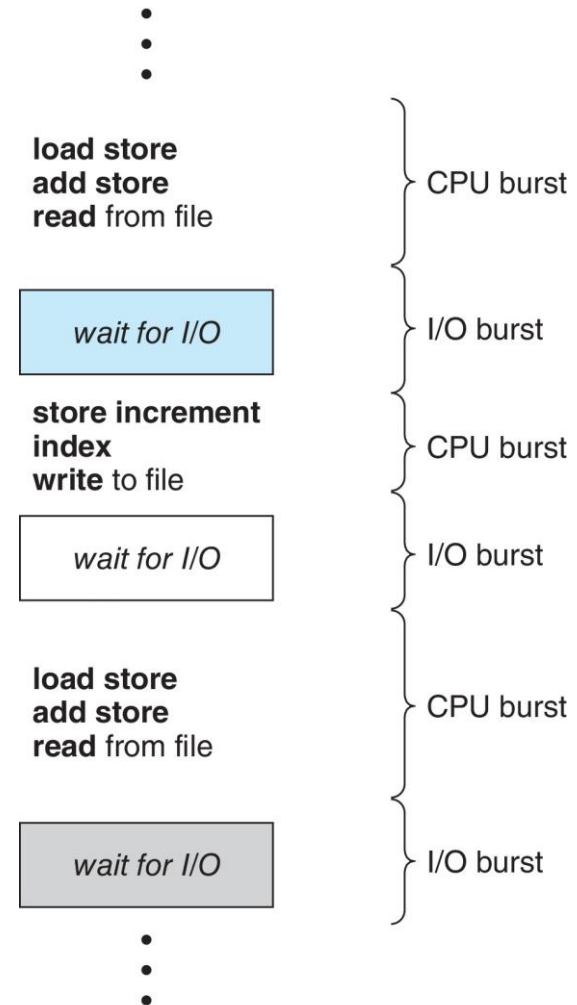- Scheduling Algorithms

Objectives

- Describe various CPU scheduling algorithms

- Assess CPU scheduling algorithms based on scheduling criteria

- Explain the issues related to multiprocessor and multicore scheduling

- Describe various real-time scheduling algorithms

- Describe the scheduling algorithms used in the Windows, Linux, and Solaris operating systems

- Apply modeling and simulations to evaluate CPU scheduling algorithms

Basic Concepts

- Maximum CPU utilization obtained with multiprogramming

- CPU–I/O Burst Cycle – Process execution consists of a **cycle** of CPU execution and I/O wait

- **CPU burst** followed by **I/O burst**

- CPU burst distribution is of main concern


```
•
•
•
load store
add store
read from file          } CPU burst

wait for I/O            } I/O burst

store increment
index
write to file           } CPU burst

wait for I/O            } I/O burst

load store
add store
read from file          } CPU burst

wait for I/O            } I/O burst
•
•
•
```

Histogram of CPU-burst Times

- Large number of short bursts
- Small number of longer bursts
- Histogram
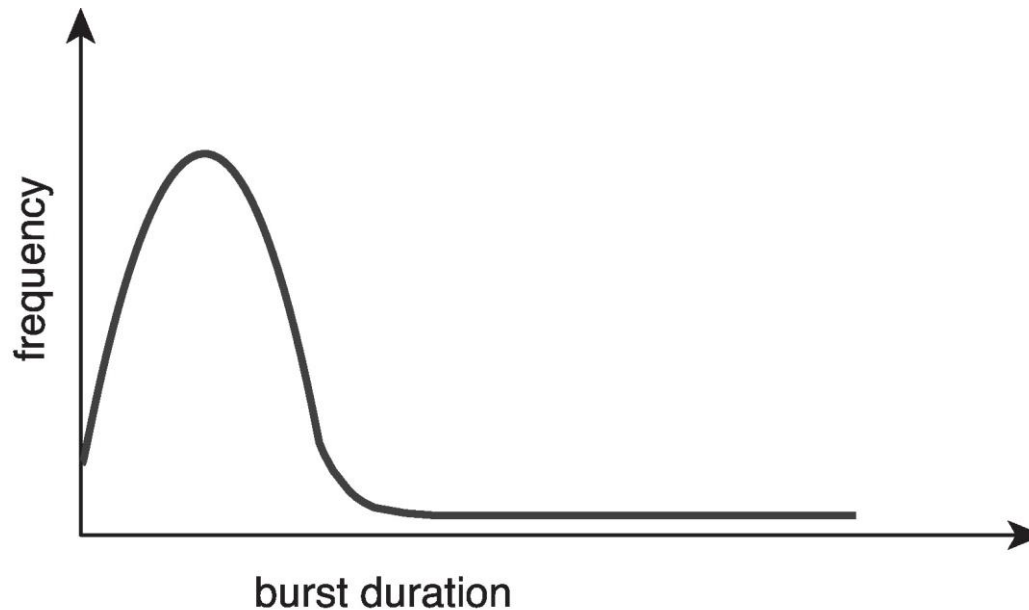
CPU Scheduler

- The **CPU scheduler** selects from among the processes in ready queue, and allocates a CPU core to one of them
  - The ready queue may be ordered in various ways
- 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
- For situations 1 and 4, there is no choice in terms of scheduling. A new process (if one exists in the ready queue) must be selected for execution.
- For situations 2 and 3, however, there is a choice.

Preemptive and Nonpreemptive Scheduling

- When scheduling takes place only under circumstances 1 and 4, the scheduling scheme is **nonpreemptive**.

- Otherwise, it is **preemptive**.

- Under Nonpreemptive scheduling, once the CPU has been allocated to a process, the process keeps the CPU until it releases it either by terminating or by switching to the waiting state.

  - What is the potential problem?

- Virtually all modern operating systems including Windows, MacOS, Linux, and UNIX use preemptive scheduling algorithms.

Preemptive Scheduling and Race Conditions

- Preemptive scheduling can result in race conditions when data are shared among several processes.

- Consider the case of two processes that share data. While one process is updating the data, it is preempted so that the second process can run. The second process then tries to read the data, which are in an inconsistent state.

  - We saw this in the bounded buffer example

- This issue will be explored in detail in Chapter 6.

Dispatcher

- Dispatcher module gives control of the CPU to the process selected by the CPU scheduler; this involves:
    - Switching context
    - Switching to user mode
    - Jumping to the proper location in the user program to restart that program
- **Dispatch latency** – time it takes for the dispatcher to stop one process and start another running
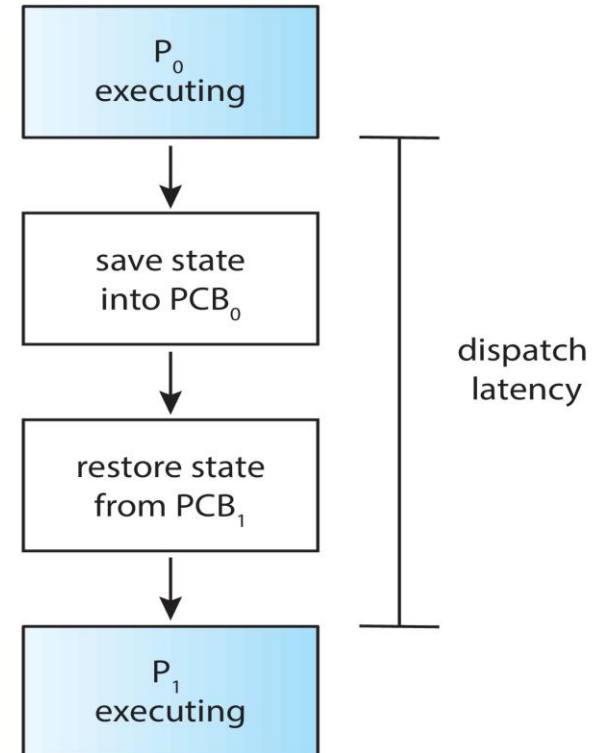
Scheduling Criteria

- **CPU utilization** – keep the CPU as busy as possible

- **Throughput** – # of processes that complete their execution per time unit

- **Turnaround time** – amount of time to execute a particular process

- **Waiting time** – amount of time a process has been waiting in the ready queue

- **Response time** – amount of time it takes from when a request was submitted until the first response is produced.

Optimization Criteria for Scheduling Algorithms

- Max CPU utilization

- Max throughput

- Min turnaround time

- Min waiting time

- Min response time

First- Come, First-Served (FCFS) Scheduling

- Example with 3 processes

Process	Burst Time
P_1	24
P_2	3
P_3	3

- Suppose that the processes arrive in the order: P_1 , P_2 , P_3
  The Gantt Chart for the above schedule is:

P₁	P₂	P₃

```
0                                  24    27    30
```

- 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:

$$P_2, P_3, P_1$$

- The Gantt chart for the schedule is:

P$_2$	P$_3$	P$_1$
0 3	6	30

- Waiting time for $P_1 = 6$; $P_2 = 0$; $P_3 = 3$
- Average waiting time: $(6 + 0 + 3)/3 = 3$
- Much better than previous case
- **Convoy effect** - short process behind long process
  - Consider one CPU-bound and many I/O-bound processes

Shortest-Job-First (SJF) Scheduling

- Associate with each process the length of its next CPU burst

  - Use these lengths to schedule the process with the shortest time

- SJF is optimal – gives minimum average waiting time for a given set of processes

- How do we determine the length of the next CPU burst?
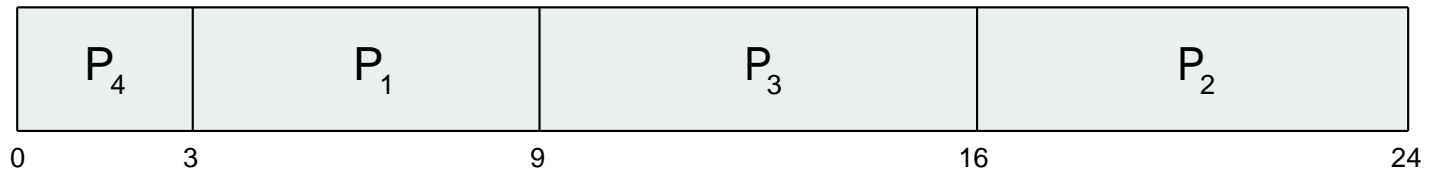
  - Could ask the user

  - Estimate

Example of SJF

Process	Burst Time
P_1	6
P_2	8
P_3	7
P_4	3

- SJF scheduling chart

P₄	P₁	P₃	P₂

P_4	P_1	P_3	P_2

0   3   9   16   24

- Average waiting time = (3 + 16 + 9 + 0) / 4 = 7

Determining Length of Next CPU Burst

- Can only estimate the length – should be similar to the previous one

  - Then pick process with shortest predicted next CPU burst

- Can be done by using the length of previous CPU bursts, using exponential averaging

  1. $t_n =$ actual length of nth CPU burst
  2. $\tau_{n+1} =$ predicted value for the next CPU burst
  3. $\alpha, 0 \leq \alpha \leq 1$
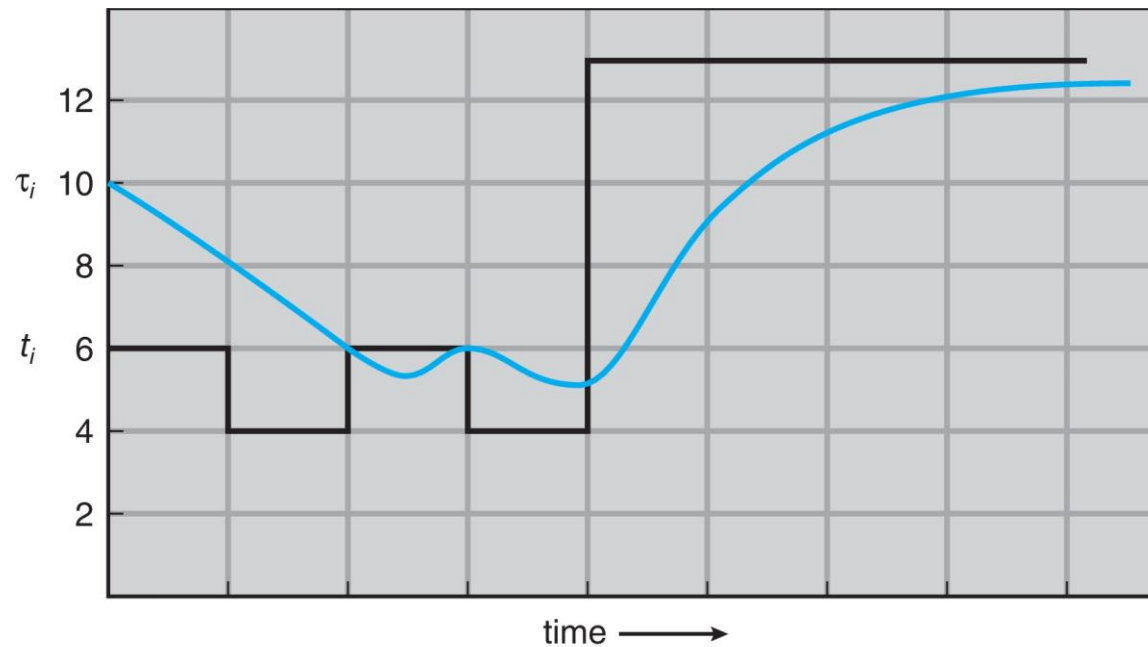 4. Define :

$$\tau_{n+1} = \alpha\, t_n + (1 - \alpha)\tau_n.$$

- Commonly, α set to ½

Prediction of the Length of the Next CPU Burst

CPU burst (t_i)		6	4	6	4	13	13	13	...
"guess" (τ_i)	10	8	6	6	5	9	11	12	...

Examples of Exponential Averaging

- $\alpha = 0$
  - $\tau_{n+1} = \tau_n$
  - Recent history does not count

- $\alpha = 1$
  - $\tau_{n+1} = \alpha\, t_n$
  - Only the actual last CPU burst counts

- If we expand the formula, we get:

$$\tau_{n+1} = \alpha\, t_n + (1 - \alpha)\alpha\, t_{n-1} + \ldots$$
$$+ (1 - \alpha)^j \alpha\, t_{n-j} + \ldots$$
$$+ (1 - \alpha)^{n+1} \tau_0$$

- Since both α and $(1 - \alpha)$ are less than or equal to 1, each successive term has less weight than its predecessor

Shortest Remaining Time First Scheduling

- Preemptive version of SJN

- Whenever a new process arrives in the ready queue, the decision on which process to schedule next is redone using the SJN algorithm.

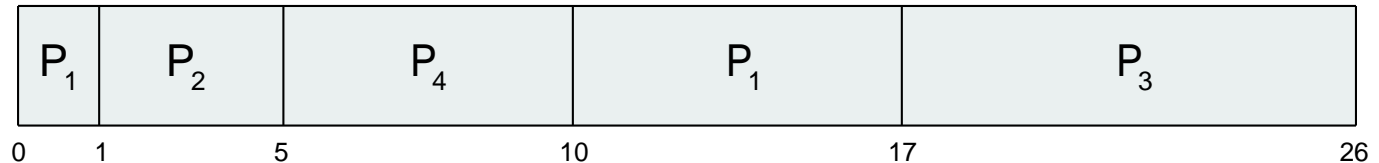- Is SRT more "optimal" than SJN in terms of the minimum average waiting time for a given set of processes?

Example of Shortest-remaining-time-first

- Now we add the concepts of varying arrival times and preemption to the analysis

Process	*Arrival* Time	Burst Time
P_1	0	8
P_2	1	4
P_3	2	9
P_4	3	5

- *Preemptive* SJF Gantt Chart

P$_1$	P$_2$	P$_4$	P$_1$	P$_3$
0 1	5	10	17	26

- Average waiting time = [(10-1)+(1-1)+(17-2)+(5-3)]/4 = 26/4 = 6.5

Round Robin (RR)

- Each process gets a small unit of CPU time (**time quantum** q), usually 10-100 milliseconds. After this time has elapsed, the process is preempted and added to the end of the ready queue.

- If there are n processes in the ready queue and the time quantum is q, then each process gets $1/n$ of the CPU time in chunks of at most q time units at once. No process waits more than $(n-1)q$ time units.

- Timer interrupts every quantum to schedule next process

- Performance

  - q large $\Rightarrow$ FIFO

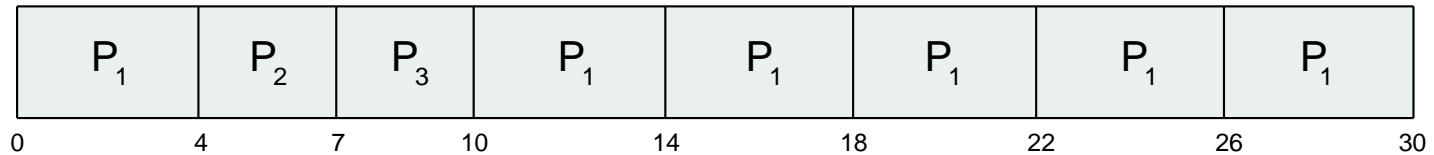 - q small $\Rightarrow q$ must be large with respect to context switch, otherwise overhead is too high

Example of RR with Time Quantum = 4

Process	Burst Time
P_1	24
P_2	3
P_3	3

- The Gantt chart is:

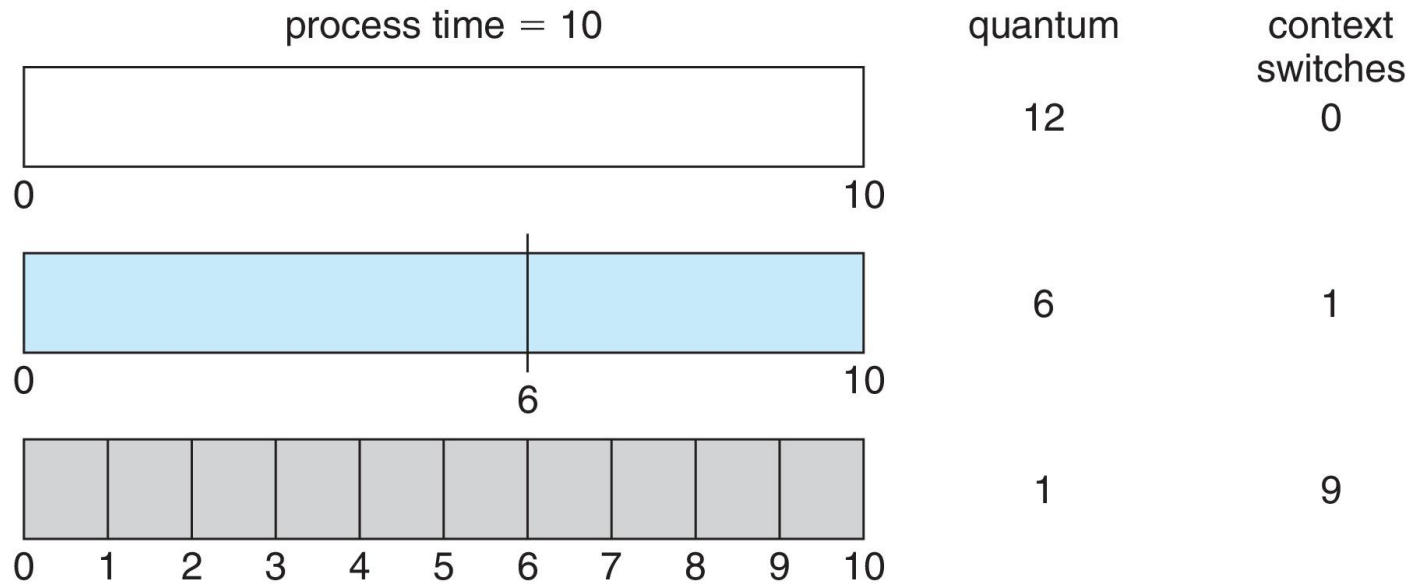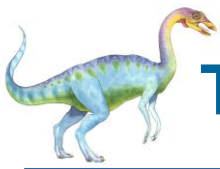| P_1	P_2	P_3	P_1	P_1	P_1	P_1	P_1

0   4   7   10   14   18   22   26   30

- Typically, higher average turnaround than SJF, but better *response*
- q should be large compared to context switch time
  - q usually 10 milliseconds to 100 milliseconds,
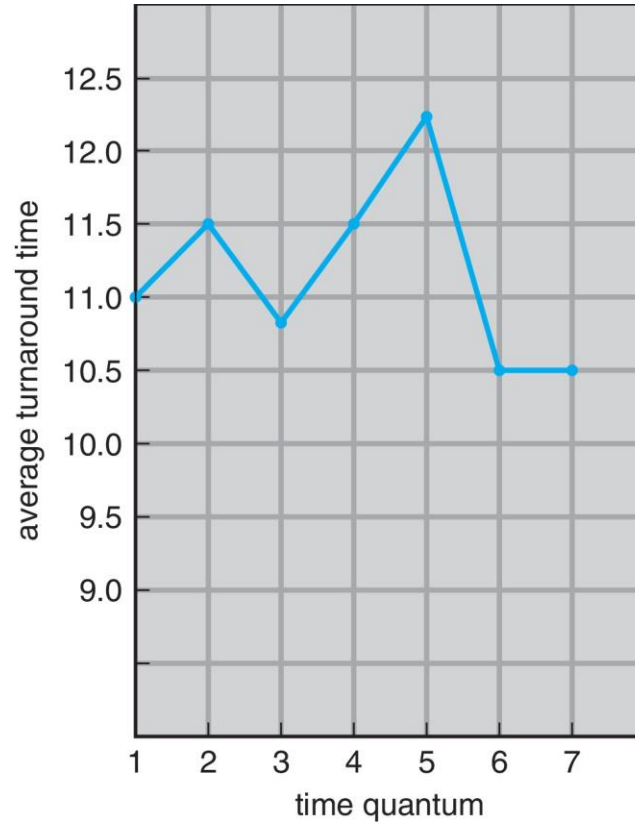 - Context switch < 10 microseconds

process time = 10

	quantum	context switches
	12	0
	6	1
	1	9

process	time
P_1	6
P_2	3
P_3	1
P_4	7

80% of CPU bursts
should be shorter than q

Priority Scheduling

- A priority number (integer) is associated with each process

- The CPU is allocated to the process with the highest priority (usually, smallest integer ≡ highest priority)

- Two schemes:

  - Preemptive

  - Nonpreemptive

- Problem ≡ **Starvation** – low priority processes may never execute

- Solution ≡ **Aging** – as time progresses increase the priority of the process

- Note: SJF is priority scheduling where priority is the inverse of predicted next CPU burst time
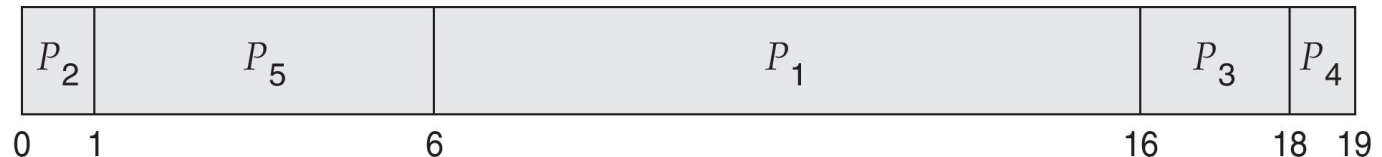
Example of Priority Scheduling

Process	Burst Time	Priority
P_1	10	3
P_2	1	1
P_3	2	4
P_4	1	5
P_5	5	2

- Priority scheduling Gantt Chart

P_2	P_5	P_1	P_3	P_4

0   1   6   16   18 19
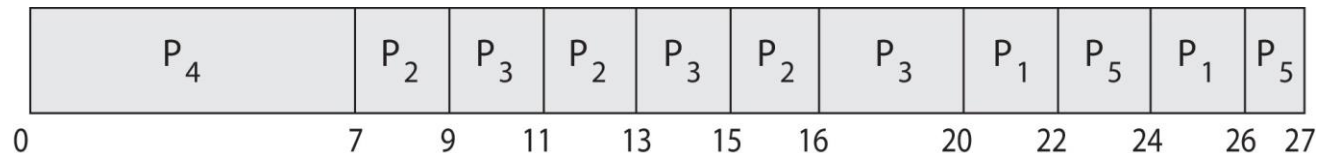
- Average waiting time = 8.2

Priority Scheduling w/ Round-Robin

- Run the process with the highest priority. Processes with the same priority run round-robin

- Example:

Process	Burst Time	Priority
P_1	4	3
P_2	5	2
P_3	8	2
P_4	7	1
P_5	3	3

- Gantt Chart with time quantum = 2

P_4	P_2	P_3	P_2	P_3	P_2	P_3	P_1	P_5	P_1	P_5

0   7   9   11   13   15   16   20   22   24   26 27
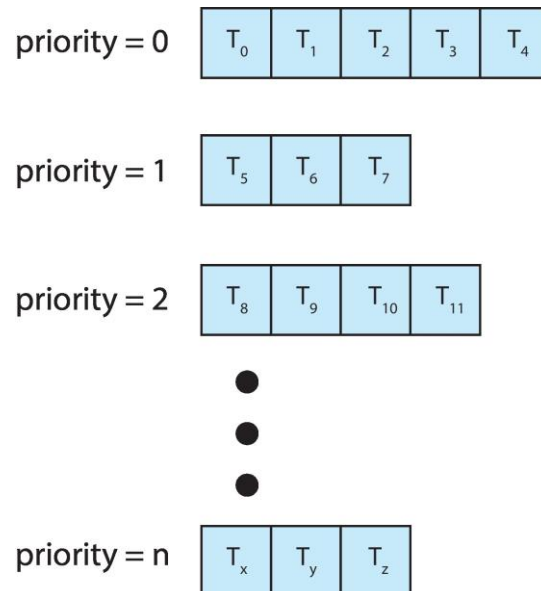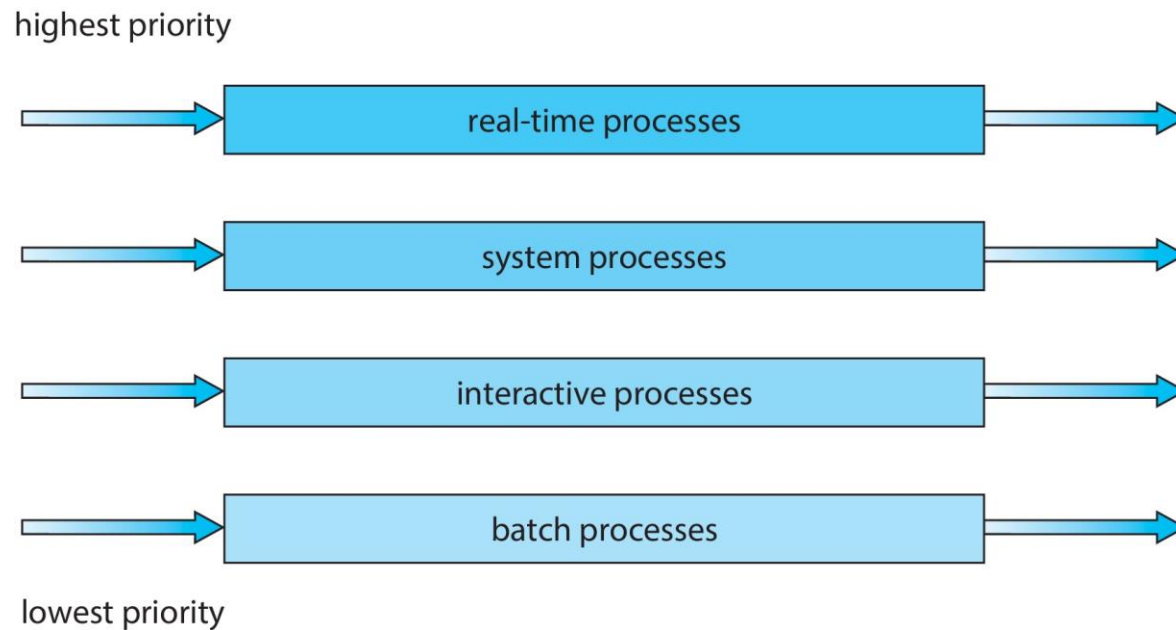
Multilevel Queue

- The ready queue consists of multiple queues

- Example:

  - Priority scheduling, where each priority has its separate queue.

  - Schedule the process in the highest-priority queue!

priority = 0	T_0	T_1	T_2	T_3	T_4

priority = 1	T_5	T_6	T_7

priority = 2	T_8	T_9	T_{10}	T_{11}

●
●
●

priority = n	T_x	T_y	T_z

Multilevel Queue

- Prioritization based upon process type
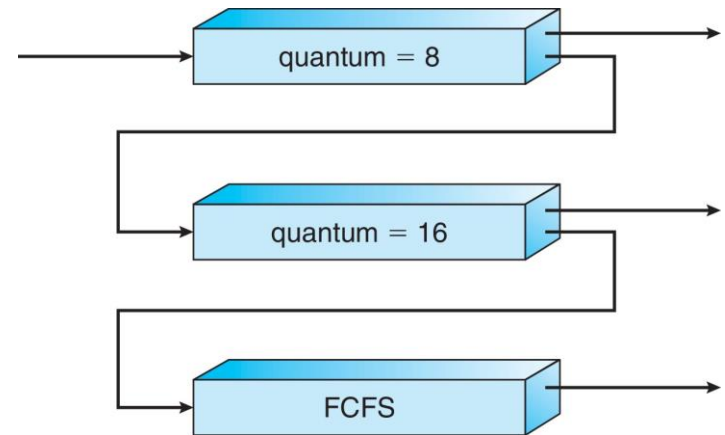
Multilevel Feedback Queue

- A process can move between the various queues.

- Multilevel-feedback-queue scheduler defined by the following parameters:

  - Number of queues

  - Scheduling algorithms for each queue

  - Method used to determine when to upgrade a process

  - Method used to determine when to demote a process

  - Method used to determine which queue a process will enter when that process needs service

- Aging can be implemented using multilevel feedback queue

Example of Multilevel Feedback Queue

- Three queues:
  - Q_0 – RR with time quantum 8 milliseconds
  - Q_1 – RR time quantum 16 milliseconds
  - Q_2 – FCFS

- Scheduling
  - A new process enters queue Q_0 which is served in RR
    - When it gains CPU, the process receives 8 milliseconds
    - If it does not finish in 8 milliseconds, the process is moved to queue Q_1
  - At Q_1 job is again served in RR and receives 16 additional milliseconds
    - If it still does not complete, it is preempted and moved to queue Q_2

quantum = 8

quantum = 16

FCFS

End of Chapter 5a