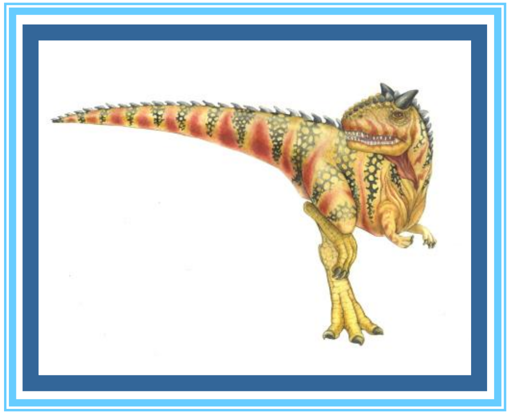
Chapter 5: Process Scheduling



Chapter 6: Process Scheduling

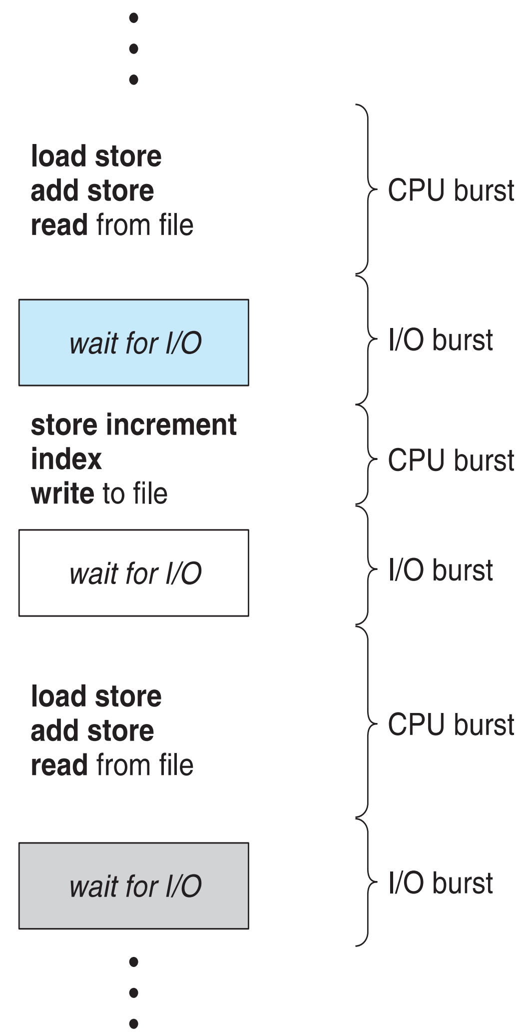
- Basic Concepts
- Scheduling Criteria
- Scheduling Algorithms
- Thread Scheduling

Objectives

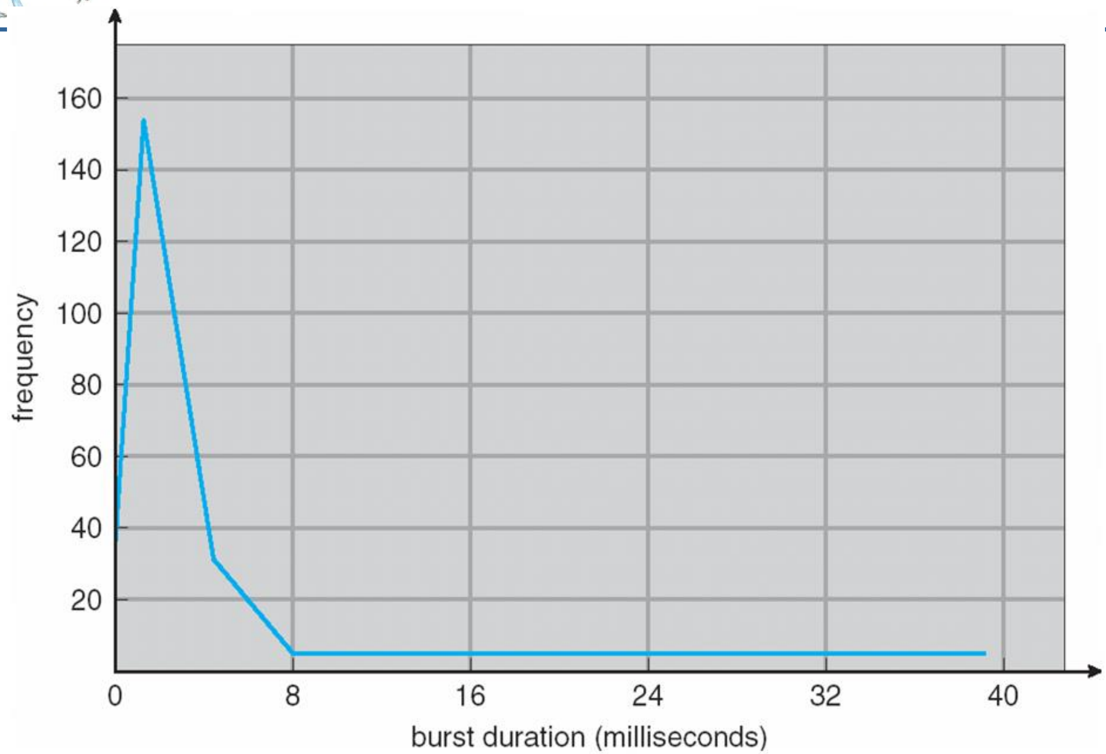
- To introduce CPU scheduling, which is the basis for multiprogrammed operating systems
- To describe various CPU-scheduling algorithms
- To discuss evaluation criteria for selecting a CPU-scheduling algorithm for a particular system
- To understand the scheduling algorithms of operating systems

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



Histogram of CPU-burst Times



- The curve is generally characterized as **exponential or hyperexponential**, with a large number of short CPU bursts and a small number of long CPU bursts
- An I/O-bound program typically has many short CPU bursts.
- A CPU-bound program might have a few long CPU bursts.

algorithm.

- This distribution is important for selecting CPU-scheduling alg

CPU Scheduler

- **Short-term scheduler** selects from among the processes in **ready queue**, and allocates the **CPU** to one of them
  - Ready Queue may be ordered in various ways(FIFO, priority etc)
- 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
- Scheduling under 1 and 4 is **nonpreemptive or cooperative**
- All other scheduling is **preemptive**
  - Consider access to shared data (may result in inconsistent data)
  - Consider preemption while in kernel mode
  - Consider interrupts occurring during crucial OS activities

Dispatcher

- Dispatcher is another module involved n CPU scheduling.
- It gives control of the CPU to the process selected by the **short-term 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

Criteria for comparing CPU-scheduling algorithm

- **CPU utilization** – Must keep the CPU as busy as **possible(40% to 90% utilization)**
- **Throughput** – # of processes that complete their execution per time unit. For long process it may be 1 process/hour and for short process it may be 10 process/sec
- **Turnaround time** – The interval from the time of submission of a process to the time of completion. Turnaround time is the sum of the **periods spent waiting to get into memory, waiting in the ready queue, executing on the CPU, and doing I/O.**
- **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**, not output (for time-sharing environment)

It is desirable to **maximize** **CPU utilization and throughput** and to **minimize** **turnaround time, waiting time, and response time**.

Scheduling Algorithm Optimization Criteria

- Max CPU utilization
- Max throughput
- Min turnaround time
- Min waiting time
- Min response time

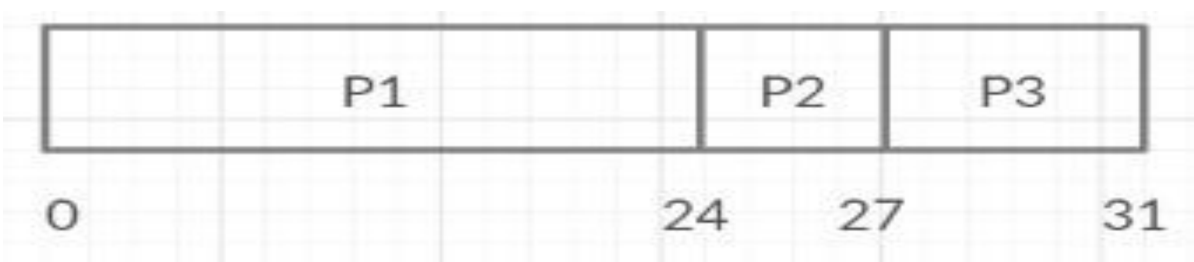
- TAT = CT – AT
- WT = TAT – BT

- **Completion Time (CT), . Arrival Time (AT),**
- **Waiting Time (WT) , Burst Time (BT):**

Example:

Process	Burst Time (in sec.)
P1	24
P2	3
P3	4

- Gantt Chart:



- Avg. TAT = (24 + 27 + 31) / 3 = 27.33 sec
- Avg. WT = (0 + 24 + 27) / 3 = 17.0 sec

First- Come, First-Served (FCFS) Scheduling

- Simplest CPU-scheduling algorithm
- With this scheme, the process that requests the CPU first is allocated the CPU first.
- The implementation of the FCFS policy is easily managed with a FIFO queue.
- On the negative side, the average waiting time under the FCFS policy is often quite long.
- Consider the example with set of processes that arrive at time 0, with the length of the CPU burst given in milliseconds:

First- Come, First-Served (FCFS) Scheduling

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 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:

$$P_2 , P_3 , P_1$$

- 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 previous case
- **Convoy effect** - short process wait for one long process to get the CPU
- This result in lower CPU and device utilization than might be possible if the shorter processes were allowed to go first.
  - Consider one long CPU-bound and many I/O-bound processes

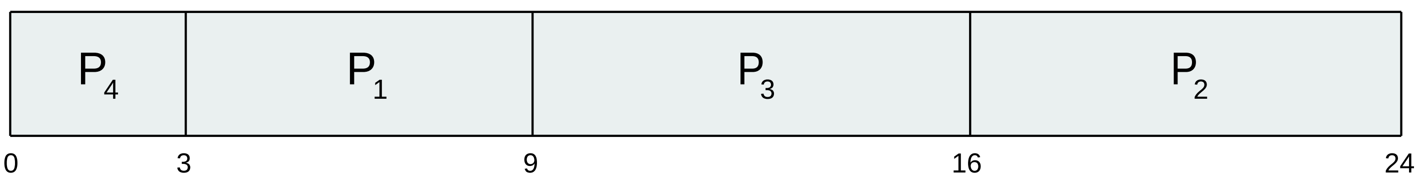
Shortest-Job-First (SJF) Scheduling

- Associates 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
  - The difficulty is knowing the length of the next CPU request
  - SJF is used frequently **in long term scheduler**, with user specifying the process time during submission.
  - Difficult to implement at s**hort-term scheduler** level.
  - For short-term scheduler next CPU burst can be calculated or predicted using the current CPU burst.

Example of SJF

<u>Process</u>	<u>Burst Time</u>
P_1	6
P_2	8
P_3	7
P_4	3

- SJF scheduling chart



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

Determining Length of Next CPU Burst

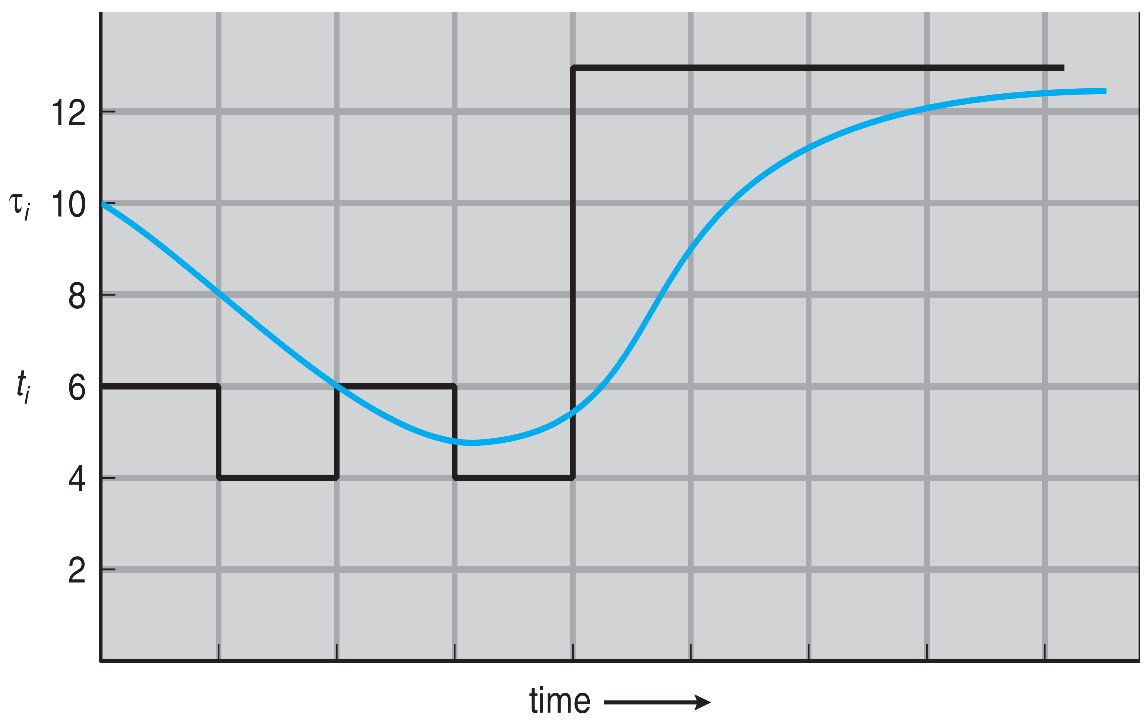
- Can only estimate the length – should be similar to the previous one
  - Then pick process with shortest predicted next CPU burst

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

  1. $t_n =$ actual length of n^{th} CPU burst
  2. $\tau_{n+1} =$ predicted value for the next CPU burst
  3. $\alpha, 0 \le \alpha \le 1$
  4. Define: $\tau_{n=1} = \alpha\, t_n + (1 - \alpha)\tau_n.$

- α controls the relative weight of recent and past history in our prediction
- Commonly, α set to ½
- If α = 1, then $\tau_{n+1} = t_n$, and only the most recent CPU burst matters.
- Preemptive version called **shortest-remaining-time-first**

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:

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

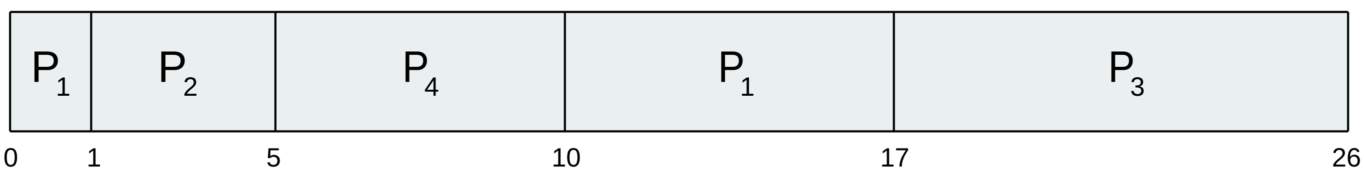
- Since both α and $(1 - \alpha)$ are less than or equal to 1, each successive term has less weight than its predecessor

Example of Shortest-remaining-time-first

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

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

- ***Preemptive* SJF Gantt Chart**



- Average waiting time = [(10-1)+(1-1)+(17-2)+5-3)]/4 = 26/4 = 6.5 msec
- What is the average waiting time of NP-SJF ?

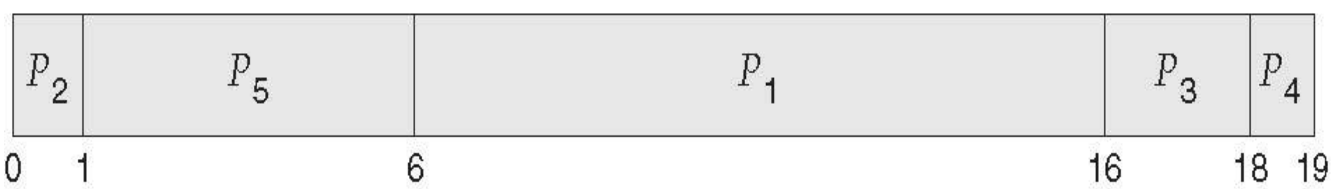
Priority Scheduling

- A priority number (integer) is associated with each process
- The CPU is allocated to the process with the highest priority (smallest integer ≡ highest priority)
  - Preemptive
  - Nonpreemptive
- SJF is priority scheduling where priority is the inverse of predicted next CPU burst time
- Problem ≡ **Starvation** – low priority processes may never execute
- Solution ≡ **Aging** – as time progresses increase the priority of the process

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



- Average waiting time = 8.2 msec

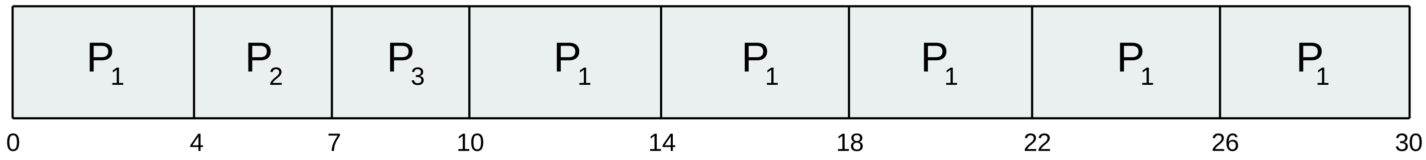
Round Robin (RR)

- 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

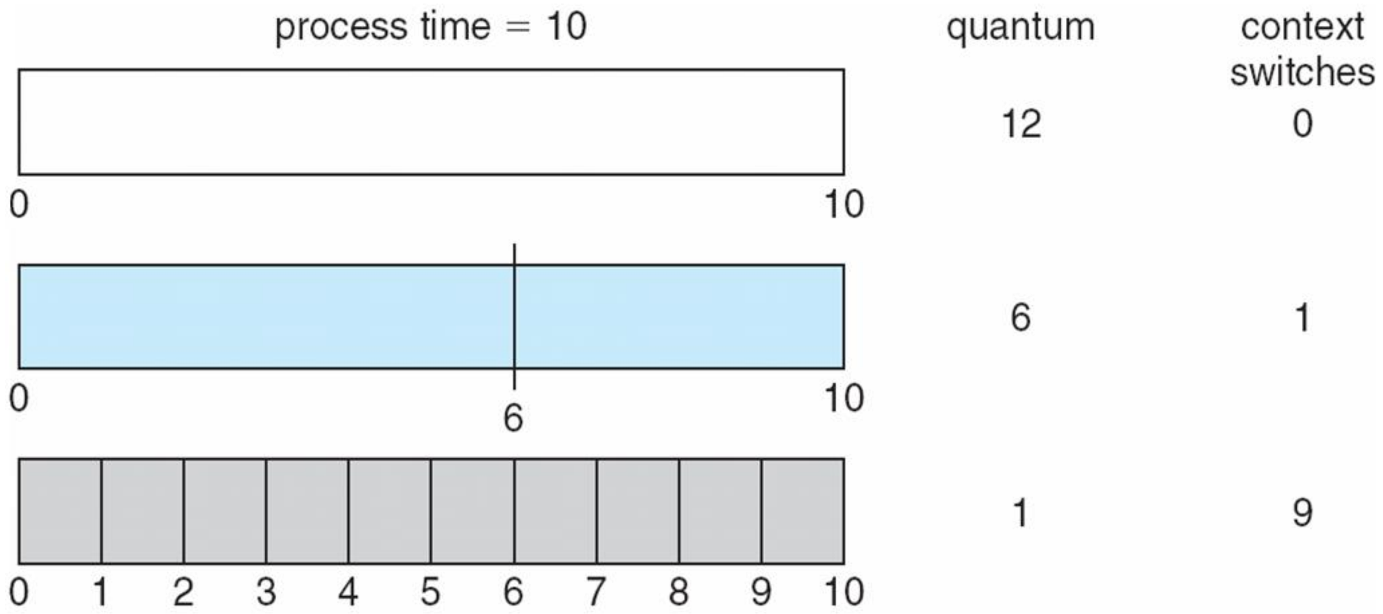
Process	Burst Time
P_1	24
P_2	3
P_3	3

- The Gantt chart is:

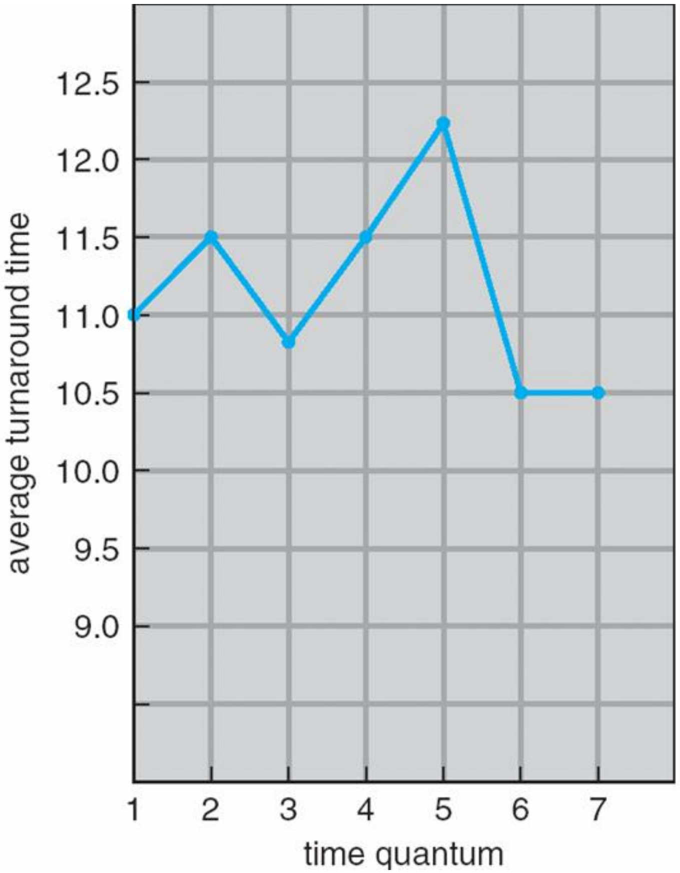


- **Process waits for, P1=(10-4)=6, P2=4, P3=7, average waiting time is 17/3=5.66 ms**
- Typically, higher average turnaround than SJF, but better ***response***
- q should be large compared to context switch time
- q usually 10ms to 100ms, context switch < 10 usec

Time Quantum and Context Switch Time



Turnaround Time Varies With The Time Quantum



process	time
P_1	6
P_2	3
P_3	1
P_4	7

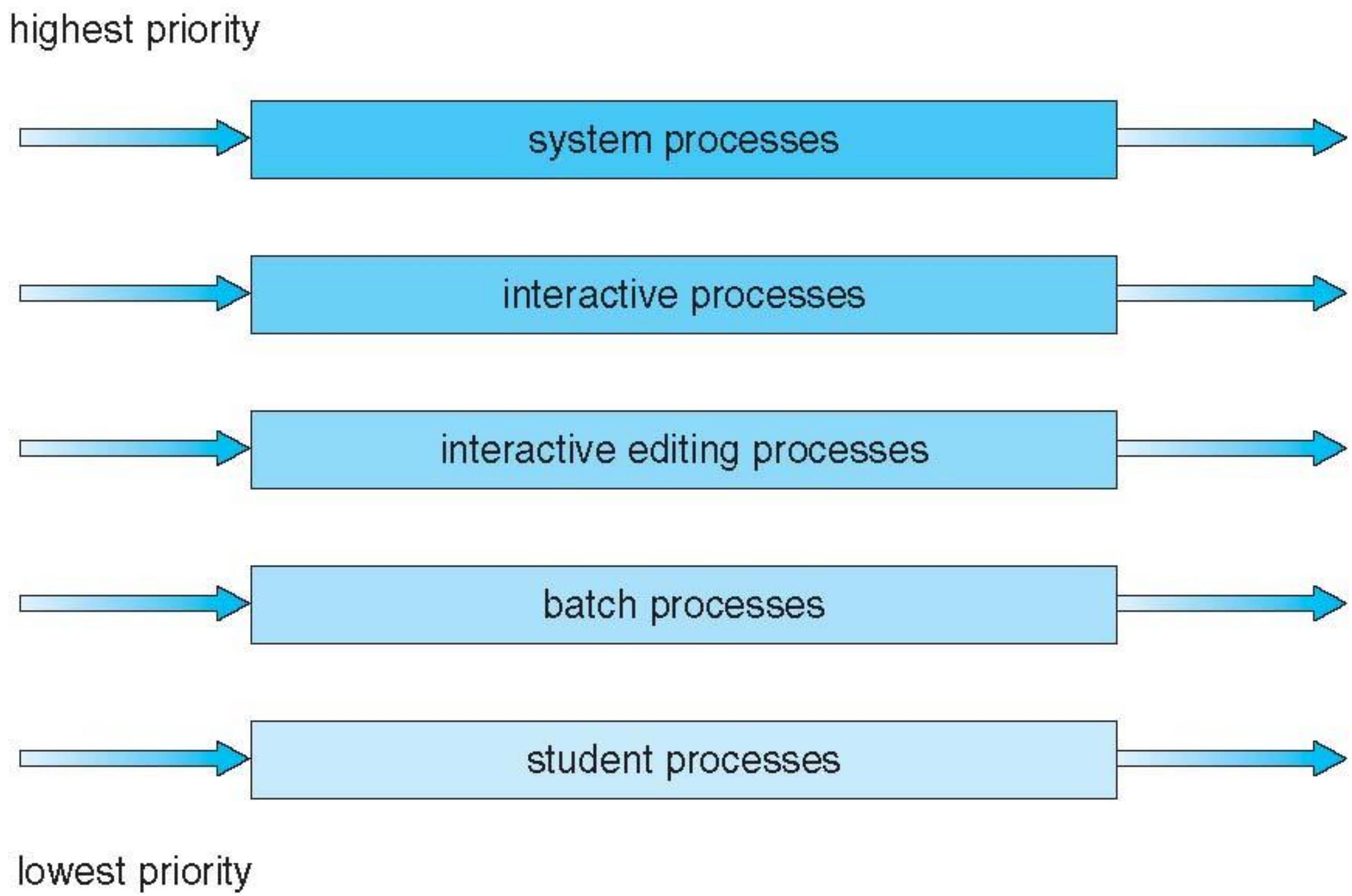
80% of CPU bursts
should be shorter than q

- Turn around time also depends upon the time quantum
- But, average turn around time does not necessarily improve with increase in time quantum, as shown in fig.
- Generally, average TAT can improve if most processes finish their next CPU burst in a single quantum

Multilevel Queue

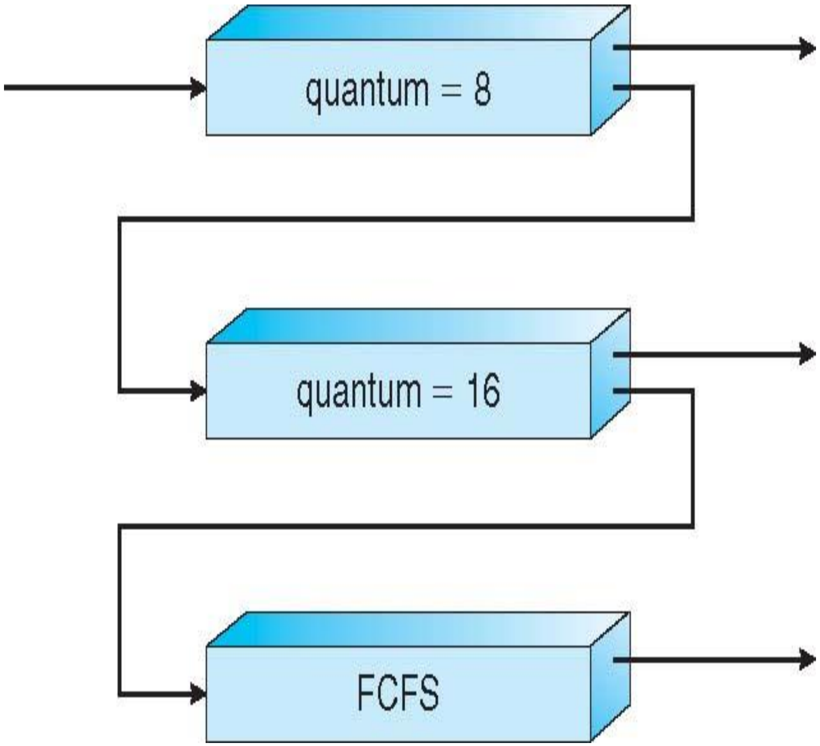
- **Ready queue** is partitioned into separate queues, eg:
  - **foreground** (interactive)
  - **background** (batch)
- Process permanently assigned a queue based upon properties like **memory size, process type, priority etc**.
- Each queue has its own scheduling algorithm:
  - foreground – RR
  - background – FCFS
- Scheduling must be done between the queues:
  - Fixed priority scheduling; (i.e., serve all from foreground then from background). Possibility of starvation.
  - Time slice – each queue gets a certain amount of CPU time which it can schedule amongst its processes; i.e., 80% to foreground in RR
  - 20% to background in FCFS

Multilevel Queue Scheduling



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



Multilevel Feedback Queue

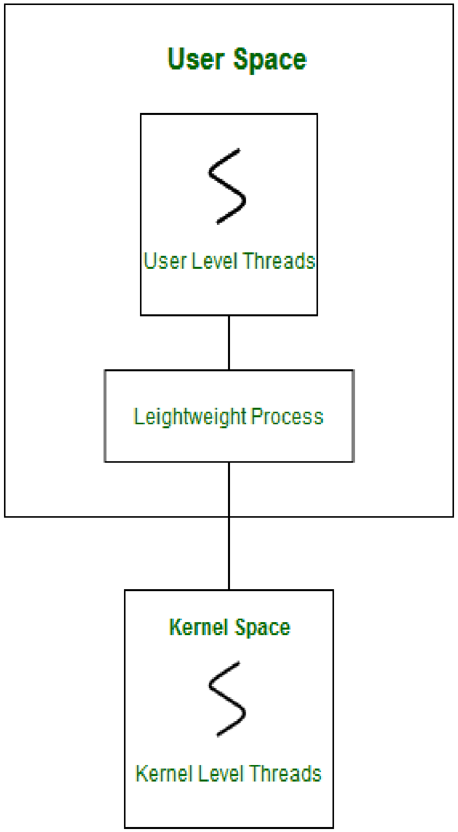
- A process can move between the various queues; aging can be implemented this way
- Multilevel-feedback-queue scheduler defined by the following parameters:
  - number of queues
  - scheduling algorithms for each queue
  - method used to determine when to upgrade a process
  - method used to determine when to demote a process
  - method used to determine which queue a process will enter when that process needs service

Thread Scheduling

- Scheduling of threads involves two boundary scheduling.
- Scheduling of **user-level threads (ULT**) to kernel-level **threads (KLT)** via lightweight process (LWP)
- Scheduling of **kernel-level threads** by the system scheduler to perform different unique OS functions.

Lightweight Process (LWP)

- Light-weight process are threads in the user space that acts as an interface for the ULT to access the physical CPU resources.
- Thread library schedules which thread of a process to run on which LWP and how long.
- The number of LWPs created by the thread library depends on the type of application.



Thread Scheduling

- **Contention Scope:** The word contention here refers to the competition among the User level threads to access the kernel resources. Thus, this control defines the extent to which contention takes place. It is defined by the application developer using the thread library.
- Contention Scope is classified as-
- .**Process Contention Scope (PCS) :**
  The contention takes place among threads **within a same process**. The thread library schedules the high-prioritized PCS thread to access the resources via available LWPs (priority as specified by the application developer during thread creation).
- **System Contention Scope (SCS) :**
  The contention takes place among **all threads in the system**. In this case, every SCS thread is associated to each LWP by the thread library and are scheduled by the system scheduler to access the kernel resources.

Pthread Scheduling

- API allows specifying either PCS or SCS during thread creation
- The POSIX Pthread library provides function ***Pthread_attr_setscope*** to define the type of contention scope for a thread during its creation.

  int Pthread_attr_setscope(pthread_attr_t *attr, int scope)

- The first parameter denotes to **which thread within the process** the scope is defined.
- The second parameter defines **the scope of contention** for the thread pointed. It takes two values.
  - PTHREAD_SCOPE_PROCESS schedules threads using PCS scheduling
  - PTHREAD_SCOPE_SYSTEM schedules threads using SCS scheduling

Exercises

1 Consider the following set of processes, with the length of the CPU burst given in milliseconds:

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

The processes are assumed to have arrived in the order P_1, P_2, P_3, P_4, P_5, all at time 0.

a. Draw four Gantt charts that illustrate the execution of these processes using the following scheduling algorithms: FCFS, SJF, nonpreemptive priority (a larger priority number implies a higher priority), and RR (quantum = 2).

b. What is the turnaround time of each process for each of the scheduling algorithms in part a?

c. What is the waiting time of each process for each of these scheduling algorithms?

d. Which of the algorithms results in the minimum average waiting time (over all processes)?

Exercise 3

Consider the following set of processes, arriving at the given times and having the following CPU burst time and priorities (Smaller number is having higher priority):

Draw a Gantt chart and calculate average waiting time and turnaround time of each process using SJF, Priority and Round robin (quantum 3 ms). Assume pre-emptive scheduling policy for SJF and Priority scheduling.

Process	Arrival Time(ms)	Burst Time (ms)	Priority
A	0	8	3
B	3	4	1
C	5	7	4
D	8	3	2

Exercises

The following processes are being scheduled using a preemptive, round-robin scheduling algorithm. Each process is assigned a numerical priority, with a higher number indicating a higher relative priority. In addition to the processes listed below, the system also has an ***idle task*** (which consumes no CPU resources and is identified as P_{idle}). This task has priority 0 and is scheduled whenever the system has no other available processes to run. The length of a time quantum is 10 units. If a process is preempted by a higher-priority process, the preempted process is placed at the end of the queue.

Thread	Priority	Burst	Arrival
P_1	40	20	0
P_2	30	25	25
P_3	30	25	30
P_4	35	15	60
P_5	5	10	100
P_6	10	10	105

Exercises

a. Show the scheduling order of the processes using a Gantt chart.

b. What is the turnaround time for each process?

c. What is the waiting time for each process?

d. What is the CPU utilization rate?

End of Chapter 5