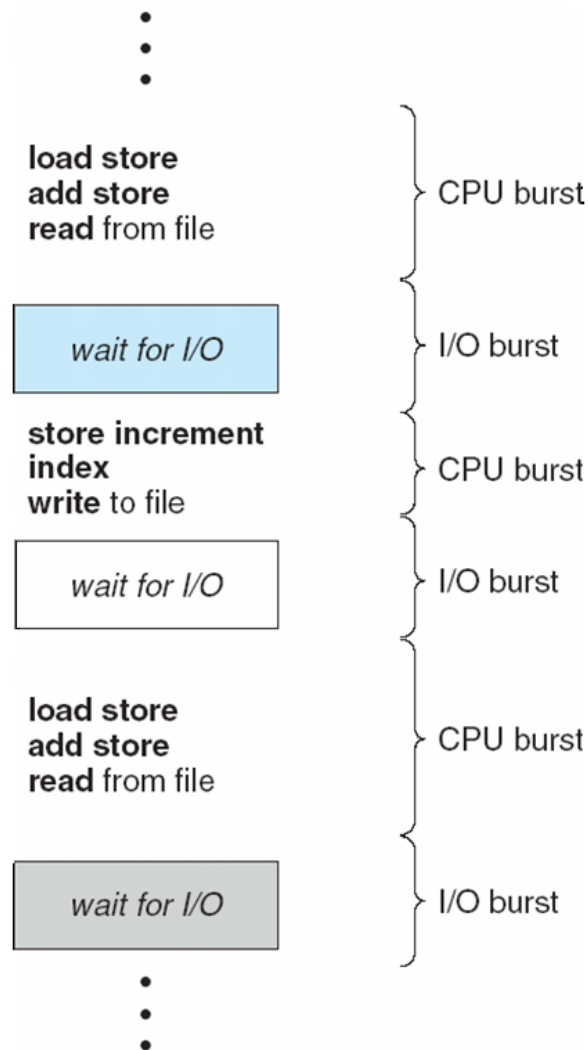


CPU Scheduling Algorithm

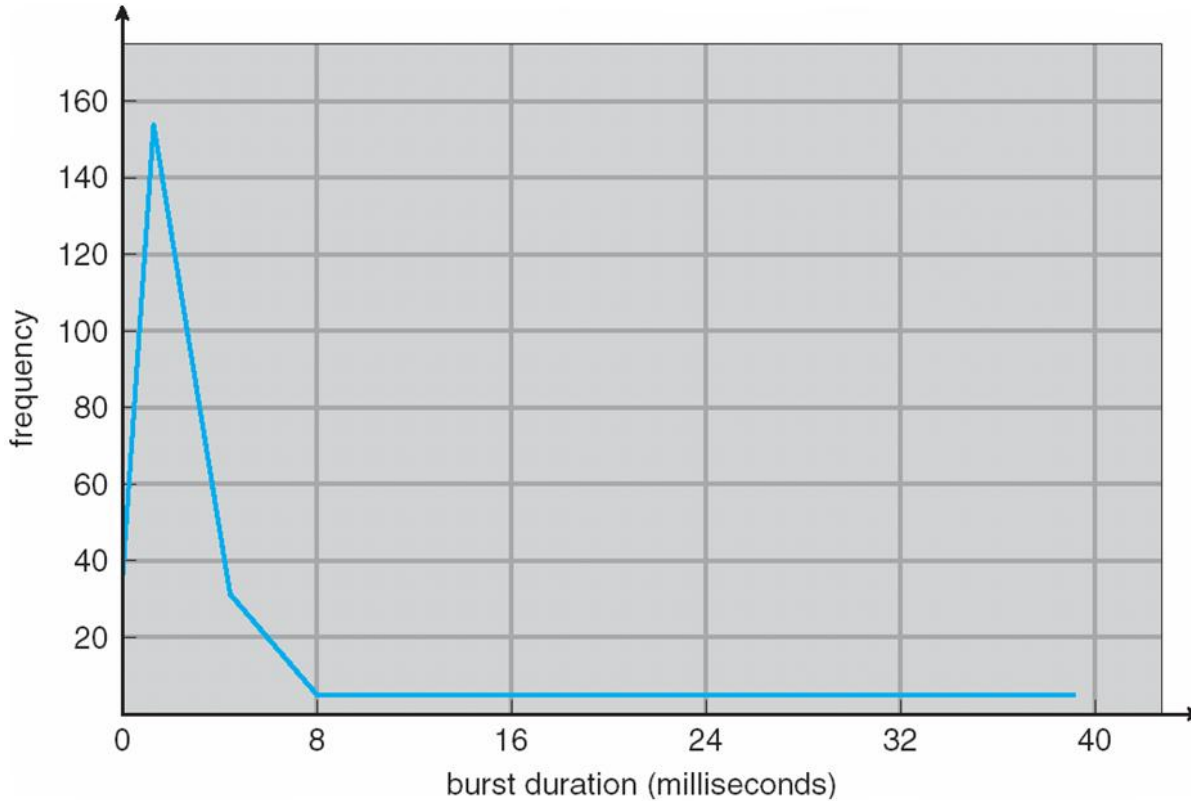
Basic Concepts

- 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** distribution

Alternating Sequence of CPU and I/O Bursts



Histogram of CPU-burst Times



CPU Scheduler

- Selects from among the processes in ready queue, and allocates the CPU to one of them
 - 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
- Scheduling under 1 and 4 is **nonpreemptive**
- All other scheduling is **preemptive**
 - Consider access to shared data
 - Consider preemption while in kernel mode
 - Consider interrupts occurring during crucial OS activities

Dispatcher

- Dispatcher module 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

- **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, not output (for time-sharing environment)

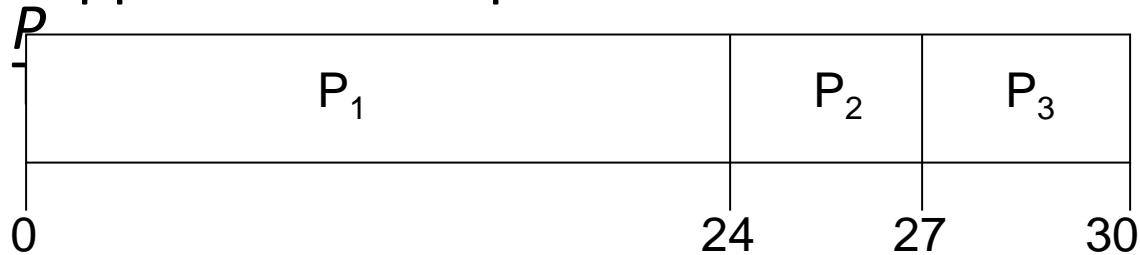
Scheduling Algorithm Optimization Criteria

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

First-Come, First-Served (FCFS) Scheduling

<u>Process</u>	<u>Burst Time</u>
P_1	24
P_2	3
P_3	3

- Suppose that the processes arrive in the order: $P_1, P_2,$



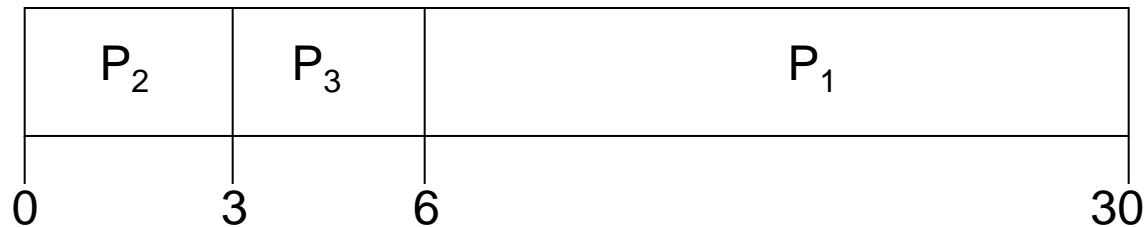
- Waiting time for $P_1 = 0$; $P_2 = 24$; $P_3 = 27$
- Average waiting time: $(0 + 24 + 27)/3 = 17$

FCFS Scheduling (Cont.)

Suppose that the processes arrive in the order:

$$P_2, P_3, P_1$$

- The Gantt chart for the schedule is:

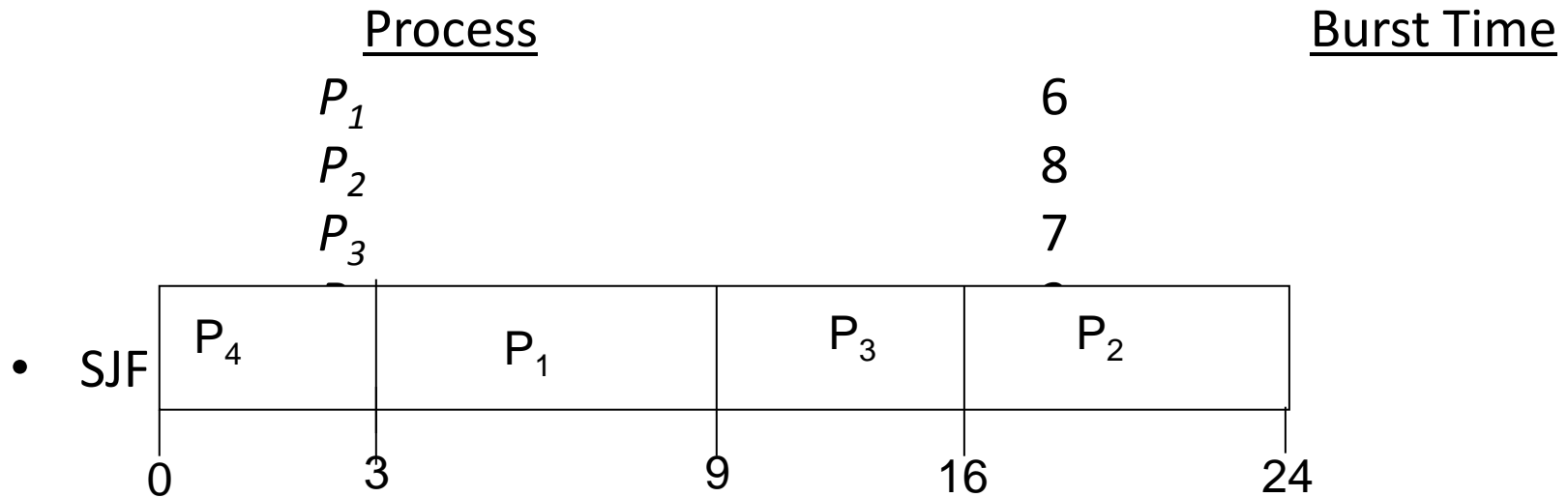


- Waiting time for $P_1 = 6$; $P_2 = 0$; $P_3 = 3$
- Average waiting time: $(6 + 0 + 3)/3 = 3$
- Much better than previous case
- **Convoy effect** - short process behind long process
 - Consider one CPU-bound and many I/O-bound processes

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
 - The difficulty is knowing the length of the next CPU request
 - Could ask the user

Example of SJF



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

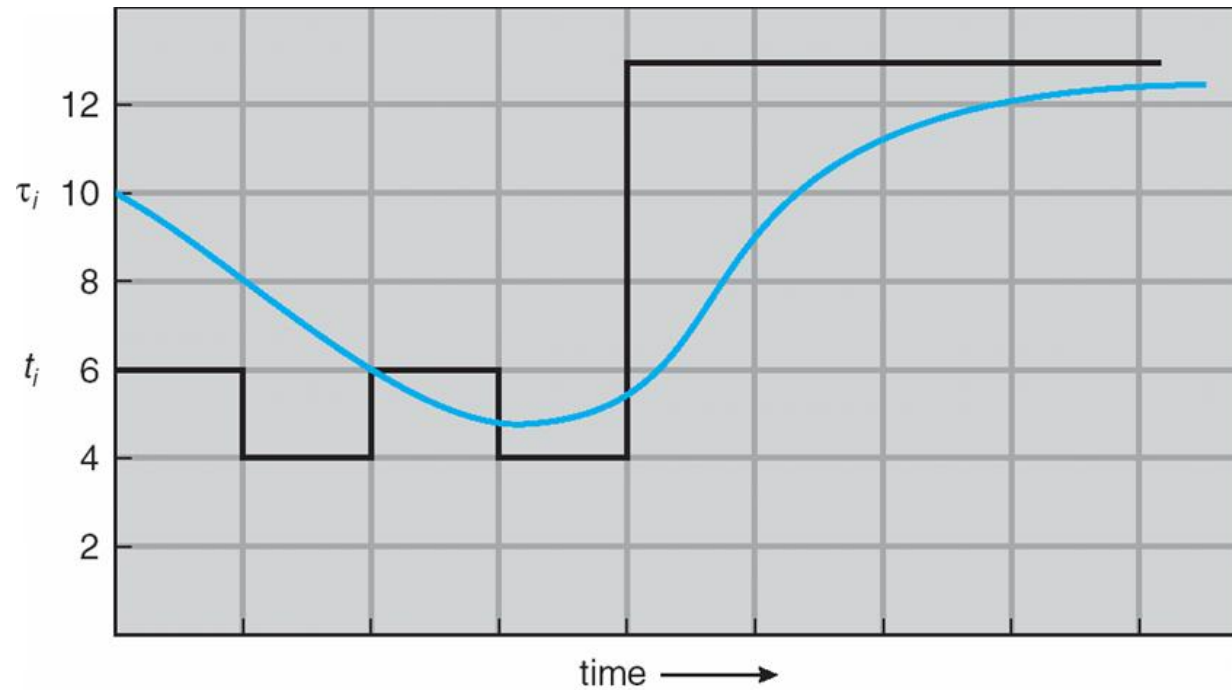
Determining Length of Next CPU Burst

- 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. τ_n = current average CPU burst
 2. τ_{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 $\frac{1}{2}$
- 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:

$$\begin{aligned}\tau_{n+1} = & \alpha t_n + (1 - \alpha)\alpha t_{n-1} + \dots \\ & + (1 - \alpha)^j \alpha t_{n-j} + \dots \\ & + (1 - \alpha)^{n+1} \tau_0\end{aligned}$$

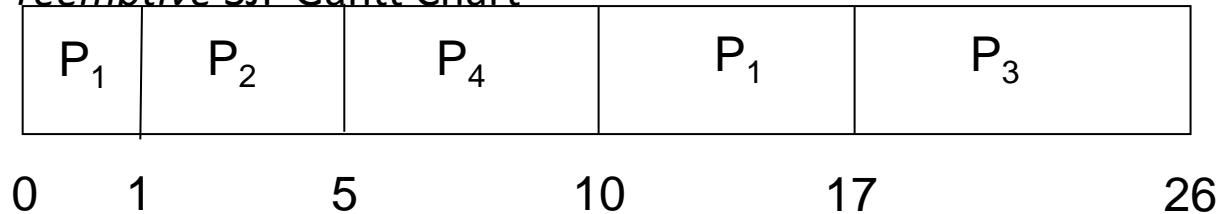
- Since both α and $(1 - \alpha)$ are less than or equal to 1, each successive term has less weight than its predecessor

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*



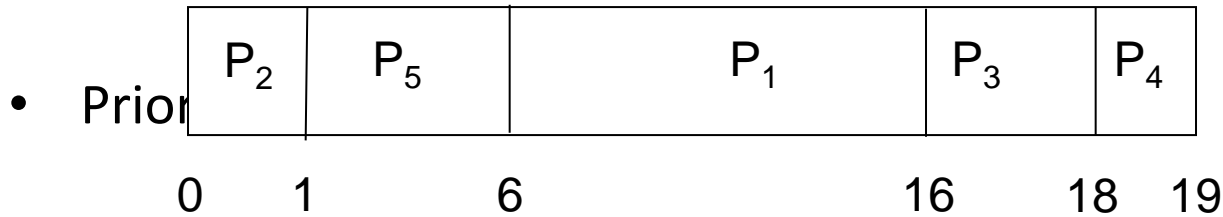
- Average waiting time = $[(10-1)+(1-1)+(17-2)+5-3]/4 = 26/4 = 6.5$ msec

Priority Scheduling

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

Example of Priority Scheduling

<u>Process</u>	<u>Burst Time</u>	<u>Priority</u>
P_1	10	3
P_2	1	1
P_3	2	4
P_4	1	5



- Average waiting time = 8.2 msec

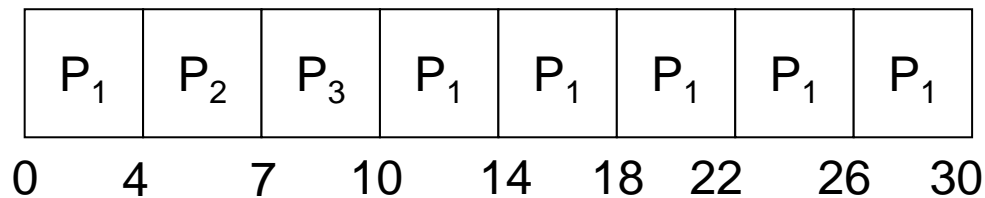
Round Robin (RR)

- 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

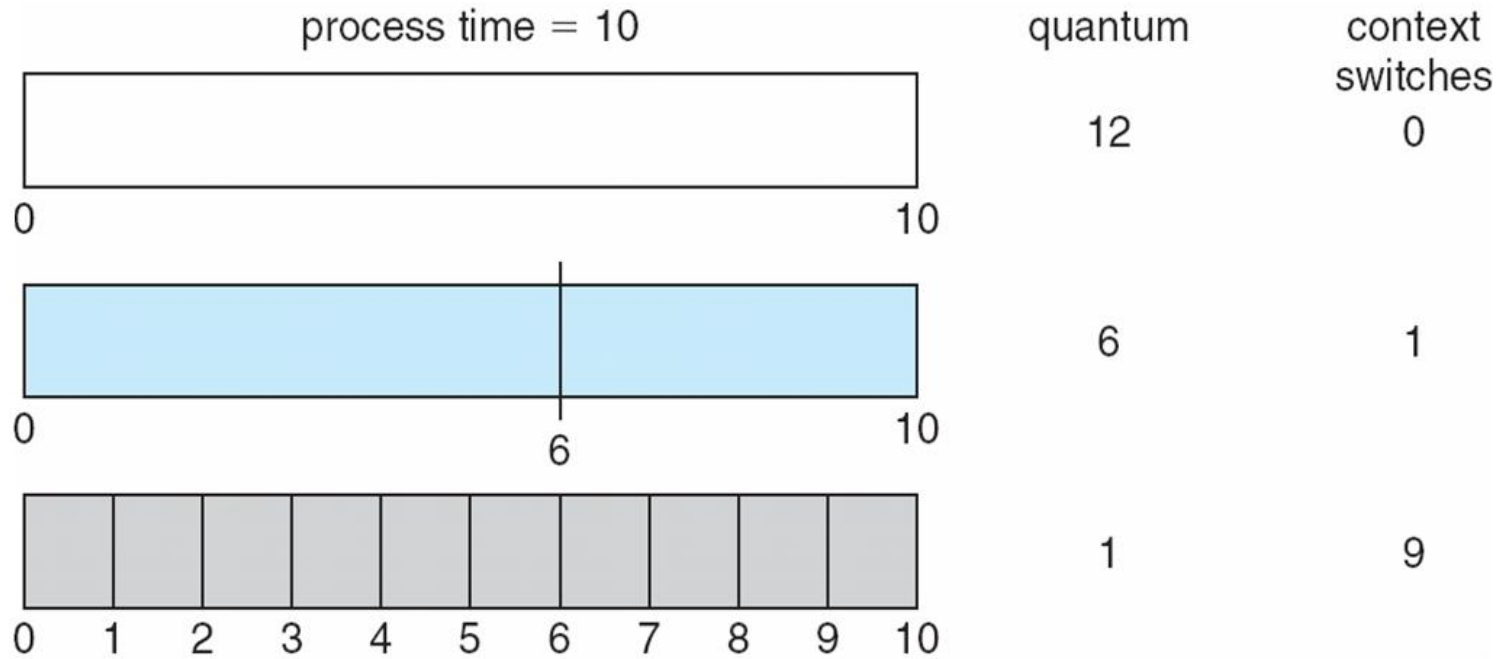
<u>Process</u>	<u>Burst Time</u>
P_1	24
P_2	3
P_3	3

- The Gantt chart is:

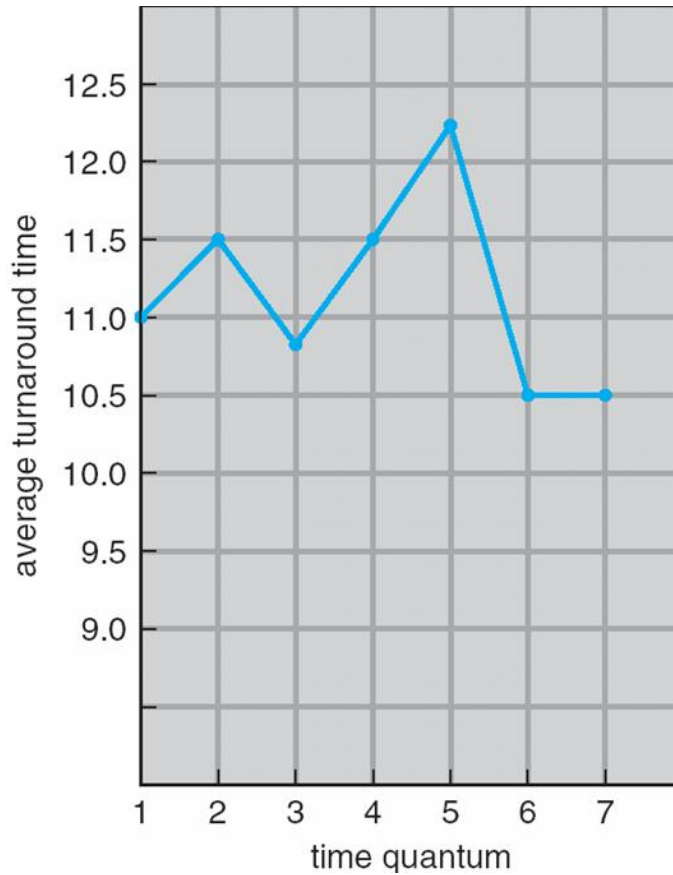


- Typically, higher average turnaround than SJF, but better *response*
- q should be large compared to context switch time
- q usually 10ms to 100ms, context switch < 10 usec

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

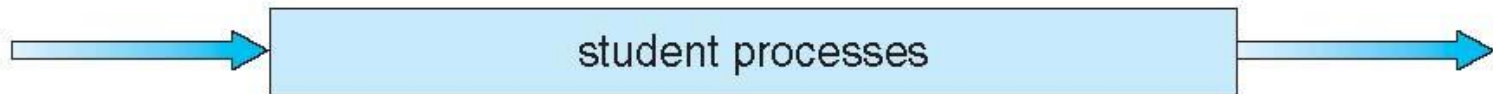
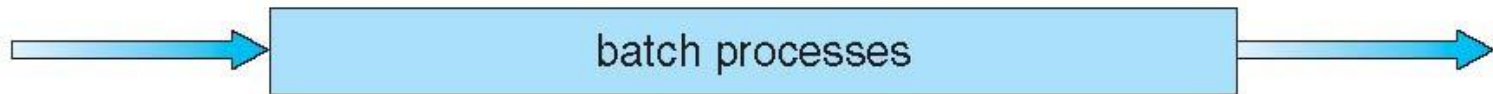
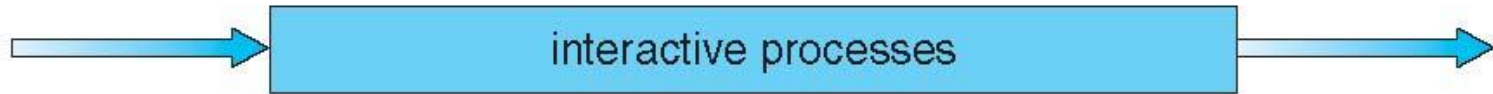
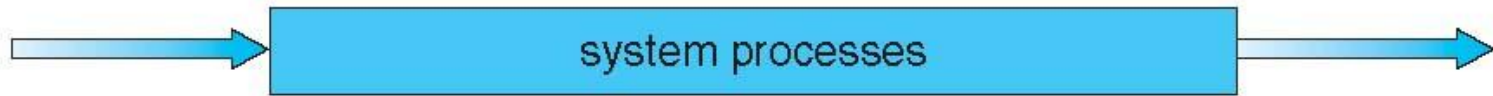
80% of CPU bursts
should be shorter than
q

Multilevel Queue

- Ready queue is partitioned into separate queues, eg:
 - foreground (interactive)
 - background (batch)
- Process permanently in a given queue
- 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

highest priority



lowest priority

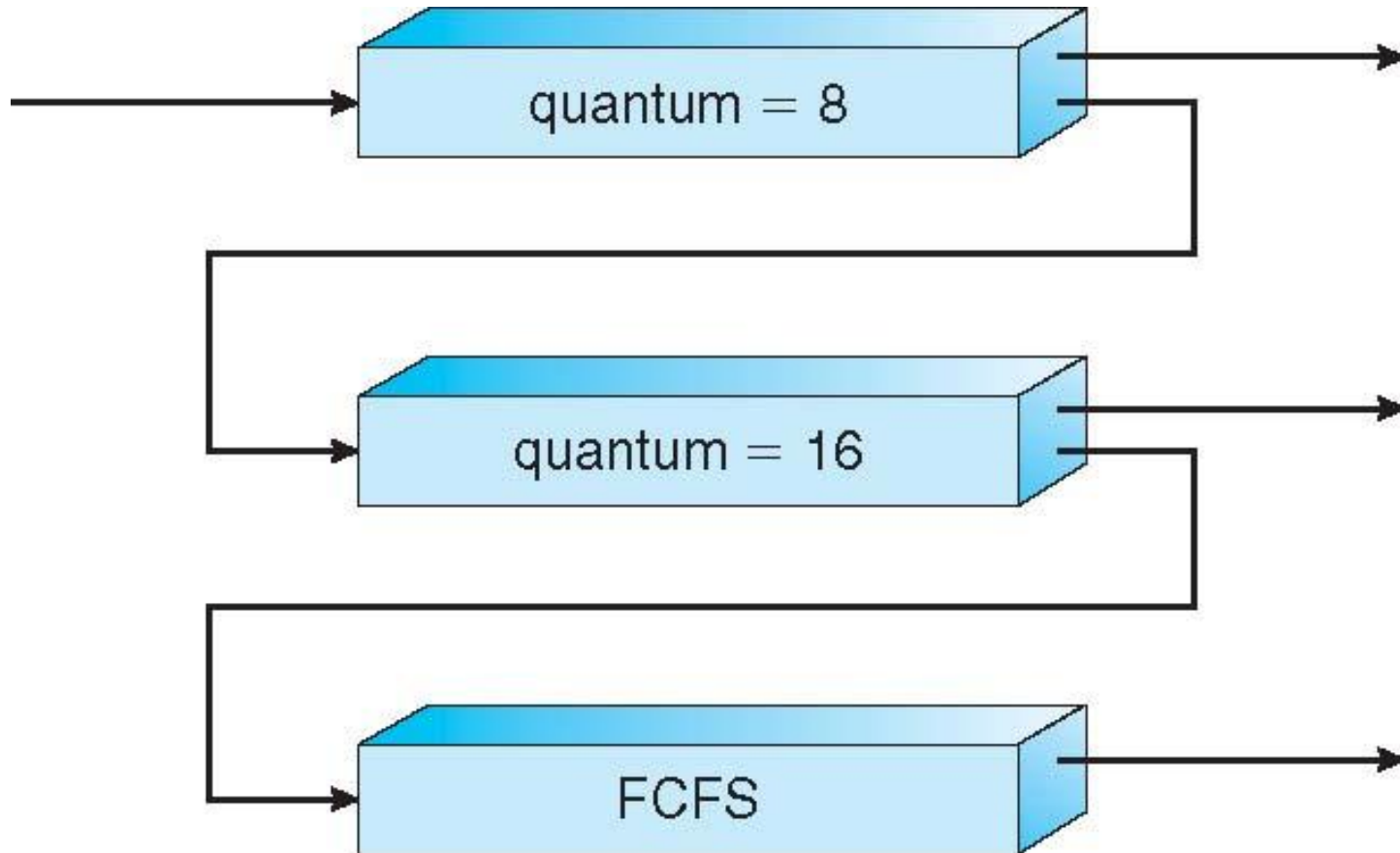
Multilevel Feedback Queue

- 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

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 Queues



Thread Scheduling

- Distinction between user-level and kernel-level threads
- When threads supported, threads scheduled, not processes
- Many-to-one and many-to-many models, thread library schedules user-level threads to run on LWP
 - Known as **process-contention scope (PCS)** since scheduling competition is within the process
 - Typically done via priority set by programmer
- Kernel thread scheduled onto available CPU is **system-contention scope (SCS)** – competition among all threads in system

Pthread Scheduling

- API allows specifying either PCS or SCS during thread creation
 - `PTHREAD_SCOPE_PROCESS` schedules threads using PCS scheduling
 - `PTHREAD_SCOPE_SYSTEM` schedules threads using SCS scheduling
- Can be limited by OS – Linux and Mac OS X only allow `PTHREAD_SCOPE_SYSTEM`