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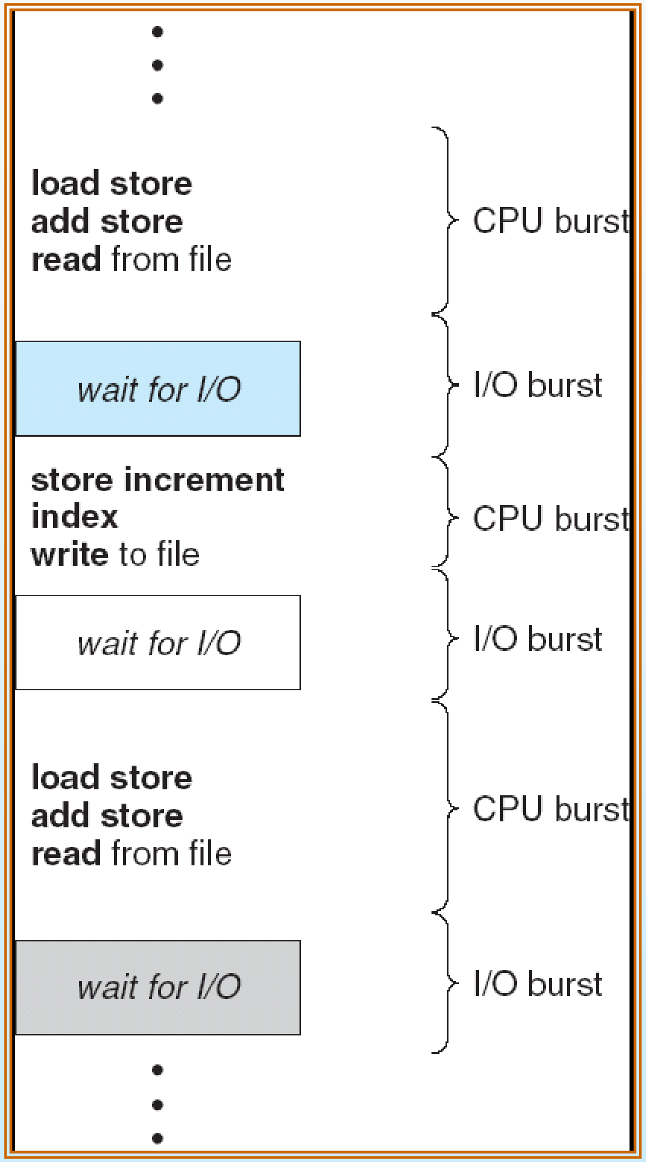
Chapter 5: CPU Scheduling

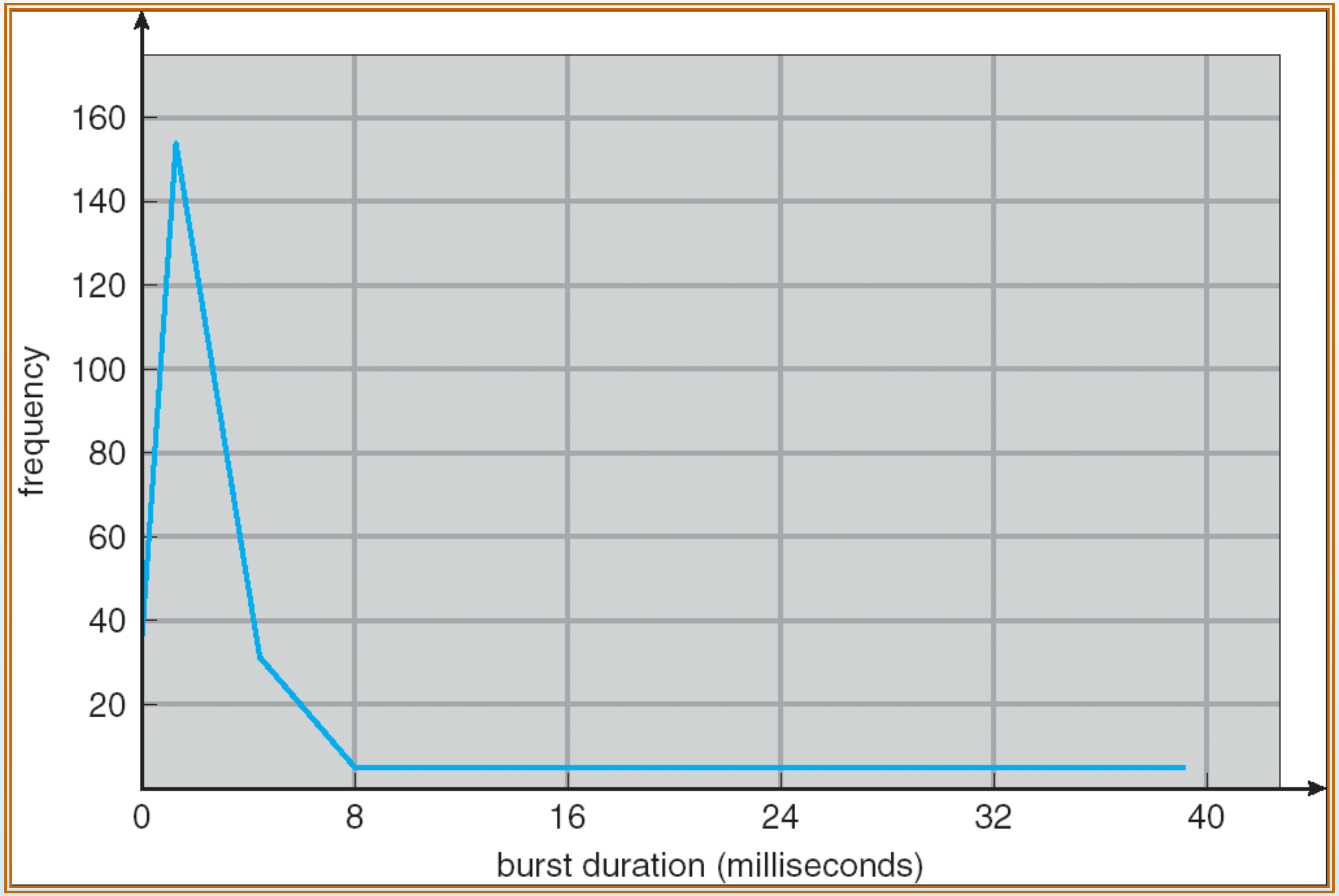
Basic Concepts

- 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 among processes in memory that are **ready** to execute; **allocates** the CPU to one of them
- 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*
- Scheduling under 2 is *preemptive*
- Scheduling under 3 can be any of both

Dispatcher

- Module that gives control of CPU to process selected by short-term scheduler; this involves:
  - switching context
  - switching to user mode
  - jumping to proper location in user program to restart that program
- *Dispatch latency* – time it takes for dispatcher to stop one process and start another running

Scheduling Criteria

- CPU utilization – keep CPU as busy as possible
- Throughput – # of processes that complete execution per time unit
- Turnaround time – amount of time to execute a particular process
- Waiting time – amount of time process waiting in ready queue
- Response time – (time-sharing environment) amount of time it takes from when request submitted until the first response produced

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 behind long process

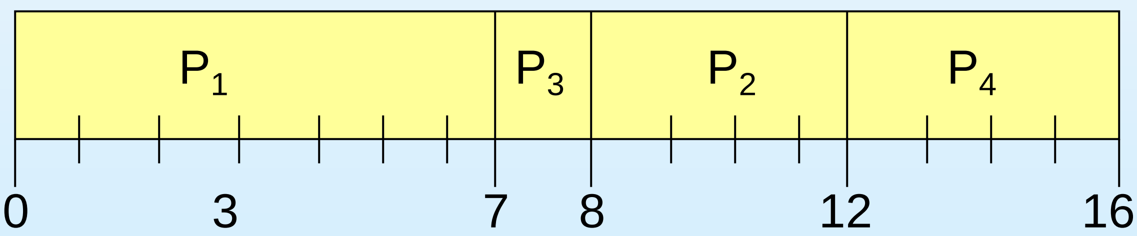
Shortest-Job-First (SJR) Scheduling

- Associate each process w/length of next CPU burst. Schedule the process with the shortest time
- Two schemes:
  - nonpreemptive – once CPU given to process, cannot be preempted
  - preemptive – new process arrives with CPU burst length less than remaining time of current executing process, **preempt**. Shortest-Remaining-Time-First (SRTF)
- SJF is optimal –minimum average waiting time for a set of processes

Example of Non-Preemptive SJF

Process	Arrival Time	Burst Time
P_1	0.0	7
P_2	2.0	4
P_3	4.0	1
P_4	5.0	4

- SJF (non-preemptive)

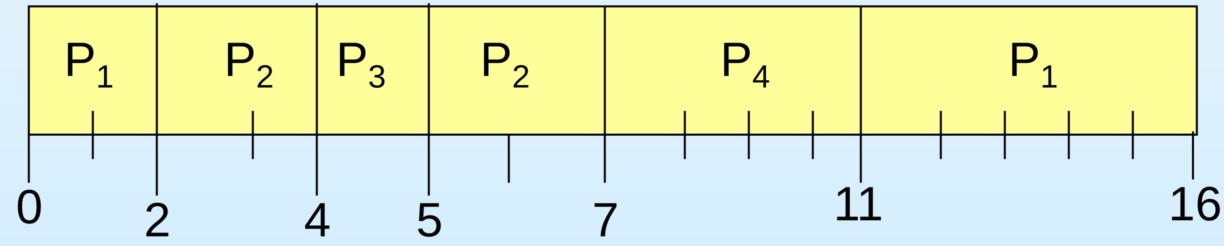


- Average waiting time = (0 + 6 + 3 + 7)/4 = 4

Example of Preemptive SJF

Process	Arrival Time	Burst Time
P_1	0.0	7
P_2	2.0	4
P_3	4.0	1
P_4	5.0	4

- SJF (preemptive)



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

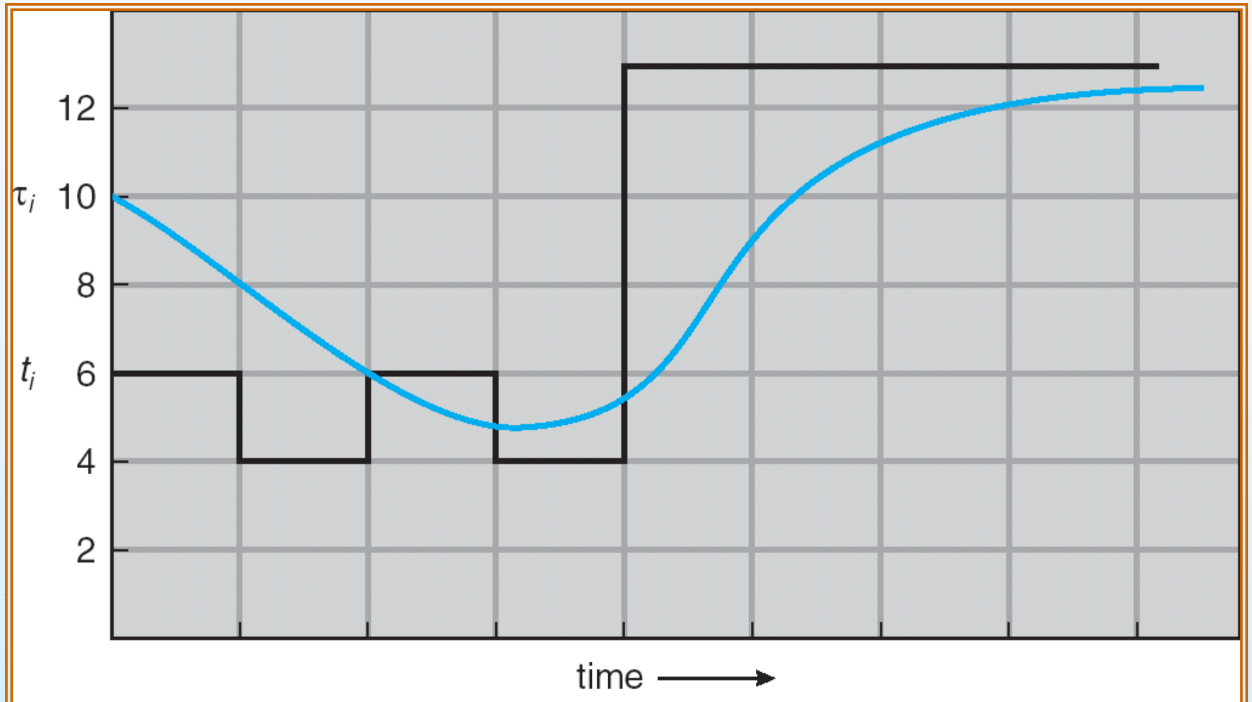
Determining Length of Next CPU Burst

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

1. $t_n =$ actual lenght 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:

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

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:

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

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

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 a priority scheduling where priority = predicted next CPU burst time
- Problem ≡ Starvation – low priority processes may never execute
- Solution ≡ Aging – as time progresses increase the priority of the process

Round Robin (RR)

- Each process: a small unit of CPU time (*time quantum*; usually 10-100 milliseconds). Time elapsed => process preempted and added to end of ready queue.
- If n processes in ready queue; quantum q, each process gets $1/n$ of CPU time in chunks of at most q time units. No process waits more than $(n-1)q$ time units.
- 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 = 20

Process	Burst Time
P_1	53
P_2	17
P_3	68
P_4	24

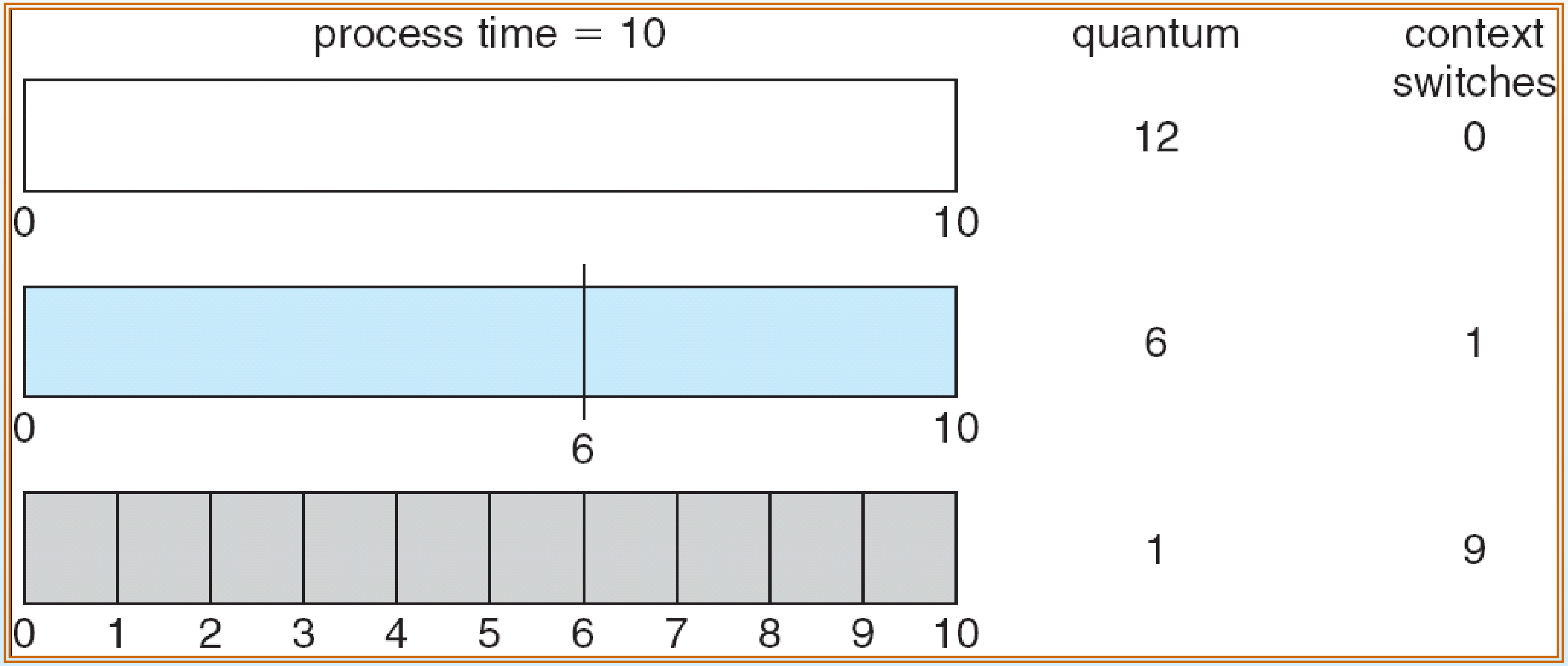
- The Gantt chart is:

P_1	P_2	P_3	P_4	P_1	P_3	P_4	P_1	P_3	P_3

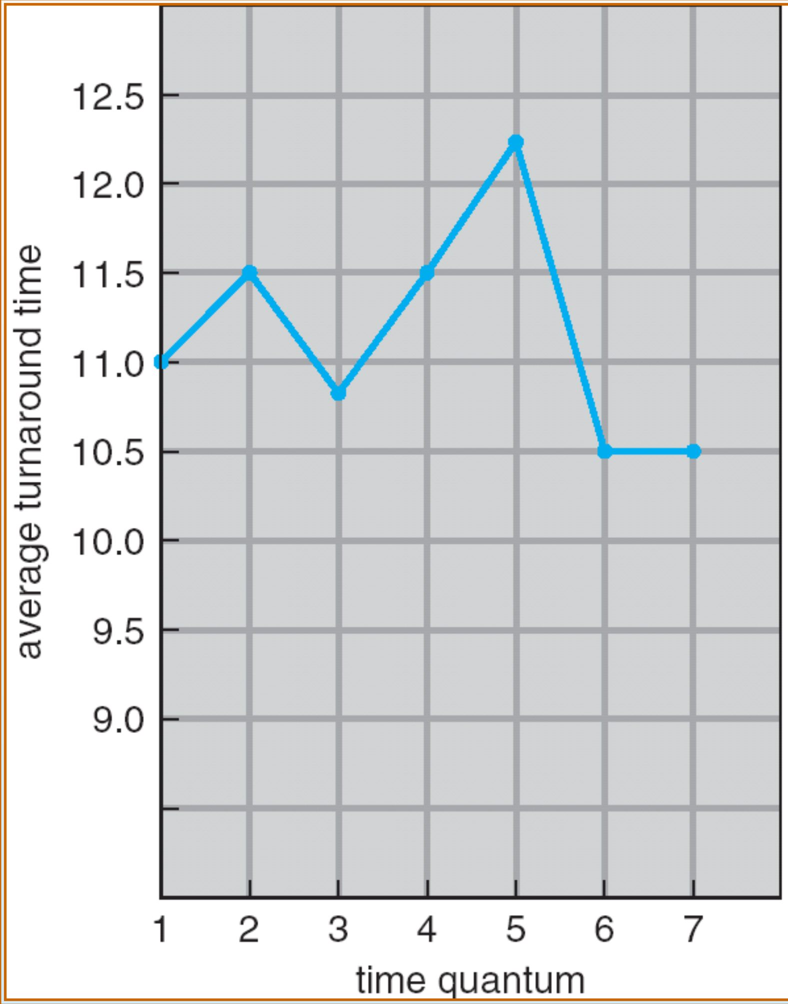
0 20 37 57 77 97 117 121 134 154 162

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

Time Quantum and Context Switch Time



Turnaround Time Varies With The Time Quantum

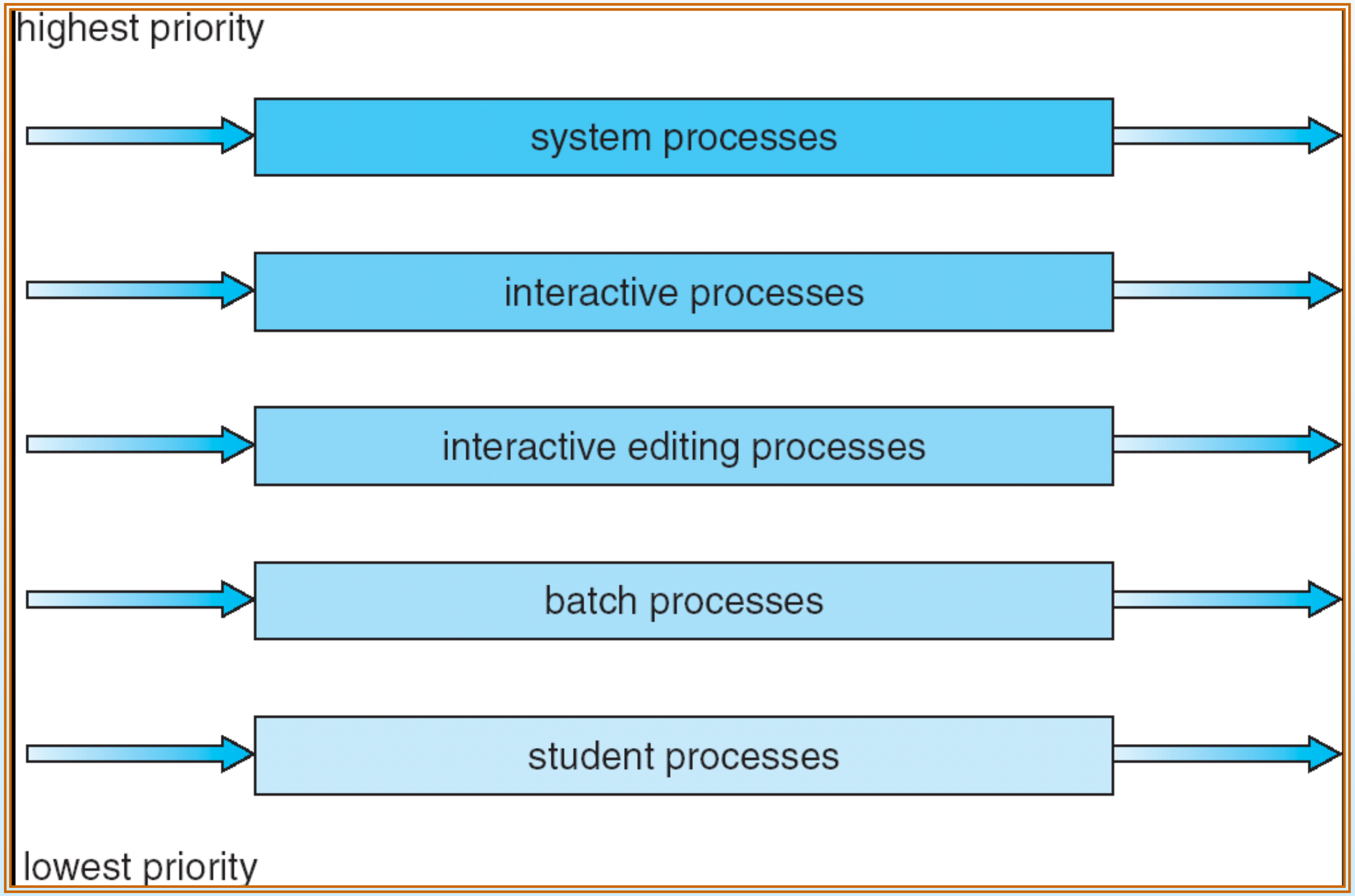


process	time
P_1	6
P_2	3
P_3	1
P_4	7

Multilevel Queue

- Ready queue partitioned into separate queues:
  foreground (interactive)
  background (batch)
- 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 background). 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



Multilevel Feedback Queue

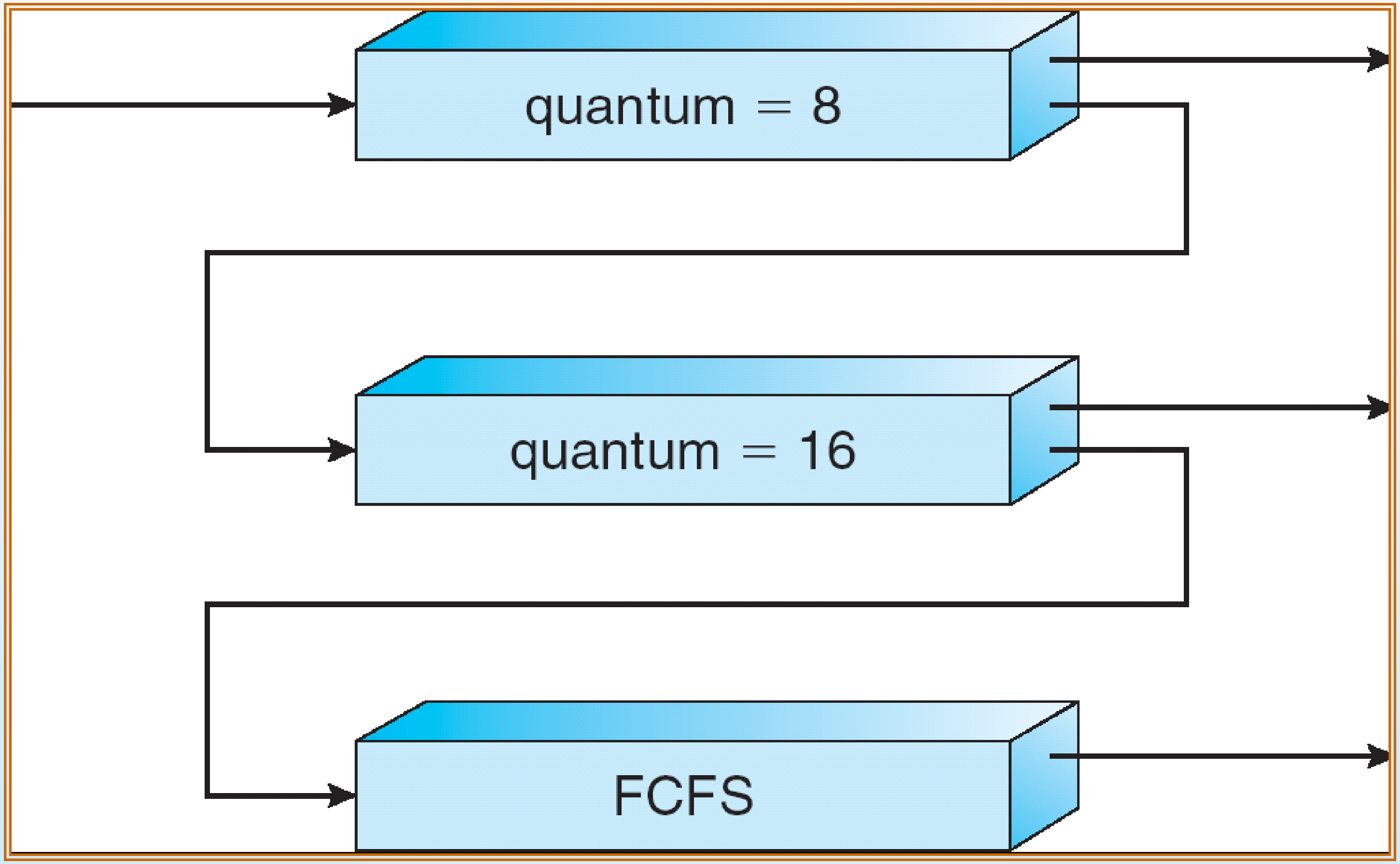
- A process can move between the queues; **aging** can be implemented this way
- Multilevel-feedback-queue scheduler defined by the following parameters:
  - number of queues
  - scheduling algorithms for each queue
  - method used to determine when to upgrade a process
  - method used to determine when 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
  - New job: Q_0 which is served FCFS.
    - When it gains CPU, job receives 8 milliseconds.
    - Does not finish? Moved to Q_1.
  - Q_1 : job served FCFS
    - receives 16 additional milliseconds.
    - not complete? preempted and moved to queue Q_2.

Multilevel Feedback Queues



Multiple-Processor Scheduling

- More complex when multiple CPUs are available
- *Homogeneous processors* within a multiprocessor
- *Load sharing*
- *Asymmetric multiprocessing* – one processor accesses the system data structures, LESSS data sharing

Real-Time Scheduling

- *Hard real-time* systems – required to complete a critical task within a guaranteed amount of time
- *Soft real-time* computing – requires that critical processes receive priority over less fortunate ones
- Rate Monotonic Scheduling (periodic tasks; shortest period first)
- Earliest Deadline First Scheduling (aperiodic tasks; the one with the earliest deadline is scheduled to execute first)

Thread Scheduling

- Local Scheduling – Threads library
  - Which thread to put onto an available kernel Thread
- Global Scheduling – OS Scheduler
  - How the kernel decides which kernel thread to run next

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End of Chapter 5