CPU Scheduling

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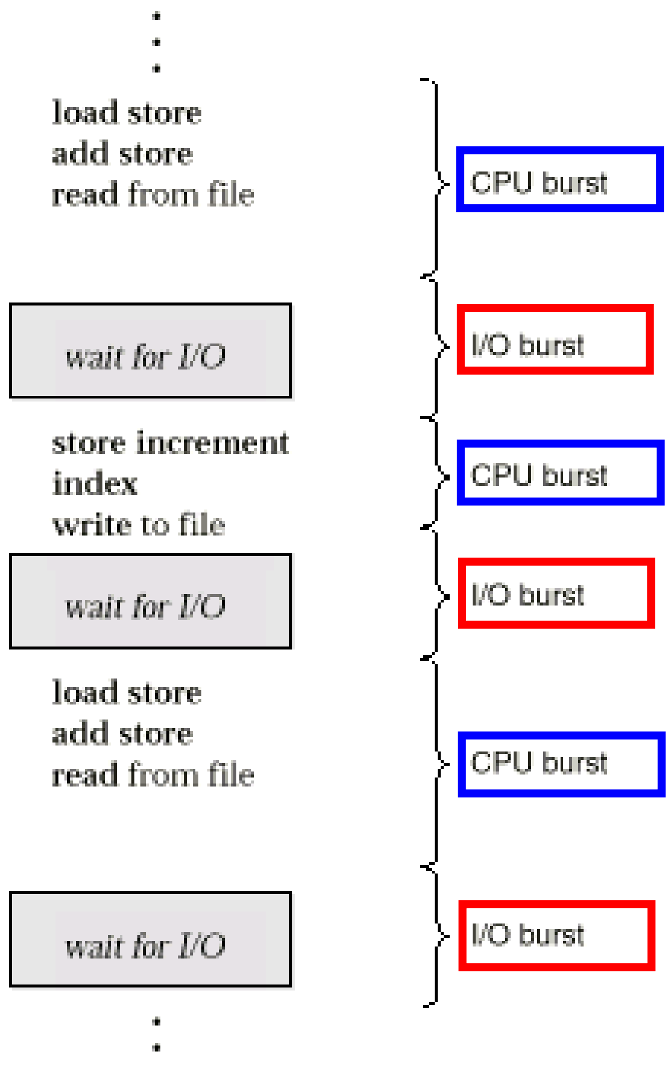
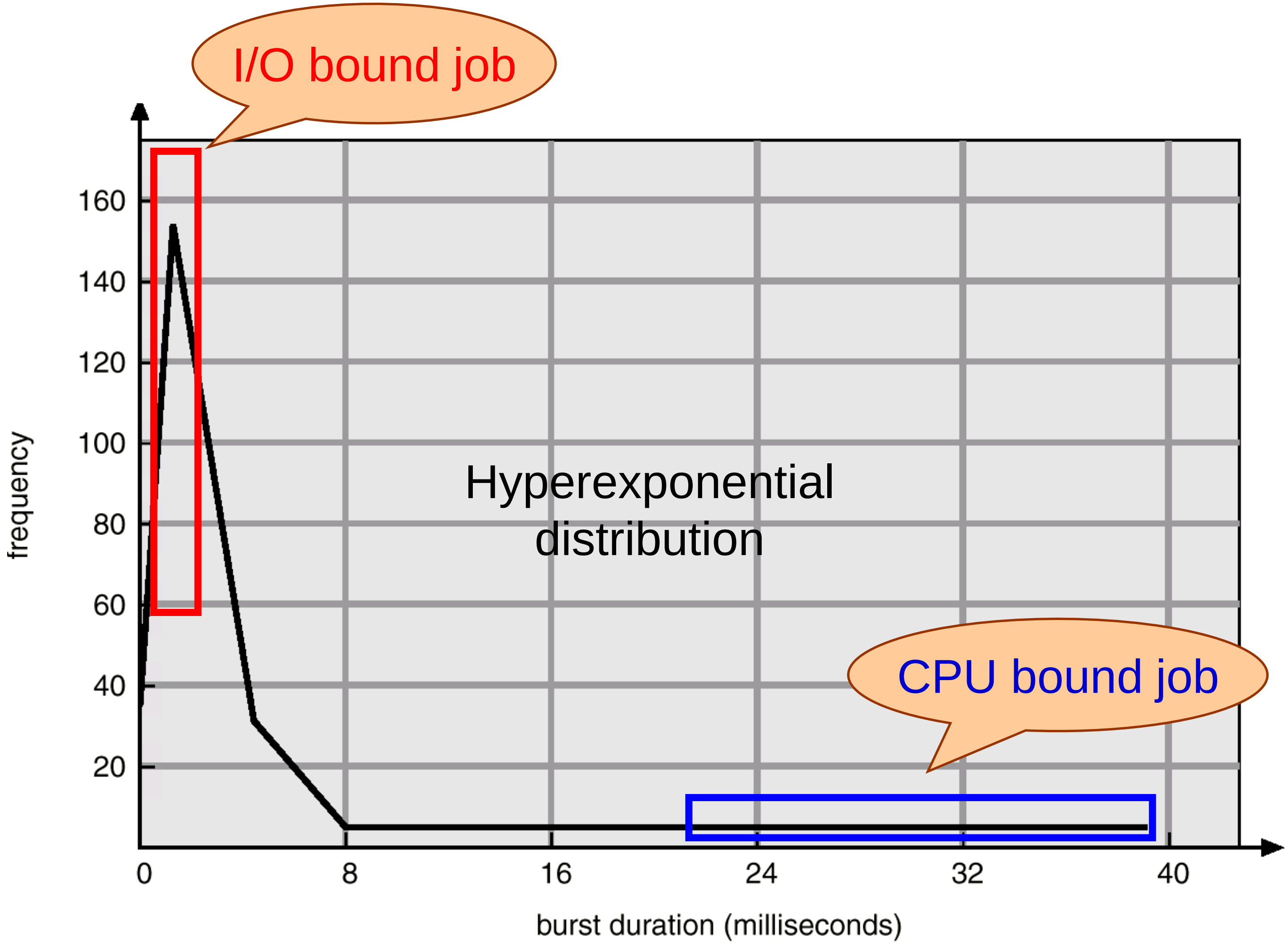
Alternating sequence of CPU and I/O Bursts



Histogram of CPU-burst Times



State Transition Diagram - revisited

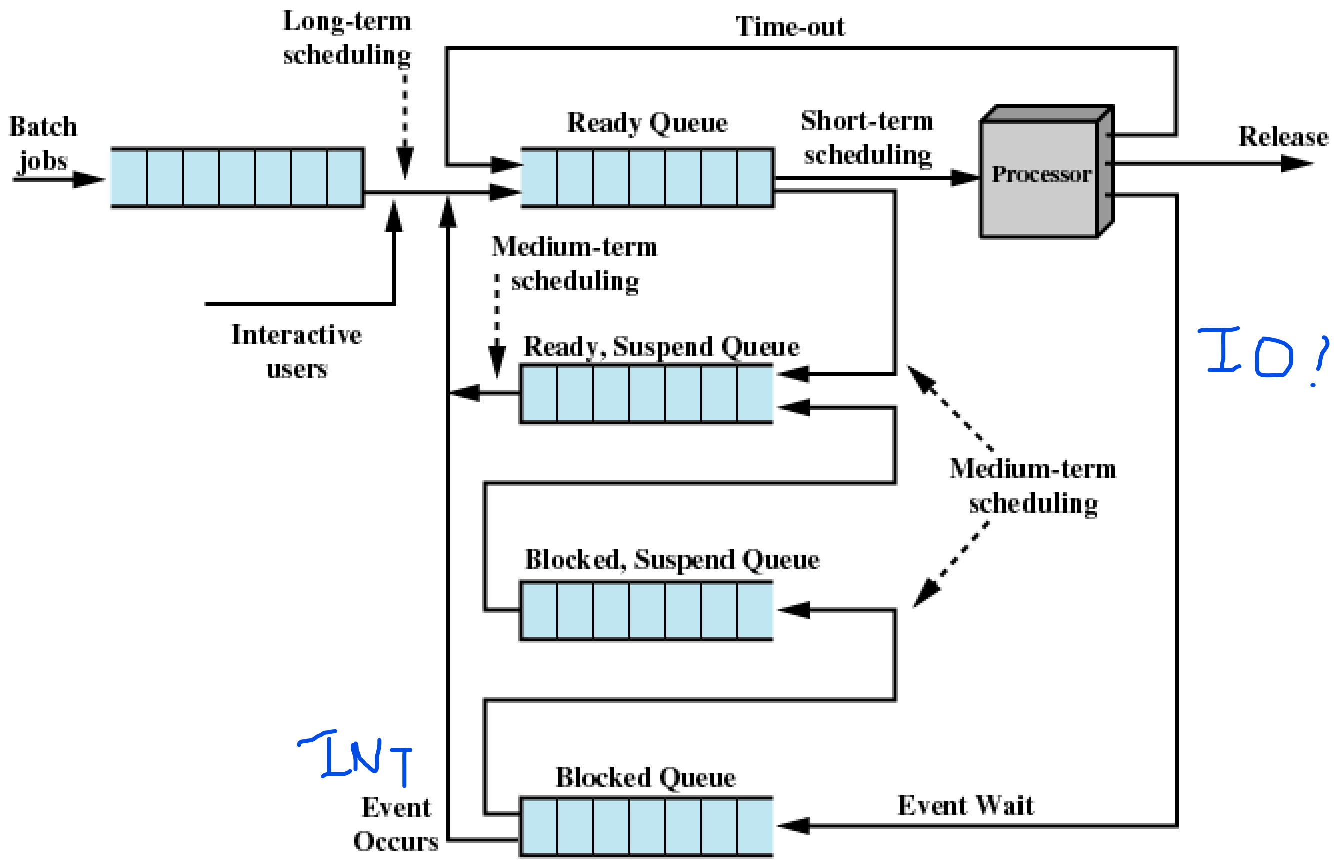


Figure 9.3 Queuing Diagram for Scheduling

CPU Scheduler

- Multiprogramming environment
- ***CPU Scheduler*** *selects* processes *in memory* that are *ready to execute*, and *allocates* the *CPU* to one of them
- CPU scheduling decisions may take place when a process:
  1. Switches from running to waiting state. (eg I/O request)
  2. Switches from running to ready state. (eg timerunout)
  3. Switches from waiting to ready. (eg I/O finished interrupt)
  4. Terminates
- If scheduling takes place only under 1 and 4 :
  - The scheduling scheme is *nonpreemptive*
- Otherwise, *preemptive* scheduling scheme

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. (Mostly, context switch overhead)

Scheduling Criteria (Performance Index)

- ***CPU utilization*** : maximize
  - keep the *CPU as busy as possible*
- ***Throughput*** : maximize
  - *# of processes* that *complete* their execution per time unit
- ***Turnaround time*** : minimize
  - amount of time to *complete a particular process*
- ***Waiting time*** : minimize
  - sum of the periods spent *waiting in the ready queue*
- ***Response time*** : minimize
  - amount of time it takes *from when a request was submitted until the first response is produced*, **not** output (for time-sharing environment)

Scheduling Algorithms

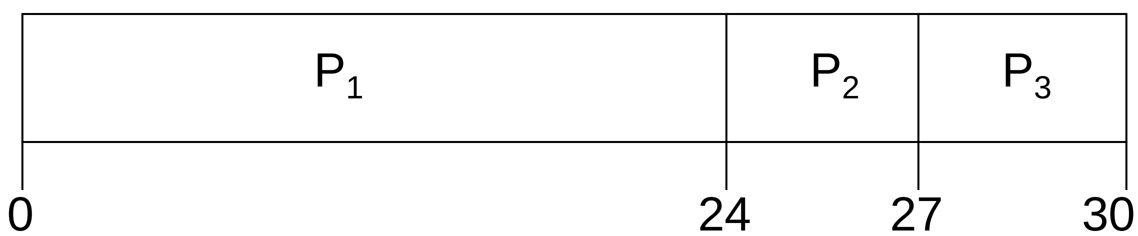
- FCFS (First-Come First-Served)
- SJF (Shortest-Job-First)
- SRTF (Shortest-Remaining-Time-First)
- Priority Scheduling
- RR (Round Robin)
- Multilevel Queue
- Multilevel Feedback Queue

FCFS Scheduling

- Example:

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 (FCFS is **nonpreemptive**):



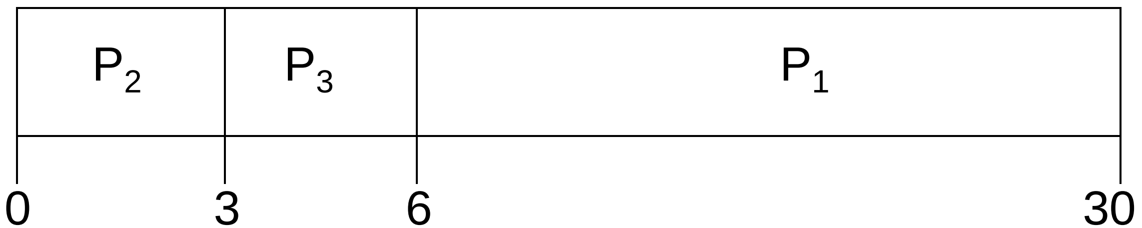
- Waiting time for P_1 = 0; P_2 = 24; P_3 = 27
- Average waiting time: (0 + 24 + 27)/3 = 17

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.
- ***<u>Convoy effect</u>*** : short process behind long process

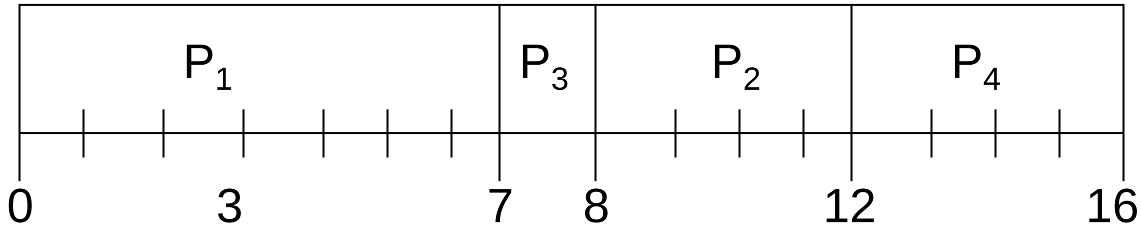
Shortest-Job-First (SJF) Scheduling

- Associate with each process *the length of its next CPU burst*
  - Use these lengths to schedule the process with the shortest time
- Two schemes:
  - ***Nonpreemptive***
    - Once CPU given to the process it cannot be preempted until completes its CPU burst
  - ***Preemptive***
    - If a new process arrives with CPU burst length less than remaining time of current executing process, preempt
    - This scheme is known as the Shortest-Remaining-Time-First (SRTF)
- SJF is optimal
  - Gives *minimum average waiting time* for a given 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)

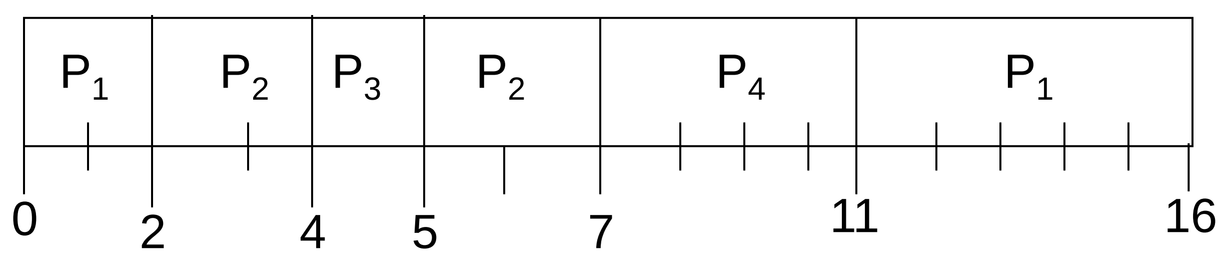


- Average waiting time = (0 + 6 + 3 + 7)/4 = 4

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) : SRTF



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

Determining Length of Next CPU Burst

- But how do you know the *length of next CPU burst?*

  (input data, branch, user …)

- Can only *estimate* the length

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

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

Examples of Exponential Averaging

- $\alpha = 0$
  - $\tau_{n+1} = \tau_n$
  - Recent history does not count.
- $\alpha = 1$
  - $\tau_{n+1} = t_n$
  - Only the actual last CPU burst counts.
- If we expand the formula, we get:

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

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

Examples of Exponential Averaging

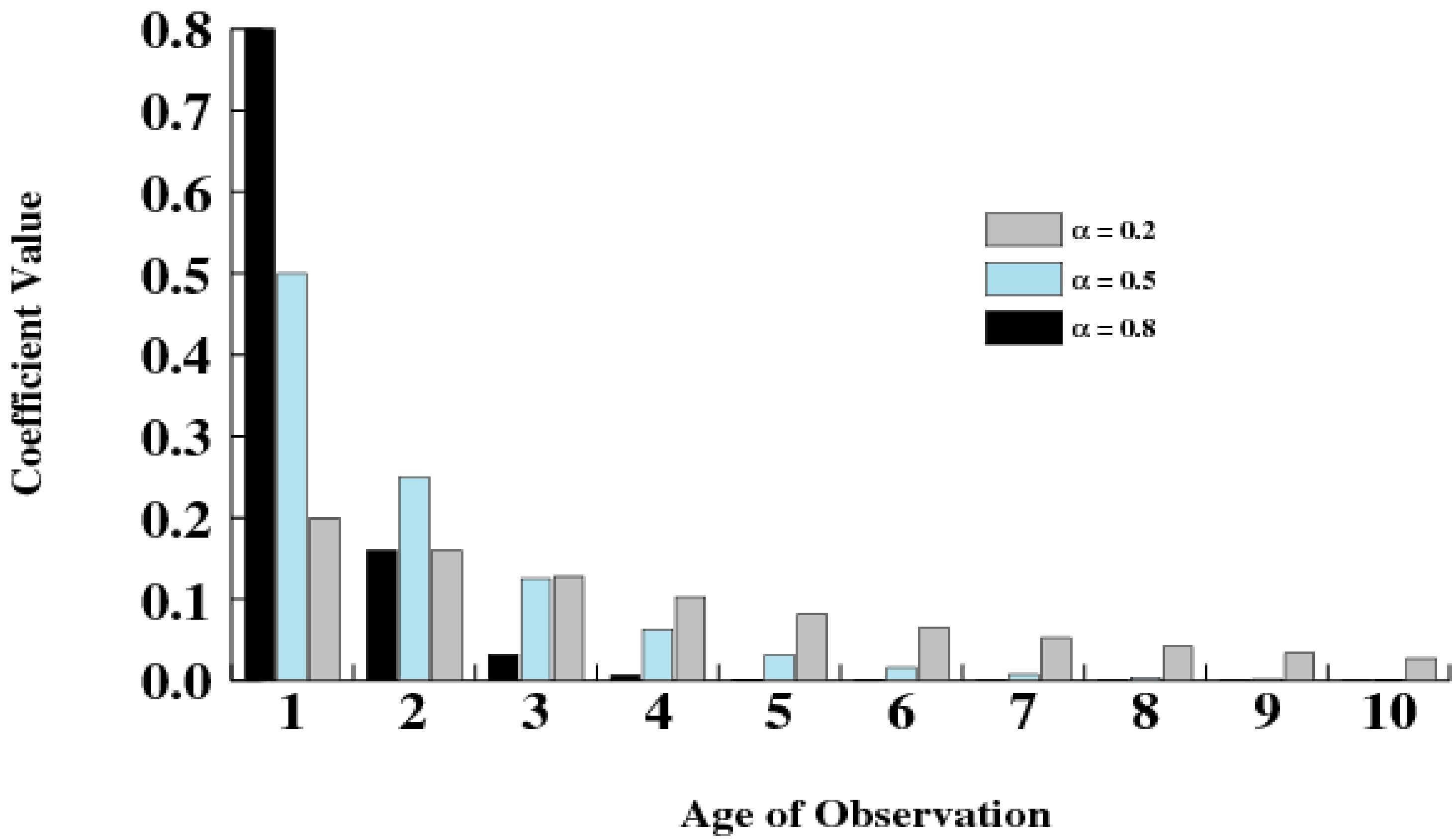
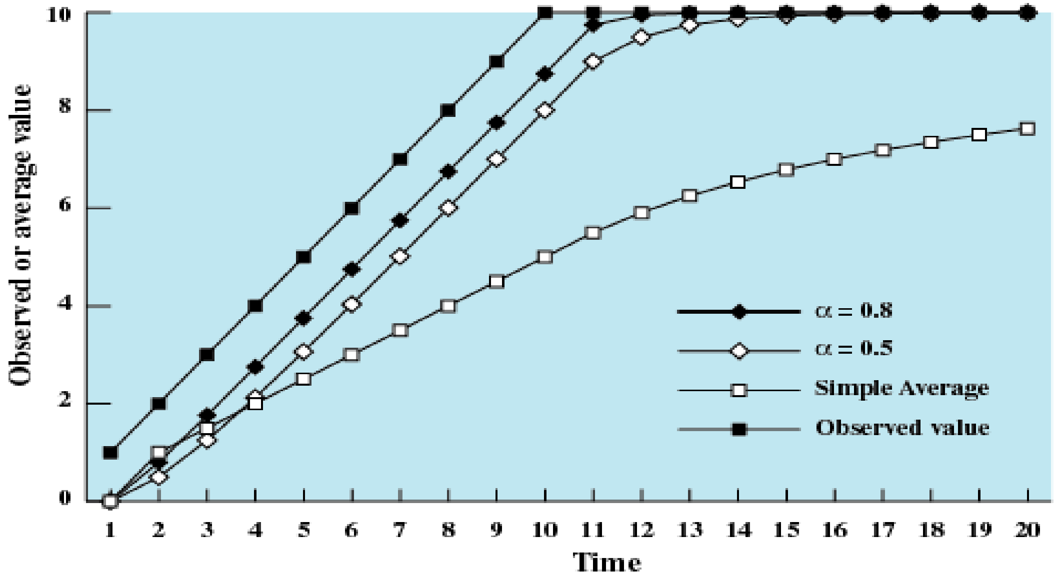
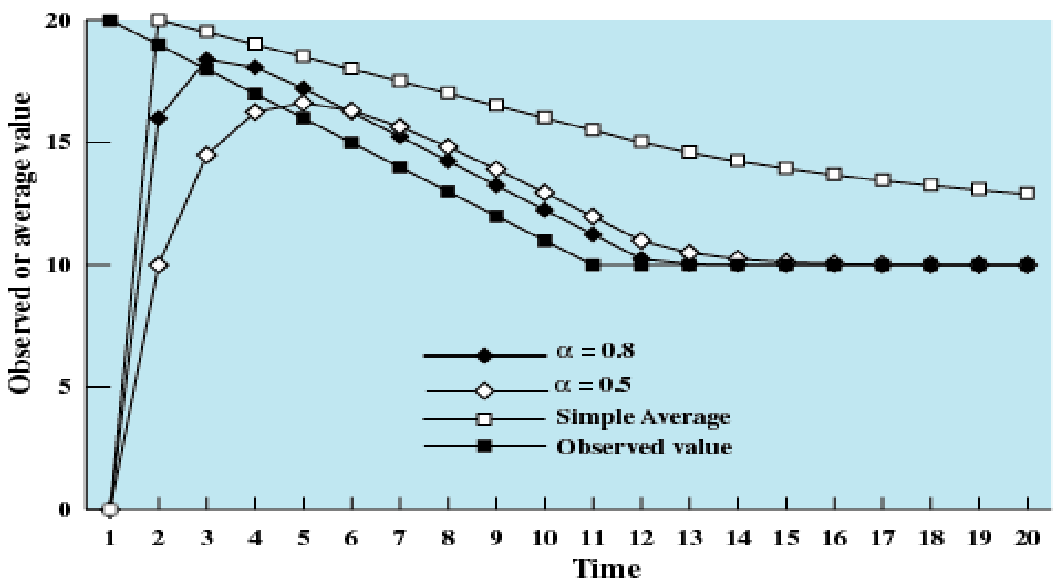


Figure 9.8 Exponential Smoothing Coefficients



(a) Increasing function



(b) Decreasing function

Figure 9.9 Use of Exponential Averaging

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 a priority scheduling where

  priority is the 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 gets a small unit of CPU time (***time quantum***)
  - 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 sec***, then each process gets 1/*n* of the CPU time in chunks of at most *q* sec at once

  $\Rightarrow$ *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: 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

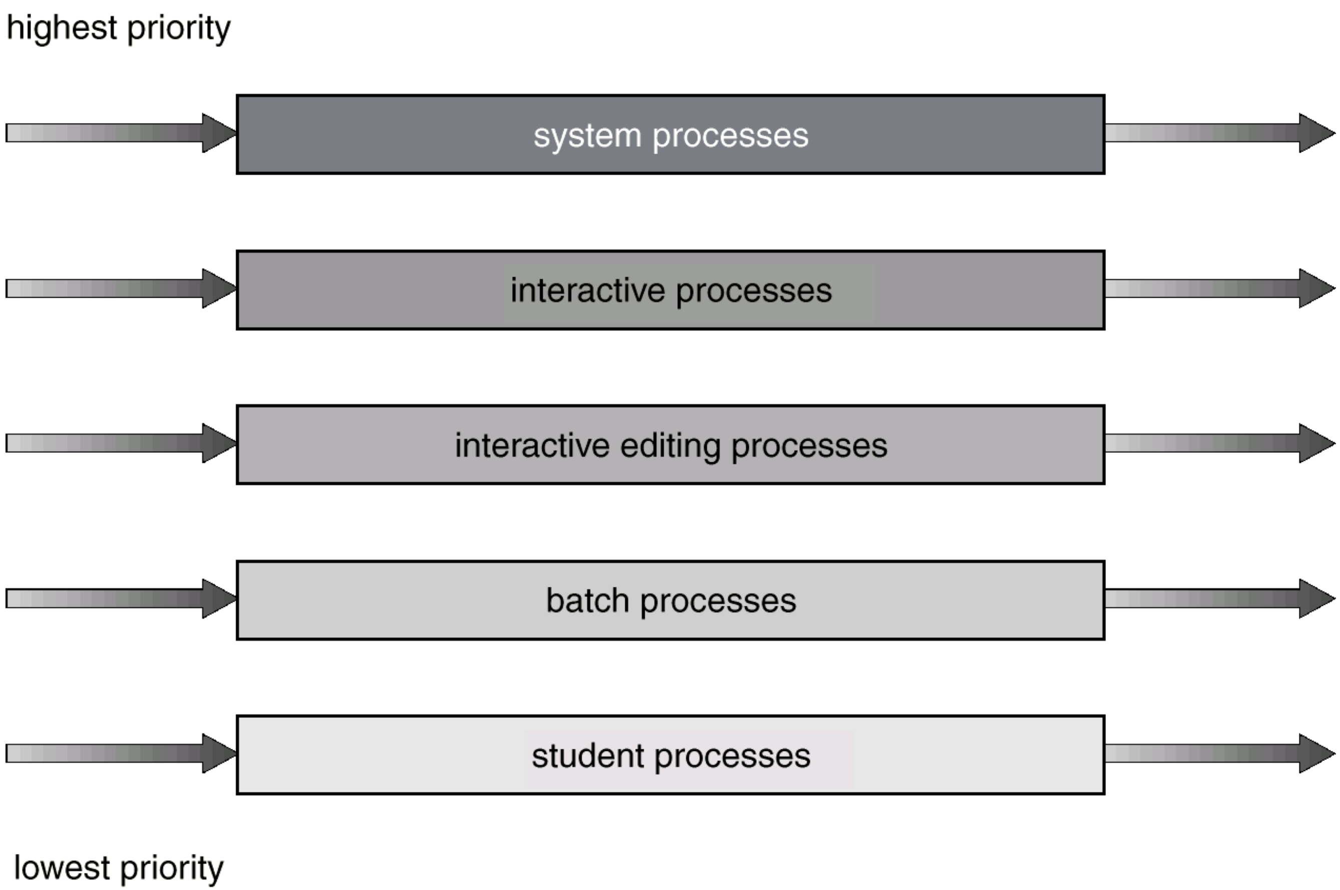
0 20 37 57 77 97 117 121 134 154 162

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

Multilevel Queue

- Ready queue is partitioned into separate queues:
  - ***foreground*** ***(interactive)***
  - ***background*** ***(batch – no human interaction)***
- Each queue has its own scheduling algorithm
  - ***foreground*** – **RR**
  - ***background*** – **FCFS**
- Scheduling must be done between the queues.
  - **Fixed priority scheduling**
    - 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
    - Eg., *80% to foreground in RR*, *20% to background in FCFS*

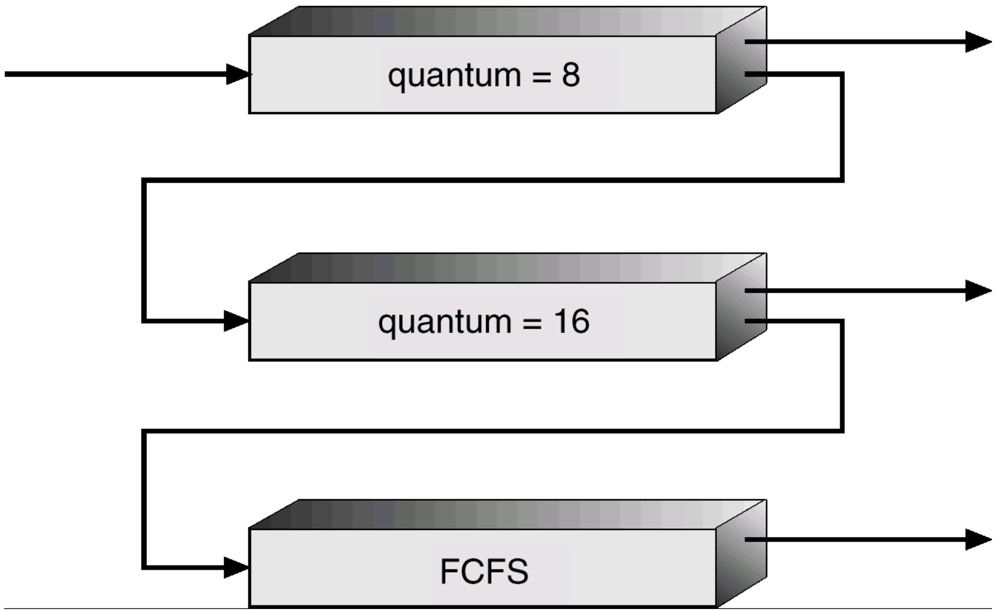
Multilevel Queue Scheduling



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

Example of Multilevel Feedback Queue



- Three queues:
  - Q_0 – time quantum 8 ms
  - Q_1 – time quantum 16 ms
  - 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 ms
  - If it still does not complete, it is preempted and moved to queue Q_2

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