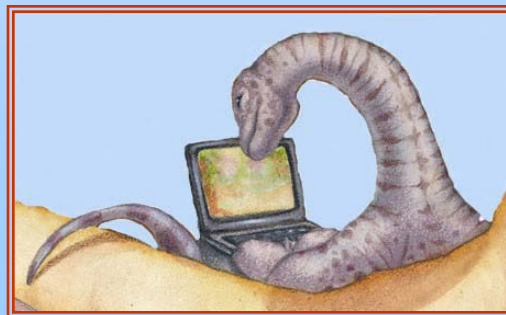# Chapter 5: CPU Scheduling

Chapter 5: CPU Scheduling

- Basic Concepts

- Scheduling Criteria

- Scheduling Algorithms

- Multiple-Processor Scheduling

- Real-Time Scheduling

- Thread Scheduling

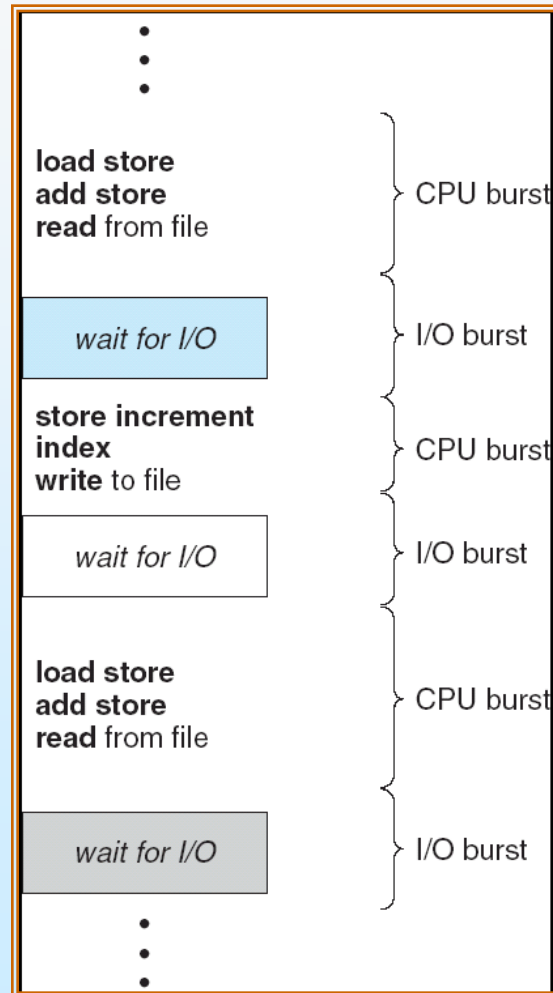- Linux Example

- Algorithm Evaluation

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
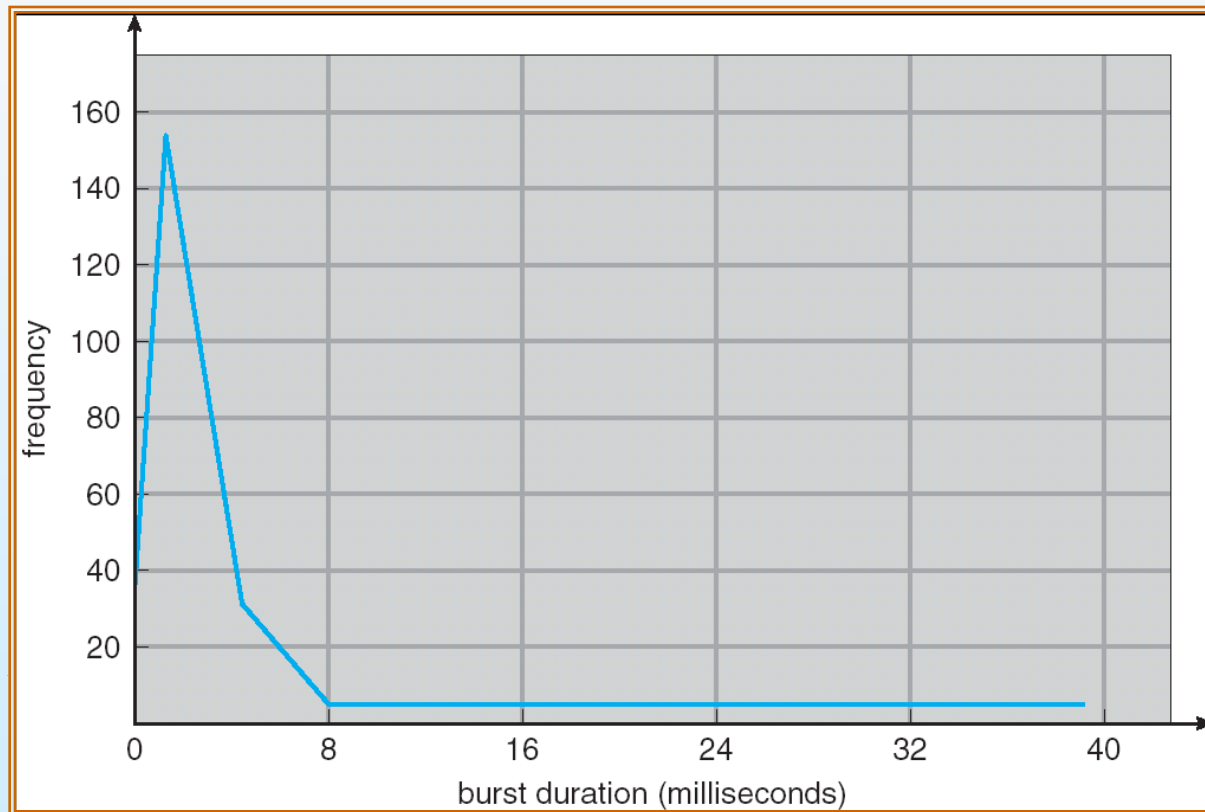
- CPU burst distribution

Histogram of CPU-burst Times

CPU Scheduler

- Selects from among the 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

    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*

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)

Optimization Criteria

- Max CPU utilization

- Max throughput

- Min turnaround time

- Min waiting time

- Min response time

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:

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

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 know as the Shortest-Remaining-Time-First (SRTF)

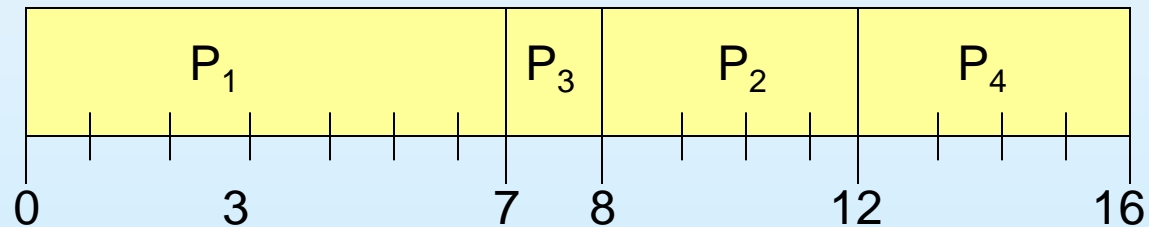- SJF is optimal – gives minimum average waiting time for a given set of processes

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)

P$_1$	P$_3$	P$_2$	P$_4$

0   3   7 8   12   16

- 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)

P_1	P_2	P_3	P_2	P_4	P_1

0   2   4   5   7   11   16
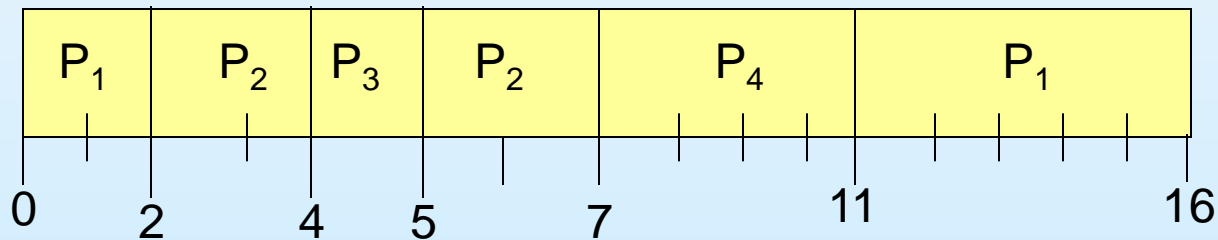
- Average waiting time = (9 + 1 + 0 +2)/4 = 3
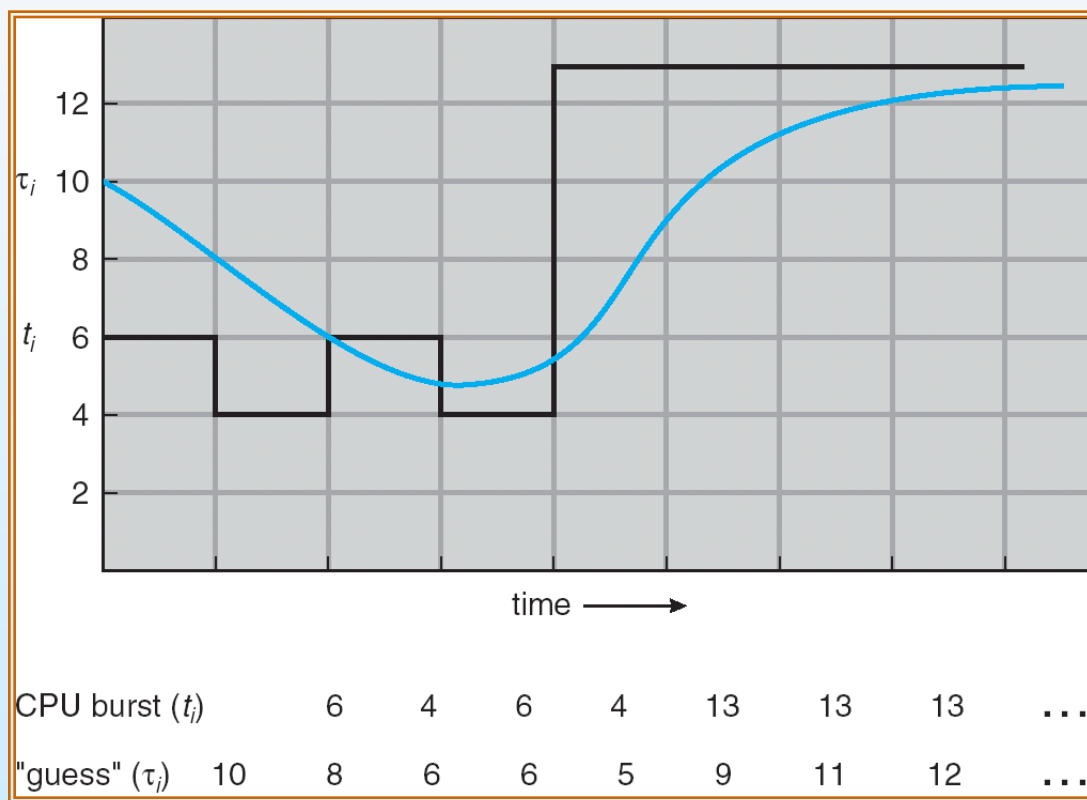
Determining Length of Next CPU Burst

- Can only estimate the length

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

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

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

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

$\alpha = \frac{1}{2}$ and $\tau_0 = 10$

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

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 algorithm where priority is the 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

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, 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.

- Performance

    - q large $\Rightarrow$ FIFO

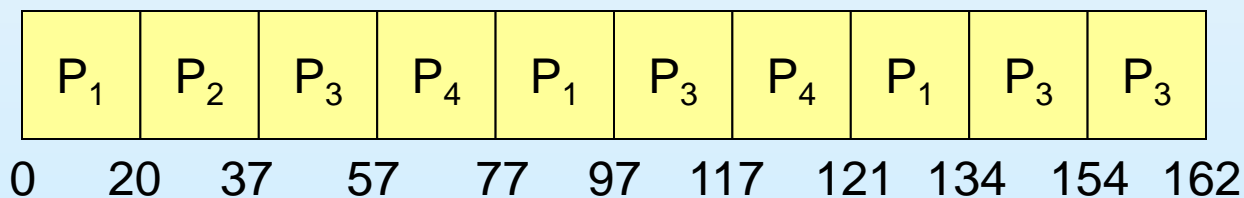   - q small $\Rightarrow q$ must be large with respect to context switch, otherwise overhead is too high

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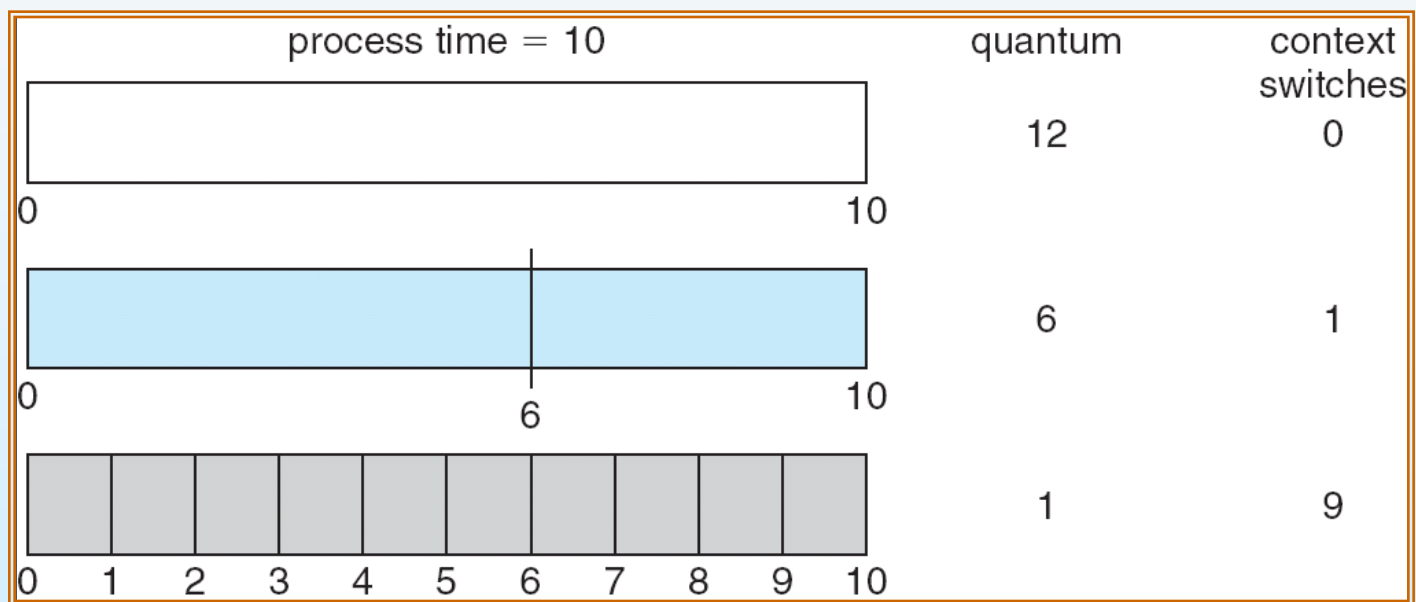
- Typically, higher average turnaround than SJF, but better *response*

Time Quantum and Context Switch Time

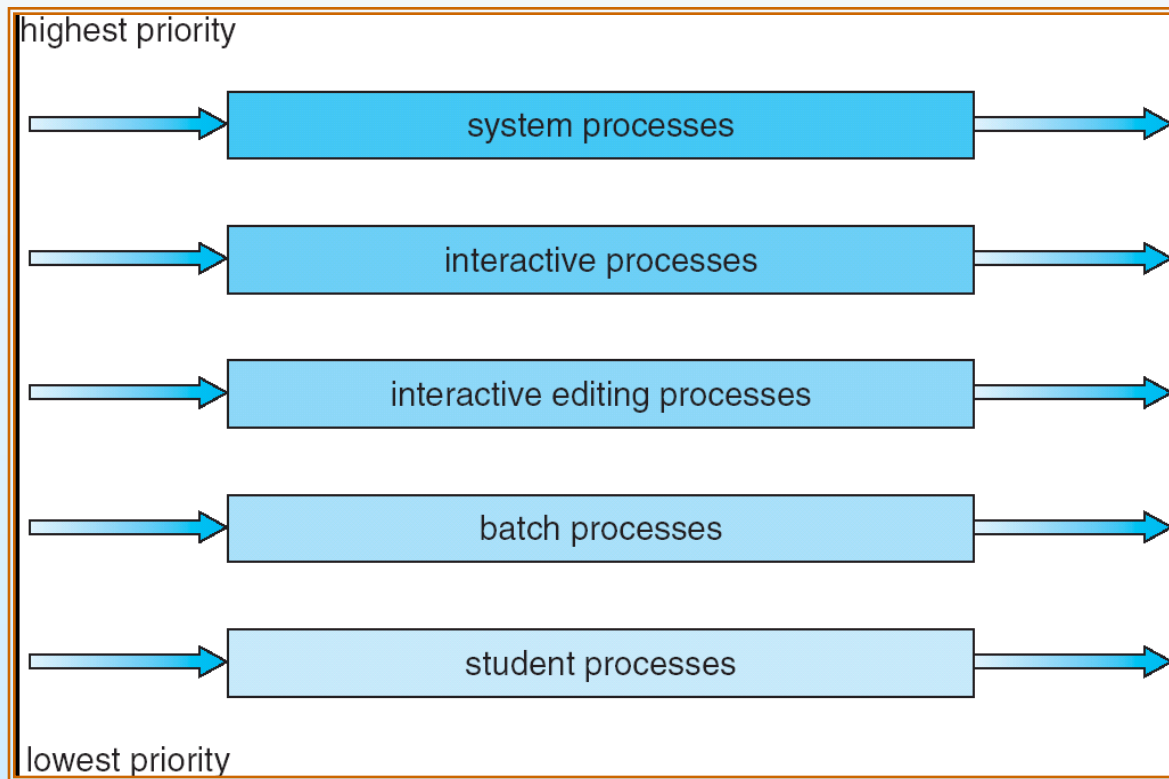| process	time
P_1	6
P_2	3
P_3	1
P_4	7
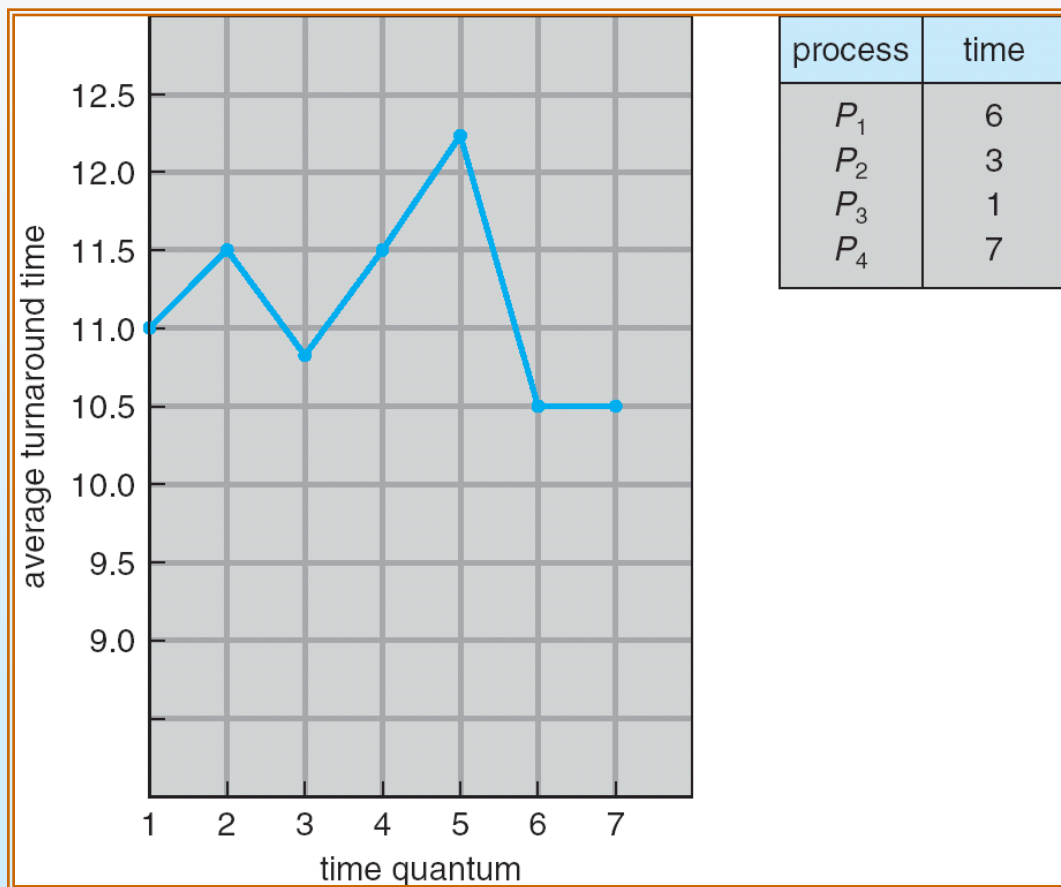
Multilevel Queue

- Ready queue is 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 from background). Possibility of starvation for background processes.

  - Time slice – each queue gets a certain amount of CPU time which it can schedule amongst its processes; e.g.

    - 80% to foreground in RR

    - 20% to background in FCFS

Multilevel Queue Scheduling

highest priority

- system processes
- interactive processes
- interactive editing processes
- batch processes
- student processes

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 promote 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

quantum = 8

quantum = 16

FCFS
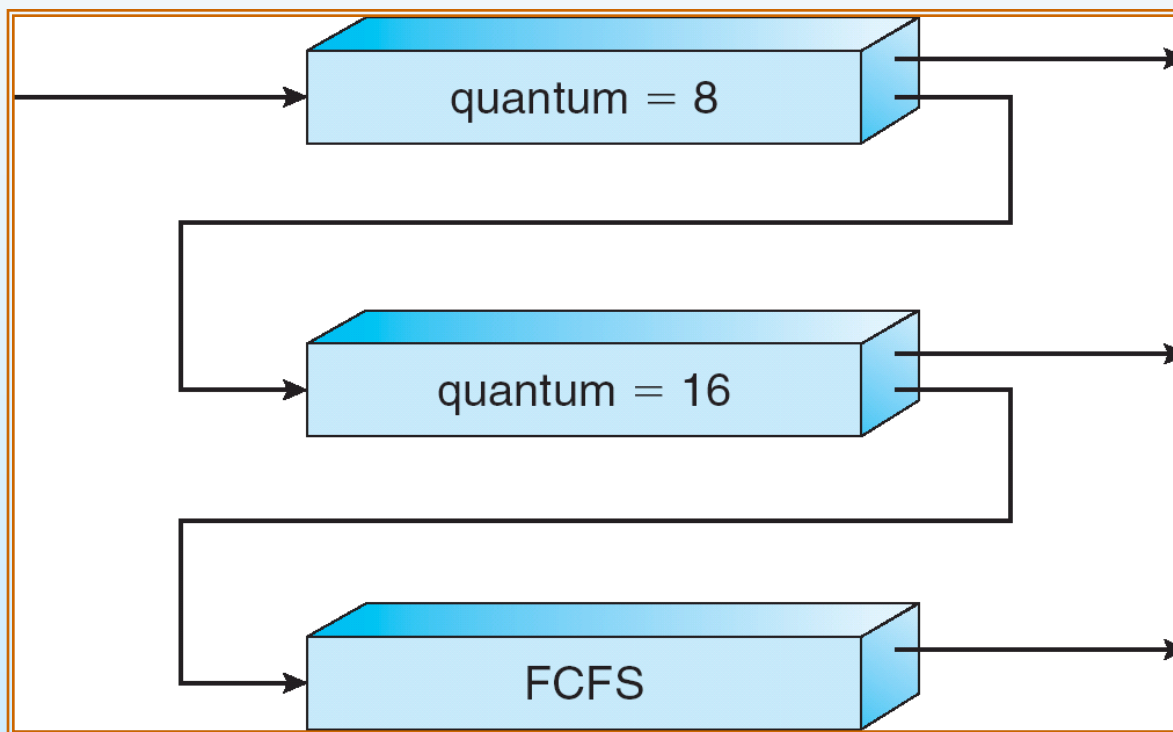
Multiple-Processor Scheduling

- CPU scheduling more complex when multiple CPUs are available

- *Homogeneous processors* within a multiprocessor

- *Load sharing*

- *Asymmetric multiprocessing* – only one processor accesses the system data structures, alleviating the need for 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 critical ones

Thread Scheduling

- Local Scheduling – How the threads library decides which thread to put onto an available kernel thread

- Global Scheduling – How the kernel decides which kernel thread to run next

Linux Scheduling

- Two algorithms: time-sharing and real-time

- Time-sharing

  - Prioritized credit-based – process with most credits is scheduled next

  - Credit subtracted when timer interrupt occurs

  - When credit = 0, another process chosen

  - When all processes have credit = 0, recrediting occurs

    - Based on factors including priority and history

- Real-time

  - Soft real-time

  - Posix.1b compliant – two classes

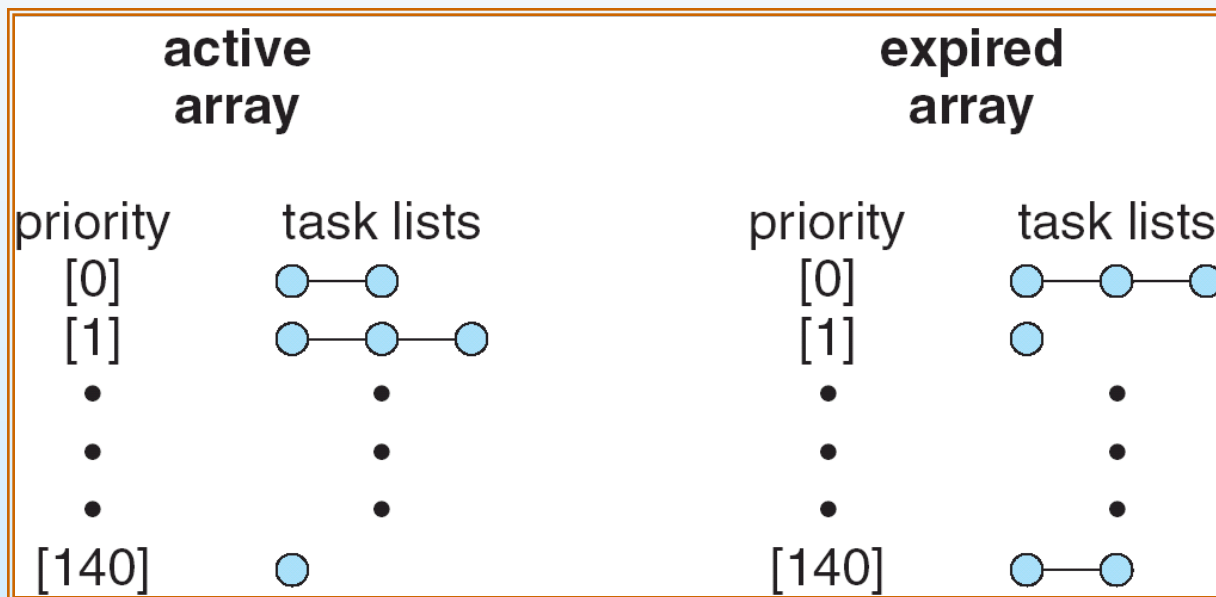   - FCFS and RR

    - Highest priority process always runs first

numeric priority	relative priority		time quantum
0	highest	real-time tasks	200 ms
•			
•			
•			
99			
100		other tasks	
•			
•			
•			
140	lowest		10 ms

Algorithm Evaluation

- Deterministic modeling – takes a particular predetermined workload and defines the performance of each algorithm for that workload

- Queueing models

- Implementation

Evaluation of CPU schedulers by simulation