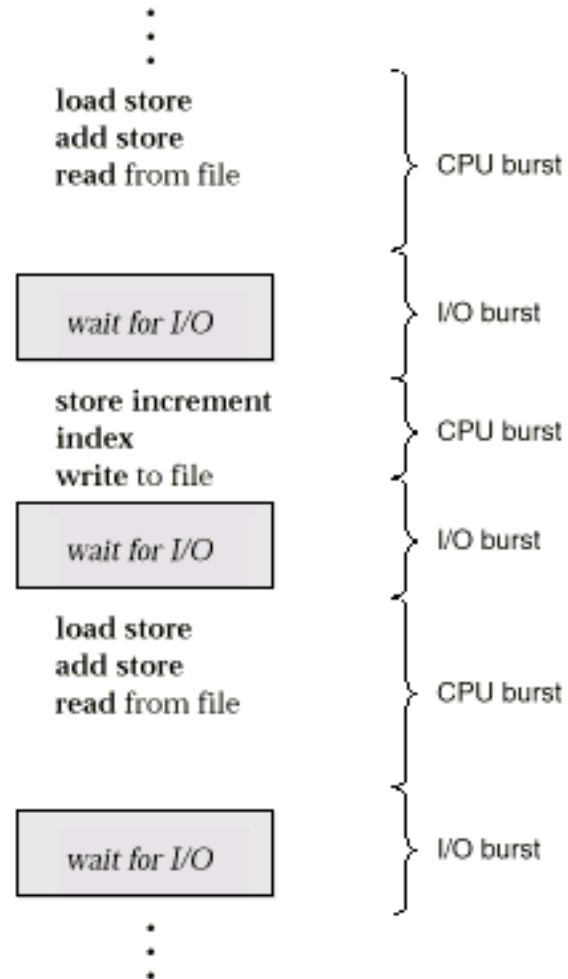# Module 6: CPU Scheduling

- Basic Concepts

- Scheduling Criteria

- Scheduling Algorithms

- Multiple-Processor Scheduling
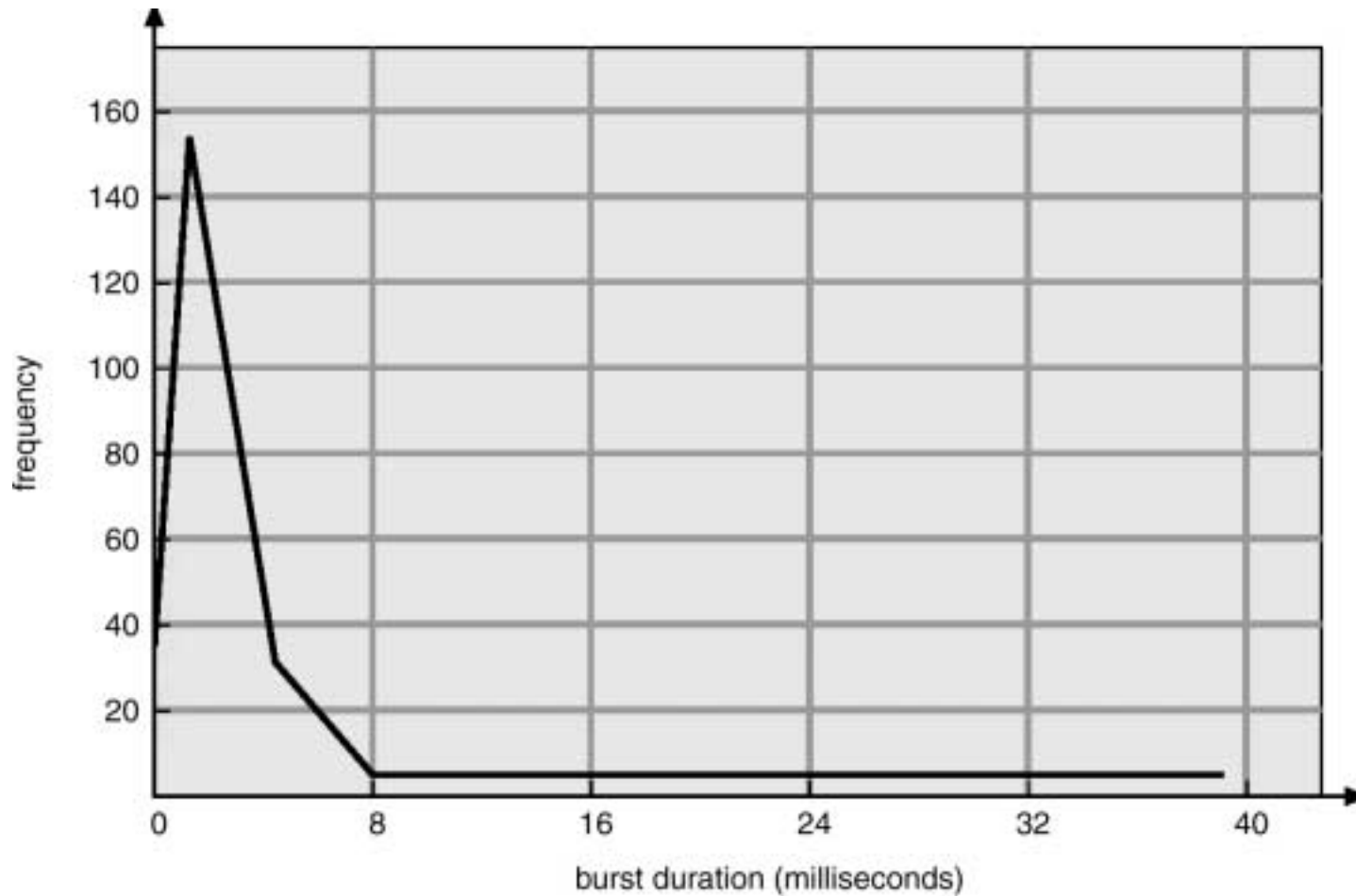
- Real-Time Scheduling

- 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

Alternating Sequence of CPU And I/O Bursts

```
        .
        .
        .
load store
add store          } CPU burst
read from file

┌─────────────┐
│ wait for I/O │    } I/O burst
└─────────────┘

store increment
index              } CPU burst
write to file

┌─────────────┐
│ wait for I/O │    } I/O burst
└─────────────┘

load store
add store          } CPU burst
read from file

┌─────────────┐
│ wait for I/O │    } I/O burst
└─────────────┘
        .
        .
        .
```

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.*

6.5

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 wiating 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

- 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:

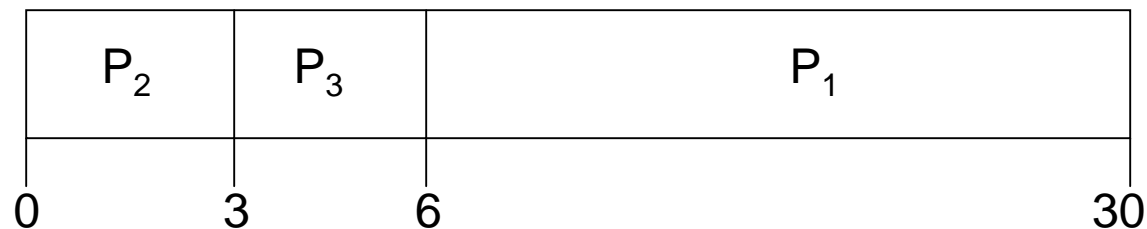| P_1	P_2	P_3

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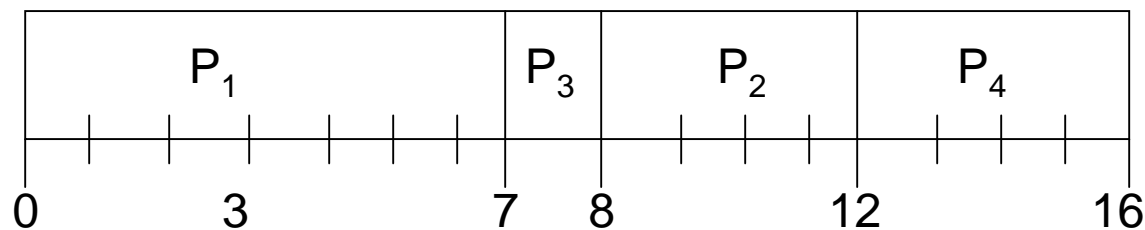
- Average waiting time = (0 + 6 + 3 + 7)/4 - 4

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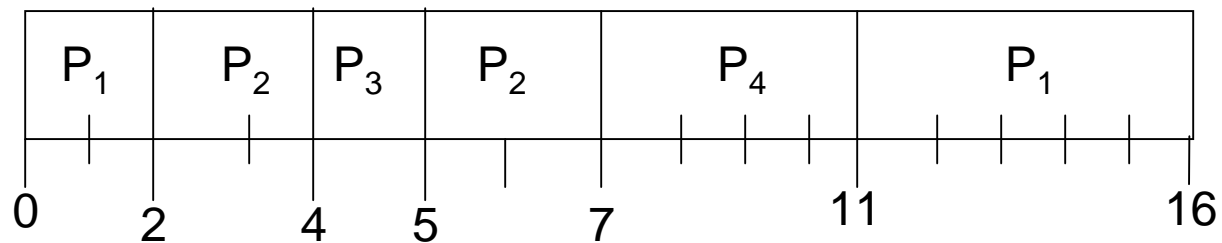
- Average waiting time = (9 + 1 + 0 +2)/4 - 3

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 lenght of nth CPU burst
  2. $\tau_{n+1} = $ predicted value for the next CPU burst
  3. $\alpha, 0 \le \alpha \le 1$
  4. Define :

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

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:

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

- 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 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.
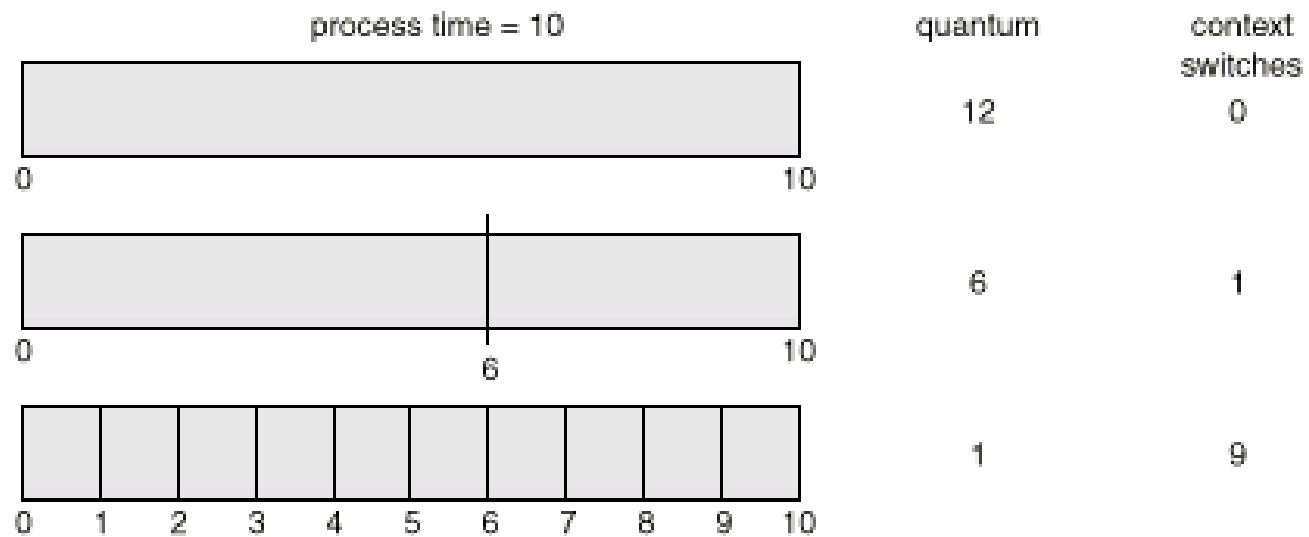
6.17

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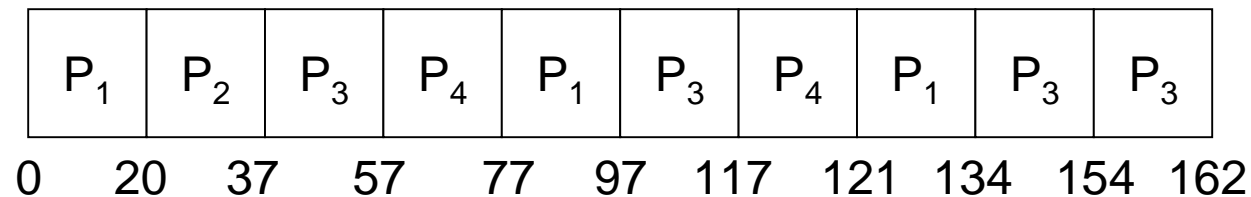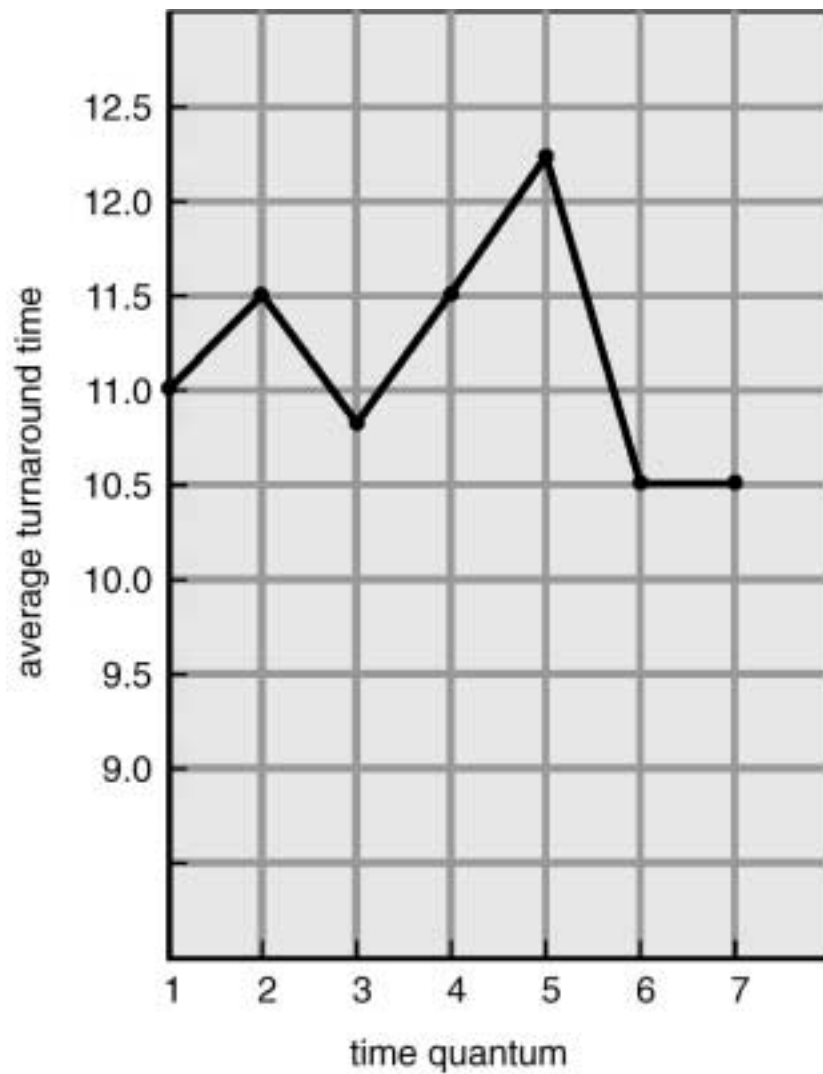
- Typically, higher average turnaround than SJF, but better *response*.

How a Smaller Time Quantum Increases Context Switches

process time = 10

quantum	context switches
12	0
6	1
1	9

Turnaround Time Varies With The Time Quantum

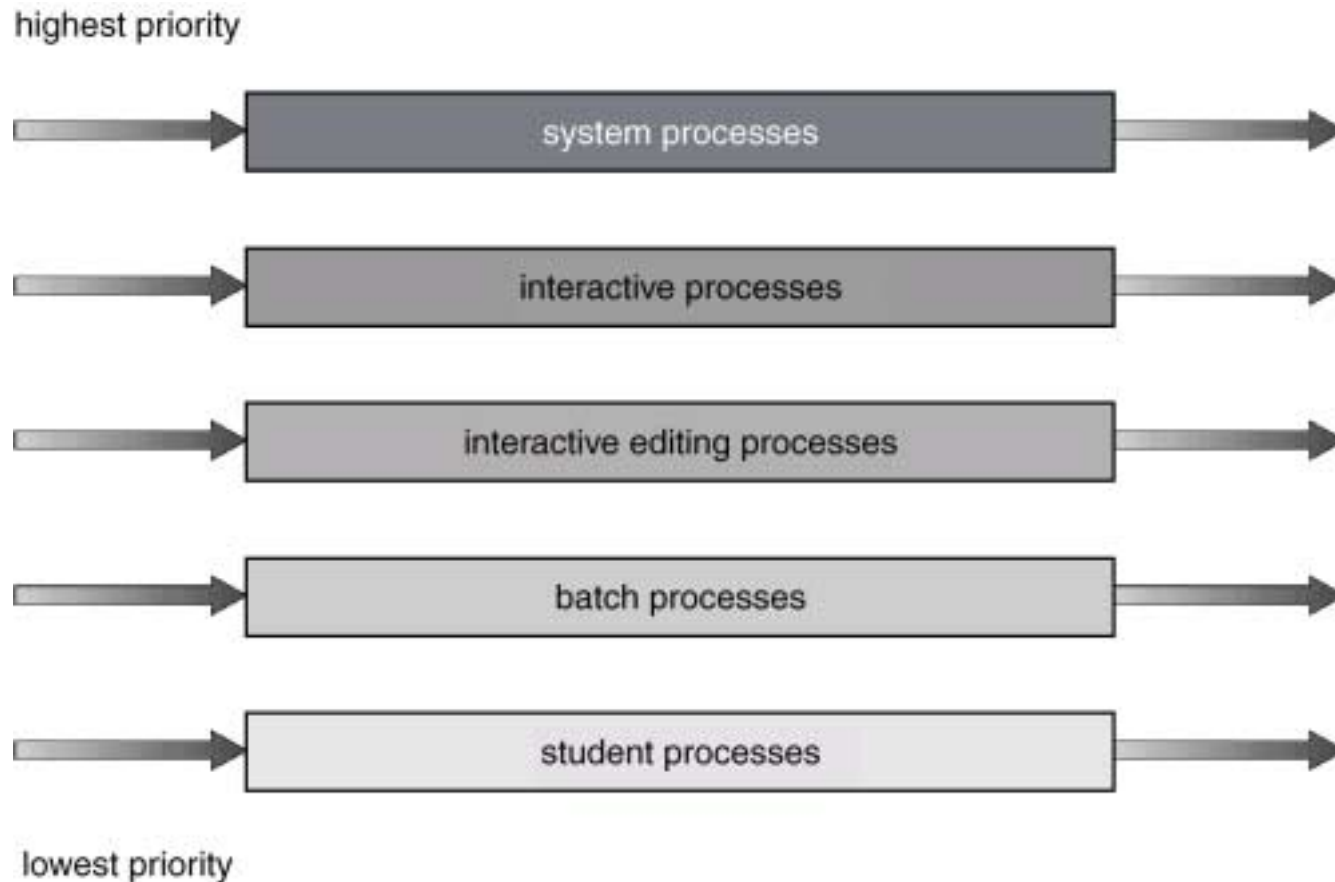| process	time
P_1	6
P_2	3
P_3	1
P_4	7

Multilevel Queue

- Ready queue 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.
  - 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

```
         ┌──────────────────────────────┐
────────▶│      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 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

Multilevel Feedback Queues

quantum = 8
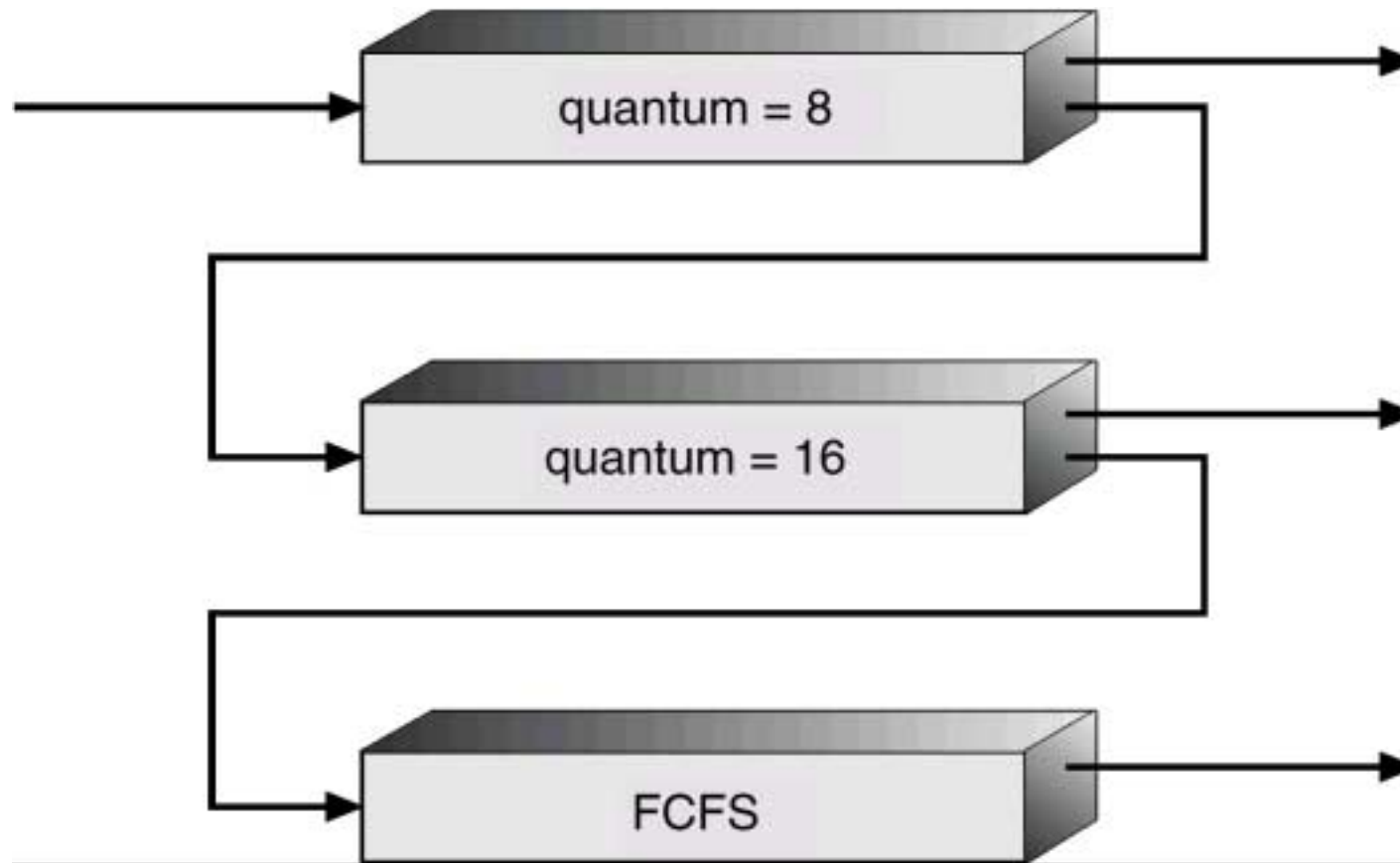
quantum = 16

FCFS

Example of Multilevel Feedback Queue

- Three queues:
  - Q_0 – time quantum 8 milliseconds
  - Q_1 – 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.

Multiple-Processor Scheduling

- CPU scheduling more complex when multiple CPUs are available.

- *Homogeneous processors* within a multiprocessor.

- *Load sharing*

- *Symmetric Multiprocessing (SMP)* – each processor makes its own scheduling decisions.

- *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 fortunate ones.
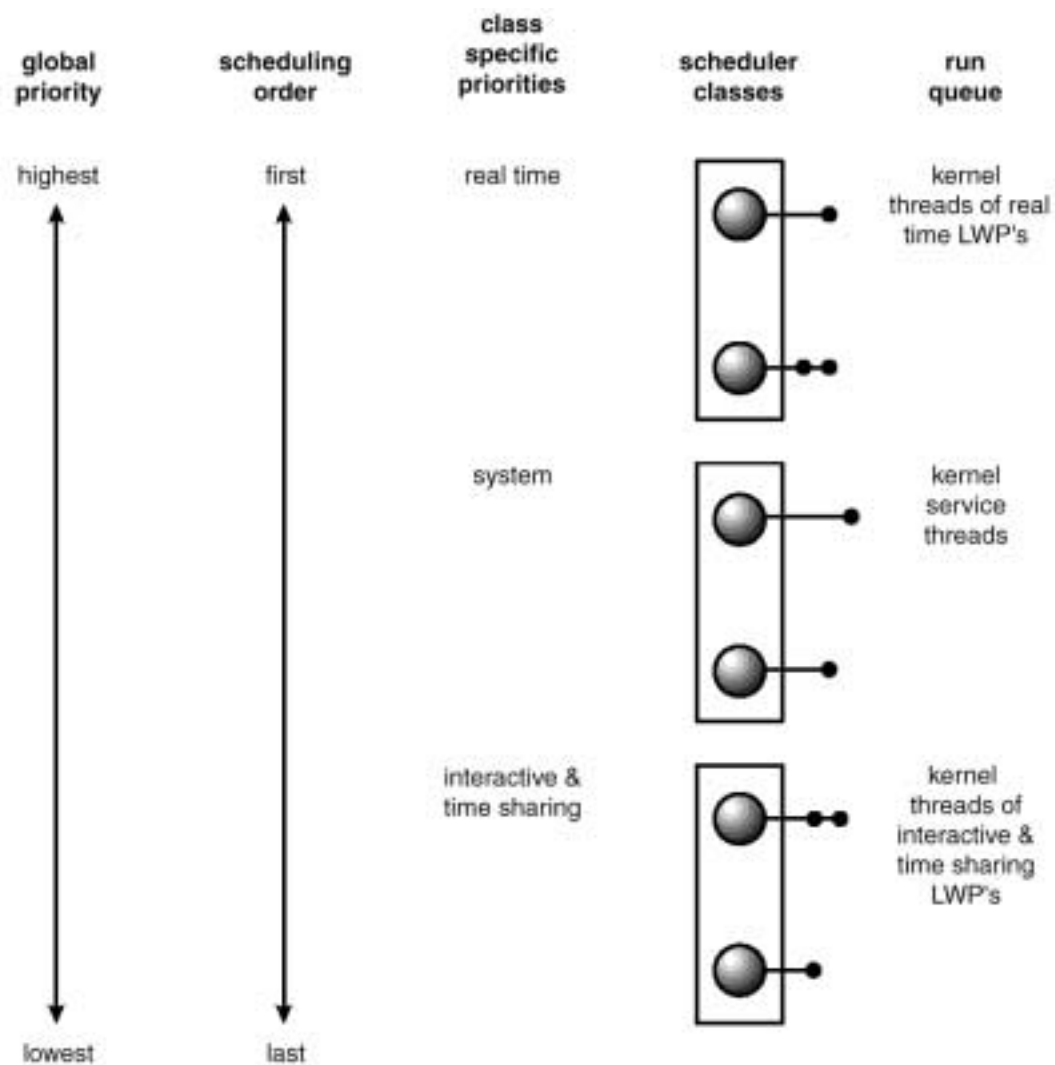
Dispatch Latency
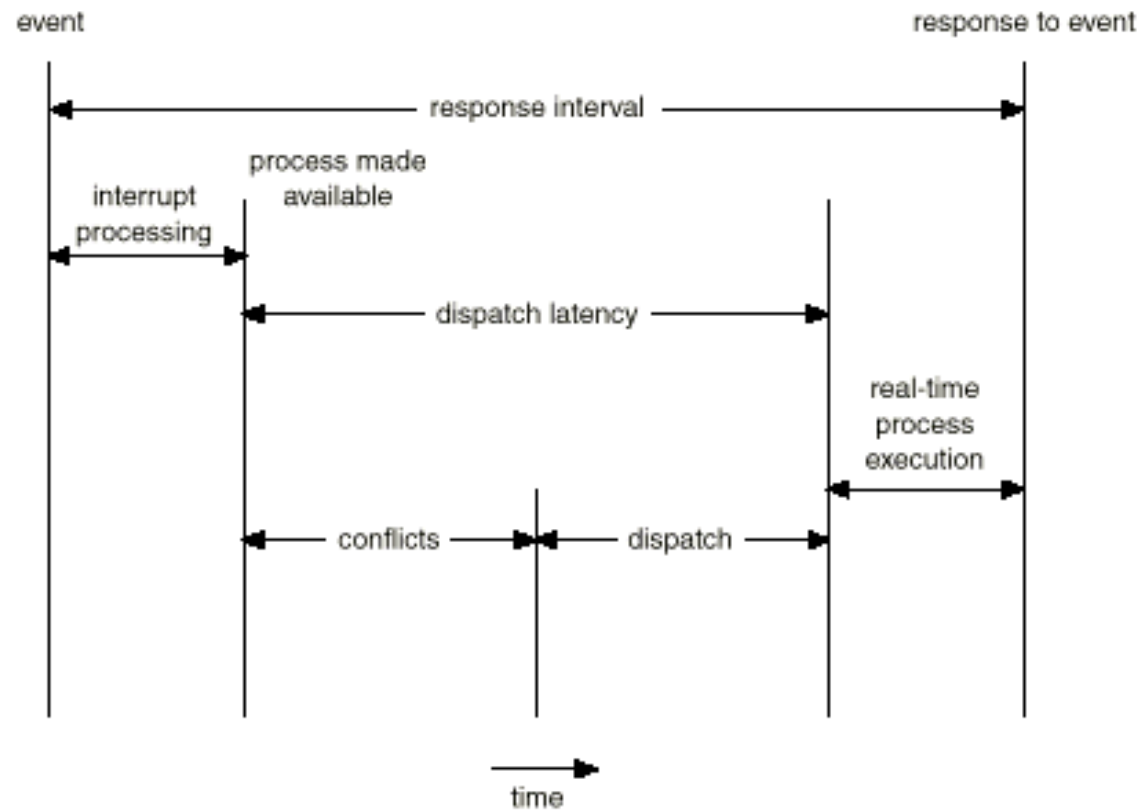
Thread Scheduling

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

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

Solaris 2 Scheduling

global priority	scheduling order	class specific priorities	scheduler classes	run queue
highest	first	real time		kernel threads of real time LWP's
		system		kernel service threads
		interactive & time sharing		kernel threads of interactive & time sharing LWP's
lowest	last			

Java Thread Scheduling

- JVM Uses a Preemptive, Priority-Based Scheduling Algorithm.

- FIFO Queue is Used if There Are Multiple Threads With the Same Priority.

Java Thread Scheduling (cont)

JVM Schedules a Thread to Run When:

- The Currently Running Thread Exits the Runnable State.

- A Higher Priority Thread Enters the Runnable State

* Note – the JVM Does Not Specify Whether Threads are Time-Sliced or Not.

Time-Slicing

- Since the JVM Doesn't Ensure Time-Slicing, the yield() Method May Be Used:

  while (true) {

      // perform CPU-intensive task

      . . .

      Thread.yield();

  }

  This Yields Control to Another Thread of Equal Priority.

Thread Priorities

- Thread Priorities:

Priority   **Comment**

Thread.MIN_PRIORITY   Minimum Thread Priority

Thread.MAX_PRIORITY   Maximum Thread Priority

Thread.NORM_PRIORITY   Default Thread Priority

Priorities May Be Set Using setPriority() method:

   setPriority(Thread.NORM_PRIORITY + 2);

Algorithm Evaluation

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

- Queuing models

- Implementation

Evaluation of CPU Schedulers by Simulation