Chapter 5: CPU Scheduling

Chapter 5: CPU Scheduling

- Basic Concepts
- Scheduling Criteria
- Scheduling Algorithms
- Thread Scheduling
- Multiple-Processor Scheduling
- Operating Systems Examples
- Algorithm Evaluation

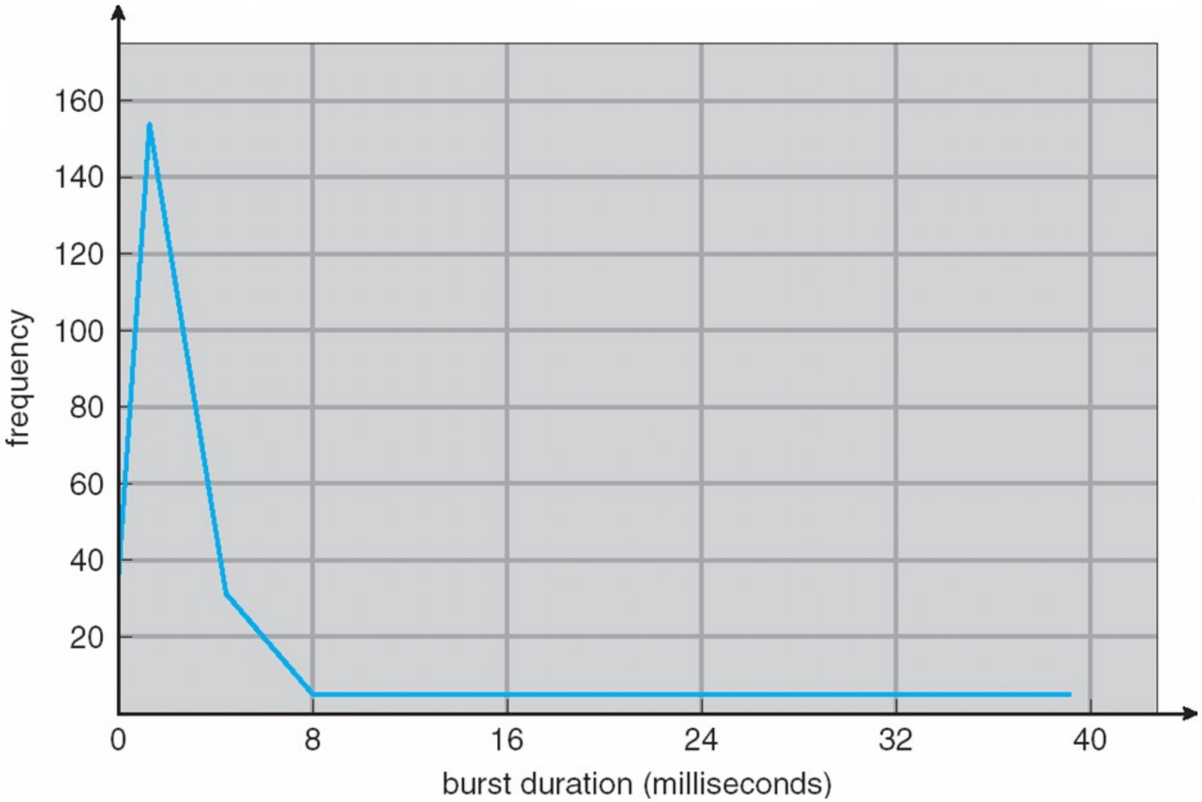
Objectives

- To introduce CPU scheduling, which is the basis for multiprogrammed operating systems
- To describe various CPU-scheduling algorithms
- To discuss evaluation criteria for selecting a CPU-scheduling algorithm for a particular system

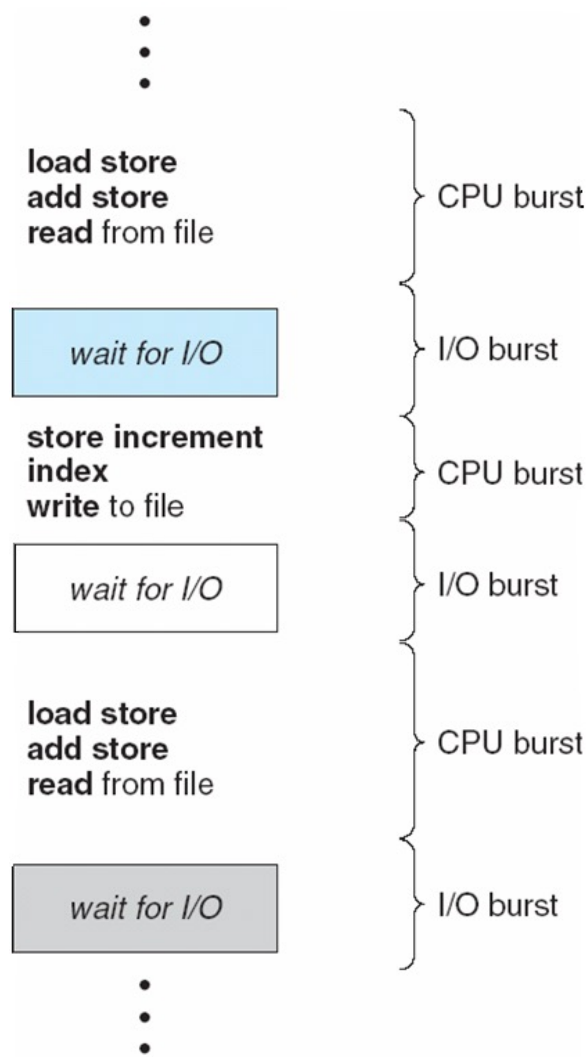
Basic Concepts

- Maximum CPU utilization obtained with multiprogramming
- CPU–I/O Burst Cycle – Process execution consists of a *cycle* of CPU execution and I/O wait (I/O burst)
- **CPU burst** distribution
  - An I/O bound program typically has many short CPU bursts.
  - A CPU-bound program might have a few long CUP bursts.
  - The distribution is important in selecting CPU-scheduling algorithm.

Histogram of CPU-burst Times



Alternating Sequence of CPU And I/O Bursts



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** (there is no choice in terms of scheduling)
- 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)

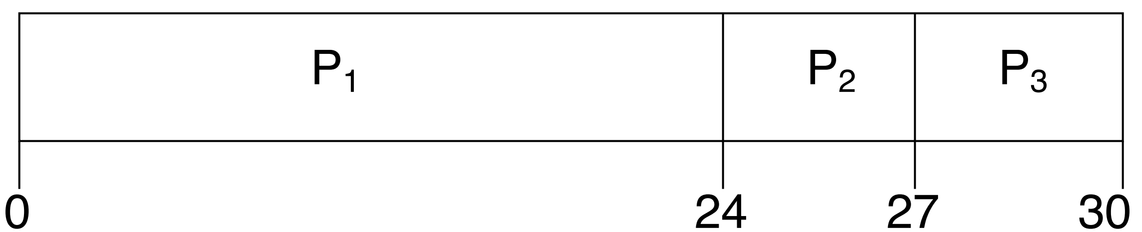
Scheduling Algorithm Optimization Criteria

- 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:



- 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 ready queue 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

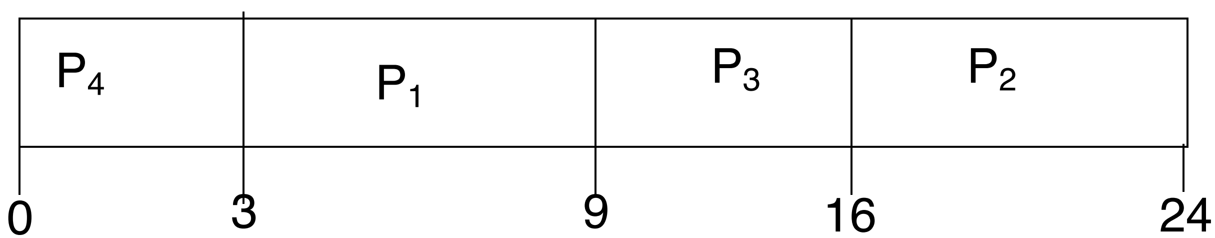
Shortest-Job-First (SJF) Scheduling

- 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

Example of SJF

Process	Arrival Time	Burst Time
P_1	0.0	6
P_2	2.0	8
P_3	4.0	7
P_4	5.0	3

- SJF scheduling chart



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

Determining Length of Next CPU Burst

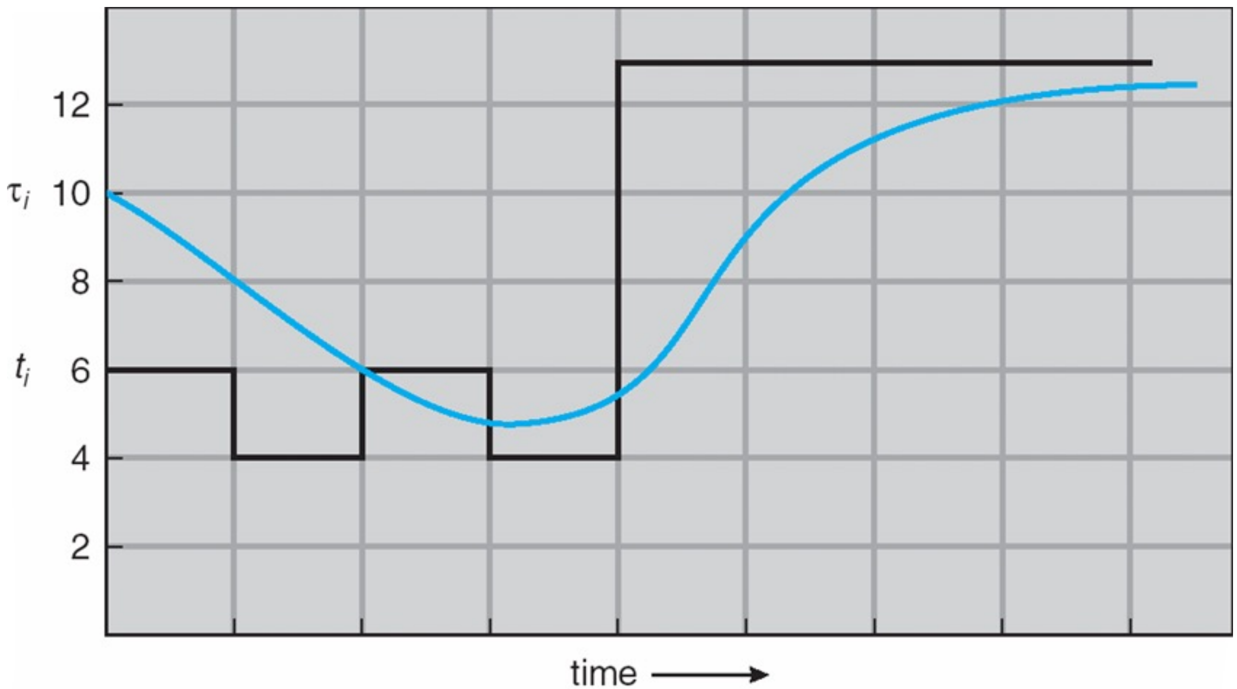
- Can only estimate the length
- Can be done by using the length of previous CPU bursts, using exponential averaging

1. $t_n =$ actual length of n^{th} CPU burst, most recent information
2. $\tau_{n+1} =$ predicted value for the next CPU burst
3. τ_n
4. $\alpha, 0 \le \alpha \le 1$
5. Define: $\tau_{n+1} = \alpha\, t_n + (1-\alpha)\tau_n$

Most recent info

Stores Past history

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:

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

- 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 ≡ 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, 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 = 4

Process	Burst Time
P_1	24
P_2	3
P_3	3

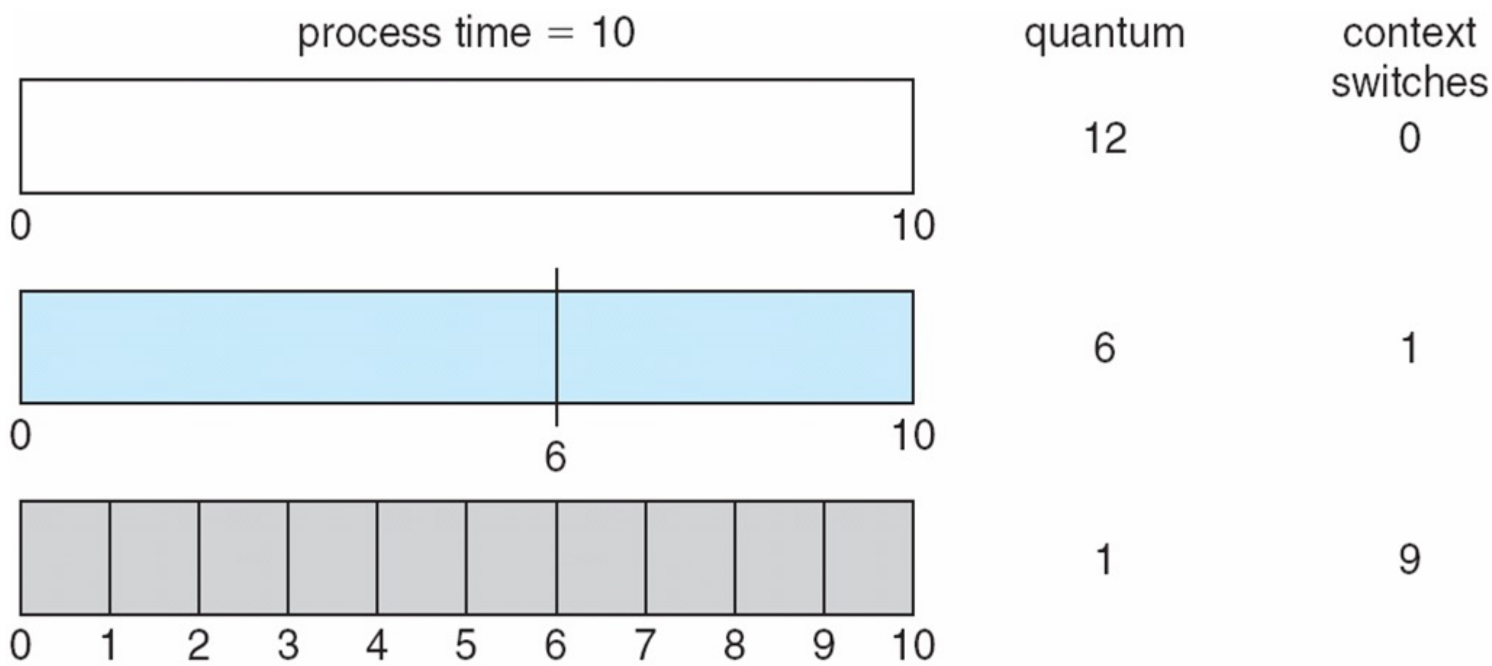
- The Gantt chart is:

P_1	P_2	P_3	P_1	P_1	P_1	P_1	P_1

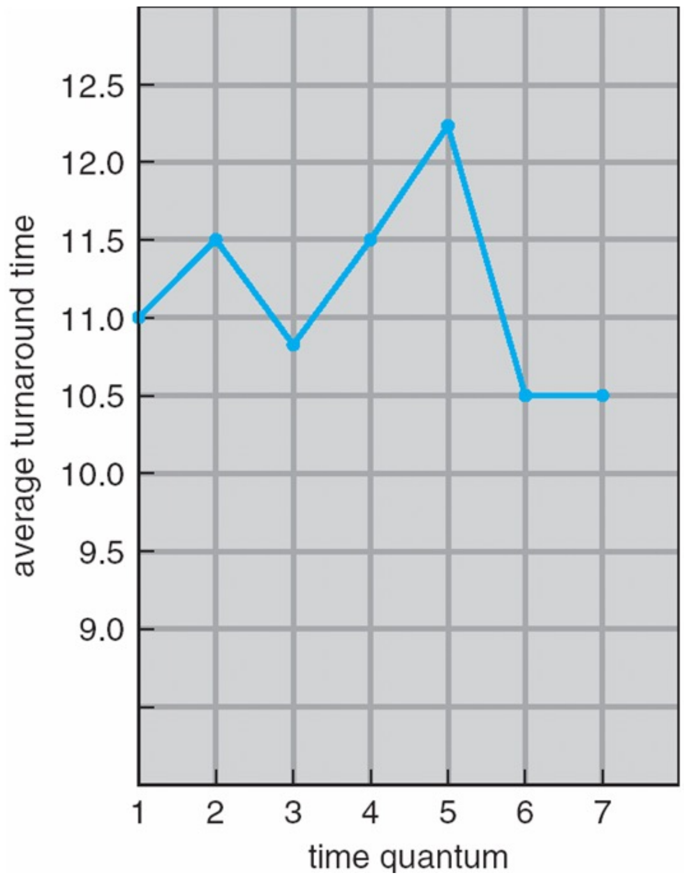
0 4 7 10 14 18 22 26 30

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

Time Quantum and Context Switch Time



Turnaround Time Varies With The Time Quantum

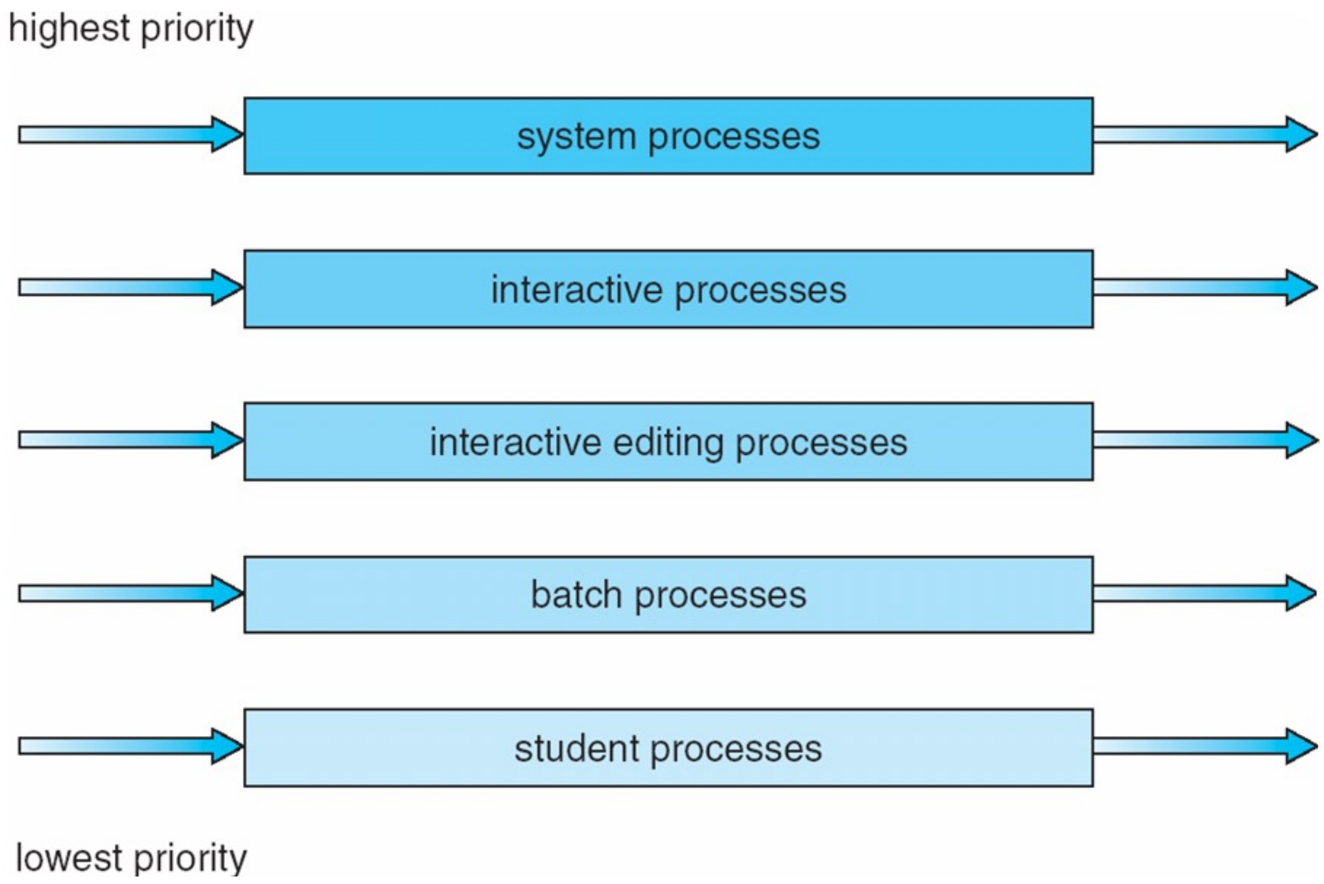


process	time
P_1	6
P_2	3
P_3	1
P_4	7

Multilevel Queue

- Ready queue 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



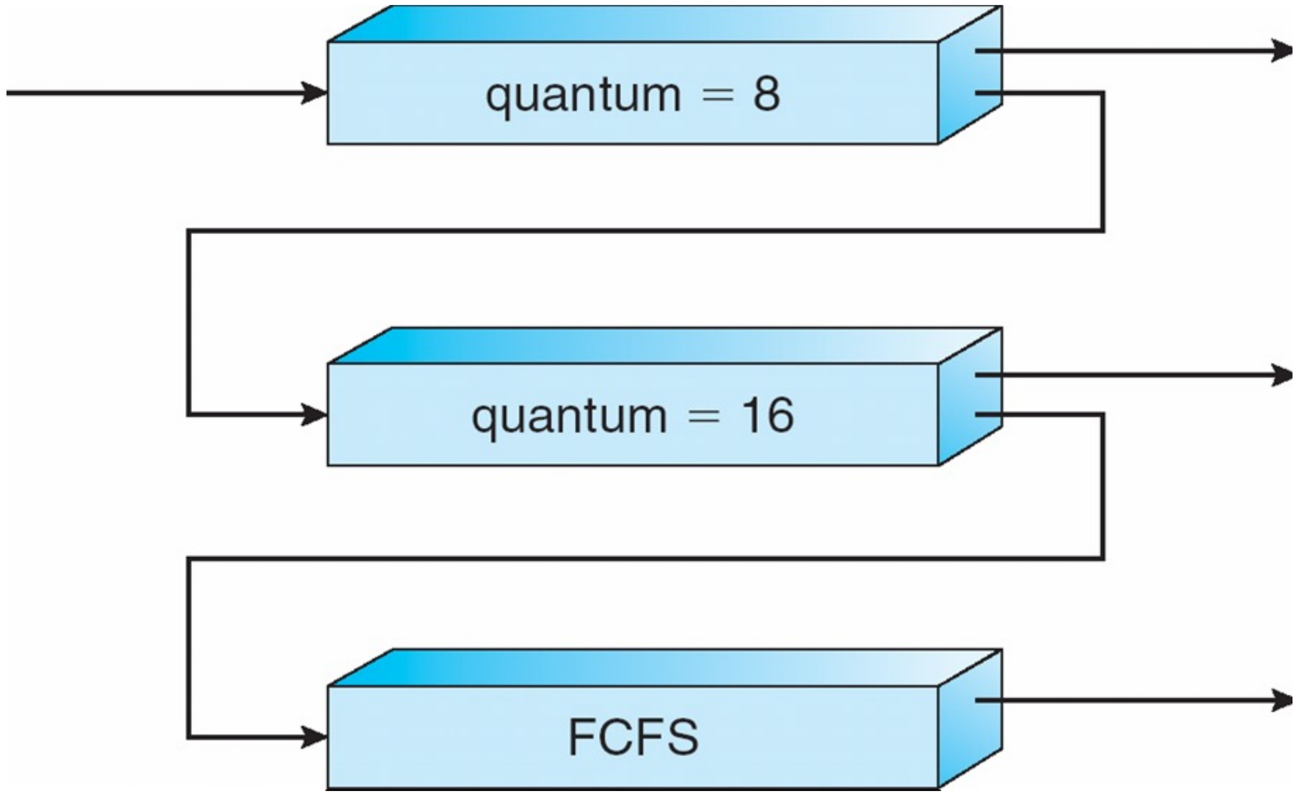
Multilevel Feedback Queue

- 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
- 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
- Kernel thread scheduled onto available CPU is **system-contention scope (SCS)** – competition among all threads in system

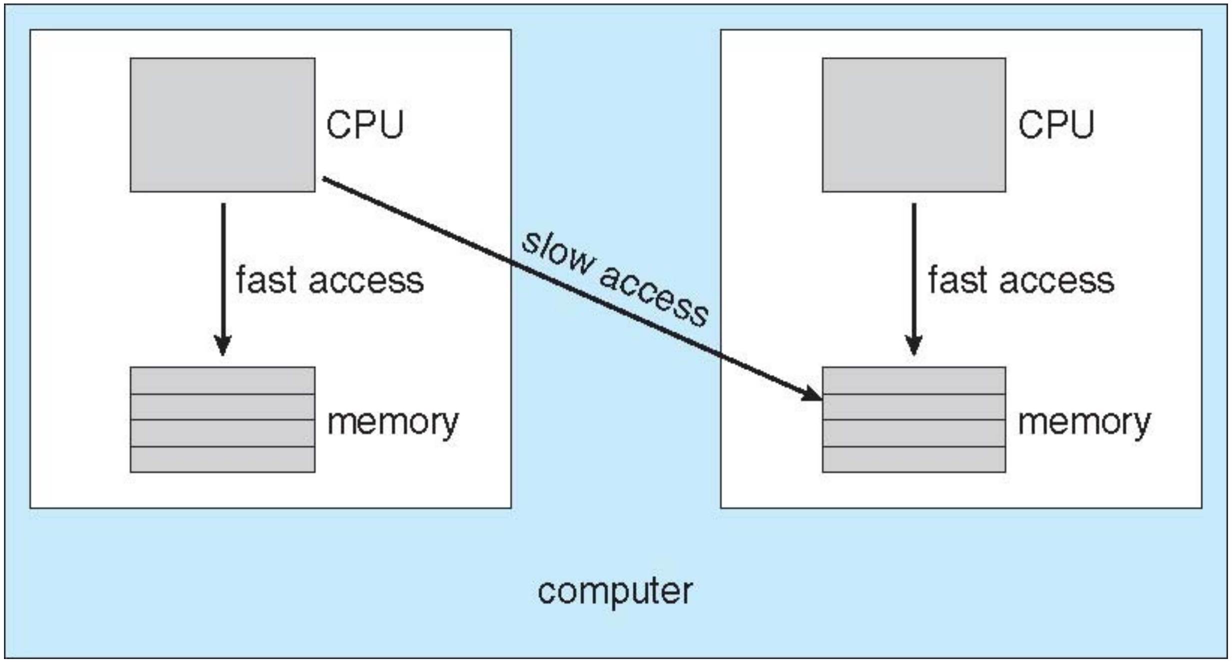
Pthread Scheduling

- 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.

Multiple-Processor Scheduling

- CPU scheduling more complex when multiple CPUs are available
- **Homogeneous processors** within a multiprocessor
- **Asymmetric multiprocessing** – only one processor accesses the system data structures, alleviating the need for data sharing
- **Symmetric multiprocessing (SMP)** – each processor is self-scheduling, all processes in common ready queue, or each has its own private queue of ready processes
- **Processor affinity** – process has affinity for processor on which it is currently running
  - **soft affinity**
  - **hard affinity**

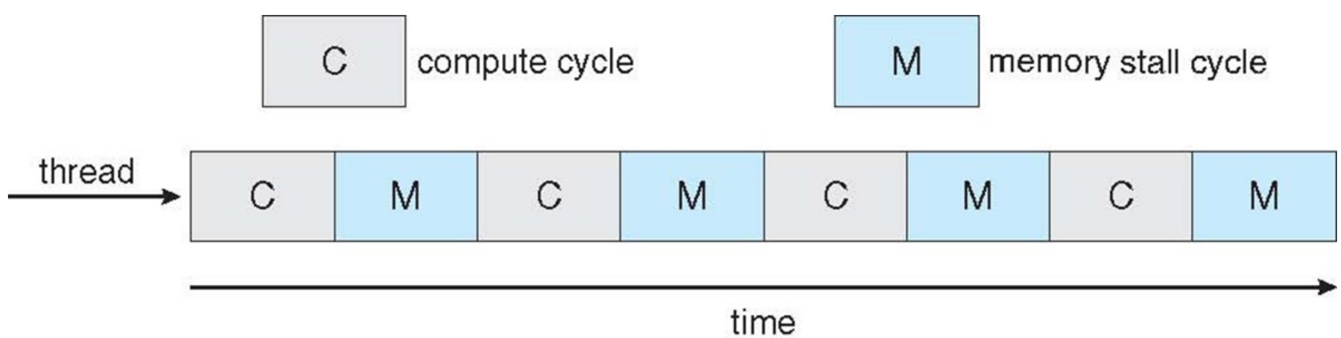
Non-uniform memory access (NUMA) and CPU Scheduling



Processor affinity. Most SMP systems try to avoid migration of processes from one processor to another, and instead attempt to keep a process running <u>on the same processor</u>.

Multicore Processors

- Recent trend to place multiple processor cores on same physical chip
- Faster and consume less power
- Multiple threads per core also growing
  - Takes advantage of **memory stall** to make progress on another thread while memory retrieve happens



Memory Stall

Operating System Examples

- Solaris scheduling
- Windows XP scheduling
- Linux scheduling

Solaris Dispatch Table

1. priority: Higher number indicates higher priority

2. Time quantum: Higher priority with smaller time slice

3. Time quantum expired: Priority after using its entire time slice,
Priority is lowered

4. Return from sleep: Priority of a thread that is returning from sleeping. Priority is boosted, which is important for good and responsive time.

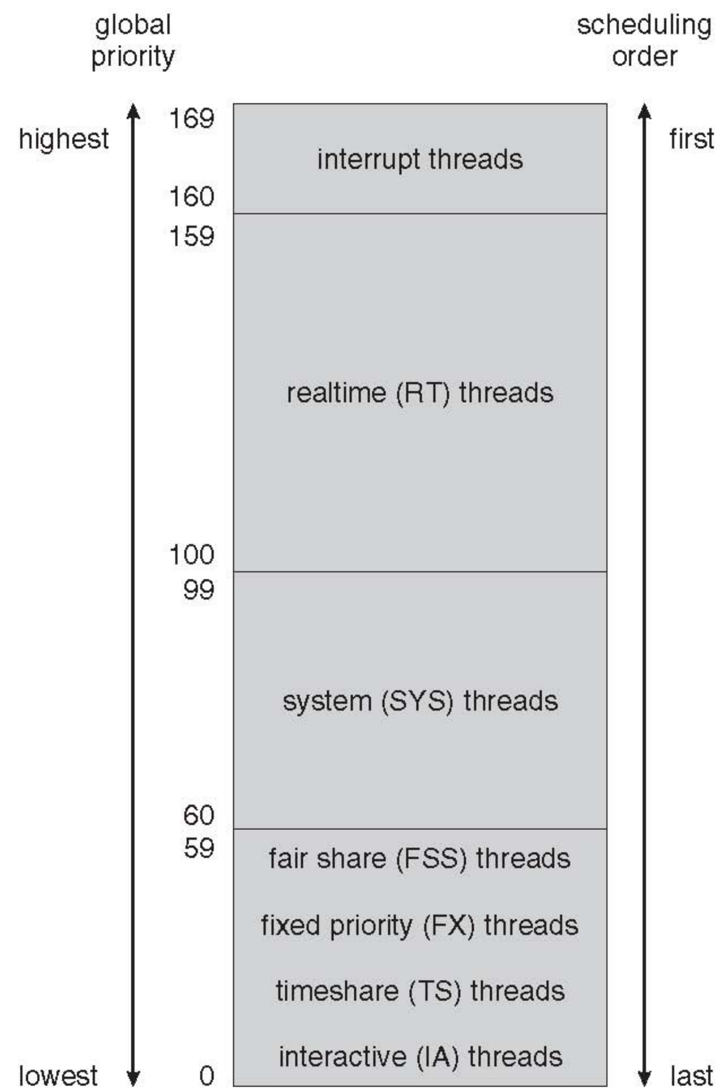
priority	time quantum	time quantum expired	return from sleep
0	200	0	50
5	200	0	50
10	160	0	51
15	160	5	51
20	120	10	52
25	120	15	52
30	80	20	53
35	80	25	54
40	40	30	55
45	40	35	56
50	40	40	58
55	40	45	58
59	20	49	59

Solaris dispatch table for time-sharing and interactive threads

Solaris Scheduling

The kernel maintains **10 threads** for servicing interrupts, which does **NOT** belong to one of six scheduling classes.

The six classes are real-time, system, fair share, fixed priority, timeshare, and interactive threads.



Windows XP Priorities

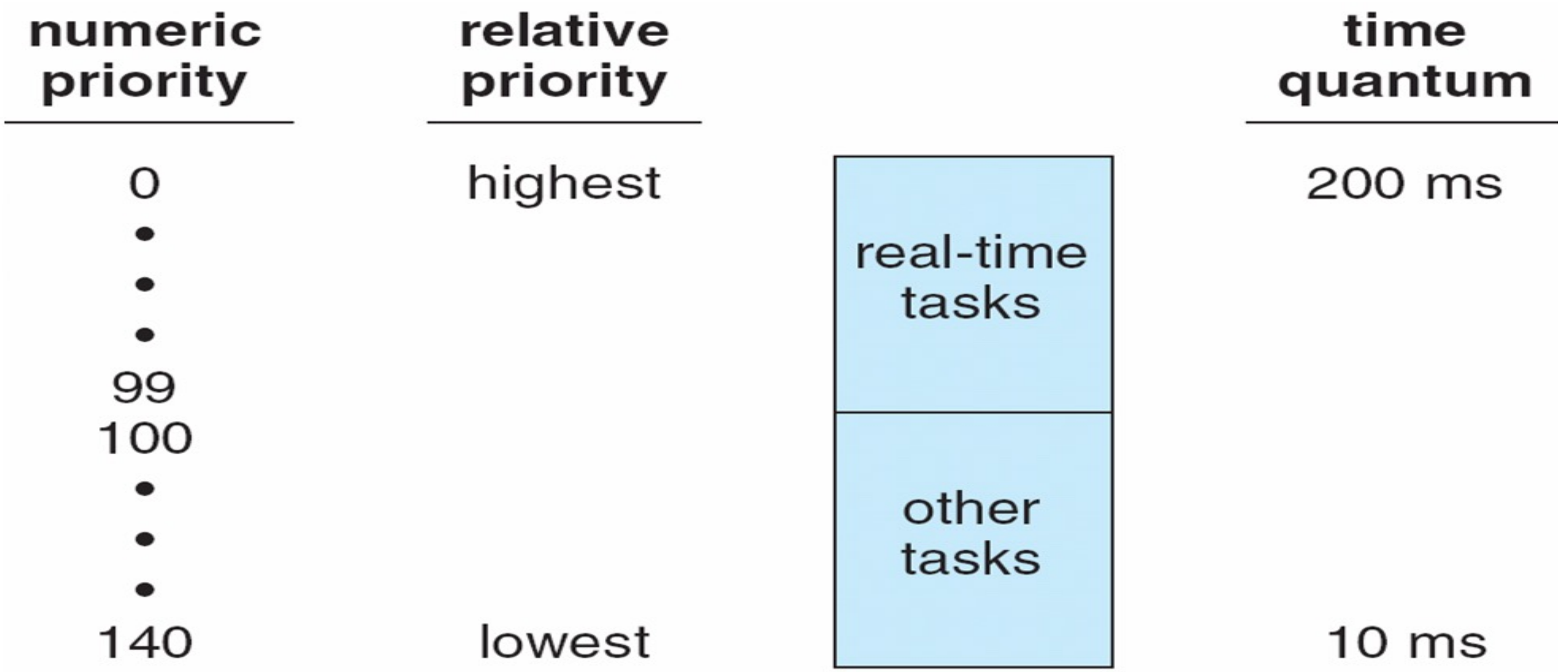
Relative priority	Priority classes					
	real-time	high	above normal	normal	below normal	idle priority
time-critical	31	15	15	15	15	15
highest	26	15	12	10	8	6
above normal	25	14	11	9	7	5
normal	24	13	10	8	6	4
below normal	23	12	9	7	5	3
lowest	22	11	8	6	4	2
idle	16	1	1	1	1	1

- The initial priority of a thread is typically the base priority of the process the thread belongs to.
- The priority is **boosted** when a thread is released from a wait operation. Waiting for keyboard gets more increase, and for disk gets moderate increase.
- XP distinguishes **foreground** and **background** processes. Quantum of foreground process is increased by 3.

Linux Scheduling

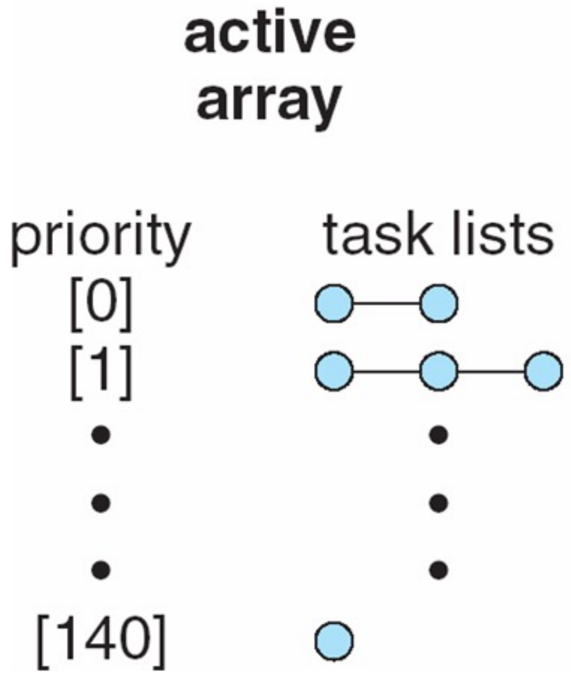
- Constant order *O*(1) scheduling time
- Two priority ranges: time-sharing and real-time
- **Real-time** range from 0 to 99 and **nice value** from 100 to 140
- Two ranges map into a global priority scheme wherein numerically lower values indicate higher priorities.

Priorities and Time-slice length



Unlike Solaris and XP, **Linux assigns higher priority tasks longer time quanta** and lower priority task shorter time quanta.

List of Tasks Indexed According to Priorities

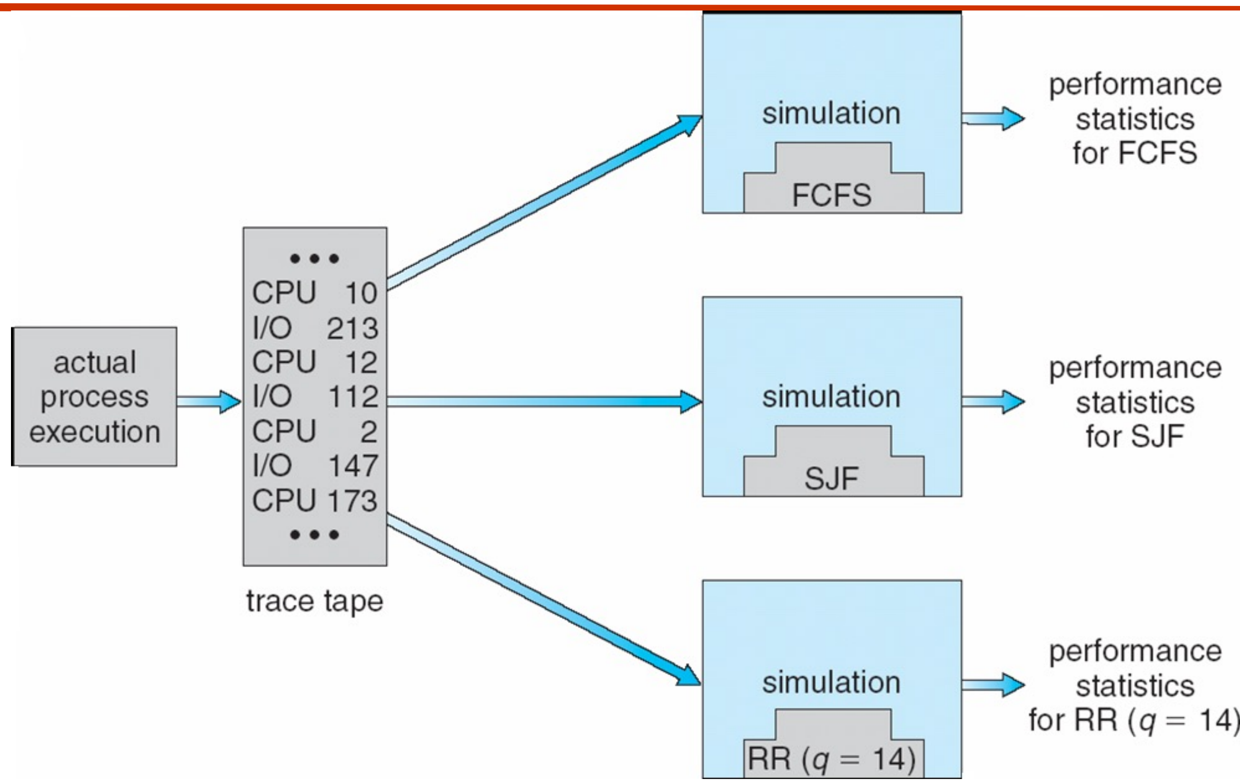


All runnable tasks are stored in run queue which has two priority arrays: active and expired.
The schedule chooses the task with highest priority from the active array for execution.
The two priority arrays are exchanged when all tasks in active arrays have exhausted their time slice.

Algorithm Evaluation

- Deterministic modeling – takes a particular predetermined workload and defines the performance of each algorithm for that workload
- Queueing models.
  - Processes vary from day to day, so there is no static set of processes to use for deterministic modeling.
  - Distribution of CPU and I/O bursts can be determined.
  - Determine if the system is stable by checking if the number of process leaving the queue is equal to the number of processes that arrive.
- Implementation
  - High cost, environment changes, can be altered by system managers or users

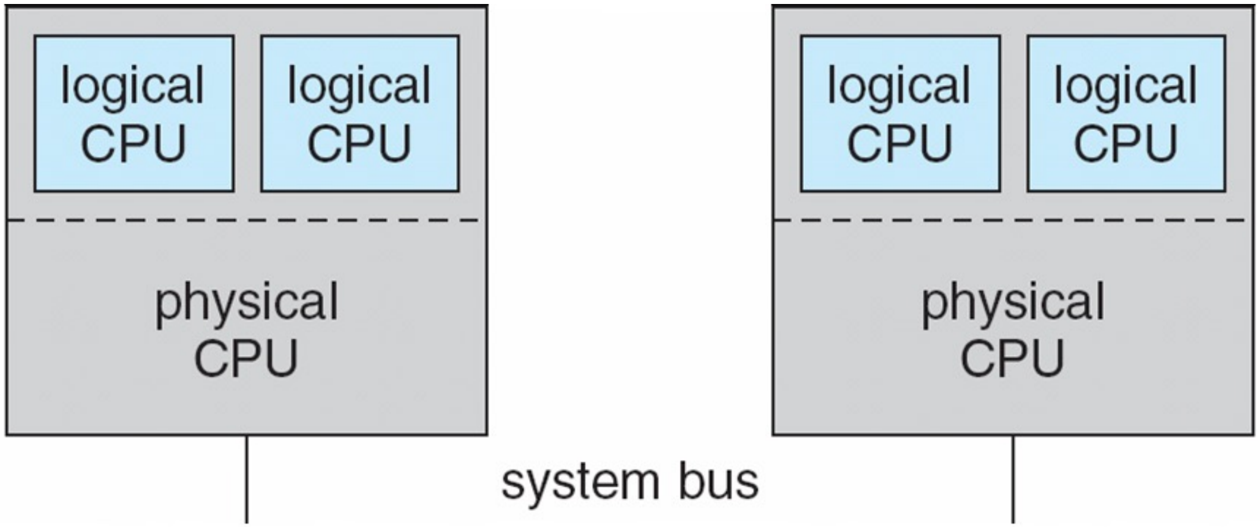
Evaluation of CPU schedulers by Simulation



- Software data structure to represent the major components of the system.
- As value of a clock increases, the simulator modify the system state to reflect activates of the devices, the processes, and the scheduler.
- The statistics will be gathered for performance of the algorithm.

End of Chapter 5

5.08


logical
CPU
logical
CPU
logical
CPU
logical
CPU
physical
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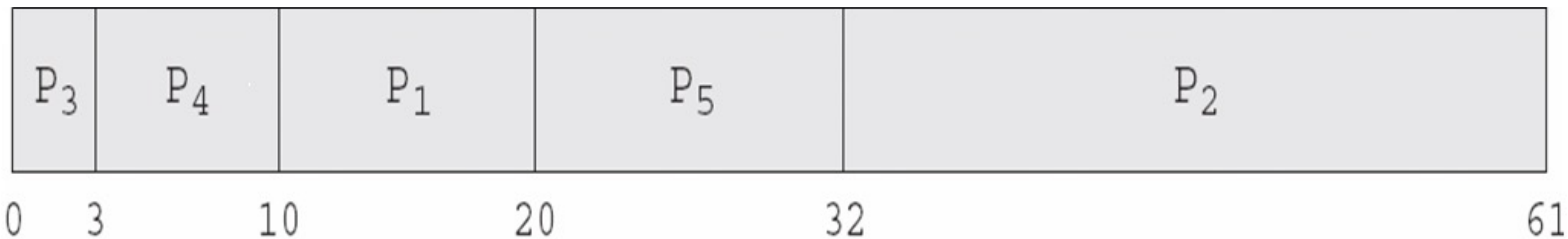
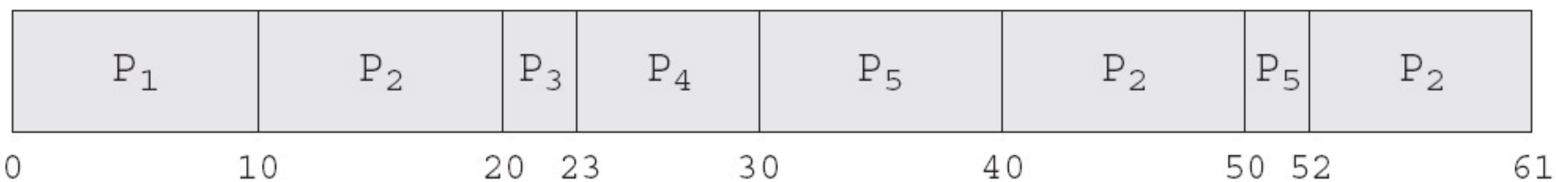
physical
CPU
system bus

In-5.7

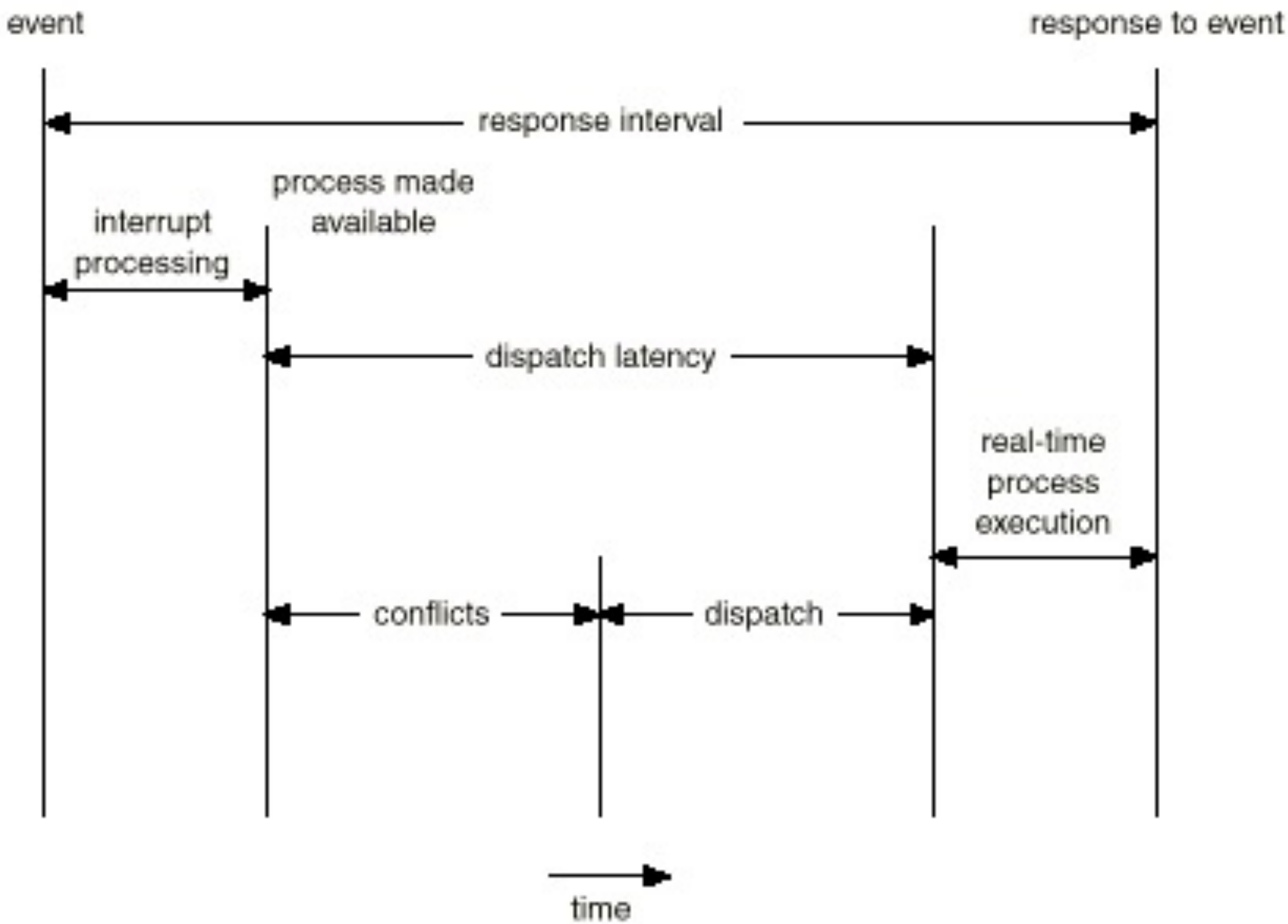
In-5.8



In-5.9



Dispatch Latency



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:

1. The Currently Running Thread Exits the Runnable State
2. 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

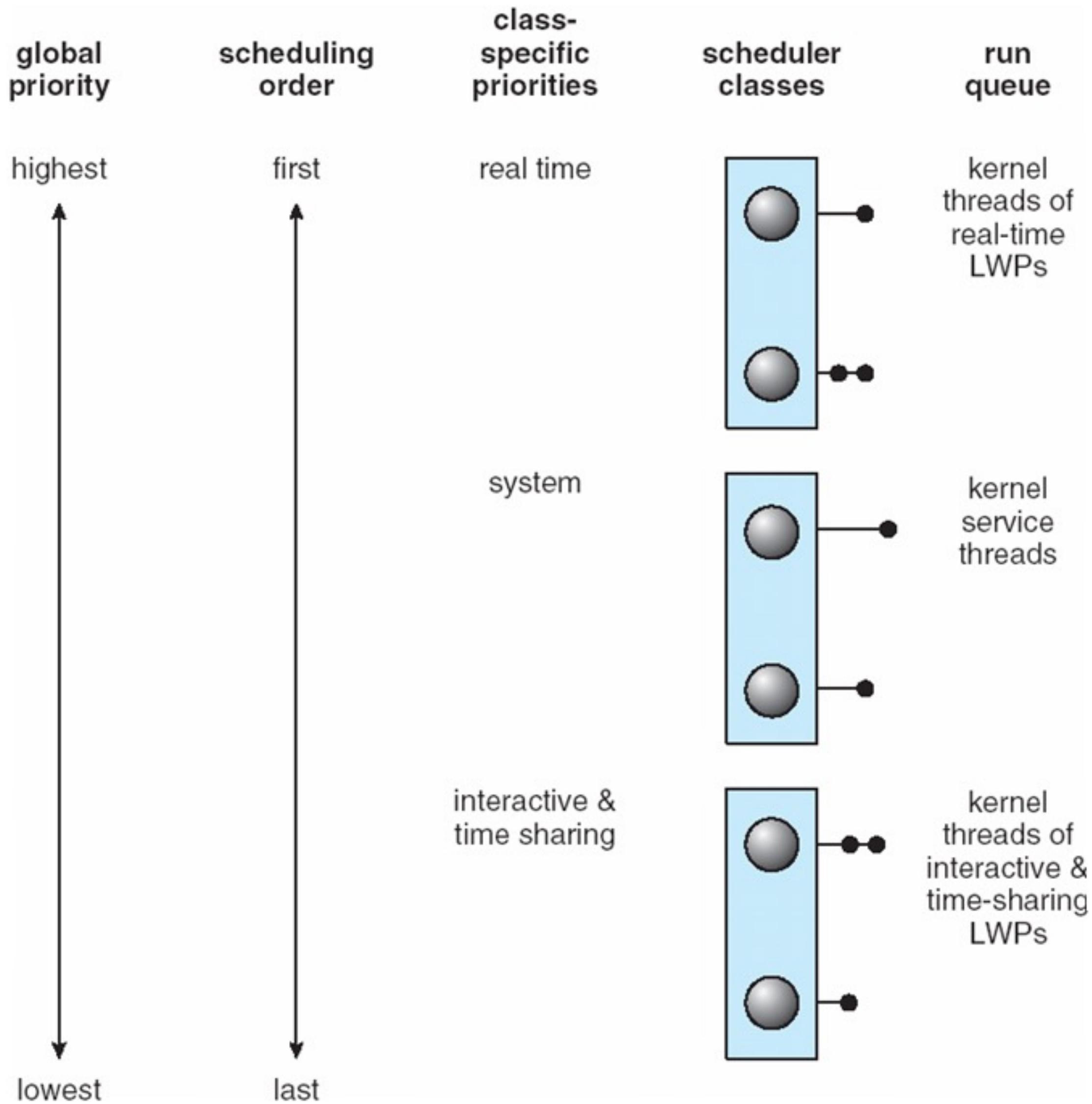
Thread Priorities

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);
```

Solaris 2 Scheduling



End of Chapter 5