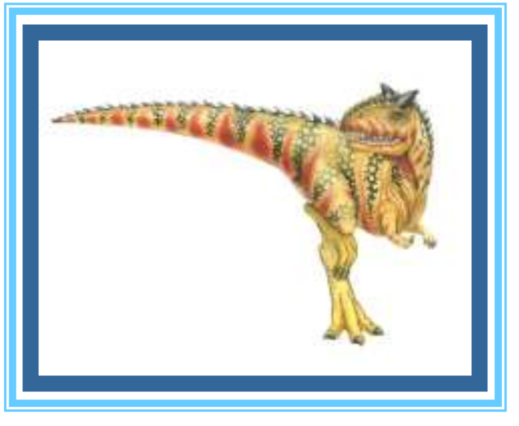
Chapter 5: CPU Scheduling



Chapter 5: CPU Scheduling

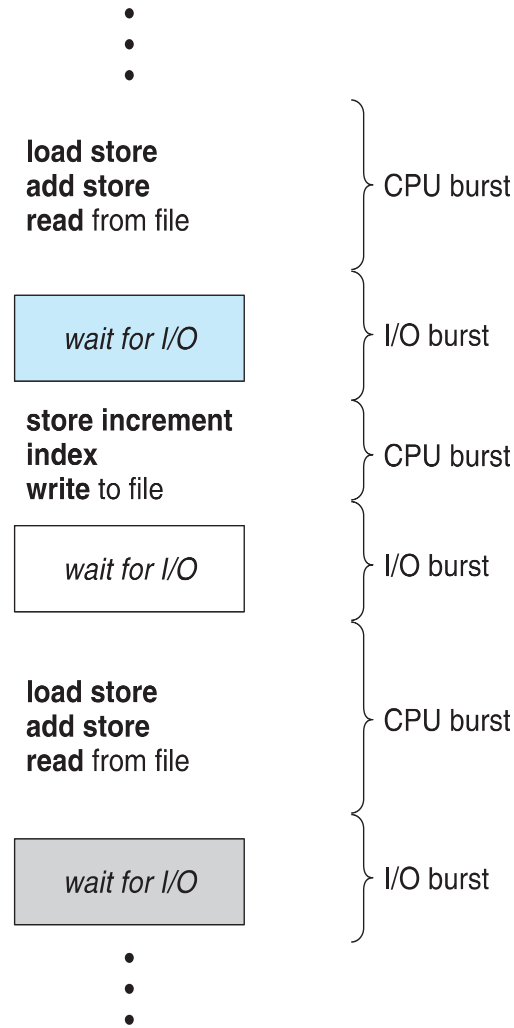
- Basic Concepts
- Scheduling Criteria
- Scheduling Algorithms
- Thread Scheduling
- Multiple-Processor Scheduling
- Real-Time CPU Scheduling
- Operating Systems Examples
- Algorithm Evaluation

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
- To examine the scheduling algorithms of several operating systems

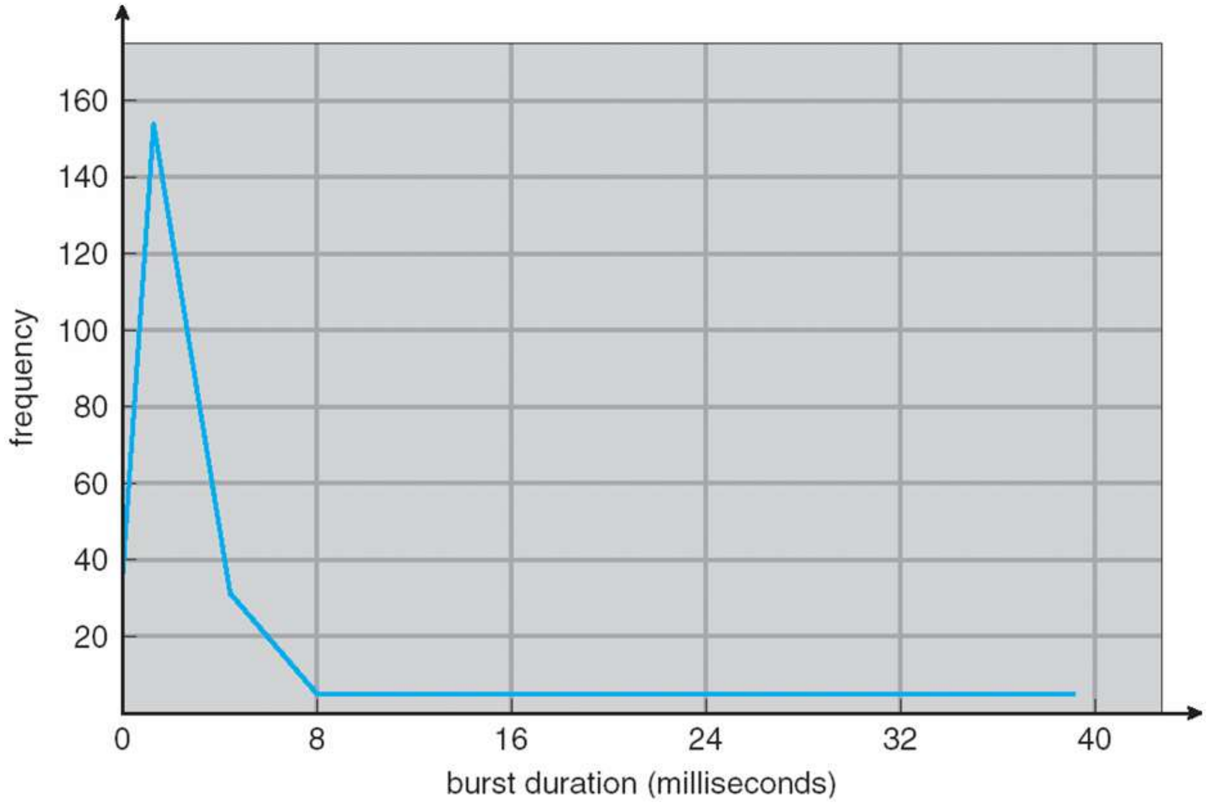
Basic Concepts

- 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** followed by **I/O burst**
- CPU burst distribution is of main concern



- Preemptive
- Non-preemptive scheduling

Histogram of CPU-burst Times



CPU Scheduler

- **Short-term scheduler** selects from among the processes in ready queue, and allocates the CPU to one of them
  - Queue may be ordered in various ways
- CPU scheduling decisions may take place when a process:
  1. When a process Switches from running to waiting state
  2. When a process Switches from running to ready state
  3. When a process Switches from waiting to ready
  4. When a process Terminates
- Scheduling under 1 and 4 is **nonpreemptive**
- All other scheduling is **preemptive,** which can result in race condition when:
  - Considering access to shared data
  - Consider preemption while in kernel mode
  - Consider interrupts occurring during crucial OS activities

Dispatcher

- Dispatcher module gives control of the CPU to the process selected by the short-term scheduler; this involves:
  - switching context from one process to another(e.g. register values, program counters)
  - 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

Dispatcher

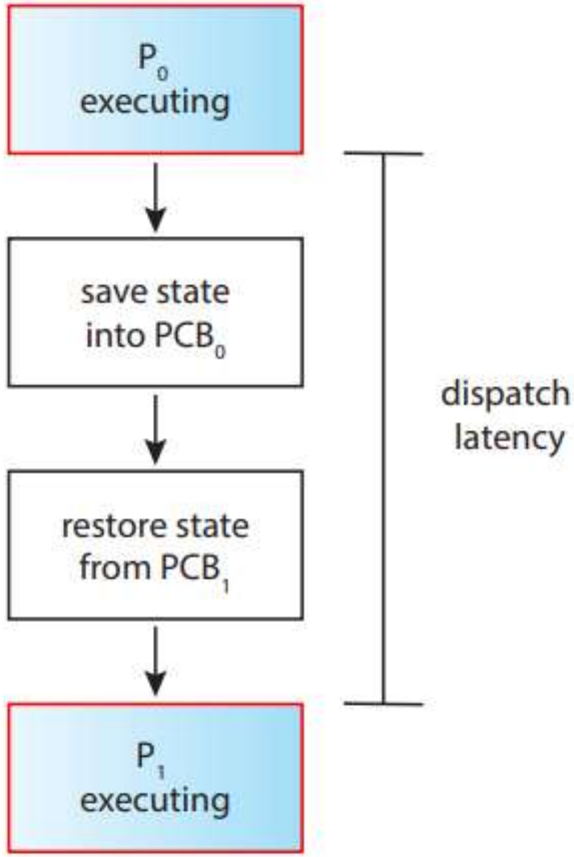


Figure 5.3 The role of the dispatcher.

Scheduling Criteria

- **CPU utilization** – measures the percentage of time the CPU is actively processing tasks verses being idle
  - keep the CPU as busy as possible
- **Throughput** – refers to the # of processes that complete their execution per time unit.
- **Turnaround time** – is the total time taken from the submission of a process to its completion, including waiting time, execution time, I/O time
  - amount of time to execute a particular process

Scheduling Criteria

- **Waiting time** – amount of time a process has been waiting in the ready queue before it gets CPU.
- **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

- Maximize
  - Max CPU utilization
  - Max throughput
- Minimize
  - Min turnaround time
  - Min waiting time
  - Min response time

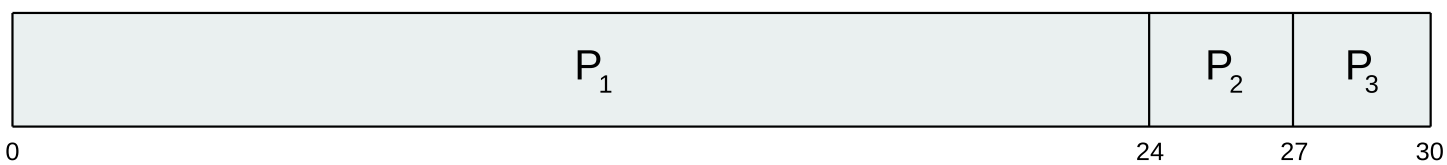
Scheduling Algorithm Optimization Criteria

- First-come, First-served
- Shortest-job first
- Shortest-remaining-time-first
- Priority
- Round-robin
- Multilevel feedback queues

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 = 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 = 3
- Much better than previous case
- **Convoy effect** - short process behind long process
  - Consider one CPU-bound and many I/O-bound processes

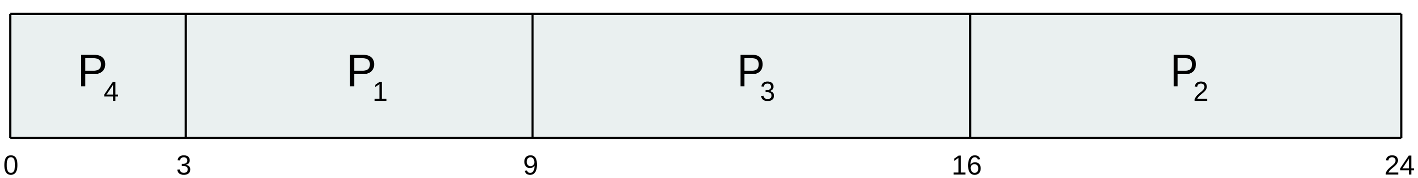
Shortest-Job-First (SJF) Scheduling

- 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

Example of SJF

Process	Burst Time
P_1	6
P_2	8
P_3	7
P_4	3

- SJF scheduling chart



- Average waiting time = ?

Example of SJF

Process	Burst Time
P_1	6
P_2	8
P_3	7
P_4	3

- SJF scheduling chart

P_4	P_1	P_3	P_2
0 – 3	3 – 9	9 – 16	16 – 24

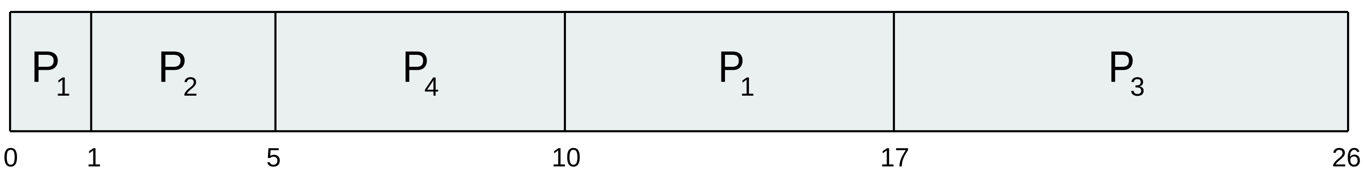
- Average waiting time = 7

Example of Shortest-remaining-time-first

- Now we add the concepts of varying arrival times and preemption to the analysis

Process	*Arrival* Time	Burst Time
P_1	0	8
P_2	1	4
P_3	2	9
P_4	3	5

- *Preemptive* SJF Gantt Chart



- Average waiting time =?

Example of Shortest-remaining-time-first

- Now we add the concepts of varying arrival times and preemption to the analysis

Process	*Arrival* Time	Burst Time
P_1	0	8
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P_3	2	9
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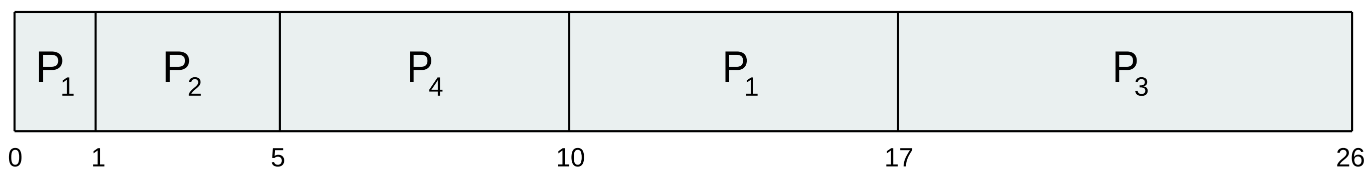
- *Preemptive* SJF Gantt Chart



- Average waiting time = 6.5 msec
- $[(10 - 1) + (1 - 1) + (17 - 2) + (5 - 3)]/4 = 26/4 = 6.5$

Priority Scheduling

- A priority number (integer) is associated with each process
- The CPU is allocated to the process with the highest priority
  - Preemptive
  - Nonpreemptive
- SJF is priority scheduling where priority is the inverse of predicted next CPU burst time
- Problem ≡ **Starvation-** low priority processes may never execute
- Solution ≡ **Aging –** as time progresses increase the priority of the process

Example of Priority Scheduling

Process	Burst Time	Priority
P_1	10	3
P_2	1	1
P_3	2	4
P_4	1	5
P_5	5	2

- Priority scheduling Gantt Chart

- Average waiting time = 8.2 msec

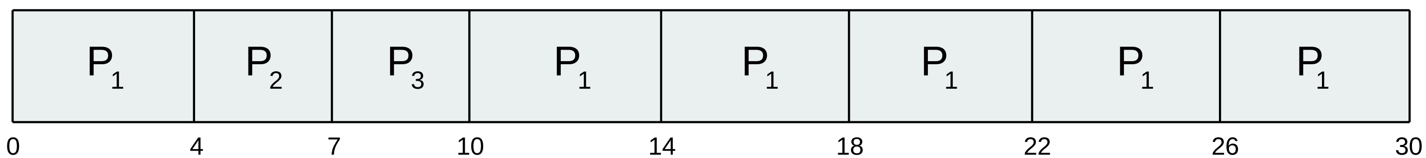
Round Robin (RR)

- Each process gets a small unit of CPU time (**time quantum** *q*), 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.
- Timer interrupts every quantum to schedule next process
- Performance
  - *q* large
  - *q* small

Example of RR with Time Quantum = 4

Process	Burst Time
P_1	24
P_2	3
P_3	3

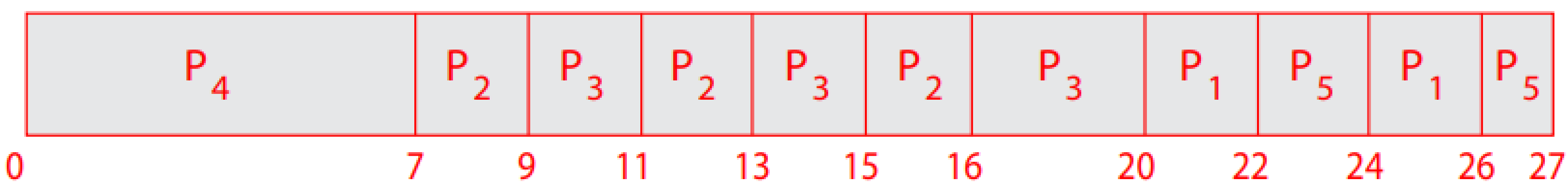
- The Gantt chart is:



- Typically, higher average turnaround than SJF, but better ***response***
- q should be large compared to context switch time
- q usually 10ms to 100ms, context switch < 10 usec

combine round-robin and priority scheduling (Quantum = 2ms)

Process	Burst Time	Priority
P_1	4	3
P_2	5	2
P_3	8	2
P_4	7	1
P_5	3	3



Multilevel Queue

- Ready queue is partitioned into separate queues, eg:
  - **foreground** (interactive)
  - **background** (batch)
- Process permanently in a given queue
- 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.

Multilevel Queue Scheduling

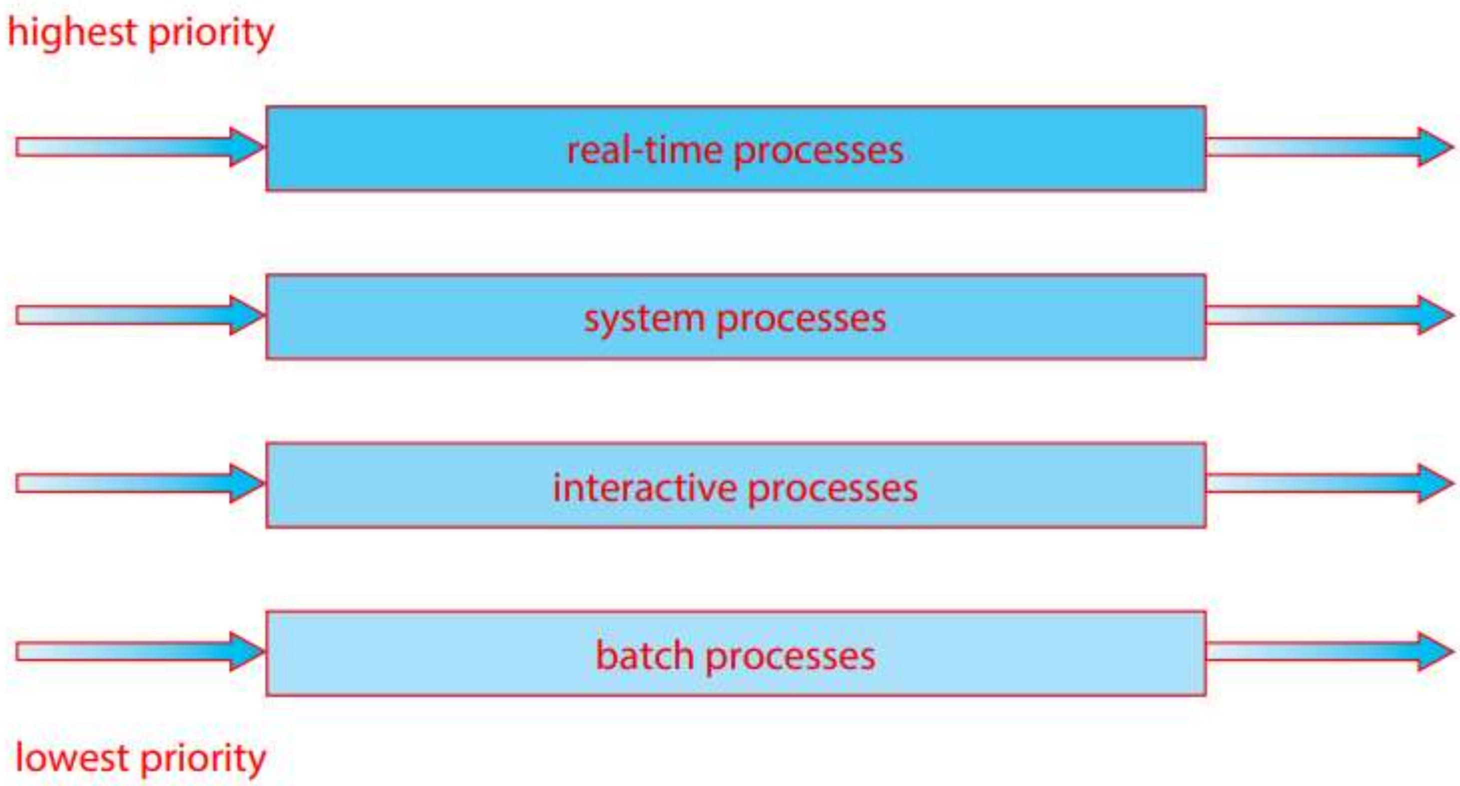
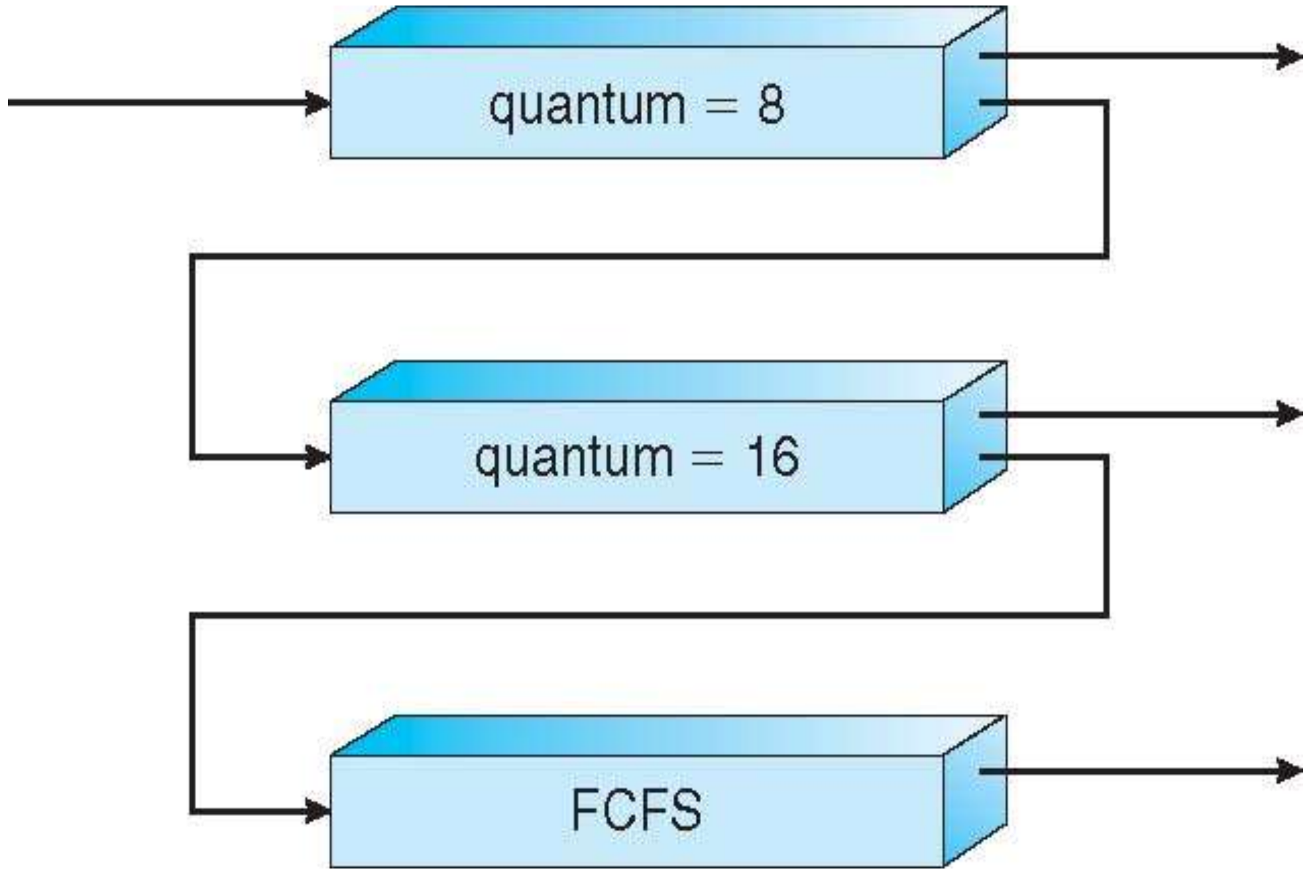


Figure 5.8 Multilevel queue scheduling.

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



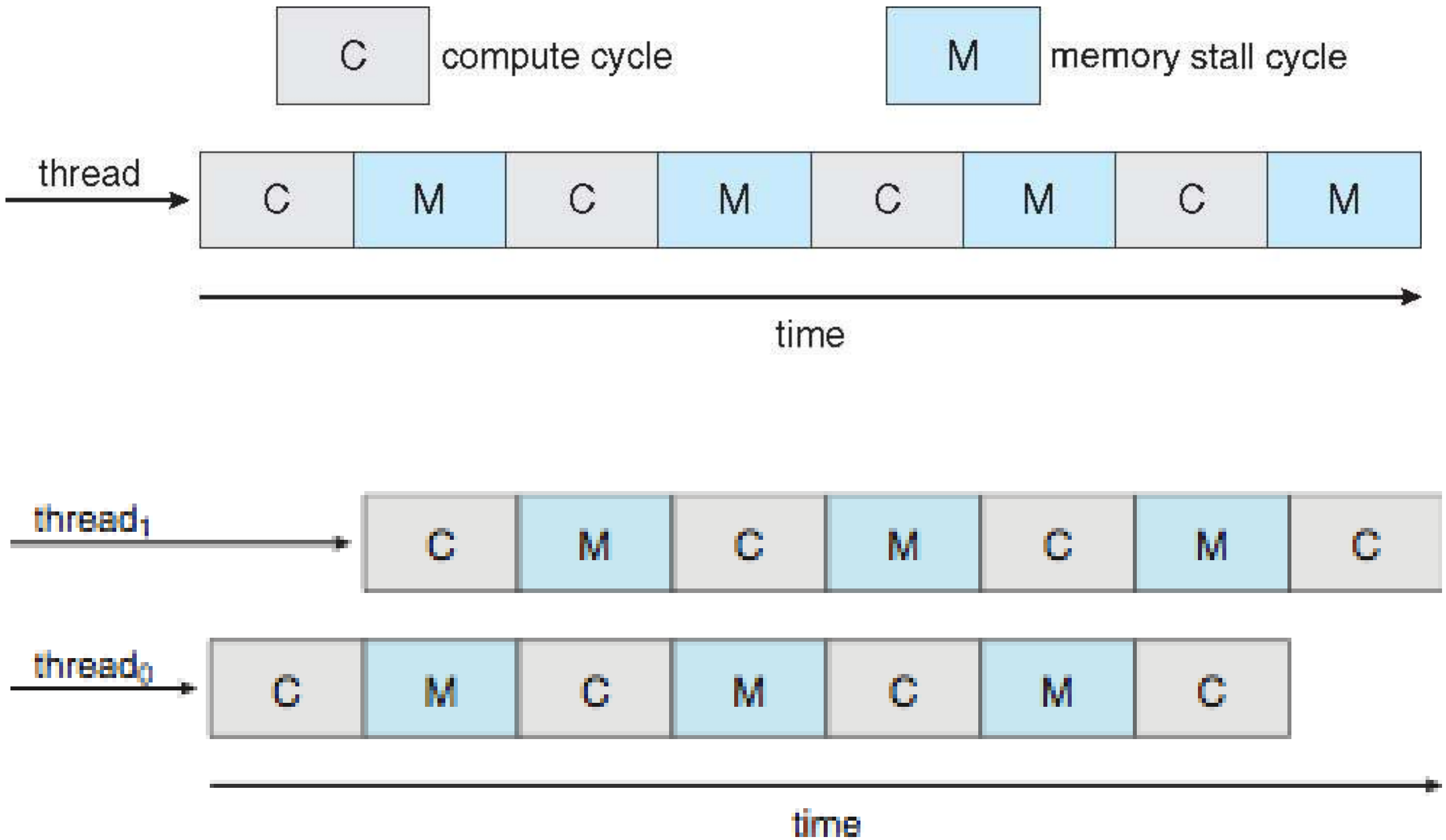
Example of Multilevel Feedback Queue

- Three queues:
  - Q_0 – RR with time quantum 8 milliseconds
  - Q_1 – RR time quantum 16 milliseconds
  - Q_2 – FCFS
- Scheduling
  - An entering process is put in queue 0.
  - A process in queue 0 is given a time quantum of 8 milliseconds.
  - If it does not finish within this time, it is moved to the tail of queue 1.
  - If queue 0 is empty, the process at the head of queue 1 is given a quantum of 16 milliseconds.
  - If it does not complete, it is preempted and is put into queue 2. Processes in queue 2 are run on an FCFS basis but are run only when queues 0 and 1 are empty.
  - To prevent starvation, a process that waits too long in a lower-priority queue may gradually be moved to a higher-priority queue. q

Multicore Processors

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

Multithreaded Multicore System



End of Chapter 5