

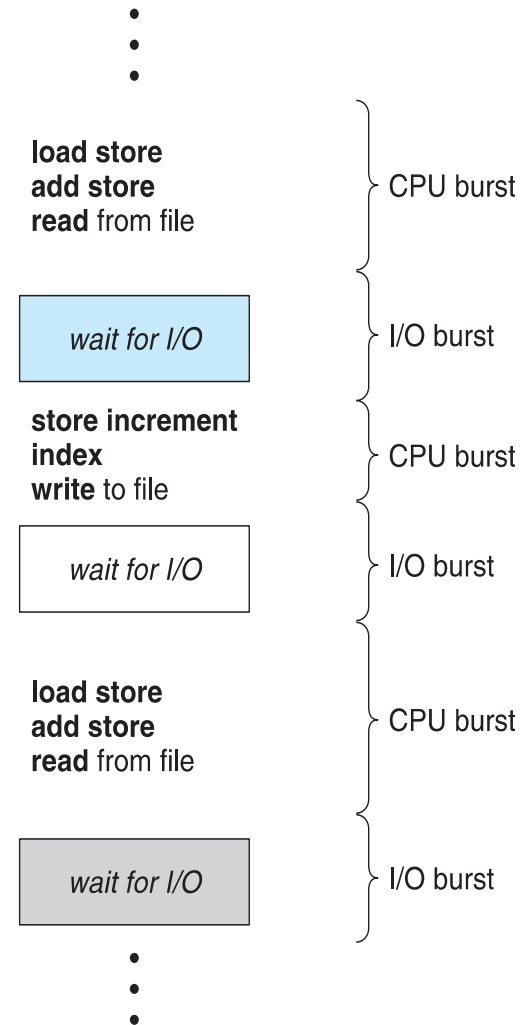
Chapter 6: CPU Scheduling





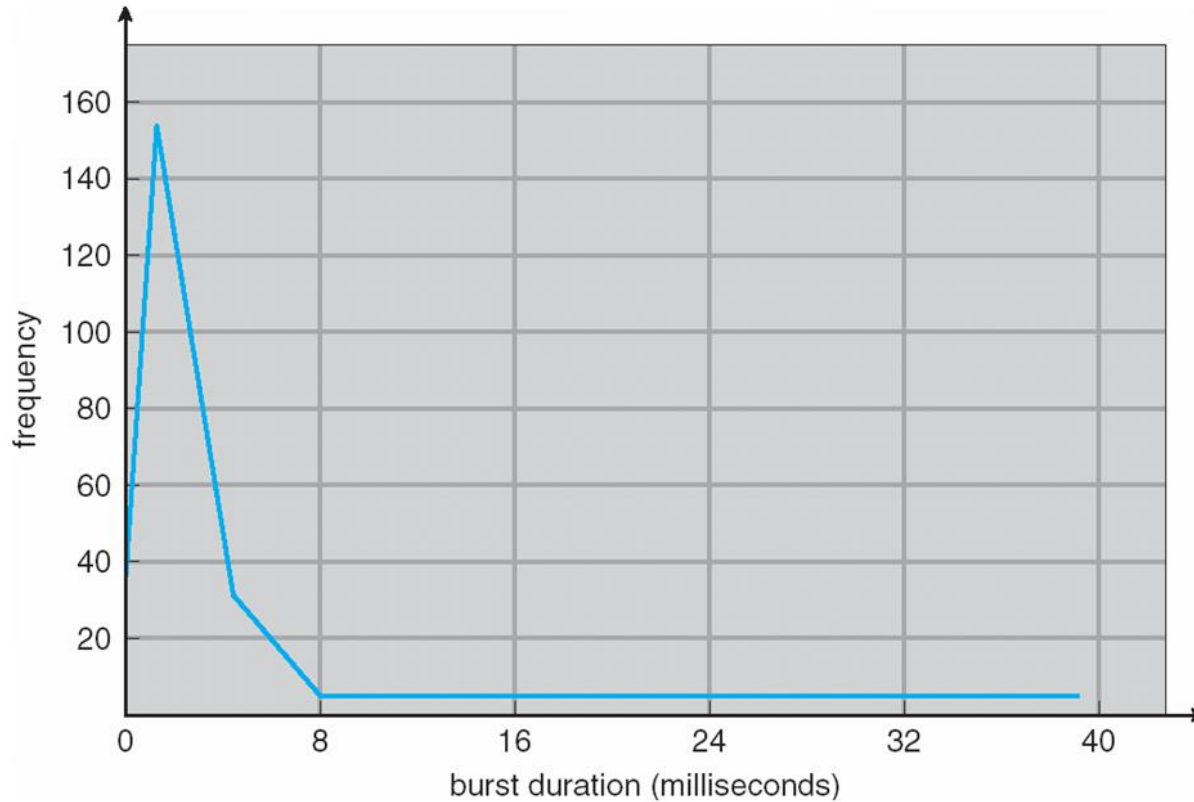
Basic Concepts

- ❑ 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





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. Switches from running to waiting state
 2. Switches from running to ready state
 3. Switches from waiting to ready
 4. Terminates
- Preemptive and non-preemptive scheduling





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

<u>Process</u>	<u>Burst Time</u>
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 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
 - 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
 - The difficulty is knowing the length of the next CPU request
 - Could ask the user

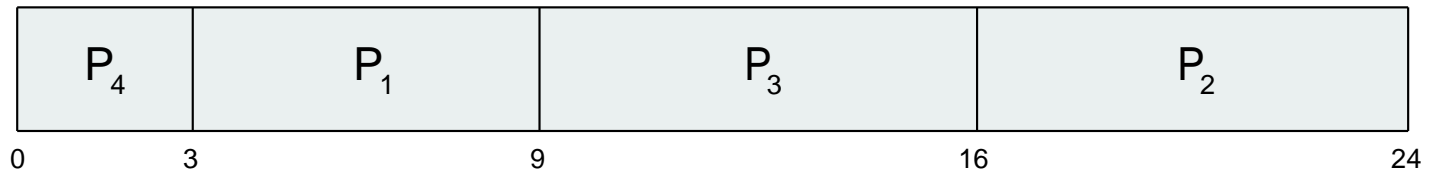




Example of SJF

<u>Process</u>	<u>Burst Time</u>
P_1	6
P_2	8
P_3	7
P_4	3

□ SJF scheduling chart



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





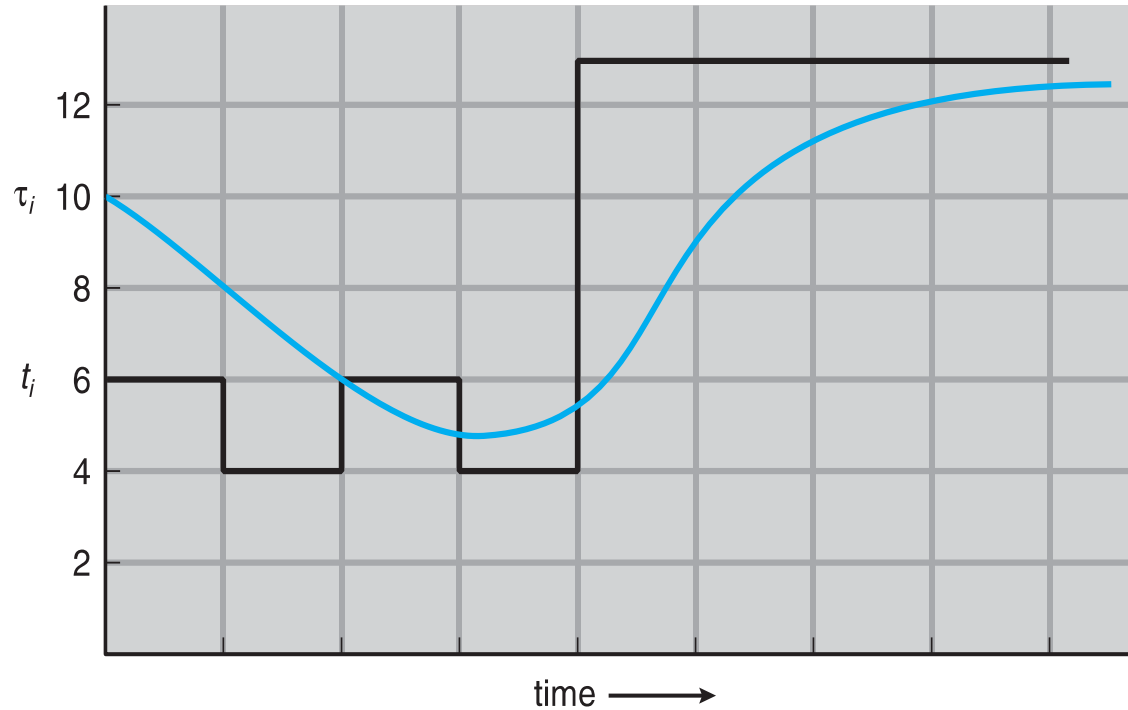
Determining Length of Next CPU Burst

- Can only estimate the length – should be similar to the previous one
 - Then pick process with shortest predicted next CPU burst
- Can be done by using the length of previous CPU bursts, using exponential averaging
 1. t_n = actual length of n^{th} CPU burst
 2. τ_{n+1} = predicted value for the next CPU burst
 3. $\alpha, 0 \leq \alpha \leq 1$
 4. Define : $\tau_{n+1} = \alpha t_n + (1 - \alpha)\tau_n$.
- Commonly, α set to $\frac{1}{2}$
- Preemptive version called **shortest-remaining-time-first**





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	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:

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

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



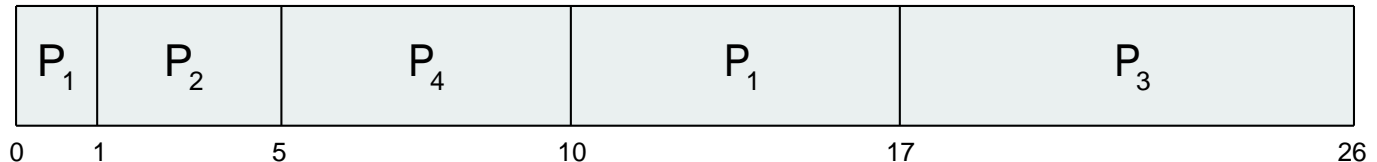


Example of Shortest-remaining-time-first

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

<u>Process</u>	<u>Arrival Time</u>	<u>Burst Time</u>
P_1	0	8
P_2	1	4
P_3	2	9
P_4	3	5

- Preemptive* SJF Gantt Chart



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





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 priority scheduling where priority is the inverse of 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





Example of Priority Scheduling

<u>Process</u>	<u>Burst Time</u>	<u>Priority</u>
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 \Rightarrow FIFO
 - q small $\Rightarrow q$ must be large with respect to context switch, otherwise overhead is too high

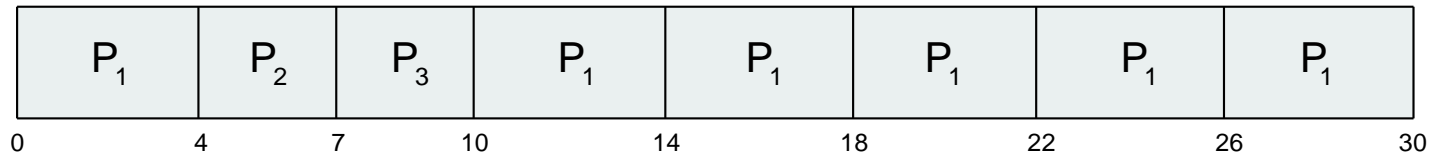




Example of RR with Time Quantum = 4

<u>Process</u>	<u>Burst Time</u>
P_1	24
P_2	3
P_3	3

- The Gantt chart is:

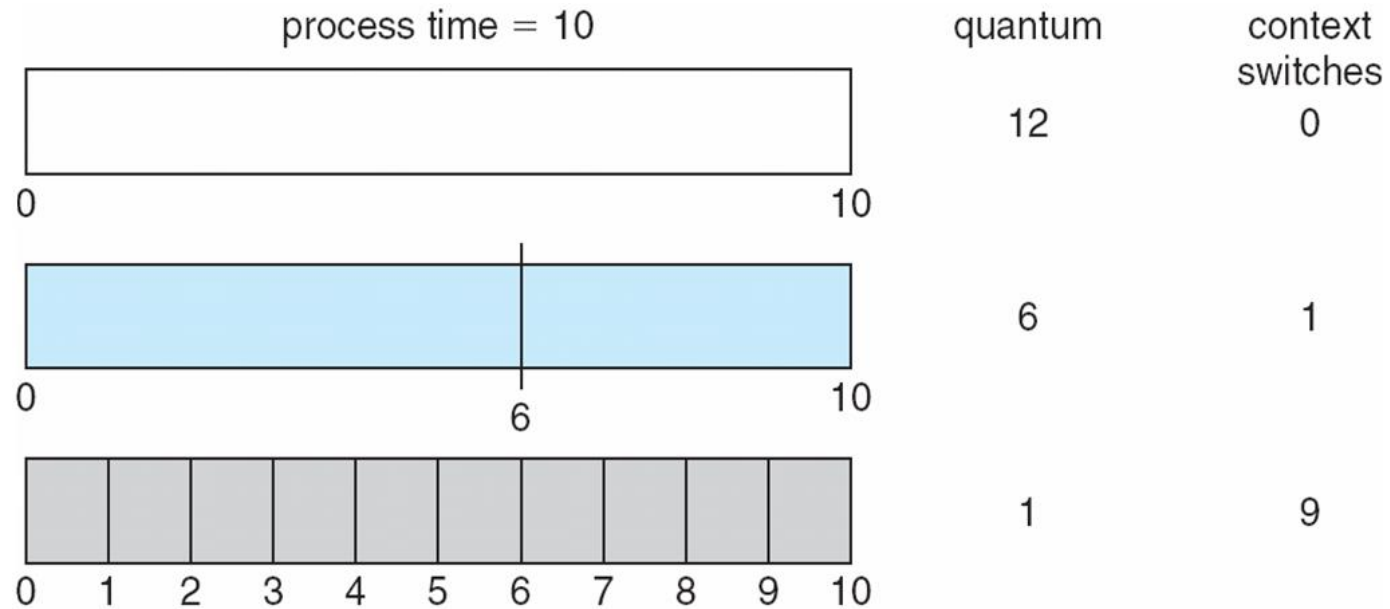


- Typically, higher average turnaround than SJF, but better **response**
- q should be large compared to context switch time
- q usually 10ms to 100ms, context switch < 10 usec





Time Quantum and Context Switch Time





Multilevel Queue

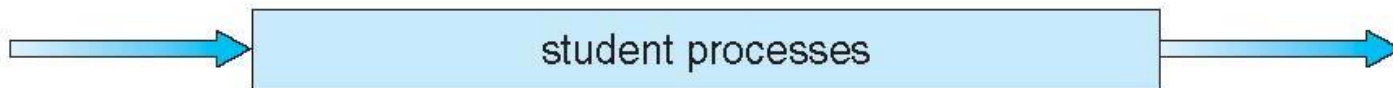
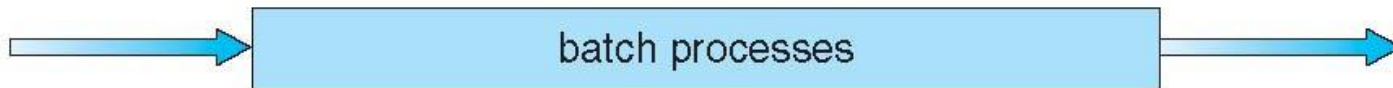
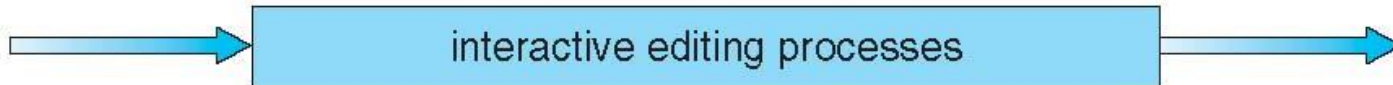
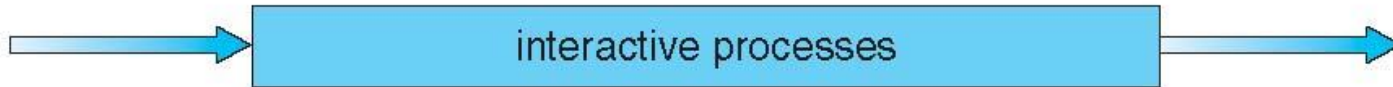
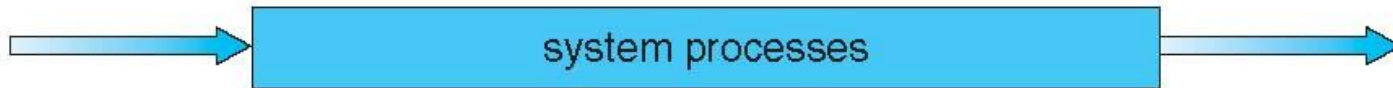
- Ready queue is partitioned into separate queues, eg:
 - **foreground** (interactive)
 - **background** (batch)
- Process permanently in a given queue
- Each queue has its own scheduling algorithm:
 - foreground – RR
 - background – FCFS
- Scheduling must be done between the queues:
 - Fixed priority 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; i.e., 80% to foreground in RR
 - 20% to background in FCFS





Multilevel Queue Scheduling

highest priority



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



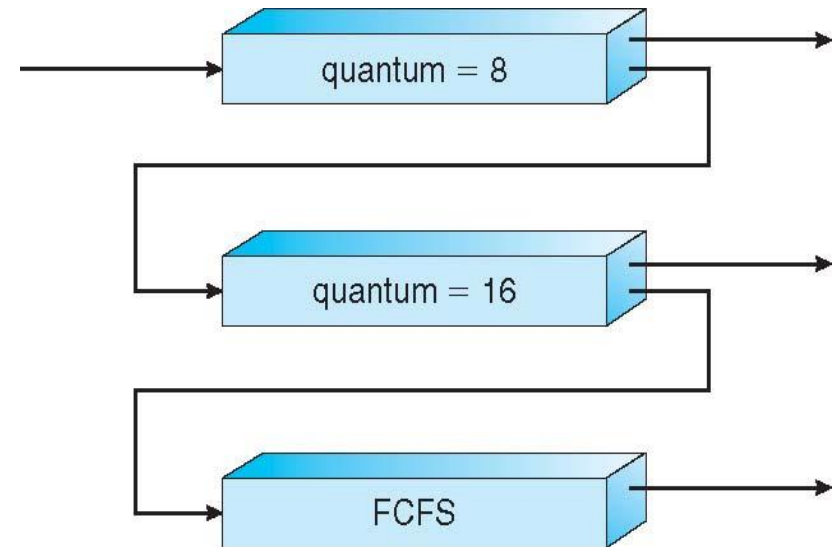


Example of Multilevel Feedback Queue

- 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





Multiple-Processor Scheduling

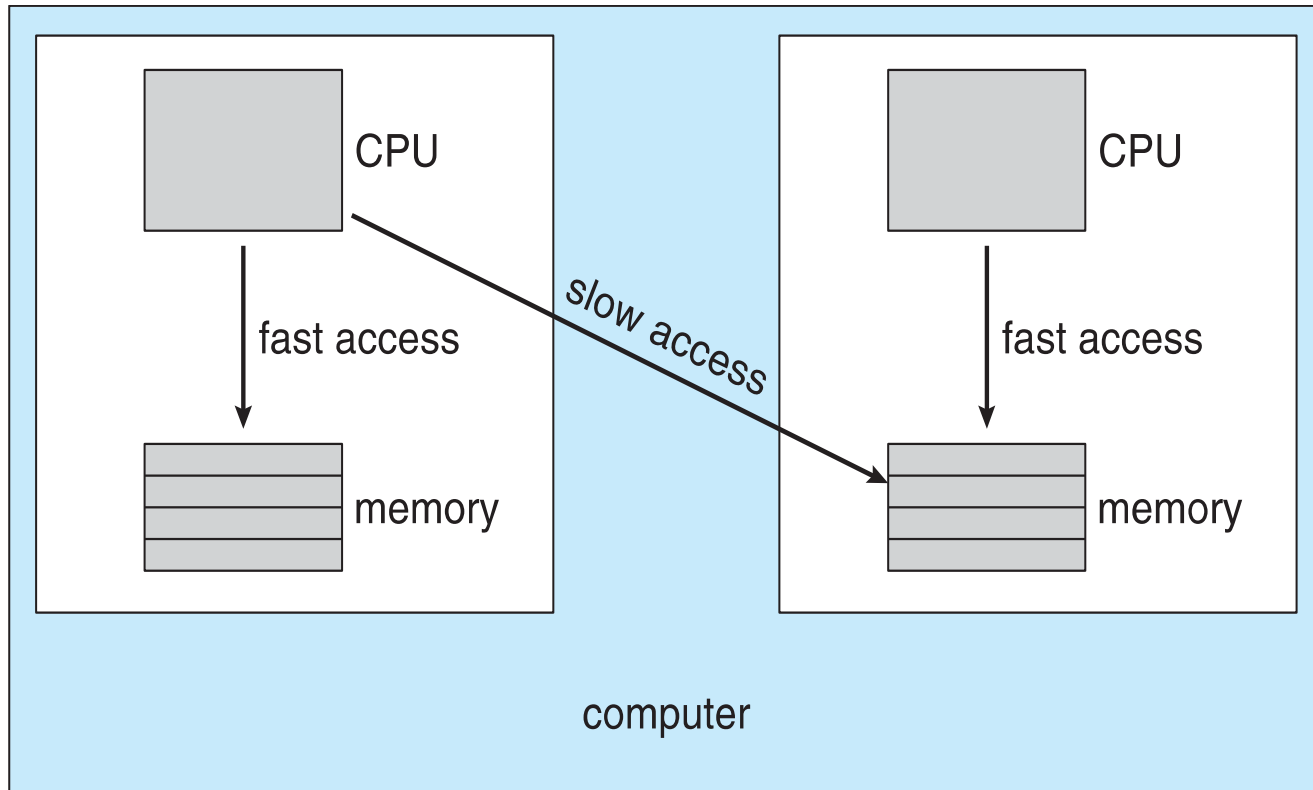
- ❑ CPU scheduling more complex when multiple CPUs are available
- ❑ **Homogeneous processors** within a multiprocessor
- ❑ **Asymmetric multiprocessing** - scheduling decisions, I/O processing, and other system activities by only one (master) processor
- ❑ **Symmetric multiprocessing (SMP)** – each processor is self-scheduling, all processes in common ready queue, or each has its own private queue of ready processes
 - ❑ Currently, most common
- ❑ **Processor affinity** – process has affinity for processor on which it is currently running
 - ❑ **soft affinity**
 - ❑ **hard affinity**
 - ❑ Variations including **processor sets**





NUMA Architecture and CPU Scheduling

Non-uniform memory access



Note that memory-placement algorithms can also consider affinity





Multiple-Processor Scheduling – Load Balancing

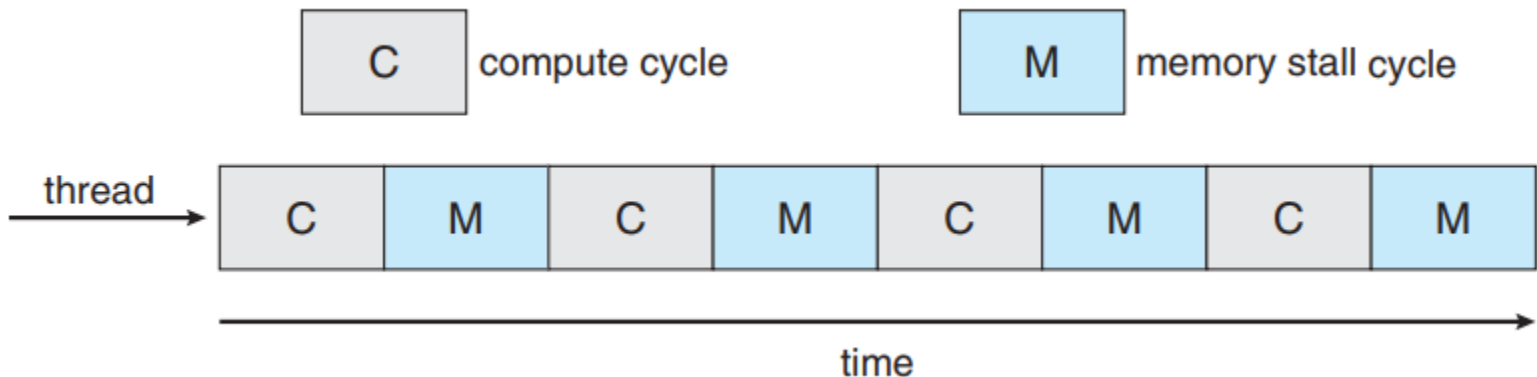
- If **Symmetric multiprocessing**, need to keep all CPUs loaded for efficiency
- **Load balancing** attempts to keep workload evenly distributed
- **Push migration** – periodic task checks load on each processor, and if found pushes task from overloaded CPU to other CPUs
- **Pull migration** – idle processors pulls waiting task from busy processor





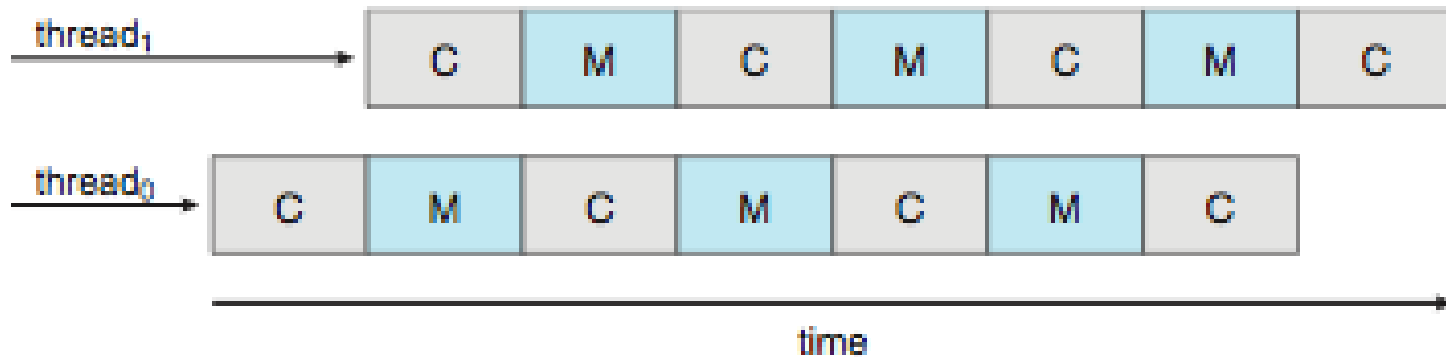
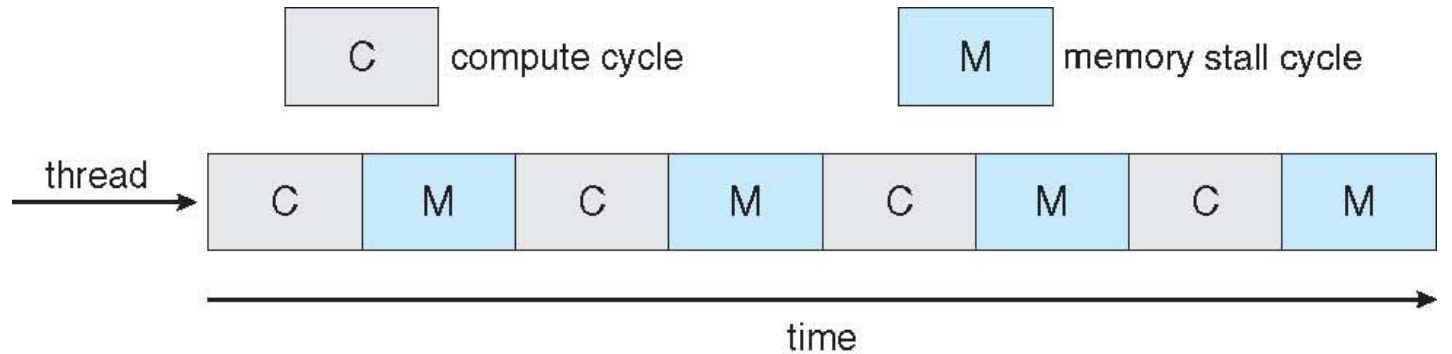
Multicore Processors

- 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 6

