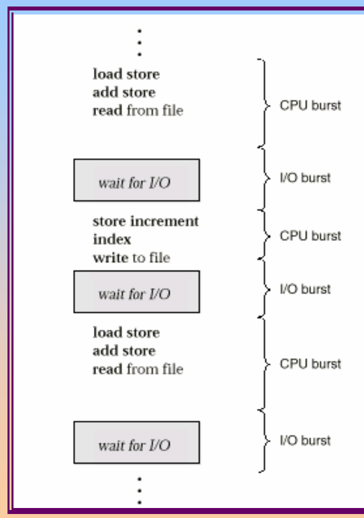
Chapter 6: CPU Scheduling

- Basic Concepts
- Scheduling Criteria
- Scheduling Algorithms
- Multiple-Processor Scheduling
- Real-Time Scheduling
- Algorithm Evaluation

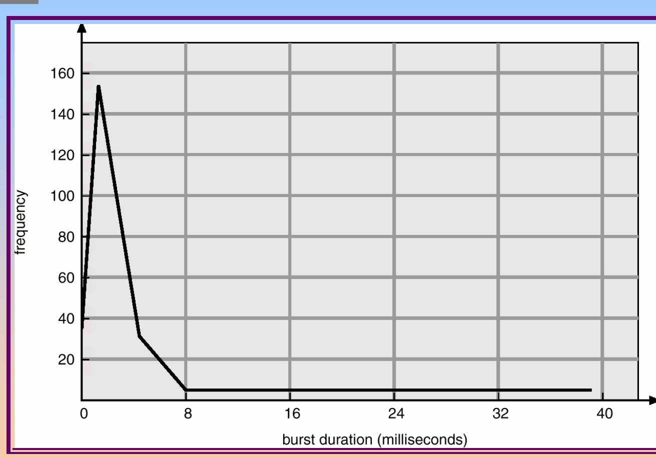
Basic Concepts

- 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



Histogram of CPU-burst Times



CPU (Short-term) 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*
  - Process retains CPU until it releases it
  - Windows 3.1, MAC OS
- All other scheduling is *preemptive.*

Issues with Preemptive Scheduling

- New mechanisms needed to ensure shared data is not in an inconsistent state (partially updated)
- System calls may change important kernel parameters
  - What happens if process preempted
- Unix (most versions) wait for system call to complete or i/o block to take place
- Also interrupts must be guarded from simultaneous use
  - Interrupts disabled at entry, reenabled at exit
- These are bad features for real time or multiprocessor systems

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)

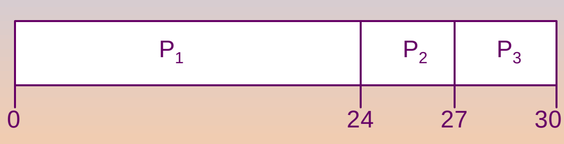
Optimization Criteria

- Max CPU utilization
- Max throughput
- Min turnaround time
- Min waiting time
- Min response time
- In theory minimize variance in 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:



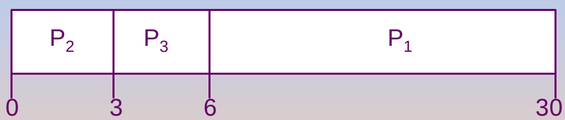
- Waiting time for $P_1 = 0$; $P_2 = 24$; $P_3 = 27$
- Average waiting time: $(0 + 24 + 27)/3 = 17$

FCFS Scheduling (Cont.)

Suppose that the processes arrive in 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

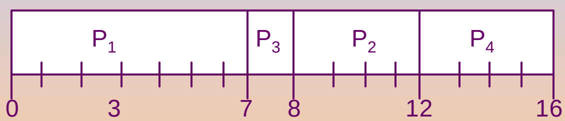
Shortest-Job-First (SJR) Scheduling

- 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)

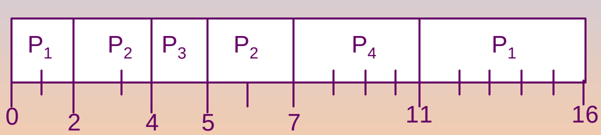


- Average waiting time = (0 + 6 + 3 + 7)/4 = 4

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)



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

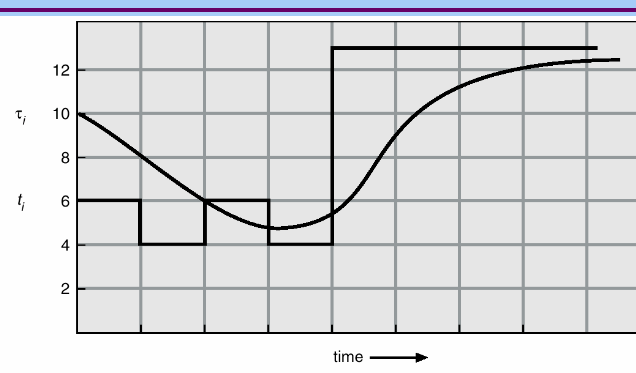
Determining Length of Next CPU Burst

- 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 n^{th} CPU burst
2. $t_{n+1} =$ predicted value for the next CPU burst
3. $a, 0 \le a \le 1$
4. Define:

$$t_{n+1} = a\, t_n + (1-a)t_n.$$

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.
- $\alpha = 1$
  - $\tau_{n+1} = t_n$
  - Only the actual last CPU burst counts.
- If we expand the formula, we get:

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

- 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 ≡ highest priority!! maybe).
  - Preemptive
  - nonpreemptive
- SJF is a priority scheduling where priority is the inverse of the predicted next CPU burst time.
- Problem ≡ Starvation (indefinite postponement) – 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 = 20

Process	Burst Time
P_1	53
P_2	17
P_3	68
P_4	24

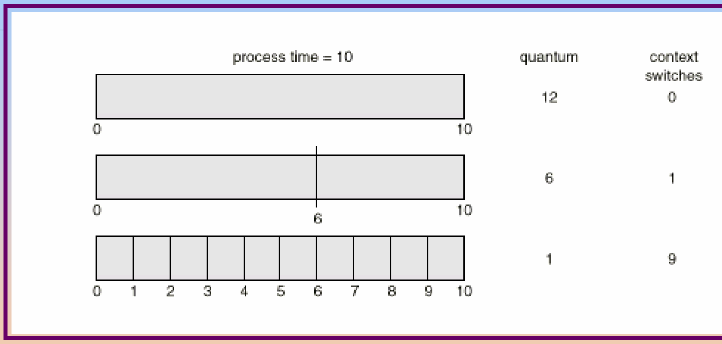
- The Gantt chart is:

P_1	P_2	P_3	P_4	P_1	P_3	P_4	P_1	P_3	P_3

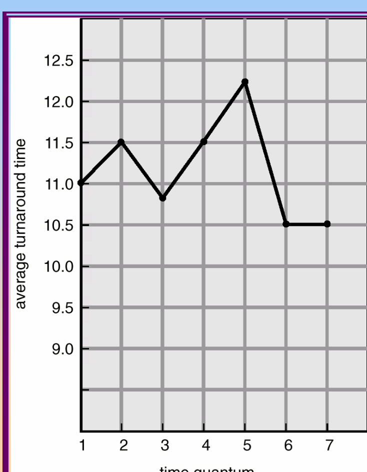
0 20 37 57 77 97 117 121 134 154 162

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

Time Quantum and Context Switch Time



Turnaround Time Varies With The Time Quantum

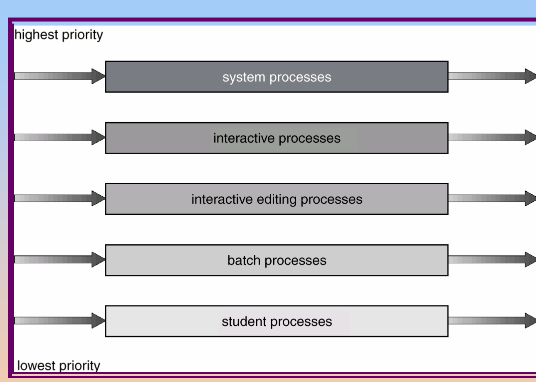


process	time
P_1	6
P_2	3
P_3	1
P_4	7

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



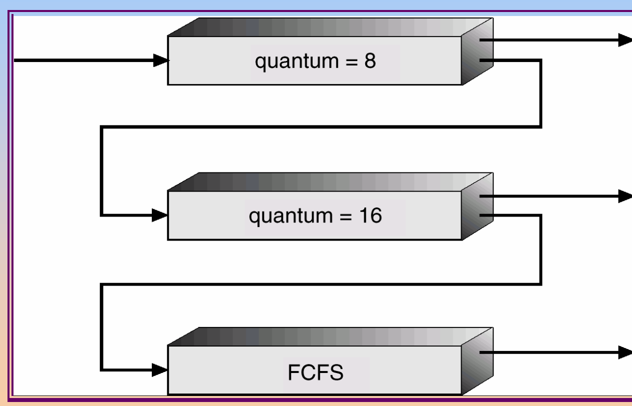
Multilevel Feedback Queue

- 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 – 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.

Multilevel Feedback Queues



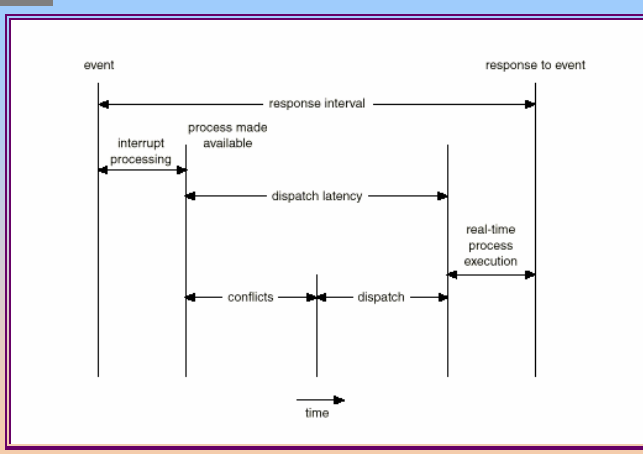
Multiple-Processor Scheduling

- CPU scheduling more complex when multiple CPUs are available.
- Assume*:*
  - *Homogeneous processors* within a multiprocessor.
  - *Uniform memory access* (UMA)
- *Load sharing* - use common ready queue
  - Symmetric – each processor examines ready queue
- *Asymmetric multiprocessing* – only one processor accesses the system data structures, alleviating the need for data sharing protection.

Real-Time Scheduling

- *Hard real-time* systems – required to complete a critical task within a guaranteed amount of time.
  - Need special purpose software on dedicated hardware
  - No secondary storage or virtual memory
- *Soft real-time* computing – requires that critical processes receive priority over less fortunate ones.
  - Need priority scheduling
  - Need small dispatch latency –difficult
  - Unix: context switch only when systems calls complete or I/O blocks
  - Can insert preemption points in system calls
  - Or make kernel preemptible
  - *Read more on this*.

Dispatch Latency

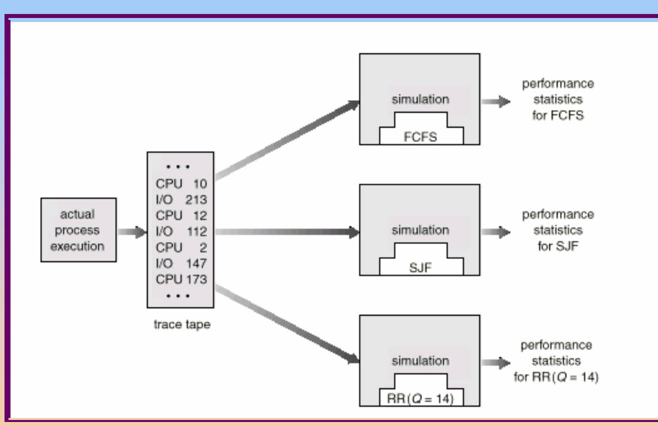


Conflict phase: preempt kernel processes/ release low priority process resources needed by higher priority processes

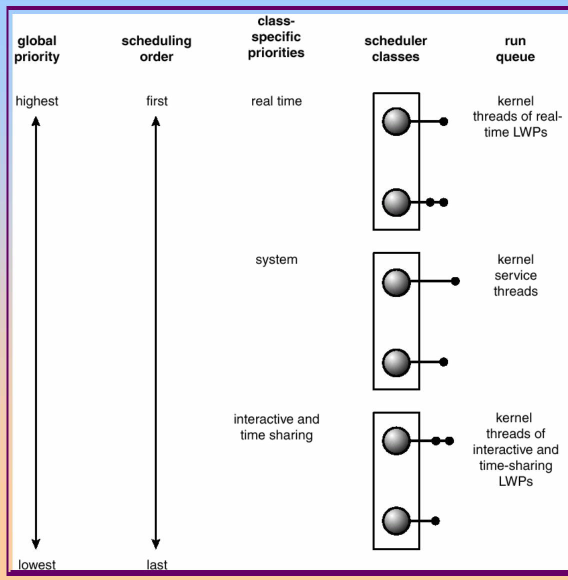
Algorithm Evaluation

- Deterministic modeling – takes a particular predetermined workload and defines the performance of each algorithm for that workload.
- Queueing models – obtain probability distribution from measured CPU and I/O bursts. Treat computer as network of queues of waiting processes with known arrival and service rates
- Simulations – represent components by software data structures.
  - Use random number generator to generate data.
  - Use trace tapes
- Implementation

Evaluation of CPU Schedulers by Simulation



Solaris 2 Scheduling



Windows 2000 Priorities

	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