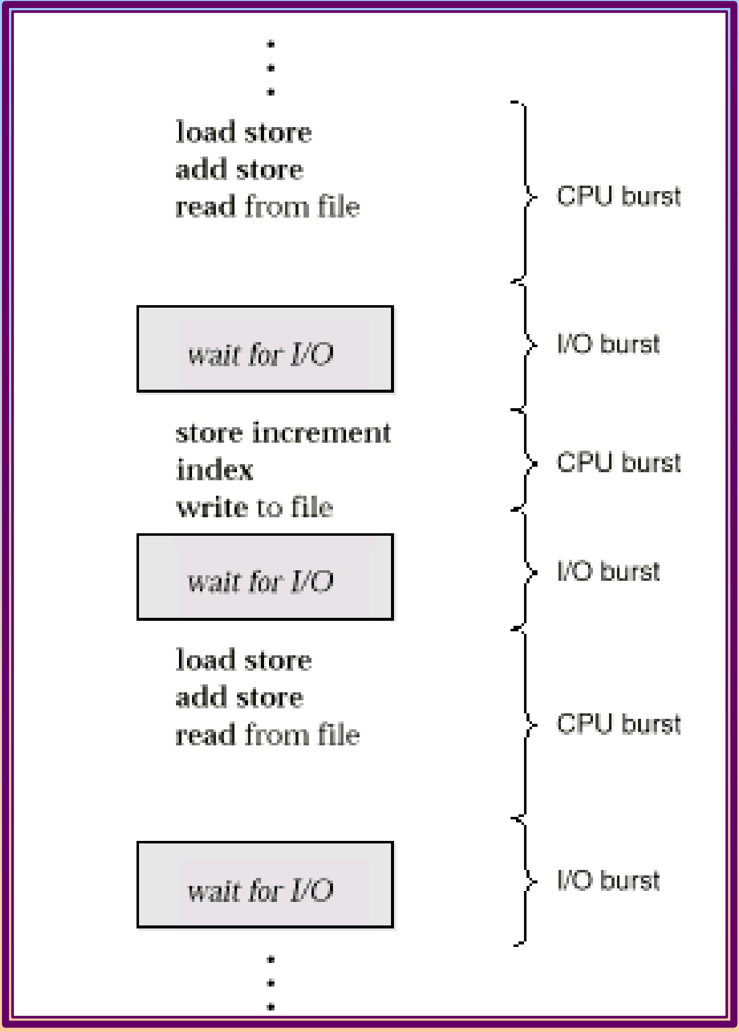
Basic Concepts

- 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

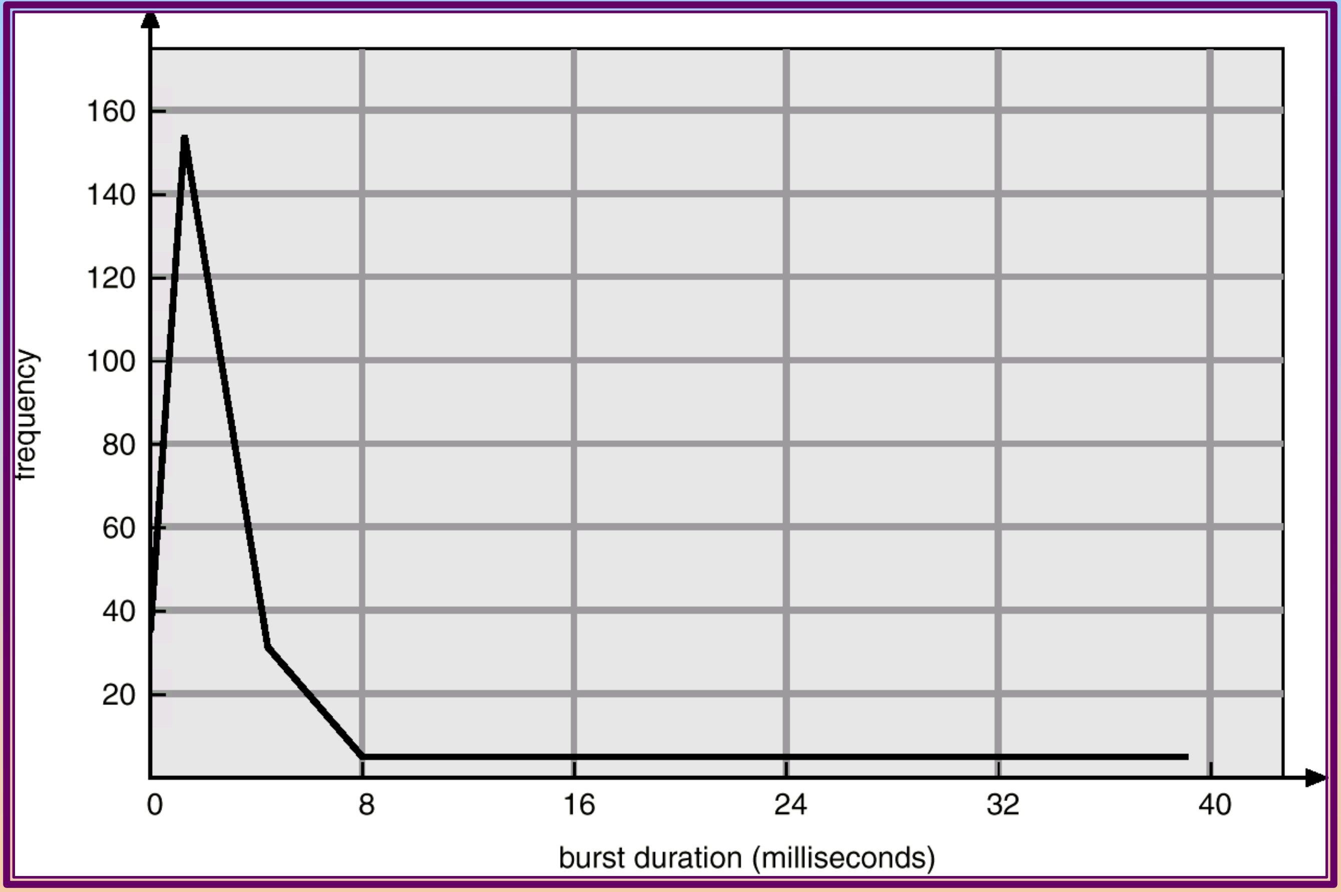
Alternating Sequence of CPU And I/O Bursts

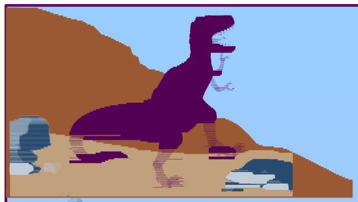


Chapter 6: CPU Scheduling

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

Histogram of CPU-burst Times

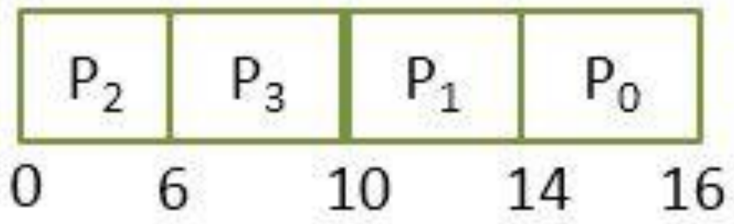




CPU Scheduler

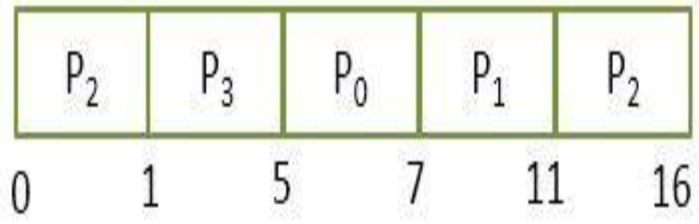
- Selects from among the processes in memory that are ready to execute, and allocates the CPU to one of them.
- CPU scheduling decisions may take place when a process:
  1. Switches from running to waiting state.
  2. Switches from running to ready state.
  3. Switches from waiting to ready.
  4. Terminates.
- Scheduling under 1 and 4 is *nonpreemptive*.
- All other scheduling is *preemptive.*

Process	Arrival Time	CPU Burst Time in millisec.
P_0	3	2
P_1	2	4
P_2	0	6
P_3	1	4



Non-Preemptive Scheduling

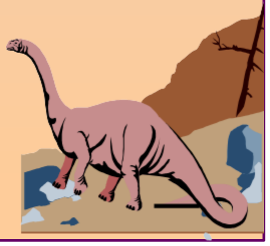
Process	Arrival Time	CPU Burst Time in millisec.
P_0	3	2
P_1	2	4
P_2	0	6
P_3	1	4



Preemptive Scheduling

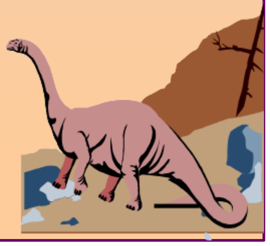
Dispatcher

- 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.



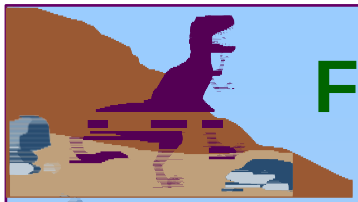
Scheduling Criteria

- 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)



Optimization Criteria

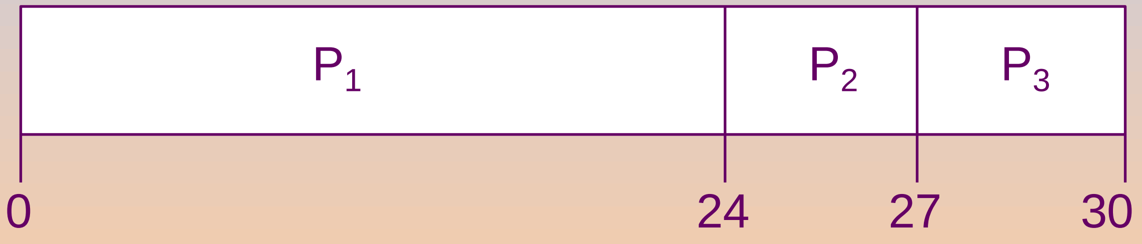
- Max CPU utilization
- Max throughput
- Min turnaround time
- Min waiting time
- Min response time



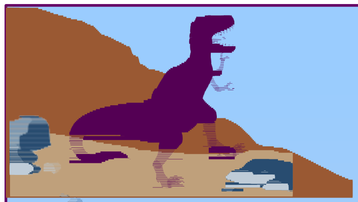
First-Come, First-Served (FCFS) Scheduling

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: $(0 + 24 + 27)/3 = 17$

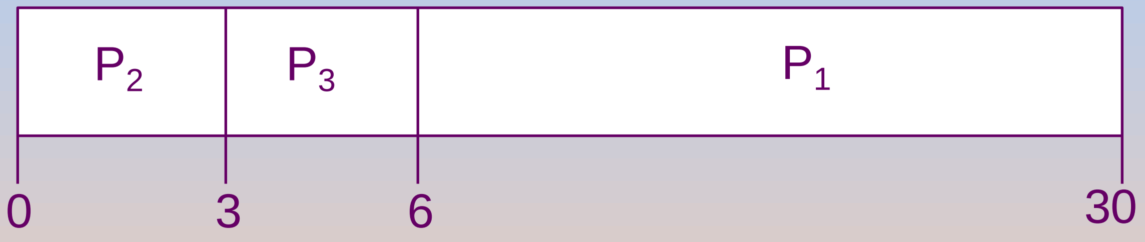


FCFS Scheduling (Cont.)

Suppose that the processes arrive in the order

$P_2 , P_3 , P_1 .$

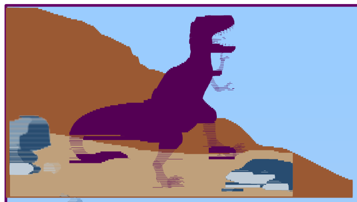
- The Gantt chart for the schedule is:



- 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

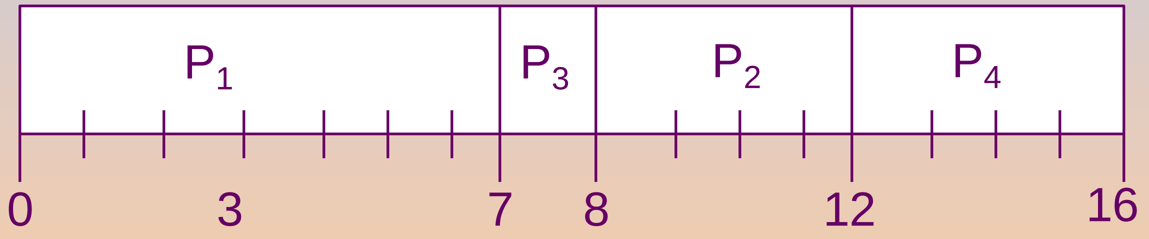
- Associate with each process the length of its next CPU burst. Use these lengths to schedule the process with the shortest time.
- Two schemes:
  - nonpreemptive – once CPU given to the process it cannot be preempted until completes its CPU burst.
  - preemptive – if a new process arrives with CPU burst 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.



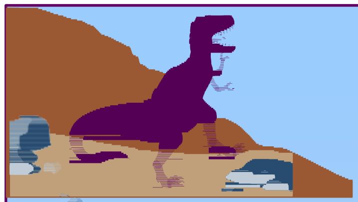
Example of Non-Preemptive SJF

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)



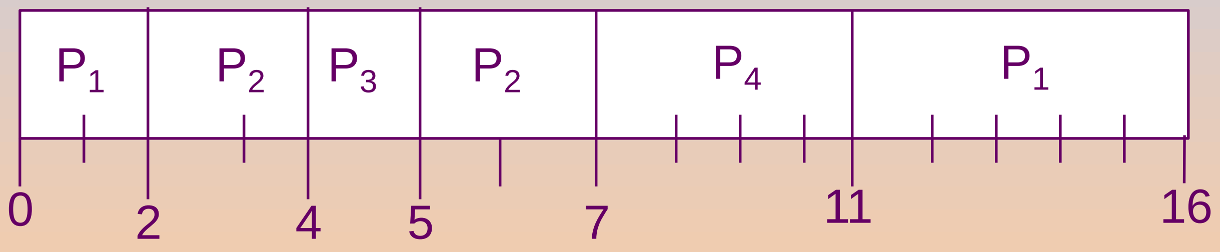
- Average waiting time = (0 + 6 + 3 + 7)/4 - 4



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

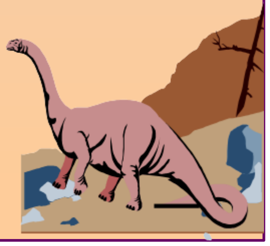
- SJF (preemptive)



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

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.



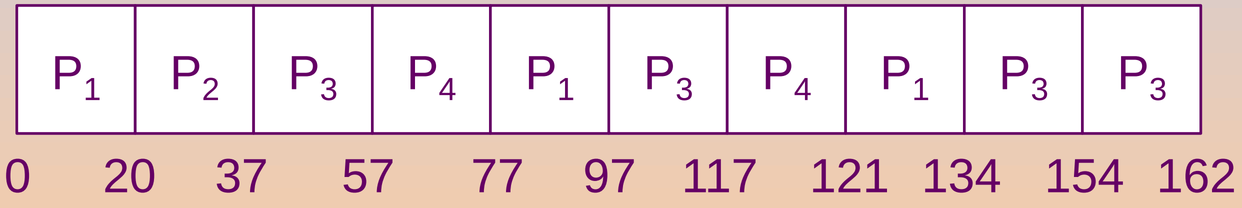
Round Robin (RR)

- 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 → FIFO
  - *q* small → *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:



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