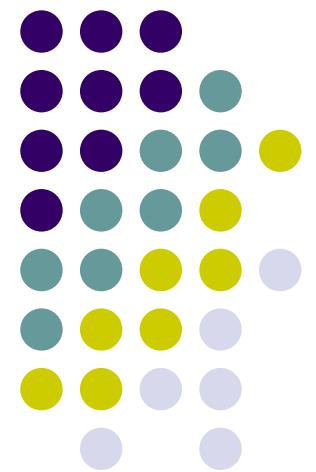


CPU Scheduling





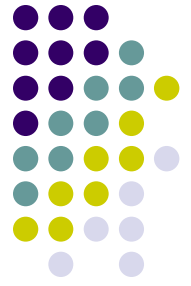
Types of jobs

- CPU-bound vs. I/O-bound
 - Maximum CPU utilization obtained with multiprogramming
- Batch, Interactive, real time
 - Different goals, affects scheduling policies



CPU Scheduler

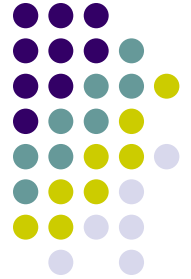
- Selects from among the processes in memory that are ready to execute, and allocates the CPU to one of them
- CPU scheduling decisions may take place when a process:
 - Switches from running to waiting state
 - Switches from running to ready state
 - Switches from waiting to ready
 - Terminates
- Scheduling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



Dispatcher

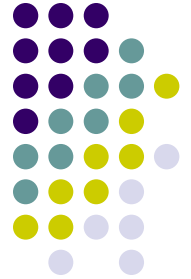
- Dispatcher module gives control of the CPU to the process selected by the CPU scheduler; this involves:
 - switching context
 - switching to user mode
 - jumping to the proper location in the user program to restart that program
- *Dispatch latency* – time it takes for the dispatcher to stop one process and start another running.

Scheduling Criteria



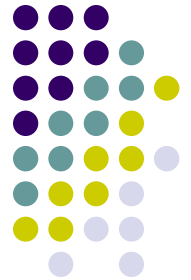
- **CPU utilization** – keep the CPU as busy as possible
- **Throughput** – # of processes that complete their execution per time unit
- **Turnaround time** – amount of time to execute a particular process
- **Waiting time** – amount of time a process has been waiting in the ready queue
- **Response 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



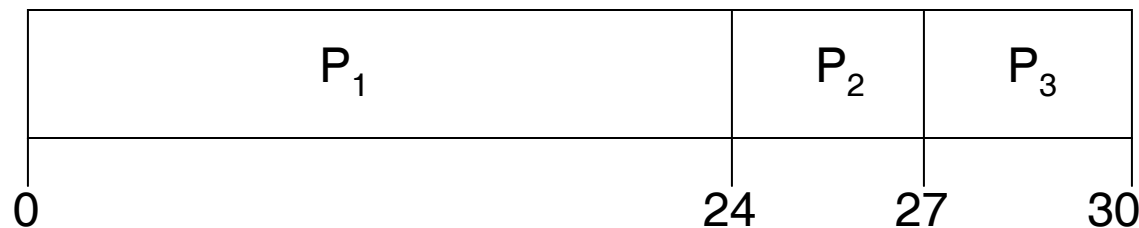
- Max CPU utilization
- Max throughput
- Min turnaround time
- Min waiting time
- Min response time

First-Come, First-Served (FCFS) Scheduling

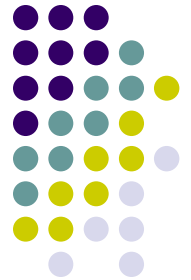


<u>Process</u>	<u>Burst Time</u>
P_1	24
P_2	3
P_3	3

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

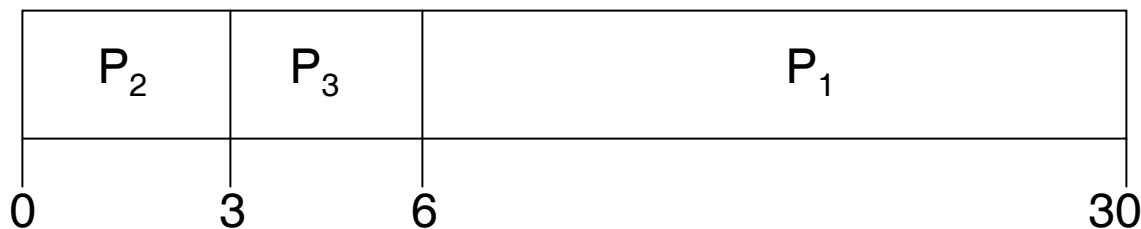


FCFS Scheduling (Cont.)

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

Shortest-Job-First (SJF) Scheduling



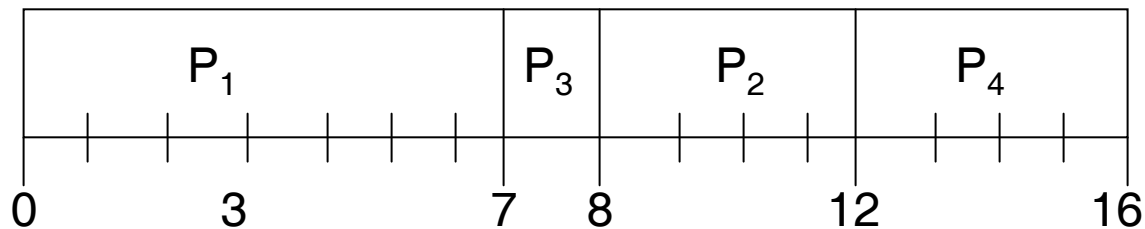
- Associate with each process the length of its next CPU burst. Use these lengths to schedule the process with the shortest time
- Two schemes:
 - nonpreemptive – once CPU given to the process it cannot be preempted until it completes its CPU burst
 - preemptive – if a new process arrives with CPU burst length less than remaining time of current executing process, preempt. This scheme is known 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



<u>Process</u>	<u>Arrival Time</u>	<u>Burst Time</u>
P_1	0.0	7
P_2	2.0	4
P_3	4.0	1
P_4	5.0	4

- SJF (non-preemptive)



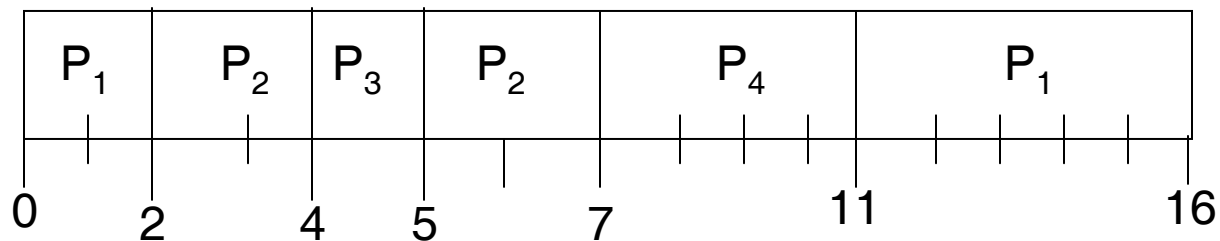
- Average waiting time = $(0 + 6 + 3 + 7)/4 = 4$



Example of Preemptive SJF

<u>Process</u>	<u>Arrival Time</u>	<u>Burst Time</u>
P_1	0.0	7
P_2	2.0	4
P_3	4.0	1
P_4	5.0	4

- SJF (preemptive)

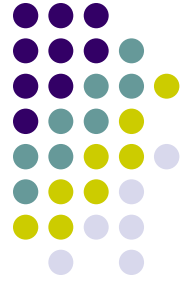


- Average waiting time = $(9 + 1 + 0 + 2)/4 = 3$

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
 - $\tau_{n+1} = \alpha t_n + (1 - \alpha)\tau_n, \quad 0 \leq \alpha \leq 1$
 - t_n = actual length of n^{th} CPU burst



Properties 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, each successive term has less weight than its predecessor
 - Recent history has more weight than old history



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 a priority scheduling where priority is the 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



Round Robin (RR)

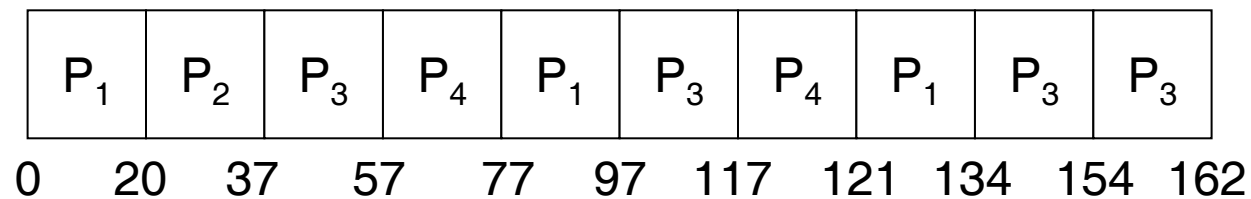
- Each process gets a small unit of CPU time (*time quantum*), usually 10-100 milliseconds. After this time has elapsed, the process is preempted and added to the end of the ready queue
- If there are n processes in the ready queue and the time quantum is q , then each process gets $1/n$ of the CPU time 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



<u>Process</u>	<u>Burst Time</u>
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*.



Multilevel Queue

- Ready queue is partitioned into separate queues: foreground (interactive) and 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 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

