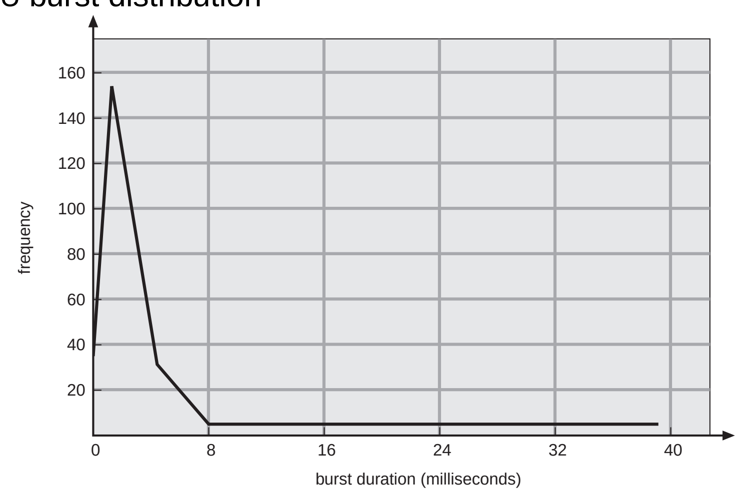
Module 5: CPU Scheduling

- 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



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*.

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

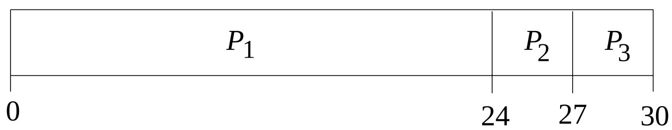
- Max CPU utilization
- Max throughput
- Min turnaround time
- Min waiting time
- Min response time

First-Come, First-Served (FCFS) Scheduling

- Example:

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:



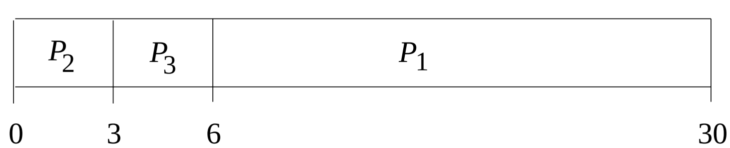
- Waiting time for $P_1 = 0$; $P_2 = 24$; $P_3 = 27$
- Average waiting time: $(0 + 24 + 27)/3 = 17$

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

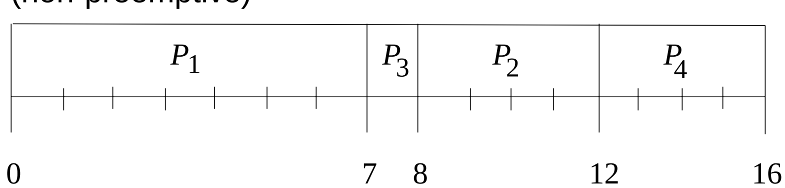
Shortest-Job-First (SJF) Scheduling

- 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

Process	Arrival Time	Burst Time
P_1	0.0	7
P_2	0.2	4
P_3	4.0	1
P_4	5.0	4

- SJF (non-preemptive)

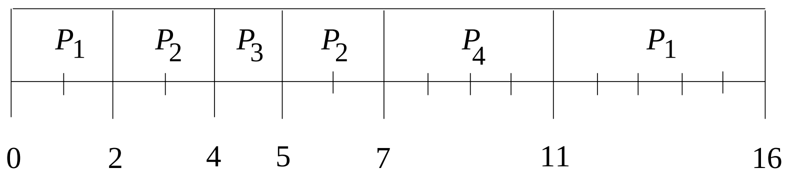


Average waiting time = (0 + 6 + 3 + 7)/4 = 4

Example of Preemptive SJF

Process	Arrival Time	Burst Time
P_1	0.0	7
P_2	0.2	4
P_3	4.0	1
P_4	5.0	4

- SRTF (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 length of n^{th} CPU burst
  2. τ_{n+1} = predicted value for the next CPU burst
  3. α, $0 \leq \alpha \leq 1$
  4. Define:

$$\tau_{n+1} = \alpha\, t_n + (1 - \alpha)\tau_n.$$

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:

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

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

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
- SJN 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: 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 SRTF, but better *response.*

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 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 algorithm 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.

Multiple-Processor Scheduling

- CPU scheduling more complex when multiple CPUs are available.
- *Homogeneous* processors within a multiprocessor.
- *Load sharing*
- *Asymmetric multiprocessing* – only one processor accesses the system data structures, alleviating the need for data sharing.

Real-Time Scheduling

- *Hard real-time* systems – required to complete a critical task within a guaranteed amount of time.
- *Soft real-time* computing – requires that critical processes receive priority over less fortunate ones.

Algorithm Evaluation

- *Deterministic modeling* – takes a particular predetermined workload and defines the performance of each algorithm for that workload.
- Queueing models
- Implementation