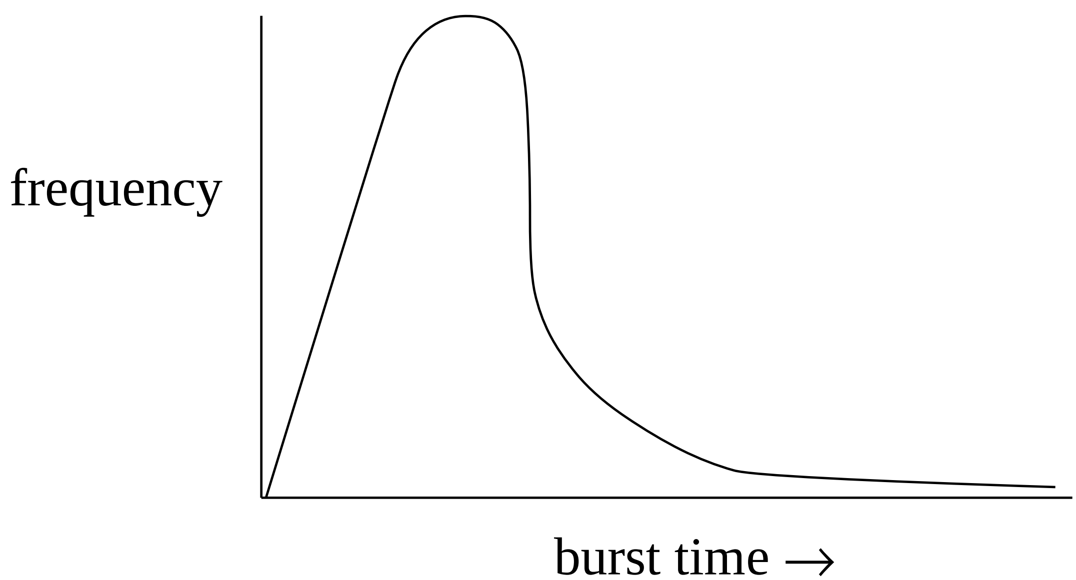
CHAPTER 5: CPU SCHEDULING

- 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



- *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*.

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

First-Come, First-Served (FCFS) Scheduling

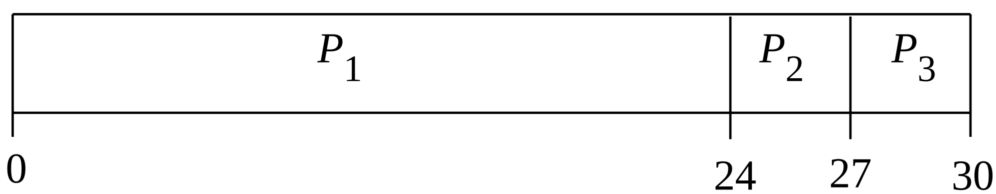
- Example:

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:



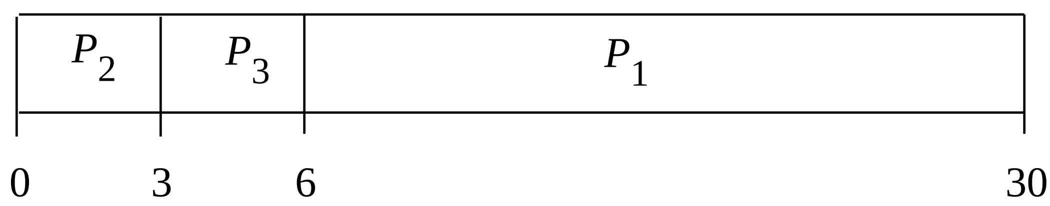
- Waiting time for: $P_1 = 0$
  $P_2 = 24$
  $P_3 = 27$

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

- 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:

  a) nonpreemptive – once CPU given to the process it cannot be preempted until it completes its CPU burst.

  b) 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 SJF

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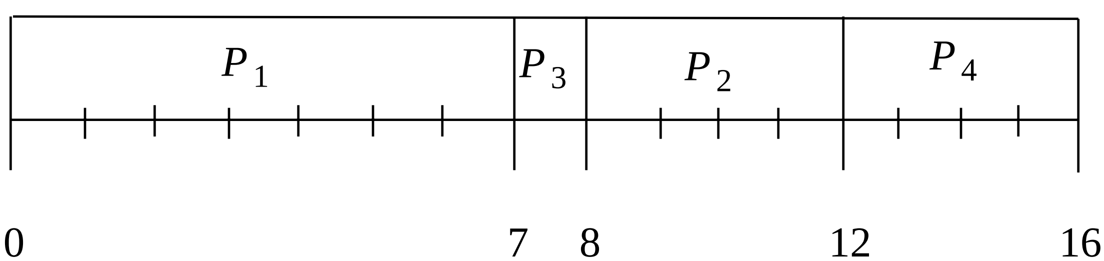
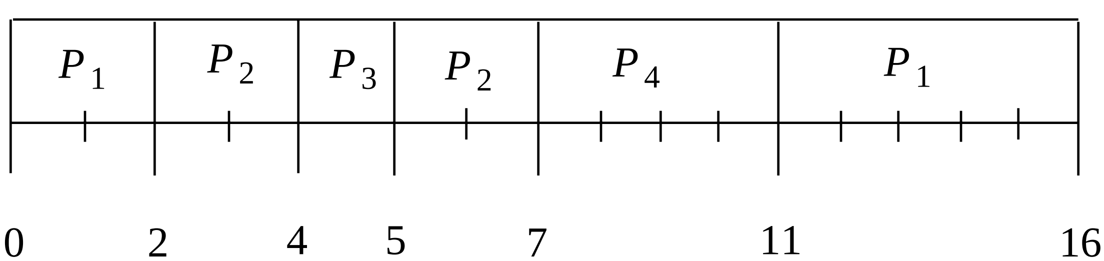
Process	Arrival time	CPU time
P_1	0	7
P_2	2	4
P_3	4	1
P_4	5	4

- SJF (non-preemptive)



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

- SRTF (preemptive)



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

How do we know the length of the 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. ψ_n = predicted value of n^{th} CPU burst

  3. $0 \le W \le 1$

  4. Define:

$$\psi_{n+1} = W * T_n + (1 - W)\,\psi_n$$

Examples:

- $W = 0$

  $\psi_{n+1} = \psi_n$

  Recent history does not count.

- $W = 1$

  $\psi_{n+1} = T_n$

  Only the actual last CPU burst counts.

- If we expand the formula, we get:

$$\psi_{n+1} = W * T_n + (1 - W) * W * T_{n-1} + (1 - W)^2 * W * T_{n-2} + \ldots + (1 - W)^q * W * T_{n-q}$$

So if $W = 1/2 \Rightarrow$ each successive term has less and less weight.

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).

  a) preemptive

  b) nonpreemptive

- SJN 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 $\Rightarrow$ 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	CPU times
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 SRT, but better *response*.

Multilevel Queue

- Ready queue is partitioned into separate queues.

  Example: foreground (interactive)
  background (batch)

- Each queue has its own scheduling algorithm.

  Example: foreground – RR
  background – FCFS

- Scheduling must be done between the queues.

  - Fixed priority scheduling

    Example: 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.

    Example:

    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