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
Alternating Sequence of CPU And I/O Bursts

- load store
- add store
- read from file

- wait for I/O
- store increment
- index
- write to file

- wait for I/O
- load store
- add store
- read from file

- CPU burst
- I/O burst
- CPU burst
- I/O burst
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*.
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
- \textit{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:

<table>
<thead>
<tr>
<th>Process</th>
<th>Burst Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_1$</td>
<td>24</td>
</tr>
<tr>
<td>$P_2$</td>
<td>3</td>
</tr>
<tr>
<td>$P_3$</td>
<td>3</td>
</tr>
</tbody>
</table>

- Suppose that the processes arrive in the order: $P_1$, $P_2$, $P_3$

The Gantt Chart for the schedule is:

<table>
<thead>
<tr>
<th></th>
<th>$P_1$</th>
<th>$P_2$</th>
<th>$P_3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
<td>24</td>
<td>27</td>
</tr>
<tr>
<td>24</td>
<td></td>
<td></td>
<td>30</td>
</tr>
</tbody>
</table>

- 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:

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th>30</th>
</tr>
</thead>
<tbody>
<tr>
<td>P_2</td>
<td>P_3</td>
<td>P_1</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>3</td>
<td>6</td>
<td>30</td>
</tr>
</tbody>
</table>

- 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 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

<table>
<thead>
<tr>
<th>Process</th>
<th>Arrival Time</th>
<th>Burst Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_1$</td>
<td>0.0</td>
<td>7</td>
</tr>
<tr>
<td>$P_2$</td>
<td>2.0</td>
<td>4</td>
</tr>
<tr>
<td>$P_3$</td>
<td>4.0</td>
<td>1</td>
</tr>
<tr>
<td>$P_4$</td>
<td>5.0</td>
<td>4</td>
</tr>
</tbody>
</table>

- SJF (non-preemptive)

- Average waiting time $= (0 + 6 + 3 + 7)/4 - 4$
### Example of Preemptive SJF

<table>
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<td>4</td>
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<tr>
<td>$P_3$</td>
<td>4.0</td>
<td>1</td>
</tr>
<tr>
<td>$P_4$</td>
<td>5.0</td>
<td>4</td>
</tr>
</tbody>
</table>

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

$$\tau_{n+1} = \alpha t_n + (1 - \alpha) \tau_n.$$
Examples of Exponential Averaging

- **α = 0**
  - $\tau_{n+1} = \tau_n$
  - Recent history does not count.

- **α = 1**
  - $\tau_{n+1} = t_n$
  - Only the actual last CPU burst counts.

- If we expand the formula, we get:
  \[
  \tau_{n+1} = \alpha t_n + (1 - \alpha) \alpha t_{n-1} + \ldots \\
  + (1 - \alpha)^i \alpha t_{n-i} + \ldots \\
  + (1 - \alpha)^{n+1} t_n \tau_0
  \]

- Since both $\alpha$ 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).
  - 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 $\Rightarrow$ FIFO
  - $q$ small $\Rightarrow q$ must be large with respect to context switch, otherwise overhead is too high.
Example: RR with Time Quantum = 20

<table>
<thead>
<tr>
<th>Process</th>
<th>Burst Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_1$</td>
<td>53</td>
</tr>
<tr>
<td>$P_2$</td>
<td>17</td>
</tr>
<tr>
<td>$P_3$</td>
<td>68</td>
</tr>
<tr>
<td>$P_4$</td>
<td>24</td>
</tr>
</tbody>
</table>

- 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.
How a Smaller Time Quantum Increases Context Switches

![Diagram showing process time and context switches]
Turnaround Time Varies With The Time Quantum

- **Graph**
  - X-axis: Time Quantum
  - Y-axis: Average Turnaround Time

- **Table**
  - Process: $P_1$, $P_2$, $P_3$, $P_4$
  - Time: 6, 3, 1, 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

- highest priority
  - system processes
- interactive processes
- interactive editing processes
- batch processes
- student processes

lowest priority
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
Multilevel Feedback Queues

quantum = 8

quantum = 16

FCFS
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 $Q_2$. 
5.26 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.
Dispatch Latency

Diagram showing the components of dispatch latency:
- Event
- Response interval
- Process made available
- Dispatch latency
- Conflict
- Dispatch
- Real-time process execution
- Time
Algorithm Evaluation

- Deterministic modeling – takes a particular predetermined workload and defines the performance of each algorithm for that workload.
- Queuing models
- Implementation
Evaluation of CPU Schedulers by Simulation

- actual process execution
  - CPU 10
  - I/O 213
  - CPU 12
  - I/O 112
  - CPU 2
  - I/O 147
  - CPU 173

- trace tape

- simulation
  - FCFS
  - performance statistics for FCFS

- simulation
  - SJF
  - performance statistics for SJF

- simulation
  - RR (Q = 14)
  - performance statistics for RR (Q = 14)