Chapter 6: 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

Histogram of CPU-burst Times
CPU (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
  - Process retains CPU until it releases it
  - Windows 3.1, MAC OS
- All other scheduling is preemptive.

Issues with Preemptive Scheduling

- New mechanisms needed to ensure shared data is not in an inconsistent state (partially updated)
- System calls may change important kernel parameters
  - What happens if process preempted
- Unix (most versions) wait for system call to complete or i/o block to take place
- Also interrupts must be guarded from simultaneous use
  - Interrupts disabled at entry, reenabled at exit
- These are bad features for real time or multiprocessor systems
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
- In theory minimize variance in response time

First-Come, First-Served (FCFS) Scheduling

<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>Time</td>
<td>0</td>
<td>24</td>
<td>27</td>
</tr>
</tbody>
</table>

- 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:

<table>
<thead>
<tr>
<th></th>
<th>$P_2$</th>
<th>$P_3$</th>
<th>$P_1$</th>
</tr>
</thead>
<tbody>
<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 (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 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

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<tr>
<th>Process</th>
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<tr>
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<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 (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:

\[
\tau_{n+1} = \alpha \cdot t_n + (1 - \alpha) \cdot \tau_n.
\]

Prediction of the Length of the Next CPU Burst

| CPU burst ($t_i$) | 6 | 4 | 6 | 4 | 13 | 13 | 13 | ...
| "guess" ($\tau_i$) | 10 | 6 | 6 | 6 | 5 | 9 | 11 | 12 | ...
Examples of Exponential Averaging

- $\alpha = 0$
  - $\tau_{n+1} = \tau_n$
  - Recent history does not count.
- $\alpha = 1$
  - $\tau_{n+1} = f_n$
  - Only the actual last CPU burst counts.
- If we expand the formula, we get:
  \[
  \tau_{n+1} = \alpha t_{n+1}(1 - \alpha) \alpha t_n - 1 + \ldots + (1 - \alpha) \alpha t_{n-1} - 1 + \ldots + (1 - \alpha)^{n-1} t_n \tau_0
  \]
  - 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 $\equiv$ highest priority!! maybe).
  - Preemptive
  - nonpreemptive
- SJF is a priority scheduling where priority is the inverse of the predicted next CPU burst time.
- Problem $\equiv$ Starvation (indefinite postponement) – 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

<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:

```
<table>
<thead>
<tr>
<th>P_1</th>
<th>P_2</th>
<th>P_3</th>
<th>P_4</th>
<th>P_1</th>
<th>P_3</th>
<th>P_4</th>
<th>P_1</th>
<th>P_3</th>
<th>P_3</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>20</td>
<td>37</td>
<td>57</td>
<td>77</td>
<td>97</td>
<td>117</td>
<td>121</td>
<td>134</td>
<td>154</td>
</tr>
</tbody>
</table>
```

- Typically, higher average turnaround than SJF, but better response.
Time Quantum and Context Switch Time

Turnaround Time Varies With The Time Quantum
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
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

- quantum = 8
- quantum = 16
- FCFS

Multiple-Processor Scheduling

- CPU scheduling more complex when multiple CPUs are available.
- Assume:
  - Homogeneous processors within a multiprocessor.
  - Uniform memory access (UMA)
- Load sharing - use common ready queue
  - Symmetric – each processor examines ready queue
- Asymmetric multiprocessing – only one processor accesses the system data structures, alleviating the need for data sharing protection.
**Real-Time Scheduling**

- **Hard real-time systems** – required to complete a critical task within a guaranteed amount of time.
  - Need special purpose software on dedicated hardware
  - No secondary storage or virtual memory
- **Soft real-time computing** – requires that critical processes receive priority over less fortunate ones.
  - Need priority scheduling
  - Need small dispatch latency – difficult
  - Unix: context switch only when systems calls complete or I/O blocks
  - Can insert preemption points in system calls
  - Or make kernel preemptible
  - *Read more on this.*

**Dispatch Latency**

Conflict phase: preempt kernel processes/ release low priority process resources needed by higher priority processes
Algorithm Evaluation

- Deterministic modeling – takes a particular predetermined workload and defines the performance of each algorithm for that workload.
- Queueing models – obtain probability distribution from measured CPU and I/O bursts. Treat computer as network of queues of waiting processes with known arrival and service rates.
- Simulations – represent components by software data structures.
  - Use random number generator to generate data.
  - Use trace tapes
- Implementation

Evaluation of CPU Schedulers by Simulation
Solaris 2 Scheduling

Windows 2000 Priorities

<table>
<thead>
<tr>
<th></th>
<th>real-time</th>
<th>high</th>
<th>above normal</th>
<th>normal</th>
<th>below normal</th>
<th>idle</th>
<th>priority</th>
</tr>
</thead>
<tbody>
<tr>
<td>time-critical</td>
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<tr>
<td>highest</td>
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<td>8</td>
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<td>2</td>
<td>2</td>
</tr>
<tr>
<td>idle</td>
<td>16</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>