CPU Scheduling

User/Kernel Threads

- **User threads**
  - Thread data structure is in user-mode memory
  - scheduling/switching done at user mode
- **Kernel threads**
  - Thread data structure is in kernel memory
  - scheduling/switching done by the OS kernel

**Benefits of user threads**
- lightweight - less context switching overhead
- flexibility - allow application-controlled scheduling

**Problems of user threads**
- can’t use more than one processor
- oblivious to kernel events, e.g., all threads in a process are put to wait when only one of them does I/O

Mixed User/Kernel Threads

- **M** user threads run on **N** kernel threads (M ≥ N)
  - **N=1**: pure user threads
  - **M=N**: pure kernel threads
  - **M>N>1**: mixed model

Solaris/Linux Threads

- **Solaris**
  - supports mixed model
- **Linux**
  - No standard user threads on Linux
  - Processes are treated similarly with threads (both called tasks)
  - Processes are tasks with exclusive address space
  - Tasks can also share the address space, open files, ...
Pthreads

- Different OS has its own thread package with different Application Programming Interfaces ⇒ poor portability.
- Pthreads
  - A POSIX standard API for thread management and synchronization.
  - API specifies behavior of the thread library, not the implementation.
  - Commonly supported in UNIX operating systems.

CPU Scheduling

- Selects from among the processes/threads that are ready to execute, and allocates the CPU to it.
- CPU scheduling may take place at:
  1. Hardware interrupt/software exception.
  2. System calls.
- Nonpreemptive:
  - Scheduling only when the current process terminates or not able to run further
- Preemptive:
  - Scheduling can occur at any opportunity possible

Scheduling Criteria

- Minimize turnaround time – amount of time to execute a particular process
- Maximize throughput – # of processes that complete their execution per time unit
- Maximize CPU utilization – the proportion of the CPU that is not idle
- Minimize response time – amount of time it takes from when a request was submitted until the first response is produced (interactivity)
- Fairness: avoid starvation

First-Come, First-Served (FCFS) Scheduling

<table>
<thead>
<tr>
<th>Process</th>
<th>CPU Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>P₁</td>
<td>24</td>
</tr>
<tr>
<td>P₂</td>
<td>3</td>
</tr>
<tr>
<td>P₃</td>
<td>3</td>
</tr>
</tbody>
</table>

Suppose that the processes arrive in the order: P₁, P₂, P₃
The schedule is:

<table>
<thead>
<tr>
<th></th>
<th>P₁</th>
<th>P₂</th>
<th>P₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>24</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>27</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Turnaround time for P₁ = 24; P₂ = 27; P₃ = 30
- Average turnaround time: (24 + 27 + 30)/3 = 27
FCFS Scheduling (Cont.)

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

- The schedule is:

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></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>

- Turnaround time for $P_1 = 30$; $P_2 = 3$; $P_3 = 6$
- Average turnaround time: $(30 + 3 + 6)/3 = 13$
- Much better than previous case.
- Short process delayed by long process: Convoy effect

Shortest-Job-First (SJR) Scheduling

- Associate with each process the length of its CPU time. Use these lengths to schedule the process with the shortest CPU time.
- Two variations:
  - nonpreemptive - once CPU given to the process it cannot be taken away until it completes.
  - preemptive - if a new process arrives with CPU time less than remaining time of current executing process, preempt.
- Preemptive SJF is optimal - gives minimum average turnaround time for a given set of processes.
- Problem:
  - don’t know the process CPU time ahead of time.

Example of Preemptive SJF

<table>
<thead>
<tr>
<th>Process</th>
<th>Arrival Time</th>
<th>CPU 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 (preemptive)

<p>| | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_1$</td>
<td>$P_2$</td>
<td>$P_3$</td>
<td>$P_4$</td>
<td></td>
<td>$P_1$</td>
</tr>
<tr>
<td>0</td>
<td>2</td>
<td>4</td>
<td>5</td>
<td>7</td>
<td>11</td>
</tr>
</tbody>
</table>

- Average turnaround time = $(16 + 5 + 1 + 6)/4 = 7$

Priority Scheduling

- A priority number (integer) is associated with each process
- The CPU is allocated to the process with the highest priority.
  - Preemptive
  - nonpreemptive
- SJF is a priority scheduling where priority is the predicted CPU 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 fixed 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
  - \( q \) small ⇒ fair, starvation-free, better interactivity
  - \( q \) large ⇒ FIFO
  - \( q \) must be large with respect to context switch cost, otherwise overhead is too high.

Cost of Context Switch

- Direct overhead of context switch
  - saving old contexts, restoring new contexts, ...
- Indirect overhead of context switch
  - caching, memory management overhead

Example of RR with Quantum = 20

<table>
<thead>
<tr>
<th>Process</th>
<th>CPU 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 schedule is:

\[
\begin{array}{cccccccccccc}
 & P_1 & P_2 & P_3 & P_4 & P_1 & P_3 & P_4 & P_1 & P_3 & P_2 & P_3 \\
0 & 20 & 37 & 57 & 77 & 97 & 117 & 121 & 134 & 154 & 162 & \\
\end{array}
\]

- Typically, higher average turnaround than SJF, but better response.

Multilevel Scheduling

- Ready tasks are partitioned into separate classes: foreground (interactive) background (batch)
- Each class has its own scheduling algorithm, foreground – RR background – FCFS
- Scheduling must be done between the classes.
  - Fixed priority scheduling; (i.e., serve all from foreground then from background). Possibility of starvation.
  - Time slice – each class gets a certain amount of CPU time which it can schedule amongst its processes; e.g.,
    - 80% to foreground in RR
    - 20% to background in FCFS
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.
- **EDF** - Earliest Deadline First Scheduling.

Linux Task Scheduling

- Linux uses two task-scheduling classes:
  - A time-sharing class for fair preemptive scheduling.
  - A real-time class that conforms to POSIX real-time standard.
- For time-sharing tasks, Linux 2.4 uses a prioritized, credit based algorithm.
  - Each task carries an static priority, a dynamic credit; initially a task’s credit is its priority
  - Scheduling is epoch-based. At each epoch
    - scheduling is ordered on the initial credit
    - Credit of the running task decrements by one at every clock tick
  - Epoch ends when no runnable tasks have any credit - recrediting
    \[ \text{credits} = \frac{\text{credits}}{2} + \text{priority} \]
  - This crediting system automatically prioritizes interactive or I/O-bound tasks.

CPU Scheduling on Multi-Processors

- **Cache affinity**
  - keep a task on a particular processor as much as possible
- **Resource contention**
  - prevent resource-conflicting tasks run simultaneously on sibling processors

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