CS 537 Notes, Section #11: Scheduling and CPU Scheduling

Scheduling

Until now we have talked about processes, from now on we will talk about *resources*, the things operated upon by processes. Resources range from cpu time to disk space to channel I/O time.

Resources fall into two classes:

- Preemptible: processor or I/O channel. Can take resource away, use it for something else, then give it back later.

  Non-preemptible: once given, it cannot be reused until process gives it back. Examples are file space, terminal, and maybe memory.

OS makes two related kinds of decisions about resources:

- Allocation: who gets what. Given a set of requests for resources, which processes should be given which resources in order to make most efficient use of the resources? Implication is that resources are not easily preemptible.
- Scheduling: how long can they keep it. When more resources are requested than can be granted immediately, in which order should they be serviced? Examples are processor scheduling (one processor, many processes), memory scheduling in virtual memory systems. Implication is that resource is preemptible.

Resource #1: the processor.

CPU Scheduling

Processes may be in any one of three general scheduling states:

- Running.

  Ready. That is, waiting for CPU time. Scheduler and dispatcher determine transitions between this and running state.

- Blocked. Waiting for some other event: disk I/O, message, semaphore, etc. Transitions into and out of this state are caused by various processes.

There are two parts to CPU scheduling:

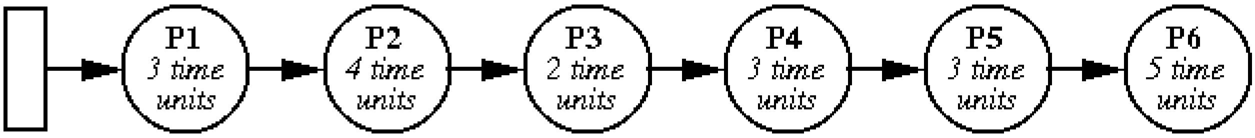
- The dispatcher provides the basic *mechanism* for running processes.
- The scheduler is a piece of OS code that decides the *priorities* of processes and how long each will run.

This is an example of policy/mechanism separation.

Goals for Scheduling Disciplines

- Efficiency of resource utilization *(keep CPU and disks busy)*.
- Minimize overhead *(context swaps)*.
- Minimize response time. (Define response time.)
- Distribute cycles equitably. What does this mean?

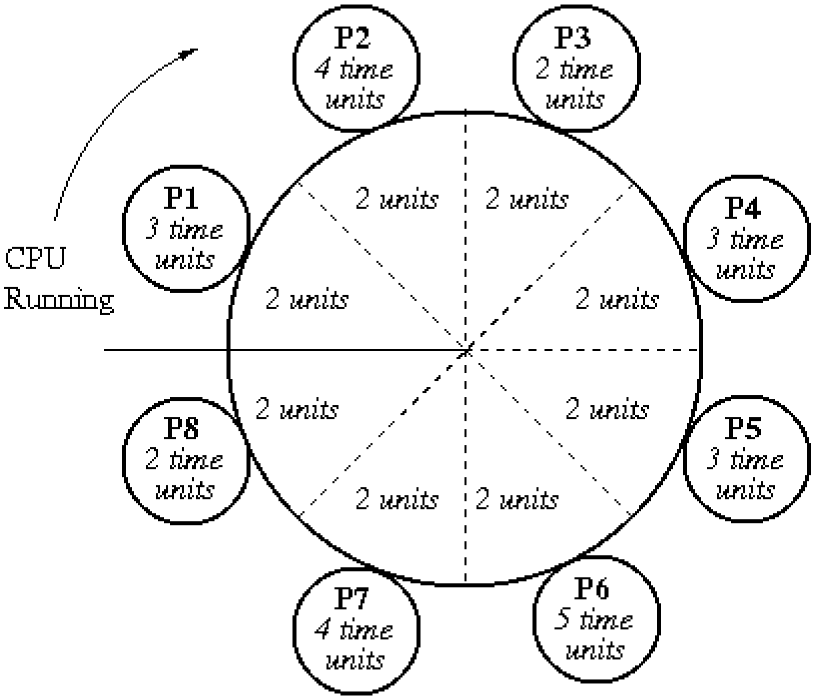
FCFS (also called FIFO): run until finished.



- In the simplest case this means uniprogramming.
- Usually, "finished" means "blocked". One process can use CPU while another waits on a semaphore. Go to back of run queue when ready.
- Problem: one process can monopolize CPU.

Solution: limit maximum amount of time that a process can run without a context switch. This time is called a *time slice*.

Round Robin: run process for one time slice, then move to back of queue. Each process gets equal share of the CPU. Most systems use some variant of this. What happens if the time slice is not chosen carefully?



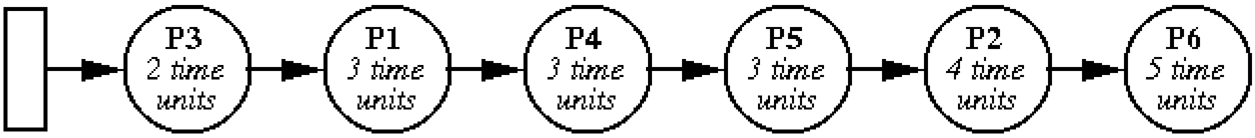
Originally, Unix had 1 sec. time slices. Too long. Most timesharing systems today use time slices of 10,000 - 100,000 instructions.

Implementation of priorities: run highest priority processes first, use round-robin among processes of equal priority. Re-insert process in run queue behind all processes of greater or equal priority.

Even round-robin can produce bad results occasionally. Go through example of ten processes each requiring 100 time slices.

What is the best we can do?

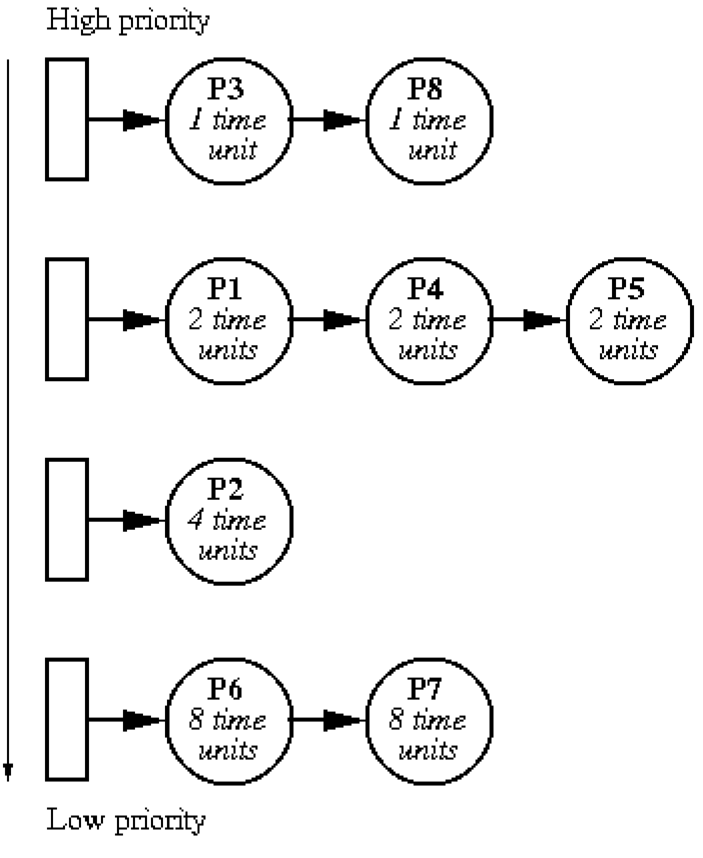
STCF: shortest time to completion first with preemption. This minimizes the average response time.



As an example, show two processes, one doing 1 ms computation followed by 10 ms I/O, one doing all computation. Suppose we use 100 ms time slice: I/O process only runs at 1/10th speed, effective I/O time is 100 ms. Suppose we use 1 ms time slice: then compute-bound process gets interrupted 9 times unnecessarily for each valid interrupt. STCF works quite nicely.

Unfortunately, STCF requires knowledge of the future. Instead, we can use *past* performance to predict *future* performance.

Exponential Queue (also called "multi-level feedback queues"): attacks both efficiency and response time problems.



- Give newly runnable process a high priority and a very short time slice. If process uses up the time slice without blocking then decrease priority by 1 and double time slice for next time.
- Go through the above example, where the initial values are 1ms and priority 100.
- Techniques like this one are called *adaptive*. They are common in interactive systems.
- The CTSS system (MIT, early 1960's) was the first to use exponential queues.

Linux's new scheduler (version 2.6) makes this all very complex:

- Two queues: one with *active* (eligible to run) processes and with *expired* (not eligible to run) processes.
- 140 priority levels, but the top 100 are reserved for "real time" processes.
- Always choose a process from the highest non-empty priority level.

- Priority level is the sum of its *static priority* and its *dynamic priority bonus*, which the scheduler assigns as an estimate of its interactivity.

  Niceness, the value that

- Static priorities range from 0-39 (number of queues) and dynamic priority bonuses range from -5 to +5.
- Time slices assigned based on static priority, giving higher-priority tasks larger time slices and lower-priority tasks shorter time slices.
- A task might not use all of its time slice at once, since it could block or be preempted before it finishes, but eventually it consumes the entire amount. When that happens, the task is usually placed on the expired array with a new time slice and a recalculated priority.
- An interactive task receives the same time slice as others at the same static priority, but the slice is divided into smaller pieces. When it finishes a piece, the task will round robin with other tasks at the same priority level. Execution rotates more frequently among interactive tasks of the same priority, but higher-priority tasks will run for longer before expiring

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Summary:

- In principle, scheduling algorithms can be arbitrary, since the system should behave the same in any event.
- However, the algorithms have crucial effects on the behavior of the system:
  - Overhead: number of context swaps.
  - Efficiency: utilization of CPU and devices.
  - Response time: how long it takes to do something.
- The best schemes are adaptive. To do absolutely best, we would have to be able to predict the future.

Priority Inversion Problem

There are some curious interactions between scheduling and synchronization. A classic problem caused by this interaction was first observed in 1979 but Butler Lampson and David Redell at Xerox.

Suppose that you have three processes:

P_1: Highest priority

P_2: Medium priority

P_3: Lowest priority

And suppose that you have the following critical section, S:

```
S:  mutex.P()
     . . .
     . . .
    mutex.V()
```

The three processes execute as follows:

1. P_3 enters S, locking the critical section.
2. P_3 is preempted by the scheduler and P_2 starts running.
3. P_2 is preempted by the scheduler and P_1 starts running.
4. P_1 tries to enter S and is blocked at the P operation.
5. P_2 starts running again, preventing P_1 from running.

So, what's going wrong here?
To really understand this situation, you should try to work out the example for yourself, before continuing to read.

- As long as process P_2 is running, process P_3 cannot run.
- If P_3 cannot run, then it cannot leave the critical section S.
- If P_3 does not leave the critical section, then P_1 cannot enter.

As a result, P_2 running (at medium priority) is blocking P_1 (at highest priority) from running. This example is not an academic one. Many designers of real-time systems, where priority can be crucial, have stumbled over issue. You can read the original paper by Lampson and Redell to see their suggestion for handling the situation. Also, do a Web search for priority inversion.
