

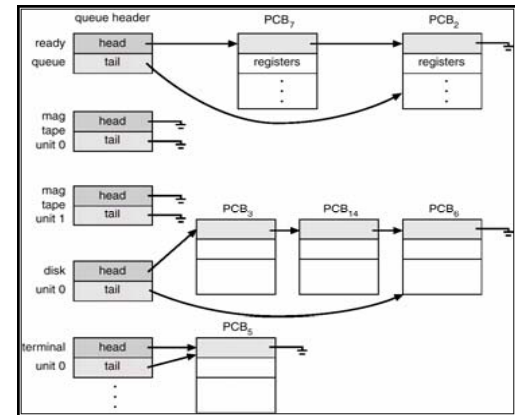
# CPU Scheduling

CS 256/456

Dept. of Computer Science, University of Rochester

# Process Queues

- Ready queue - set of all processes ready for execution.
- Device queues - set of processes waiting for an I/O device.
- Process migration between the various queues.

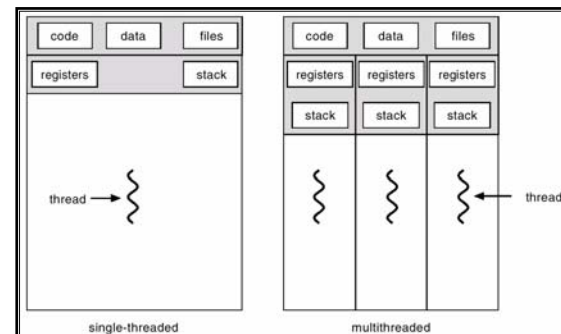


# Process Termination

- Process executes last statement and gives the control to the OS (**exit**).
  - Notify parent if it is **wait**-ing.
  - Deallocate process' resources.
- The OS may forcefully terminate a process.
  - Software exceptions
  - Receiving certain signals

# Processes and Threads

- Thread - a program in execution; without a dedicated address space.
- OS memory protection is only applied to processes.



## Why Use Threads?

- Multithreading is used for parallelism/concurrency. But why not multiple processes?
- Memory sharing.
- Efficient synchronization between threads
- Less context switch overhead

## User/Kernel Threads

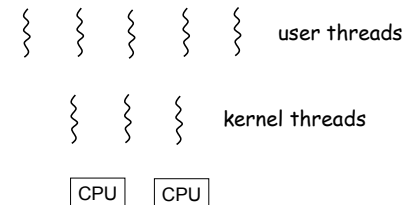
- What is really happening when the execution of one thread switches to another?
  - save the registers (including the SP) of the old thread;
  - restore the registers of the new thread;
  - set the new PC appropriately for the new thread;
- Does this need help from the OS kernel?
- Can you do it in C/Java?
- Does process switching need help from the OS kernel?
- 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

## User/Kernel Threads (cont.)

- Benefits of user threads
  - lightweight - less context switching overhead
  - more efficient synchronization??
  - 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 ( $M \geq N$ )
  - $N=1$ : 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

Process	CPU 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 schedule is:



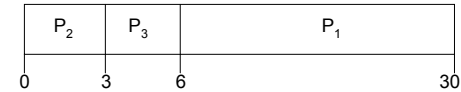
- Turnaround time for  $P_1 = 24$ ;  $P_2 = 27$ ;  $P_3 = 30$
- Average turnaround time:  $(24 + 27 + 30)/3 = 27$

## FCFS Scheduling (Cont.)

Suppose that the processes arrive in the order

$$P_2, P_3, P_1.$$

- The schedule is:



- 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*

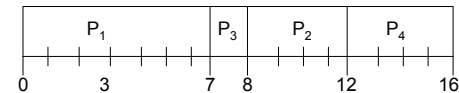
## Shortest-Job-First (SJR) Scheduling

- 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 Non-Preemptive SJF

Process	Arrival Time	CPU Time
$P_1$	0.0	7
$P_2$	2.0	4
$P_3$	4.0	1
$P_4$	5.0	4

- SJF (non-preemptive)



- Average turnaround time =  $(7 + 10 + 4 + 11)/4 = 8$

## Example of Preemptive SJF

Process	Arrival Time	CPU Time
$P_1$	0.0	7
$P_2$	2.0	4
$P_3$	4.0	1
$P_4$	5.0	4

- SJF (preemptive)



- 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  $\Rightarrow$  fair, starvation-free, better interactivity
  - $q$  large  $\Rightarrow$  FIFO
  - $q$  must be large with respect to context switch cost, otherwise overhead is too high.

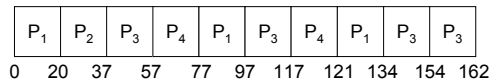
## Cost of Context Switch

- 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

Process	CPU Time
$P_1$	53
$P_2$	17
$P_3$	68
$P_4$	24

- The schedule is:



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

## 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; 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 between multiple tasks.
  - A real-time class that conforms to POSIX real-time standard. (FIFO/RR)
- For time-sharing tasks, Linux 2.4 uses a prioritized, credit based algorithm.
  - Scheduling is prioritized based on the initial credit
  - Credit of the running task decrements by one at every clock tick
  - Recrediting when no runnable tasks have any credit

$$\text{credits} = \frac{\text{credits}}{2} + \text{priority}$$

- This crediting system automatically prioritizes interactive or I/O-bound tasks.

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