COS 318: Operating Systems

CPU Scheduling

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(http://www.cs.princeton.edu/courses/cos318/)

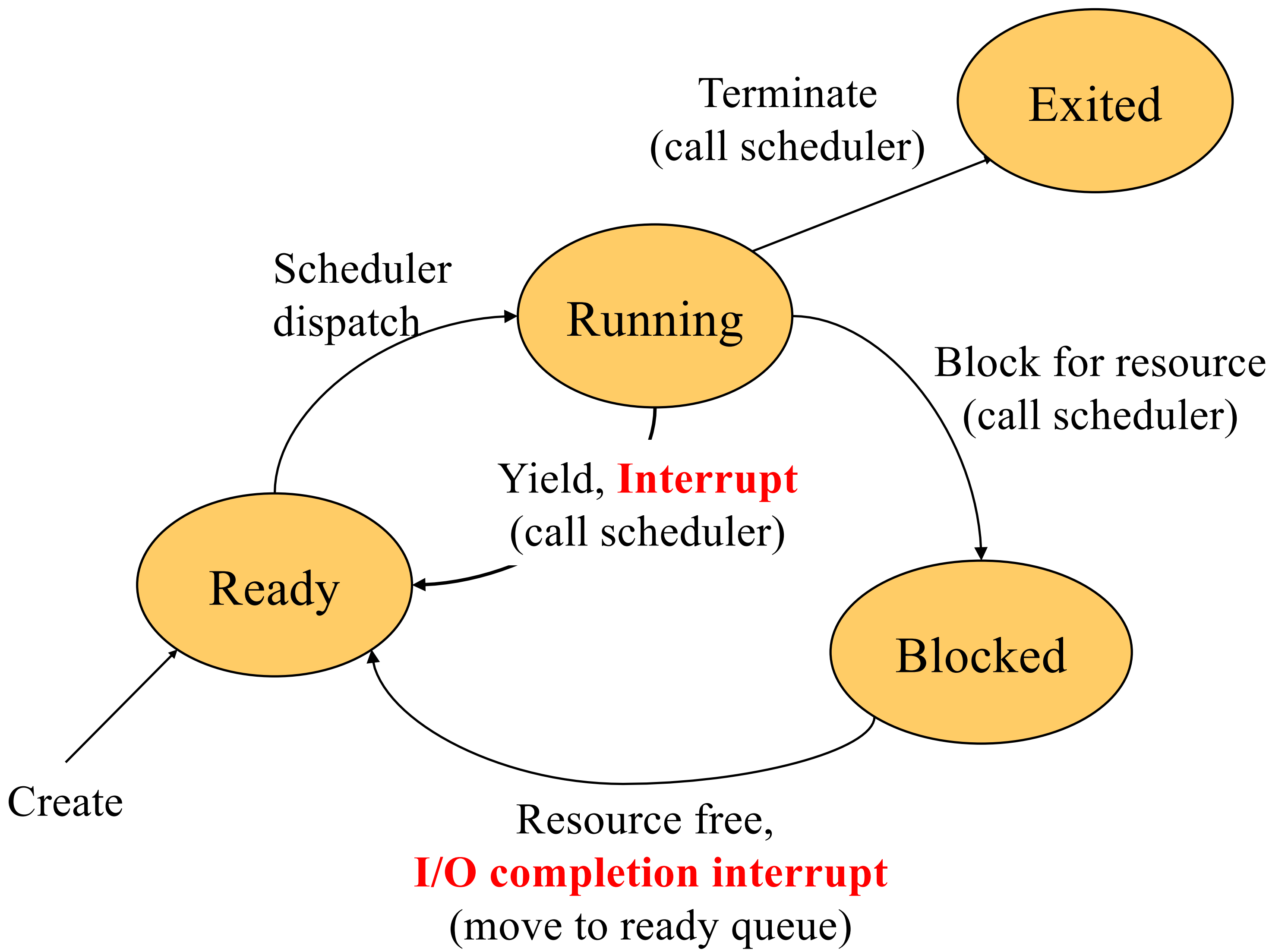
Today's Topics

- CPU scheduling basics
- CPU scheduling algorithms

CPU Scheduler

- Selects from among the processes/threads that are ready to execute (in *ready* state), and allocates the CPU to one of them (puts in *running* state).
- CPU scheduling can be *non-preemptive* or *pre-emptive*
- *Non-preemptive* scheduling decisions may take place when a process changes state:
  1. switches from running to waiting state
  2. switches from running to ready state
  3. switches from waiting to ready
  4. terminates
- All other scheduling is *preemptive*
  - E.g. may be driven by an interrupt

Preemptive and Non-Preemptive Scheduling



Scheduling Criteria

- Assumptions made here
  - One process per user and one thread per process
  - Processes are independent
- Scheduling Goals
  - Minmize response time (interactive) or turnaround time (batch)
    - Time from submission of job/operation to its completion
    - Job/operation could be keystroke in editor or running a big science simulation
  - Maximize throughput (operations/jobs per second)
    - Minimize overhead (e.g. context switching)
    - Use system resources efficiently (CPU, memory, disk, etc)
  - Fairness and proportionality
    - Share CPU in some equitable way, or that meets users' expectations
    - Everyone makes some progress; no one starves

Some Problem Cases in Scheduling

- Scheduler completely blind about job types
  - Little overlap between CPU and I/O
- Optimization involves favoring jobs of type “A” over “B”
  - Lots of A’s implies B’s starve
- Interactive process gets trapped behind others
  - Response time bad for no good reason.
- Priorities: A depends on B and A’s priority > B’s
  - B never runs, so A doesn’t continue

Scheduling Algorithms

- Simplified view of scheduling:
  - Save process state (to PCB)
  - Pick which process to run next
  - Dispatch process

First-Come-First-Serve (FCFS) Policy

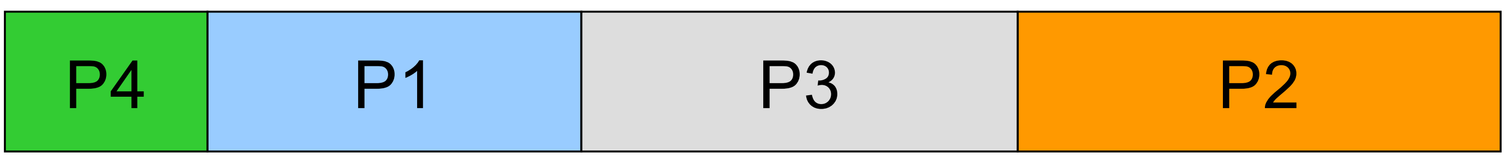
- Schedule tasks in the order they arrive
  - Run them until completion or they block or they yield
- Example 1
  - P1 = 24 sec, P2 = 3 sec, and P3 = 3 sec, submitted ‘same’ time in that order
  - Avg. response time = (24+27+30)/3 = 27. Avg. wait time (0+24+27)/3 = 17

- Example 2
  - Same jobs but come in different order: P2, P3 and P1
  - Average response time = (3 + 6 + 30) / 3 = 13 sec, avg wait time: 3 sec

- FIFO pro: Simple. Con: Short jobs get stuck behind long ones

Shortest Job First (SJF) Scheduling

- Shortest Remaining Time to Completion First (SRTCF)
- Whenever scheduling decision is to be made, schedule process with shortest remaining time to completion
  - Non-preemptive case: straightforward (if time can be estimated)
  - Preemptive case: if new process arrives with smaller remaining time, preempt running process and schedule new one
- Simple example: all arrive at same time:
  - P1 = 6sec, P2 = 8sec, P3 = 7sec, P4 = 3sec

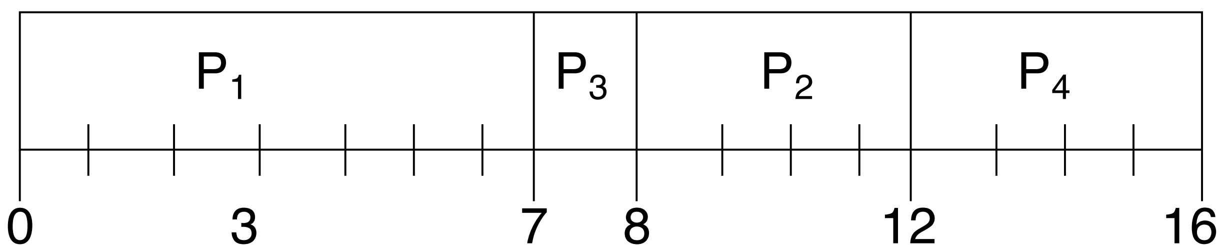


- Can you do better, in average response time?
- Issues with this approach?

Example of non-preemptive SJF

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

- SJF (non-preemptive)

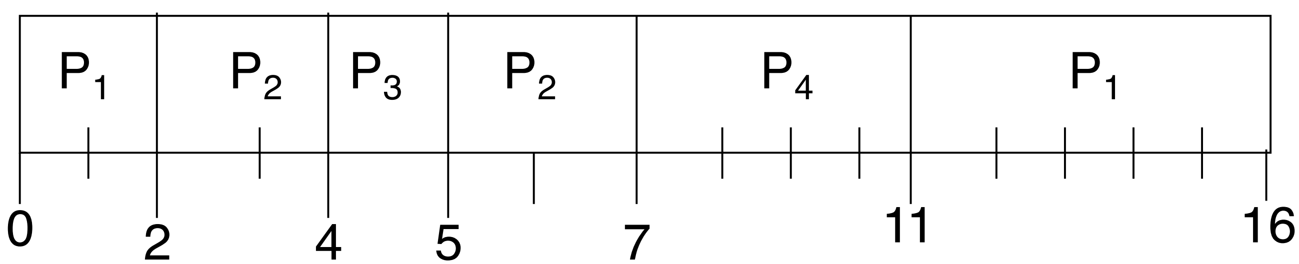


- Average waiting time = (0 + 6 + 3 + 7)/4 = 4

Example of preemptive SJF

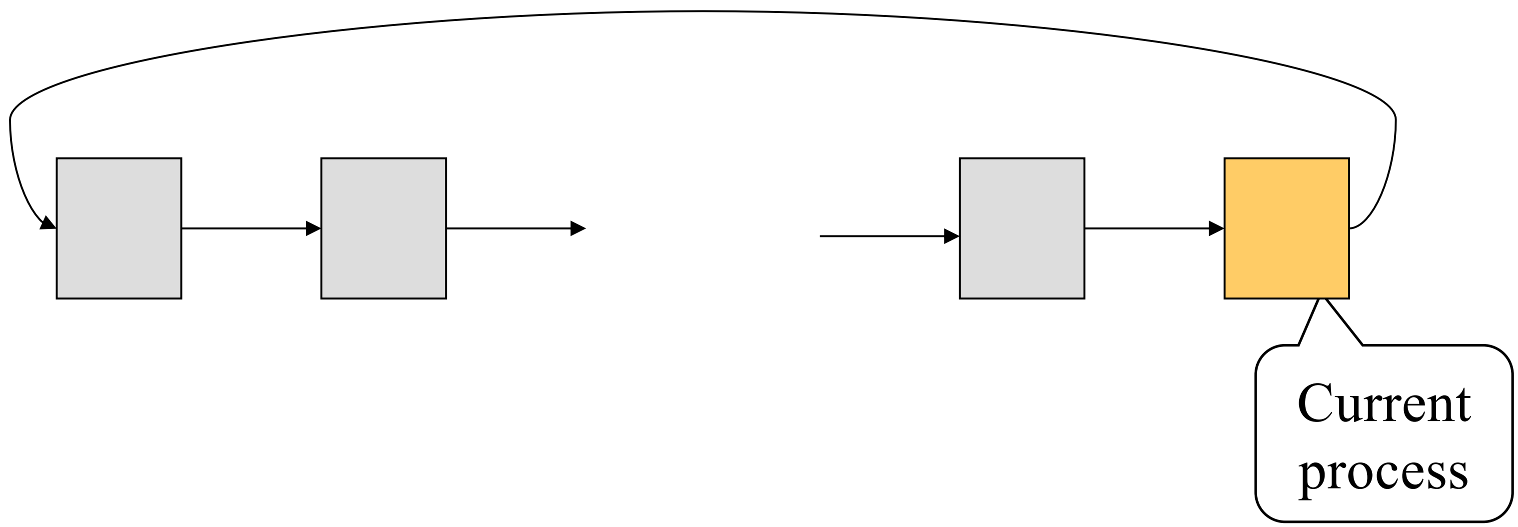
Process	Arrival Time	Burst Time
P_1	0.0	7
P_2	2.0	4
P_3	4.0	1
P_4	5.0	4

- SJF (preemptive)



- Average waiting time = (9 + 1 + 0 +2)/4 = 3

Round Robin



- Similar to FCFS, but with a time slice for timer interrupt
  - Time-interrupted process is moved to end of queue
- FCFS for preemptive scheduling
- Real systems also have I/O interrupts in the mix

- How do you choose time slice?

FCFS vs. Round Robin

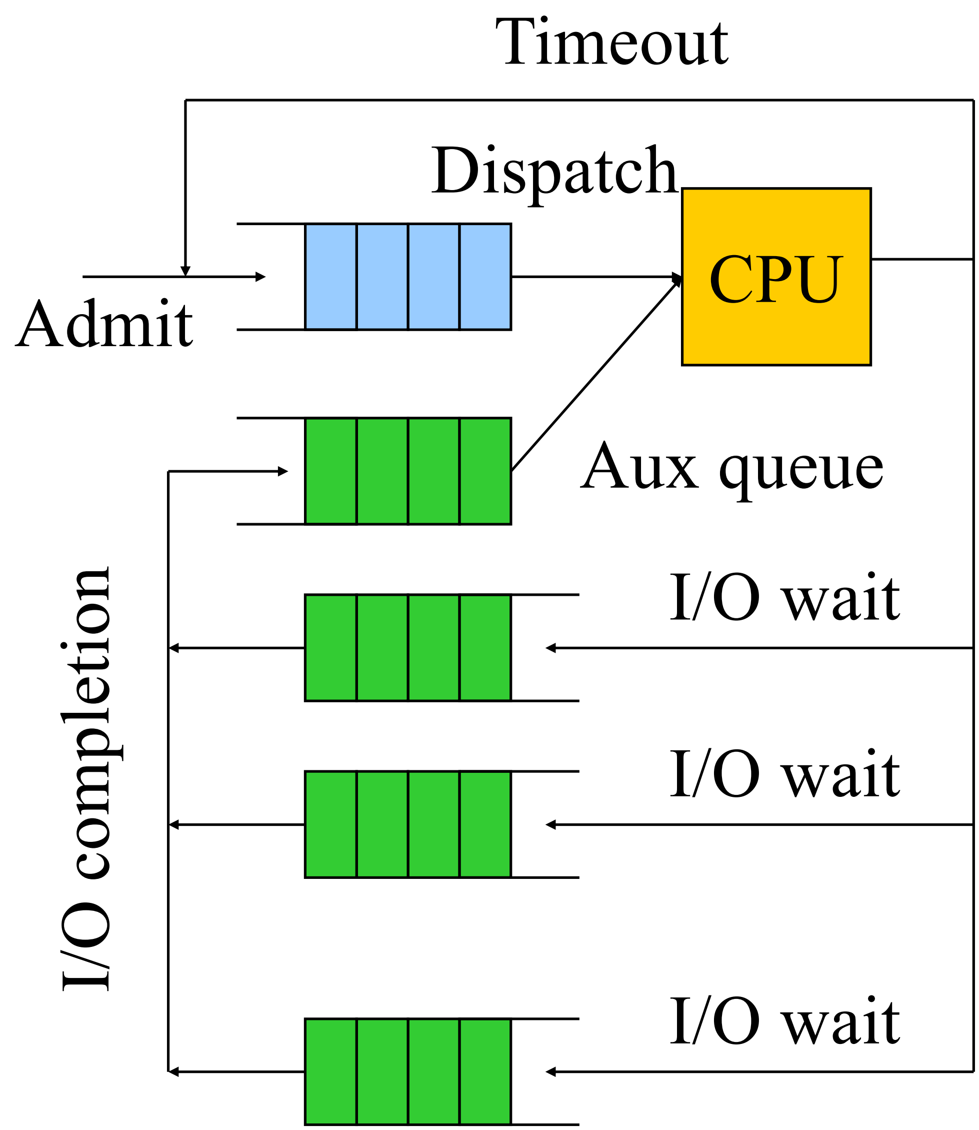
- Example
  - 10 jobs and each takes 100 seconds
- FCFS (non-preemptive scheduling)
  - job 1: 100s, job2: 200s, ... , job10: 1000s
- Round Robin (preemptive scheduling)
  - time slice 1sec and no overhead
  - job1: 991s, job2: 992s, ... , job10: 1000s
- Comparisons
  - Round robin is much worse (avg turnaround time) for jobs about the same length
  - Both are fair, but RR is bad in the case where FIFO is optimal
  - But, e.g. for streaming video, RR is good, since everyone makes progress and gets a share “all the time”

Resource Utilization Example

- A, B, and C run forever (in this order)
  - A and B each uses 100% CPU forever
  - C is a CPU plus I/O job (1ms CPU + 10ms disk I/O)
- Time slice 100ms
  - A (100ms CPU), B (100ms CPU), C (1ms CPU + 10ms I/O), …
- Time slice 1ms
  - A (1ms CPU), B (1ms CPU), C (1ms CPU), A (1ms CPU), B (1ms CPU), C(10ms I/O) || A, B, …, A, B
- What do we learn from this example?

Virtual Round Robin

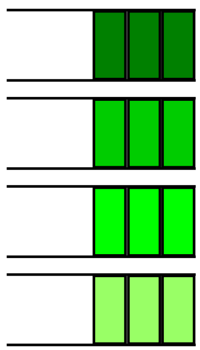
- I/O bound processes go to auxiliary queue (instead of ready queue) to get scheduled
- Aux queue is FIFO
- Aux queue has preference over ready queue



Priority Scheduling

- Not all processes are equal, so rank them
- The method
  - Assign each process a priority
  - Run the process with highest priority in the ready queue first
  - Adjust priority dynamically (I/O wait raises the priority, reduce priority as process runs)
- Why adjusting priorities dynamically
  - T1 at priority 4, T2 at priority 1 and T2 holds lock L
  - Scenario
    - T1 tries to acquire L, fails, blocks.
    - T3 enters system at priority 3.
    - T2 never gets to run, and T1 is never unblocked

Multi-level Feedback Queues (MFQ)



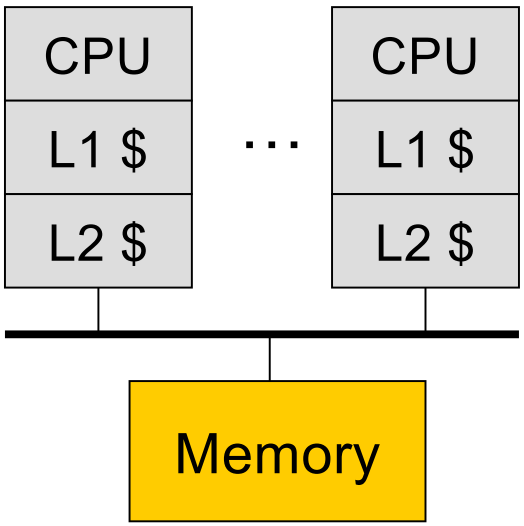
Priority	Time slices
4	1
3	2
2	4
1	8

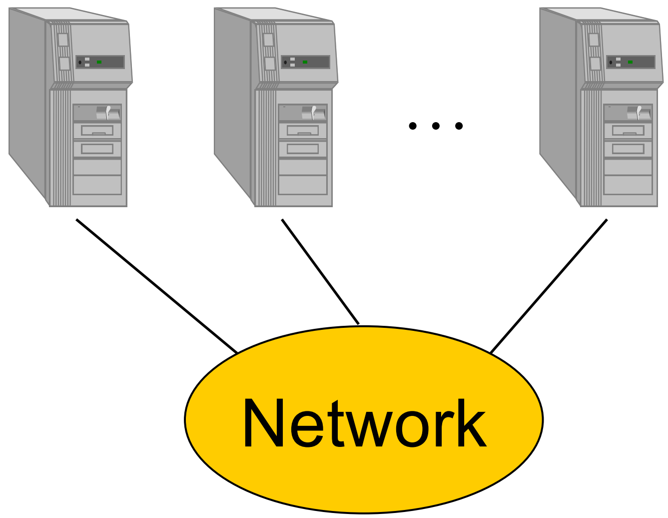
- Round-robin queues, each with different priority
- Higher priority queues have shorter time slices
- Jobs start at highest priority queue
- If timeout expires, drop one level
- If timeout doesn't expire, stay or pushup one level
- What does this method do?

Lottery Scheduling

- Motivations
  - SJF does well with average response time, but is unfair (long jobs can be starved)
  - Need a way to give everybody *some* chance of running
- Lottery method
  - Give each job a number of tickets
  - Randomly pick a winning ticket
  - To approximate SJF, give short jobs more tickets
  - To avoid starvation, give each job at least one ticket
  - Cooperative processes can exchange tickets

Multiprocessor and Cluster





Multiprocessor architecture

- Cache coherence
- Single OS

Cluster or multicomputer

- Distributed memory
- An OS in each box

Multiprocessor/Cluster Scheduling

- Design issue
  - Process/thread to processor assignment
- Gang scheduling (co-scheduling)
  - Threads of the same process will run together
  - Processes of the same application run together
- Dedicated processor assignment
  - Threads will be running on specific processors to completion
  - Is this a good idea?

Real-Time Scheduling

- Two types of real-time
  - Hard deadline
    - Must meet, otherwise can cause fatal error
  - Soft Deadline
    - Meet most of the time, but not mandatory
- Admission control
  - Take a real-time process only if the system can guarantee the "real-time" behavior of all processes.
  - Assume periodic processes. The jobs are schedulable, if the following holds:

$$\sum \frac{C_i}{T_i} \leq 1$$

where C_i = computation time, and T_i = period

Rate Monotonic Scheduling (Liu & Layland 73)

- Assumptions
  - Each periodic process must complete within its period
  - No process is dependent on any other process
  - A process needs same amount of CPU time on each burst
  - Non-periodic processes have no deadlines
  - Process preemption occurs instantaneously (no overhead)
- Main ideas of RMS
  - Assign each process a fixed priority = frequency of occurrence
  - Run the process with highest priority
- Example
  - P1 runs every 30ms gets priority 33 (33 times/sec)
  - P2 runs every 50ms gets priority 20 (20 times/sec)

Earliest Deadline Scheduling

- Assumptions
  - When a process needs CPU time, it announces its deadline
  - No need to be periodic process
  - CPU time needed may vary
- Main idea of EDS
  - Sort ready processes by their deadlines
  - Run the first process on the list (earliest deadline first)
  - When a new process is ready, it preempts the current one if its deadline is closer
- Example
  - P1 needs to finish by 30sec, P2 by 40sec and P3 by 50sec
  - P1 goes first
  - More in MOS 7.4.4

BSD 4.3 Multi-Queue Priority Scheduling

- "1 sec" preemption
  - Preempt if a process doesn't block or complete within 1 sec
- Priority is recomputed every second
  - P_i = base + (CPU_{i-1}) / 2 + nice, where $CPU_i = (U_i + CPU_{i-1}) / 2$
  - Base is the base priority of the process
  - U_i is process utilization in interval i
- Priorities
  - Swapper
  - Block I/O device control
  - File operations
  - Character I/O device control
  - User processes

Linux Scheduling

- Time-sharing scheduling
  - Each process has a priority and # of credits
  - Process with the most credits will run next
  - I/O event increases credits
  - A timer interrupt causes a process to lose a credit, until zero credits reached at which time process is interrupted
  - If no process has credits, then the kernel issues credits to all processes: credits = credits/2 + priority
- Real-time scheduling
  - Soft real-time (really just higher priority threads: FIFO or RR)
  - Kernel cannot be preempted by user code

Windows Scheduling

- Classes and priorities
  - Real time: 16 static priorities
  - Variable: 16 variable priorities, start at a base priority
    - If a process has used up its quantum, lower its priority
    - If a process waits for an I/O event, raise its priority
- Priority-driven scheduler
  - For real-time class, do round robin within each priority
  - For variable class, do multiple queue
- Multiprocessor scheduling
  - For N processors, run N-1 highest priority threads on N-1 processors and run remaining threads on a single processor
  - A thread will wait for processors in its affinity set, if there are other threads available (for variable priorities)

Summary

- Best algorithms may depend on your primary goals
  - FIFO simple, optimal avg response time for tasks of equal size, but can be poor avg reponse time if tasks vary a lot in size
  - SJF gives the minimal average response time, but can be not great in variance of response times
  - RR has very poor avg response time for equal size tasks, but is close to SJF for variable size tasks
  - Small time slice is important for improving I/O utilization
  - If tasks have mix of processing and I/O, do well under SJF but can do poorly under RR
  - Priority and its variations are used in most systems
  - Lottery scheduling is flexible
  - Multi-queue can achieve a good balance
  - Admission control is important in real-time scheduling