CPU Scheduling

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Based on slides from Kai Li and J.P. Singh, Princeton University

Outline

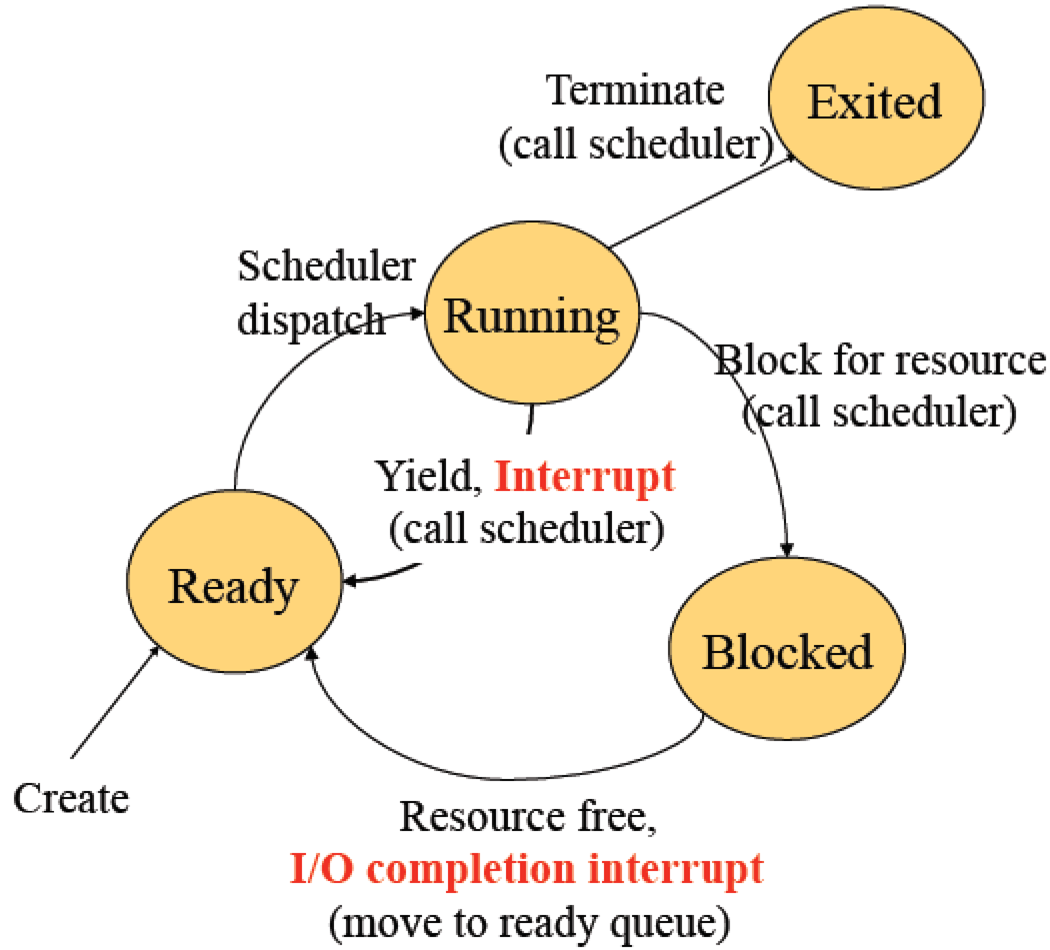
- CPU Scheduling basics
- CPU Scheduling algorithms
- Real-world examples

When to Schedule?

- Process/thread creation
- Process/thread exit
- Blocking on I/O or synchronization
- I/O interrupt
- Clock interrupt (preemptive scheduling)

Preemptive vs. Non-Preemptive Scheduling

- Preemptive scheduling:
  - Running → ready
  - Blocked → ready
  - Running → blocked
  - Terminate
- Non-preemptive scheduling:
  - Running → blocked
  - Terminate
- Batch vs. interactive scheduling vs. real-time



Scheduling Criteria

- Assumptions:
  - One program per user and one thread per process
  - Programs are independent
- Goals for batch and interactive systems:
  - Provide fairness
  - Everyone makes some progress → no one starves
  - Maximize CPU utilization
    - Not including idle process
  - Maximize throughput
    - Operations/ second (min overhead, maximum resource utilization)
  - Minimize turnaround time
    - Batch jobs: time to execute (from submission to completion)
  - Shorten response time
    - Interactive jobs: time until response (e.g. typing on keyboard)
  - Proportionality
    - Meet user's expectations

Question

- What are the goals for PCs vs. servers?
  - Average response time vs. throughput
  - Average response time vs. fairness

Problem Cases

- Completely blind about job types
  - No CPU and I/O overlap
- Optimization involves favoring jobs of type A over type B
  - Lot's of A's? → B's starve
- Interactive process trapped behind others
  - Response time bad for no good reason
- Priorities: A depends on B, and A's priority > B's priority
  - B never runs

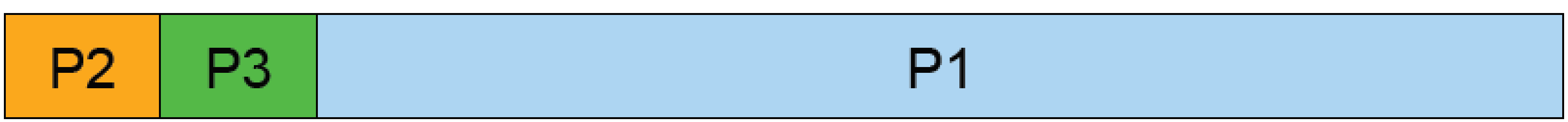
Scheduling Algorithms

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

First-Come First-Serve (FCFS) Policy

- What does it mean?
  - Run to completion
  - Run until blocked or yields
- Example 1
  - P1 = 24sec, P2 = 3sec, and P3 = 3sec, submitted together
  - Average response time = (24 + 27 + 30) / 3 = 27

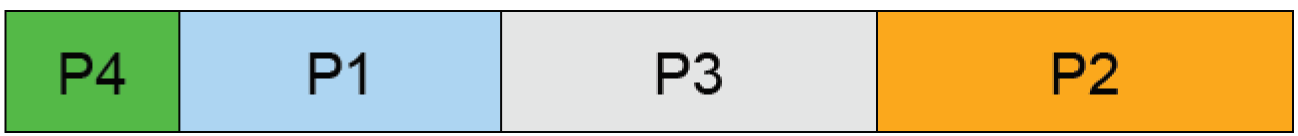
- Example 2
  - Same jobs but come in different order: P2, P3 and P1
  - Average response time = (3 + 6 + 30) / 3 = 13



(Gantt graph)

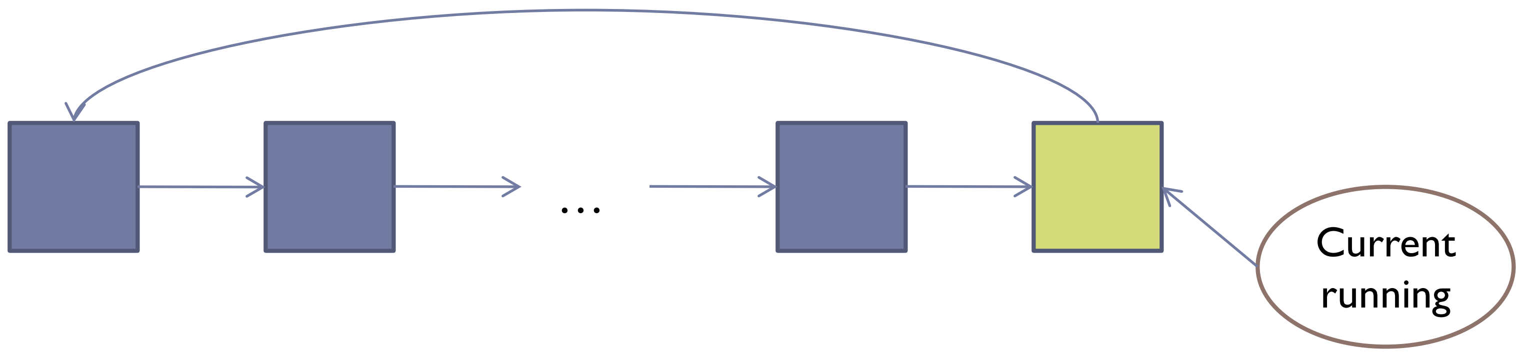
STCF and SRTCF

- Shortest Time to Completion First
  - Non-preemptive
- Shortest Remaining Time to Completion First
  - Preemptive version
- Example
  - P1 = 6sec, P2 = 8sec, P3 = 7sec, P4 = 3sec
  - All arrive at the same time



- Can you do better than SRTCF in terms of average response time?
- Issues with this approach?

Round Robin



- Similar to FCFS, but add a time slice for timer interrupt
- 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 (turnaround time) for jobs about the same length
  - Round robin is better for short jobs

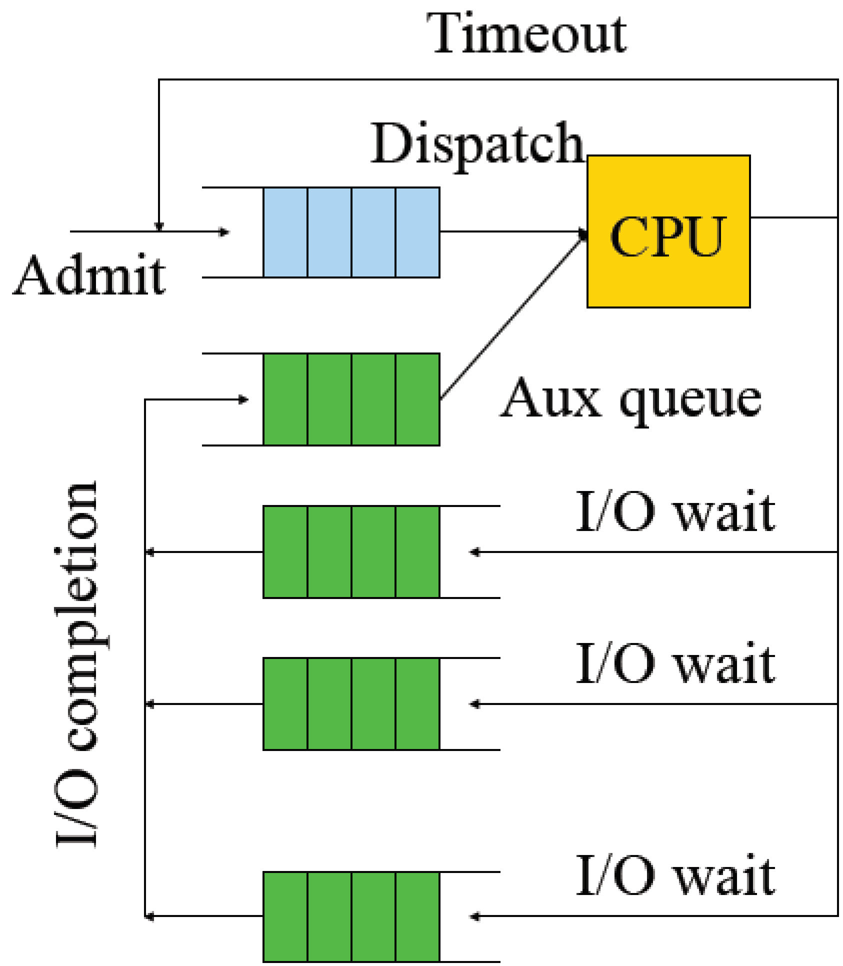
Resource Utilization Example

- 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

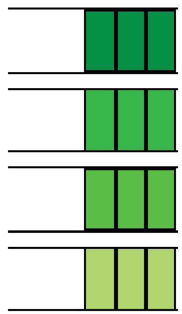
- Aux queue is FIFO
- I/O bound processes go to aux queue (instead of ready queue) to get scheduled
- Aux queue has preference over ready queue



Priority Scheduling

- Obvious
  - 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!

Priority Scheduling



Priority	Time slices
4	1
3	2
2	4
1	8

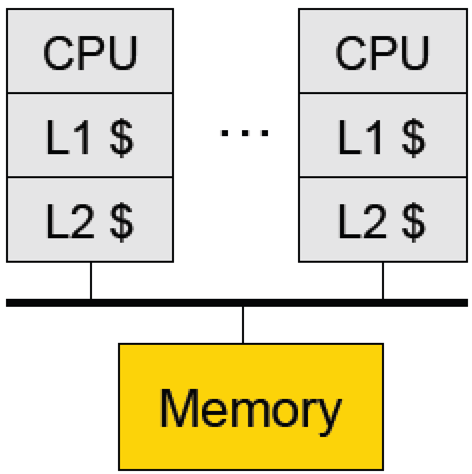
- Jobs start at highest priority queue
- If timeout expires, drop one level
- If timeout doesn’t expires, stay or pushup one level

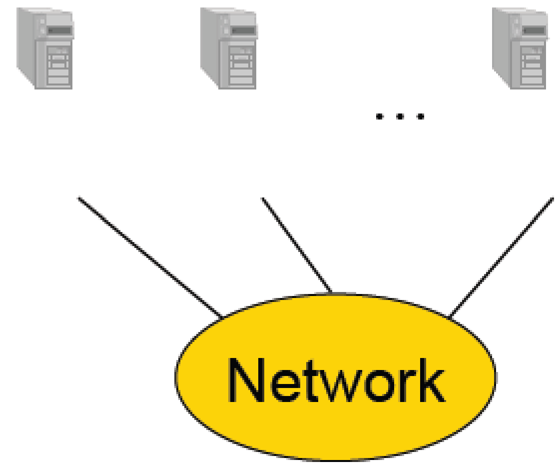
- What does this method do?

Lottery Scheduling

- Motivations
  - SRTCF does well with average response time, but unfair
- Lottery method
  - Give each job a number of tickets
  - Randomly pick a winning tickets
  - To approximate SRTCF, give short jobs more tickets
  - To avoid starvation, give each job at least one ticket
  - Cooperative processes can exchange tickets
- Question: how do you compare this method with priority scheduling?

Multi-processor and Cluster





- Multi-processor (-core) architecture
  - Cache coherence
  - Single OS
- Cluster
  - Distributed memory
  - An OS in each box
  - Multiple schedulers

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
- The jobs are schedulable, if the following holds:

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

where Ci = computation time, and Ti = period

Rate Monotonic Scheduling (Liu & Layland 73)

- Assumptions
  - Each periodic process must complete within its period
  - No process is dependent on any other process
  - Each process needs the 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
  - Proven to be optimal
- 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 7.5.4

4.3 BSD Scheduling with Multi-Queue

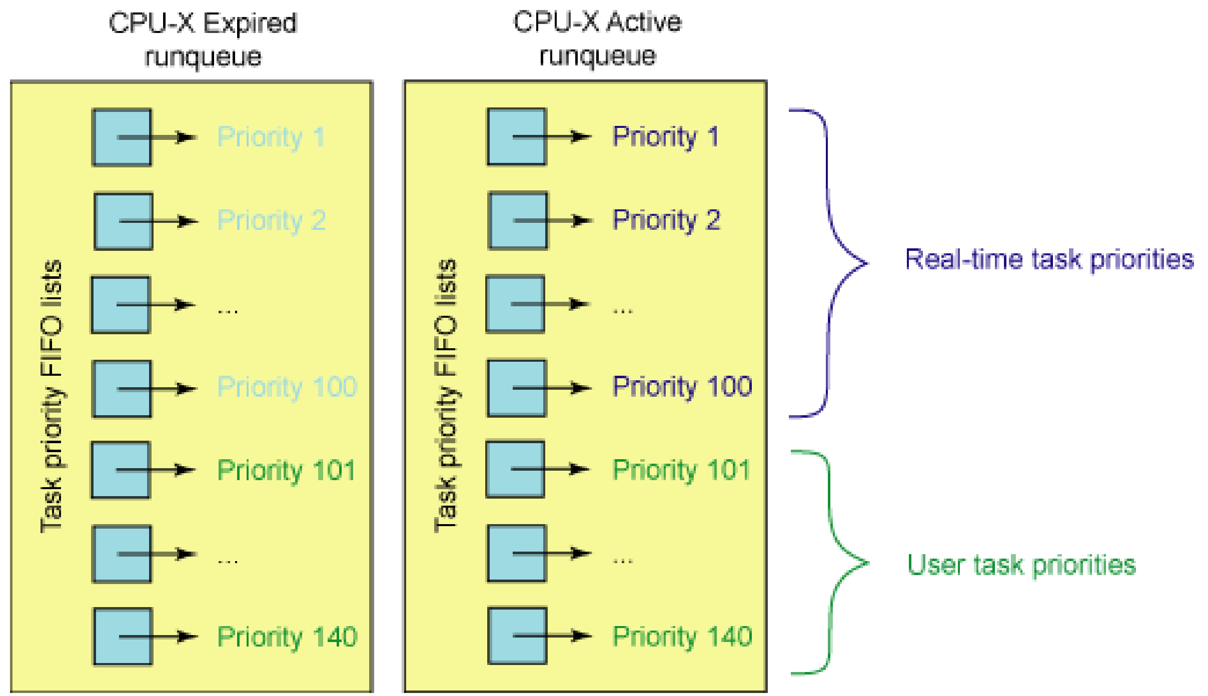
- "1 sec" preemption
  - Preempt if a process doesn't block or complete within 1 second
- Priority is recomputed every second
  - P_i = base + (CPU_{i-1}) / 2 + nice, where CPU_i = (U_i + CPU_{i-1}) / 2
  - Base is the base priority of the process
  - U_i is process utilization in interval i
- Priorities
  - 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
  - I/O event will raise the priority
  - Process with the most credits will run next
  - A timer interrupt causes a process to lose a credit
  - If no process has credits, then the kernel issues credits to all processes: credits = credits/2 + priority
- Real-time scheduling
  - Soft real-time
  - Kernel cannot be preempted by user code
- More in MOS 10.3.4

Linux 2.6 Scheduler

Source:
http://www.ibm.com/developerworks/linux/library/l-scheduler/



- Improvements:
  - O(1) scheduling overhead → scales to thousands of threads
  - Better SMP support:
    - Processor affinity
    - Per queue locking
    - Load balancing
  - Preemption

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)
- More in MOS 11.4.3

Summary

- Different scheduling goals
  - Depend on what systems you build
- Scheduling algorithms
  - Small time slice is important for improving I/O utilization
  - STCF and SRTCF give the minimal average response time
  - Priority and its variations are in most systems
  - Lottery is flexible
  - Real-time depends on admission control