CS 537
Lecture 3
Scheduling

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Scheduling

- In discussing process management, we talked about context switching between processes/thread on the ready queue
  - but, we glossed over the details of which process is chosen next
  - making this decision is called scheduling
    - scheduling is policy
    - context switching is mechanism
- Today, we'll look at:
  - the goals of scheduling
    - starvation
  - well-known scheduling algorithms
    - standard UNIX scheduling

Types of Resources

- Resources can be classified into one of two groups
- Type of resource determines how the OS manages it

1) Non-preemptible resources
   - Once given resource, cannot be reused until voluntarily relinquished
   - Resource has complex or costly state associated with it
   - Need many instances of this resource
   - Example: Blocks on disk
   - OS management: allocation
     - Decide which process gets which resource
2) Preemptible resources
   - Can take resource away, give it back later
   - Resource has little state associated with it
   - May only have one of this resource
   - Example: CPU
   - OS management: scheduling
     - Decide order in which requests are serviced
     - Decide how long process keeps resource

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Multiprogramming and Scheduling

- Multiprogramming increases resource utilization and job throughput by overlapping I/O and CPU
  - We look at scheduling policies
    - which process/thread to run, and for how long
  - schedulable entities are usually called jobs
    - processes, threads, people, disk arm movements, …

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Scheduling

- The scheduler is the module that moves jobs from queue to queue
  - the scheduling algorithm determines which job(s) are chosen to run next, and which queues they should wait on
  - the scheduler is typically run when:
    - a job switches from running to waiting
    - when an interrupt occurs
      - especially a timer interrupt
    - when a job is created or terminated
- There are two major classes of scheduling systems
  - in preemptive systems, the scheduler can interrupt a job and force a context switch
  - in non-preemptive systems, the scheduler waits for the running job to explicitly (voluntarily) block

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CPU Scheduler

- Selects from among the processes in memory that are ready to execute, and allocates the CPU to one of them
- CPU scheduling decisions may take place when a process:
  1. Switches from running to waiting state
  2. Switches from running to ready state
  3. Switches from waiting to ready
  4. Terminates
- Scheduling under 1 and 4 is **nonpreemptive**
- All other scheduling is **preemptive**

Dispatcher

- Dispatcher module gives control of the CPU to the process selected by the short-term scheduler; this involves:
  - switching context
  - switching to user mode
  - jumping to the proper location in the user program to restart that program
- **Dispatch latency** – time it takes for the dispatcher to stop one process and start another running

Process Model

- Workload contains collection of jobs (processes)
- Process alternates between CPU and I/O bursts
  - CPU-bound jobs: Long CPU bursts

  - I/O-bound: Short CPU bursts

  - I/O burst = process idle, switch to another "for free"
  - Problem: don't know job's type before running
    - Need job scheduling for each ready job
    - Schedule each CPU burst

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Scheduling Goals

- Scheduling algorithms can have many different goals (which sometimes conflict)
  - maximize job throughput `(#jobs/s)`
  - minimize job turnaround time ($T_{finish} - T_{arrive}$)
  - Minimze response time ($T_{start} - T_{arrive}$)
  - Minimize overhead: Reduce number of context switches
  - Maximize fairness: All jobs get same amount of CPU over some time interval
- Goals may depend on type of system
  - **batch system:** strive to maximize job throughput and minimize turnaround time
  - **interactive systems**: minimize response time of interactive jobs (such as editors or web browsers)

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Scheduler Anti-goals

- Schedulers typically try to prevent starvation
  - starvation occurs when a process is prevented from making progress, because another process has a resource it needs
- A poor scheduling policy can cause starvation
  - e.g., if a high-priority process always prevents a low-priority process from running on the CPU

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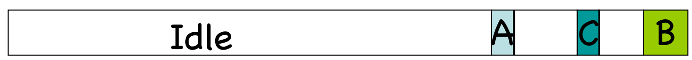
Gantt Chart

- Illustrates how jobs are scheduled over time on CPU

  Example:

- Can have CPU and disk. Usually I/O at end of burst



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First-in-First-Out (FIFO)

- Idea: Maintain FIFO list of jobs as they arrive
  - Non-preemptive policy
  - Allocate CPU to job at head of list

Job	Arrival	CPU burst
A	0	10
B	1	2
C	2	4

Average turnaround time:
(10 + (12-1) + (16-2))/3=11.67

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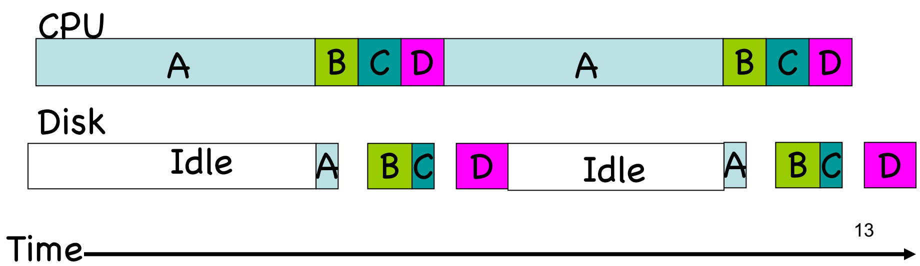
FIFO Discussion

- Advantage: Very simple implementation
- Disadvantage
  - Waiting time depends on arrival order
  - Potentially long wait for jobs that arrive later
  - Convoy effect: Short jobs stuck waiting for long jobs
    - Hurts waiting time of short jobs
    - Reduces utilization of I/O devices
    - Example: 1 mostly CPU-bound job, 3 mostly I/O-bound jobs



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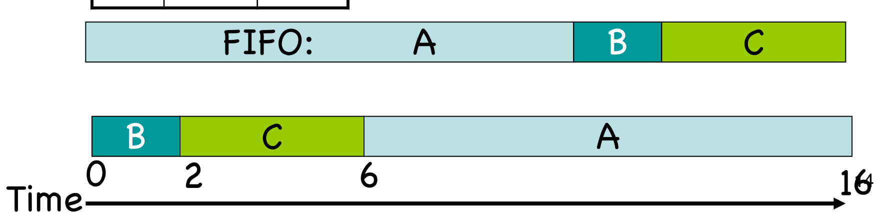
Shortest-Job-First (SJF)

- Idea: Minimize average wait time by running shortest CPU-burst next
  - Non-preemptive
  - Use FCFS if jobs are of same length

Job	Arrival	CPU burst
A	0	10
B	0	2
C	0	4

FIFO average turnaround: 11.67

SJF Average turnaround:
((16-0)+(6-0)+(2-0))/3 = 8



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SJF Discussion

- Advantages
  - Provably optimal for minimizing average wait time (with no preemption)
    - Moving shorter job before longer job improves waiting time of short job more than it harms waiting time of long job
  - Helps keep I/O devices busy
  - Useful in everyday life
    - Express lines at supermarket?
- Disadvantages
  - Not practical: Cannot predict future CPU burst time
    - OS solution: Use past behavior to predict future behavior
  - Starvation: Long jobs may never be scheduled

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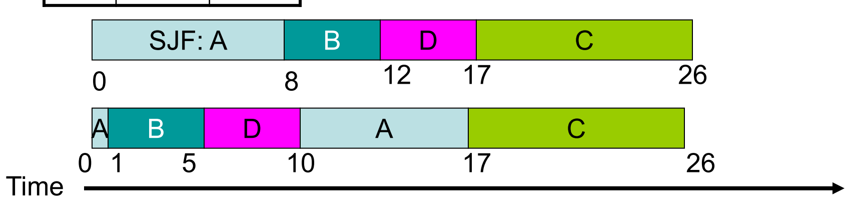
Shortest-Time-to-Completion-First (STCF)

- Idea: Add preemption to SJF
  - Schedule newly ready job if shorter than remaining burst for running job

Job	Arrival	CPU burst
A	0	8
B	1	4
C	2	9
D	3	5

SJF Average turnaround:
((8-0)+(12-1)+(26-2) +(17-3))/4= 14.25

STCF Average turnaround:
((17-0)+(5-1)+(26-2)+(10-3))/4 = 13



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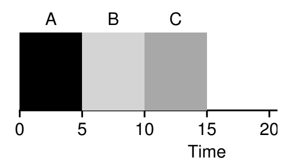
Interactive Jobs

- STCF good for:
  - Batch jobs
  - Known execution time
- Interactive jobs:
  - Execute short period, then sleep
  - STCF bad: if multiple jobs arrive, must wait for them to complete
- Better Metric:
  - response time = $T_{start} - T_{arrive}$

Job	Arrival	CPU burst
A	0	5
B	0	5
C	0	5



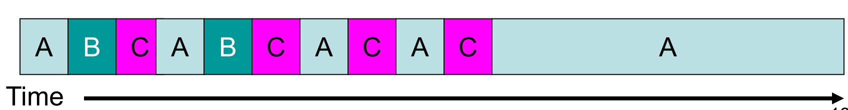
Round-Robin (RR)

- Idea: Run each job for a time-slice and then move to back of FIFO queue
  - Preempt job if still running at end of time-slice

Job	Arrival	CPU burst
A	0	10
B	1	2
C	2	4

RR Average Response: 0
RR Average turnaround: 8.75

STCF Response: 1.3
STCF turnaround: 7.5

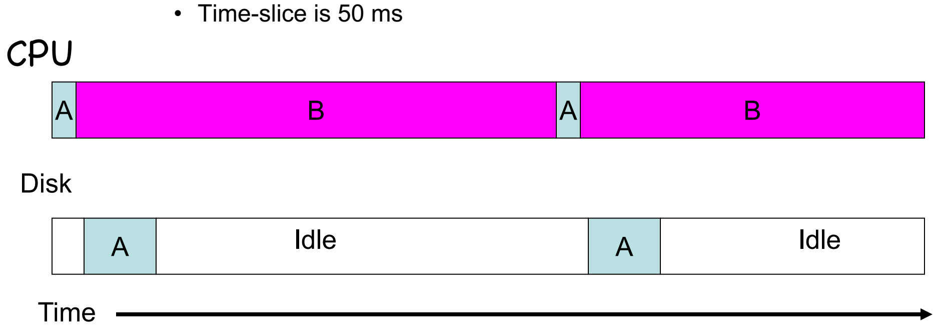


RR Discussion

- Advantages
  - Jobs get fair share of CPU
  - Shortest jobs finish relatively quickly
- Disadvantages
  - Poor average waiting time with similar job lengths
    - Example: 10 jobs each requiring 10 time slices
    - RR: All complete after about 100 time slices
    - FIFO performs better!
  - Performance depends on length of time-slice
    - If time-slice too short, **pay overhead of context switch**
    - If time-slice too long, degenerate to FCFS

RR Time-Slice

- IF time-slice too long, degenerate to FIFO
  - Example:
    - Job A w/ 1 ms compute and 10ms I/O
    - Job B always computes
    - Time-slice is 50 ms



Goal: Adjust length of time-slice to match CPU burst

Priority-Based

- Idea: Each job is assigned a priority
  - **Schedule highest priority ready job**
    - Low priority jobs wait if **any** high priority job ready
- May be preemptive or non-preemptive
- Priority may be static or dynamic
  - static = set once by program / user / admin
    - e.g. make the video player high priority to avoid skips
  - dynamic = adjust priorities as you run
    - foreground window is higher priority
    - Jobs that just waited for I/O get higher priority

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Priority with Preemption Example

- Mechanism: sort ready queue by priority
- Higher priority is better

Job	Arrival	CPU burst	Prio
A	0	10	5
B	1	2	10
C	2	4	3

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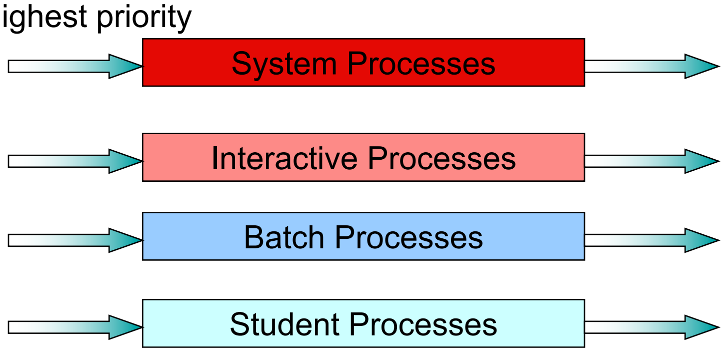
Priority Advantages/Disadvantages

- Advantages
  - Static priorities work well for real time systems
    - guarantee jobs get serviced
    - Known set of jobs, so can assign priorities (e.g. radio in a cellphone is high priority, browser is low priority)
  - Dynamic priorities work well for general workloads
    - can react to changes in programs and workloads
- Disadvantages
  - Low priority jobs can starve
  - How to choose priority of each job?
- Goal: **Adjust priority of job to match CPU burst**
  - Approximate SCTF by giving short jobs high priority

Multi-Level Queues

- Implement multiple ready queues based on job “type”
- Always run from highest priority queue

Highest priority

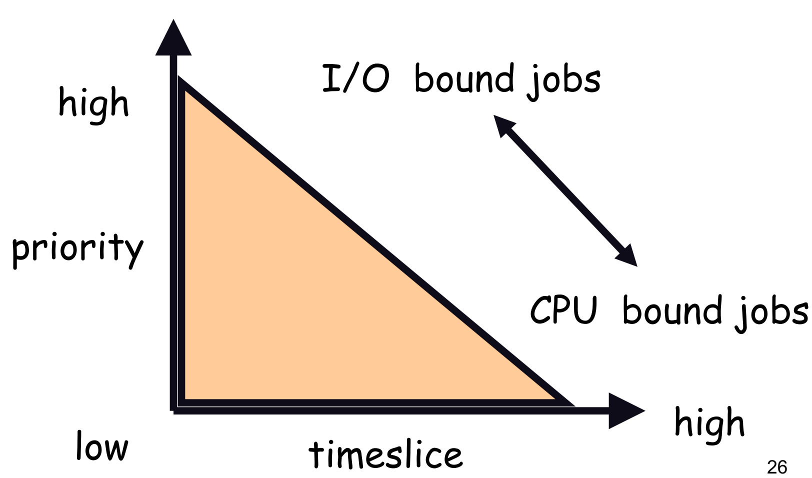


Lowest priority

Using multiple queues

- Problem: Classifying jobs into queues is difficult
  - A process may have CPU-bound phases as well as interactive ones
- Idea: use behavior to determine priority
  - Interactive -> short CPU burst -> higher priority
  - Batch -> long CPU burst -> lower priority

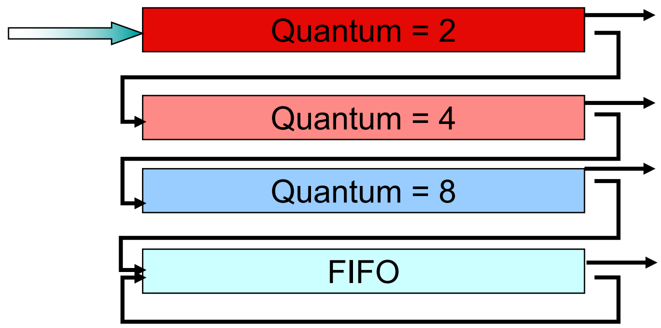
A Multi-level System



Multilevel Feedback Queues

- Jobs move from queue to queue based on job behavior
  - Does it use up quantum -> downgrade
  - Waits for too long -> upgrade

Highest priority



Lowest priority

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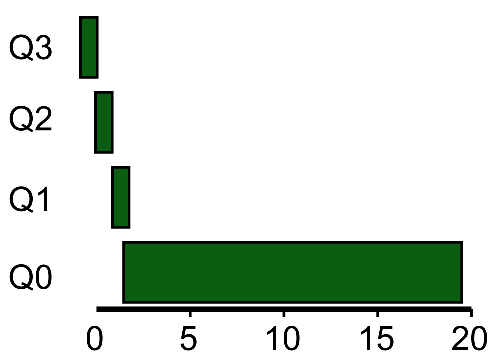
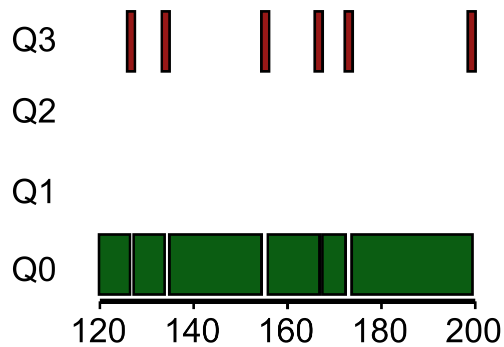
One Long Job (Example)

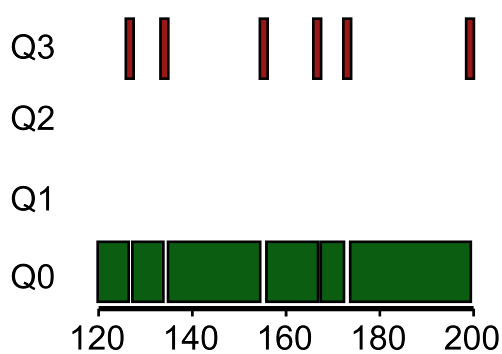


An Interactive Process Joins



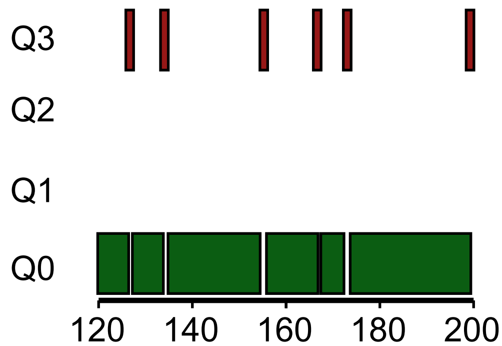
Interactive process never uses entire time slice, so never demoted

Problems with MLFQ?



Problems
- unforgiving + starvation
- gaming the system

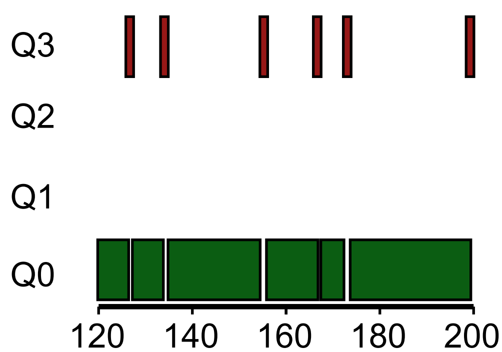
Prevent Starvation



Problem: Low priority job may never get scheduled

Periodically boost priority of all jobs (or all jobs that haven't been scheduled)

Prevent Gaming



Problem: High priority job could trick scheduler and get more CPU by performing I/O right before time-slice ends

Fix: Account for job's total run time at priority level
(instead of just this time slice);
downgrade when exceed threshold

Implementing MLFQ

- Table specifying each priority, time slice
- Preemption: will preempt lower priority thread when higher becomes able to run
- Table driven MLFQ. Priority 0 is lowest, priority 7 is highest
  - If quantum expires, priority is lowered (**Expire prio**)
  - If wake up from sleep / IO, priority gets a boost (**wake level**)
  - If waits too long without executing, gets priority boost (**wait level**)

Table Example

Priority	Quantum (ms)	Quantum expired Prio	MaxWait (ms)	Wait Level	Wake Level
0	1000	0	10000	1	3
1	200	0	4000	2	4
2	100	1	2000	3	4
3	70	2	1000	4	5
4	40	3	600	5	5
5	20	4	200	6	6
6	10	5	100	7	7
7	5	6	0	7	7

Job starts at priority 4, runs for 200 ms?
Many jobs at priority 7, a job at priority 3 wants to run?