IE 411: Operating Systems

CPU Scheduling

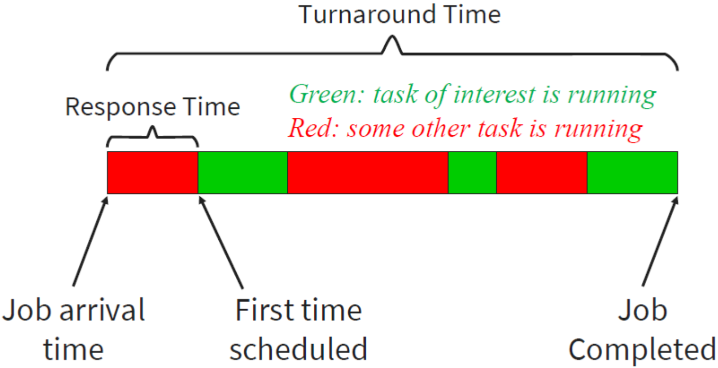
The scheduling problem

- Which process should the OS run?
  - if no runnable process (i.e. no process in the ready state), run the idle task
  - if a single process runable, run this one
  - if more than one runnable process, a scheduling decision must be taken
- Scheduler: code (logic) that decides which process to run as per some policy
- Today: What are the basic scheduling policies? When do they work well?

Standard usage

- Refer to schedulable entities as jobs — could be processes, threads, etc.
- Job: a task that needs a period of CPU time
- Job arrival time
  - when the job was first submitted
- Job run time
  - Time needed to run the task without contention

Scheduling metrics



- Execution time: sum of green periods
- Waiting time: sum of red periods
- Turnaround time: sum of both

Performance terminology

- Turnaround time: How long?
  - User-perceived time to complete some job (completion_time - arrival_time)
- Response time:
  - User-perceived time before first output (initial_schedule_time - arrival_time)
- Waiting time: How much thumb-twiddling?
  - Time on the ready queue (not running)

Performance terminology

- Throughput: How many jobs over time?
  - The rate at which jobs are completed
- Overhead: How much useless work?
  - Time lost due to switching between jobs
- Fairness: How equally are jobs treated?
  - Jobs get same amount of CPU time over some interval

Workload assumptions (to be relaxed later)

1. Each job runs for the same amount of time
2. All jobs arrive at the same time
3. All jobs only use the CPU (no I/O)
4. Run-time of each job is known

Scheduling basics

Workloads:

arrival_time
run_time

Scheduling Policies:

FIFO
SJF (SJN, SPN)
STCF
RR

Metrics:

turnaround_time
response_time

FIFO

- Run jobs to completion in arrival_time order
  - aka FCFS (first come first served)
- simple, minimal context switch overhead

JOB	arrival_time (s)	run_time (s)
A	~0	10
B	~0	10
C	~0	10

Time	
0	A arrives
0	B arrives
0	C arrives
0	run A
10	complete A
10	run B
20	complete B
20	run C
30	complete C

FIFO: Identical jobs

- Gantt chart: illustrates how jobs are scheduled over time on a CPU

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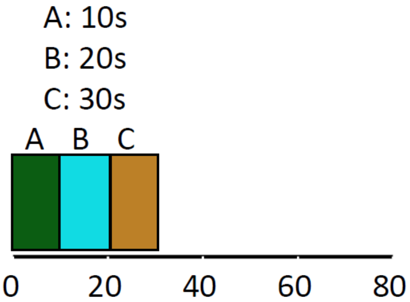

- What is the average turnaround time?
    - $(10+20+30)/3 = 20$s

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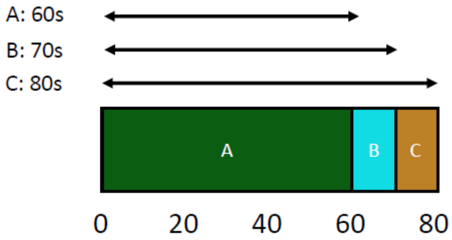
FIFO: Convoy effect

- Problem: turnaround time can suffer when short jobs must wait for long jobs

JOB	arrival_time (s)	run_time (s)
A	~0	60
B	~0	10
C	~0	10



Average turnaround time: 70s

Shortest Job First (SJF)

- Idea: choose job with the smallest run_time
  - aka shortest job next (SJN), shortest process next (SPN)
- Consider our previous example

JOB	arrival_time (s)	run_time (s)
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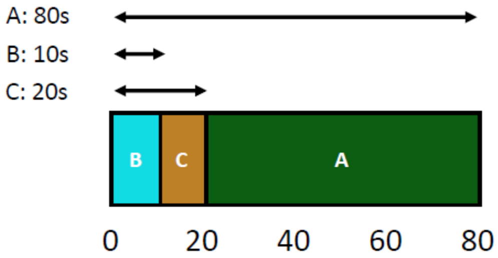
What is the average turnaround time with SJF?

SJF turnaround time



- What is the average turnaround time?
    - $(80+10+20)/3 = 36.7$s
- Average turnaround with FIFO: 70s

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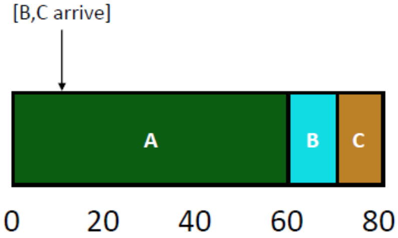
SJF with late arrivals



JOB	arrival_time (s)	run_time (s)
A	~0	60
B	~10	10
C	~10	10

- What is the average turnaround time?
  - (60 + (70-10) + (80-10)) / 3 = 63.3s

Preemptive scheduling

- FIFO and SJF are non-preemptive
  - Only schedule new job when previous job voluntarily relinquishes CPU (performs I/O or exits)
- Preemptive: potentially schedule different job at any point by taking CPU away from running job

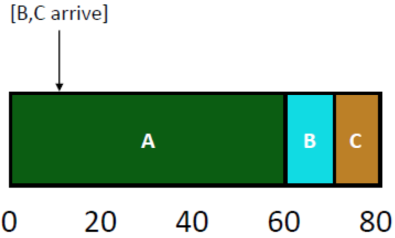
Shortest Time-to-Completion First (STCF)

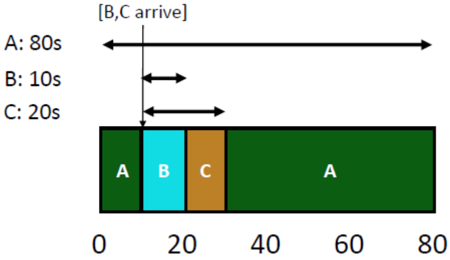
- SJF + preemption
- Select job with the least remaining time to run next
- Consider our previous example

JOB	arrival_time (s)	run_time (s)
A	~0	60
B	~10	10
C	~10	10

- Average turnaround time with STCF?

SJF vs. STCF





- Average turnaround time with STCF
  - $((80\text{-}0) + (20\text{-}10) + (30\text{-}10))/3 = 36.7s$
- Average turnaround time with SJF
  - 63.3s

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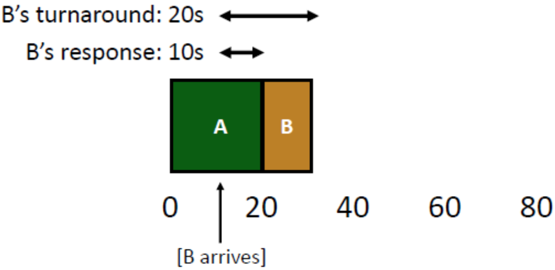
Response vs. turnaround

- Response time: first run time - arrival time

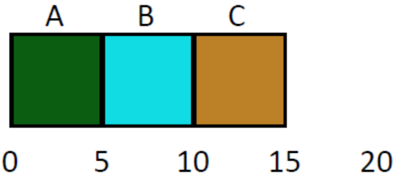


- FIFO, SJF, and STCF can have poor response time

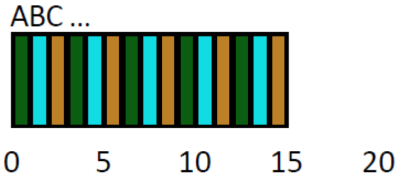
Round-Robin (RR)

- Each job allowed to run for a quantum
    - quantum = some configured period of time
- Context is switched (at the latest) at the end of the quantum – premption!
- Next job is the one on the ready queue that hasn't run for the longest amount of time

FIFO vs RR



Avg Response Time?
(0+5+10)/3 = 5



Avg Response Time?
(0+1+2)/3 = 1

RR Pros and Cons

- In what way is RR worse?
  - Avg. turnaround time with equal job length is horrible
- Other reasons why RR could be better?
  - If don't know run-time of each job, gives short jobs a chance to run and finish fast

Time quantum

- What is a good quantum size?
- Too long, and it morphs into FIFO
- Too short, and time is wasted on context switching
- Typical quantum: about 100X cost of context switch ($\sim$ 100 ms vs. $<<$ 1 ms)

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Incorporating I/O

- When a job initiates an I/O request
  - The job is blocked waiting for I/O completion
  - The scheduler should schedule another job on the CPU
- When the I/O completes
  - An interrupt is raised
  - The OS moves the process from blocked back to the ready state

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(Need smarter, fancier scheduler)

Multi Level Feedback Queue (MLFQ)

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  - minimize turnaround time
  - minimize response time (for interactive jobs)
- Invented by Fernando J. Corbato in 1962 – won ACM Turing Award
- Used by FreeBSD, Mac OS X, Solaris, Linux 2.6, Windows NT

MLFQ Basic Setup

- The MLFQ has a number of distinct queues, each assigned a different priority level
- At any given time, a job that is ready to run is on a single queue
- MLFQ uses priorities to decide which job should run at a given time

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  - for jobs in the same queue (priority), Round Robin is used

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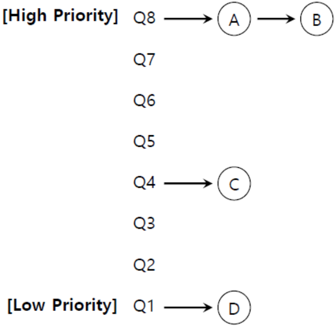

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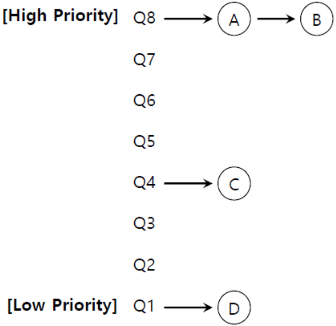

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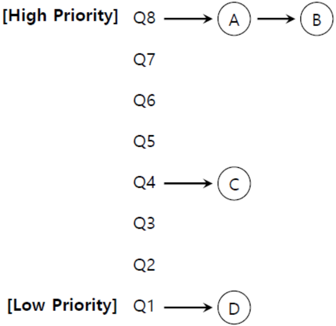

- Would C and D ever run? No!
- So how could we make C and D to run?

MLFQ: Changing job priority

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  - Should keep its priority high
- MLFQ uses history of a job to predict its future behavior

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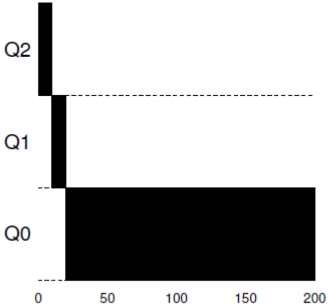
Example

- One long-running job
- Time slice length $=$ 10 ms



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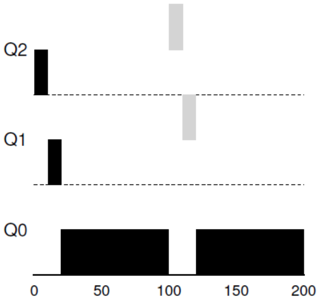

- Two jobs: A (shown in black), and B (shown in gray)
- A is CPU-intensive; it is running in the the lowest-priority queue after two time slices

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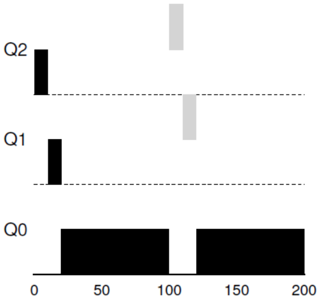

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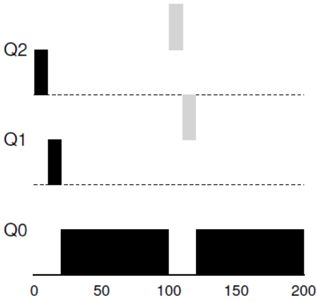

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- MLFQ approximates SJF for job B in this case

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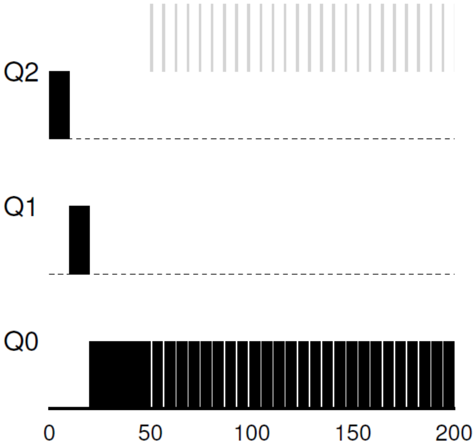

- Job A has run some time $\rightarrow$ drops to the lowest priority queue

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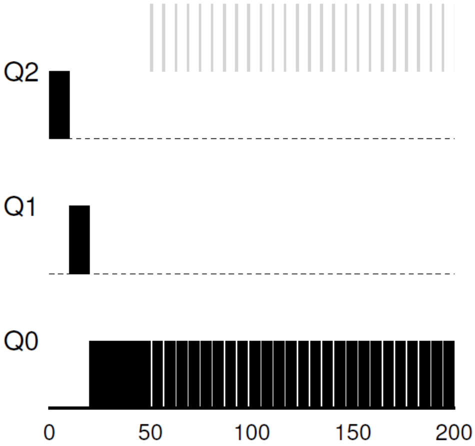

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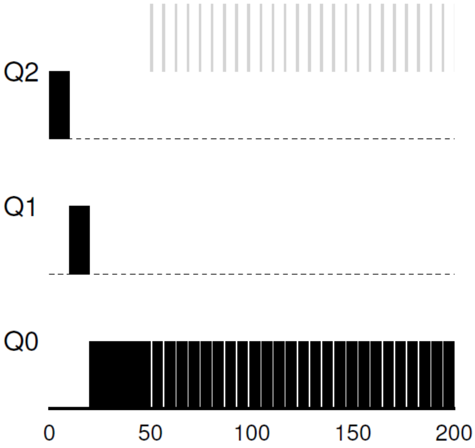

- Job A has run some time $\rightarrow$ drops to the lowest priority queue
- Job B is an interactive job: it needs CPU only for 1 ms before performing an I/O
- Because B keeps releasing the CPU before its time slice is complete, MLFQ keeps B at the highest priority $\rightarrow$ minimize response time

MLFQ Rules

- Rules thus far
  - Rule 1: If Priority(A) $>$ Priority(B), A runs (B doesn't)
  - Rule 2: If Priority(A) $=$ Priority(B), A & B run in RR
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- Game the scheduler
  - After running 99% of a time slice, issue an I/O
  - The job gains higher percentage of CPU time
- What if a CPU-bound job becomes I/O-bound?

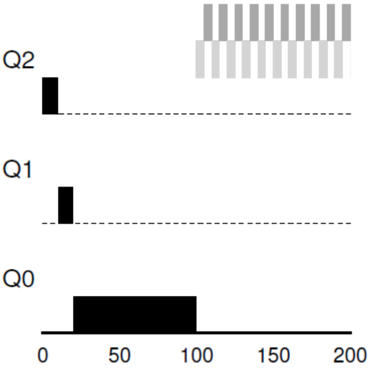
How can we fix these problems?

MLFQ: With priority boost

- Priority boost
  - Reset all jobs to topmost queue after time interval S
- Solves two problems
  - no starvation: low priority jobs will eventually become high priority, acquire CPU time
  - dynamic behavior: a CPU bound job that has become interactive will now be high priority

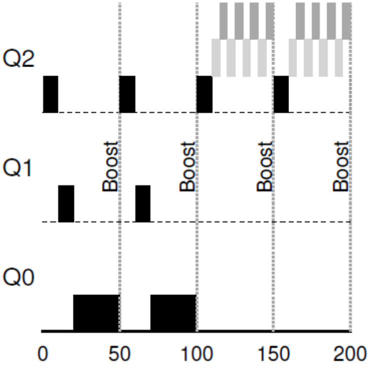
MLFQ: Without priority boost

- A long-running job A
- At time $T = 100$, two interactive jobs show up (B and C)
- B and C each run on CPU for 10 ms, followed by 10 ms of I/O



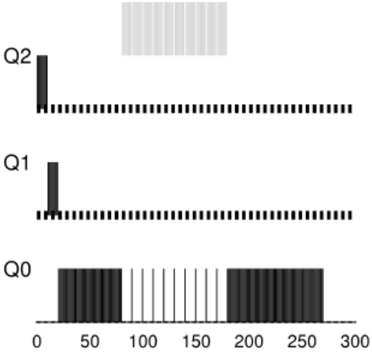
MLFQ: With priority boost

- Assume there is a priority boost every 50 ms



Gaming of scheduler

- Rules 4a and 4b let a job game the scheduler
- Trick: repeatedly relinquish just before the time slice expires



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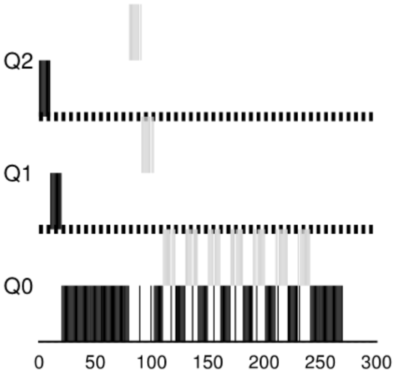

Tuning MLFQ

- The high-priority queues $\rightarrow$ Short time slices
  - E.g., 10 or fewer milliseconds
- The Low-priority queue $\rightarrow$ Longer time slices
  - E.g., 100 milliseconds