CS 423
Operating System Design
CPU Scheduling Policies
Jan 27

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Figures and slides ack: Prof. Shivaram Venkataraman (Wisconsin)

Logistics

Next lecture: TAs will walkthrough MP0
Everyone to use EngrIT VMs for MPs

4Cr: 1st paper has been added to course web-page
Review due before start of Feb3rd class (2pm CST)

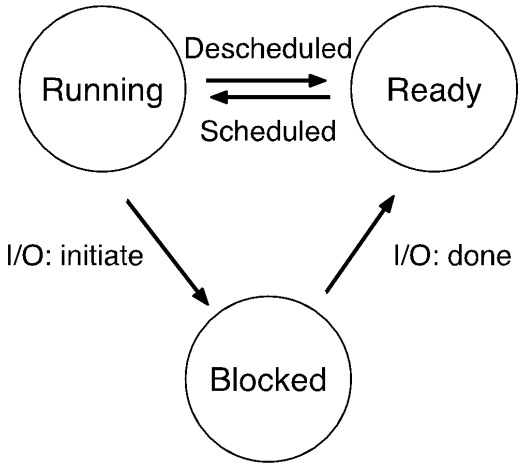
This lecture:

1. Recap scheduling mechanism
2. Scheduling policies

RECAP: SCHEDULING MECHANISM

Process: abstraction to virtualize the CPU

Use time sharing to switch between processes



When and to which process to switch – policy

How to switch processes – mechanism

How many processes can be in each state simultaneously?

RECAP: SCHEDULING MECHANISM

Limited Direct Execution (LDE)

- Natively run the program on CPU
- Use system calls for restricted ops, such as accessing devices
- Use timer interrupt to grab control from user process

RECAP: CPU STATE OF A PROCESS

RECAP: SYSCALL

LEARNING OUTCOMES

Scheduling policies

- How does the OS decide ***which*** process to run?
- What are some of the metrics to optimize for?
- What are some of the policies: FCFS, SJF, STCF, RR, MLFQ
- What to do when OS doesn't have complete information?
- How to handle mix of interactive and batch processes?

Terminology

Workload: set of **jobs** (arrival time, run_time)

Job: process that runs for some time period

Processes move between READY & BLOCKED

Scheduler: Decide which READY job to run

Metric: measure of scheduling quality (e.g., turnaround time, response time, fairness)

APPROACH

Assumptions about the workload

Scheduling policy

Pick one or more Metric(s)

METRIC 1: TURNAROUND TIME

Turnaround time = *completion_time - arrival_time*

Example:

Process A arrives at time t = 10, finishes t = 30

Process B arrives at time t = 10, finishes t = 50

Turnaround time

A = 20, B = 40

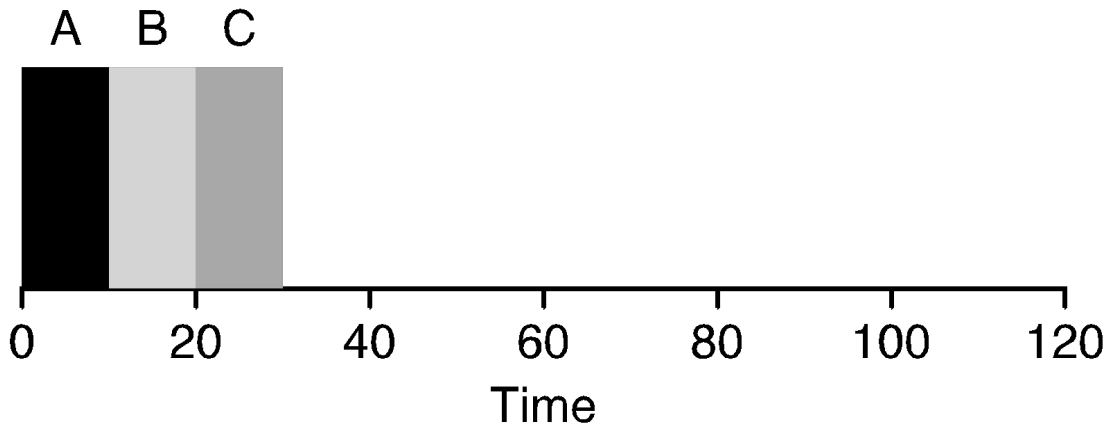
Average = 30

ASSUMPTIONS

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

FIFO / FCFS

Job	arrival(s)	run time (s)	turnaround (s)
A	~0	10	
B	~0	10	
C	~0	10	



Average
Turnaround
Time =

ASSUMPTIONS

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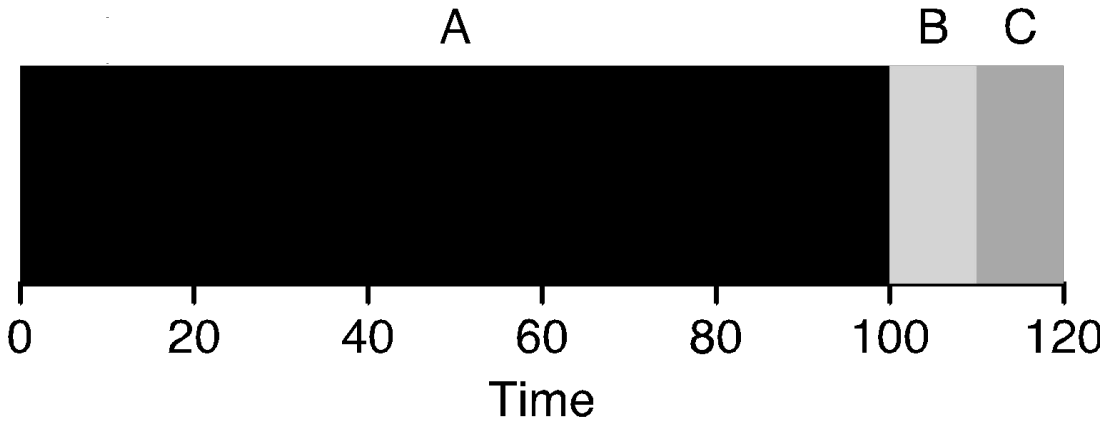
How will FIFO perform without this assumption?

When FIFO is Bad

Job	Arrival(s)	run time (s)
A	~0	100
B	~0	10
C	~0	10

Average Turnaround Time?



What is one schedule that could be better?

CHALLENGE

Turnaround time suffers when short jobs must wait for long jobs

Convoy effect: e.g., everyone slowed down by a slow vehicle in a single-lane road

New scheduler:

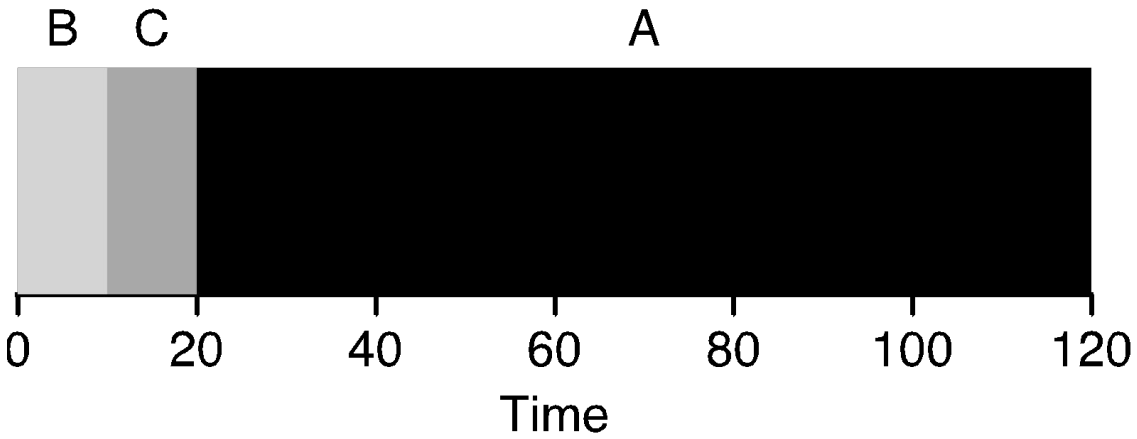
SJF (Shortest Job First)

Choose job with shortest run-time!

(note: we assume the OS knows the time for each job)

SHORTEST JOB FIRST (SJF)

Job	Arrival(s)	run time (s)	Turnaround (s)
A	~0	100	
B	~0	10	
C	~0	10	



Average Turnaround Time

SJF Theory

SJF is provably optimal for minimizing turnaround time (assuming no preemption)

Intuition:

Moving shorter job before long job improves the turnaround time of the short job more than it harms the turnaround time of the long job

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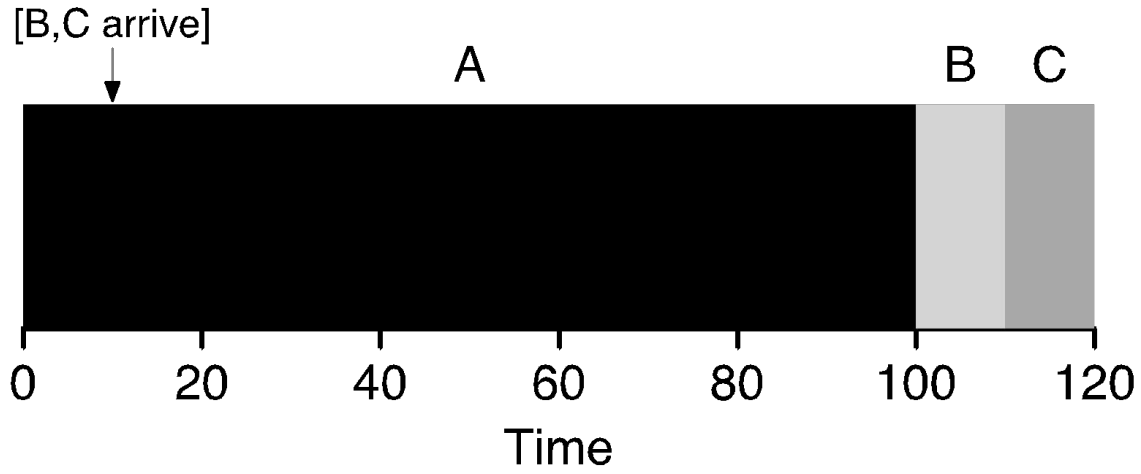
Job	Arrival(s)	run time (s)
A	~0	100
B	10	10
C	10	10

What will be the schedule with SJF?

Take a min, chat with neighbors, and sketch the schedule and calculate the turnaround time

Job	Arrival(s)	run time (s)
A	~0	100
B	10	10
C	10	10

Average Turnaround Time ?



TA time(A):
TA time(B):
TA time(C):

Avg = ?

PREEMPTIVE SCHEDULING

Previous schedulers:

FIFO and SJF are non-preemptive

Only schedule new job when previous job voluntarily relinquishes CPU (after it exits)

Preemptive: Schedule different job by taking CPU away from running job

STCF (Shortest Time-to-Completion First) - preemptive version of SJF

Always run job that will complete the quickest

ASSUMPTIONS

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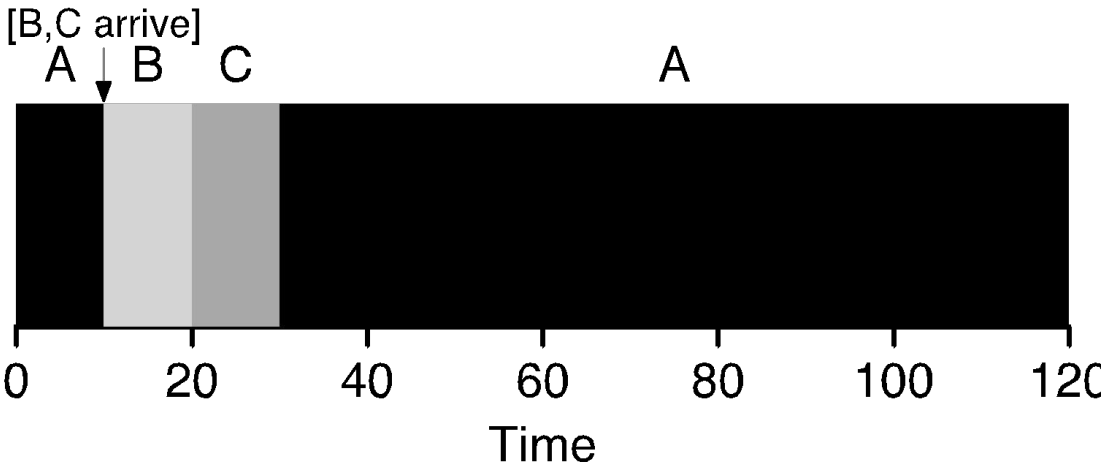
PREEMPTIVE STCF

Job	Arrival(s)	run time (s)
A	~0	100
B	10	10
C	10	10



Average Turnaround Time

(10 + 20 + 120)/ 3
= 50s

PREEMPTIVE STCF

Job	Arrival(s)	run time (s)
A	~0	15
B	10	10
C	10	10

What is the schedule and turnaround time here?

ASSUMPTIONS

1. ~~Each job runs for the same amount of time~~
2. ~~All jobs arrive at the same time~~
3. ~~Once started, each job runs to completion~~
4. ~~All jobs only use the CPU (no I/O)~~
5. Run-time of each job is known (perfect knowledge)

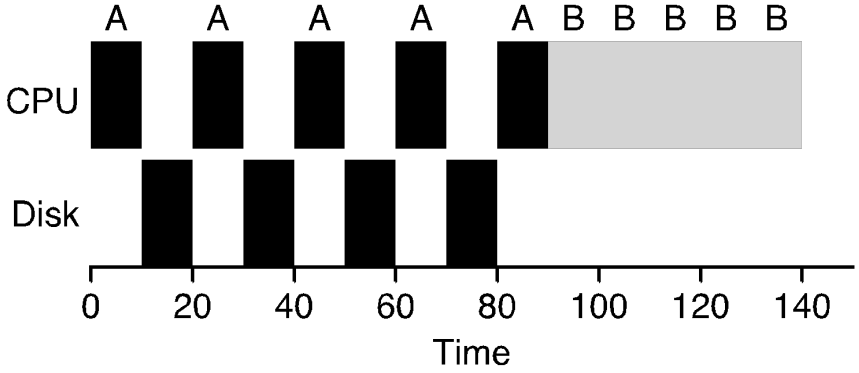
NOT IO AWARE

Assume A and B need 50ms compute each
But…A issues an IO (that takes 10ms) after running for 10ms
B issues no IOs

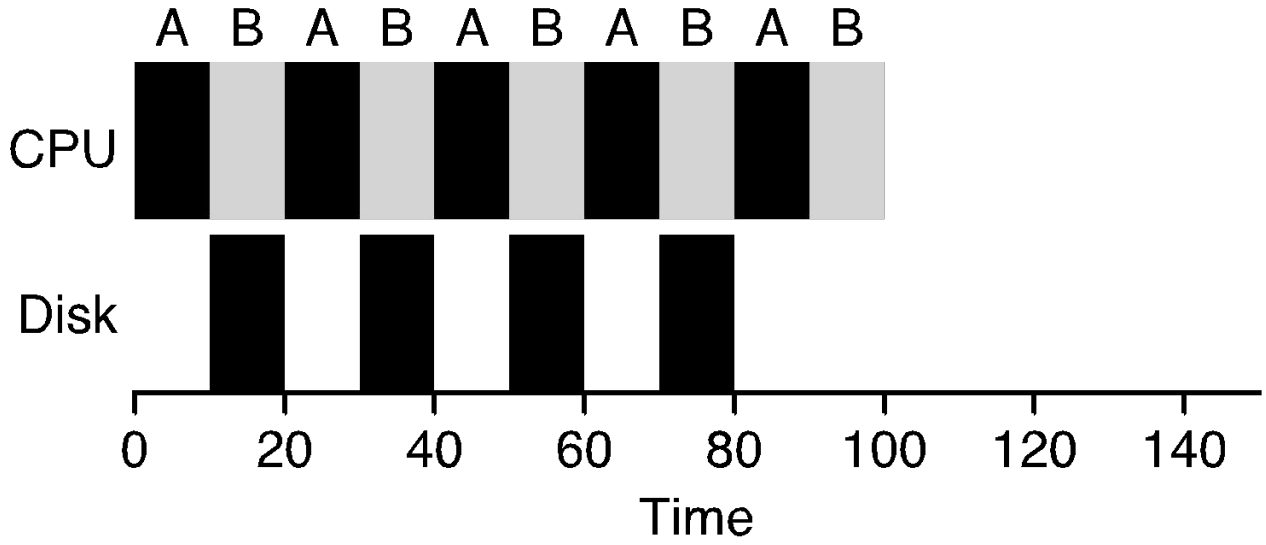
STCF: if not IO-aware, can pick A initially

If you consider the entire process A

as a single job



I/O AWARE SCHEDULING



Each 10ms
sub-job of A is
shorter than Job B

With STCF,
Job A preempts Job B

Treat Job A as 5 separate 10ms sub-jobs
When one sub-job completes I/O, another sub-job is ready

ASSUMPTIONS

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~~5. Run-time of each job is known (perfect knowledge)~~

What if you don’t know job runtime?

For metric of turnaround time:
If jobs have same length:

Then FIFO works well

If jobs have different lengths:

SJF is better than FIFO

Key question: How can OS get short jobs to complete first if OS doesn’t know which are short?

Solution: Round Robin (RR)

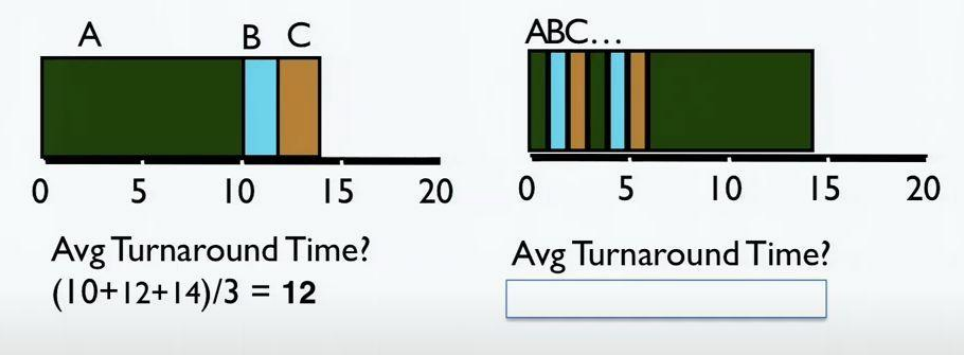
Idea: alternate ready processes for a fixed-length time (called slice or quantum)

Preemptive

Short jobs will finish after fewer time slices

Short jobs will finish sooner than long ones

Different Job Lengths and Turnaround Time

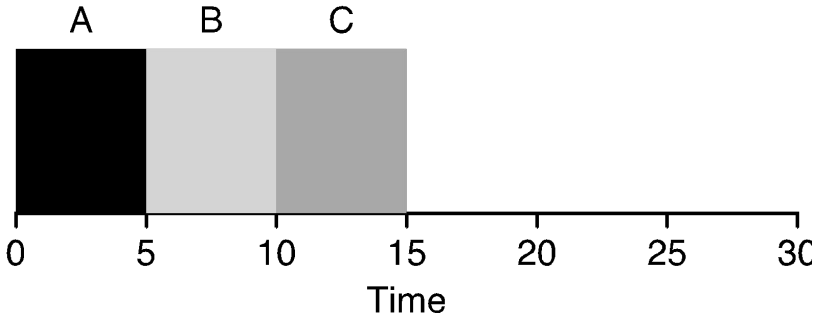


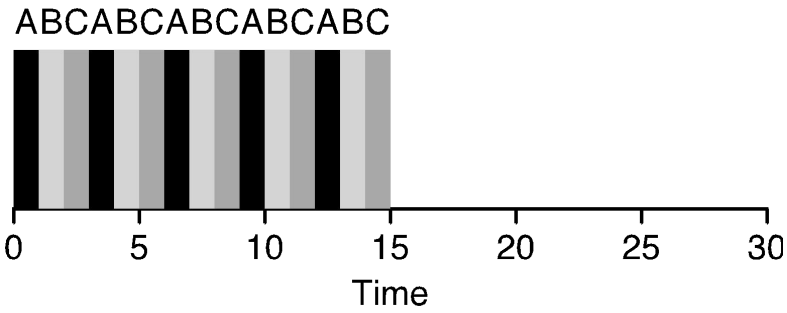
All arrive at t=0 but A arrives a little earlier (so gets scheduled 1st in FIFO)
Turnaround time in RR: ?

Turnaround time in SJF: ?

Say RR uses 1ms timeslice

ROUND ROBIN SCHEDULER

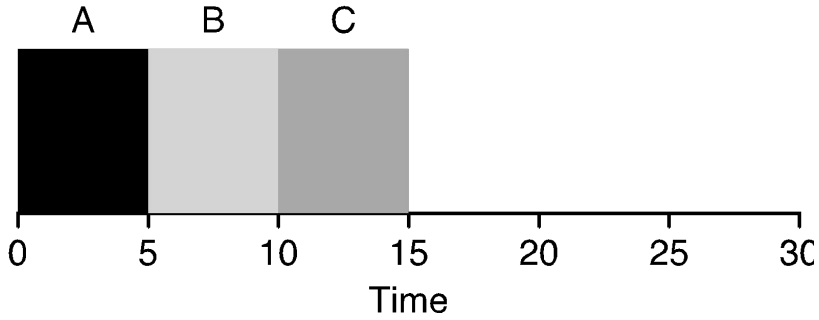


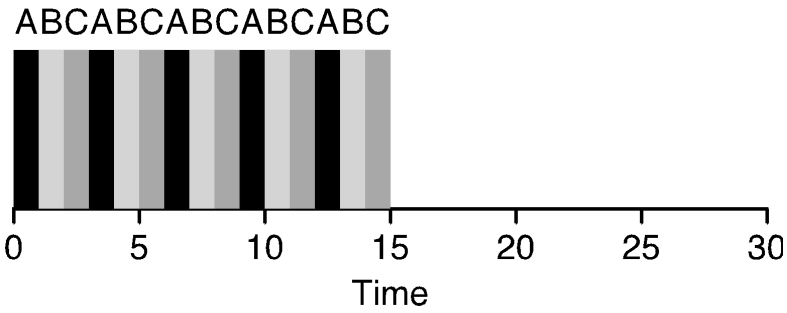


When is RR bad in terms of turnaround time?

When jobs are equal length…

ROUND ROBIN





Average Turnaround Time

(5 + 10 + 15)/3 = 10s

(13 + 14 + 15)/3 = 14s

Batch vs Interactive

Turnaround time is a good metric for CPU-bound programs

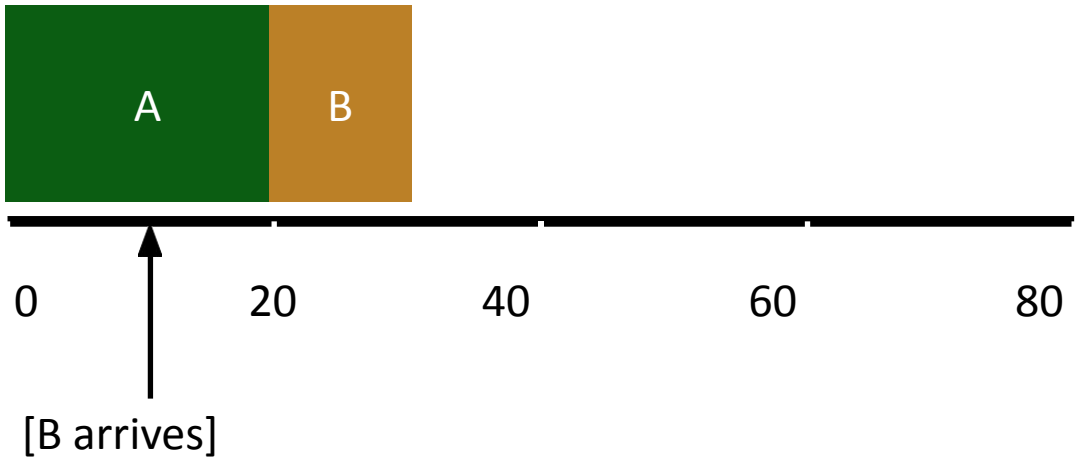
It is not a good metric for interactive programs

METRIC 2: RESPONSE TIME

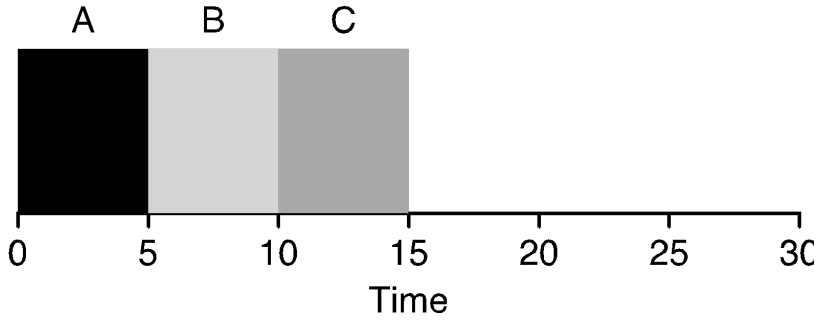
Response time = *first_run_time - arrival_time*

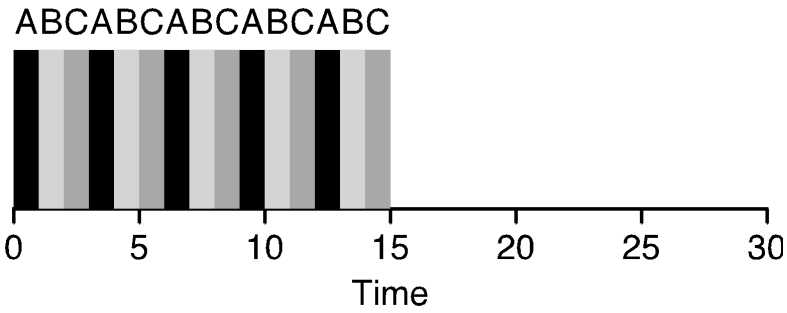
B's turnaround: 20s

B's response: 10s



ROUND ROBIN





Average Response Time

(0 + 5 + 10)/3 = 5s

(0 + 1 + 2)/3 = 1s

Average Turnaround Time

(5 + 10 + 15)/3 = 10s

(13 + 14 + 15)/3 = 14s

TRADE-OFFS

Round robin increases turnaround time, decreases response time
Trade-off: fairness vs turnaround time

Tuning challenges:

What is a good time slice?

What is the overhead in context switching? (hint: not just saving and restoring state)

Round robin: doesn't have to know the job length

Short jobs will complete before long jobs (like SJF)

ASSUMPTIONS

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MULTI-LEVEL FEEDBACK QUEUE

MLFQ: GENERAL PURPOSE SCHEDULER

Must support two job types with distinct goals

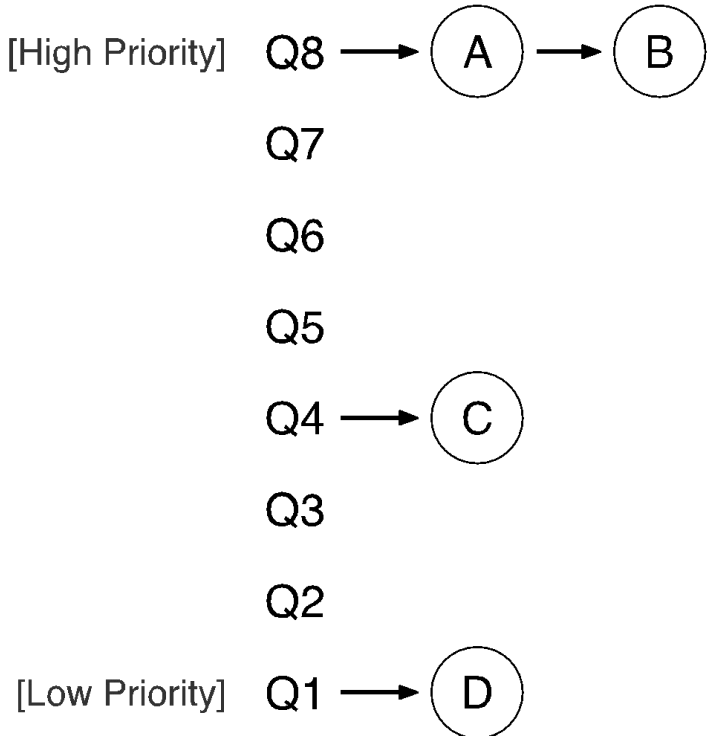
- "interactive" programs care about response time
- "batch" programs care about turnaround time

Approach:

Multiple levels of round-robin
Higher levels have higher priority

Processes are preemptable

MLFQ EXAMPLE



"Multi-level" – Each level is a queue

Rules for MLFQ

Rule 1: If priority(A) > Priority(B)
A runs

Rule 2: If priority(A) == Priority(B),
A & B run in RR

CHALLENGES

How to set priority?

Does a process stay on one queue or move across queues?

Approach:

Use recent past behavior of process to predict future

Common approach in systems when don’t have perfect knowledge

If interactive recently, will likely be interactive in the near future

MORE MLFQ RULES

Rule 1: If priority(A) > Priority(B), A runs

Rule 2: If priority(A) == Priority(B), A & B run in RR

Rule 3: Processes start at top priority

Rule 4: If job uses whole slice, demote process

(longer time slices at lower priorities)

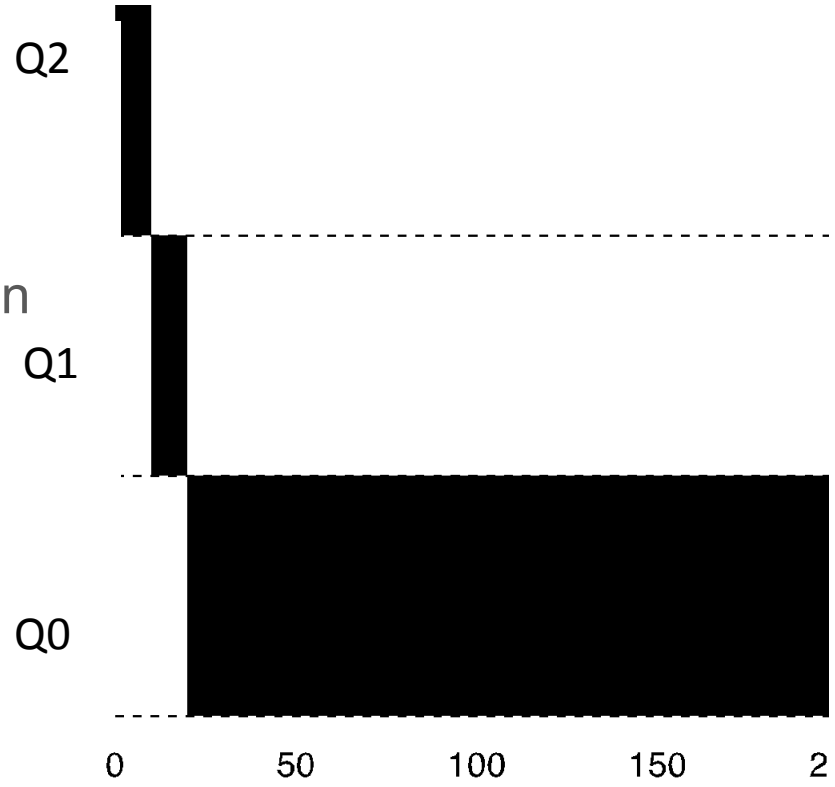
ONE LONG JOB

Starts at top

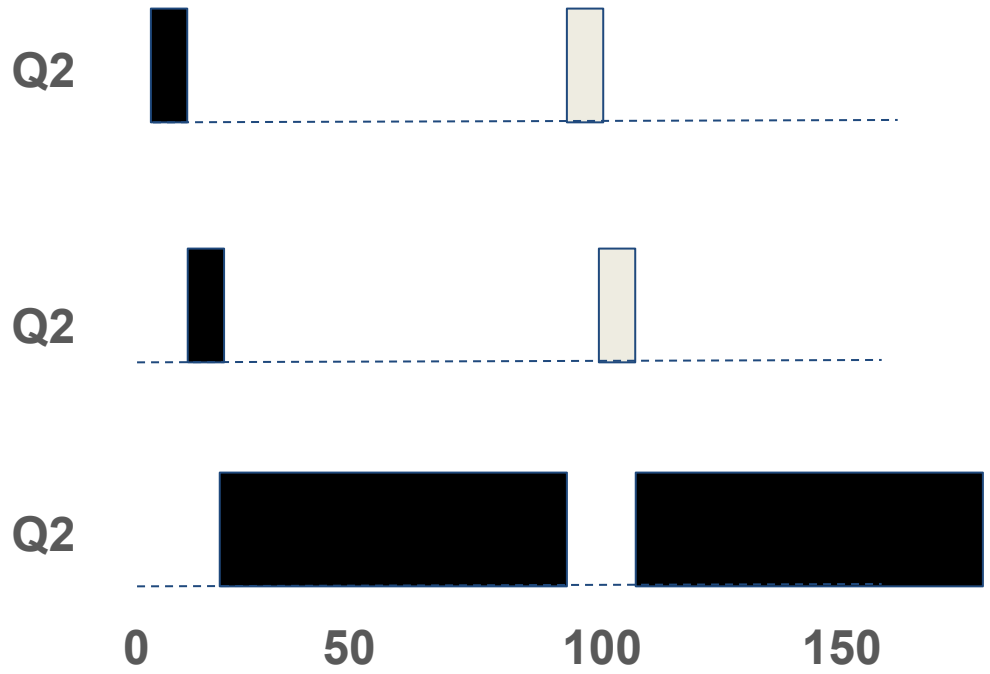
Uses whole slice

Moves down

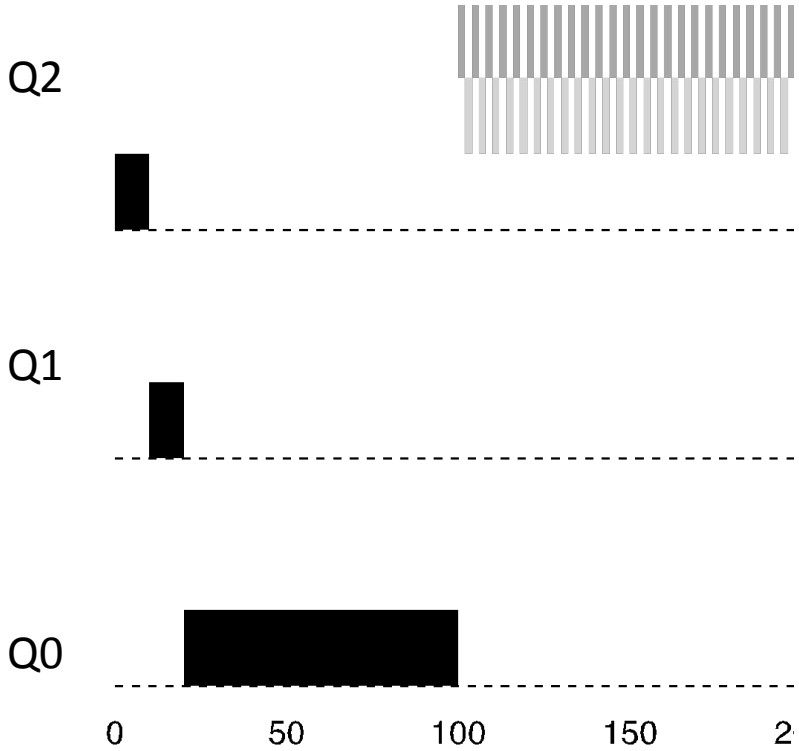
Moves down again



INTERACTIVE SHORT PROCESS JOINS

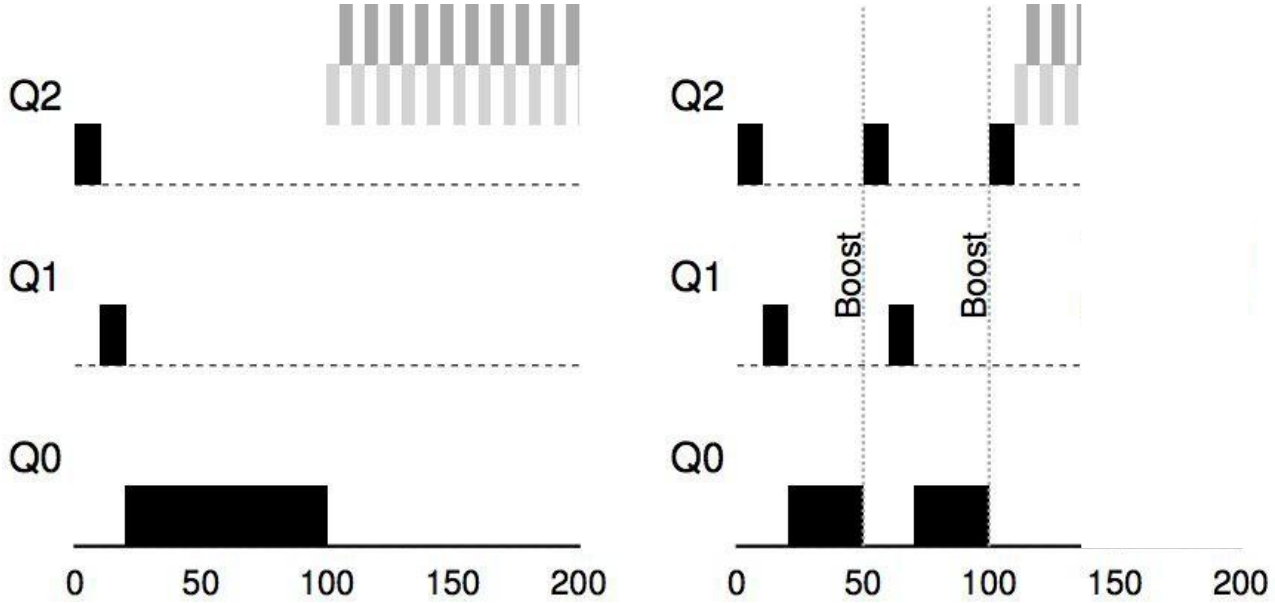


MLFQ PROBLEMS?



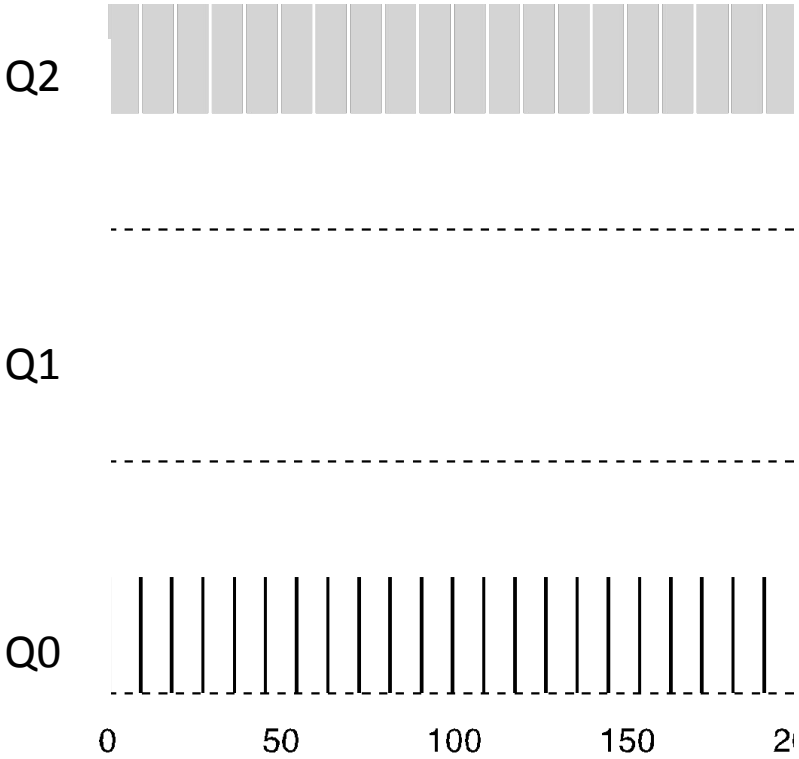
What is the problem with this schedule ?

AVOIDING STARVATION



Rule 5: After some time period S, move all the jobs in the system to the topmost queue.

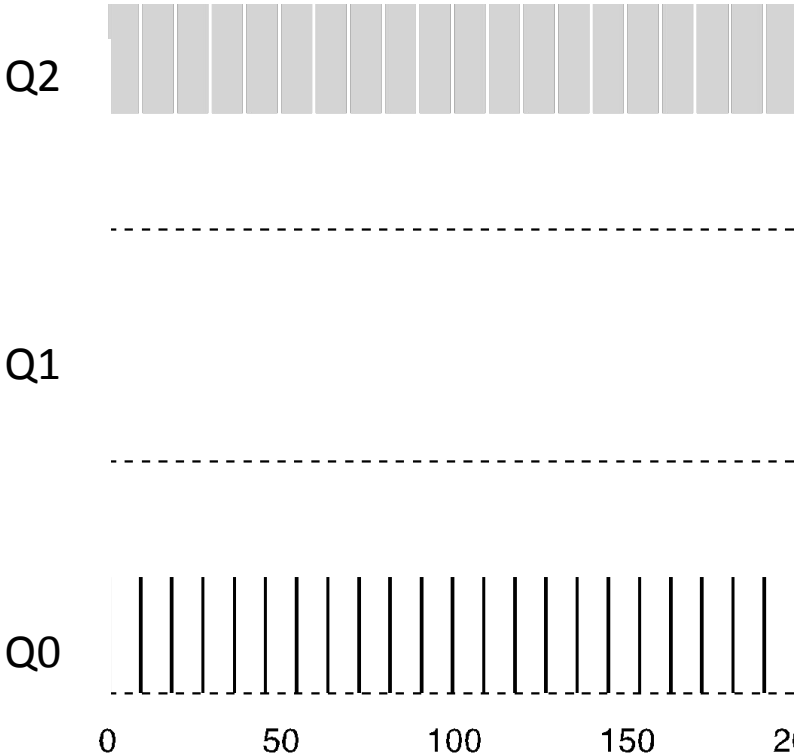
GAMING THE SCHEDULER ?



Job could trick scheduler by doing I/O just before time-slice end

When high-pri job is blocked, low pri job gets to run but when ready, it preempts the low-pri job

GAMING THE SCHEDULER ?



Job could trick scheduler by doing I/O just before time-slice end

Rule 4*: Account for total run time at priority level
Downgrade when exceed threshold

MLFQ Summary

Works well with a mix of compute-intensive and interactive jobs
Can finish shorter jobs earlier

5 rules to implement MLFQ

Versions of it are used in BSD, Sun Solaris, Windows NT, and Linux.

But multi-core versions!

FAIRNESS: Quick Detour

How to define? 4 kids share a cake, each gets 25%

If one kid can eat only 10%, is it fair to force her to eat 25%?

Min-max Fairness: Least demanding gets fair share first
Kid1 takes 10%

Her 15% is divvied up: others kids entitled to 30%

fair share

SUMMARY

Scheduling Policies

- Understand workload characteristics like arrival, CPU, I/O
- Scope out goals, metrics (turnaround time, response time)
- Metrics: Latency vs throughput

Real-life schedulers are complicated beasts

- Lots of trade-offs based
- Past behavior is good predictor of future behavior