Hello !

CPU SCHEDULING

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CS 537, Fall 2024

ADMINISTRIVIA

- Project 1 is due tomorrow!
- Still on the waitlist?
  - Email shivaram@cs.wisc.edu and enrollment@cs.wisc.edu
- Project 2 out tomorrow → xv6

Office hours
→ Thursdays 3pm
CS 7367

AGENDA / LEARNING OUTCOMES

Scheduling

- How does the OS decide what process to run?
- What are some of the metrics to optimize for?

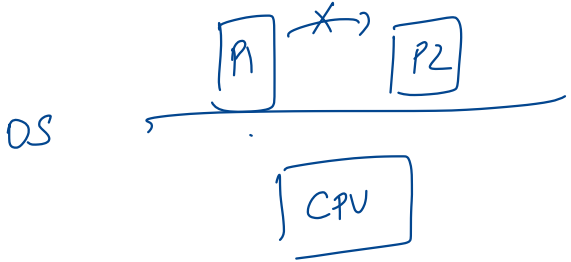
Policies

- How to handle interactive and batch processes?
- What to do when OS doesn't have complete information?

RECAP

RECAP: SCHEDULING MECHANISM

Process: Abstraction to virtualize CPU



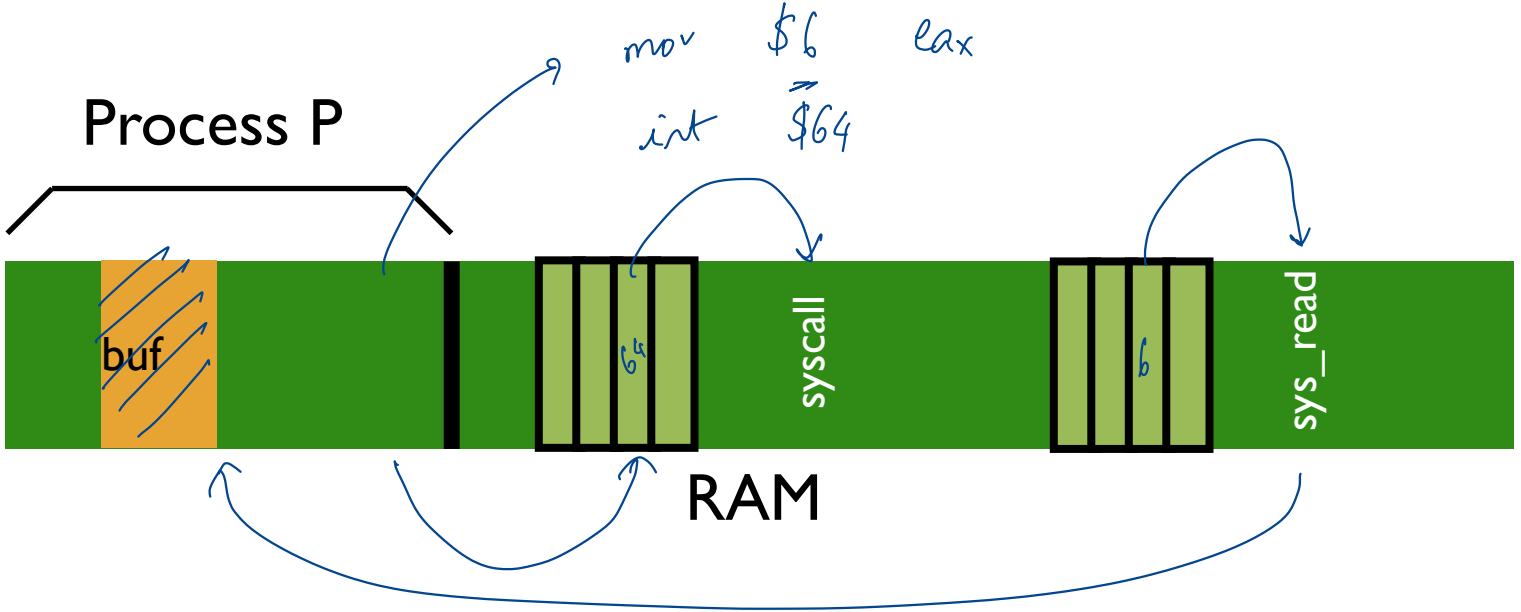
Role of the OS

- Protection: How can we ensure user process can't harm others?
- Sharing: Reschedule processes for fairness, efficiency

RECAP: SYSCALL

Separate user-mode from kernel mode for security

Syscall: call kernel mode functions



DISPATCH MECHANISM

OS runs dispatch loop

scheduler

```
while (1) {
        run process A for some time-slice
        stop process A and save its context
        load context of another process B
}
```

Cooperative
↳ yield()

Timer interrupts
↳ periodic interrupt

Question 1: How does dispatcher gain control?

Question 2: What must be saved and restored?

Operating System | Hardware | Program

schedule()

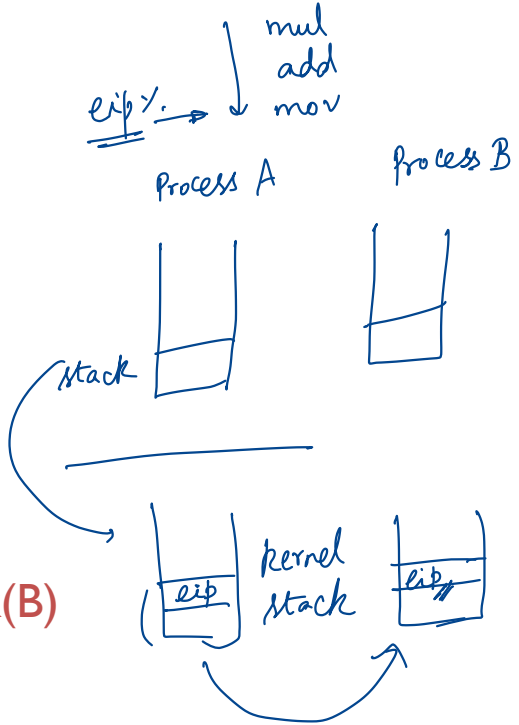
periodic

timer interrupt
save regs(A) to k-stack(A)
move to kernel mode
jump to trap handler

Handle the trap
Call switch() routine
save kernel regs(A) to proc-struct(A)
restore kernel regs(B) from proc-struct(B)
switch to k-stack(B)
return-from-trap (into B)

restore regs(B) from k-stack(B)
move to user mode
jump to B's IP

Process A



Process B

SUMMARY

Process

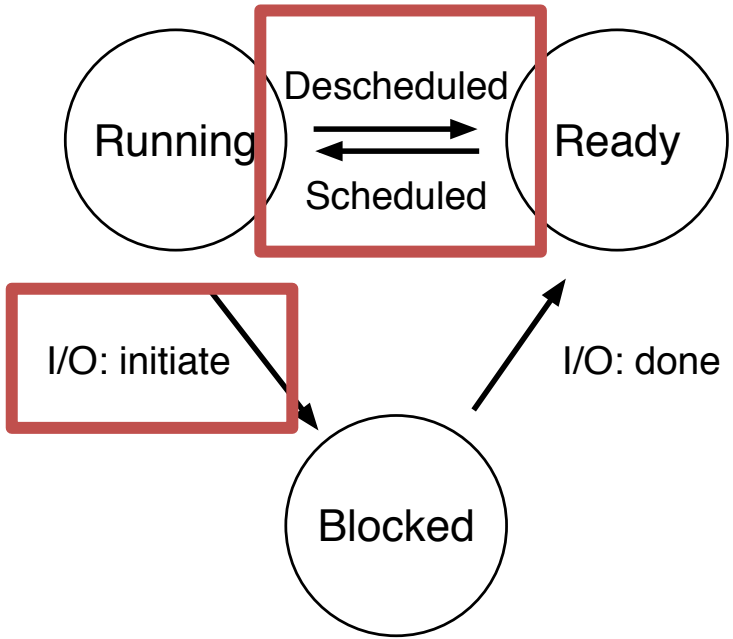
Process: Abstraction to virtualize CPU

Use time-sharing in OS to switch between processes

Key aspects

- Use system calls to run access devices etc. from user mode
- Context-switch using interrupts for multi-tasking

How do you decide which process is scheduled / de-scheduled



POLICY ?

VOCABULARY

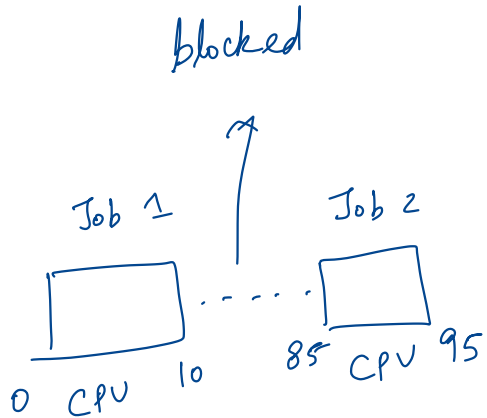
Workload: set of **jobs** (arrival time, run_time)

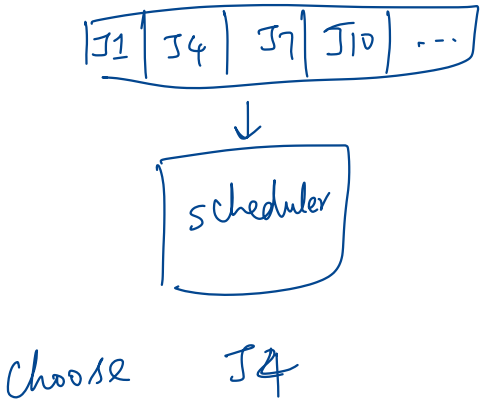
Job ~ Current execution of a process

- Alternates between CPU and I/O
- Moves between ready and blocked queues

Scheduler: Decides which ready job to run

Metric: measurement of scheduling quality





APPROACH

Assumptions

↳ strictest

Scheduling policy

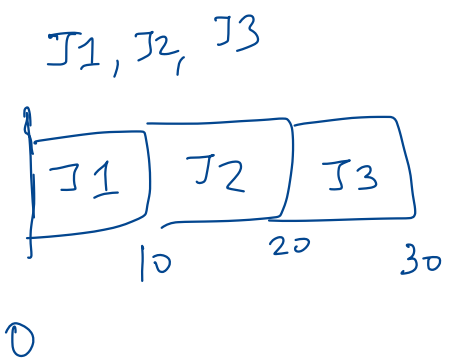
→

Metric

↳ How long does a job wait before it recieves CPU

ASSUMPTIONS

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



J1, J2, J3

↓

Schedule

METRIC 1: TURNAROUND TIME

Turnaround time = *completion_time - arrival_time*

Example:

Process A arrives at time t = 10, finishes t = 30 30 - 10 = 20

Process B arrives at time t = 10, finishes t = 50 50 - 10 = 40

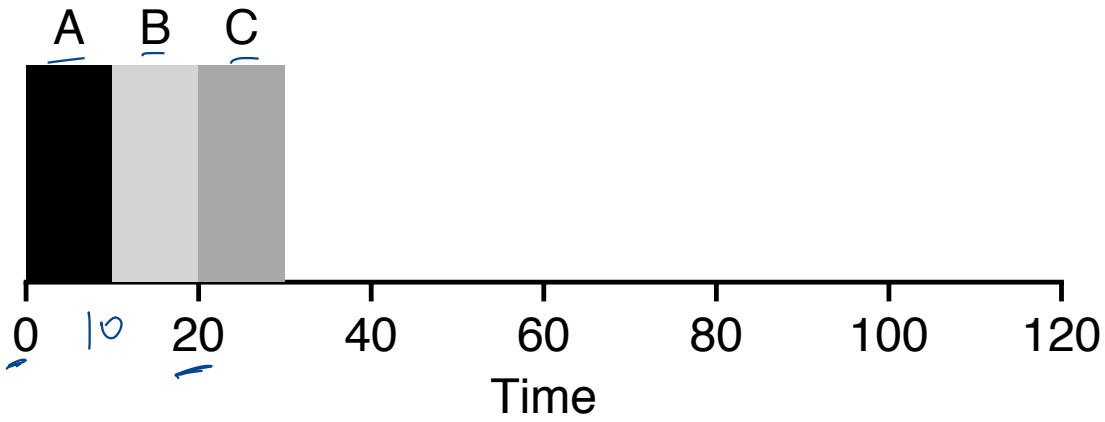
Turnaround time

A = 20, B = 40

Average = 30

FIFO / FCFS

Job	arrival(s)	run time (s)	turnaround (s)
A	~0	10	10
B	~0	10	20
C	~0	10	30



Average Turnaround Time = 20

ASSUMPTIONS

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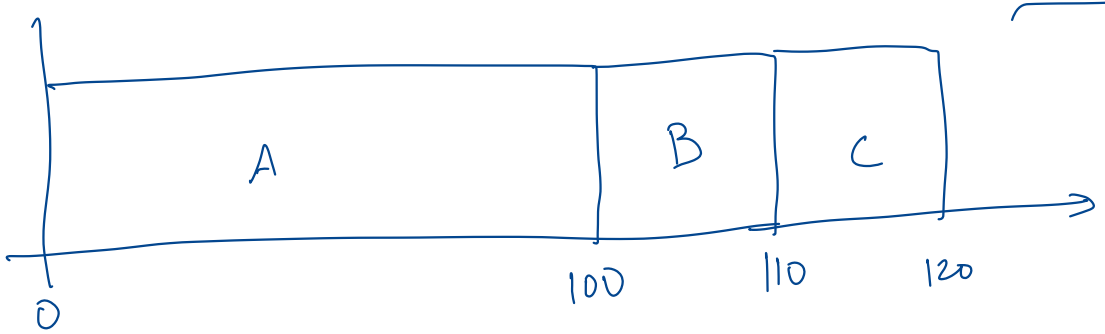
Turn around time

A = 100 — 100

B = 10 — 110

C = 10 — 120

Average 110



CHALLENGE

Turnaround time suffers when short jobs must wait for long jobs

New scheduler:

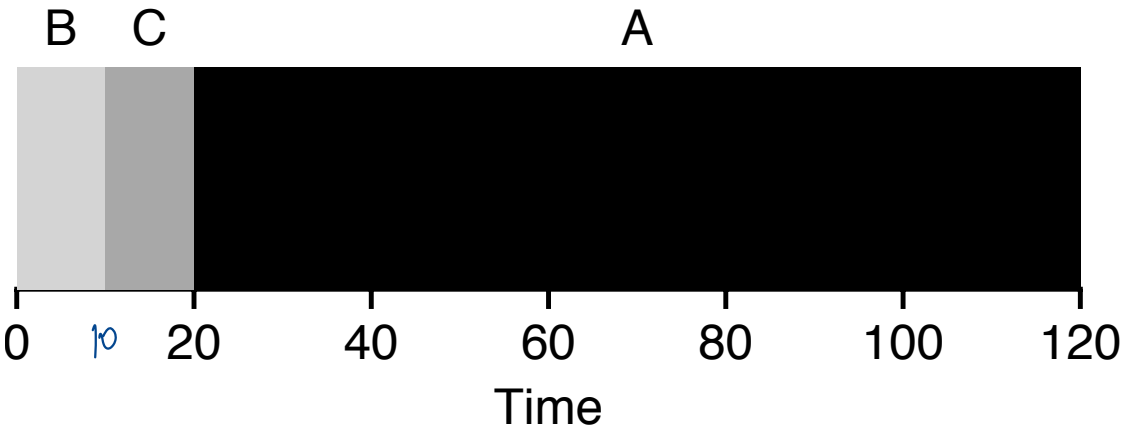
SJF (Shortest Job First)

Choose job with smallest run time!

SHORTEST JOB FIRST (SJF)

Job	Arrival(s)	run time (s)	Turnaround (s)
A	~0	100	120
B	~0	10	10
C	~0	10	20

Optimal policy to minimize avg. turn around time



Average Turnaround Time 50

ASSUMPTIONS

~~1. Each job runs for the same amount of time~~

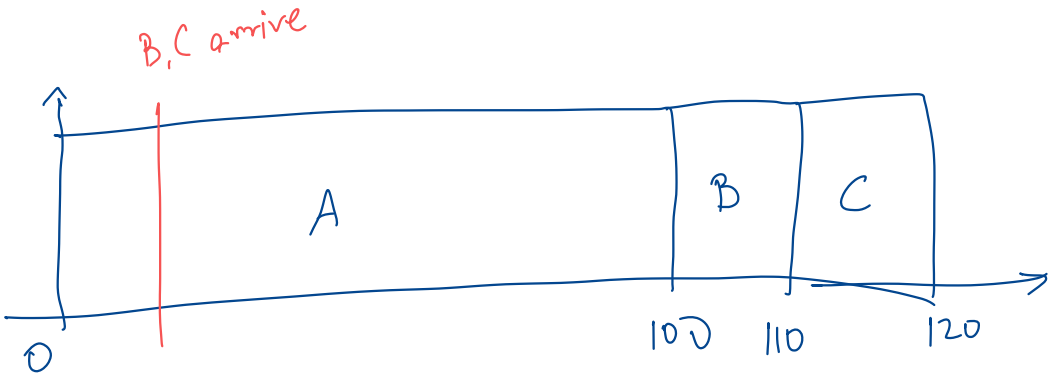
2. All jobs arrive at the same time

3. All jobs only use the CPU (no I/O)

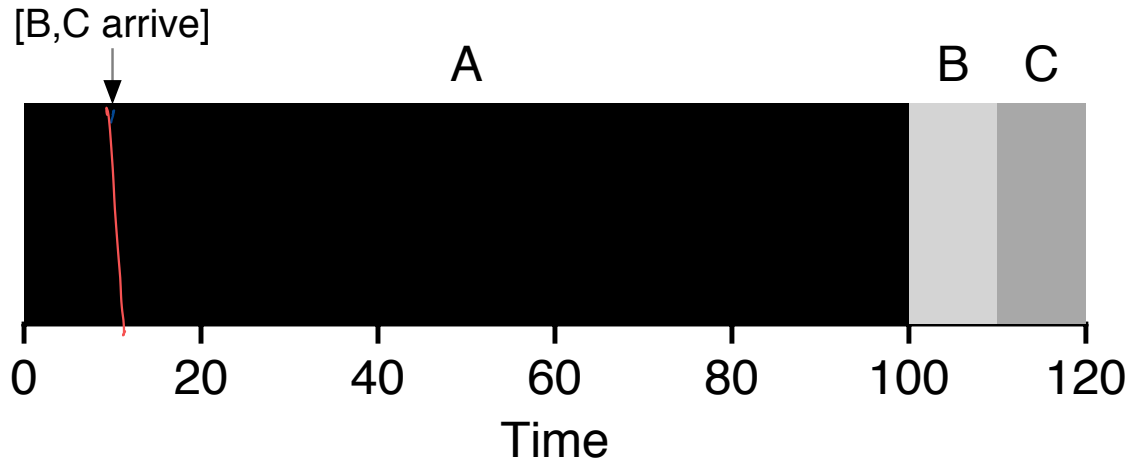
4. Run-time of each job is known

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

What will be the schedule with SJF?



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



Average Turnaround Time ?

(100 + 110 + 120)/ 3
= 110s

PREEMPTIVE SCHEDULING

Previous schedulers:

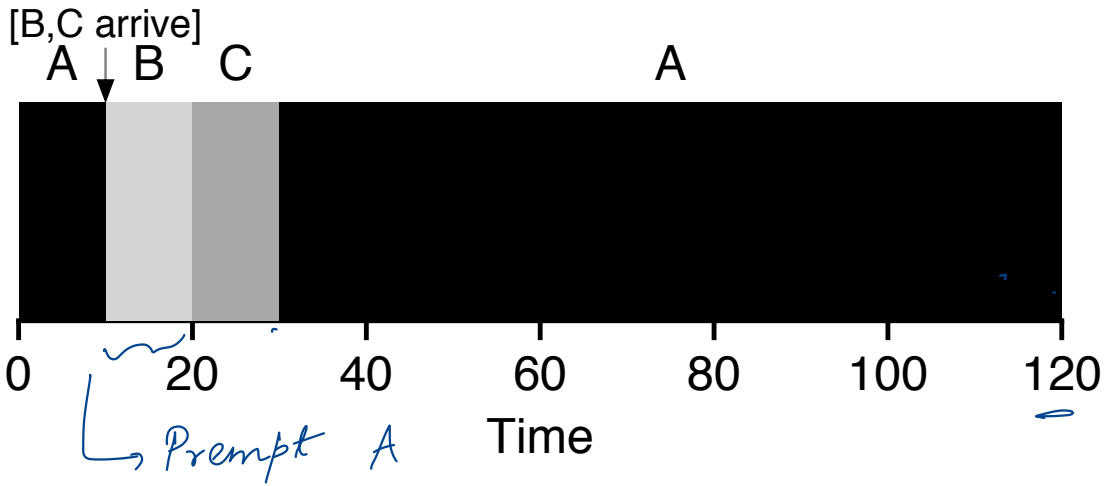
- FIFO and SJF are non-preemptive
- Only schedule new job when previous job voluntarily relinquishes CPU

New scheduler:

- Preemptive: Schedule different job by taking CPU away from running job
- STCF (Shortest Time-to-Completion First)
- Always run job that will complete the quickest

PREMPTIVE SCTF

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



Average Turnaround Time

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

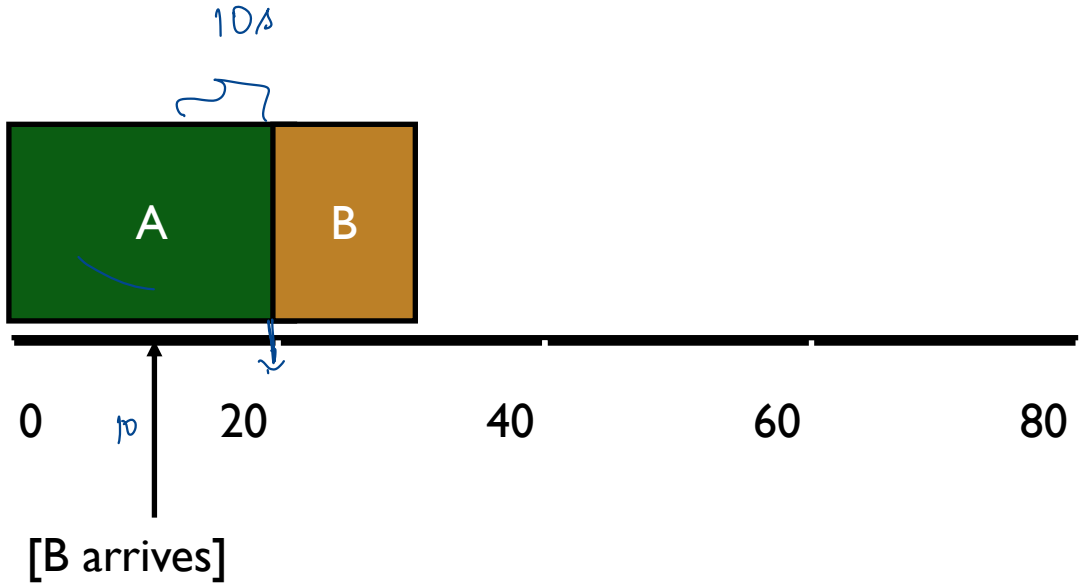
B C

METRIC 2: RESPONSE TIME

Response time = *first_run_time - arrival_time*

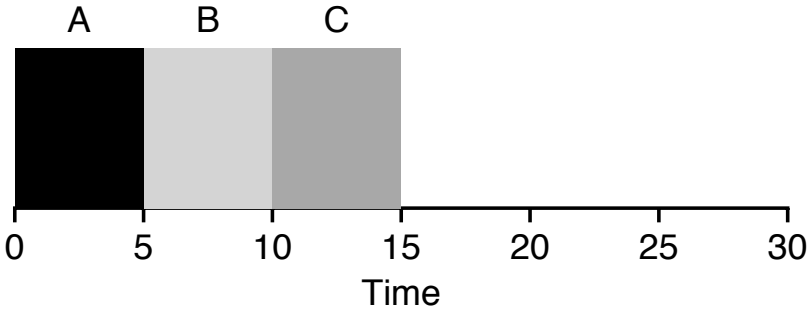
B's turnaround: 20s

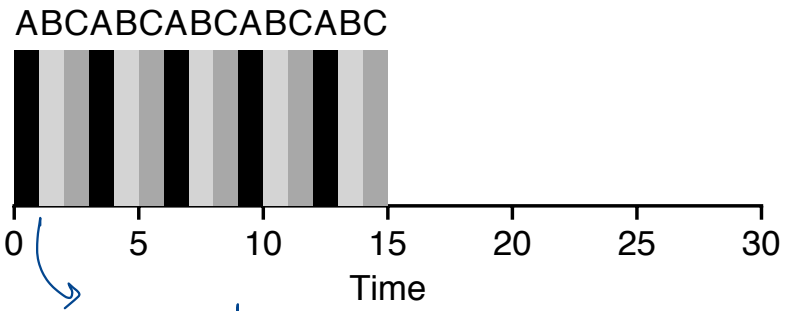
B's response: 10s



ROUND ROBIN SCHEDULER

A, B, C arrive at 0





overhead

Key idea: Switch more often to reduce response time

response time

A = 0

B = 5

C = 10

Turn around

5

10

15

TA

13

14

15

response time

A = 0

B = 1

C = 2

switch duration

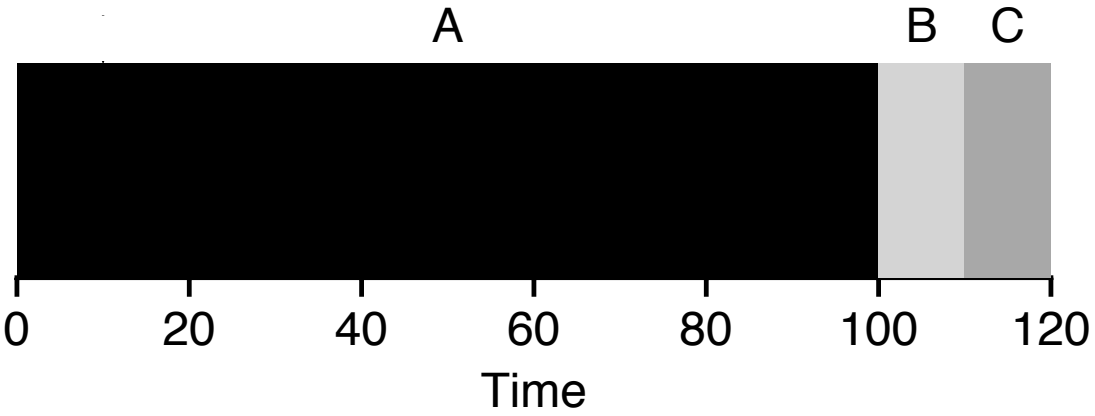
↳ responsiveness

overhead

QUIZ2

https://tinyurl.com/cs537-fa24-q2

Job	Arrival(s)	run time (s)	
A	~0	100	100
B	~0	10	110
C	~0	10	120



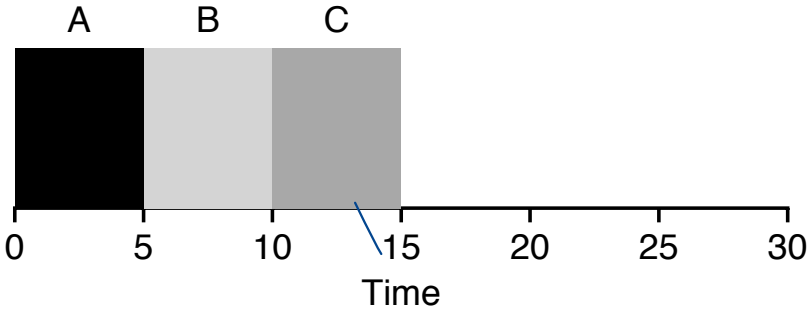
Average Turnaround Time ?

110

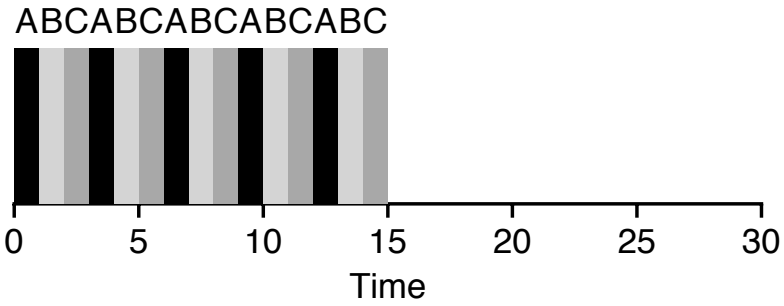
What is one schedule that could be better?

B, C, A or C, B, A

QUIZ2



FCFS



Round Robin every 1s

Average Response Time?

$\frac{0 + 5 + 10}{3} = 5$

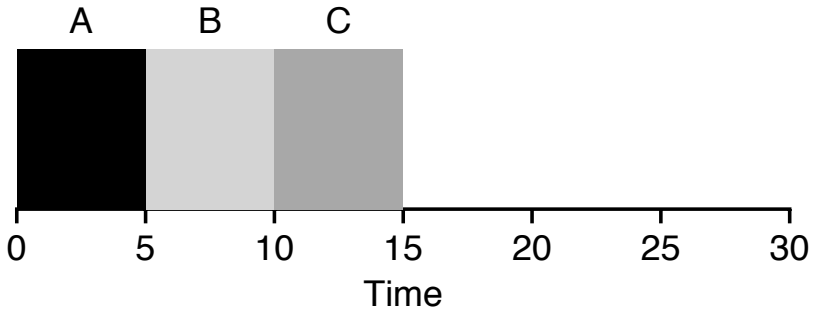
$\frac{0 + 1 + 2}{3} = 1$

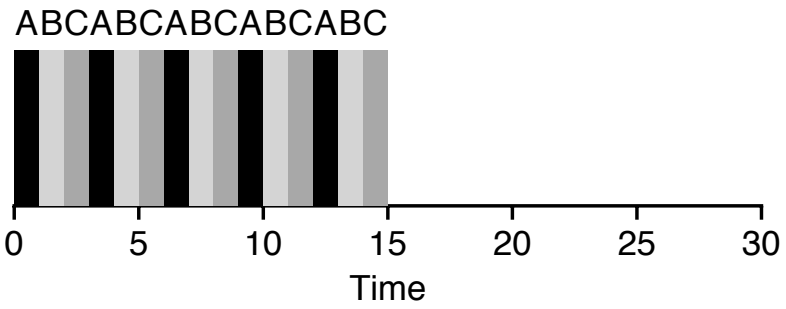
Average Turnaround Time?

$\frac{5 + 10 + 15}{3} = 10$

$\frac{13 + 14 + 15}{3} = 14$

QUIZ2: 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

Tuning challenges:

- What is a good time slice for round robin?
- What is the overhead of context switching?

how long does a process run before interruption

1, 5, 10

ASSUMPTIONS

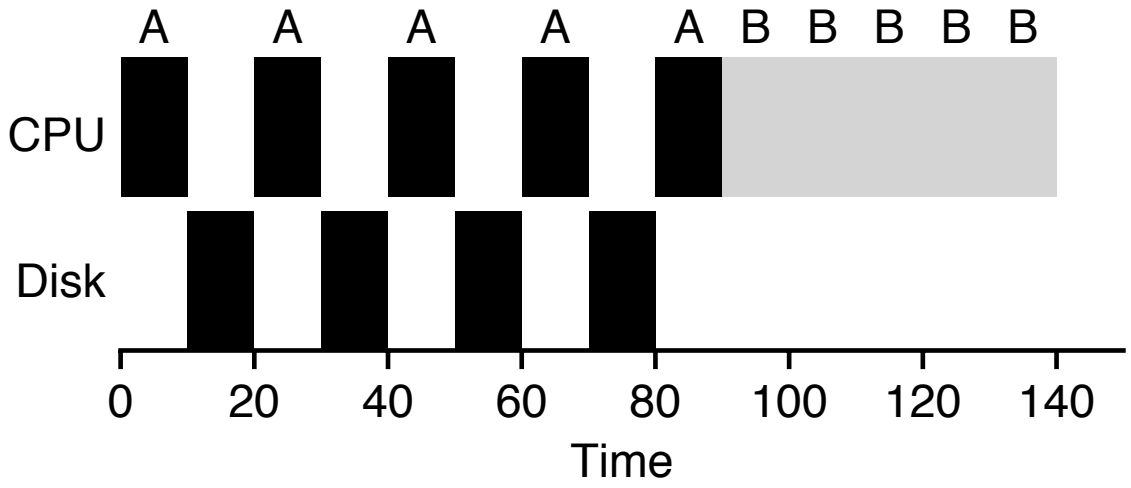
~~1. Each job runs for the same amount of time~~

~~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

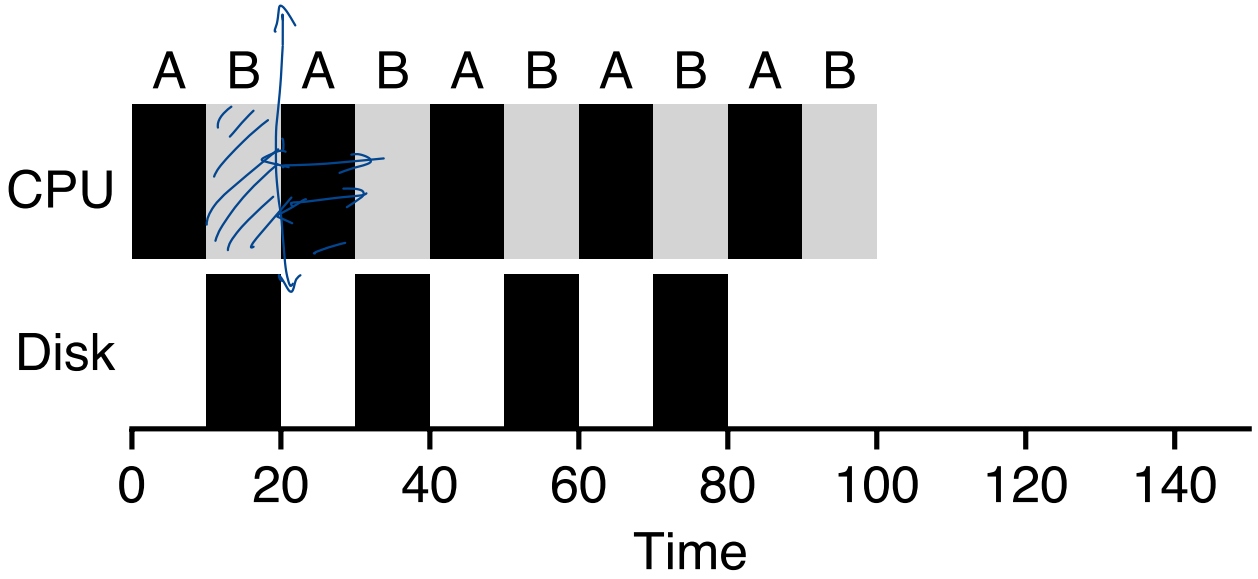
NOT IO AWARE



Blocked

Job holds on to CPU while blocked on disk!

I/O AWARE SCHEDULING



Each CPU burst is shorter than Job B

With SCTF,
Job A preempts Job B

Treat Job A as separate CPU bursts.
When Job A completes I/O, another Job A is ready

ASSUMPTIONS

~~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

MULTI-LEVEL FEEDBACK QUEUE

MLFQ

MLFQ: GENERAL PURPOSE SCHEDULER

Must support two job types with distinct goals

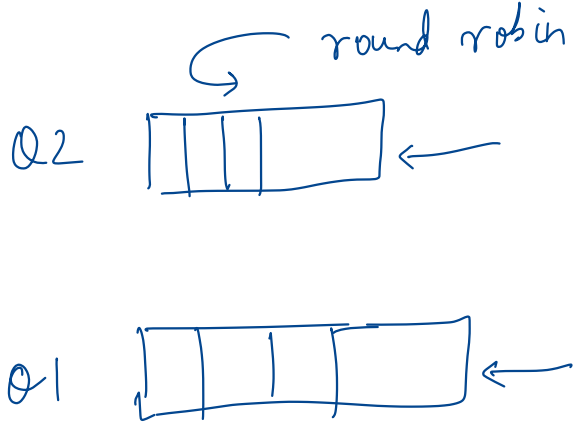
- "interactive" programs care about response time
- "batch" programs care about turnaround time

Approach:

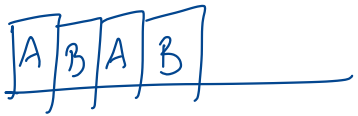
Multiple levels of round-robin

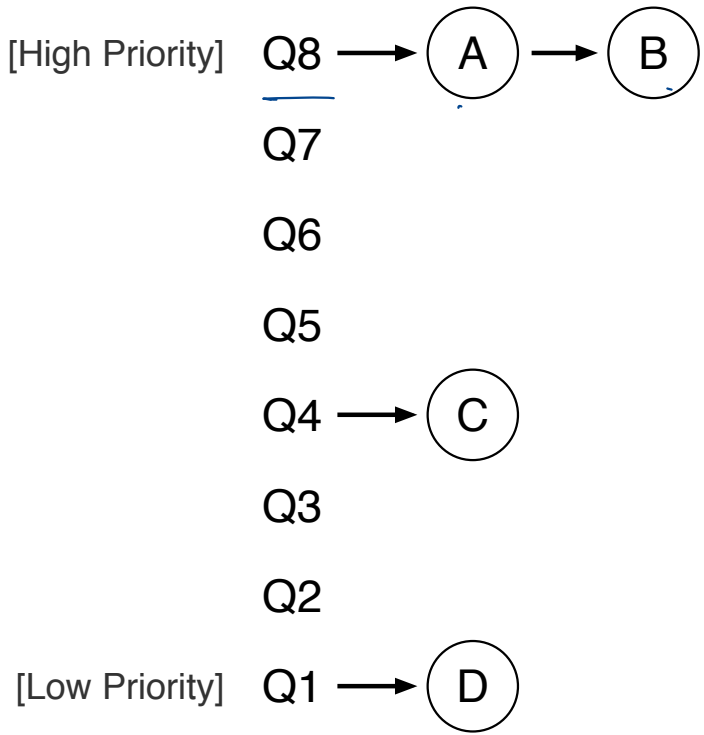
Each level has higher priority than lower level

Can preempt them



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?

What do we do when a new process arrives?

Does a process stay in one queue or move between queues?

Approach:

Use past behavior of process to predict future!

Guess how CPU burst (job) will behave based on past CPU bursts

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

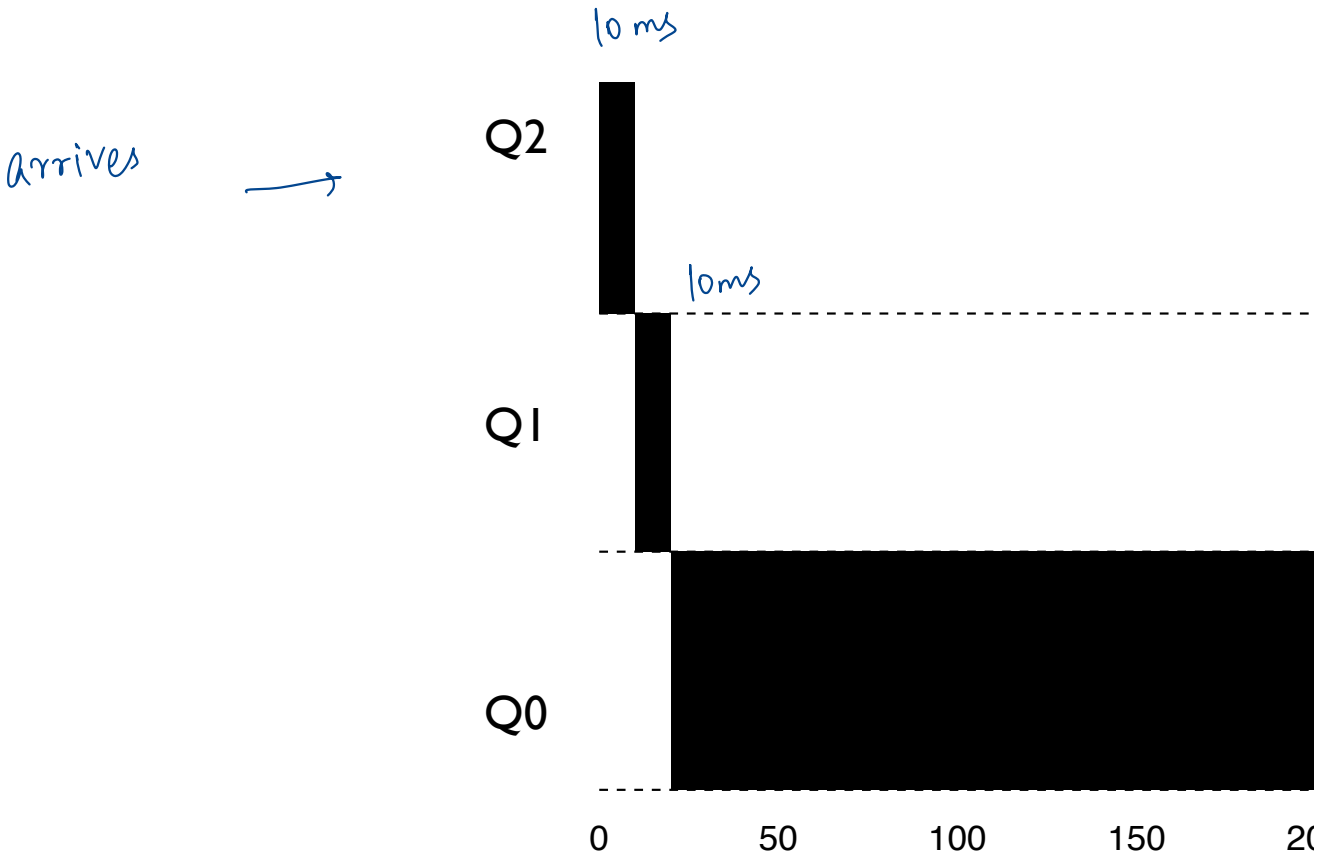
(longer time slices at lower priorities)

time slice as 10 ms in Q 8

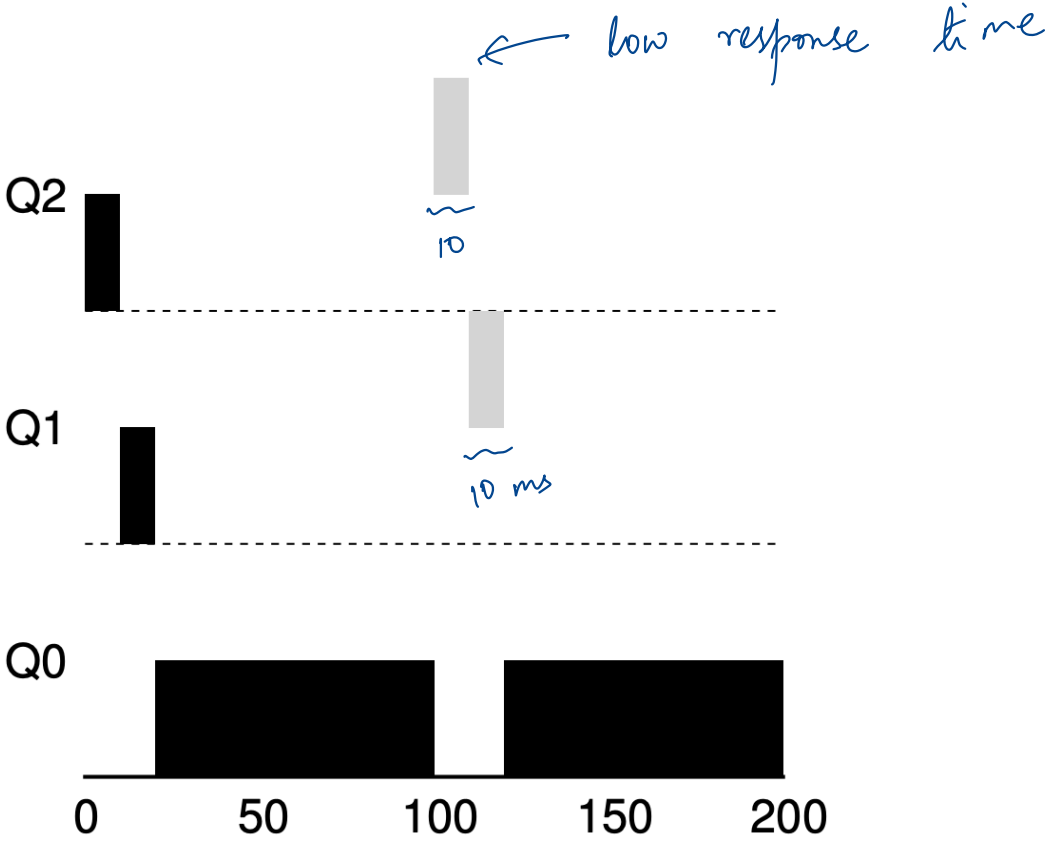
40 ms in Q 4

100 ms in Q 1

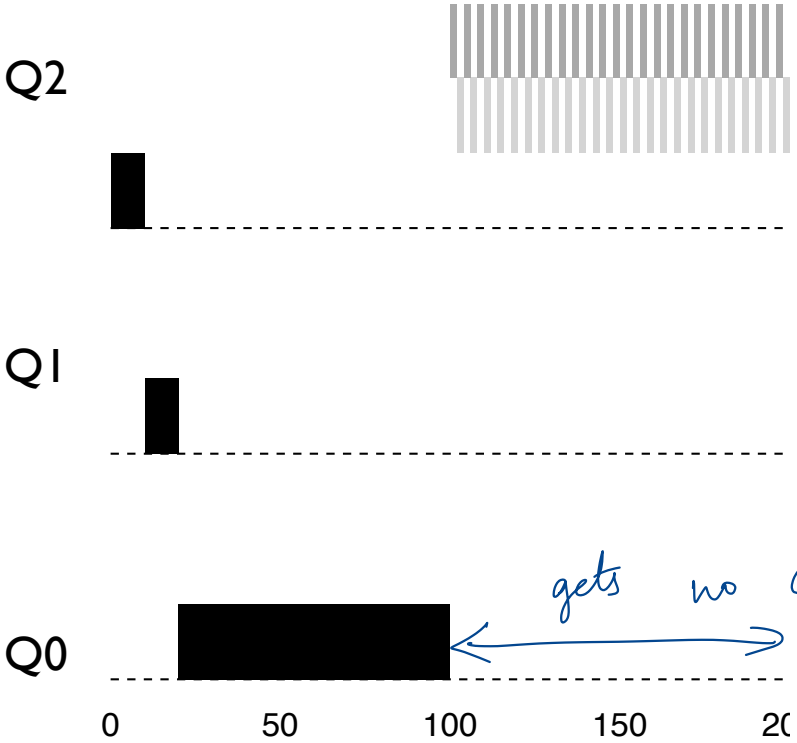
ONE LONG JOB



INTERACTIVE PROCESS JOINS



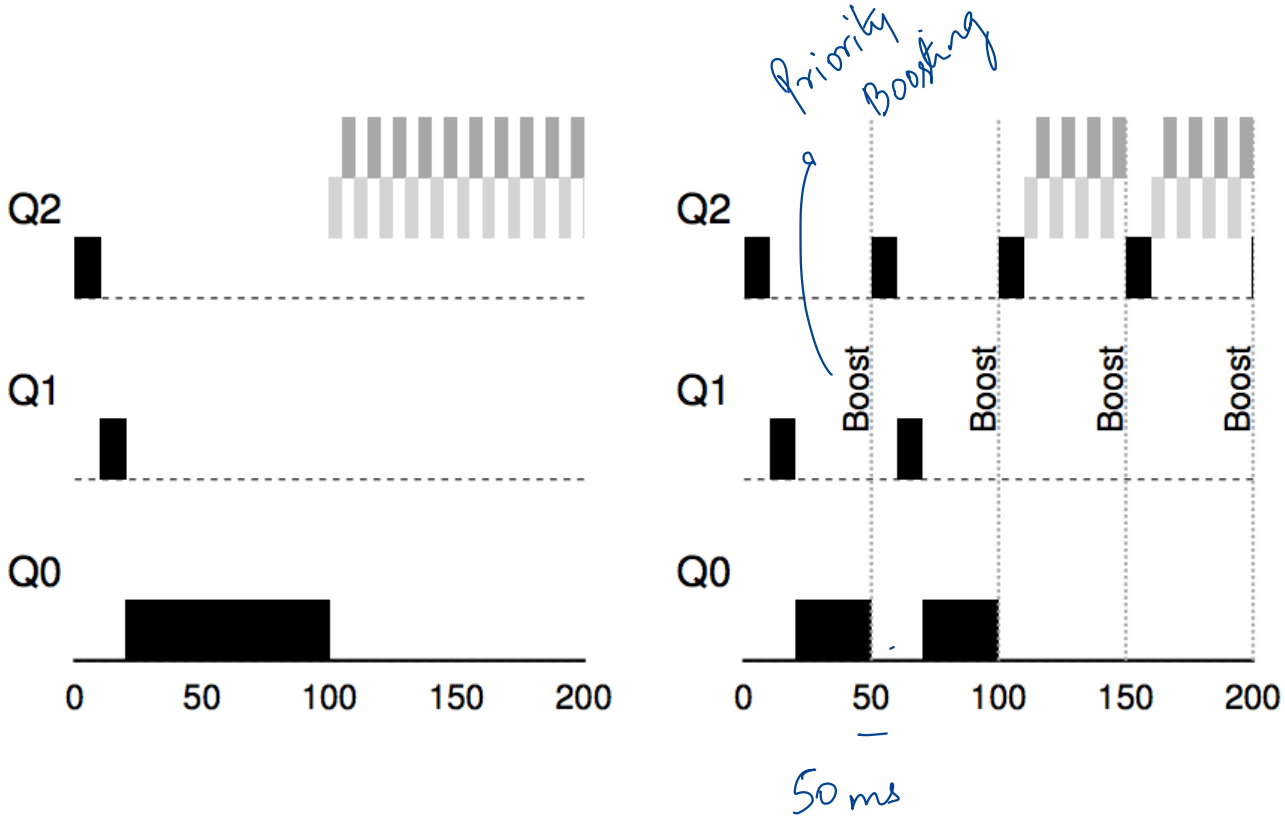
MLFQ PROBLEMS?



What is the problem with this schedule ?

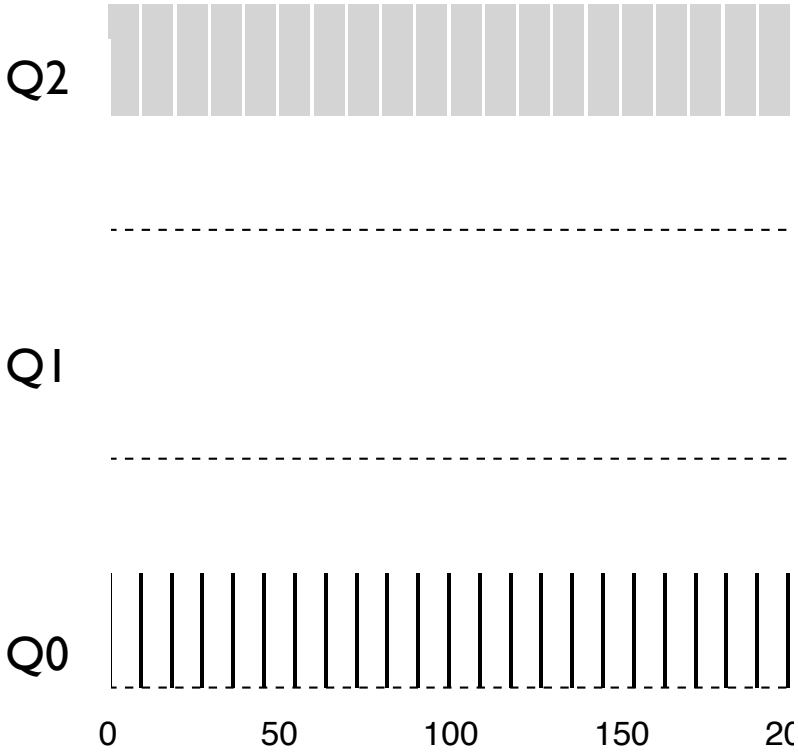
gets no CPU for a long time period → Starvation

AVOIDING STARVATION



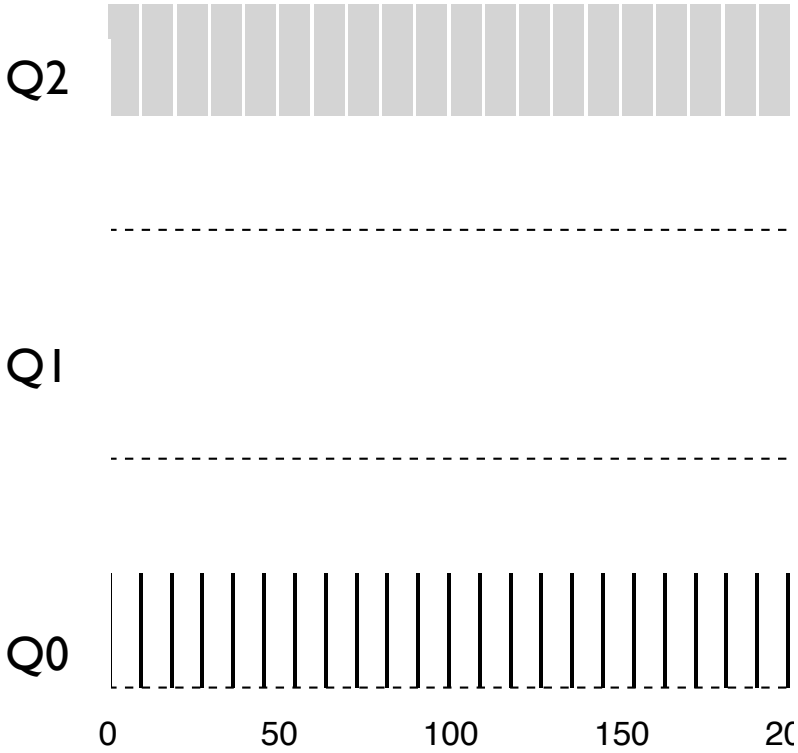
Rule 5: After some time period S, move all the jobs in the system to the topmost queue.

GAMING THE SCHEDULER ?



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

GAMING THE SCHEDULER ?



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

Rule 4*: Once a job uses up its time allotment at a given level (regardless of how many times it has given up the CPU), its priority is reduced

SUMMARY

Scheduling Policies

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

Approach

- Trade-offs based on goals, metrics (RR vs. SCTF)
- Past behavior is good predictor of future behavior?

NEXT STEPS

Project 1: Due tomorrow at 11:59pm

Project 2: Out tomorrow!