CS 423
Operating System Design: CPU Scheduling Policies
1/29

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Logistics

Next lecture: TA will walkthrough MP0

This lecture:

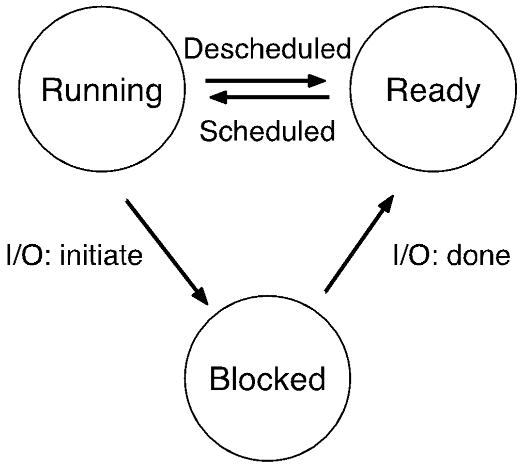
Recap scheduling mechanism

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:

Natively run the program on CPU

Use system calls to do restricted things like accessing devices

Use timer interrupts to grab control from user process and switch to different processes

Operating System

Hardware

Program

Process A

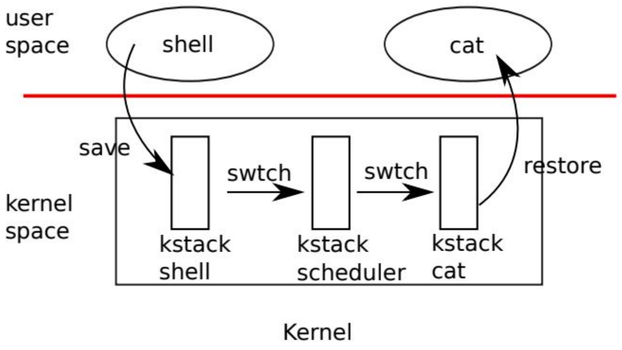
timer interrupt
save regs(A) to k-stack(A)
move to kernel mode
jump to trap handler

Handle the trap
Call switch() routine
 save kernel regs(A) to proc-struct(A)
 restore kernel regs(B) from proc-struct(B) // when were B's regs saved!?
 switch to k-stack(B) // this is the key point
 return-from-trap (into B)

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

Process B

xv6 Example (If you are interested)



There is a separate per-cpu scheduler thread in xv6 that makes the policy decision

If you are interested: take a look at

https://github.com/mit-pdos/xv6-public

proc.c: “sched” function where the old user process switches into the scheduler thread

proc.c: “scheduler” function where the scheduler switches into the new user process

End of RECAP

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 ~ current CPU burst of a process

Processes move b/w CPU and IO

Scheduler: Decides which ready job to run

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

APPROACH

Assumptions

Metric

Scheduling policy

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

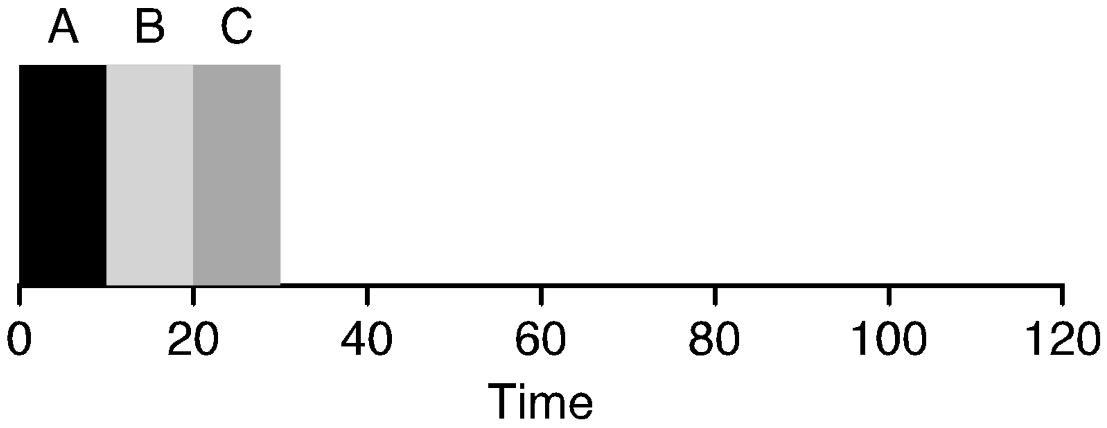
Average = 30

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

~~1. Each job runs for the same amount of time~~
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4. All jobs only use the CPU (no I/O)
5. Run-time of each job is known (perfect knowledge)

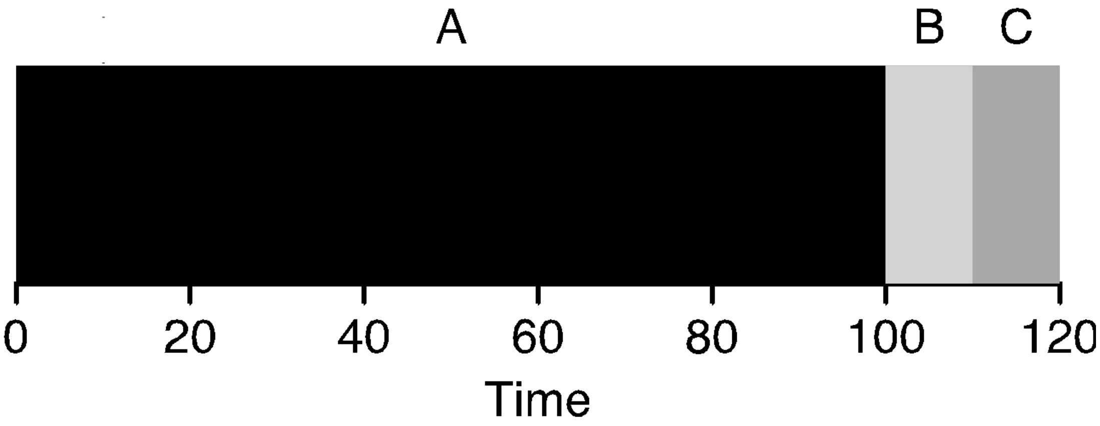
How will FIFO perform without this assumption?

Talk to your neighbors…let’s get back after a minute

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 car in a single-lane road

New scheduler:

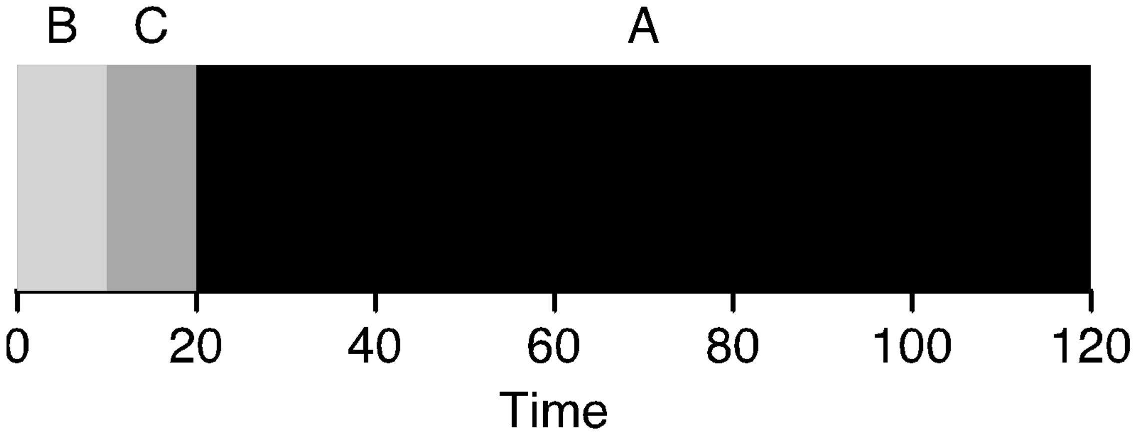
SJF (Shortest Job First)

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

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)

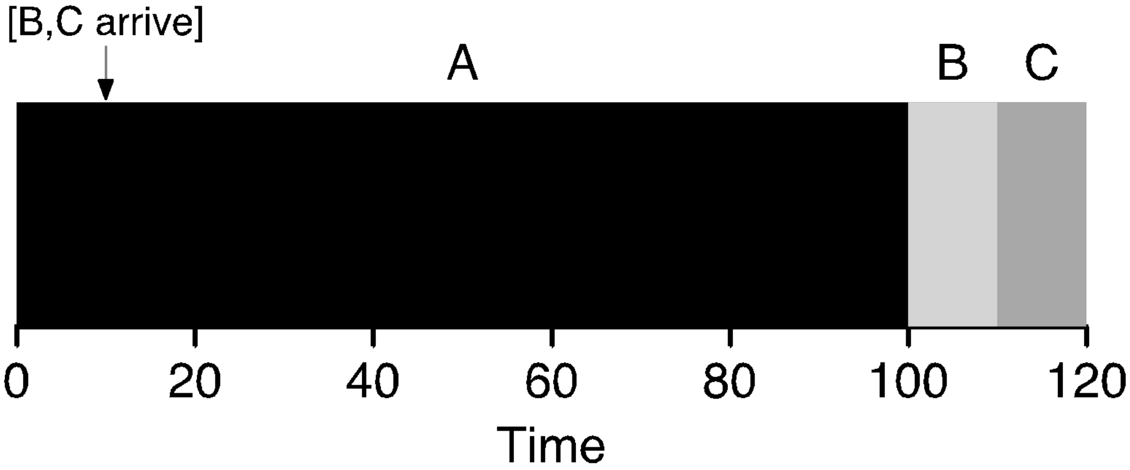
5. Run-time of each job is known (perfect knowledge)

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

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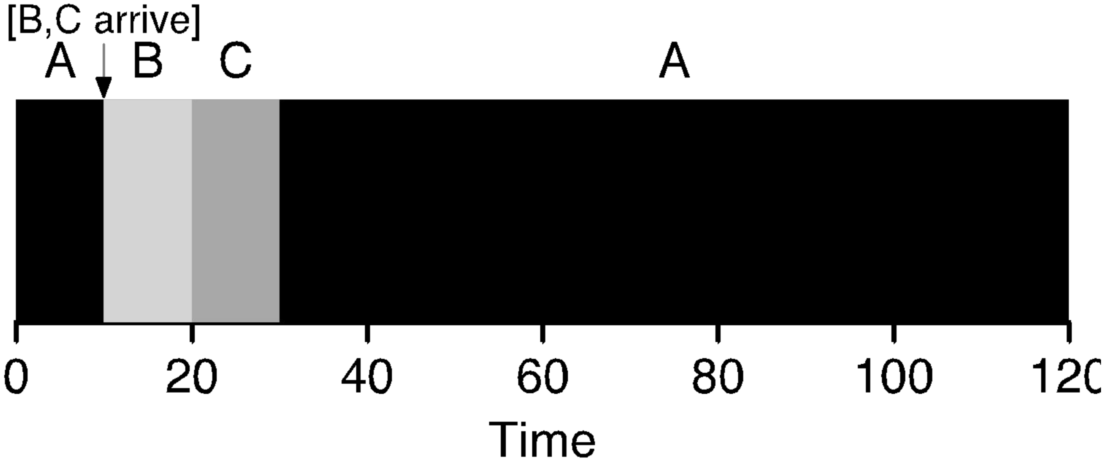
PREMPTIVE STCF

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



Average Turnaround Time

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

PREMPTIVE 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

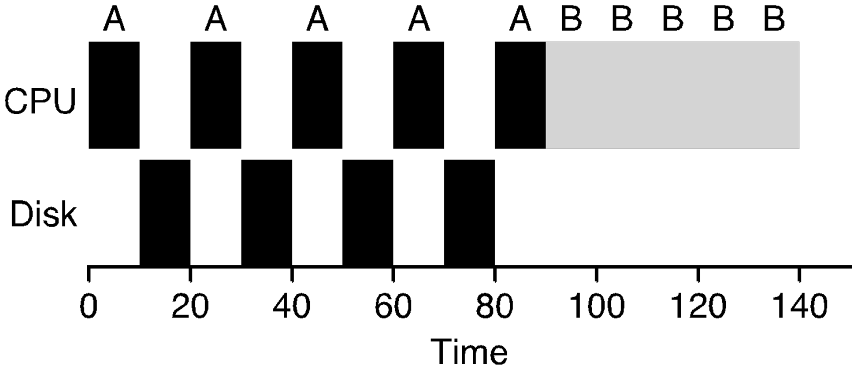
But…A does 10ms compute and then does IO which takes 10ms

B is a CPU-bound job

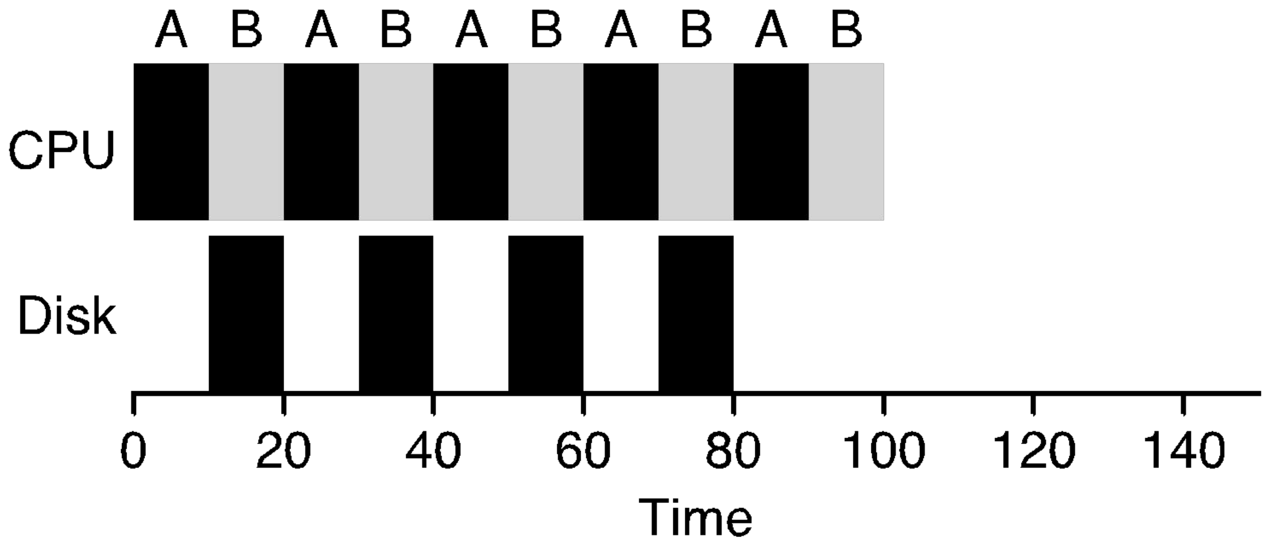
SCTF: if not IO-aware, can pick A initially

If you consider the entire process A

as a single job



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

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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)

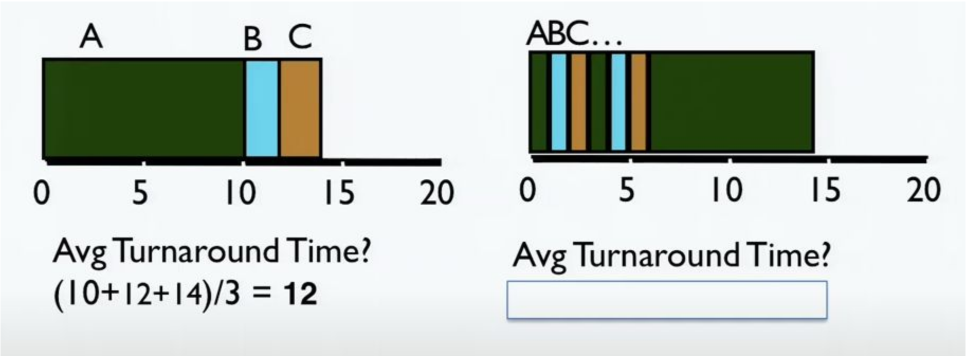
Idea: alternate ready processes for a fixed-length time (called slice or quantum)

Preemptive

Short jobs will finish after fewer time slices

Short jobs will finish sooner than long ones

Different Job Lengths and Turnaround Time



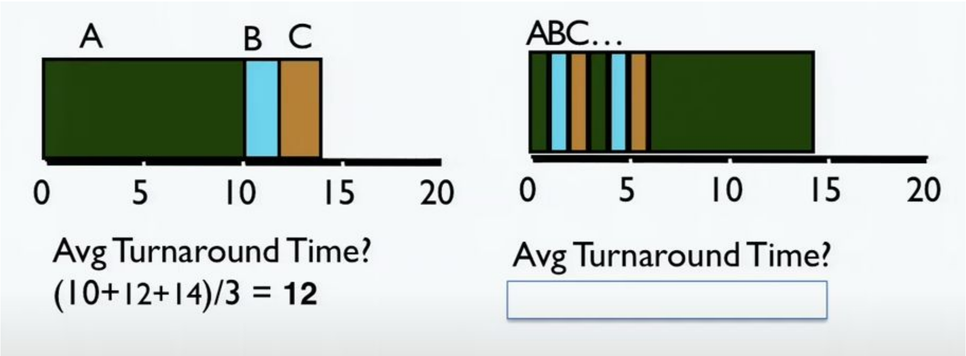
All arrive at t=0 but A arrives a little earlier (so gets scheduled 1st in FIFO)

Turnaround time in RR: ?

Turnaround time in SJF: ?

Chat with your neighbors for 1 mins and let's get back…

Different Job Lengths and Turnaround Time



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

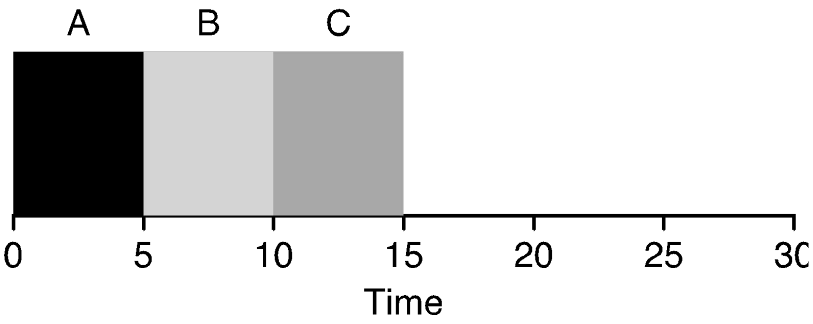
Turnaround time in RR:

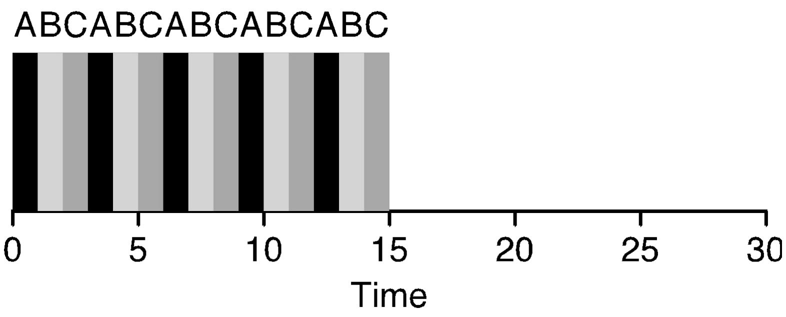
Turnaround time in SJF:

For variable length jobs, RR gets close to SJF in turnaround time and is better than FIFO

When you don’t know job lengths, RR does reasonably well when job lengths are different

ROUND ROBIN SCHEDULER

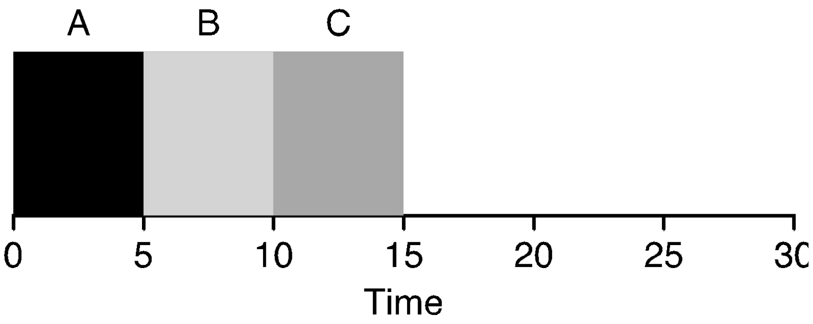


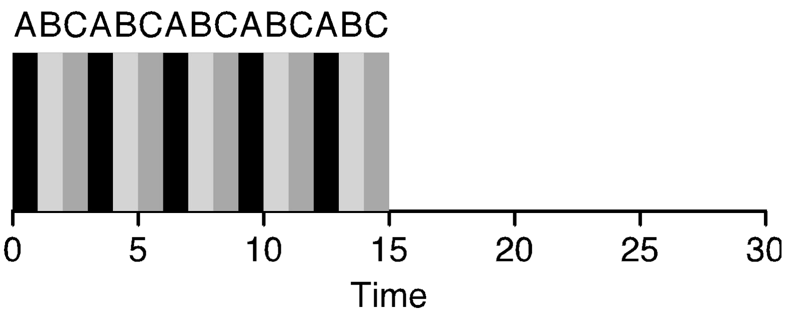


When is RR bad in terms of turnaround time?

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

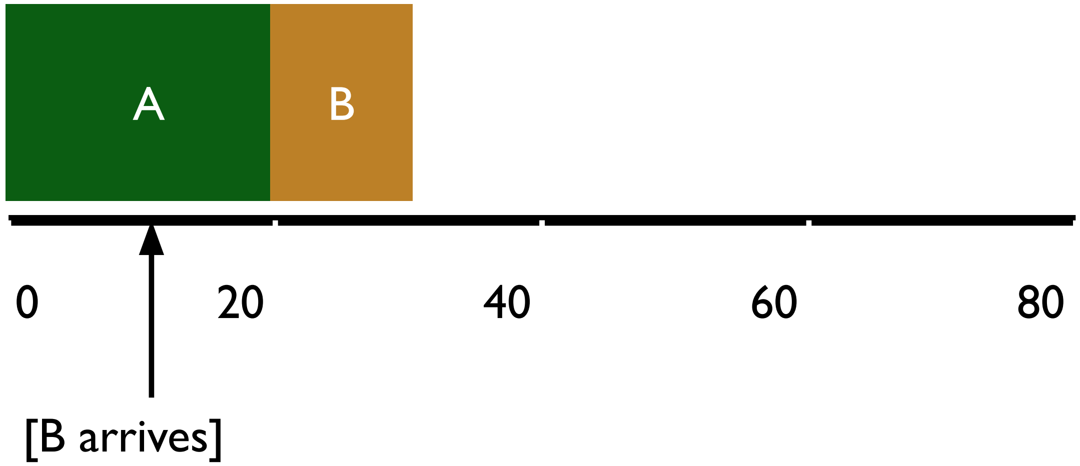
It is not a good metric for interactive programs

METRIC 2: RESPONSE TIME

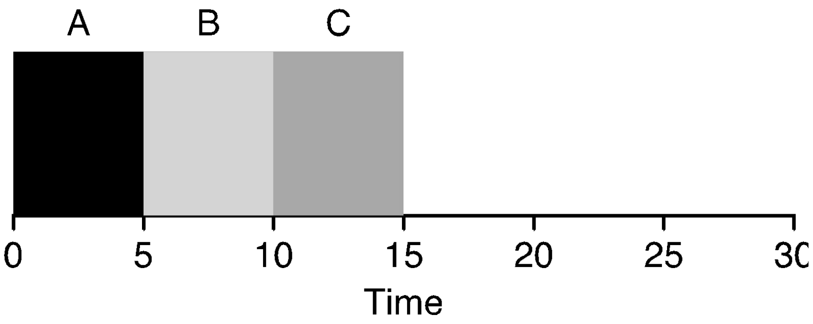
Response time = *first_run_time - arrival_time*

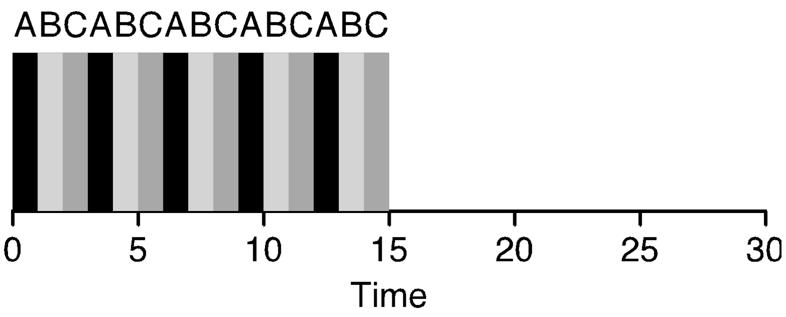
B's turnaround: 20s

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

Tuning challenges:

What is a good time slice for round robin?

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

1. ~~Each job runs for the same amount of time~~
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5. ~~Run-time of each job is known (perfect knowledge)~~

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

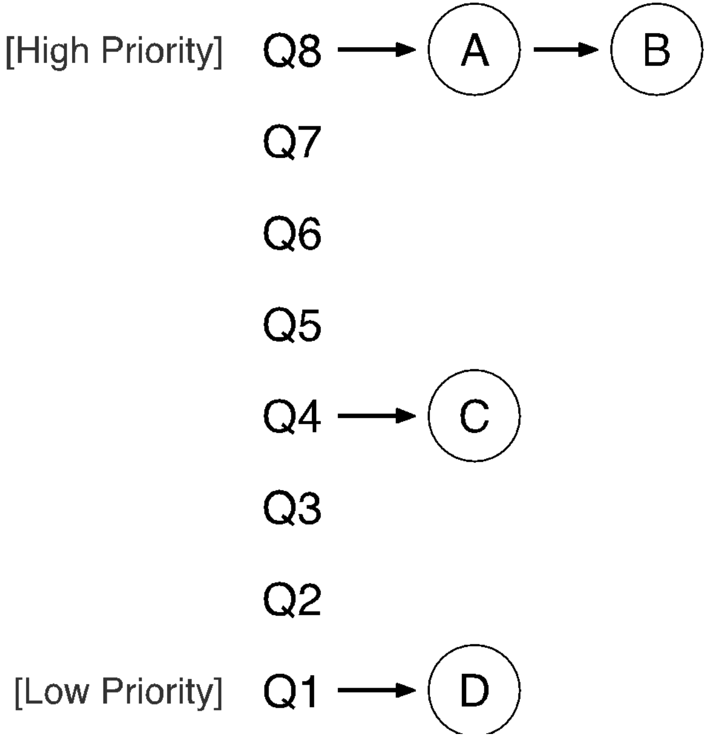
Approach:

Multiple levels of round-robin

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?

Does a process stay in one queue (static) or move between queues (dynamic)?

Approach:

Use past behavior of process to predict future!

Common approach in systems when don’t have perfect knowledge

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)

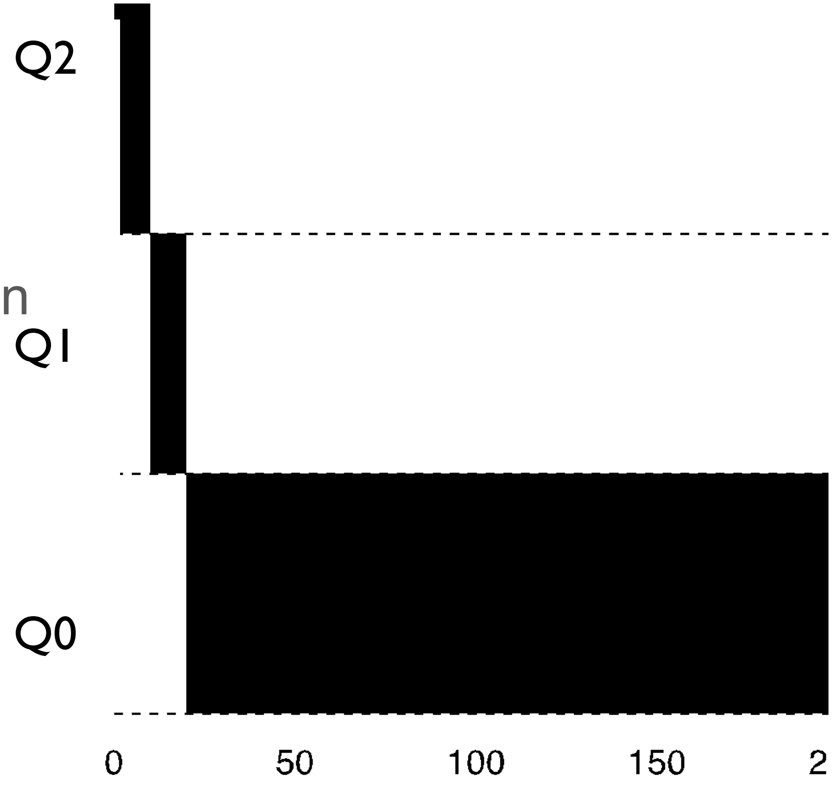
ONE LONG JOB

Starts at top

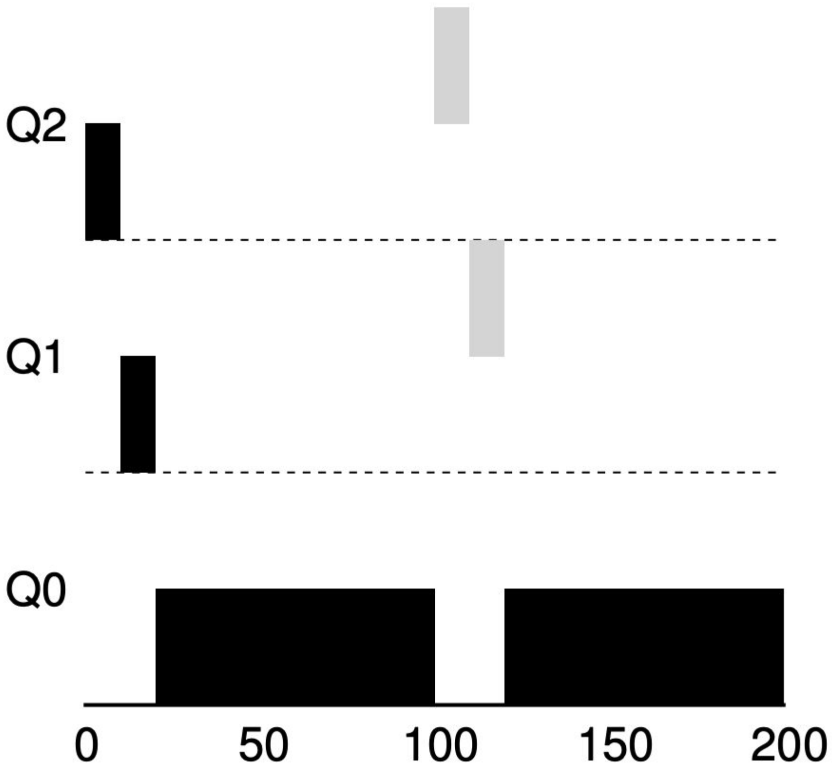
Uses whole slice

Moves down

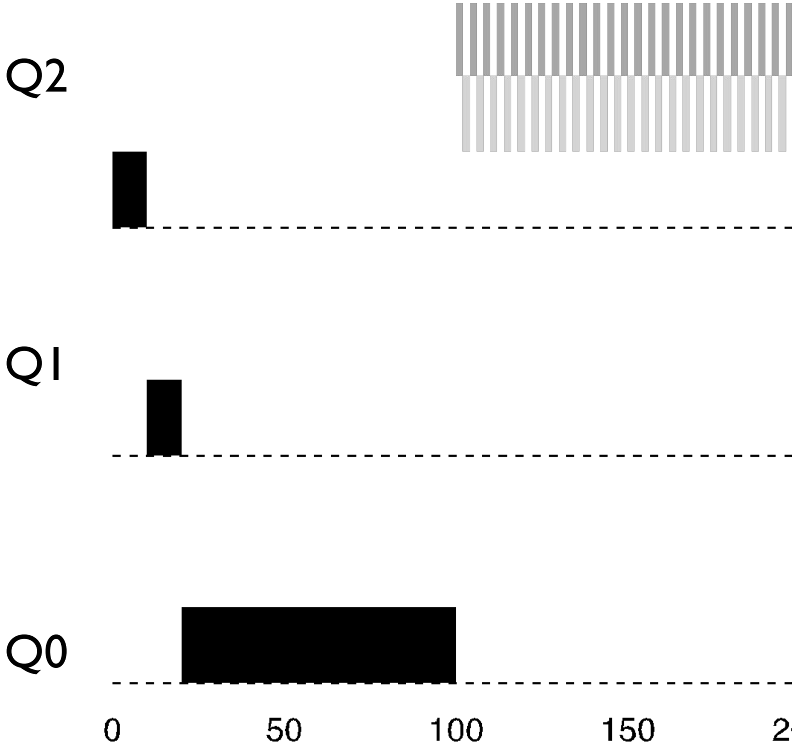
Moves down again



INTERACTIVE SHORT PROCESS JOINS

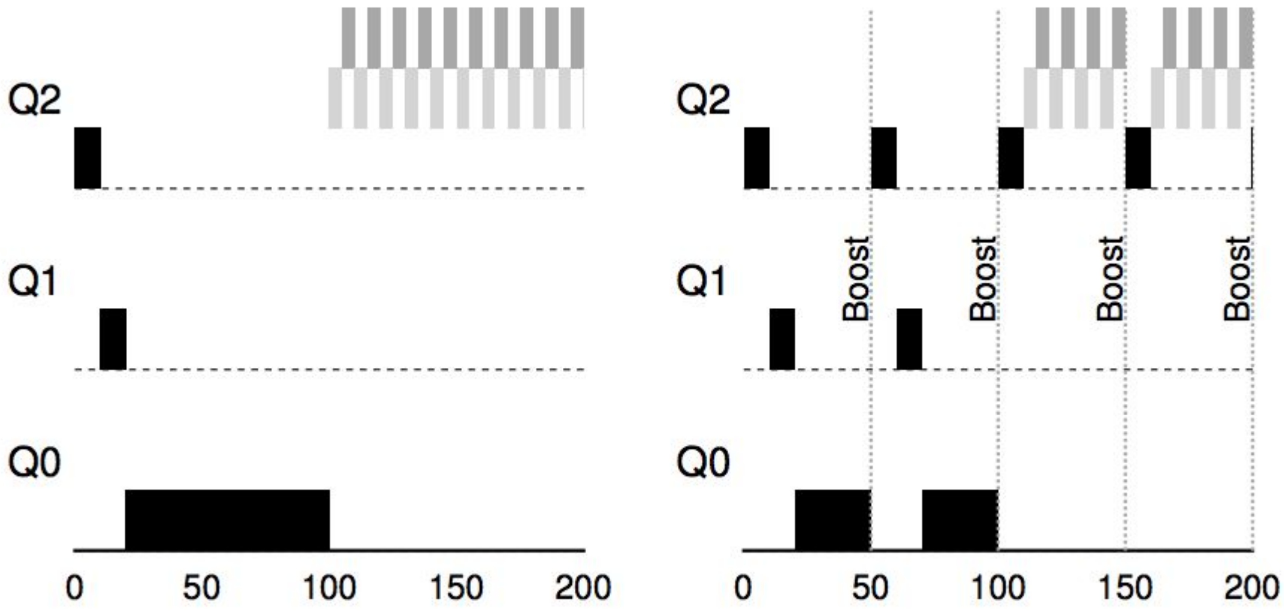


MLFQ PROBLEMS?



What is the problem with this schedule ?

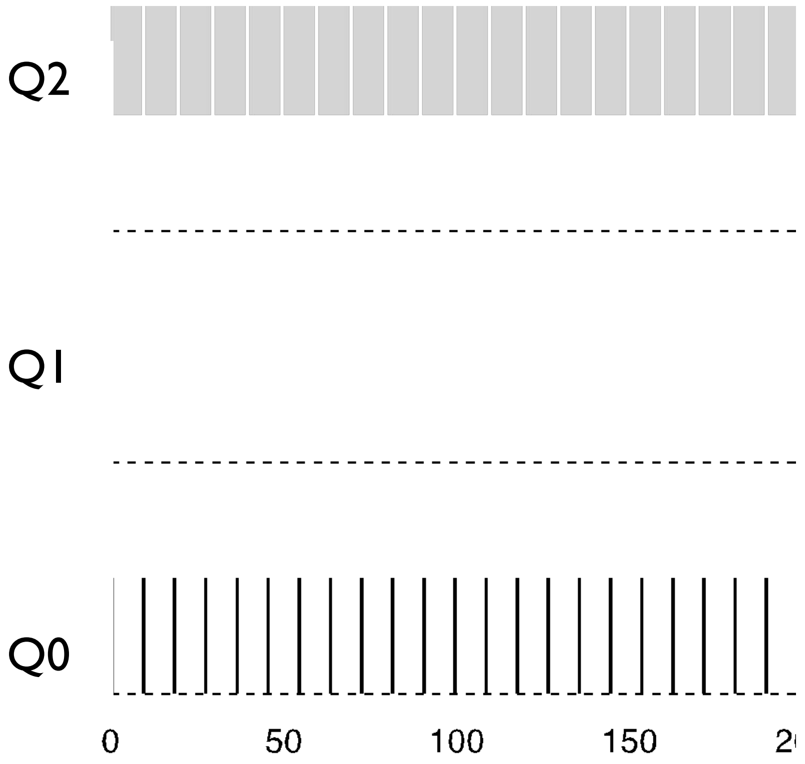
AVOIDING STARVATION



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

Q: After the second boost, why are *all* jobs not run in RR!?

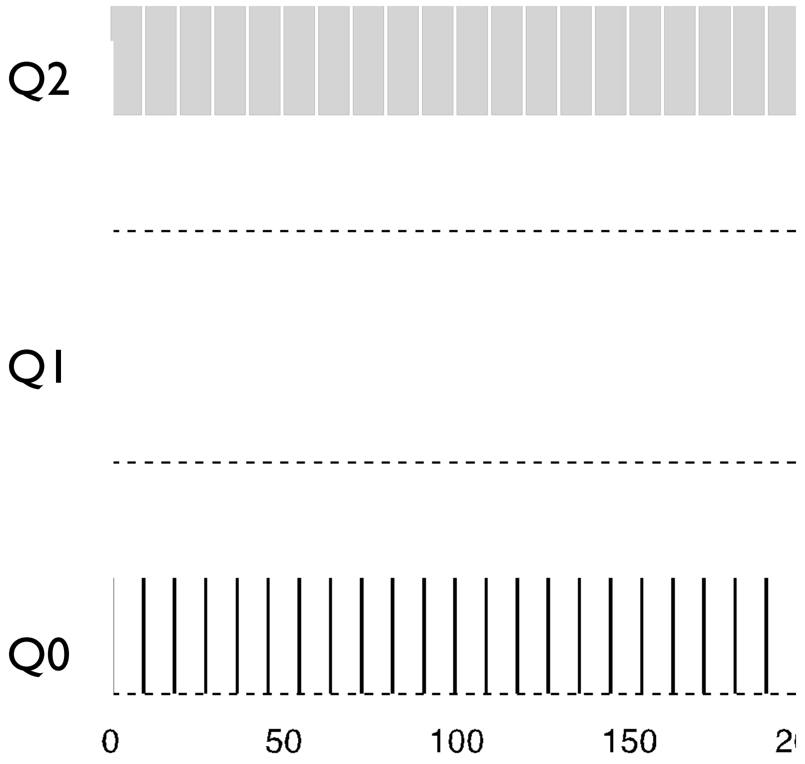
GAMING THE SCHEDULER ?



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

Used in BSD, Sun Solaris, Windows NT and subsequent versions

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