Scheduling

Questions Answered in this Lecture:

- What are some different scheduling policies?
- When do they work well?

Announcements

- Project 1a in; Project 1b out
- Project 1a: If I can't associate your code with you, your project will not be graded (i.e, *zero*). **Read instructions carefully!**
- Reading: go read OSTEP Chapters 7 & 8, plus other readings I've linked
- Read the excerpt on process scheduling code for Linux
- Note on plagiarism

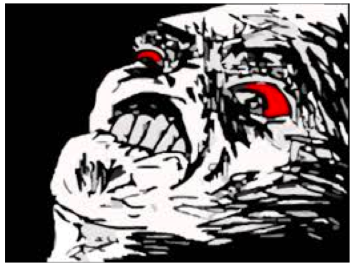
CPU Virtualization: Two Components

- Dispatcher -> mechanism (last week)
  - *How* do we switch from one process to another (ctx switch)
  - *How* do we save state of one process?
  - *How* do we interrupt the running process?
  - *How* do we pick the next one to run?

- Scheduler -> policy (today)

Scheduling

- This is an *old* problem! Not just applicable to OS (or computing systems for that matter)
- First well studied in the operations research (OR) community
  - "How do I best schedule my workers on the factory floor?"
  - "In what order to I send items down my assembly line?"
- You'll never be able to forget this stuff at the grocery store
- Or the DMV
- Or the gate at O'Hare
- WHY CANT THE WORLD BE AS EFFICIENT AS MY OS?!



Abstracting Away

- The problem put generally:
  - n resources
  - k users (k is almost always >> n)
  - Come up with a mapping in the time domain from users to resources
- Someone's got to wait
- We need queues…..
- *Queueing Theory*

The Parlance

- Workload: Intuitively, the set of things that'll use our scheduler
  - Accurately, the set of ***job*** descriptions (arrival time, runtime)
  - As process moves between CPU (doing work) and I/O (waiting for something else to do the work), process goes from ready queue to blocked queue
- Scheduler: Code (logic) that decides *which* job to run
- Metric: a measurement of quality

Metrics we care about

- **Turnaround time**: time it takes for the job to complete once they're submitted (`completion_time – arrival_time`)
- **Response time**: time it takes for interactive jobs to become active (`initial_schedule_time – arrival_time`)
- **Waiting time**: Job should not be queued (in the ready q) for long
- **Throughput**: completed jobs per unit time
- **Utilization**: expensive devices (CPUs, GPUs, etc.) should remain busy
- **Overhead**: number of context switches
- **Fairness**: jobs get same amount of CPU time over some interval

Workload 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

Scheduling Basics

Workloads:
- arrival_time
- run_time

Scheduling Policies:
- FIFO
- SJF (SJN, SPN)
- STCF
- RR

Metrics:
- turnaround_time
- response_time

Example: Workload, scheduler, metric

Job	Arrival_time (s)	Run_time (s)
A	~0	10
B	~0	10
C	~0	10

FIFO: First In, First Out

- also called FCFS (first come first served)
- run jobs in *arrival_time* order

What is our turnaround?: *completion_time - arrival_time*

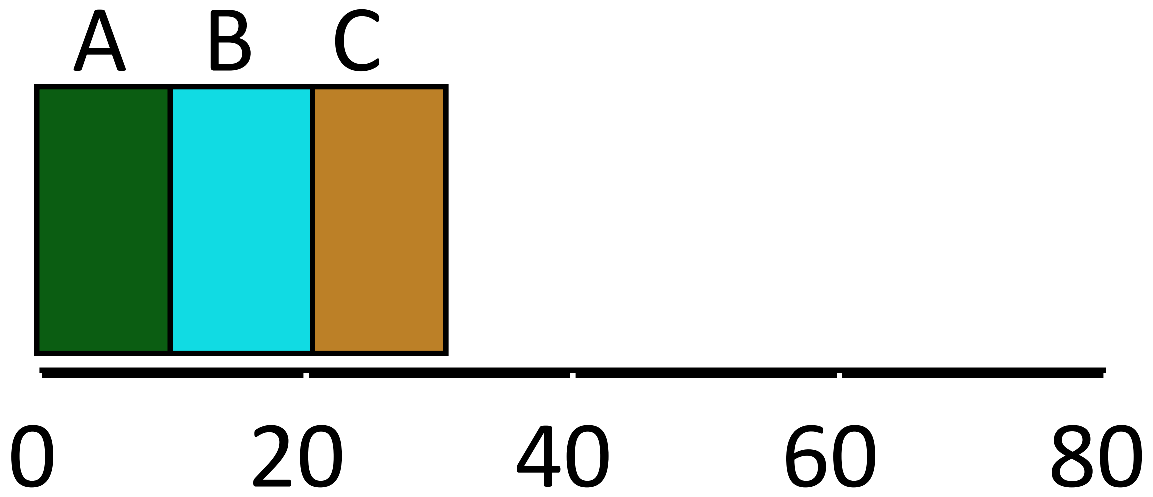
FIFO: Event Trace

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)

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

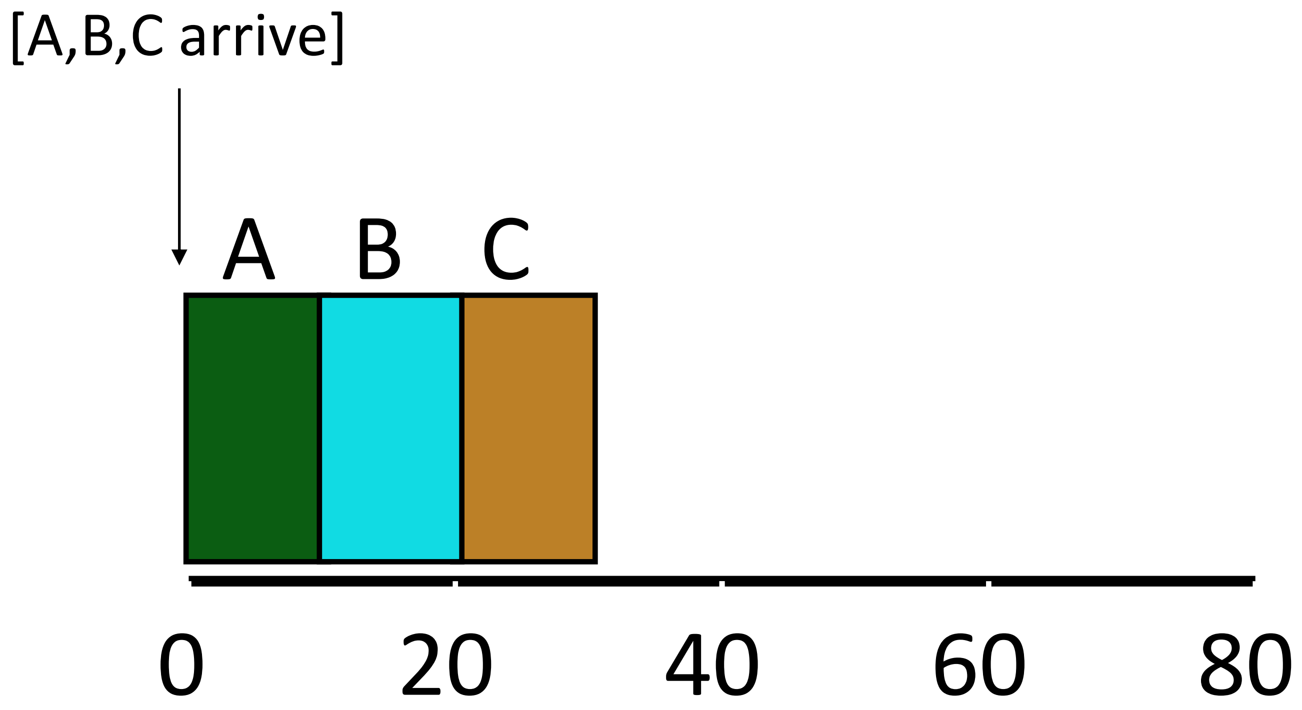


Gantt chart:

Illustrates how jobs are scheduled over time on a CPU

FIFO: (Identical Jobs)

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



What is the average turnaround time?

Def: *turnaround_time = completion_time - arrival_time*

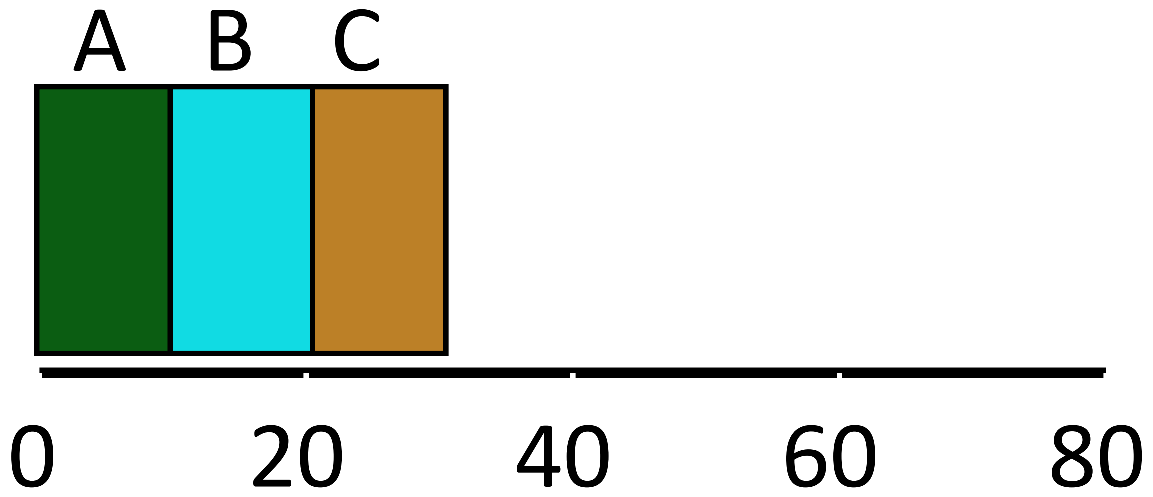
FIFO: (Identical Jobs)

A: 10s

B: 20s

C: 30s

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



What is the average turnaround time?

(10+20+30)/3 = 20s

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- turnaround_time
- response_time

Workload Assumptions

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2. All jobs arrive at the same time
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4. Run-time of each job is known

Any Problematic Workloads for FIFO?

Workload: ?

Scheduler: FIFO

Metric: turnaround is high

Example: Big First Job

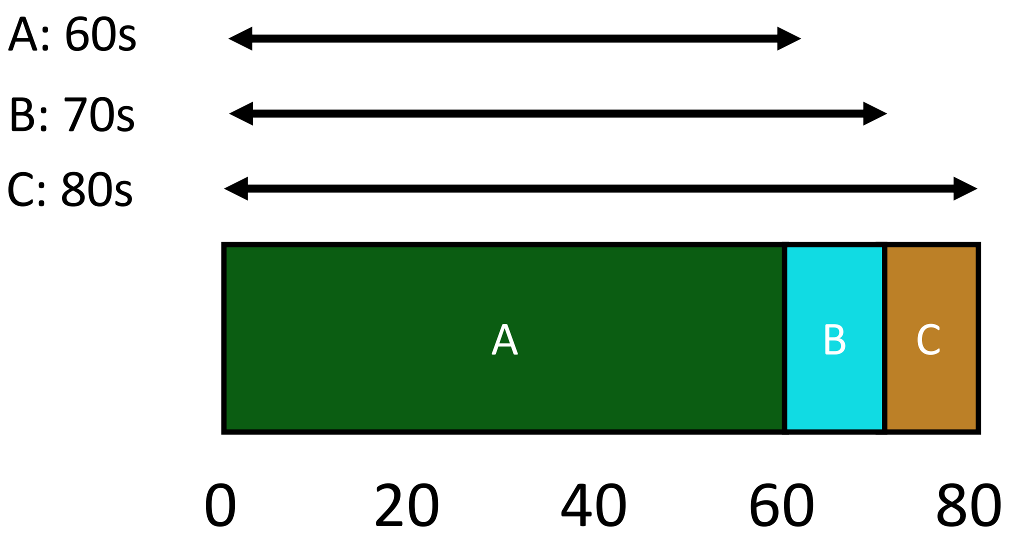
JOB	arrival_time (s)	run_time (s)
A	~0	60
B	~0	10
C	~0	10

Draw Gantt chart for this workload and policy…

What is the average turnaround time?

Example: Big First Job

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



Average turnaround time: **70s**

Convoy Effect

Passing the Tractor

Problem with Previous Scheduler:

FIFO: Turnaround time can suffer when short jobs must wait for long jobs

New scheduler:

SJF (Shortest Job First)

Also (Shortest job next SJN, shortest process next (SPN))

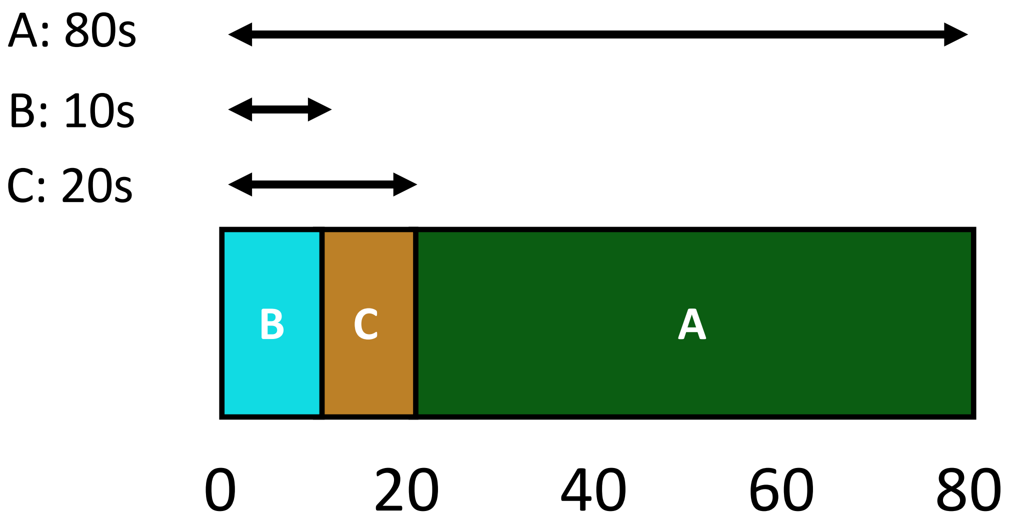
Choose job with smallest *run_time*

Shortest Job First

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

What is the average turnaround time with SJF?

SJF Turnaround Time



What is the average turnaround time with SJF?

(80 + 10 + 20) / 3 = **~36.7s**

Average turnaround with FIFO: 70s

For minimizing average turnaround time (with no preemption):
SJF is provably optimal

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

Scheduling Basics

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Workload Assumptions

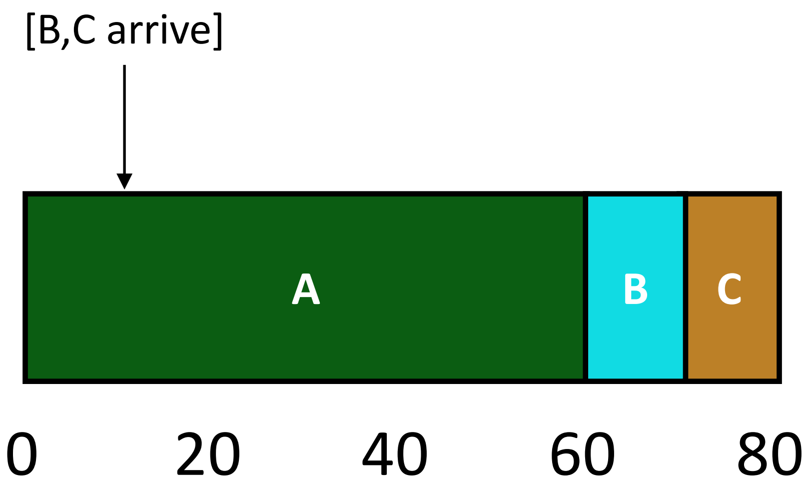
1. ~~Each job runs for the same amount of time~~
2. ~~All jobs arrive at the same time~~
3. All jobs only use the CPU (no I/O)
4. Run-time of each job is known

Shortest Job First (Arrival Time)

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

What is the average turnaround time with SJF?

Stuck Behind a Tractor Again



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

Prev schedulers:

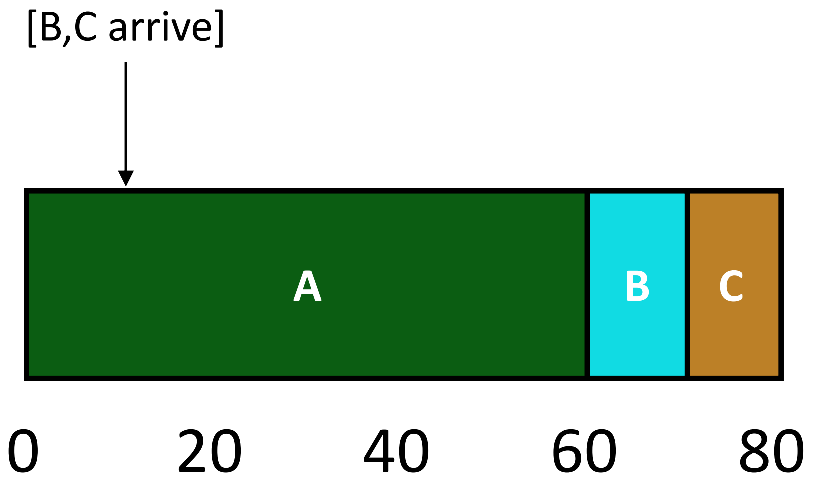
- FIFO and SJF are non-preemptive
- Only schedule new job when previous job voluntarily relinquishes CPU (performs I/O or exits)

New scheduler:

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

NON-PREEMPTIVE: SJF

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

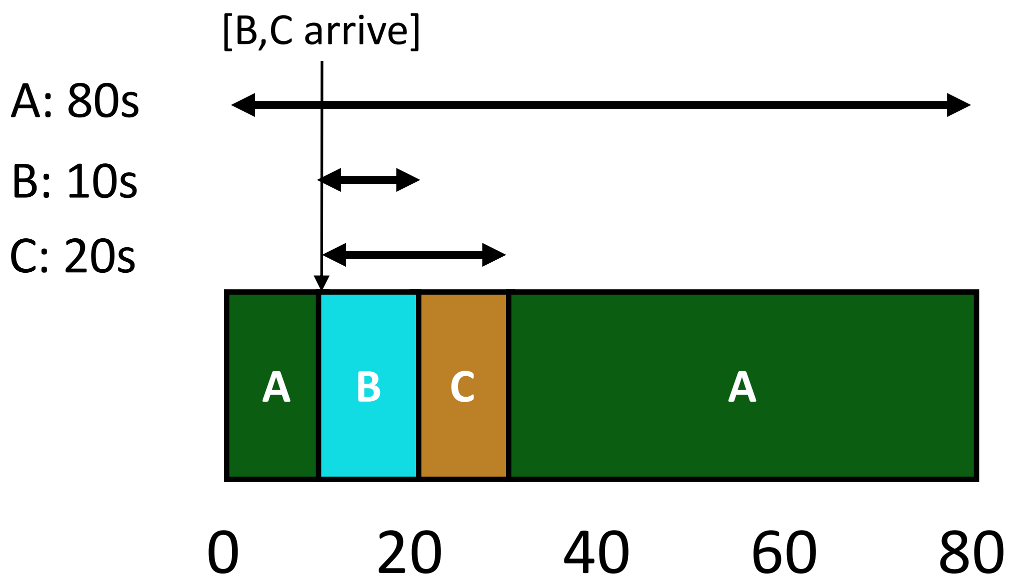


Average turnaround time:

(60 + (70 – 10) + (80 – 10)) / 3 = **63.3s**

Preemptive: STCF

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



Average turnaround time with STCF?

36.6

Average turnaround time with SJF: **63.3s**

Scheduling Basics

Workloads:
- arrival_time
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Scheduling Policies:
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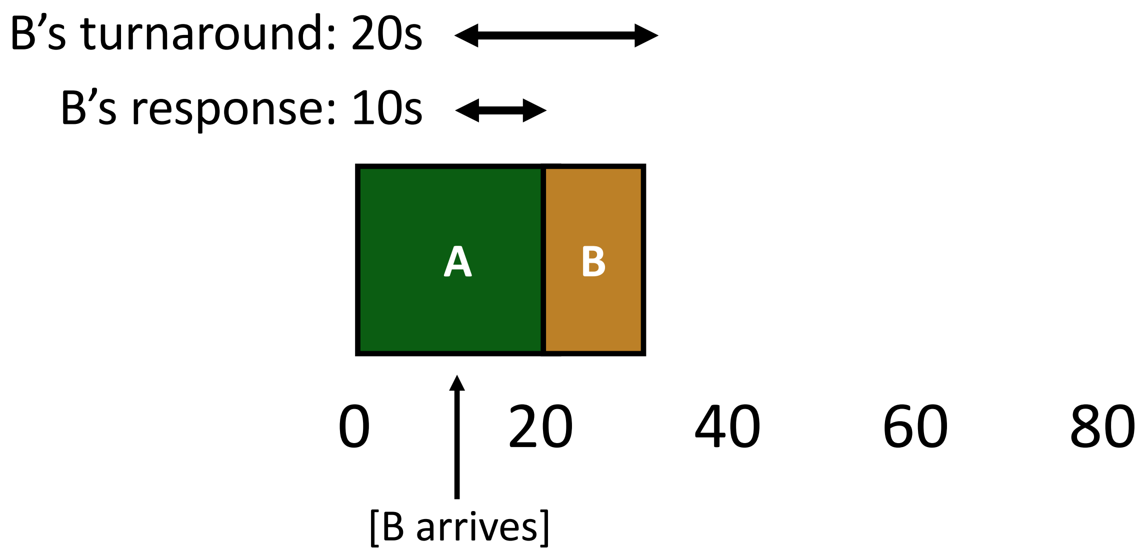
- STCF
- RR

Metrics:
- turnaround_time
- response_time

Response Time

- Sometimes we care about when a job starts instead of when it finishes
- New metric:
  - response_time = first_run_time – arrival_time

Response vs. Turnaround



Round-Robin

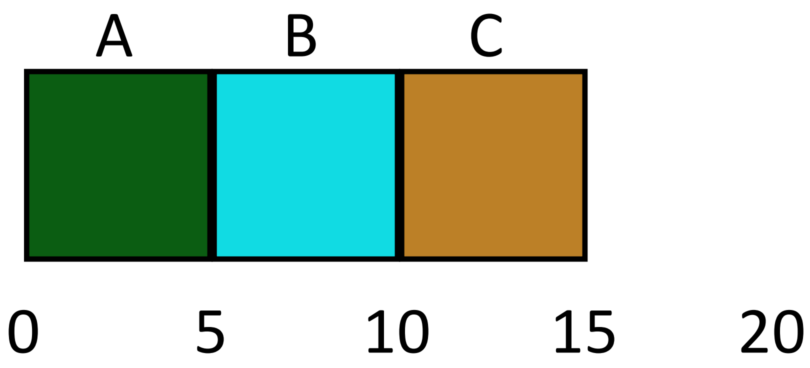
Prev schedulers:

FIFO, SJF, and STCF can have poor response time

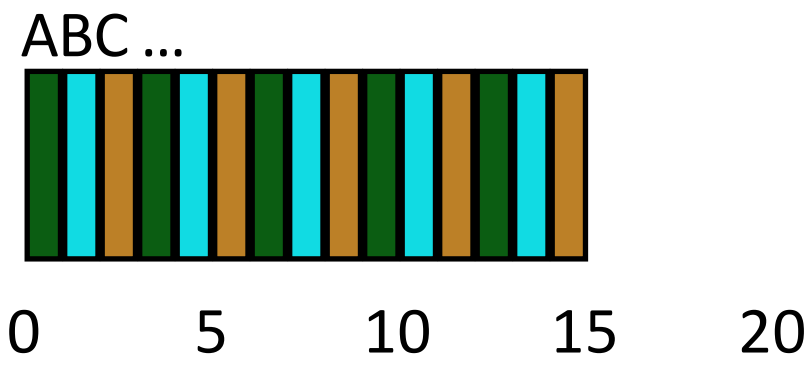
New scheduler: RR (Round Robin)

Alternate ready processes every fixed-length time-slice

FIFO vs RR



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



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

In what way is RR worse?
Ave. turn-around time with equal job lengths 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

Scheduling Basics

Workloads:

arrival_time

run_time

Scheduling Policies:

FIFO

SJF (SJN, SPN)

STCF

RR

Metrics:

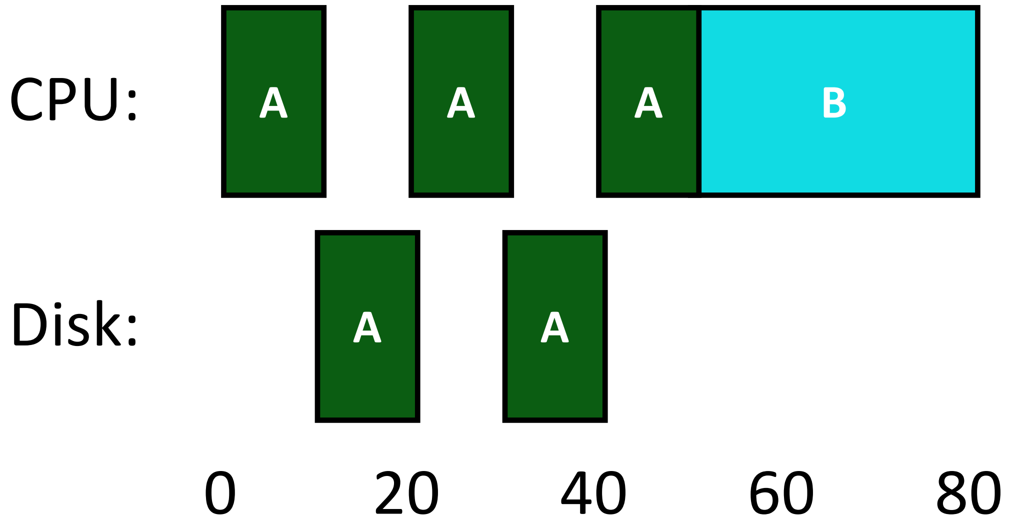
turnaround_time

response_time

Workload Assumptions

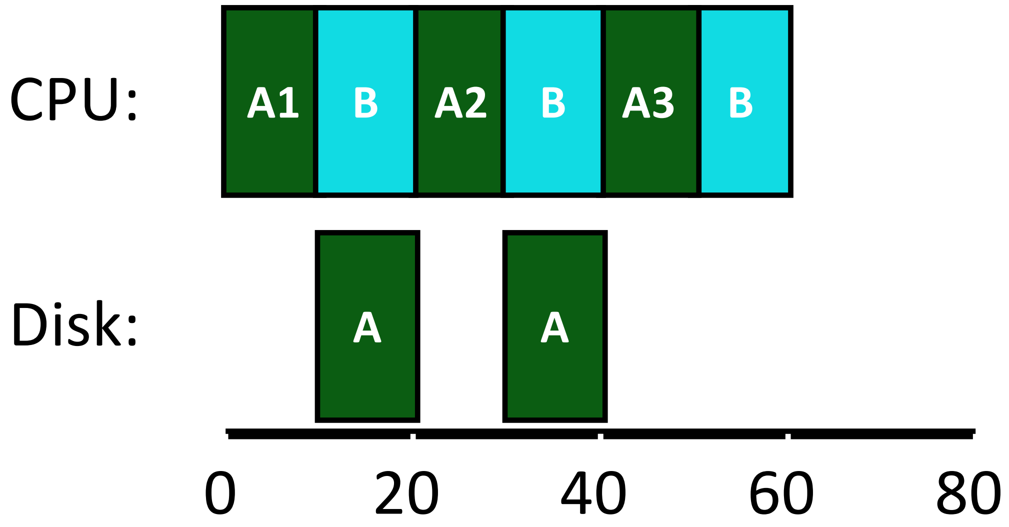
1. ~~Each job runs for the same amount of time~~
2. ~~All jobs arrive at the same time~~
3. ~~All jobs only use the CPU (no I/O)~~
4. Run-time of each job is known

Not I/O Aware



Don’t let Job A hold on to CPU while blocked waiting for disk

I/O Aware (Overlap)



Treat Job A as 3 separate CPU bursts
When Job A completes I/O, another Job A is ready

Each CPU burst is shorter than Job B, so with SCTF,
Job A preempts Job B

Workload 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~~

(Need smarter, fancier scheduler)

MLFQ
(Multi-Level Feedback Queue)

Goal: general-purpose scheduling

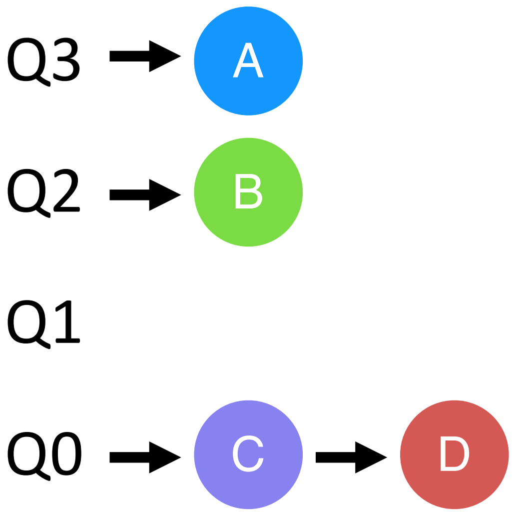
Must support two job types with distinct goals
- "interactive" programs care about response time
- "batch" programs care about turnaround time

Approach: multiple levels of round-robin;
each level has higher priority than lower levels and preempts them

Priorities

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

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



"Multi-level"

How to know how to set priority?

Approach 1: nice
Approach 2: history "feedback"

History

- Use past behavior of process to predict future behavior
  - Common technique in systems
- Processes alternate between I/O and CPU work
- Guess how CPU burst (job) will behave based on past CPU bursts (jobs) of this process

More MLFQ Rules

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

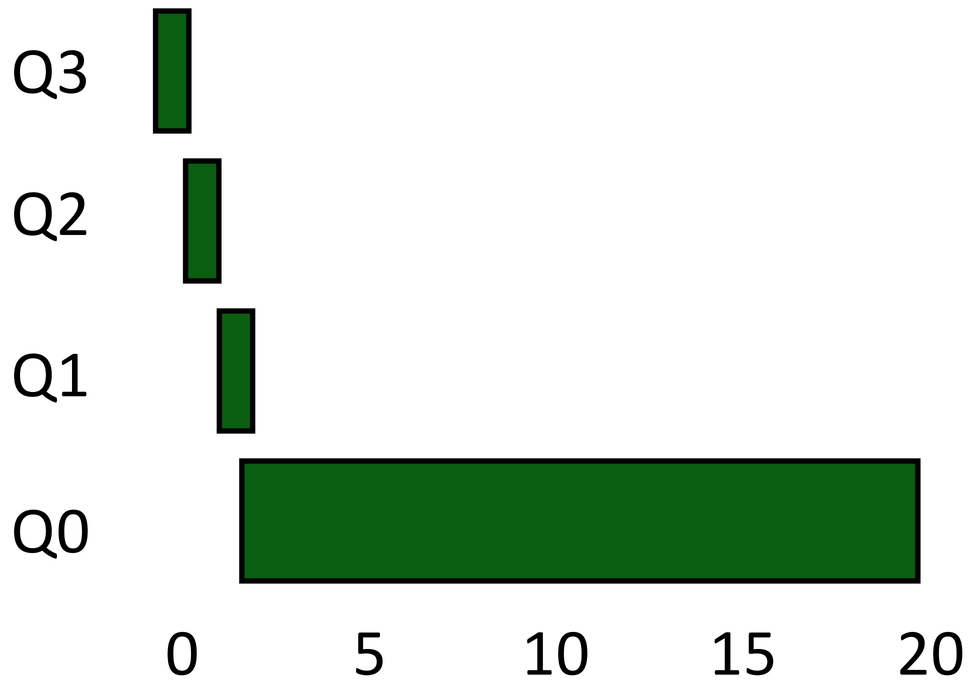
Rule 2: If priority(A) == Priority(B), A & B run in RR

More rules:

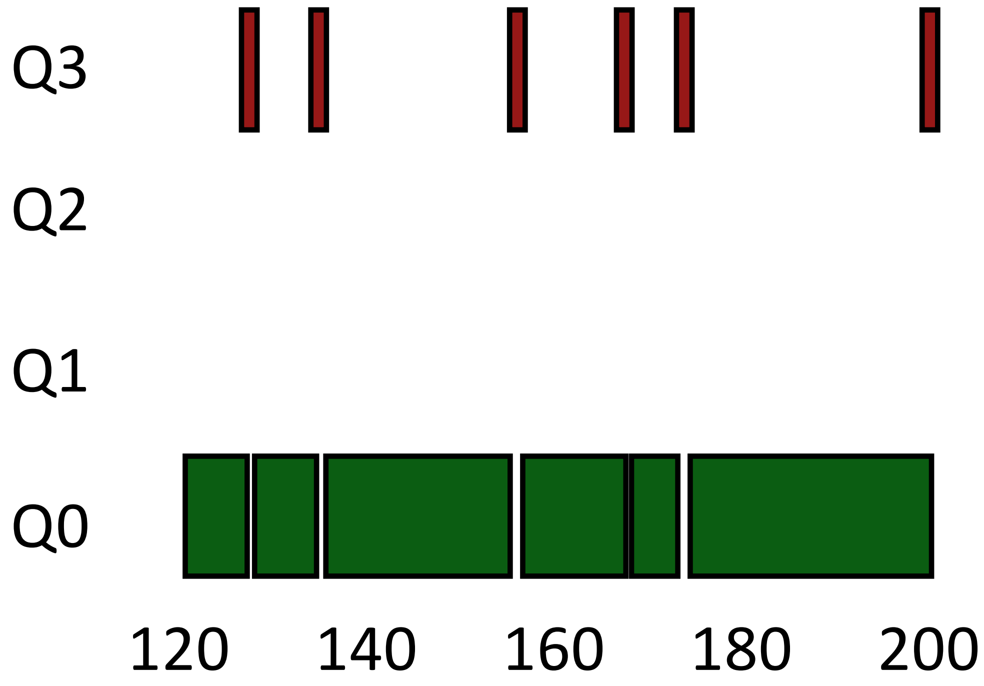
Rule 3: Processes start at top priority

Rule 4: If job uses whole slice, demote process (longer time slices at lower priorities)

One Long Job (Example)

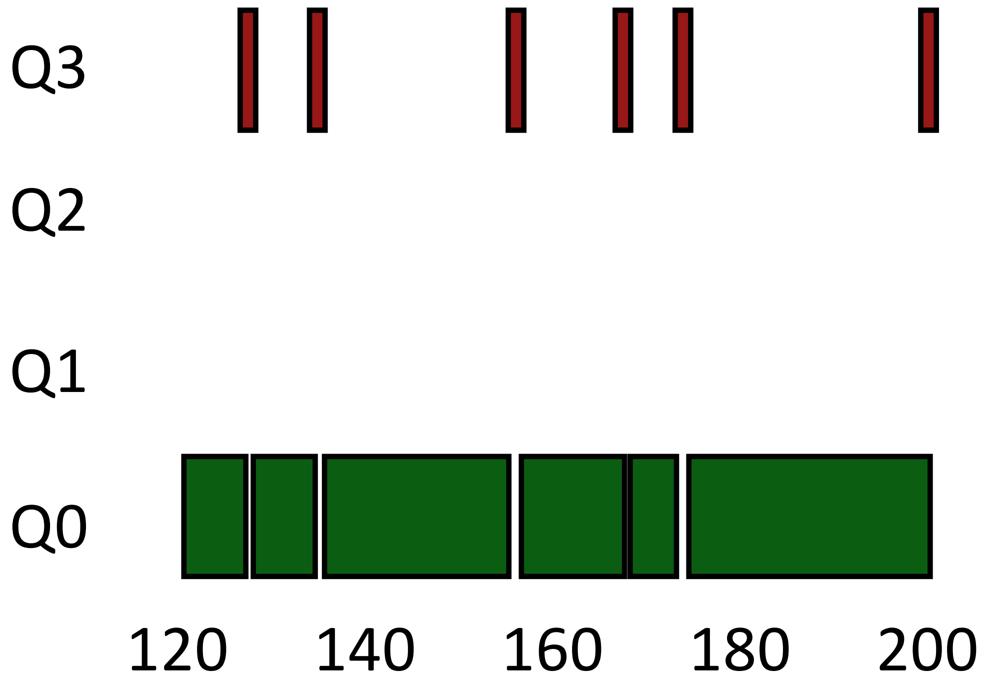


An Interactive Process Joins



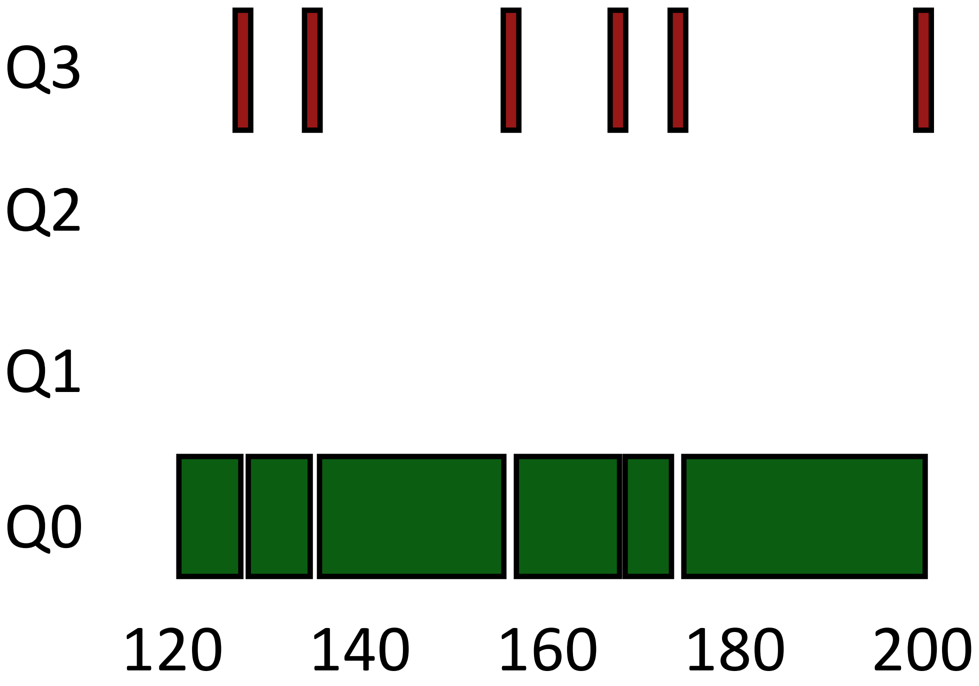
Interactive process never uses entire time slice, so never demoted

Problems with MLFQ?



Problems
- unforgiving + starvation
- gaming the system

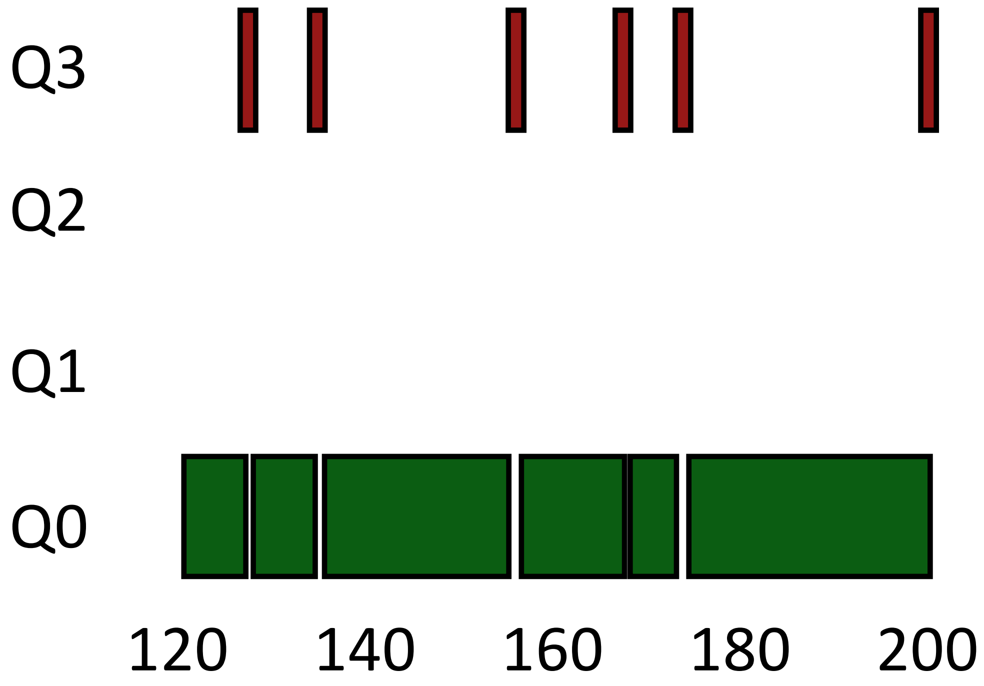
Prevent Starvation



Problem: Low priority job may never get scheduled

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

Prevent Gaming



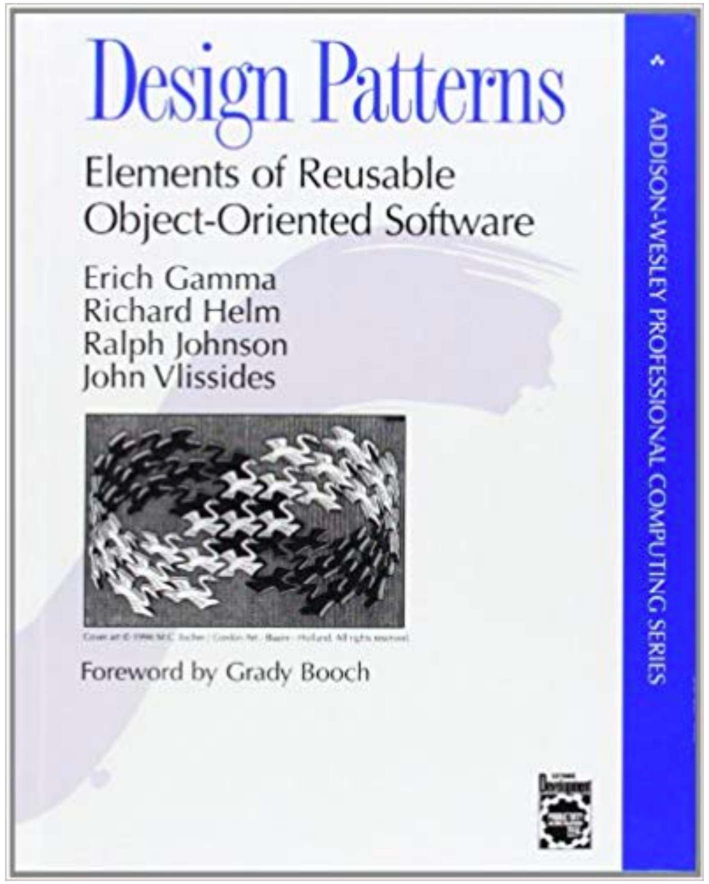
Problem: High priority job could trick scheduler and get more CPU by performing I/O right before time-slice ends

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

Programming Patterns: *The Bridge Pattern*

- Used to separate policy from mechanism
- More generally, *separate an implementation from its abstraction*

Gang of Four (GOF) Book



```
Proc * candidate = curr;
Schedule () {
     for (I = 0; I < NUM_PROCS; i++) {
          if (procs[i].priority > candidate)
               candidate = procs[i];
          }
     }
     switch_to(candidate);
```

The Bridge

```
Proc * next;
Schedule () {
	next = scheduler->policy->choose_next(sched_state);
	switch_to(next);
}
```

The Bridge

```
Proc * next;
Schedule () {
	next = scheduler->policy->choose_next(sched_state);
	switch_to(next);
}
```

Linux 0.1

```
/* this is the scheduler proper: */
while (1) {
    c = -1;
    next = 0;
    i = NR_TASKS;
    p = &task[NR_TASKS];
    while (--i) {
        if (!*--p)
            continue;
            if ((*p)->state == TASK_RUNNING && (*p)->counter > c)
                c = (*p)->counter, next = i;
    }
    if (c) break;
    for(p = &LAST_TASK ; p > &FIRST_TASK ; --p)
        if (*p)
            (*p)->counter = ((*p)->counter >> 1) + (*p)->priority;
}
switch_to(next);
```

TODO

- Work on project 1b! Due next Monday
- Do your reading, check out optional reading
  - Multiprocessor scheduling
  - Lottery Scheduling
  - Linux processes and scheduler