CPU Scheduling
(Chapters 7-11)

CS 4410
Operating Systems

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The Problem

You’re the cook at State Street Diner

- customers continuously enter and place orders 24 hours a day
- dishes take varying amounts to prepare

What is your *goal*?

- minimize average latency
- minimize maximum latency
- maximize throughput

Which *strategy* achieves your goal?

Goals depend on context

What if instead you are:

- the owner of an (expensive) container ship and have cargo across the world
- the head nurse managing the waiting room of the emergency room
- a student who has to do homework in various classes, hang out with other students, eat, and occasionally sleep

Schedulers in the OS

- CPU Scheduler selects a process to run from the run queue
- Disk Scheduler selects next read/write operation
- Network Scheduler selects next packet to send or process
- Page Replacement Scheduler selects page to evict

We'll focus on **CPU Scheduling**

Kernel Operation (conceptual, simplified)

1. Initialize devices
2. Initialize "first process"
3. `while (TRUE) {`
   - while device interrupts pending
     - handle device interrupts
   - while system calls pending
     - handle system calls
   - **if run queue is non-empty**
     - select process and switch to it
   - otherwise
     - wait for device interrupt

`}`

Performance Terminology

Task/Job

- User request: e.g., mouse click, web request, shell command, …

Response time (latency, delay): How long?

- User-perceived time to do some task.

Initial waiting time: When do I start?

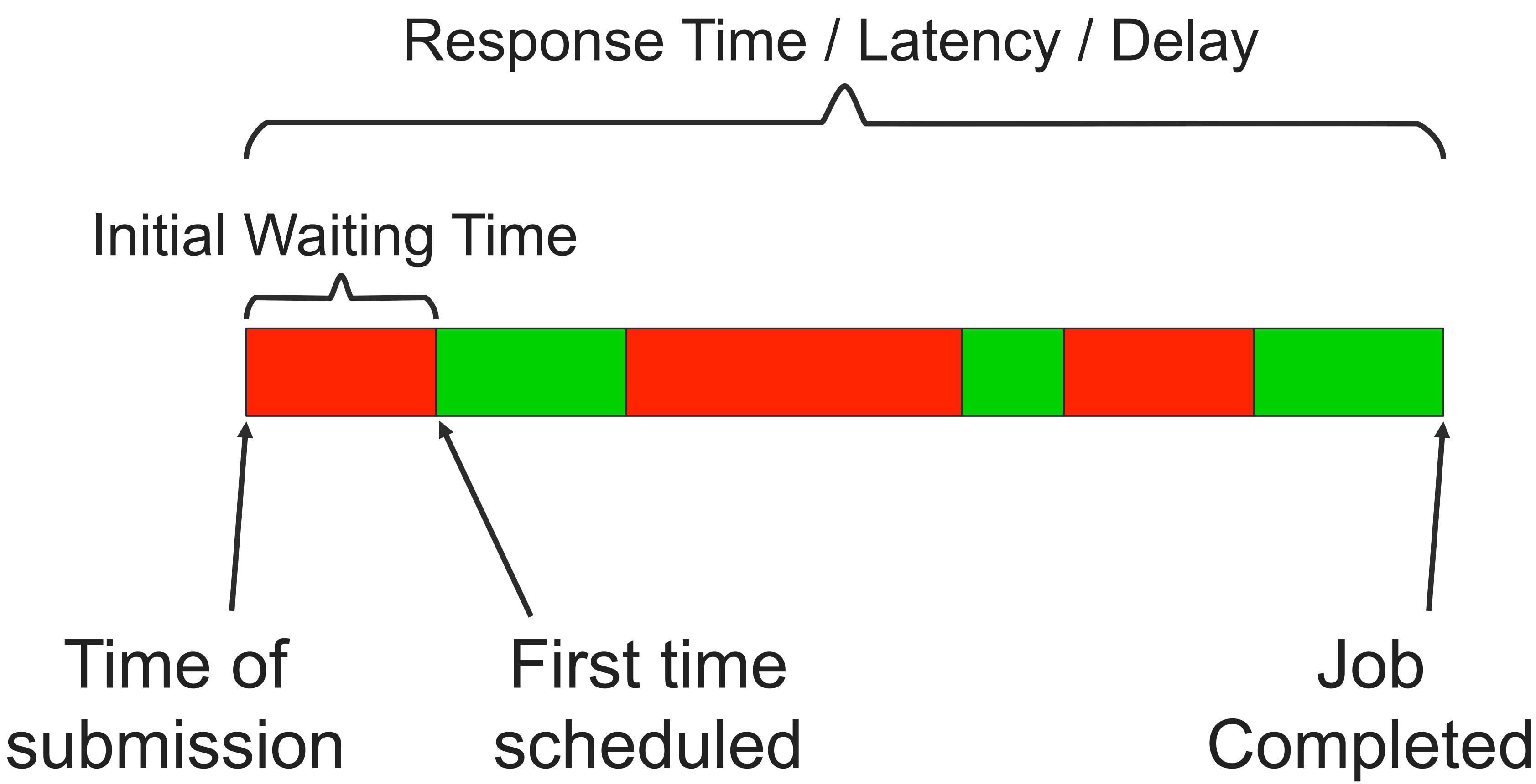
- User-perceived time before task begins.

Total waiting time: How much thumb-twiddling?

- Time on the run queue but not running.

Terminology Alert!

Per Job or Task Metrics



Total Waiting Time: sum of “red” periods

More Performance Terminology

Throughput: How many tasks over time?

- The rate at which tasks are completed.

Predictability: How consistent?

- Low variance in response time for repeated requests.

Overhead: How much extra work?

- Time to switch from one task to another.

Fairness: How equal is performance?

- Equality in the number and timeliness of resources given to each task.

Starvation: How bad can it get?

- The lack of progress for one task, due to resources given to a higher priority task.

The Perfect Scheduler

- Minimizes latency
- Maximizes throughput
- Maximizes utilization:
  keeps all devices busy
- Meets deadlines:
  think image processing, car brakes, *etc.*
- Is Fair:
  everyone makes progress, no one starves

No such scheduler exists! ☹

When does scheduler run?

Non-preemptive

Process runs until it voluntarily yields CPU

- process blocks on an event (*e.g.*, I/O or synchronization)
- process yields
- process terminates

Preemptive

All of the above, plus:

- Timer and other interrupts
- When processes cannot be trusted to yield
- Incurs some overhead

Process Model

Processes switch between CPU & I/O bursts

CPU-bound jobs: Long CPU bursts

I/O-bound: Short CPU bursts

Problems:

- don’t know job’s type before running
- jobs also change over time

Basic scheduling algorithms:

- First in first out (FIFO)
- Shortest Job First (SJF)
- Round Robin (RR)

First In First Out (FIFO)

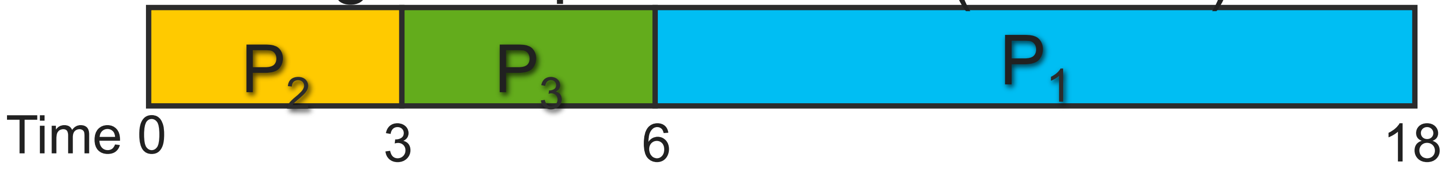
Processes P_1, P_2, P_3 with compute time 12, 3, 3

Scenario 1: arrival order P_1, P_2, P_3

Average Response Time: (12+15+18)/3 = 15

Scenario 2: arrival order P_2, P_3, P_1

Average Response Time: (3+6+18)/3 = 9



FIFO Roundup

+ Simple
+ Low-overhead
+ No Starvation
+ Optimal avg. response time if all tasks same size

– Poor avg. response time if tasks have variable size

– Average response time very sensitive to arrival time

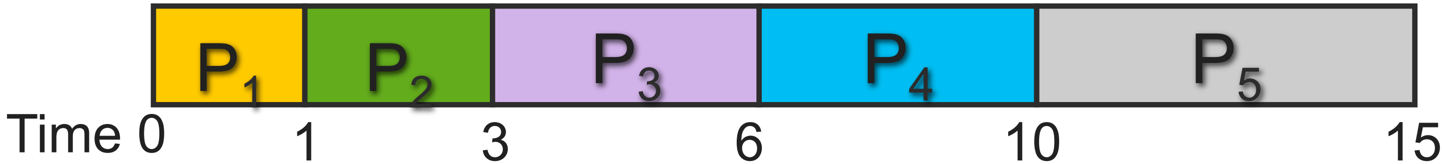
– Not responsive to interactive tasks

Shortest Job First (SJF)

Schedule in order of estimated completion† time

Scenario : each job takes as long as its number

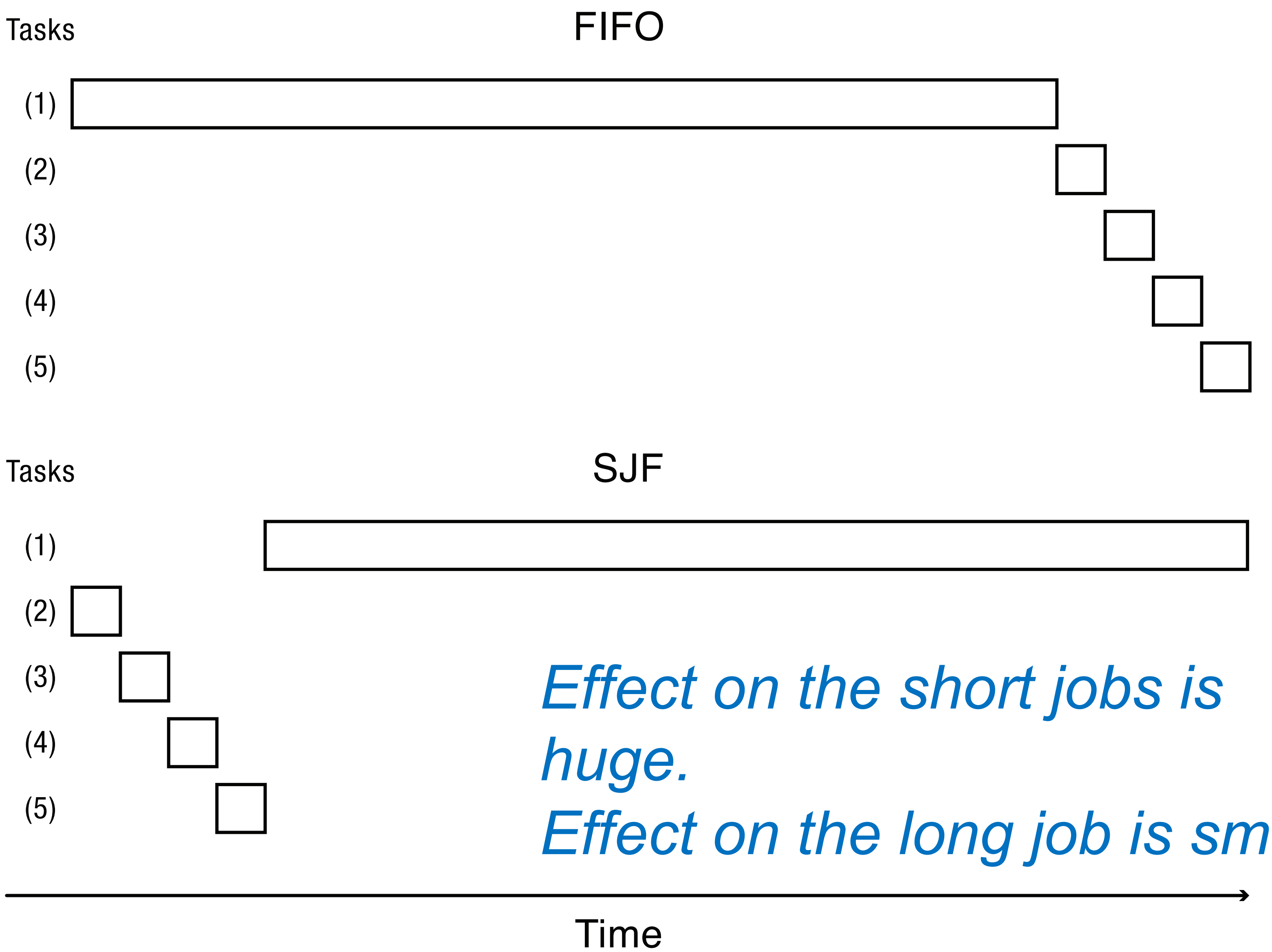
Average Response Time: (1+3+6+10+15)/5 = 7



Would another schedule improve avg response time?

†with preemption, remaining time

FIFO vs. SJF



Effect on the short jobs is huge.
Effect on the long job is small.

Shortest Job First Prediction

How to approximate duration of next CPU-burst

- Based on the durations of the past bursts
- Past can be a good predictor of the future

- **No need to remember entire past history!**

Use exponential average:

t_n actual duration of n^{th} CPU burst

τ_n predicted duration of n^{th} CPU burst

τ_{n+1} predicted duration of $(n+1)^{th}$ CPU burst

$$\tau_{n+1} = \alpha\tau_n + (1- \alpha)\, t_n$$

$0 \leq \alpha \leq 1$, α determines weight placed on past behavior

SJF Roundup

+ Optimal average response time (when jobs available simultaneously)

– Pessimal variance in response time

– Needs estimate of execution time
– Can starve long jobs
– Frequent context switches

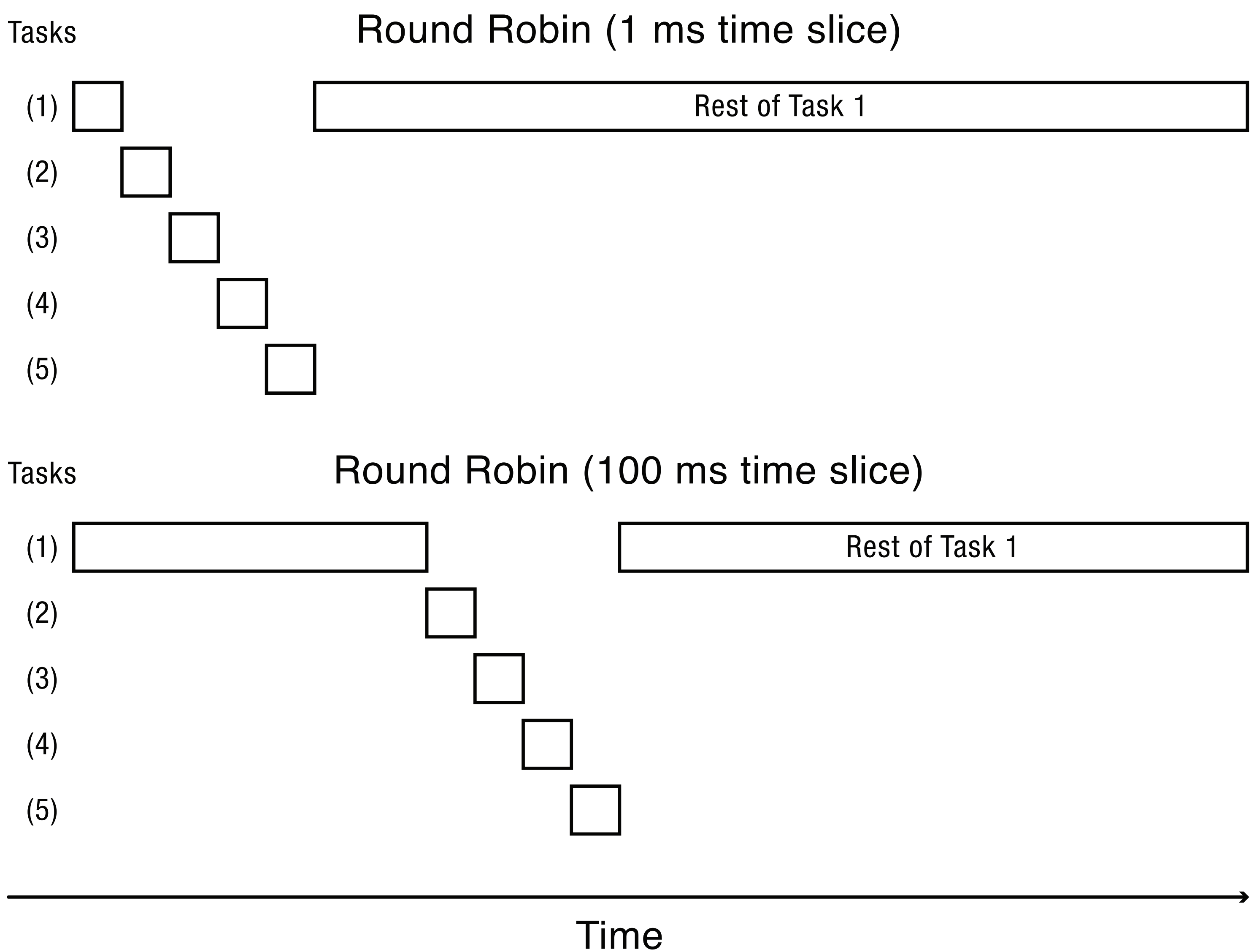
Round Robin (RR)

- Each process allowed to run for a quantum
- Context is switched (at the latest) at the end of the quantum

What is a good quantum size?

- Too long, and it morphs into FIFO
- Too short, and much time lost context switching
- Typical quantum: about 100X cost of context switch (~100ms vs. << 1 ms)

Effect of Quantum Choice in RR



Round Robin vs FIFO

Assuming no overhead to time slice, is Round Robin always better than FIFO?

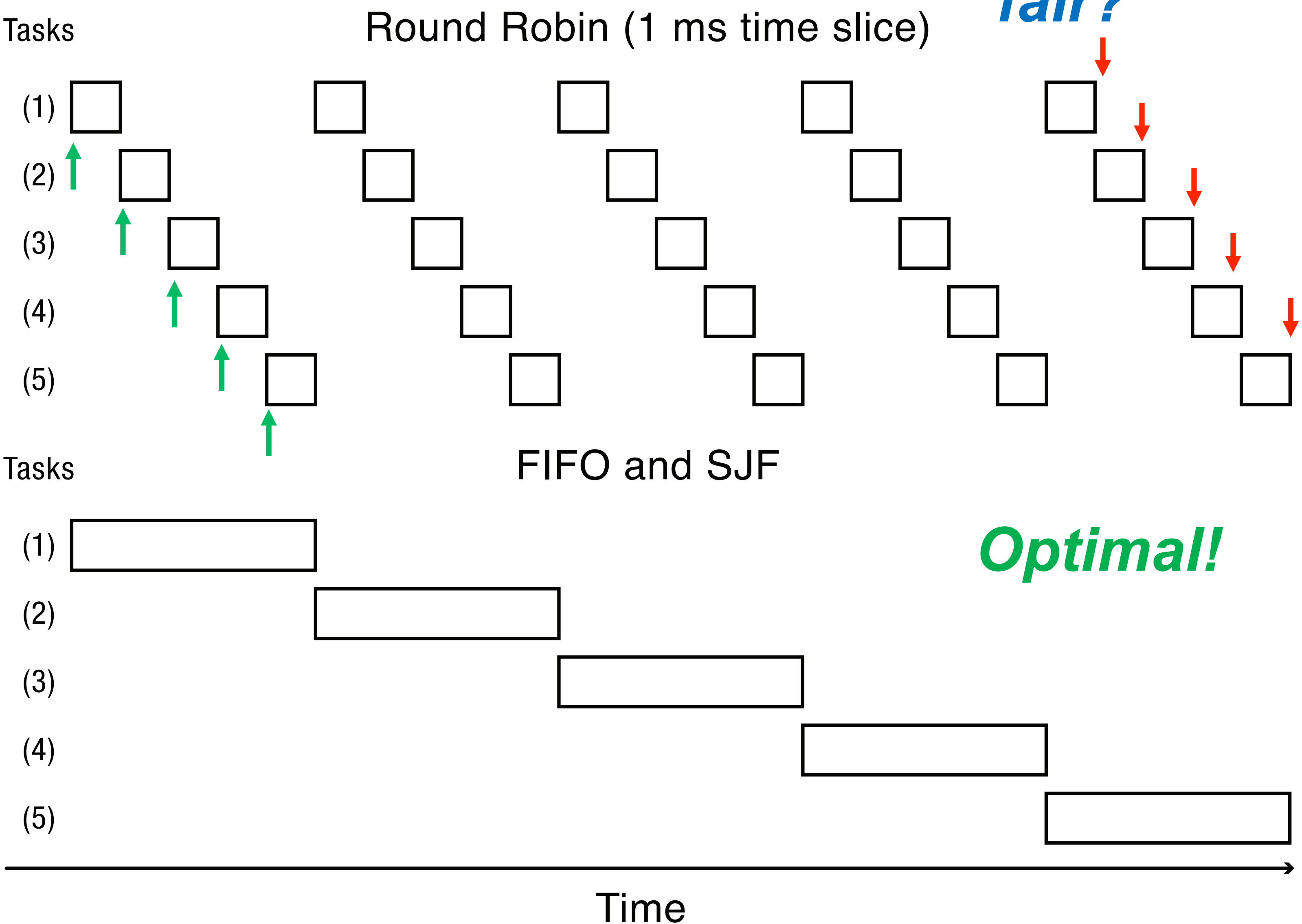
What's the worst case scenario for Round Robin?

- What's the least efficient way you could get work done this semester using RR?

Round Robin vs. FIFO

Tasks of same length that start ~same time

At least it's fair?

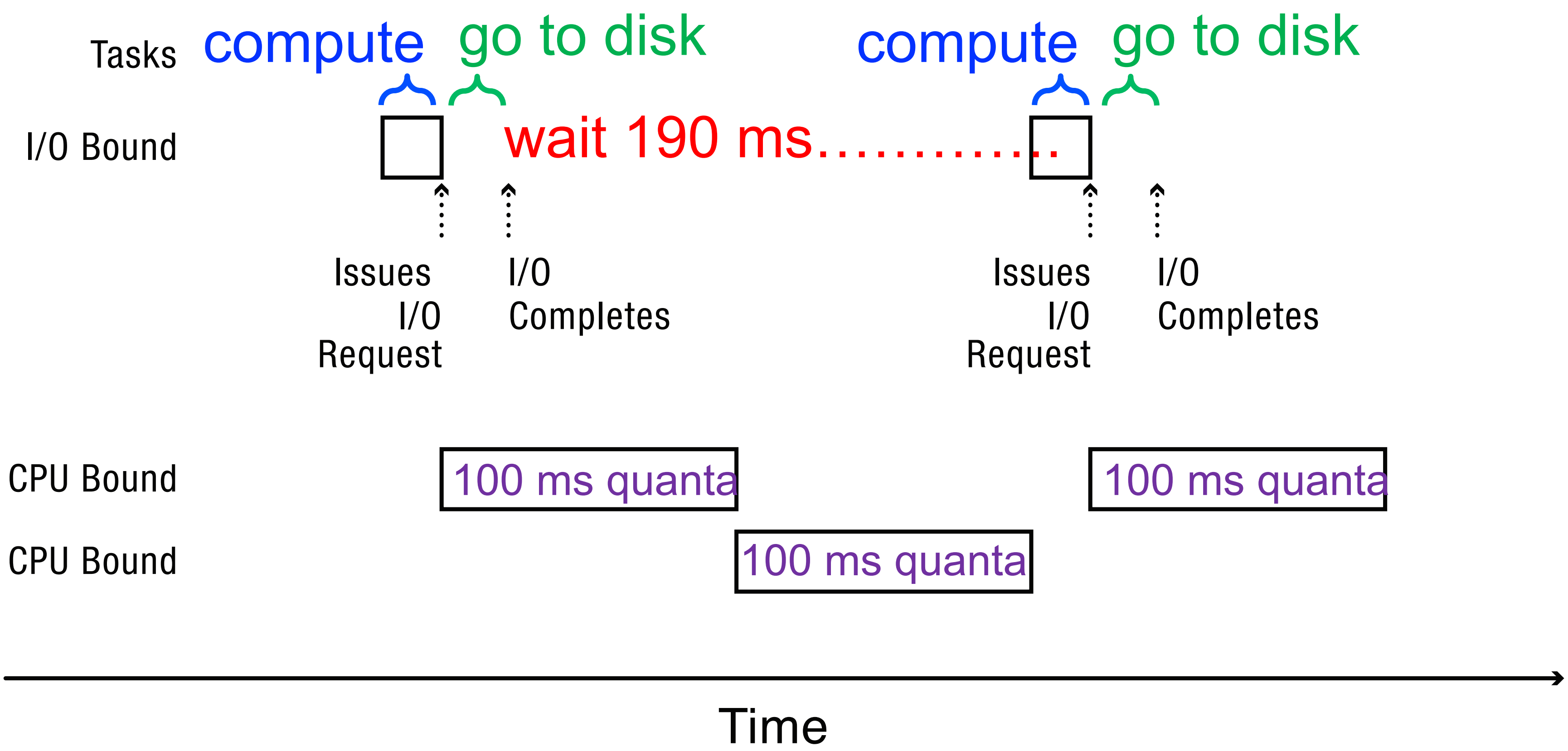


More Problems with Round Robin

Mixture of one I/O Bound tasks + two CPU Bound Tasks

I/O bound: compute, go to disk, repeat

→ *RR doesn't seem so fair after all….*



RR Roundup

+ No starvation
+ Can reduce response time
+ Low Initial waiting time

– Overhead of context switching
– Mix of I/O and CPU bound

– Particularly bad for simultaneous, equal length jobs

Priority-based scheduling algorithms:

- Priority Scheduling
- Multi-level Queue Scheduling
- Multi-level Feedback Queue Scheduling

Priority Scheduling

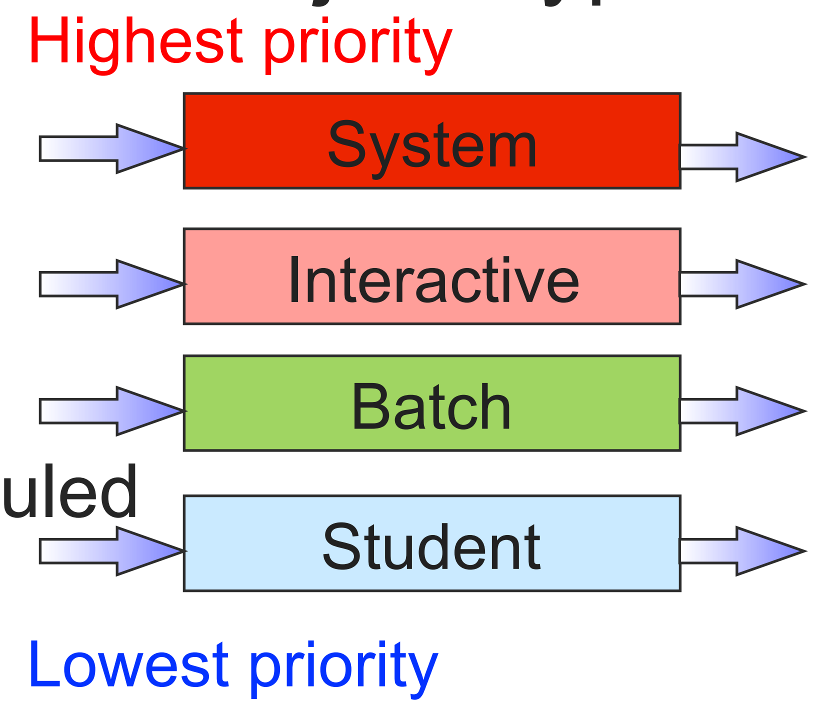
- Assign a number to each job and schedule jobs in (increasing) order
- Reduces to SJF if τ_n is used as priority
- To avoid starvation, change job's priority with time (aging)

Multi-Level Queue Scheduling

Multiple ready queues based on job "type"

- interactive processes
- CPU-bound processes
- batch jobs
- system processes
- student programs

Different queues may be scheduled using different algorithms



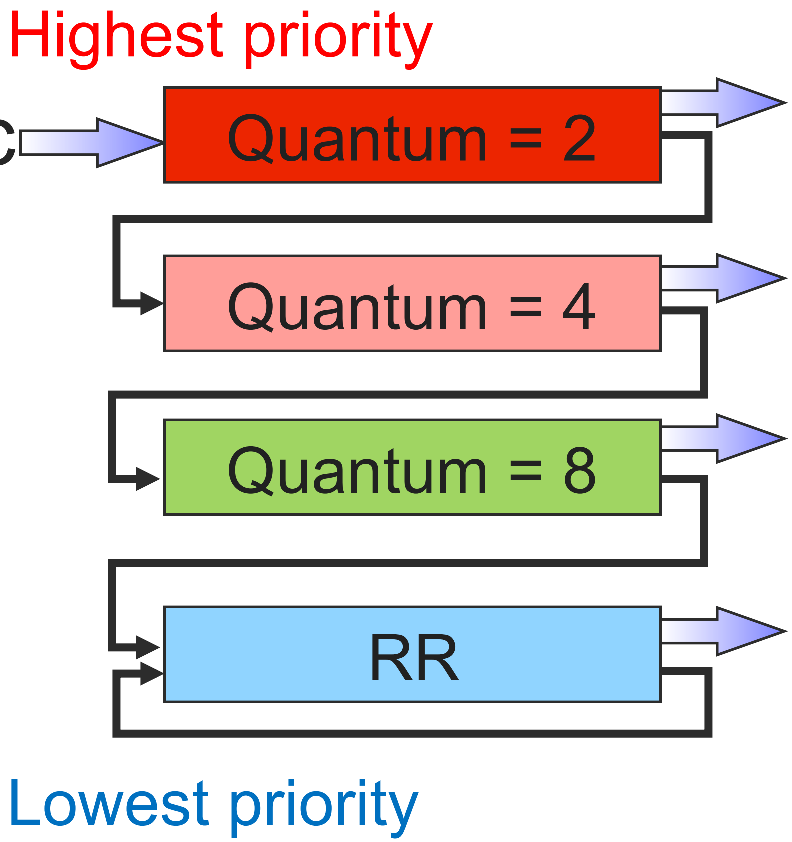
– Queue classification difficult

(Process may have CPU-bound and interactive phases)

– No queue re-classification

Multi-Level Feedback Queues

- Like multilevel queue, but assignments are not static
- Jobs start at the top
  - Use your quantum? move down
  - Don't? Stay where you are



Need parameters for:

- Number of queues
- Scheduling alg. per queue
- When to upgrade/downgrade job

Problem Revisited

- Cook at State Street Diner: how to minimize the average wait time for food?
  (most restaurants use FCFS)

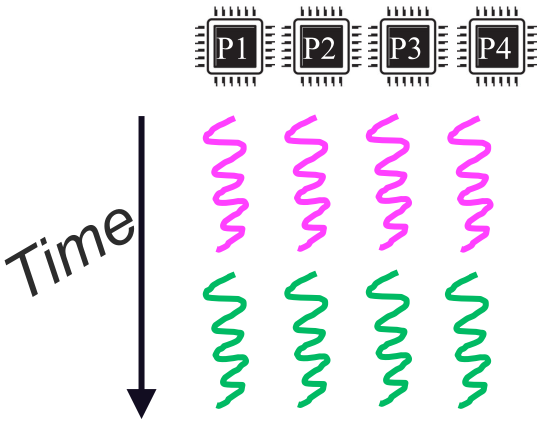
- Nurse in the emergency room

- Student with assignments, friends, and a need for sleep

Thread Scheduling

Threads share code & data segments

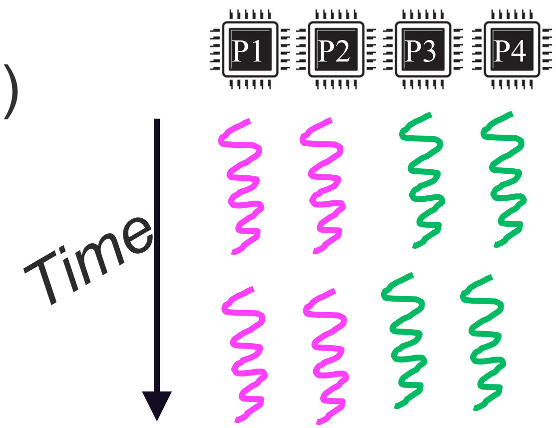
- **Option 1: Ignore this fact**
- **Option 2: Gang scheduling***
  - all threads of a process run together (pink, green)



- **Option 3: Space-based affinity***
  - assign tasks to processors (pink → P1, P2)

  \+ Improve cache hit ratio
- **Option 4: Two-level scheduling**
  - schedule processes, and within each process, schedule threads

  \+ Reduce context switching overhead and improve cache hit ratio



***multiprocessor only**

Real-Time Scheduling

Real-time processes have timing constraints

- Expressed as deadlines or rate requirements

Common RT scheduling policies

- Earliest deadline first (EDF) (priority = deadline)
  - Task A: I/O (1ms compute + 10 ms I/O), deadline = 12 ms
  - Task B: compute, deadline = 10 ms
- Priority Inheritance
  - High priority task (needing lock) donates priority to lower priority task (with lock)