CPU Scheduling
(Chapters 7-11)

CS 4410
Operating Systems

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COMPUTING AND INFORMATION SCIENCE

[R. Agarwal, L. Alvisi, A. Bracy, M. George, F.B. Schneider, E.G. Sirer, R. Van Renesse]

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 turnaround time?
- minimize maximum turnaround time?
- 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

`}`

Job Characteristics

Job or Task

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

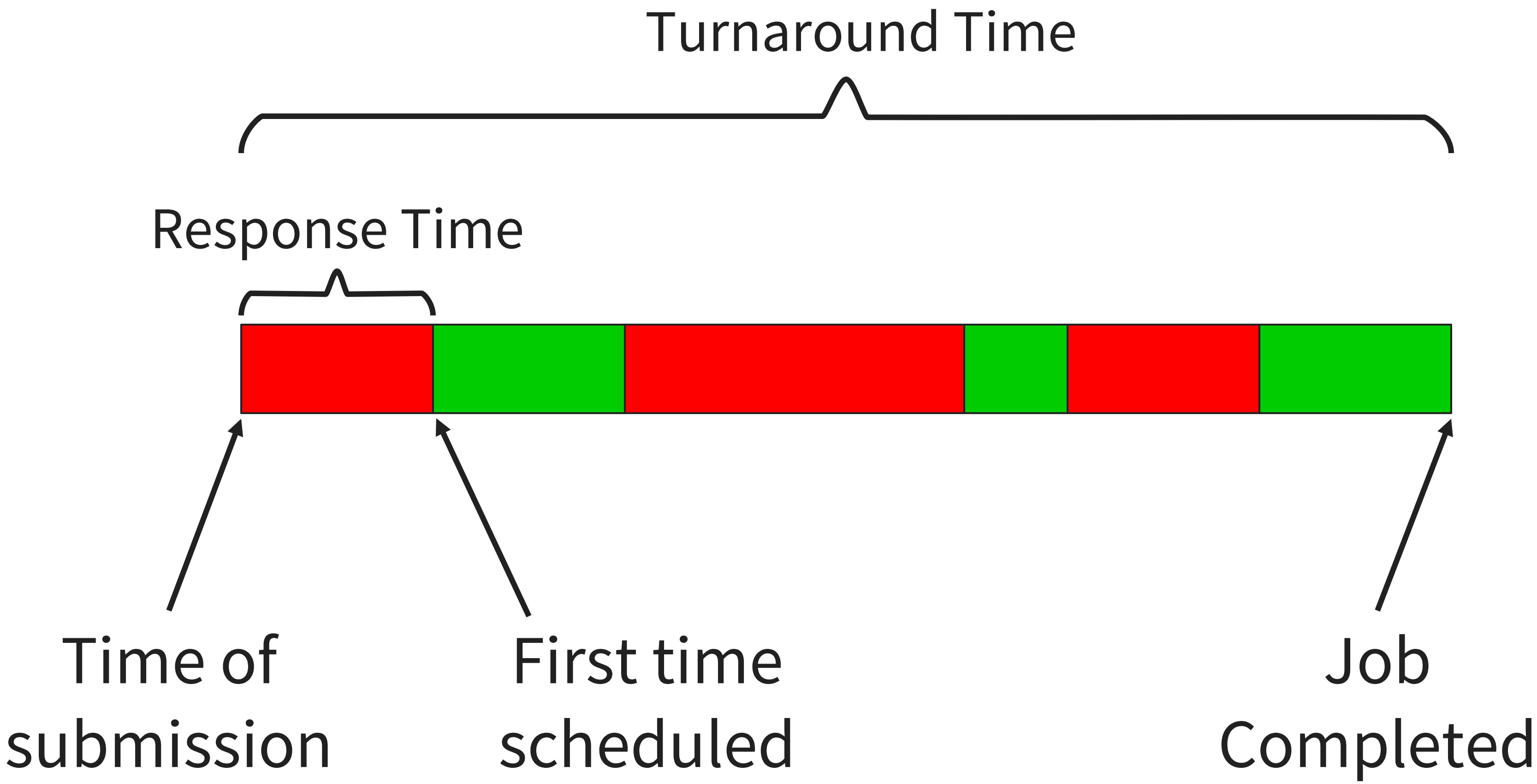
Job Arrival time

Job Execution time

- Time needed to run the task without contention

Nomenclature warning: no agreement on any of these terms or the ones that follow

Important Metrics of Scheduling



- Execution Time: sum of green periods
- Total Waiting Time: sum of red periods
- Turnaround Time: sum of both

Performance Terminology

Turnaround time: How long?

- User-perceived time to complete some job.

Response time: When does it start?

- User-perceived time before job can produce first output.

Total Waiting Time: How much thumb-twiddling?

- Time on the run queue but not running.

More Performance Terminology

Throughput: How many jobs over time?

- The rate at which jobs are completed.

Predictability: How consistent?

- Low variance in turnaround time for repeated jobs.

Overhead: How much useless work?

- Time lost due to switching between jobs.

Fairness: How equal is performance?

- Equality in the resources given to each job.

Starvation: How bad can it get?

- The lack of progress for one job, due to resources given to higher priority jobs.

The Perfect Scheduler

- Minimizes response time and turnaround time
- Maximizes throughput
- Maximizes utilization (aka “work conserving”):
  - keeps all devices busy
- Meets deadlines:
  - think watching a video, car brakes, *etc.*
- Is Fair:
  - everyone makes progress, no one starves
- Is Envy-Free:
  - no job wants to switch its schedule with another

No such scheduler exists! ☹

When does scheduler run?

Non-preemptive

Job runs until it voluntarily yields CPU:

- job blocks on an event (*e.g.*, I/O or P(sem))
- job explicitly *yields*
- job terminates

Preemptive

All of the above, plus:

- Timer and other interrupts
  - When jobs cannot be trusted to yield explicitly
- Incurs some context switching overhead

Process Model

Jobs switch between CPU & I/O bursts

CPU-bound jobs: Long CPU bursts

I/O-bound jobs: 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)

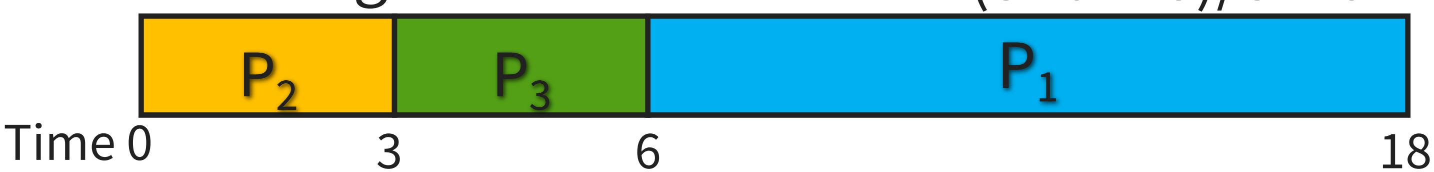
Processes (jobs) P_1, P_2, P_3 with execution time 12, 3, 3
All have same arrival time

Scenario 1: schedule order P_1, P_2, P_3

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

Scenario 2: schedule order P_2, P_3, P_1

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



FIFO Roundup

- \+ Simple
- \+ Low-overhead
- \+ No Starvation

– Average turnaround time very sensitive to schedule order

– Not responsive to interactive jobs

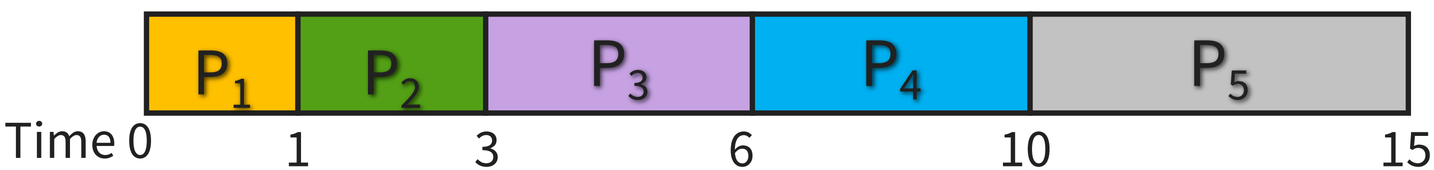
How to minimize average turnaround time?

Shortest Job First (SJF)

Schedule in order of estimated execution† time

Scenario : each job takes as long as its number

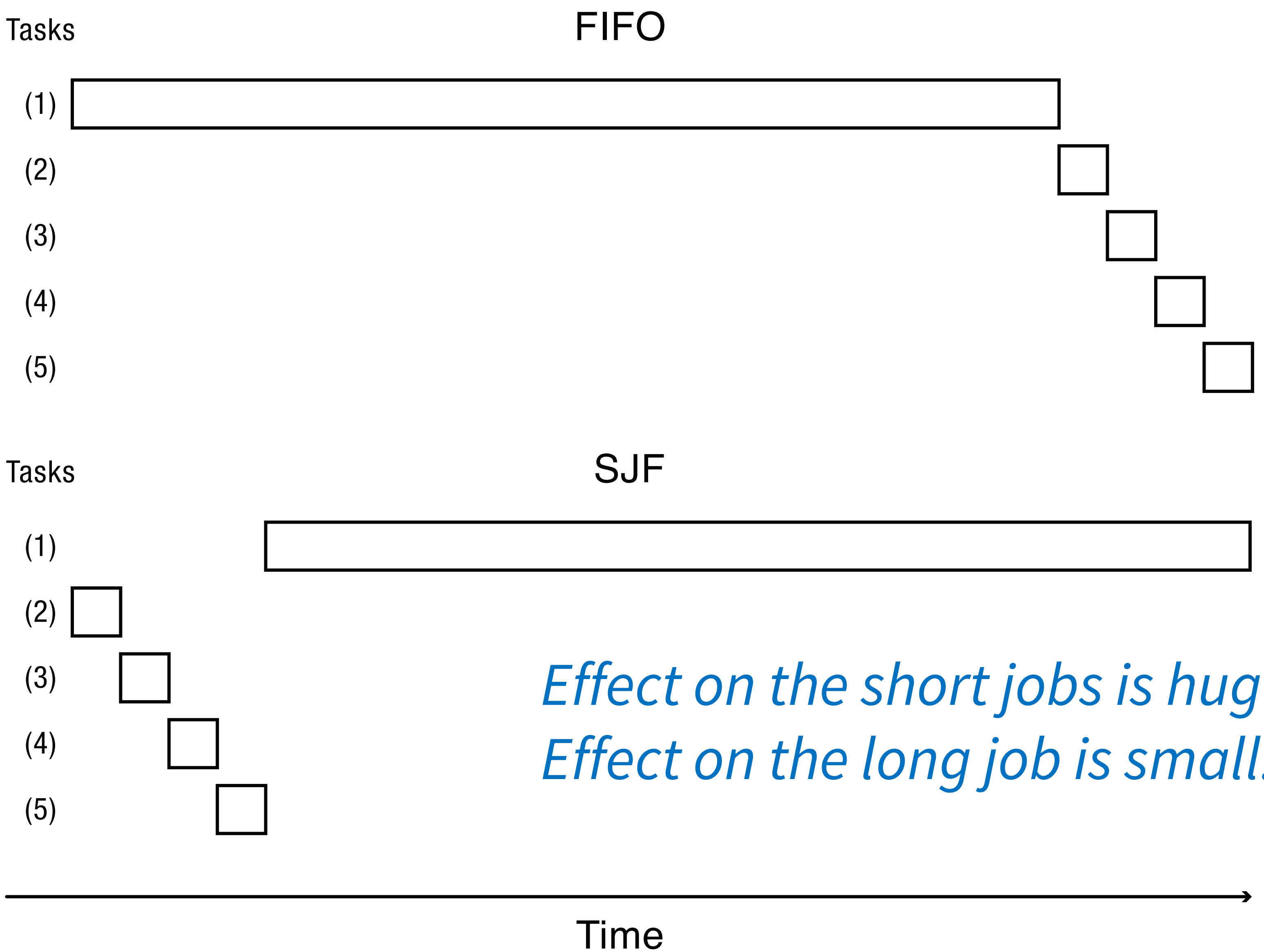
Average Response Time: (1+3+6+10+15)/5 = 7



Would another schedule improve avg turnaround time?

†with preemption, remaining execution 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
- Use past as a predictor of the future

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

Use *exponential moving 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 turnaround time

– Pessimal variance in turnaround time
– Needs estimate of execution time

– Can starve long jobs

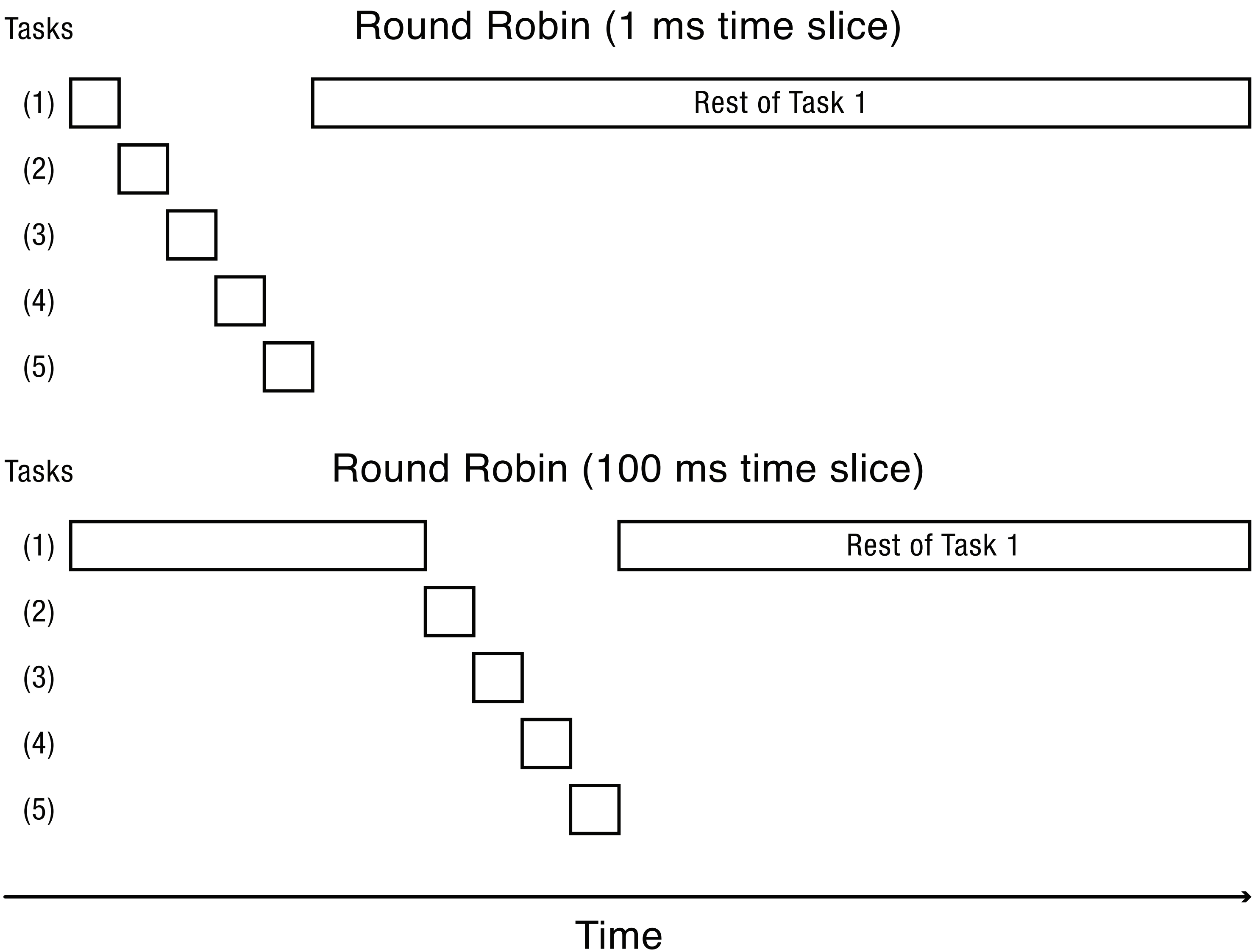
Round Robin (RR)

- Each job 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 is wasted on context switching
- Typical quantum: about 100X cost of context switch (~100ms vs. << 1 ms)

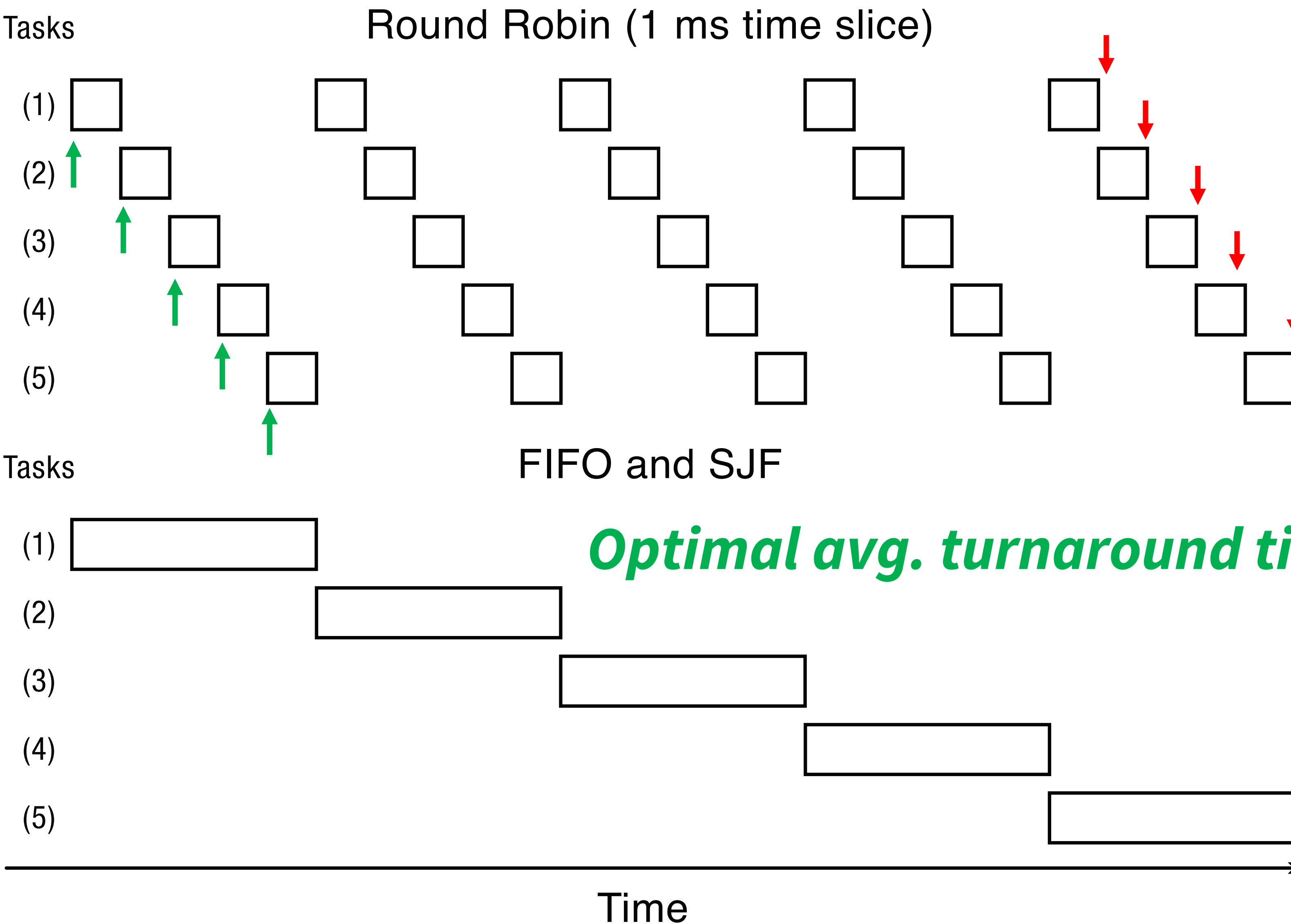
Effect of Quantum Choice in RR



Round Robin vs. FIFO

Tasks of same length that start ~same time

At least it's fair?



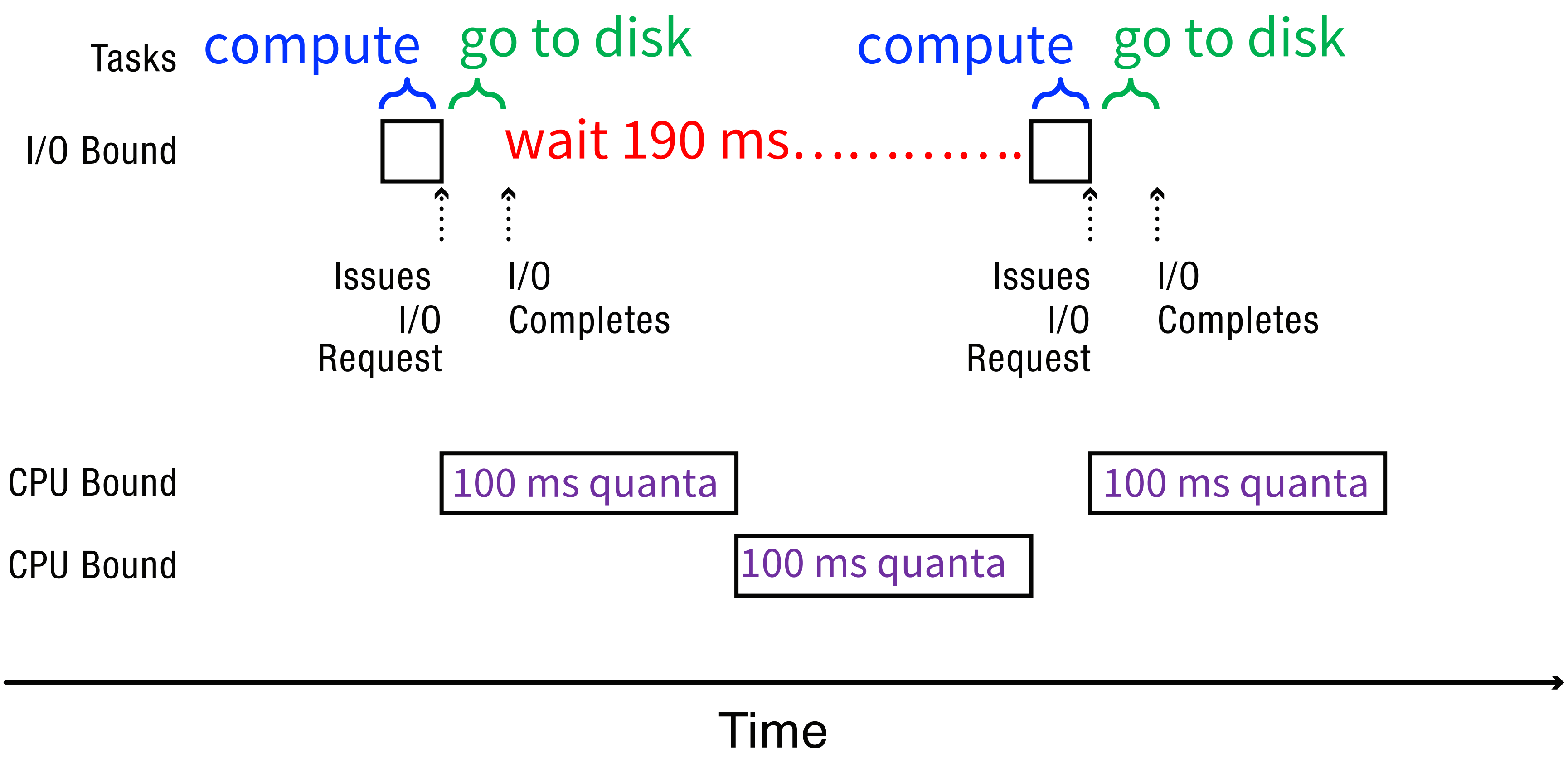
Optimal avg. turnaround time!

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

– Context switch overhead
– Mix of I/O and CPU bound

–bad avg. turnaround time for equal length jobs

Priority-based scheduling algorithms:

- Priority Scheduling
- Real-Time Scheduling
- Multi-level Queue Scheduling
- Multi-level Feedback Queue Scheduling

Priority Scheduling

- Assign a number to each job and schedule jobs in (increasing) order

- Can implement any scheduling policy
  - e.g., reduces to SJF if τ_n is used as priority

- To avoid starvation, improve job's priority with time (aging)

Real-Time Scheduling

Real-time processes have timing constraints

- Expressed as deadlines or rate requirements

Common RT scheduling policies

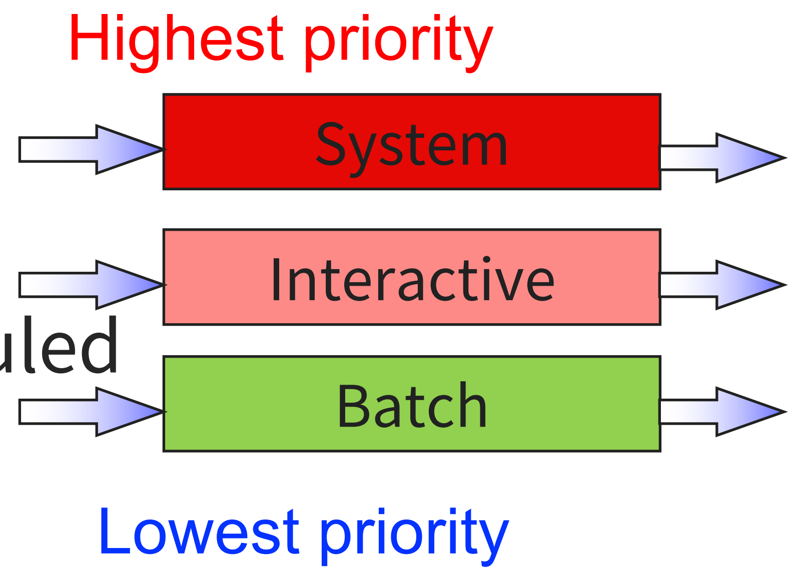
- Earliest deadline first (EDF) (priority = deadline)
- Priority Inheritance
  - Recall priority inversion: high priority process wants to get lock held by low priority process
  - Solution: High priority process (needing lock) temporarily donates priority to lower priority process (with lock)

Multi-Level Queue Scheduling

Multiple ready queues based on job “type”

- system jobs
- interactive jobs
- background batch jobs

Different queues may be scheduled using different algorithms



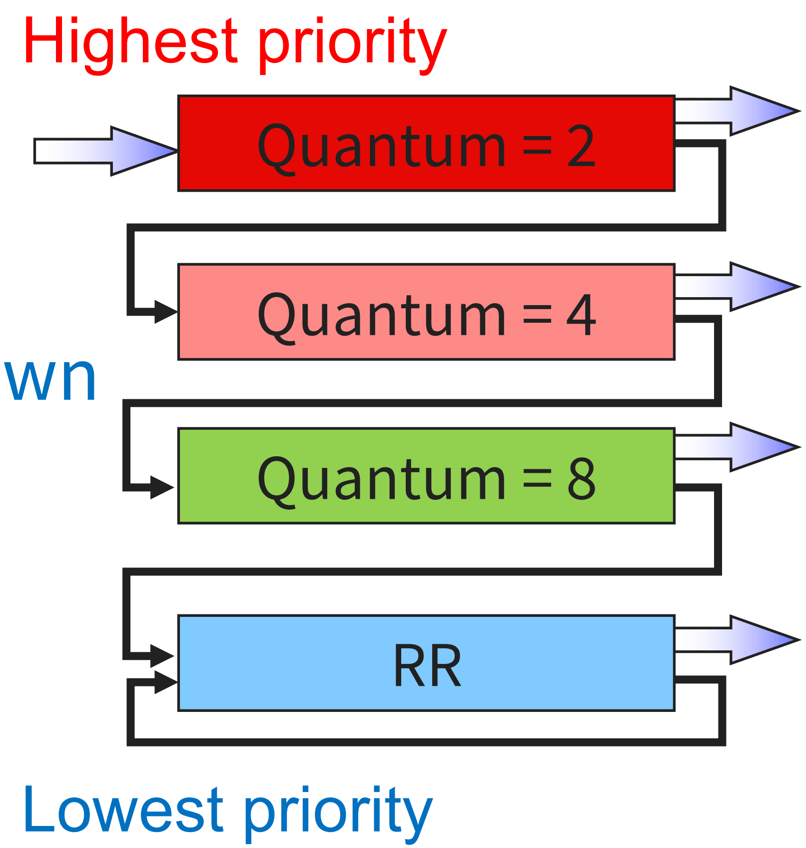
– Queue classification difficult

(Job 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



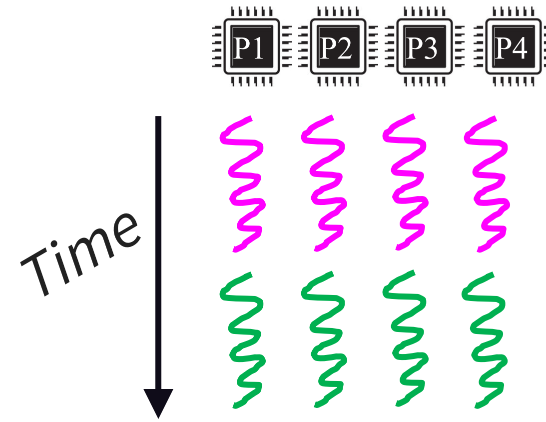
Need parameters for:

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

Thread Scheduling

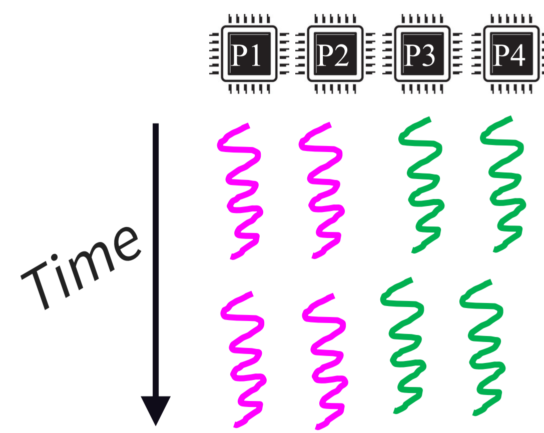
Threads share code & data segments

- **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



***multiprocessor only**