

# Lecture 17: CPU Scheduling

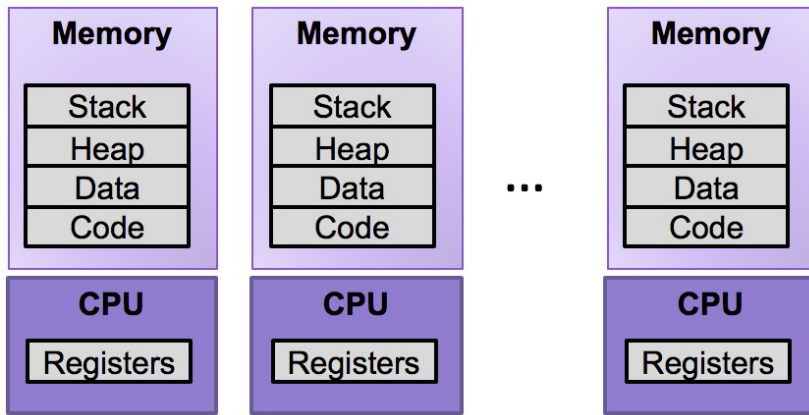
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CS 105

Fall 2023

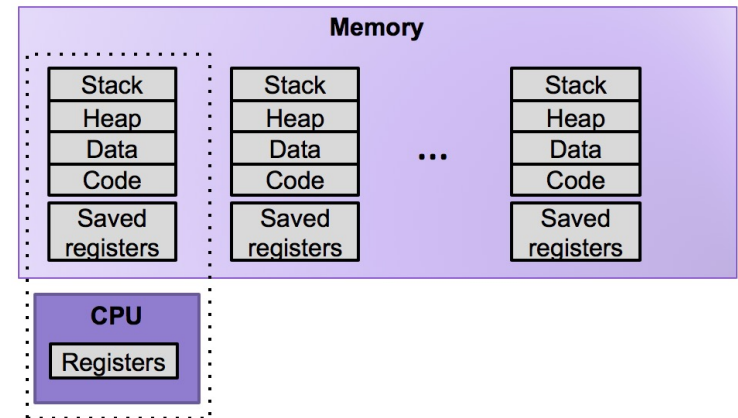
# Review: Multiprocessing

## The Illusion



- Abstraction: logical control flow within a process

## The Reality



- Context switching b/n processes
- User cannot predict how instructions will interleave

# Real-world Examples

- Restaurants handling orders
- DMV handling customers
- Students handling assignments
- Hospitals handling patients

# Possible Metrics

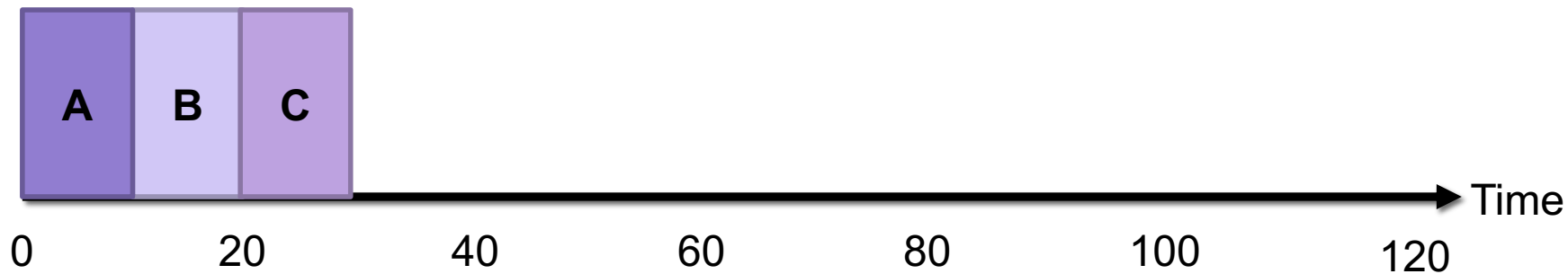
- **Latency:** how much time between when a job is requested and when a job is completed
- **Response time:** how much time between when a job is requested and when you start processing the job
- **Throughput:** the rate at which jobs are completed

# Simplifying Assumptions (for now)

- 1) Once you start a job, you complete that job before beginning the next job
- 2) The run-time of each job is known in advance
- 3) All jobs only use the CPU

# First In, First Out (FIFO)

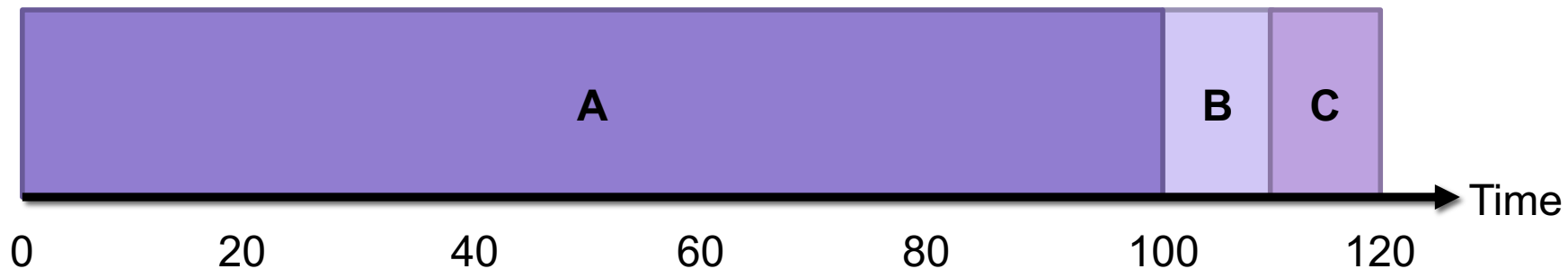
- Jobs are scheduled in the order they arrive
- Example:
  - Job A arrives at time 0, takes time 10 to complete
  - Job B arrives at time 5, takes time 10 to complete
  - Job C arrives at time 10, takes time 10 to complete



- Average Latency =  $\frac{10+15+20}{3} = 15$
- Average Response =  $\frac{0+5+10}{3} = 5$
- Throughput =  $\frac{3}{30} = .1$

# Exercise 1: First In, First Out (FIFO)

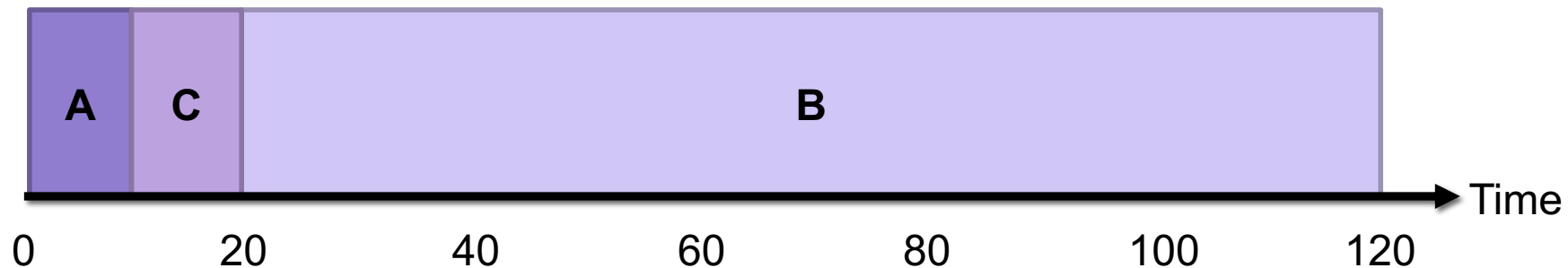
- Jobs are scheduled in the order they arrive
- Example:
  - Job A arrives at time 0, takes time 100 to complete
  - Job B arrives at time 5, takes time 10 to complete
  - Job C arrives at time 10, takes time 10 to complete



- Average Latency =  $\frac{100+105+110}{3} = 105$
- Average Response =  $\frac{0+95+100}{3} = 65$
- Throughput =  $\frac{3}{120} = .025$

# Shortest Job First (SJF)

- Jobs are scheduled in order of length (shortest first)
- Example:
  - Job A arrives at time 0, takes time 10 to complete
  - Job B arrives at time 5, takes time 100 to complete
  - Job C arrives at time 10, takes time 10 to complete

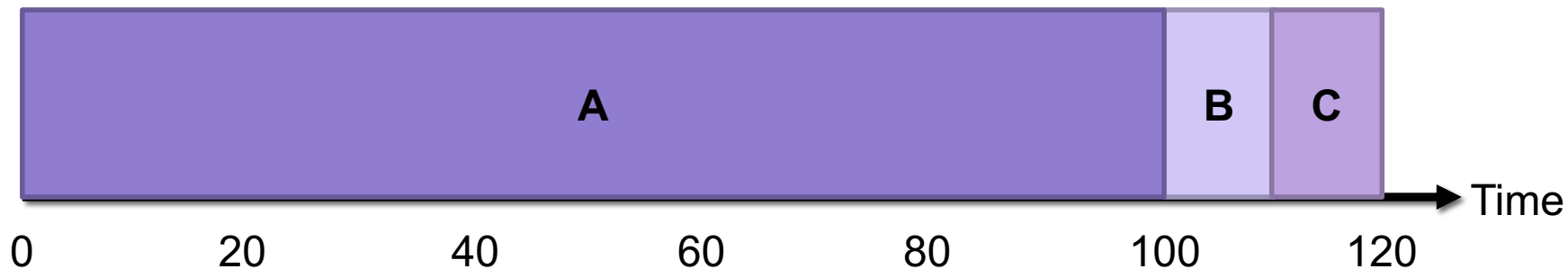


- Average Latency =  $\frac{10+115+10}{3} = 45$
- Average Response =  $\frac{0+15+0}{3} = 5$
- Throughput =  $\frac{3}{120} = .025$



# Exercise 2: Shortest Job First (SJF)

- Jobs are scheduled in order of length (shortest first)
- Example:
  - Job A arrives at time 0, takes time 100 to complete
  - Job B arrives at time 5, takes time 10 to complete
  - Job C arrives at time 10, takes time 10 to complete



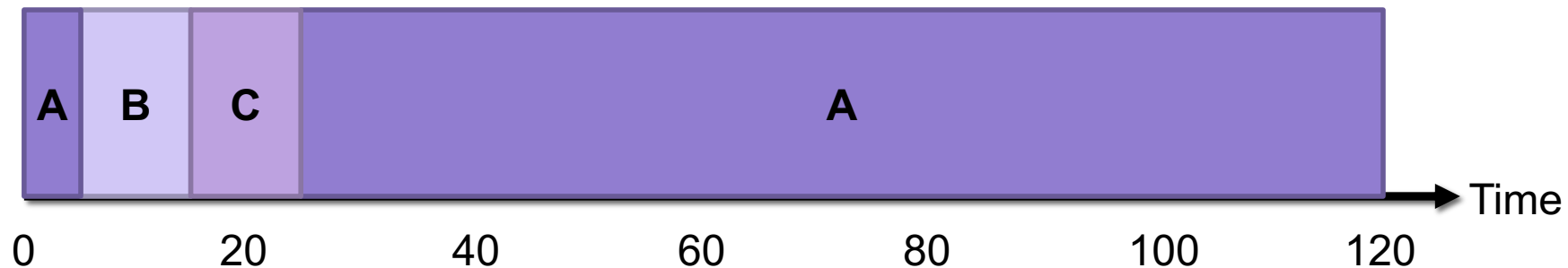
- Average Latency =  $\frac{100+105+110}{3} = 105$
- Average Response =  $\frac{0+95+100}{3} = 65$
- Throughput =  $\frac{3}{120} = .025$

# Simplifying Assumptions (for now)

- ~~1) Once you start a job, you complete that job before beginning the next job~~
- 2) The run-time of each job is known in advance
- 3) All jobs only use the CPU

# Shortest Time-to-Completion First (STCF)

- The job with the shortest time-to-completion is scheduled next
- If a job arrives with a shorter time-to-completion then the current job, it preempts the current job
- Example:
  - Job A arrives at time 0, takes time 100 to complete
  - Job B arrives at time 5, takes time 10 to complete
  - Job C arrives at time 10, takes time 10 to complete



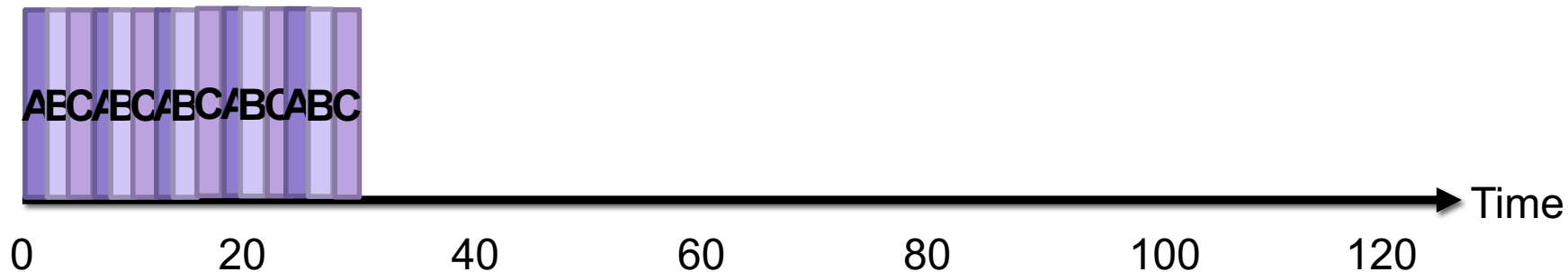
- Average Latency =  $\frac{120+10+15}{3} = 48.3$
- Average Response =  $\frac{0+0+5}{3} = 1.6$
- Throughput =  $\frac{3}{120} = .025$

# Simplifying Assumptions (for now)

- ~~1) Once you start a job, you complete that job before beginning the next job~~
- ~~2) The run-time of each job is known in advance~~
- 3) All jobs only use the CPU

# Round Robin (RR)

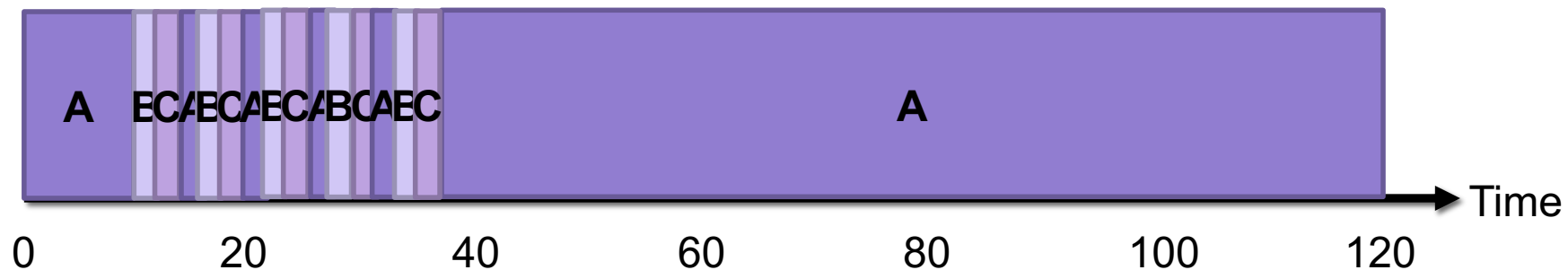
- Run jobs for a fixed time slice (e.g., 2), cycle through all job that are not yet completed
- Example:
  - Job A arrives at time 0, takes time 10 to complete
  - Job B arrives at time 0, takes time 10 to complete
  - Job C arrives at time 0, takes time 10 to complete



- Average Latency =  $\frac{26+28+30}{3} = 28$
- Average Response =  $\frac{0+2+4}{3} = 2$
- Throughput =  $\frac{3}{30} = .1$

# Exercise 3: Round Robin (RR)

- Run jobs for a fixed time slice (e.g., 2), cycle through all job that are not yet completed
- Example:
  - Job A arrives at time 0, takes time 100 to complete
  - Job B arrives at time 10, takes time 10 to complete
  - Job C arrives at time 10, takes time 10 to complete



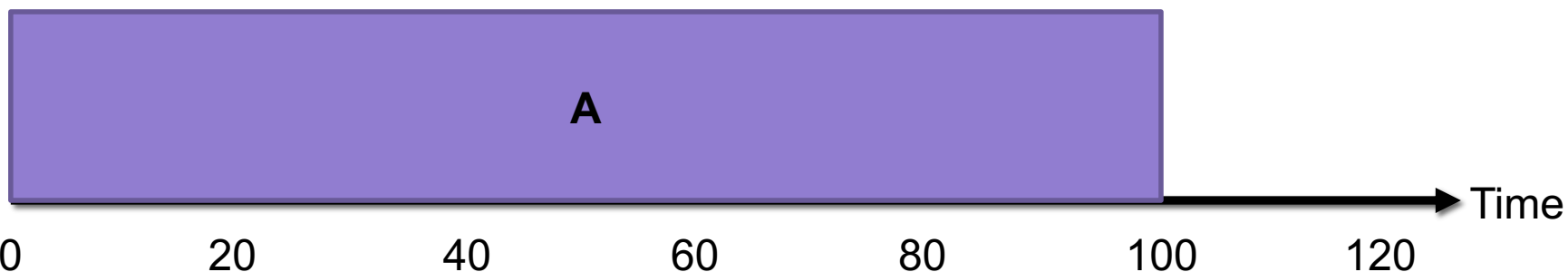
- Average Latency =  $\frac{120+26+28}{3} = 58$
- Average Response =  $\frac{0+0+2}{3} = .6$
- Throughput =  $\frac{3}{120} = .025$

# Simplifying Assumptions (for now)

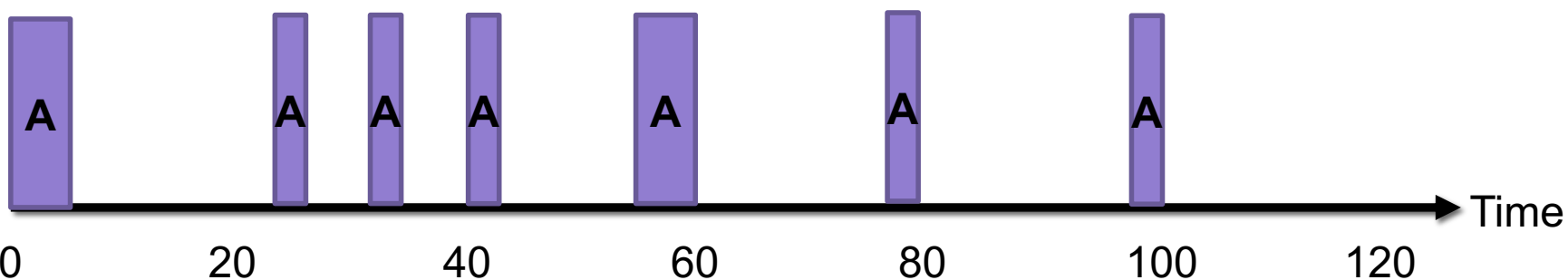
- ~~1) Once you start a job, you complete that job before beginning the next job~~
- ~~2) The run-time of each job is known in advance~~
- ~~3) All jobs only use the CPU~~

# Processes are not all the same

- CPU-bound processes use a lot of CPU
  - e.g., compiling, scientific computing applications, mp3 encoding



- I/O-bound processes use CPU in short bursts
  - e.g., browsing small webpages, indexing a file system



- Balanced processes are somewhere in between
  - e.g., playing videos, moving windows around



# Comparing Scheduling Algorithms

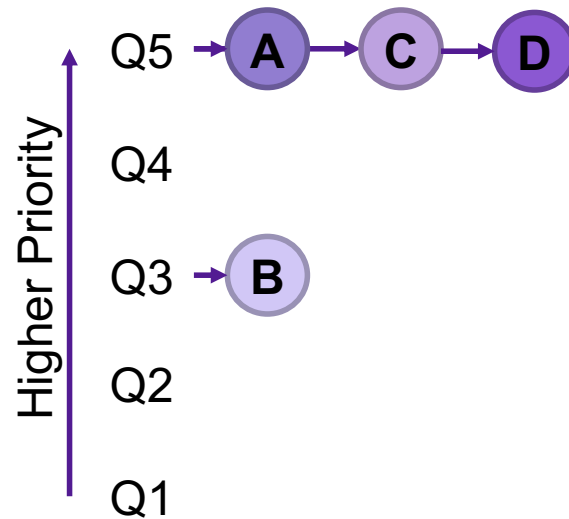
- FIFO
  - works well if jobs are short
  - otherwise bad latency and bad response time
- STCF
  - good latency
  - very uneven response time (bad fairness)
  - assumes run-time of each job is known in advance
- RR
  - good response time
  - bad latency + overhead of context switching
  - poor fairness for mixes of CPU-bound and I/O-bound

# Multi-level Feedback Queues

- **Goal:** optimize latency while minimizing response time for interactive jobs without knowing run-time of jobs in advance
- General idea: maintain multiple queues, each with a different priority level

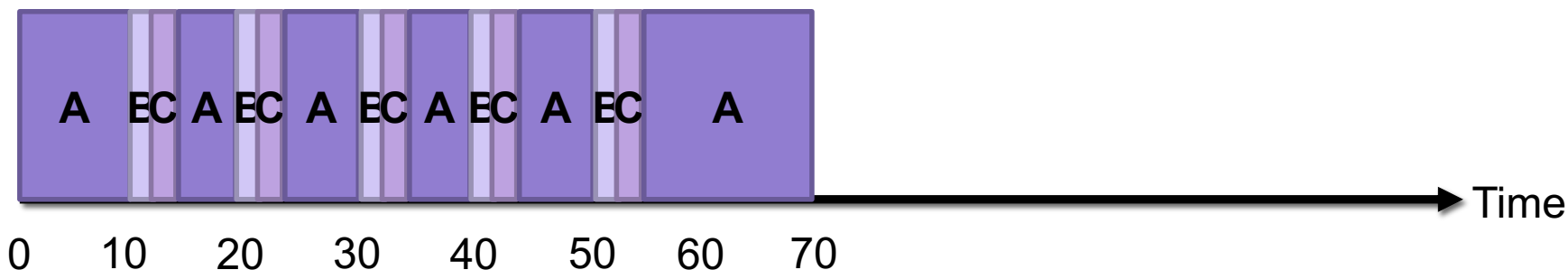
Scheduling rules:

- 1) If  $\text{Priority}(A) > \text{Priority}(B)$ , run A
- 2) If  $\text{Priority}(A) = \text{Priority}(C)$ , run A and C Round Robin
- 3) When a job enters the system, it is placed in the highest priority queue
- 4) Once a job uses up its time allotment at current priority level, it moves down one queue
- 5) After some time period, move all jobs in the system to the highest priority queue



# Example: Multi-level Feedback Queue

- Multilevel feedback queue with four levels with a time slice of 10 in the highest priority queue, 20 in the next, 40 in the next, and 80 in the lowest priority queue. Priorities reset every 200ms.
- Example:
  - Job A arrives first at time 0 and uses the CPU for 50ms before finishing.
  - Job B arrives at time 1. Job B loops five times; for each iteration of the loop, B uses the CPU for 2ms and then does I/O for 8ms.
  - Job C arrives at time 2. Job C is identical to Job B except for arrival time.



# Schedulers in Operating Systems

- **CPU Scheduler** selects next process to run from the runnable pool
- **Page Replacement Scheduler** selects page to evict
- **Disk Scheduler** selects next read/write operation to perform
- **Network Scheduler** selects next packet to send/process