CPU Scheduling

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CPU Scheduler

- A ***CPU scheduler*** is responsible for
  - Removal of running process from the CPU
  - Selection of the next running process
    - Based on a particular strategy

Goals for a Scheduler

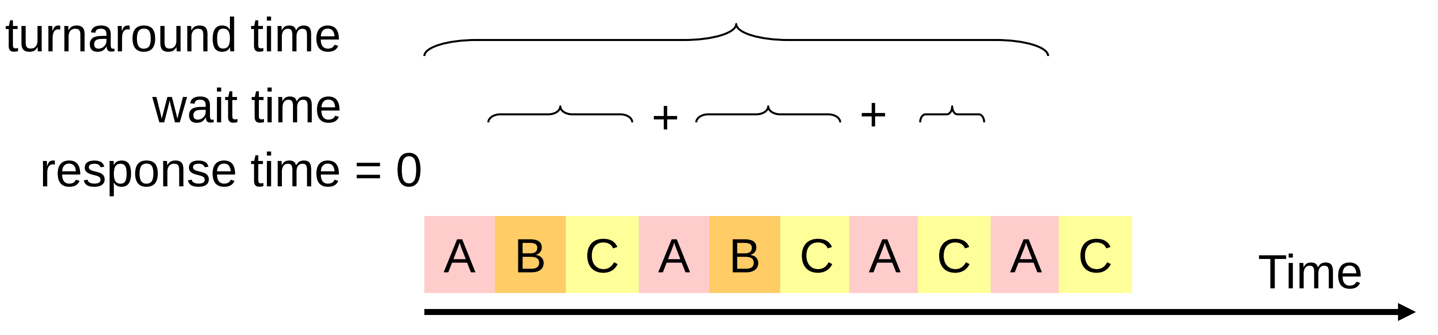
- Maximize
  - ***CPU utilization***: keep the CPU as busy as possible
  - ***Throughput***: the number of processes completed per unit time

Goals for a Scheduler

- Minimize
  - ***Response time***: the time of submission to the time the first response is produced
  - ***Wait time***: total time spent waiting in the ready queue
  - ***Turnaround time***: the time of submission to the time of completion

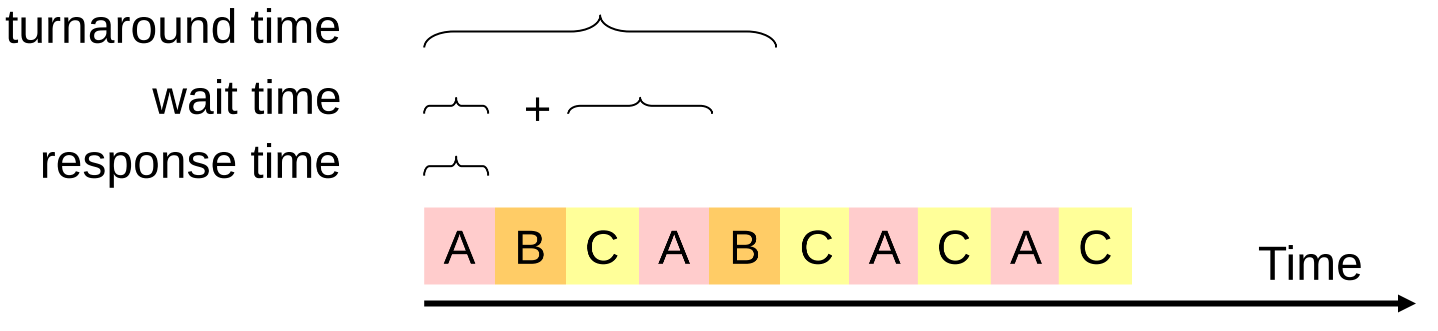
Goals for a Scheduler

- Suppose we have processes A, B, and C, submitted at time 0
- We want to know the response time, waiting time, and turnaround time of process A



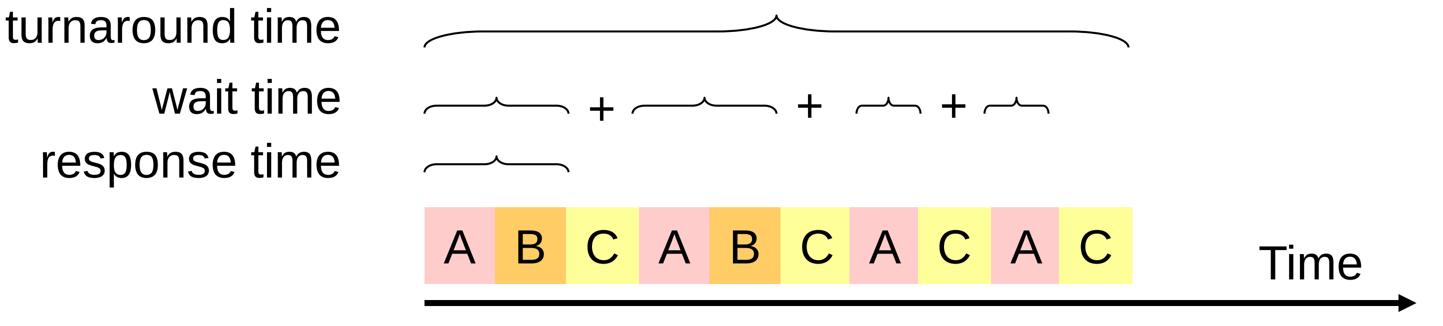
Goals for a Scheduler

- Suppose we have processes A, B, and C, submitted at time 0
- We want to know the response time, waiting time, and turnaround time of process B



Goals for a Scheduler

- Suppose we have processes A, B, and C, submitted at time 0
- We want to know the response time, waiting time, and turnaround time of process C



Goals for a Scheduler

- Achieve ***fairness***
  - There are tensions among these goals

Assumptions

- Each user runs one process
- Each process is single threaded
- Processes are independent

- They are not realistic assumptions; they serve to simplify analyses

Scheduling Policies

- FIFO (first in, first out)
- Round robin
- SJF (shortest job first)
- Multilevel feedback queues
- Lottery scheduling

FIFO

- ***FIFO***: assigns the CPU based on the order of requests
  - ***Nonpreemptive***: A process keeps running on a CPU until it is blocked or terminated
  - Also known as FCFS (first come, first serve)

  + Simple

  - Short jobs can get stuck behind long jobs

Round Robin

- ***Round Robin (RR)*** periodically releases the CPU from long-running jobs
  - Based on timer interrupts so short jobs can get a fair share of CPU time
  - ***Preemptive***: a process can be forced to leave its running state and replaced by another running process
  - ***Time slice***: interval between timer interrupts

More on Round Robin

- If time slice is too long
  - Scheduling degrades to FIFO
- If time slice is too short
  - Throughput suffers
  - Context switching cost dominates

More on Round Robin

- Round robin based on FIFO
  - Gives time slice to process that has waited longest to run
  - Used to choose next process to run

More on Round Robin

- Suppose we have three jobs of equal length

Round Robin

- Which job goes next?

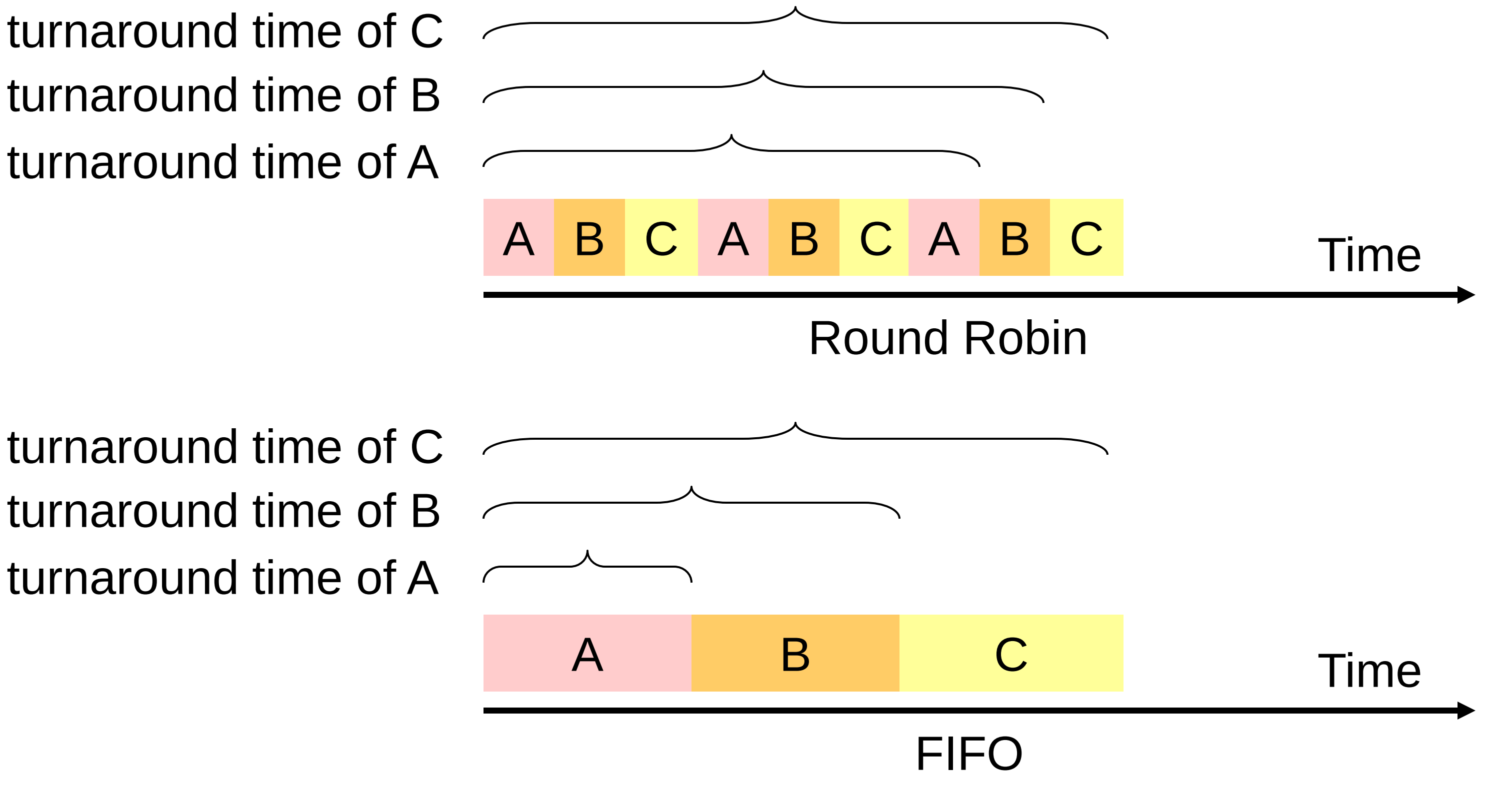
Round Robin

FIFO vs. Round Robin

- With zero-cost context switch, is RR always better than FIFO?

FIFO vs. Round Robin

- Suppose we have three jobs of equal length



FIFO vs. Round Robin

- Round Robin

  + Shorter response time

  + Fair sharing of CPU

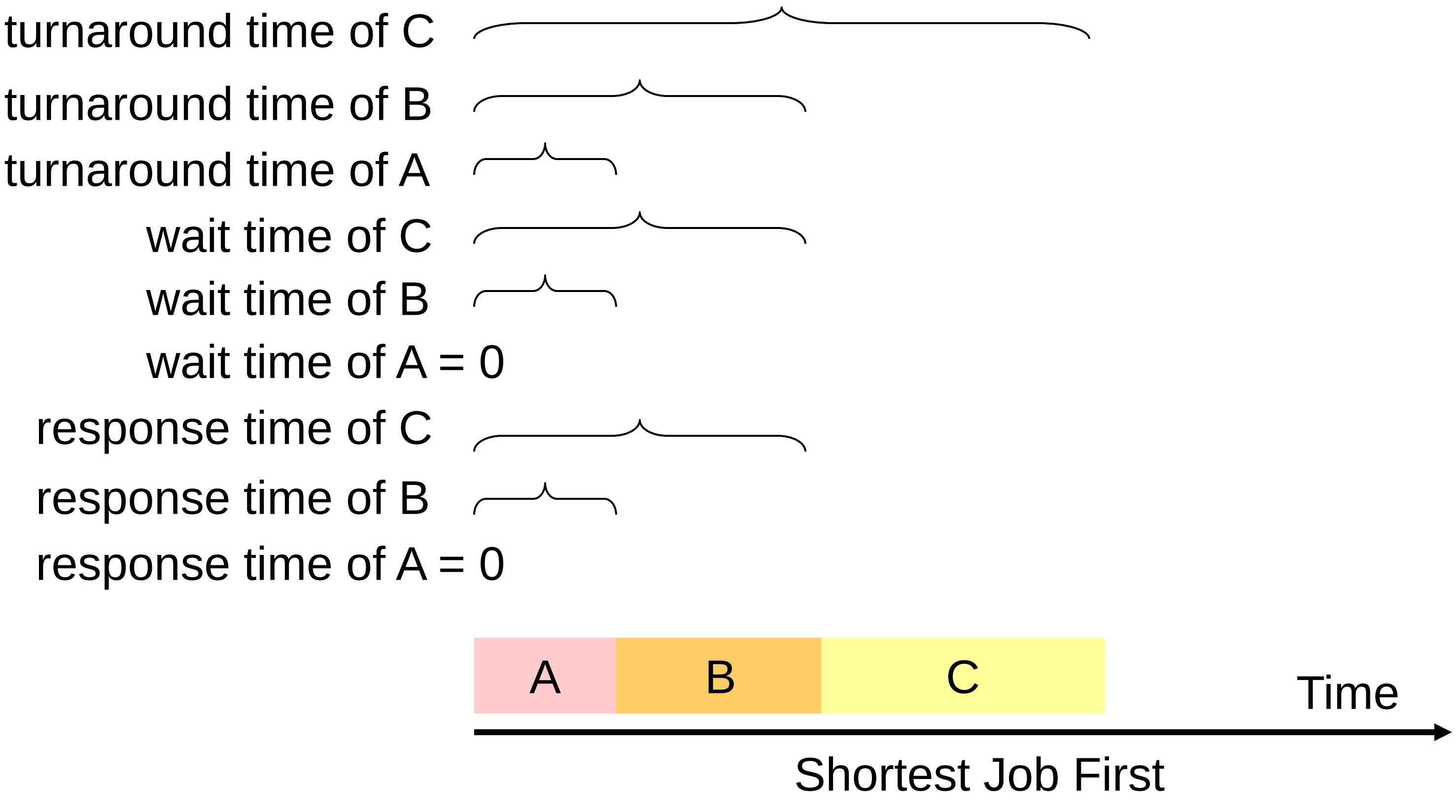
  - Not all jobs are preemptive

  - Not good for jobs of the same length

Shortest Job First (SJF)

- ***SJF*** runs whatever job puts the least demand on the CPU, also known as ***STCF (shortest time to completion first)***
  - \+ Provably optimal
  - \+ Great for short jobs
  - \+ Small degradation for long jobs
- Real life example: supermarket express checkouts

SJF Illustrated



Shortest Remaining Time First (SRTF)

- ***SRTF***: a preemptive version of SJF
  - If a job arrives with a shorter time to completion, SRTF preempts the CPU for the new job
  - Also known as ***SRTCF (shortest remaining time to completion first)***
  - Generally used as the base case for comparisons

SJF and SRTF vs. FIFO and Round Robin

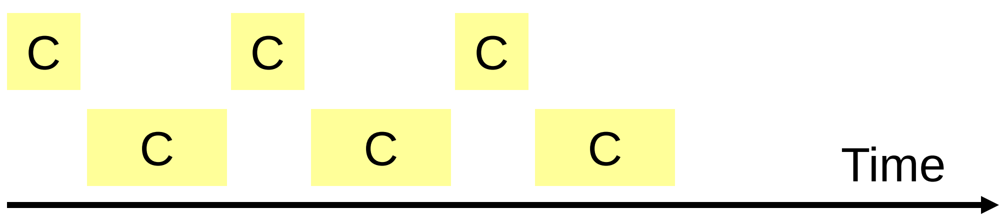
- If all jobs are the same length, SJF → FIFO
  - FIFO is the best you can do
- If jobs have varying length
  - Short jobs do not get stuck behind long jobs under SRTF

A More Complicated Scenario (Arrival Times = 0)

- Process A (6 units of CPU request)
  - 100% CPU
  - 0% I/O

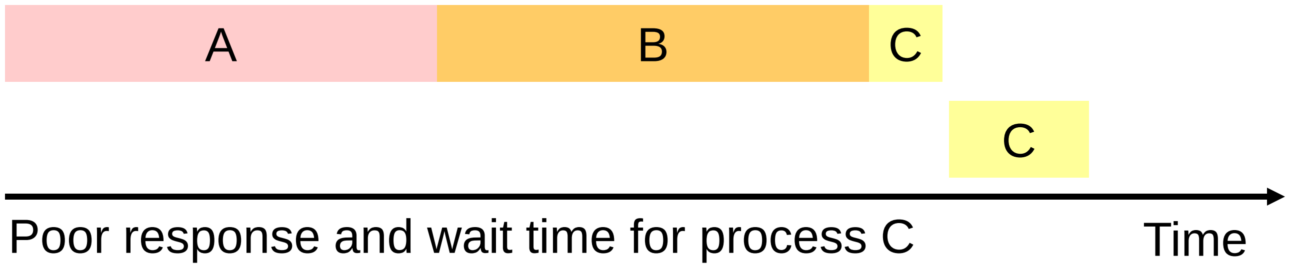
- Process B (6 units of CPU request)
  - 100% CPU
  - 0% I/O

- Process C (infinite loop)
  - 33% CPU
  - 67% I/O



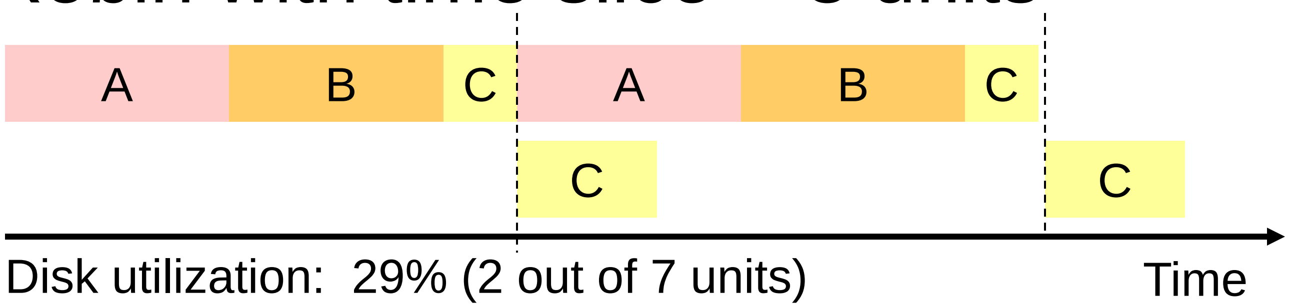
A More Complicated Scenario

- FIFO
  - CPU
  - I/O



Poor response and wait time for process C

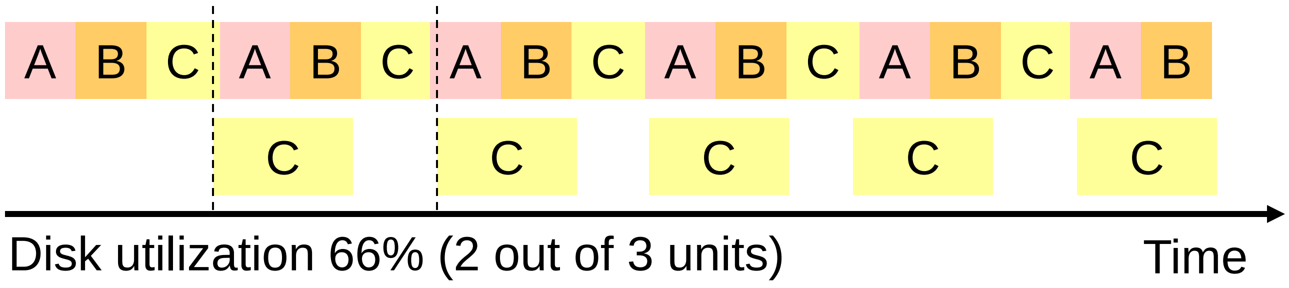
- Round Robin with time slice = 3 units
  - CPU
  - I/O



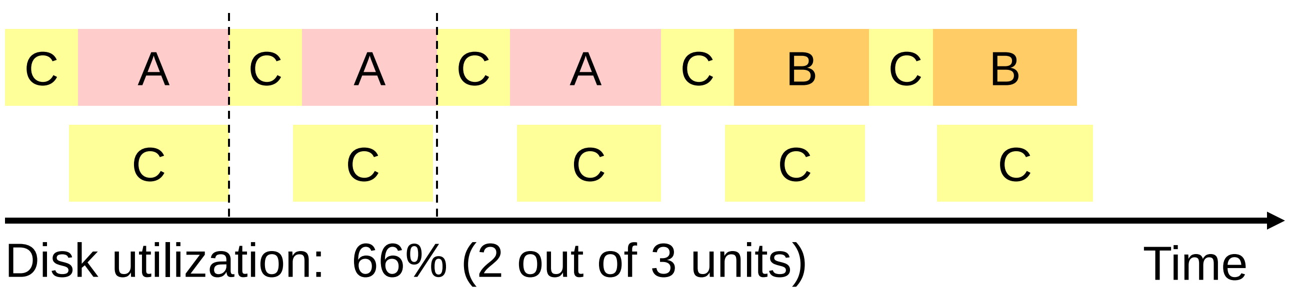
Disk utilization: 29% (2 out of 7 units)

A More Complicated Scenario

- Round Robin with time slice = 1 unit
  - CPU
  - I/O



- SRTF
  - CPU
  - I/O



Drawbacks of Shortest Job First

- ***Starvation***: constant arrivals of short jobs can keep long ones from running
- There is no way to know the completion time of jobs (most of the time)
  - Some solutions
    - Ask the user, who may not know any better
    - If a user cheats, the job is killed

Priority Scheduling (Multilevel Queues)

- ***Priority scheduling***: The process with the highest priority runs first
- Priority 0: C
- Priority 1: A
- Priority 2: B
- Assume that low numbers represent high priority

Priority Scheduling

Priority Scheduling

+ Generalization of SJF
  - With SJF, priority = 1/requested_CPU_time
- Starvation

Multilevel Feedback Queues

- ***Multilevel feedback queues*** use multiple queues with different priorities
  - Round robin at each priority level
  - Run highest priority jobs first
  - Once those finish, run next highest priority, etc
  - Jobs start in the highest priority queue
  - If time slice expires, drop the job by one level
  - If time slice does not expire, push the job up by one level

Multilevel Feedback Queues

time = 0

- Priority 0 (time slice = 1):

- Priority 1 (time slice = 2):
- Priority 2 (time slice = 4):

Multilevel Feedback Queues

time = 1

- Priority 0 (time slice = 1):
- Priority 1 (time slice = 2):
- Priority 2 (time slice = 4):

Multilevel Feedback Queues

time = 2

- Priority 0 (time slice = 1): C
- Priority 1 (time slice = 2): A B
- Priority 2 (time slice = 4):

Multilevel Feedback Queues

time = 3

- Priority 0 (time slice = 1):
- Priority 1 (time slice = 2): 

- Priority 2 (time slice = 4):

Multilevel Feedback Queues

time = 3

- Priority 0 (time slice = 1):
- Priority 1 (time slice = 2): 

- Priority 2 (time slice = 4):

suppose process A is blocked on an I/O

Multilevel Feedback Queues

time = 3

- Priority 0 (time slice = 1): A
- Priority 1 (time slice = 2): B C
- Priority 2 (time slice = 4):

suppose process A is blocked on an I/O

Multilevel Feedback Queues

time = 5

- Priority 0 (time slice = 1): A
- Priority 1 (time slice = 2): C
- Priority 2 (time slice = 4):

suppose process A is returned from an I/O

Multilevel Feedback Queues

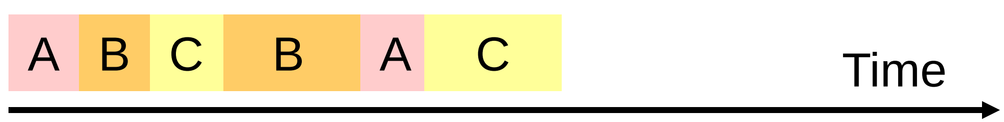
time = 6

- Priority 0 (time slice = 1):
- Priority 1 (time slice = 2): C
- Priority 2 (time slice = 4):

Multilevel Feedback Queues

time = 8

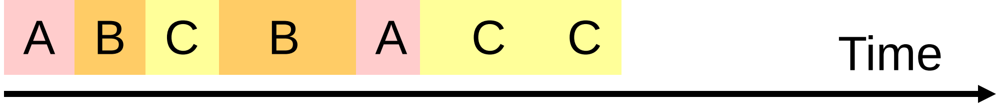
- Priority 0 (time slice = 1):
- Priority 1 (time slice = 2):
- Priority 2 (time slice = 4): C



Multilevel Feedback Queues

time = 9

- Priority 0 (time slice = 1):
- Priority 1 (time slice = 2):
- Priority 2 (time slice = 4):



Multilevel Feedback Queues

- Approximates SRTF
  - A CPU-bound job drops like a rock
  - I/O-bound jobs stay near the top
  - Still unfair for long running jobs
  - Counter-measure: ***Aging***
    - Increase the priority of long running jobs if they are not serviced for a period of time
    - Tricky to tune aging

Lottery Scheduling

- ***Lottery scheduling*** is an adaptive scheduling approach to address the fairness problem
  - Each process owns some tickets
  - On each time slice, a ticket is randomly picked
  - On average, the allocated CPU time is proportional to the number of tickets given to each job

Lottery Scheduling

- To approximate SJF, short jobs get more tickets
- To avoid starvation, each job gets at least one ticket

Lottery Scheduling Example

- short jobs: 10 tickets each
- long jobs: 1 ticket each

# short jobs/# long jobs	% of CPU for each short job	% of CPU for each long job
1/1	91%	9%
0/2	0%	50%
2/0	50%	0%
10/1	10%	1%
1/10	50%	5%