

# 8: Scheduling: The Multi-Level Feedback Queue

Operating System: Three Easy Pieces

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# Multi-Level Feedback Queue (MLFQ)

- ▣ A Scheduler that learns from the past to predict the future.
- ▣ Objective:
  - ◆ Optimize **turnaround time** → Run shorter jobs first
  - ◆ Minimize **response time** without *a priori knowledge of job length*.

# MLFQ: Basic Rules

- MLFQ has a number of distinct **queues**.
  - ◆ Each queue is assigned a different priority level.
- A job that is ready to run is on a single queue.
  - ◆ A job **on a higher queue** is chosen to run.
  - ◆ Use round-robin scheduling among jobs in the same queue

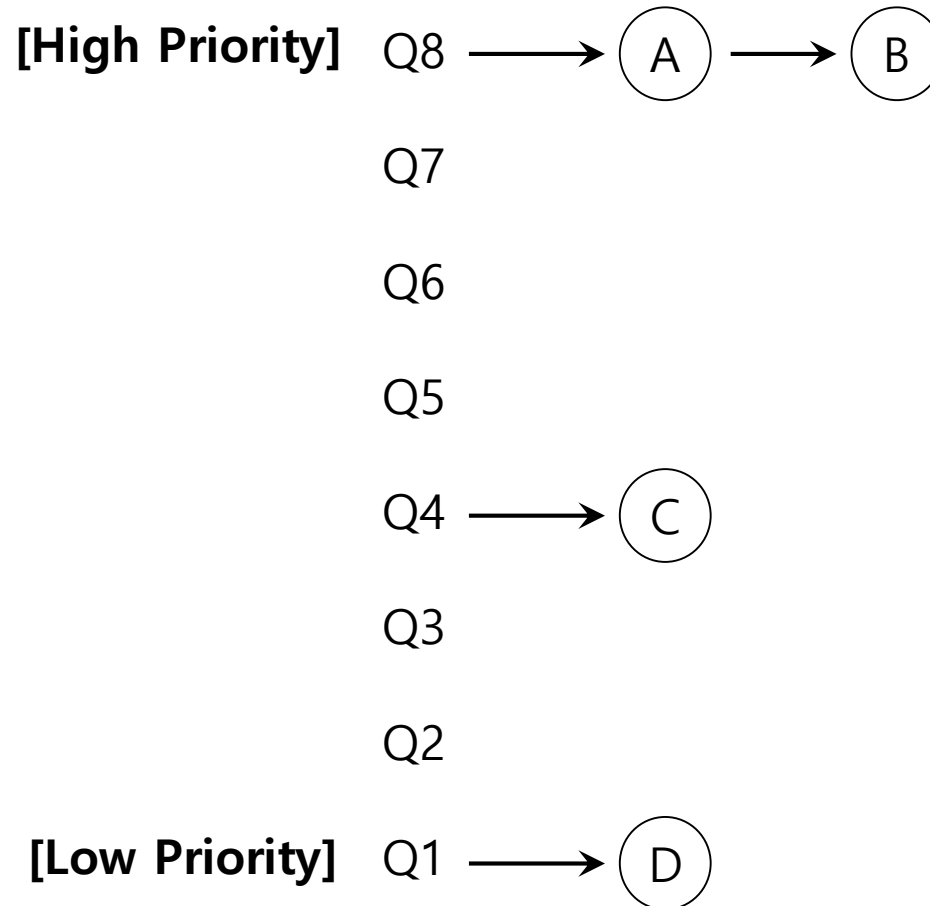
**Rule 1:** If  $\text{Priority}(A) > \text{Priority}(B)$ , A runs (B doesn't).

**Rule 2:** If  $\text{Priority}(A) = \text{Priority}(B)$ , A & B run in RR.

# MLFQ: Basic Rules (Cont.)

- ▣ MLFQ varies the priority of a job based on its observed behavior.
- ▣ Example:
  - ◆ A job repeatedly relinquishes the CPU while waiting IOs → Keep its priority high
  - ◆ A job uses the CPU intensively for long periods of time → Reduce its priority.

# MLFQ Example



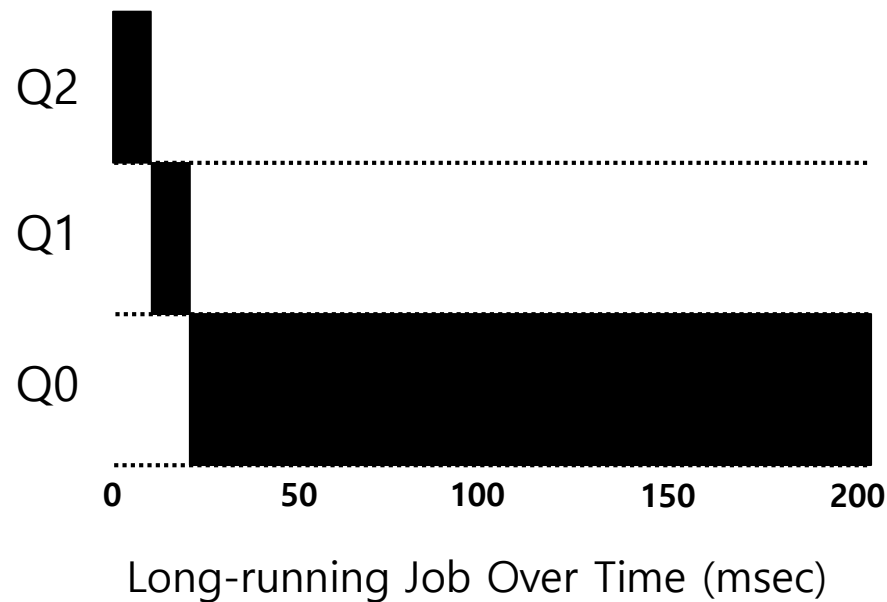
# MLFQ: How to Change Priority

- MLFQ priority adjustment algorithm:
  - ◆ **Rule 3:** When a job enters the system, it is placed at the highest priority
  - ◆ **Rule 4a:** If a job uses up an entire time slice while running, its priority is reduced (i.e., it moves down on queue).
  - ◆ **Rule 4b:** If a job gives up the CPU before the time slice is up, it stays at the same priority level

**In this manner, MLFQ approximates SJF**

# Example 1: A Single Long-Running Job

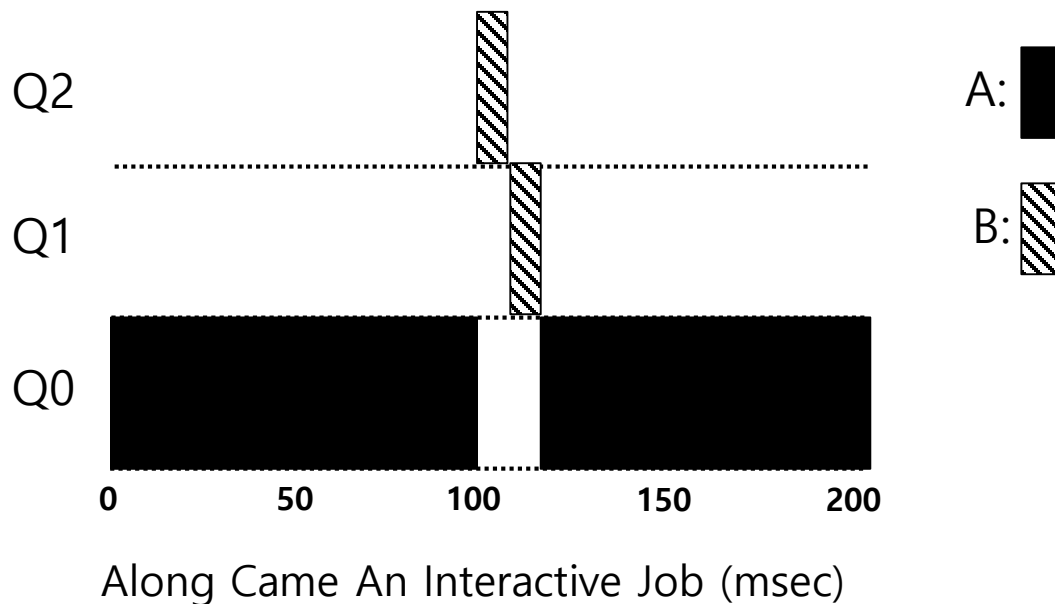
- ▣ A three-queue scheduler with time slice 10ms



# Example 2: Along Came a Short Job

## □ Assumption:

- ◆ **Job A:** A long-running CPU-intensive job
- ◆ **Job B:** A short-running interactive job (20ms runtime)
- ◆ A has been running for some time, and then B arrives at time  $T=100$ .

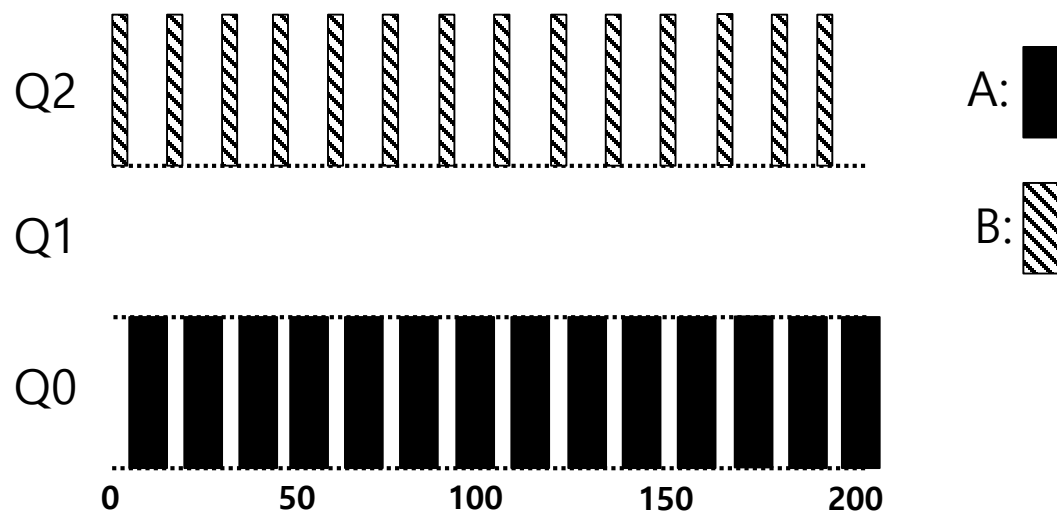




# Example 3: What About I/O?

## Assumption:

- ♦ **Job A:** A long-running CPU-intensive job
- ♦ **Job B:** An interactive job that need the CPU only for 1ms before performing an I/O



A Mixed I/O-intensive and CPU-intensive Workload (msec)

**The MLFQ approach keeps an interactive job at the highest priority**

# Problems with the Basic MLFQ

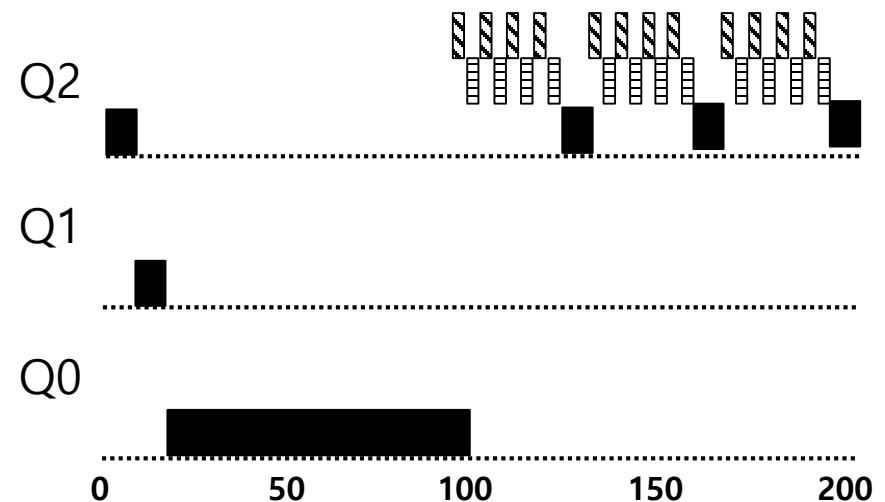
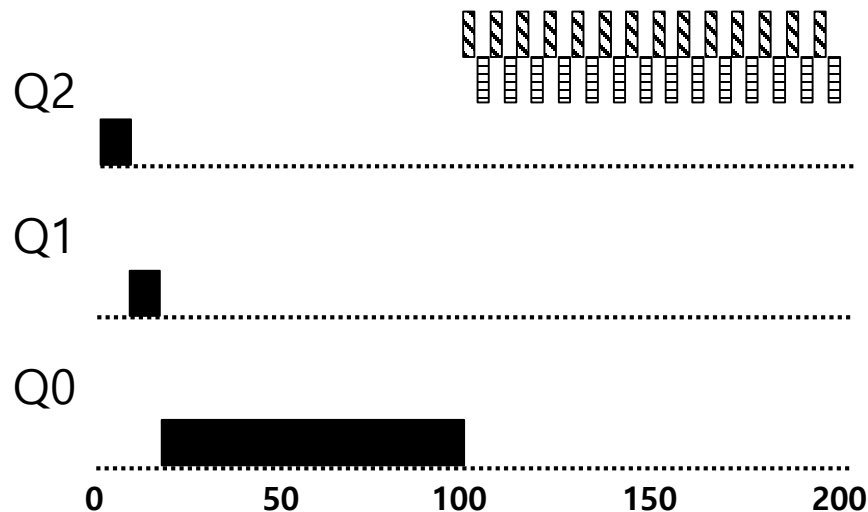
- ❑ Starvation
  - ◆ If there are “too many” interactive jobs in the system.
  - ◆ Lon-running jobs will never receive any CPU time.
  
- ❑ Game the scheduler
  - ◆ After running 99% of a time slice, issue an I/O operation.
  - ◆ The job gain a higher percentage of CPU time.
  
- ❑ A program may change its behavior over time.
  - ◆ CPU bound process → I/O bound process

# The Priority Boost




- ▣ **Rule 5:** After some time period  $S$ , move all the jobs in the system to the topmost queue.

- ◆ Example:

- A long-running job(A) with two short-running interactive job(B, C)

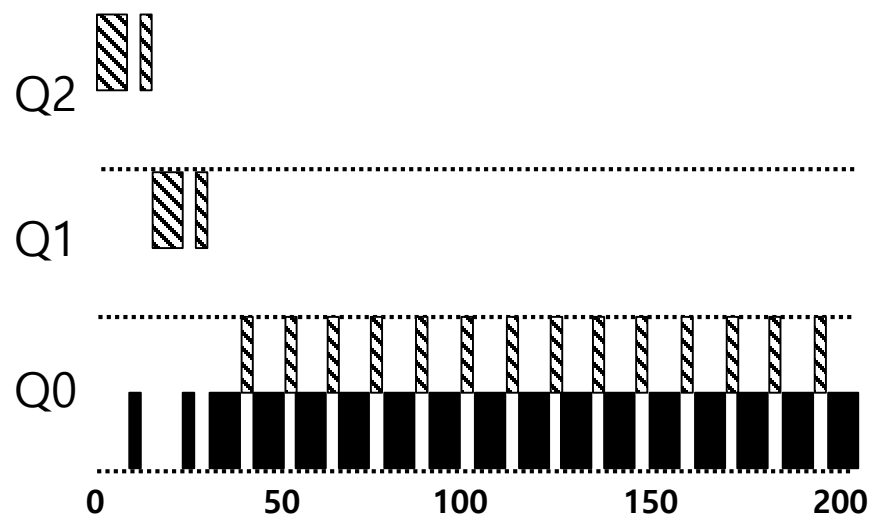
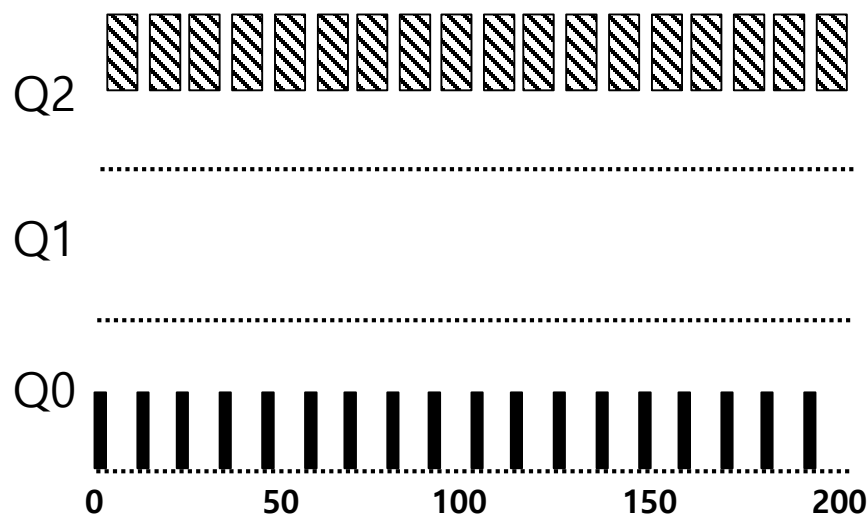


Without(Left) and With(Right) Priority Boost

A:  B:  C: 

# Better Accounting

- How to prevent gaming of our scheduler?
- Solution:
  - ◆ **Rule 4** (Rewrite Rules 4a and 4b): Once a job **uses up its time allotment** at a given level (regardless of how many times it has given up the CPU), **its priority is reduced**(i.e., it moves down on queue).

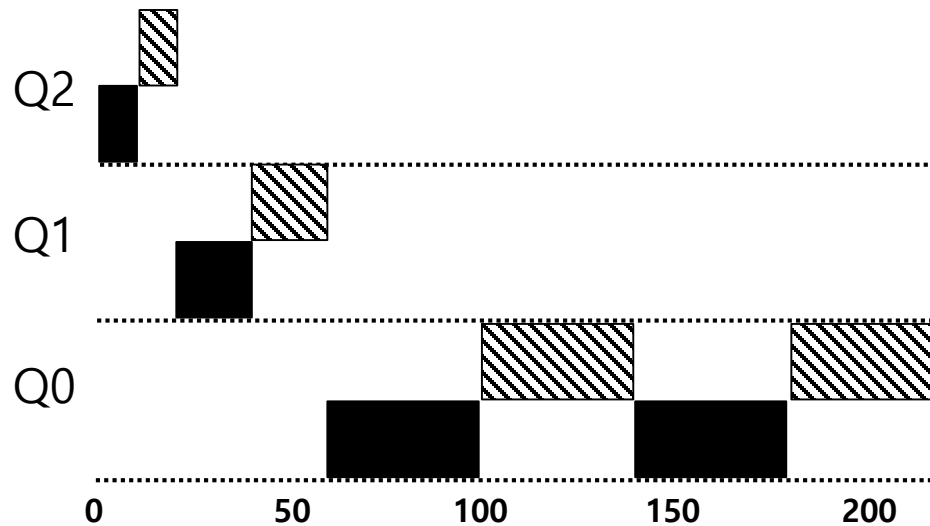


Without(Left) and With(Right) Gaming Tolerance

# Tuning MLFQ And Other Issues

## Lower Priority, Longer Quanta

- ◆ The high-priority queues → Short time slices
  - E.g., 10 or fewer milliseconds
- ◆ The Low-priority queue → Longer time slices
  - E.g., 100 milliseconds



Example) 10ms for the highest queue, 20ms for the middle,  
40ms for the lowest

# The Solaris MLFQ implementation

- ▣ For the Time-Sharing scheduling class (TS)
  - ◆ 60 Queues
  - ◆ Slowly increasing time-slice length
    - The highest priority: 20msec
    - The lowest priority: A few hundred milliseconds
  - ◆ Priorities boosted around every 1 second or so.

# MLFQ: Summary

- The refined set of MLFQ rules:
  - ◆ **Rule 1:** If  $\text{Priority}(A) > \text{Priority}(B)$ , A runs (B doesn't).
  - ◆ **Rule 2:** If  $\text{Priority}(A) = \text{Priority}(B)$ , A & B run in RR.
  - ◆ **Rule 3:** When a job enters the system, it is placed at the highest priority.
  - ◆ **Rule 4:** Once a job uses up its time allotment at a given level (regardless of how many times it has given up the CPU), its priority is reduced(i.e., it moves down on queue).
  - ◆ **Rule 5:** After some time period  $S$ , move all the jobs in the system to the topmost queue.

- ❑ Disclaimer: This lecture slide set was initially developed for Operating System course in Computer Science Dept. at Hanyang University. This lecture slide set is for OSTEP book written by Remzi and Andrea at University of Wisconsin.