Operating Systems

8: Scheduling:
The Multi-Level Feedback Queue

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 queues is assigned a different priority level.

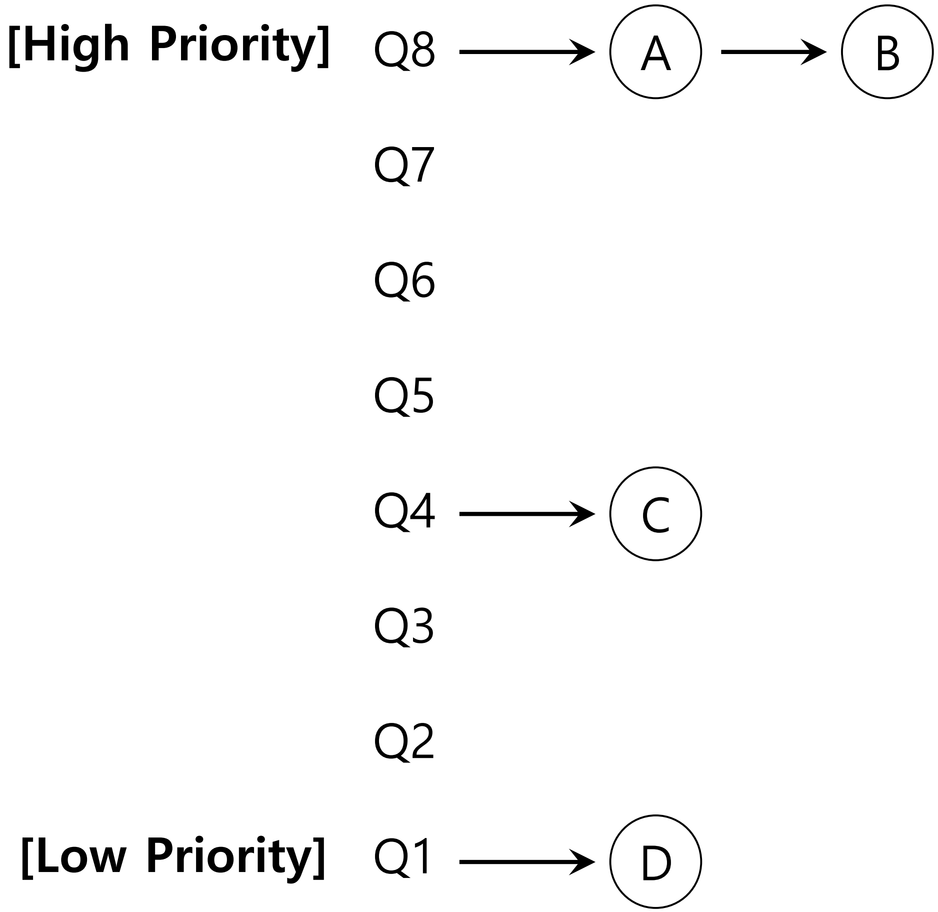
- A job that is ready to run is on a single queue.
  - A job **on a higher queue** is chosen to run.
  - Use round-robin scheduling among jobs in the same queue

Rule 1: If Priority(A) > Priority(B), A runs (B doesn't).
Rule 2: If Priority(A) = 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



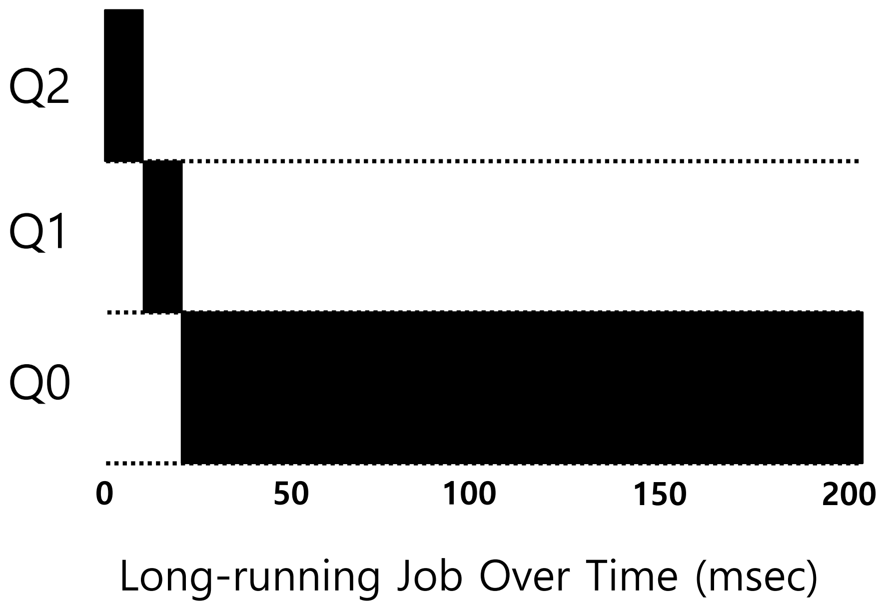
MLFQ: How to Change Priority

- 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

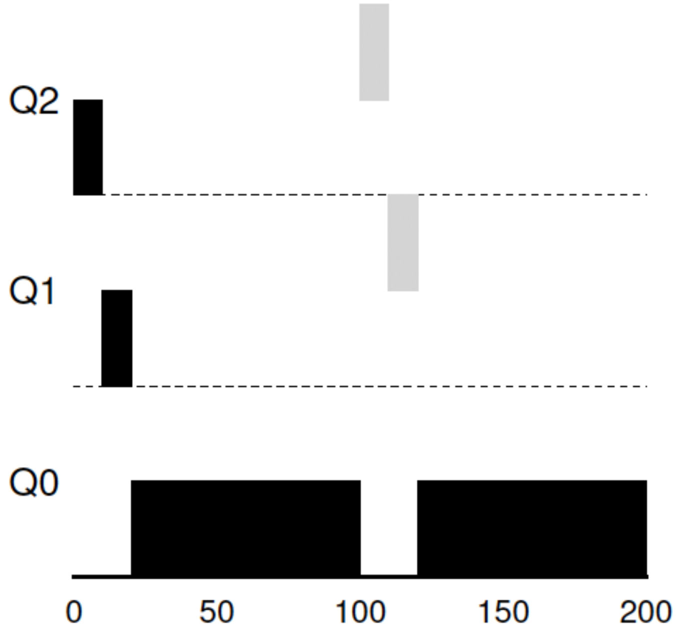
Example 1: A Single Long-Running Job

- A three-queue scheduler with time slice 10ms



Example 2: Along Came a Short Job

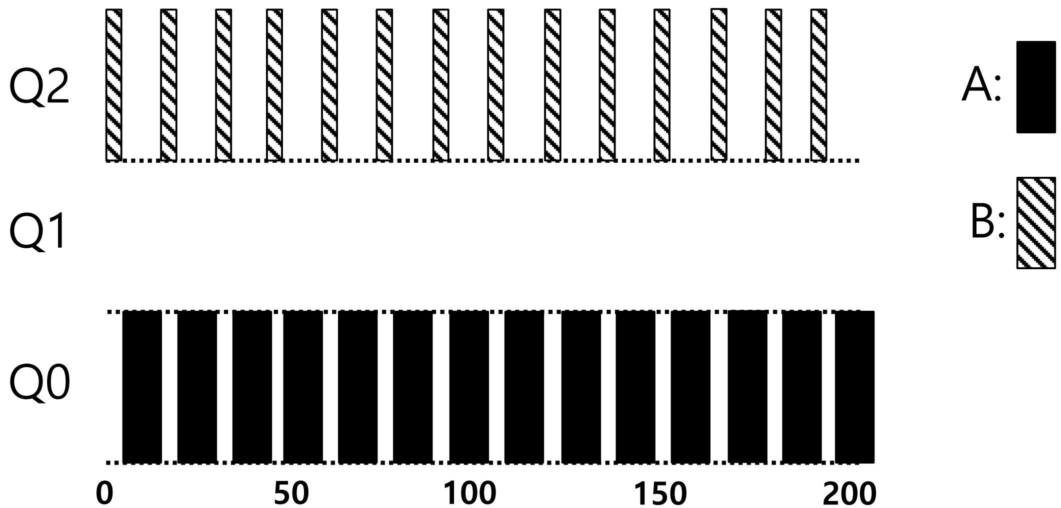
- Assumption:
  - **Job A**: A long-running CPU-intensive job
  - **Job B**: A short-running interactive job (20ms runtime)
  - A has been running for some time, and then B arrives at time T=100.



Along Came An Interactive Job (msec)

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

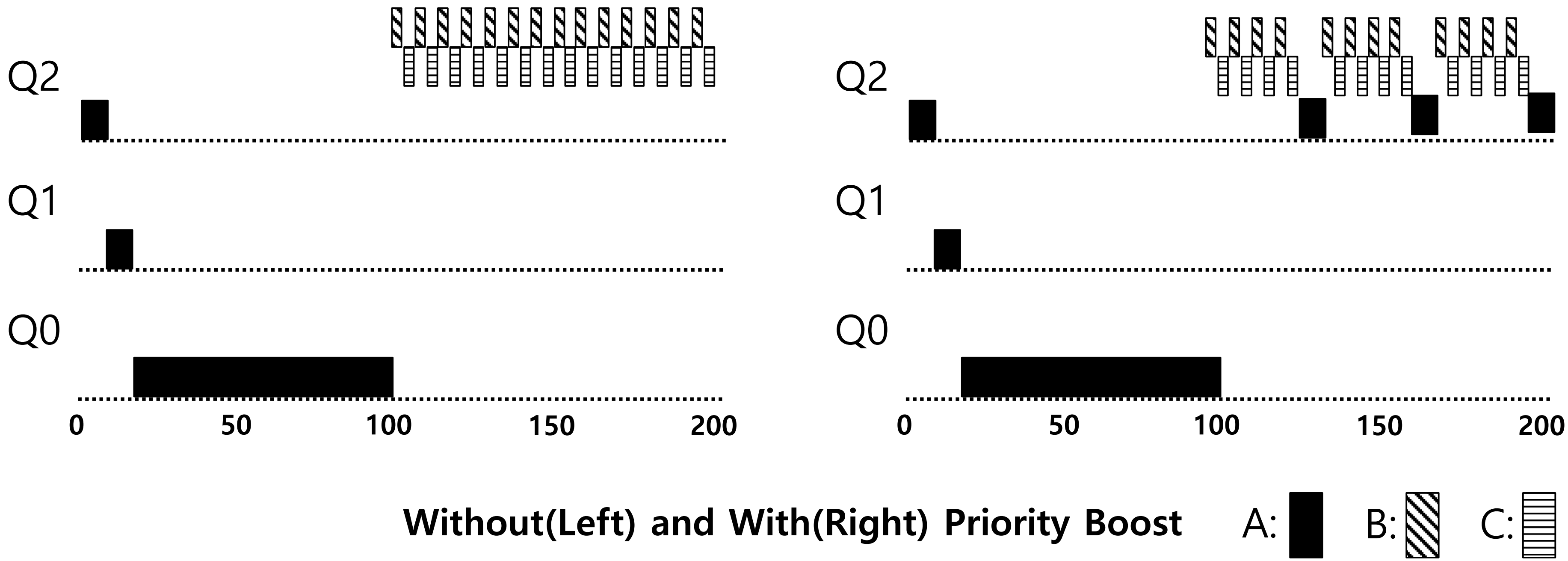
- Starvation
  - If there are “too many” interactive jobs in the system.
  - Lon-running jobs will never receive any CPU time.

- 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

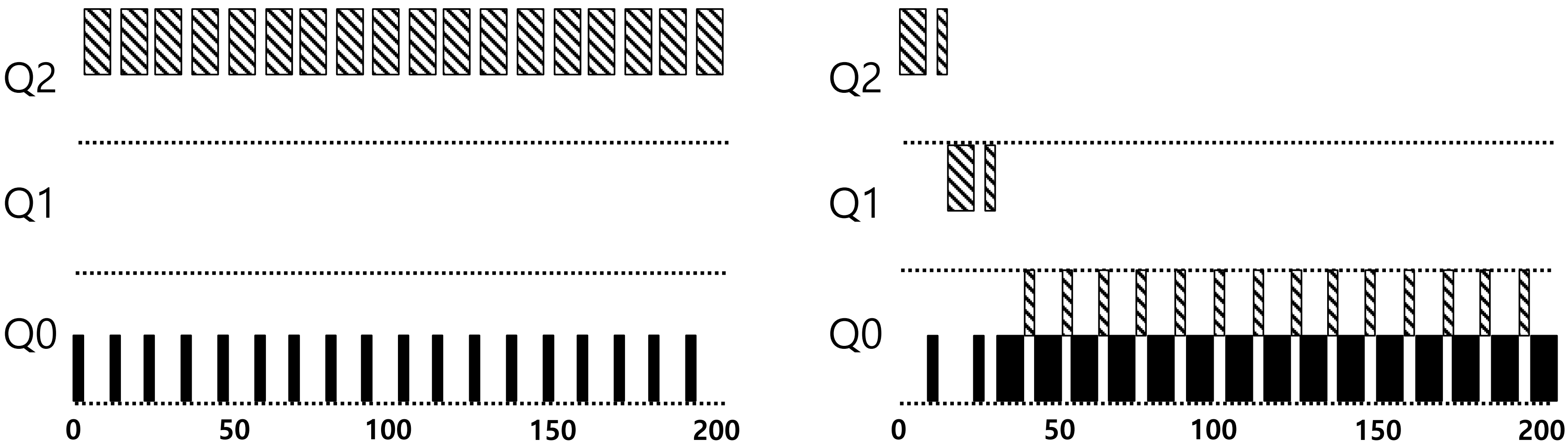
- **Rule 5:** After some time period S, move all the jobs in the system to the topmost queue.
  - Example:
    - A long-running job(A) with two short-running interactive job(B, C)



Without(Left) and With(Right) Priority Boost

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).

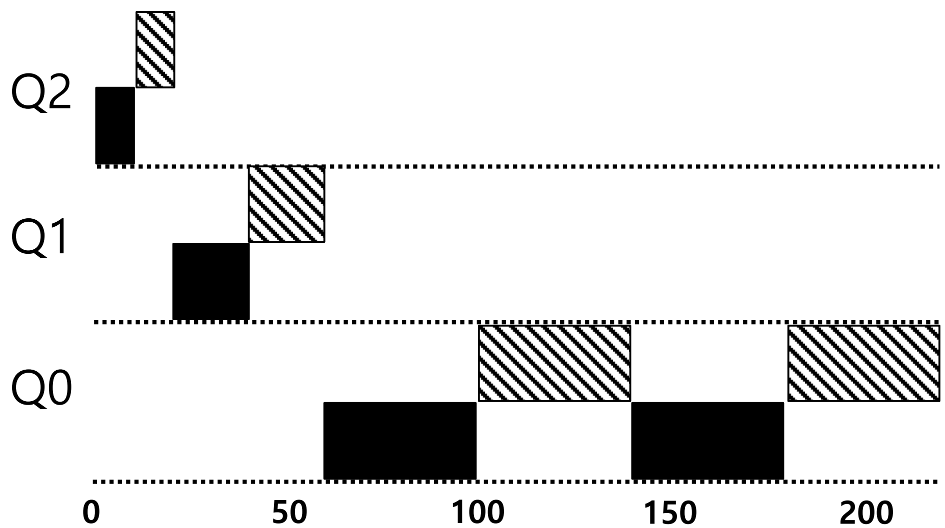


Without(Left) and With(Right) Gaming Tolerance

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.

FreeBSD Scheduler(4.3)

- MLFQ without queue.
- Instead, use formula.
- Compute the priority of a process based upon
  - How much CPU a process has used.
  - Boost priority by decay.
  - Take the advice from the user (`nice`).
- For efficiency, use queue.

MLFQ: Summary

- The refined set of MLFQ rules:
  - **Rule 1:** If Priority(A) > Priority(B), A runs (B doesn't).
  - **Rule 2:** If Priority(A) = 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.
- Beauty of MLFQ
  - It does not require prior knowledge on the CPU usage of a process.