

# CSE 323: Operating System Design

## Virtual CPU (Scheduling)

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## Lecture Topics

Scheduling has two aspects:

- 1 How to switch from one process to another?
- 2 What process should run next?

Divide-and-conquer by OS:

- Mechanism: context switch (how to switch)
- Mechanism: preemption (keeping control)
- Policy: scheduling (where to switch to)
  - [we discuss this first. . .]

This slide deck covers chapters 7–10 in OSTEP.

## What is a Scheduling *Policy*?

The context switch *mechanism* will take care of **how** the kernel switches from one process to another, namely by storing its context and restoring the context of the other process.



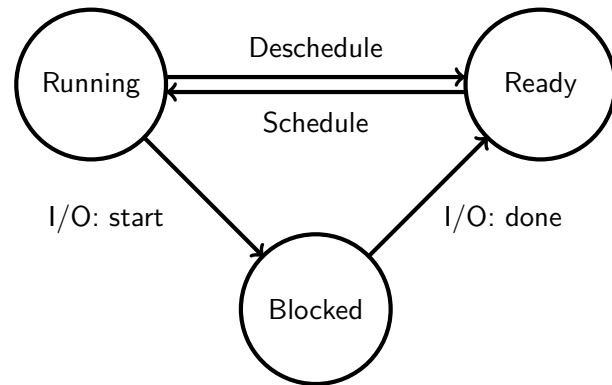
The scheduling policy determines **which** process should run next. If there is only one “ready” process then the answer is easy. If there are more processes then the policy decides in which order processes execute.

## Scheduler Metrics

When analyzing scheduler policies, we use the following terms:

Metric	Definition	Goal
<i>Utilization</i>	what fraction of time is the CPU executing a program	maximize
<i>Turnaround time</i>	total global time from process creation to process exit	minimize
<i>Response time</i>	time from becoming ready to being scheduled	minimize
<i>Fairness</i>	all processes get a fair share of CPU over time	no starvation
<i>Progress</i>	allow processes to make forward progress	minimize kernel interrupts

## Reminder: Process States



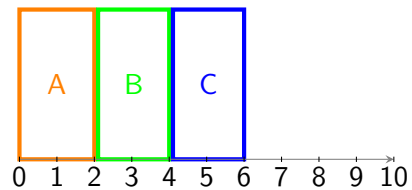
## Scheduling Assumptions

Let's understand scheduler policies step by step. We start with some simplifying assumptions

- Each job runs for the same amount of time
- All jobs arrive at the same time
- All jobs only use the CPU (no I/O)
- Run-time of jobs is known
- For now, we assume a single CPU

## First In, First Out (FIFO)

- Tasks A, B, C of len=2 arrive at T=0 (0,2)
- Average turnaround
  - $(2+4+6)/3 = 4$
- Average response
  - $(0+2+4)/3 = 2$



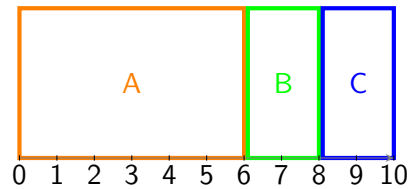
Finding: easy, simple, straight forward. What are drawbacks?

## Scheduling Assumptions

- ***Each job runs for the same amount of time***
- All jobs arrive at the same time
- All jobs only use the CPU (no I/O)
- Run-time of jobs is known

## FIFO challenge: long running task

- Task A is now of len=6
- Average turnaround
  - $(6+8+10)/3 = 8$
- Average response
  - $(0+6+8)/3 = 4.7$

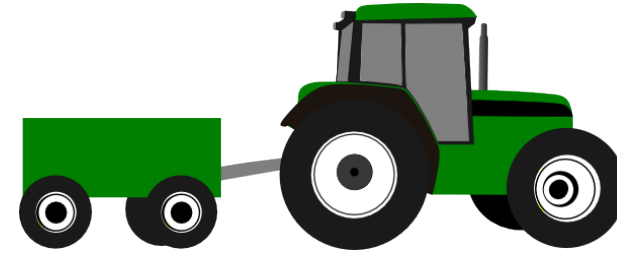


Finding: long jobs delay short jobs, turnaround/response time suffer!

## SJF: Shortest Job First

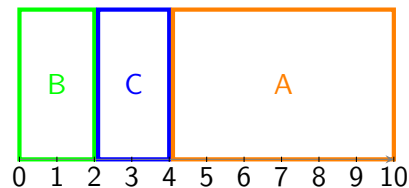
- Long running tasks delay other tasks (convoy effect: one long running task delays many short running tasks like a truck followed by many cars)
- Short jobs must wait for completion of long task

New scheduler: choose ready job with shortest runtime!



## SJF: turnaround

- Task A is now of len=6
- Average turnaround
  - $(2+4+10)/3 = 5.3$
- Average response
  - $(0+2+4)/3 = 2$

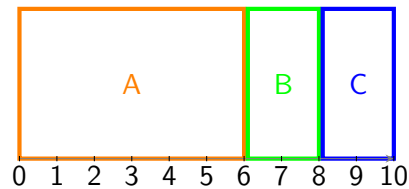


## Scheduling Assumptions

- Each job runs for the same amount of time
- **All jobs arrive at the same time**
- All jobs only use the CPU (no I/O)
- Run-time of jobs is known

## SJF: another convoy!

- Tasks B, C now arrive at 1
- Average turnaround
  - $(6+7+9)/3 = 7.3$
- Average response
  - $(0+5+7)/3 = 4$



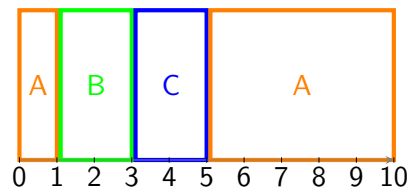
Finding: long running jobs cannot be interrupted, delay short jobs

## Preemptive Scheduling

- Previous schedulers (FIFO, SJF) are non-preemptive. Non-preemptive schedulers only switch to another process if the current process gives up the CPU voluntarily.
- Preemptive schedulers may take CPU control at any time, switching to another process according to the scheduling policy.
- New scheduler: Shortest Time to Completion First (**STCF**), always run the job that will complete the fastest.

## Preemptive Scheduling: STCF

- Tasks B, C now arrive at 1
- Average turnaround
  - $(2+4+10)/3 = 5.3$
- “First” response
  - $(0+0+2)/3 = 0.7$
  - Task A takes a break!



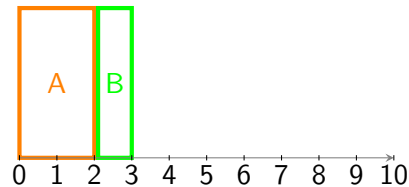
Finding: reschedule whenever new jobs arrive, prioritize short jobs

## Next Metric: Response Time

- So far, we have optimized for turnaround time (i.e., completing the tasks as fast as possible).
- On an interactive system, response time is equally important, i.e., how long it takes until a task is scheduled.

## Turnaround vs Response Time

- Tasks A (2,0) and B (1, 1)
- B turnaround: 2
- B response time: 1



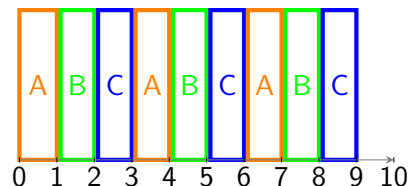
## Round Robin (RR)

- Previous schedulers optimize for turnaround.
- Optimize response time: alternate ready processes every fixed-length time slice.

## Round Robin (RR)

- Tasks A, B, C (0, 3)
- $(7+8+9)/3 = 8$  for RR
- $(3+6+9)/3 = 6$  for SJF

- Average response time
  - $(0+1+2)/3 = 1$
- Compare to FIFO where average response time is 3
- Turnaround increases



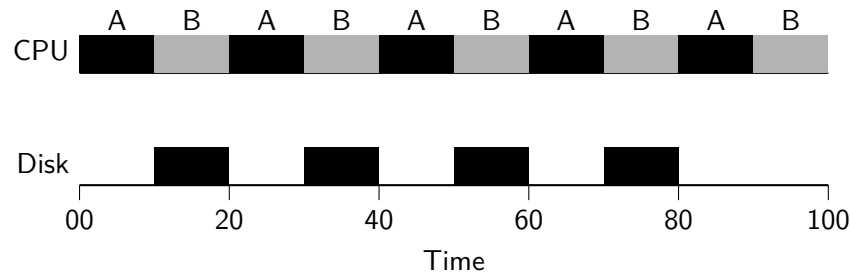
Finding: responsiveness increases turnaround (for equally long tasks)

## Scheduling Assumptions

- Each job runs for the same amount of time
- All jobs arrive at the same time
- **All jobs only use the CPU (no I/O)**
- Run-time of jobs is known

## I/O Awareness

- So far, the scheduler only considers preemptive events (i.e., the timer runs out) or process termination/creation to reschedule.
- I/O is usually incredibly slow and can be carried out asynchronously



Finding: scheduler must consider I/O, unused time used by others

## Scheduling Assumptions

- Each job runs for the same amount of time
- All jobs arrive at the same time
- All jobs only use the CPU (no I/O)
- **Run-time of jobs is known**

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## Advanced Scheduling: Multi-Level Feedback Queue (MLFQ)

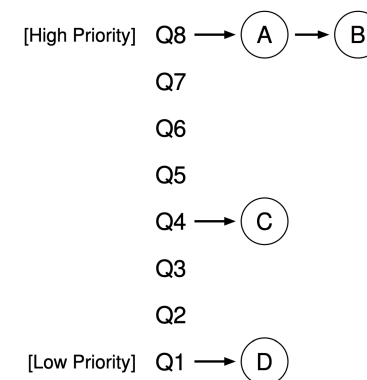
- Goal: general purpose scheduling

**Challenge:** The scheduler must support both long running background tasks (batch processes) and low latency foreground tasks (interactive processes).

- Batch process: response time not important, cares for long run times (reduce the cost of context switches, cares for lots of CPU, not when)
- Interactive process: response time critical, short bursts (context switching cost not important, not much CPU needed but frequently)

## MLFQ: Basics

**Approach:** multiple levels of round robin (one queue per level)



- Each level has higher priority and preempts all lower levels
- Process at higher level will always be scheduled first
- Set of rules adjusts priorities dynamically

- Rule 1: if  $\text{prio}(A) > \text{prio}(B)$  then A runs.
- Rule 2: if  $\text{prio}(A) == \text{prio}(B)$  then A, B run in RR.

## MLFQ: Priority Adjustments

Goal: use **past behavior** as predictor for future behavior.

- Rule 3: processes start at top priority
- Rule 4: if process uses up full time slice, lower its priority
  - keep at same level if it voluntarily yields (e.g., for I/O)

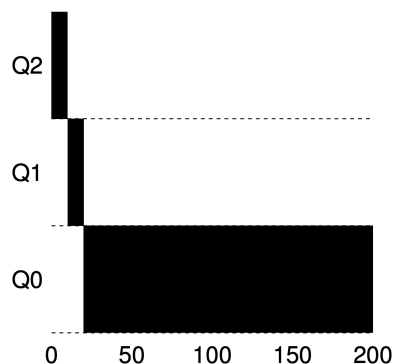


Figure 1: CPU-intensive job getting to the bottom queue over time

## MLFQ: Serving Interactive Jobs

A short or interactive job may come later. Automatically gets higher priority with Rules 3-4 in place.

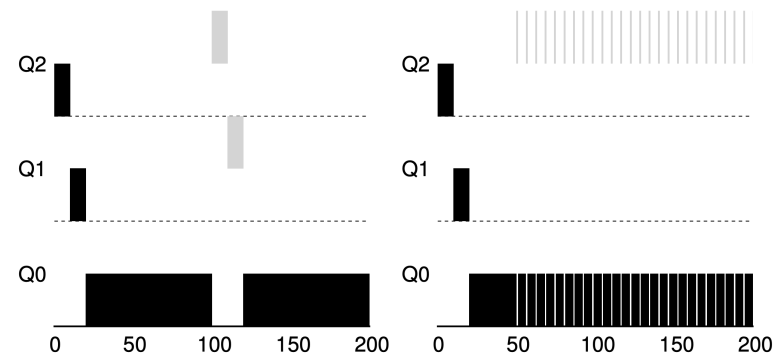


Figure 2: MLFQ Serving short or interactive jobs

All good? Do you see any problem?

## MLFQ Challenges: Starvation

Low priority (long-running) tasks may never run on a busy system.

- Rule 5: periodically move all jobs to the topmost queue

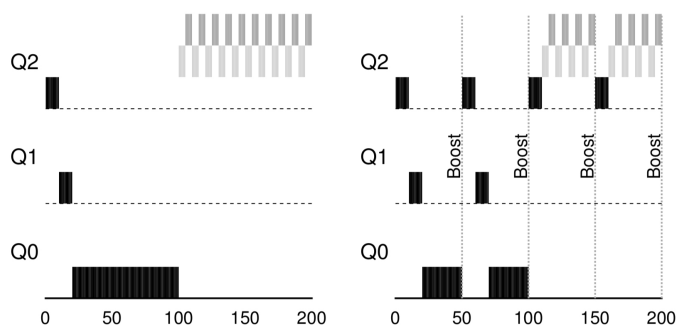


Figure 3: MLFQ prevents starvation via periodic priority boosts

## MLFQ Challenges: Gaming the Scheduler

High priority process could yield before its time slice is up, remaining at high priority.

- [Updated] Rule 4: account for total time at priority level (and not just time of the last time slice)

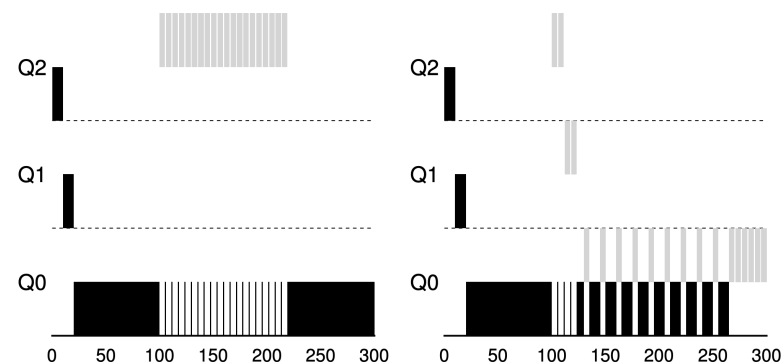


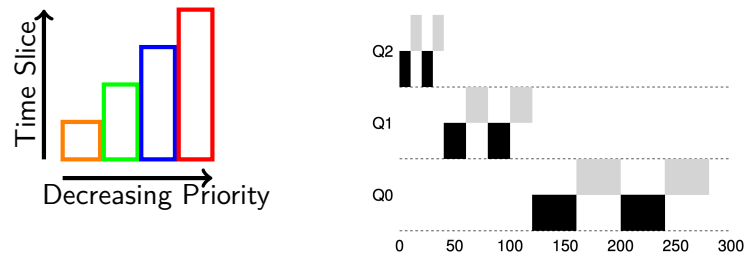
Figure 4: Impact of incorporating Gaming Tolerance

## MLFQ: Serving CPU-bound and IO-bound Processes

- Interactive Processes: require quick responses and have short CPU bursts.
- Batch Processes: can tolerate delays but need long & uninterrupted CPU time.

Remember where *context switching* can become costly?

**High levels have short time slices, lower levels run for longer**



## MLFQ Summary

- Rule 1: if  $\text{prio}(A) > \text{prio}(B)$  then A runs.
- Rule 2: if  $\text{prio}(A) == \text{prio}(B)$  A, B run in RR
- Rule 3: new processes start with top priority
- Rule 4: lower process' priority when whole time slice is used
- Rule 5: periodically move all jobs to the topmost queue

## [Self-Study] More Scheduling Algorithms

Due to time constraints, we will stop with scheduling policies here.

For interested readers, I recommend exploring the following chapters.

- **Scheduling: Proportional Share**
  - Lottery Scheduling
  - Stride Scheduling
  - Completely Fair Scheduler (CFS)
- **Multiprocessor Scheduling**
  - Single-Queue Multiprocessor Scheduling (SQMS)
  - Multi-Queue Multiprocessor Scheduling (MQMS)

## Scheduling Mechanisms

How does the kernel switch from one process to another?

- Context switch saves running process' state in kernel structure
- Context switch restores state of next process
- Context switch transfers control to next process and "returns"

How does the kernel stay in control?

- Processes may `yield()` or execute I/O
- Configurable timer interrupts let OS take control

Note: a context switch is **transparent** to the process



## Mechanism: Context Switch

A context switch is a mechanism that allows the OS to store the current process state and switch to some other, previously stored context.

Reasons for a context switch:

- The process completes/exits
- The process executes a slow H/W operation (loading from disk) and the OS switches to another task that is ready
- The hardware requires OS help and issues an interrupt
- The OS decides to preempt the task and switch to another task (i.e., the processes has used up its time slice)

## Mechanism: Preemption

If a task never gives up control (`yield()`), exits, or performs I/O then it could run forever and the OS could not gain control.

The OS therefore sets a timer before scheduling a process. If the timer expires, the hardware interrupts the execution of the process and switches to the kernel. The kernel then decides if the process may continue.

## Summary

- Context switch and preemption are fundamental mechanisms that allow the OS to remain in control and to implement higher level scheduling policies.
- Schedulers need to optimize for different metrics: utilization, turnaround, response time, fairness and forward progress
  - FIFO: simple, non-preemptive scheduler
  - SJF: non-preemptive, prevents process jams
  - STFC: preemptive, prevents jams of late processes
  - RR: preemptive, great response time, bad turnaround
  - MLFQ: preemptive, more realistic
- Insight: past behavior is good predictor for future behavior