TCSS 422: OPERATING SYSTEMS

INTRODUCTION TO CPU SCHEDULING, MULTI-LEVEL FEEDBACK QUEUE (MLFQ)

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OBJECTIVES – 4/14

- Questions from 4/9
- Active Reading Quiz – Ch. 7
- Assignment 0
- Chapter 7: Scheduling Introduction
  - Scheduling metrics
  - SJF, STCF, RR schedulers
- Chapter 8: Multi-level Feedback Queue
  - MLFQ Scheduler
  - Job Starvation
  - Gaming the Scheduler
  - Examples

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MATERIAL / PACE

- Please classify your perspective on material covered in today's class (56 respondents):
- 1-mostly review, 5-equal new/review, 10-mostly new
- **Average – 7.875 (↑ *from 7.52*)**

- Please rate the pace of today's class:
- 1-slow, 5-just right, 10-fast
- **Average – 5.93 (↑ from 5.82)**

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FEEDBACK FROM 4/9

- ***So the OS performs a context switch from the user process to the kernel process when it needs to perform a system trap?***
- It depends on the kind of trap:
- **System calls (planned)**- results from kernel API call. Context switches to kernel worker process to perform requested work which requires privileged access to the hardware
- **Interrupts (events)/Exceptions (errors)-**
- *****Key difference between interrupt handling and context switch*****
- Code executed by interrupt / exception handler is not a process
- Code is a kernel control path that runs at the expense of the same process that was running when the interrupt occurred.
- Invoking interrupt handlers is lighter weight than a context switch
- Less context; requires less time to set up and tear down.
- More similar to a function call

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FEEDBACK - 2

- ***A system trap is also when the OS needs to step in to ensure the process doesn't crash correct?***

- The trap type would likely be an "exception handler" trap.

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FEEDBACK - 3

- ***Is user mode and kernel mode a strict dichotomy? Where does super user fit into this?***

- The CPU also includes mode 1 for running code directly on the CPU from virtual machines.
  - Mode helps Virtual Machines run faster when their code can run directly on the processor without software emulation
  - Original VMs ran all code in USER MODE as they were not trusted
  - CPU extensions for virtualization have helped by allowing untrusted instructions from VMs to be trapped and replaced
- Super user is the root user in Linux that has default permission to read/write/execute all files, configure user accounts, groups, install software and more
  - Super user is essentially a built-in administrator account

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FEEDBACK - 4

- ***I'm unsure about the difference between turnaround time versus execution time***
- **Turnaround time**: also known as the wall-clock or watch time
- This is the time that transpires from the users perspective from when an task is started until it completes
- This is the "real" value output from the Linux "time" command
- **Execution time**: also known as CPU time
- The time the task actually runs actively on the CPU.
- Add the "user" plus "sys" from the Linux "time" command
- Indicates time the CPU spent in user vs. kernel (sys) mode

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FEEDBACK - 5

- ***We covered chapter 4, 5, and 6 last week.***
- ***I would like to read the book chapters too, but is it enough to just watch the lectures and read the powerpoints?***
- It is recommended to read ***all*** of the chapters we cover in class
- They are relatively short and go quickly
- This is especially important if the content is new to you
- Obtaining the information multiple times, in multiple ways may help with retention
- This question is a perfect segue to …

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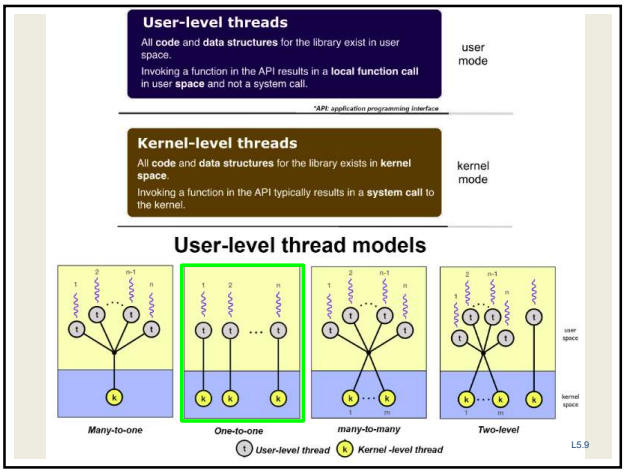

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  - Job Starvation
  - Gaming the Scheduler
  - Examples

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"QUIZ" 0 – C PROGRAMMING BACKGROUND SURVEY

- Original submission moved to "Ungraded Surveys"
- New Placeholder records points for Quiz 0 under: Assignments → Tutorials/Quizzes/In-class Activities
- Scores posted

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CHAPTER 7- SCHEDULING: INTRODUCTION

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SCHEDULING METRICS

- **Metrics**: A standard measure to quantify to what degree a system possesses some property. Metrics provide *repeatable* techniques to quantify and compare systems.
- **Measurements** are the numbers derived from the application of metrics

- Scheduling Metric #1: **Turnaround time**
- The time at which the job completes minus the time at which the job arrived in the system

$$T_{turnaround} = T_{completion} - T_{arrival}$$

- How is turnaround time different than execution time?

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SCHEDULING METRICS - 2

- Scheduling Metric #2: **Fairness**
  - Jain's fairness index
  - Quantifies if jobs receive a fair share of system resources

$$\mathcal{J}(x_1, x_2, \ldots, x_n) = \frac{(\sum_{i=1}^{n} x_i)^2}{n \cdot \sum_{i=1}^{n} x_i^2}$$

- n processes
- x_i is time share of each process
- worst case = 1/n
- best case = 1

- Consider n=3, worst case = .333, best case=1
- With n=3 and x_1=.2, x_2=.7, x_3=.1, fairness=.62
- With n=3 and x_1=.33, x_2=.33, x_3=.33, fairness=1

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SCHEDULING METRICS - 3

- Scheduling Metric #3: **Response Time**
- Time from when job arrives until it starts execution

$$T_{response} = T_{firstrun} - T_{arrival}$$

- STCF, SJF, FIFO
  - can perform poorly with respect to response time

What scheduling algorithm(s) can help minimize response time?

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RR: ROUND ROBIN

- Run each job awhile, then switch to another distributing the CPU evenly (fairly)
- Scheduling Quantum is called a time slice
- Time
  a mu
  time
  period.

Process	Burst Time
P1	12

RR is fair, but performs poorly on metrics such as turnaround time

Round Robin scheduling algorithm Gantt chart

Scheduling Quantum = 5 seconds

P1	P2	P3	P4	P5	P1	P2	P4	P1
0	5	10	14	19	24	29	32	37	39

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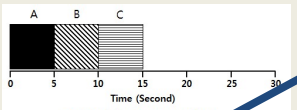
RR EXAMPLE

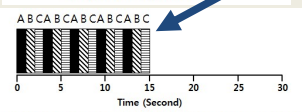
- ABC arrive at time=0, each run for 5 seconds



SJF (Bad for Response Time)

OVERHEAD not considered

$$T_{average\ response} = \frac{0+5+10}{3} = 5sec$$



RR with a time-slice of 1sec (Good for Response Time)

$$T_{average\ response} = \frac{0+1+2}{3} = 1sec$$

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ROUND ROBIN: TRADEOFFS

Short Time Slice	Long Time Slice
Fast Response Time	Slow Response Time
High overhead from context switching	Low overhead from context switching

- Time slice impact:
  - Turnaround time (for earlier example): ts(1,2,3,4,5)=14,14,13,14,10
  - Fairness: round robin is always fair, J=1

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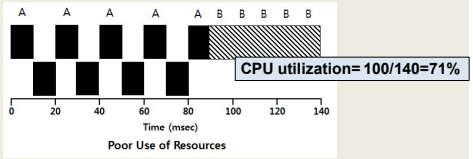
SCHEDULING WITH I/O

- STCF scheduler
  - A: CPU=50ms, I/O=40ms, 10ms intervals
  - B: CPU=50ms, I/O=0ms
  - Consider A as 10ms subjobs (CPU, then I/O)
- Without considering I/O:



Poor Use of Resources

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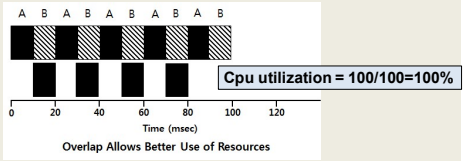
SCHEDULING WITH I/O - 2

- When a job initiates an I/O request
  - A is blocked, waits for I/O to compute, frees CPU
  - STCF scheduler assigns B to CPU
- When I/O completes → raise interrupt
  - Unblock A, STCF goes back to executing A: (10ms sub-job)



Overlap Allows Better Use of Resources

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Which scheduler, thus far, best address fairness and average response time of jobs?

Respond at **PollEv.com/wesleylloyd641**

Text **WESLEYLLOYD641** to **22333** once to join, then **1, 2, 3, 4, 5...**

First In - First Out (FIFO)	1
Shortest Job First (SJF)	2
Shortest Time to Completion First (STCF)	3
Round Robin	4
None of the Above	5
All of the Above	6

Start the presentation to see live content. Still no live content? Install the app or get help at PollEv.com/app

Total Results

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QUESTION: SCHEDULING FAIRNESS

- Which scheduler, this far, best addresses fairness and average response time of jobs?
- First In – First Out (FIFO)
- Shortest Job First (SJF)
- Shortest Time to Completion First (STCF)
- Round Robin (RR)
- None of the Above
- All of the Above

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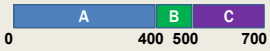
SCHEDULING METRICS

- Consider Three jobs (A, B, C) that require: $time_A$=400ms, $time_B$=100ms, and $time_C$=200ms
- All jobs arrive at time=0 in the sequence of A B C.
- Draw a scheduling graph to help compute the **average response time (ART)** and **average turnaround time (ATT)** scheduling metrics for the FIFO scheduler.

Example:



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What is the Average Response Time of the FIFO scheduler?

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What is the Average Turnaround Time of the FIFO scheduler?

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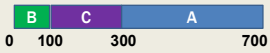
SCHEDULING METRICS

- Consider Three jobs (A, B, C) that require: $time_A$=400ms, $time_B$=100ms, and $time_C$=200ms
- All jobs arrive at time=0 in the sequence of A B C.
- Draw a scheduling graph to help compute the **average response time (ART)** and **average turnaround time (ATT)** scheduling metrics for the SJF scheduler.

Example:



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What is the Average Response Time of the Shortest Job First Scheduler?

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What is the Average Turnaround Time of the Shortest Job First Scheduler?

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TCSS 422 WILL RETURN AT ~2:45PM

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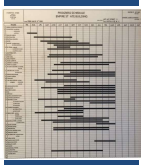
CHAPTER 8 – MULTI-LEVEL FEEDBACK QUEUE (MLFQ) SCHEDULER



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MULTI-LEVEL FEEDBACK QUEUE

- Objectives:
  - Improve turnaround time:
    Run shorter jobs first
  - Minimize response time:
    Important for interactive jobs (UI)
- Achieve without a priori knowledge of job length

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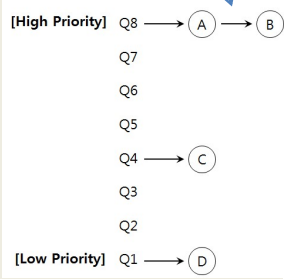
MLFQ - 2

Round-Robin within a Queue

- Multiple job queues
- Adjust job priority based on observed behavior
- Interactive Jobs
  - Frequent I/O → keep priority high
  - Interactive jobs require fast response time (GUI/UI)
- Batch Jobs
  - Require long periods of CPU utilization
  - Keep priority low



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MLFQ: DETERMINING JOB PRIORITY

- New arriving jobs are placed into highest priority queue
- If a job uses its entire time slice, priority is reduced (↓)
  - Jobs appears CPU-bound ("batch" job), not interactive (GUI/UI)
- If a job relinquishes the CPU for I/O priority stays the same

MLFQ approximates SJF

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MLFQ: LONG RUNNING JOB

- Three-queue scheduler, time slice=10ms

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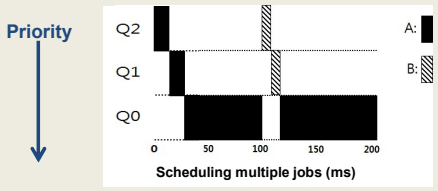
MLFQ: BATCH AND INTERACTIVE JOBS

- $A_{arrival\_time}$=0ms, A_{run_time}=200ms,
- B_{run_time} =20ms, $B_{arrival\_time}$ =100ms



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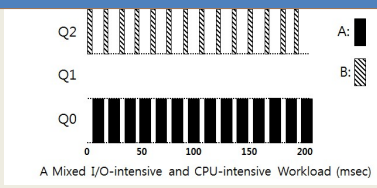
MLFQ: BATCH AND INTERACTIVE - 2

- Continuous interactive job (B) with long running batch job (A)
  - Low response time is good for B
  - A continues to make progress

The MLFQ approach keeps interactive job(s) at the highest priority



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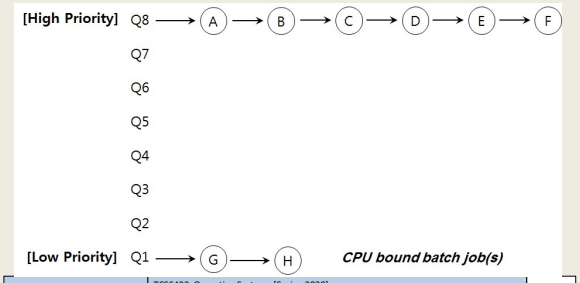
MLFQ: ISSUES

- Starvation



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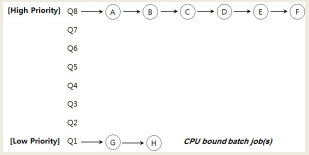
MLFQ: ISSUES - 2

- Gaming the scheduler
  - Issue I/O operation at 99% completion of the time slice
  - Keeps job priority fixed – never lowered
- Job behavioral change
  - CPU/batch process becomes an interactive process



Priority becomes stuck

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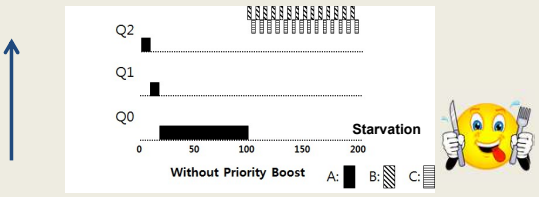
RESPONDING TO BEHAVIOR CHANGE



- Priority Boost
  - Reset all jobs to topmost queue after some time interval S

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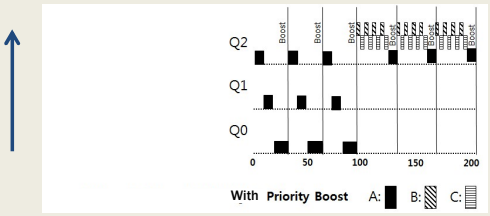
RESPONDING TO BEHAVIOR CHANGE - 2

- With priority boost
  - Prevents starvation



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KEY TO UNDERSTANDING MLFQ – PB

- Without priority boost:
- **Rule 1:** If Priority(A) > Priority(B), A runs (B doesn't).
- **Rule 2:** If Priority(A) = Priority(B), A & B run in RR.
- **KEY:** If time quantum of a higher queue is filled, then we don't run any jobs in lower priority queues!!!

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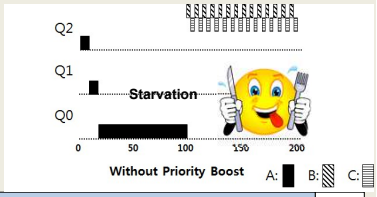
STARVATION EXAMPLE

- **Consider 3 queues:**
- Q2 – HIGH PRIORITY – Time Quantum 10ms
- Q1 – MEDIUM PRIORITY – Time Quantum 20 ms
- Q0 – LOW PRIORITY – Time Quantum 40 ms
- Job A: 200ms no I/O
- Job B: 5ms then I/O
- Job C: 5ms then I/O
- Q2 fills up, starves Q1 & Q0
- A makes no progress



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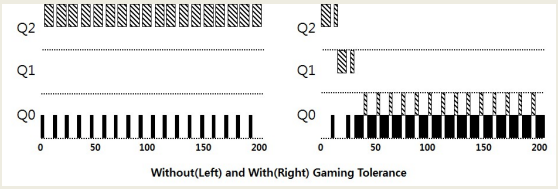
PREVENTING GAMING

- Improved time accounting:
  - Track total job execution time in the queue
  - Each job receives a fixed time allotment
  - When allotment is exhausted, job priority is lowered



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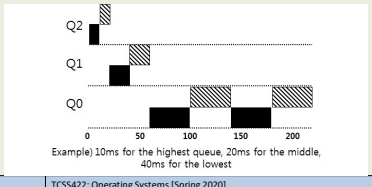
MLFQ: TUNING

- Consider the tradeoffs:
  - How many queues?
  - What is a good time slice?
  - How often should we "Boost" priority of jobs?
  - What about different time slices to different queues?



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PRACTICAL EXAMPLE

- Oracle Solaris MLFQ implementation
  - 60 Queues → w/ slowly increasing time slice (high to low priority)
  - Provides sys admins with set of editable table(s)
  - Supports adjusting time slices, boost intervals, priority changes, etc.
- Advice
  - Provide OS with hints about the process
  - Nice command → Linux

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MLFQ RULE 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.

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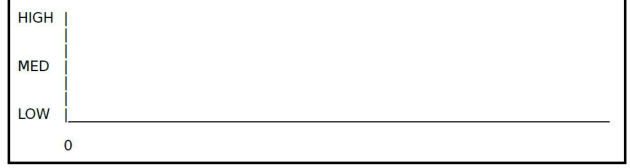
Jackson deploys a 3-level MLFQ scheduler. The time slice is 1 for high priority jobs, 2 for medium priority, and 4 for low priority. This MLFQ scheduler performs a Priority Boost every 6 timer units. When the priority boost fires, the current job is preempted, and the next scheduled job is run in round-robin order.

Job	Arrival Time	Job Length
A	T=0	4
B	T=0	16
C	T=0	8

(11 points) Show a scheduling graph for the MLFQ scheduler for the jobs above.
Draw vertical lines for key events and be sure to label the X-axis times as in the example.
Please draw clearly. An unreadable graph will loose points.



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EXAMPLE

- Question:
- Given a system with a quantum length of 10 ms in its highest queue, how often would you have to boost jobs back to the highest priority level to guarantee that a single long-running (and potentially starving) job gets at least 5% of the CPU?
- Some combination of n short jobs runs for a total of 10 ms per cycle without relinquishing the CPU
  - E.g. 2 jobs = 5 ms ea; 3 jobs = 3.33 ms ea, 10 jobs = 1 ms ea
  - n jobs always uses full time quantum (10 ms)
  - Batch jobs starts, runs for full quantum of 10ms
  - All other jobs run and context switch totaling the quantum per cycle
  - If 10ms is 5% of the CPU, when must the priority boost be ???
  - **ANSWER** → ***Priority boost should occur every 200ms***

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QUESTIONS

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WILL RETURN IN A FEW MINUTES

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