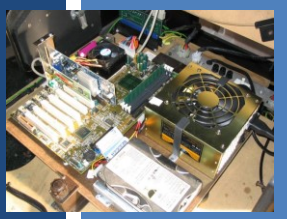
TCSS 422: OPERATING SYSTEMS



Introduction to OS Schedulers

Wes J. Lloyd
School of Engineering and Technology
University of Washington - Tacoma

1

TEXT BOOK COUPON

- 10% off textbook code: **WRITING10** (*through Friday Apr 18*)
- https://www.lulu.com/shop/andrea-arpaci-dusseau-and-remzi-arpaci-dusseau/operating-systems-three-easy-pieces-hardcover-version-110/hardcover/product-15gjeeky.html?q=three+easy+pieces+operating+systems&page=1&pageSize=4
- With coupon textbook is only $35.78 + tax & shipping

2

TCSS 422 – OFFICE HRS – SPRING 2025

- Office Hours plan for Spring (by Zoom):
- Monday 11:30am - 12:30p GTA Xinghan
- Tuesday 11:30am - 12:30p GTA Xinghan
- Wednesday 11:00am - 12:00p Instructor Wes
- Friday 12:00pm - 1:00p Wes or Xinghan

- Office hours this Friday April 18th
  - Xinghan

- Instructor is available after class at 6pm in CP 229 each day

3

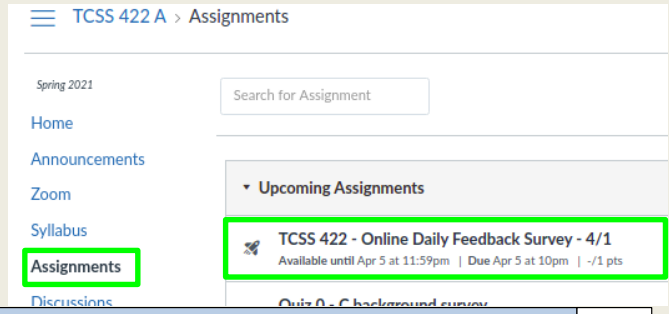
OBJECTIVES – 4/15

- Questions from 4/10
- Assignment 0
- C Tutorial - Pointers, Strings, Exec in C
- Chapter 6: Limited Direct Execution
- Chapter 7: Scheduling Introduction
  - Scheduling metrics
    - Turnaround time, Jain's Fairness Index, Response time
  - FIFO, SJF, STCF, RR schedulers
- Chapter 8: Multi-level Feedback Queue
  - MLFQ Scheduler
  - Job Starvation
  - Gaming the Scheduler
  - Examples

4

ONLINE DAILY FEEDBACK SURVEY

- Daily Feedback Quiz in Canvas – Available After Each Class
- Extra credit available for completing surveys ***ON TIME***
- Tuesday surveys: due by ~ Wed @ 11:59p
- Thursday surveys: due ~ Mon @ 11:59p



5

TCSS 422 - Online Daily Feedback Survey - 4/1

Quiz Instructions

Question 1 0.5 pts

On a scale of 1 to 10, please classify your perspective on material covered in today's class:

1	2	3	4	5	6	7	8	9	10
Mostly Review To Me				Equal New and Review					Mostly New to Me

Question 2 0.5 pts

Please rate the pace of today's class:

1	2	3	4	5	6	7	8	9	10
Slow				Just Right					Fast

6

MATERIAL / PACE

- Please classify your perspective on material covered in today's class (48 of 63 respondents – 76.2%) :
- 1-mostly review, 5-equal new/review, 10-mostly new
- **Average – 6.47 (↓ - previous 6.64)**

- Please rate the pace of today's class:
- 1-slow, 5-just right, 10-fast
- **Average – 4.83 (↓ - previous 5.29)**

7

FEEDBACK FROM 4/10

- ***How does the kernel keep track of process/PID pairs?***
- > what is the Linux kernel data structure that is used to describe a process ?

8

FEEDBACK - 2

- ***Can you explain how the path works in detail?***
- ***I understand that the path is where a program will look and that it is a collection of folders, but how is this actually stored?***
- The PATH is an environment variable
- It is persistent for the lifetime of the shell
- BASH shell inherits the default system path from:
  - `/etc/environment`
- In your local bash resource file, you can modify the path var
  - `~/.bashrc`
  - "`~/`" is an alias for your home directory
  - `cd ~/` goes home…
- Append to path:
  - `export PATH=$PATH:/monkeys`

9

FEEDBACK - 3

- ***How will the quizzes and midterm exam be structured? What type of questions can we expect on those assessments?***
- Poll EV questions provide samples
- Practice Quizzes (as Activities in Canvas) from examples
- Look for various sample problems starting in Chapter 7

10

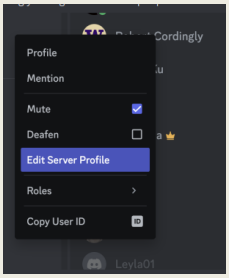
FEEDBACK FROM 4/4

- ***Wait function parameter being null is still a bit unclear***
- There are two variants for the wait() API
- wait(), and waitpid()
  - See 'man 2 wait' for manual page
- wait() takes an optional integer as a 'flag'
- These flags provide instructions for how the API should behave
- If NULL, then there is no special behavior
- The manual page details specific behavior for various constants:
- **WIFEXITED** – return true if child terminated normally
- **WEXITSTATUS** – return exit status of child
- **WIFSIGNALED** – returns true if child process terminated by signal

11

TCSS 422 DISCORD SERVER

- Please join the TCSS 422 A – Spring 2025 Discord Server
- https://discord.gg/H7PPZ5ArFW
- Under Edit Server Profile:
  Please update your 'Server Nickname'
  to your real name or UW NET ID
  THANK YOU



12

OBJECTIVES – 4/15

- Questions from 4/10
- **Assignment 0**
- C Tutorial - Pointers, Strings, Exec in C
- Chapter 6: Limited Direct Execution
- Chapter 7: Scheduling Introduction
  - Scheduling metrics
    - Turnaround time, Jain's Fairness Index, Response time
  - FIFO, SJF, STCF, RR schedulers
- Chapter 8: Multi-level Feedback Queue
  - MLFQ Scheduler
  - Job Starvation
  - Gaming the Scheduler
  - Examples

13

TCSS 422 – SET VMS

- School of Engineering and Technology hosted Ubuntu 24.04 VMs for TCSS 422 – Spring 2025 are created
- The VMs are on the UW Tacoma private network
- The instructor has requested instructions for off-campus access (i.e. VPN setup, etc.)

14

OBJECTIVES – 4/15

- Questions from 4/10
- Assignment 0
- **C Tutorial - Pointers, Strings, Exec in C**
- Chapter 6: Limited Direct Execution
- Chapter 7: Scheduling Introduction
  - Scheduling metrics
    - Turnaround time, Jain's Fairness Index, Response time
  - FIFO, SJF, STCF, RR schedulers
- Chapter 8: Multi-level Feedback Queue
  - MLFQ Scheduler
  - Job Starvation
  - Gaming the Scheduler
  - Examples

15

FINISH CHAPTER 5

- Switch to Lecture 4 Slides
- Slides L4.34 to L4.59 (thru system calls and traps)

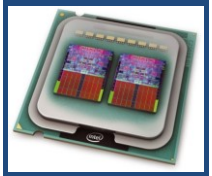
16

OBJECTIVES – 4/15

- Questions from 4/10
- Assignment 0
- C Tutorial - Pointers, Strings, Exec in C
- **Chapter 6: Limited Direct Execution**
- Chapter 7: Scheduling Introduction
  - Scheduling metrics
    - Turnaround time, Jain's Fairness Index, Response time
  - FIFO, SJF, STCF, RR schedulers
- Chapter 8: Multi-level Feedback Queue
  - MLFQ Scheduler
  - Job Starvation
  - Gaming the Scheduler
  - Examples

17

CH. 6: LIMITED DIRECT EXECUTION



18

CHAPTER 6

- Chapter 6: Limited Direct Execution
  - Direct execution
  - Limited direct execution
  - CPU modes
  - System calls and traps
  - **Cooperative multi-tasking**
  - Context switching and preemptive multi-tasking

19

MULTITASKING

- How/when should the OS regain control of the CPU to switch between processes?
- Cooperative multitasking (mostly pre 32-bit)
  - < Windows 95, Mac OSX
  - Opportunistic: running programs must give up control
    - User programs must call a special **yield** system call
    - When performing I/O
    - Illegal operations
  - (POLLEV)
    What problems could you for see with this approach?

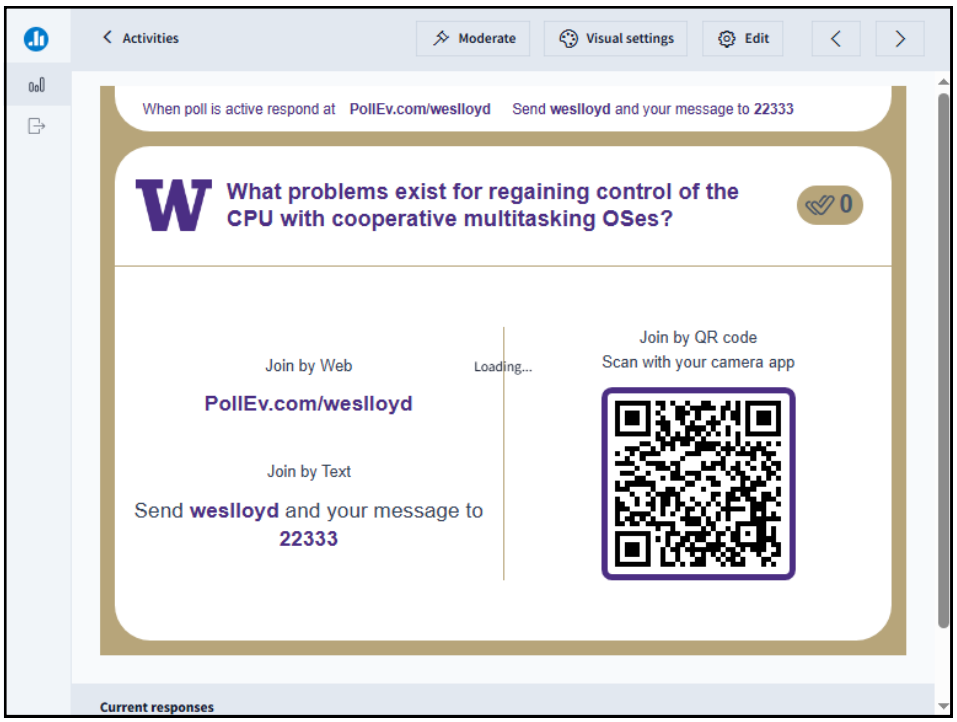
20

MULTITASKING

- How/when should the OS regain control of the CPU to switch between processes?
- Cooperative multitasking (mostly pre-32 bit)
  - <
  - Op
    - When performing I/O
    - Illegal operations
  - (POLLEV)
    What problems could you for see with this approach?

A process gets stuck in an infinite loop.
→ **Reboot the machine**

21



22

QUESTION: MULTITASKING

- What problems exist for regaining the control of the CPU with cooperative multitasking OSes?

23

MULTITASKING - 2

- Preemptive multitasking (32 & 64 bit OSes)
- >= Mac OSX, Windows 95+

- Timer interrupt
  - Raised at some regular interval (in ms)
  - Interrupt handling
    1. Current program is halted
    2. Program states are saved
    3. OS Interrupt handler is run (kernel mode)

- (PollEV) What is a good interval for the timer interrupt?

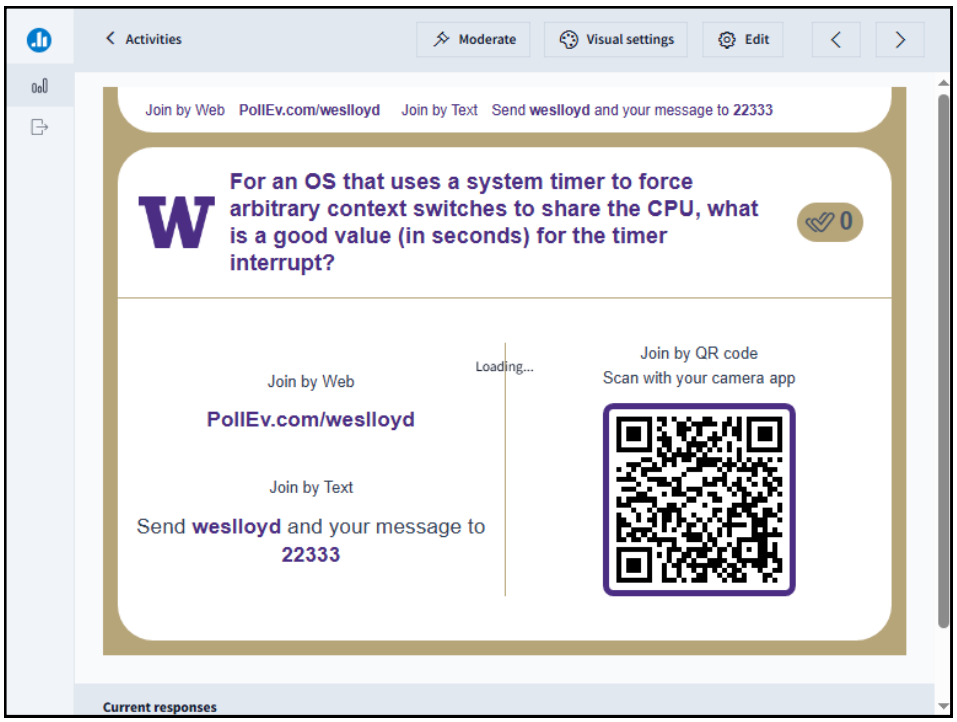
24

MULTITASKING - 2

- Preemptive multitasking (32 & 64 bit OSes)
- >= Mac OSX, Windows 95+
- Timer
  - Rais
  - Inte
    1. Current program is halted
    2. Program states are saved
    3. OS Interrupt handler is run (kernel mode)
- (PollEV) What is a good interval for the timer interrupt?

A timer interrupt gives OS the ability to run again on a CPU.

25



26

QUESTION: TIME SLICE

- For an OS that uses a system timer to force arbitrary context switches to share the CPU, what is a good value (in seconds) for the timer interrupt?

27

QUESTION: TIME SLICE

- For an OS that uses a system timer to force arbitrary context switches to share the CPU, what is a good value (in seconds) for the timer interrupt?
  - Typical time slice for process execution is **10 to 100 milliseconds**
  - Typical context switch overhead is (*switch between processes*) **0.01 milliseconds**
    - 0.1% of the time slice (1/1000th)

28

CHAPTER 6

- Chapter 6: Limited Direct Execution
  - Direct execution
  - Limited direct execution
  - CPU modes
  - System calls and traps
  - Cooperative multi-tasking
  - **Context switching and preemptive multi-tasking**

29

CONTEXT SWITCH

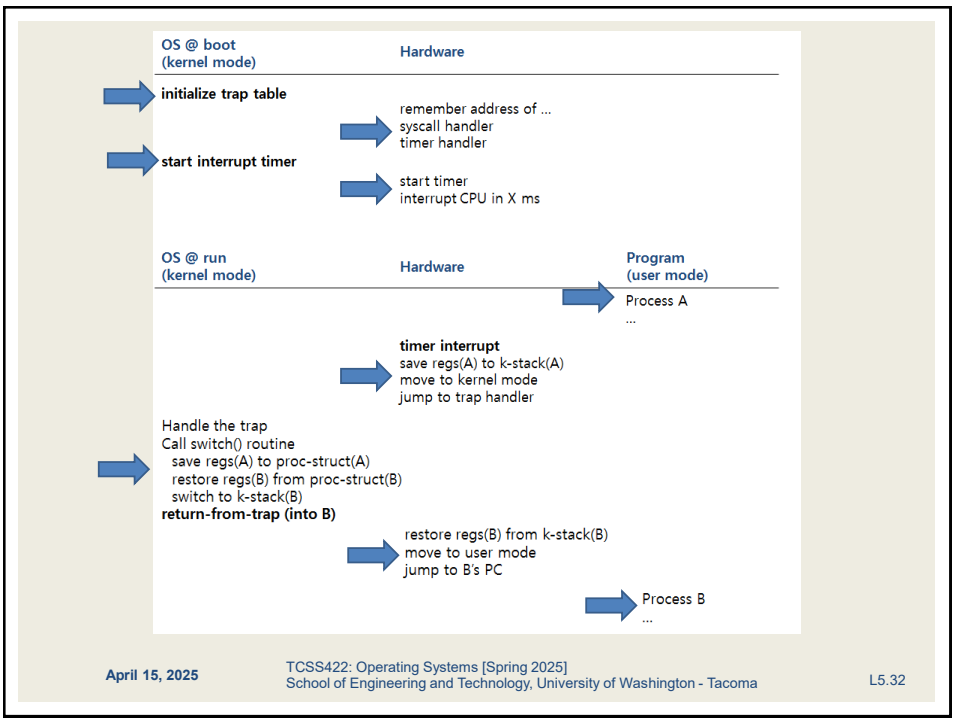
- Preemptive multitasking initiates "trap" into the OS code to determine:
  - Whether to continue running the **current process**, or switch to a **different one**.
  - If the decision is made to switch, the OS performs a context switch swapping out the current process for a new one.

30

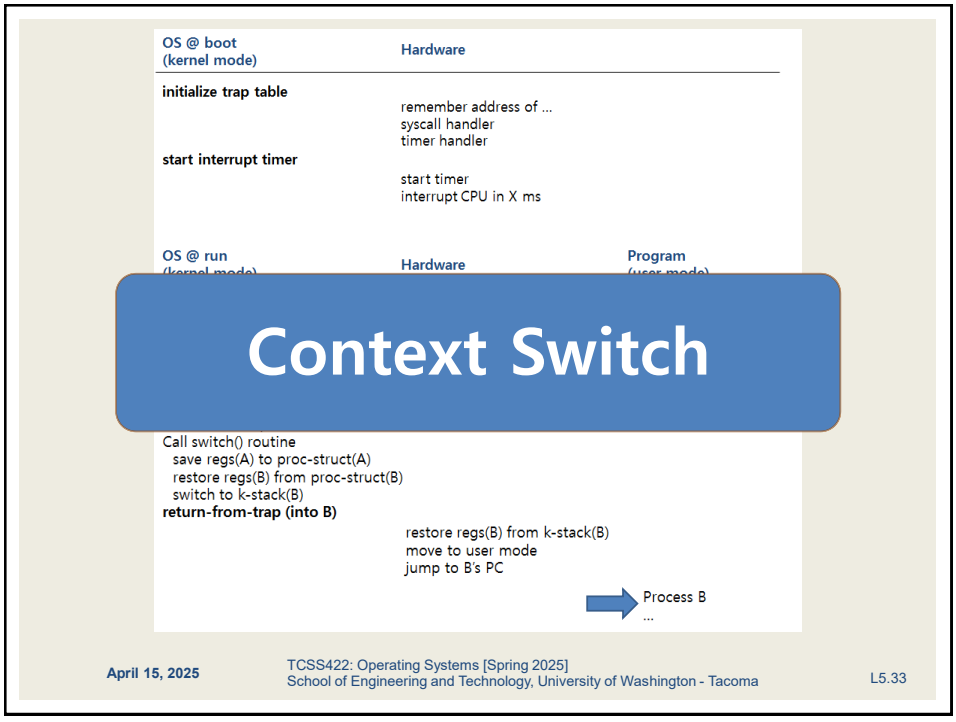
CONTEXT SWITCH - 2

1. Save register values of the current process to its kernel stack
   - General purpose registers
   - PC: program counter (instruction pointer)
   - kernel stack pointer
2. Restore soon-to-be-executing process from its kernel stack
3. Switch to the kernel stack for the soon-to-be-executing process

31



32



33

INTERRUPTED INTERRUPTS

- What happens if during an interrupt (trap to kernel mode), another interrupt occurs?
- Linux
  - < 2.6 kernel: non-preemptive kernel
  - >= 2.6 kernel: preemptive kernel

34

PREEMPTIVE KERNEL

- Use "locks" as markers of regions of non-preemptibility (non-maskable interrupt)
- Preemption counter (`preempt_count`)
  - begins at zero
  - increments for each lock acquired (not safe to preempt)
  - decrements when locks are released
- Interrupt can be interrupted when `preempt_count=0`
  - It is safe to preempt (maskable interrupt)
  - the interrupt is more important

35

OBJECTIVES – 4/15

- Questions from 4/10
- Assignment 0
- C Tutorial - Pointers, Strings, Exec in C
- Chapter 6: Limited Direct Execution
- **Chapter 7: Scheduling Introduction**
  - **Scheduling metrics**
    - **Turnaround time, Jain's Fairness Index**, Response time
  - FIFO, SJF, STCF, RR schedulers
- Chapter 8: Multi-level Feedback Queue
  - MLFQ Scheduler
  - Job Starvation
  - Gaming the Scheduler
  - Examples

36

CHAPTER 7- SCHEDULING: INTRODUCTION

37

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?

38

WE WILL RETURN AT ~4:55PM

39

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

40

With n=3 and x_1=.2, x_2=.7, x_3=.1

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

41

With n=3 and x_1=.2, x_2=.7, x_3=.1

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

$$\frac{(.2+.7+.1)^2}{3 \cdot \left[(.2)^2 + (.7)^2 + (.1)^2\right]} = \frac{1}{1.62} = .617$$

$\frac{1}{3}$ TO 1

$3 \cdot (.04 + .49 + .01)$

$3 \cdot (.54)$

1.62

42

With n=3 and x_1=.33, x_2=.33, x_3=.33

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

43

With n=3 and x_1=.33, x_2=.33, x_3=.33

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

$\frac{.33 + .33 + .33}{3 \cdot (.33)^2 + (.33)^2 + (.33)^2} \rightarrow \frac{1}{.9801} \rightarrow 1$

$3 \cdot (.1089 + .1089 + .1089)$

$3 \cdot (.3267)$

$3 \cdot ((.333)^2 + \ldots\ldots)$

$.9801$

$.998001$

$\frac{1}{.998} \rightarrow 1.002$

44

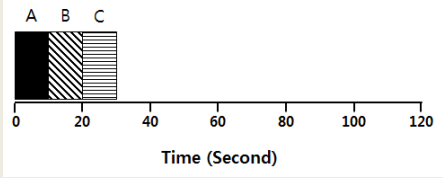
OBJECTIVES – 4/15

- Questions from 4/10
- Assignment 0
- C Tutorial - Pointers, Strings, Exec in C
- Chapter 6: Limited Direct Execution
- Chapter 7: Scheduling Introduction
  - Scheduling metrics
    - Turnaround time, Jain's Fairness Index, Response time
  - FIFO, SJF, STCF, RR schedulers
- Chapter 8: Multi-level Feedback Queue
  - MLFQ Scheduler
  - Job Starvation
  - Gaming the Scheduler
  - Examples

45

SCHEDULERS

- FIFO: first in, first out
  - Very simple, easy to implement
- Consider
  - 3 x 10sec jobs, arrival: A B C, duration 10 sec each



$$Average\ turnaround\ time = \frac{10 + 20 + 30}{3} = 20\ sec$$

46

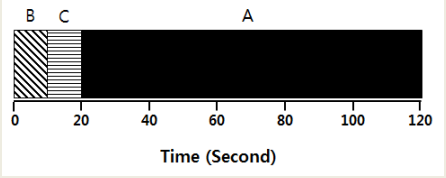
OBJECTIVES – 4/15

- Questions from 4/10
- Assignment 0
- C Tutorial - Pointers, Strings, Exec in C
- Chapter 6: Limited Direct Execution
- Chapter 7: Scheduling Introduction
  - Scheduling metrics
    - Turnaround time, Jain's Fairness Index, Response time
  - FIFO, SJF, STCF, RR schedulers
- Chapter 8: Multi-level Feedback Queue
  - MLFQ Scheduler
  - Job Starvation
  - Gaming the Scheduler
  - Examples

47

SJF: SHORTEST JOB FIRST

- Given that we know execution times in advance:
  - Run in order of duration, shortest to longest
  - Non preemptive scheduler
  - This is not realistic
  - Arrival: A B C, duration a=100 sec, b/c=10sec

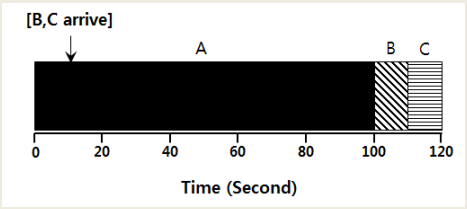


$$Average\ turnaround\ time = \frac{10 + 20 + 120}{3} = 50\ sec$$

48

SJF: WITH RANDOM ARRIVAL

- If jobs arrive at any time: duration a=100s, b/c=10s
- A @ t=0sec, B @ t=10sec, C @ t=10sec



$$Average\ turnaround\ time = \frac{100 + (110 - 10) + (120 - 10)}{3} = 103.33\ sec$$

49

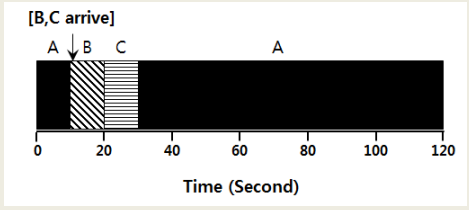
OBJECTIVES – 4/15

- Questions from 4/10
- Assignment 0
- C Tutorial - Pointers, Strings, Exec in C
- Chapter 6: Limited Direct Execution
- Chapter 7: Scheduling Introduction
  - Scheduling metrics
    - Turnaround time, Jain's Fairness Index, Response time
  - FIFO, SJF, STCF, RR schedulers
- Chapter 8: Multi-level Feedback Queue
  - MLFQ Scheduler
  - Job Starvation
  - Gaming the Scheduler
  - Examples

50

STCF: SHORTEST TIME TO COMPLETION FIRST

- Consider: duration a=100sec, b/c=10sec
  - A_{len}=100 $A_{arrival}$=0
  - B_{len}=10, $B_{arrival}$=10, C_{len}=10, $C_{arrival}$=10



$$Average\ turnaround\ time = \frac{(120-0)+(20-10)+(30-10)}{3} = 50\ sec$$

51

OBJECTIVES – 4/15

- Questions from 4/10
- Assignment 0
- C Tutorial - Pointers, Strings, Exec in C
- Chapter 6: Limited Direct Execution
- **Chapter 7: Scheduling Introduction**
  - **Scheduling metrics**
    - Turnaround time, Jain's Fairness Index, **Response time**
  - FIFO, SJF, STCF, RR schedulers
- Chapter 8: Multi-level Feedback Queue
  - MLFQ Scheduler
  - Job Starvation
  - Gaming the Scheduler
  - Examples

52

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?

53

OBJECTIVES – 4/15

- Questions from 4/10
- Assignment 0
- C Tutorial - Pointers, Strings, Exec in C
- Chapter 6: Limited Direct Execution
- Chapter 7: Scheduling Introduction
  - Scheduling metrics
    - Turnaround time, Jain's Fairness Index, Response time
  - FIFO, SJF, STCF, RR schedulers
- Chapter 8: Multi-level Feedback Queue
  - MLFQ Scheduler
  - Job Starvation
  - Gaming the Scheduler
  - Examples

54

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.

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

Process	Burst Time
P1	12

Round Robin scheduling algorithm Gantt chart

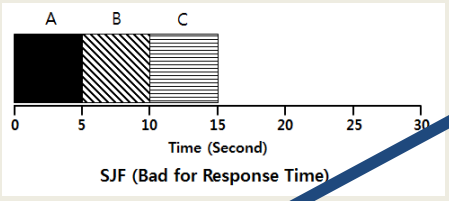
Scheduling Quantum = 5 seconds

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

55

RR EXAMPLE

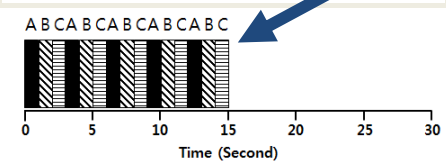
- ABC arrive at time=0, each run for 5 seconds



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)

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

56

ROUND ROBIN: TRADEOFFS

Short Time Slice

Fast Response Time

High overhead from context switching

Long Time Slice

Slow Response Time

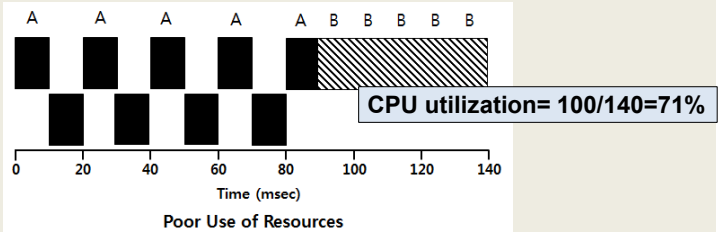
Low overhead from context switching

- 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

57

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:

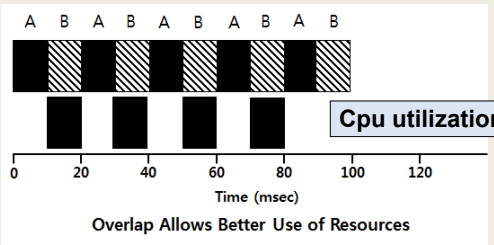


Poor Use of Resources

58

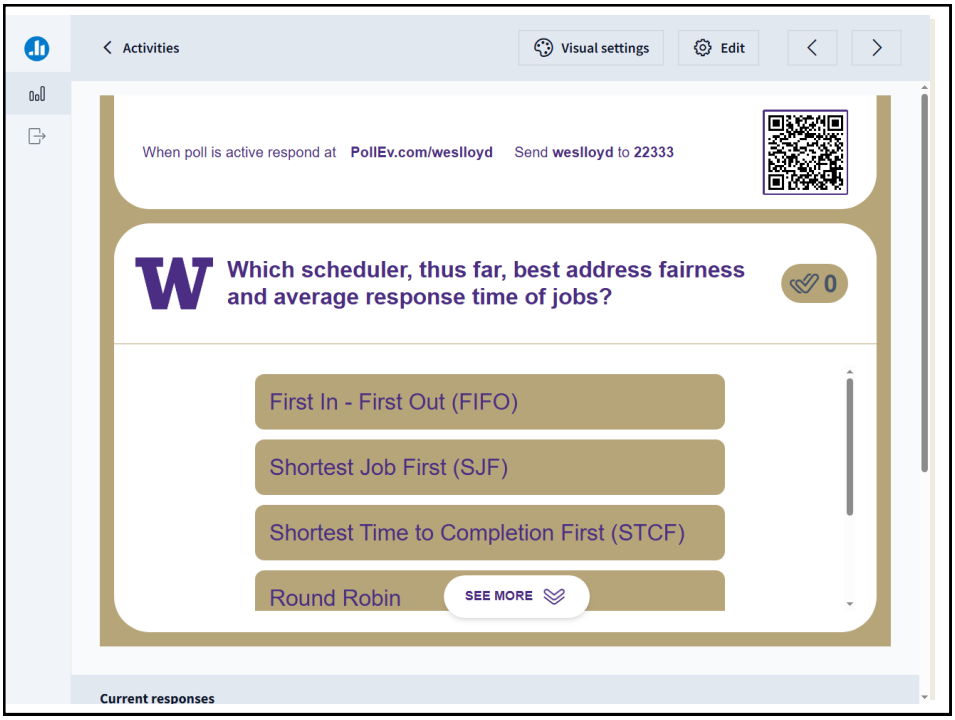
SCHEDULING WITH I/O - 2

- 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

59



60

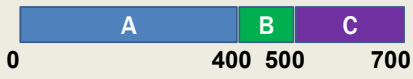
QUESTION: SCHEDULING FAIRNESS

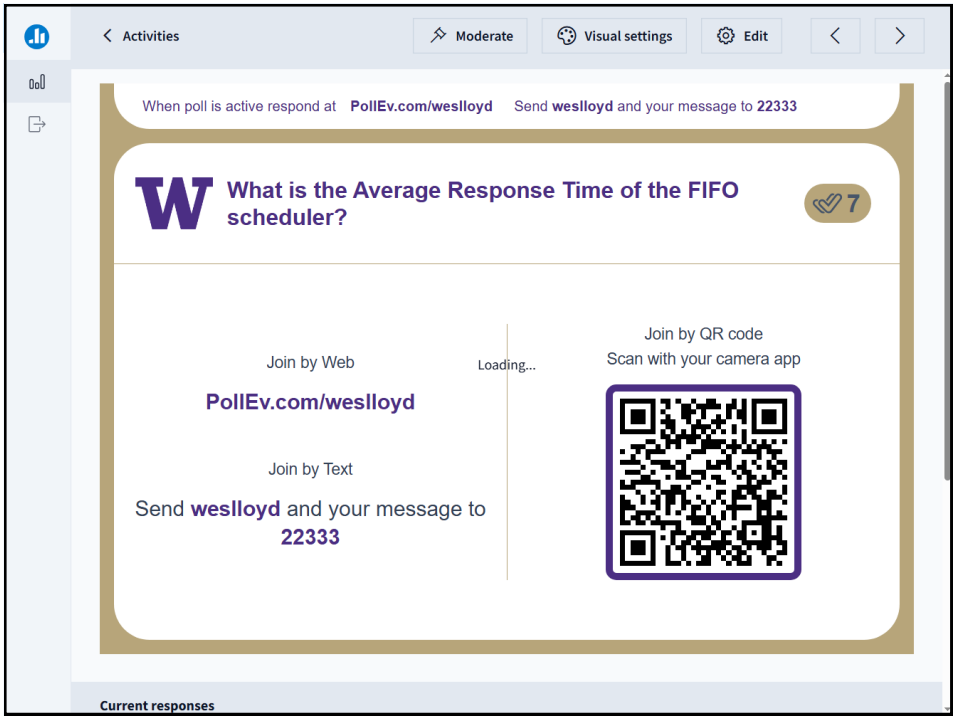
- Which scheduler, this far, best addresses fairness and average response time of jobs?
- First In – First Out (FIFO)
- Shortest Job First (SJF)
- Shortest Time to Completion First (STCF)
- Round Robin (RR)
- None of the Above
- All of the Above

SCHEDULING METRICS

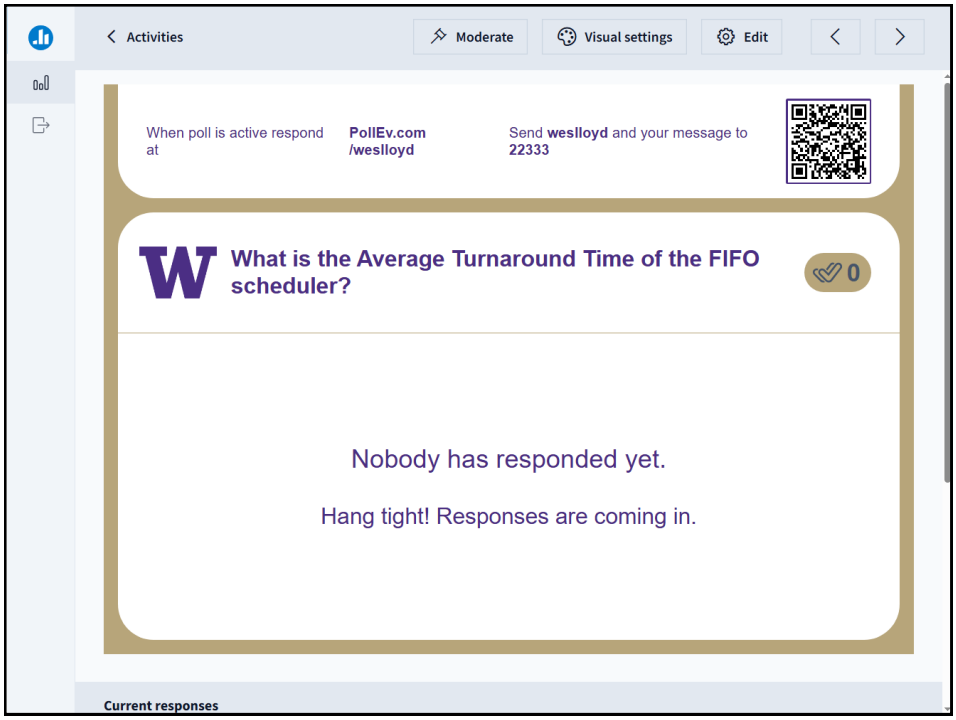
- Consider Three jobs (A, B, C) that require: $time_A$=400ms, $time_B$=100ms, and $time_C$=200ms
- All jobs arrive at time=0 in the sequence of A B C.
- Draw a scheduling graph to help compute the **average response time (ART)** and **average turnaround time (ATT)** scheduling metrics for the FIFO scheduler.

Example:




Activities
Moderate
Visual settings
Edit
When poll is active respond at PollEv.com/weslloyd Send weslloyd and your message to 22333
What is the Average Response Time of the FIFO scheduler?
7
Join by Web
PollEv.com/weslloyd
Join by Text
Send weslloyd and your message to 22333
Loading...
Join by QR code
Scan with your camera app
Current responses

63

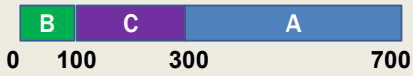

Activities
Moderate
Visual settings
Edit
When poll is active respond at PollEv.com /weslloyd
Send weslloyd and your message to 22333
What is the Average Turnaround Time of the FIFO scheduler?
0
Nobody has responded yet.
Hang tight! Responses are coming in.
Current responses

64

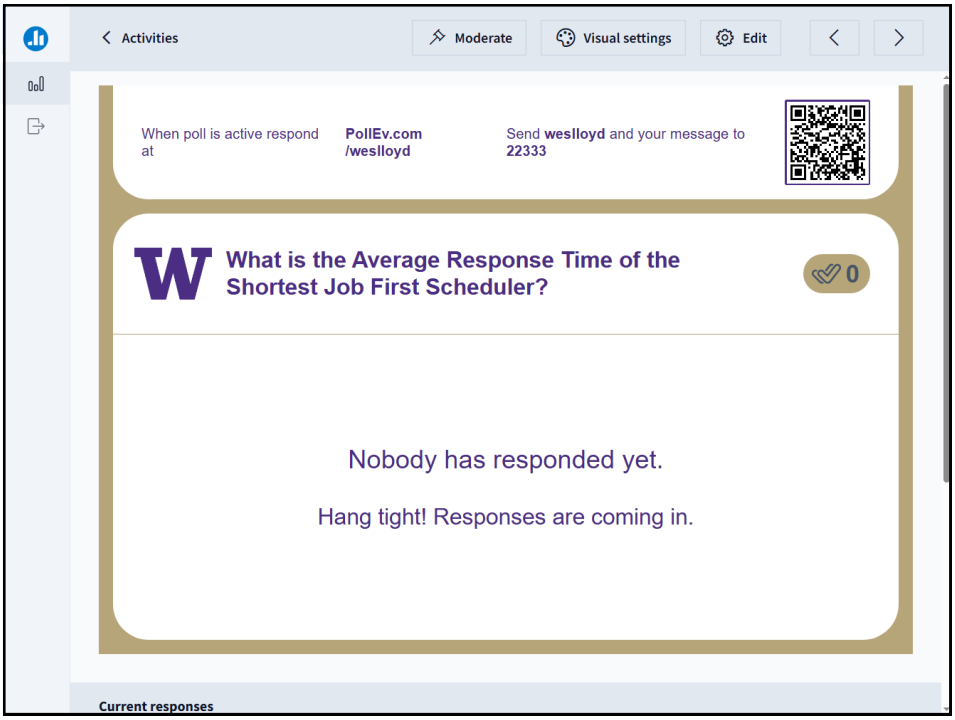
SCHEDULING METRICS

- 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.

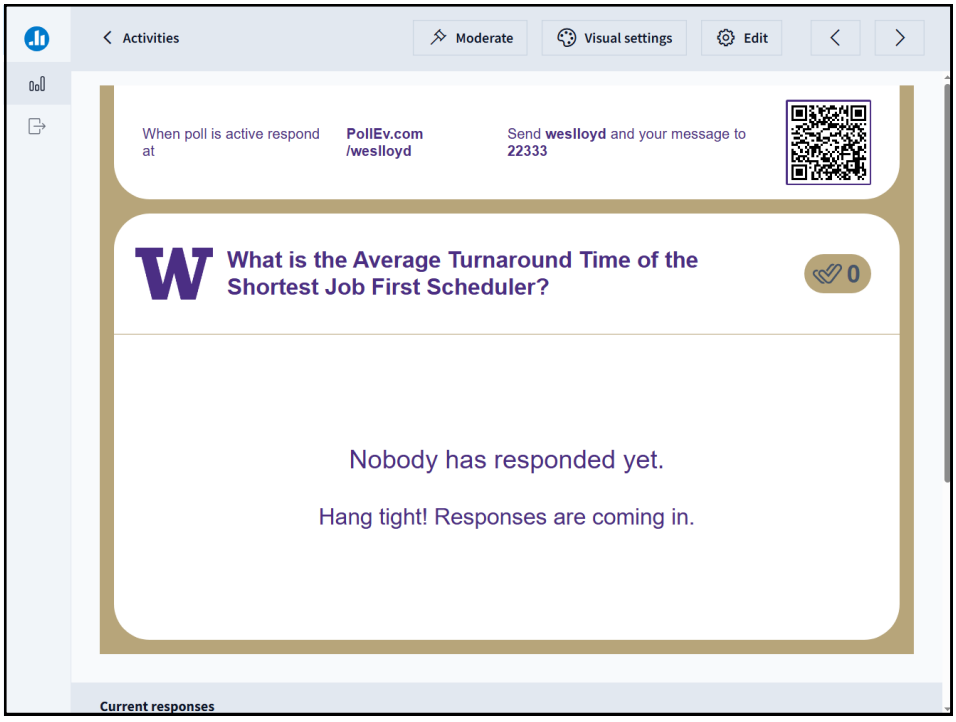
Example:



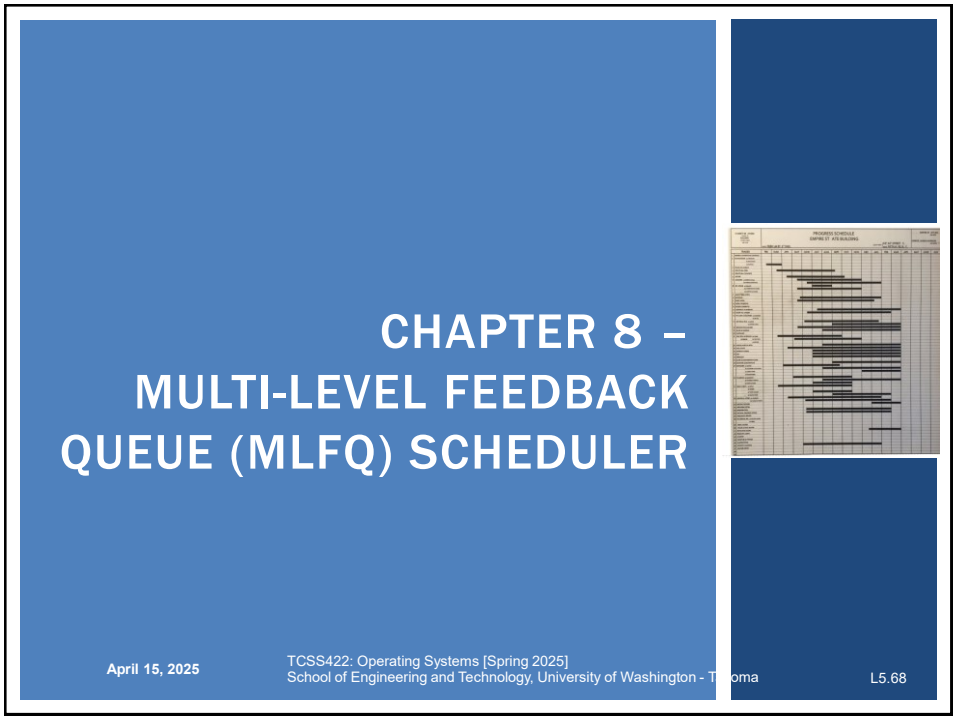
65



66


Activities
Moderate
Visual settings
Edit
When poll is active respond at
PollEv.com /weslloyd
Send weslloyd and your message to 22333
What is the Average Turnaround Time of the Shortest Job First Scheduler?
0
Nobody has responded yet.
Hang tight! Responses are coming in.
Current responses

67


CHAPTER 8 – MULTI-LEVEL FEEDBACK QUEUE (MLFQ) SCHEDULER
April 15, 2025
TCSS422: Operating Systems [Spring 2025]
School of Engineering and Technology, University of Washington - Tacoma
L5.68

68

OBJECTIVES – 4/15

- Questions from 4/10
- Assignment 0
- C Tutorial - Pointers, Strings, Exec in C
- Chapter 6: Limited Direct Execution
- Chapter 7: Scheduling Introduction
  - Scheduling metrics
    - Turnaround time, Jain's Fairness Index, Response time
  - FIFO, SJF, STCF, RR schedulers
- Chapter 8: Multi-level Feedback Queue
  - **MLFQ Scheduler**
  - Job Starvation
  - Gaming the Scheduler
  - Examples

69

MULTI-LEVEL FEEDBACK QUEUE

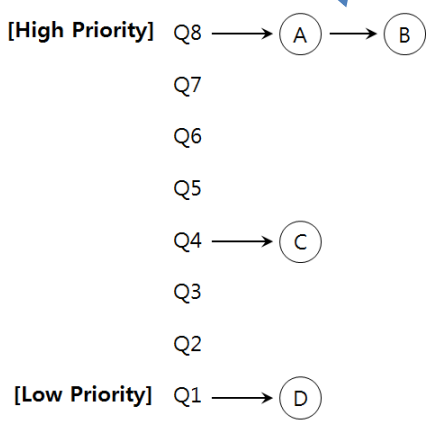
- Objectives:
  - Improve turnaround time:
    Run shorter jobs first
  - Minimize response time:
    Important for interactive jobs (UI)
- Achieve without a priori knowledge of job length

70

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



71

MLFQ: DETERMINING JOB PRIORITY

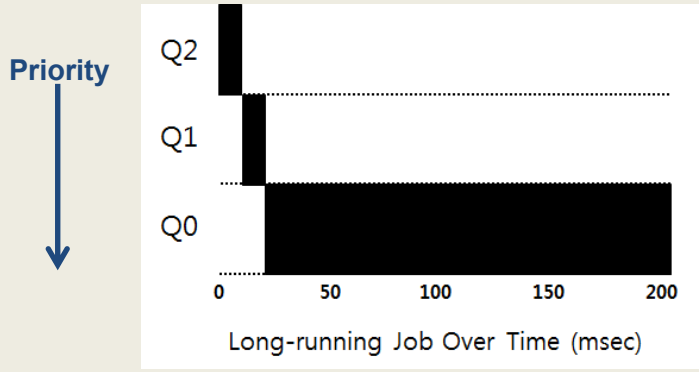
- New arriving jobs are placed into highest priority queue
- If a job uses its entire time slice, priority is reduced (↓)
  - Jobs appears CPU-bound ("batch" job), not interactive (GUI/UI)
- If a job relinquishes the CPU for I/O priority stays the same

MLFQ approximates SJF

72

MLFQ: LONG RUNNING JOB

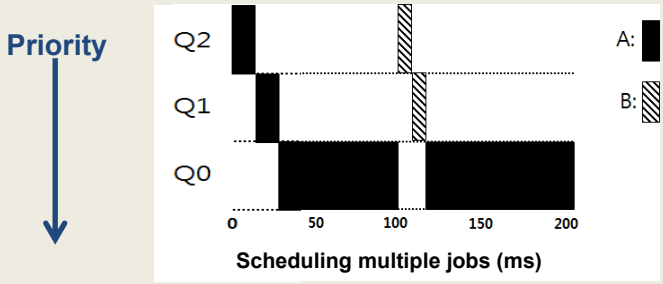
- Three-queue scheduler, time slice=10ms



73

MLFQ: BATCH AND INTERACTIVE JOBS

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

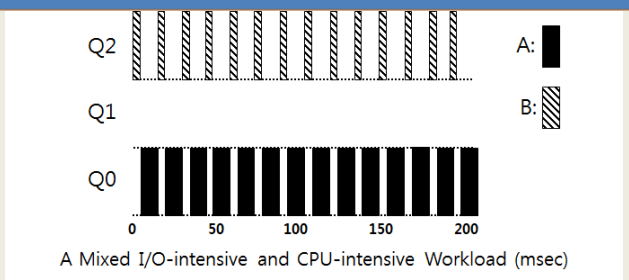


74

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



75

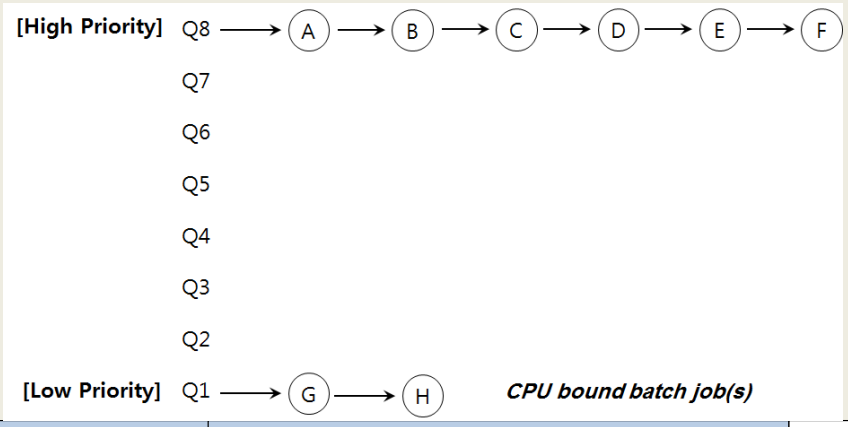
OBJECTIVES – 4/15

- Questions from 4/10
- Assignment 0
- C Tutorial - Pointers, Strings, Exec in C
- Chapter 6: Limited Direct Execution
- Chapter 7: Scheduling Introduction
  - Scheduling metrics
    - Turnaround time, Jain's Fairness Index, Response time
  - FIFO, SJF, STCF, **RR** schedulers
- Chapter 8: Multi-level Feedback Queue
  - MLFQ Scheduler
  - **Job Starvation**
  - Gaming the Scheduler
  - Examples

76

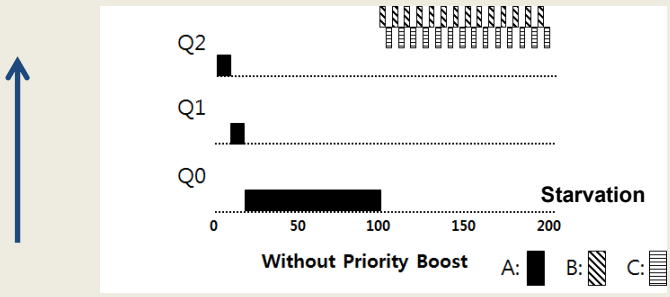
MLFQ: ISSUES

- Starvation



77

RESPONDING TO BEHAVIOR CHANGE

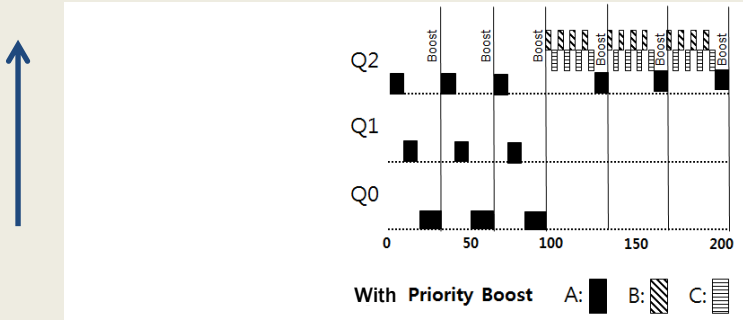


- Priority Boost
  - Reset all jobs to topmost queue after some time interval S

78

RESPONDING TO BEHAVIOR CHANGE - 2

- With priority boost
  - Prevents starvation



79

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.

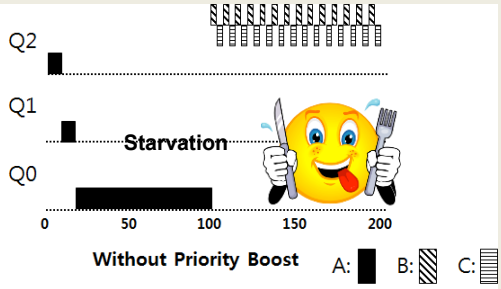
- **KEY**: If time quantum of a higher queue is filled, then we don't run any jobs in lower priority queues!!!

80

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



81

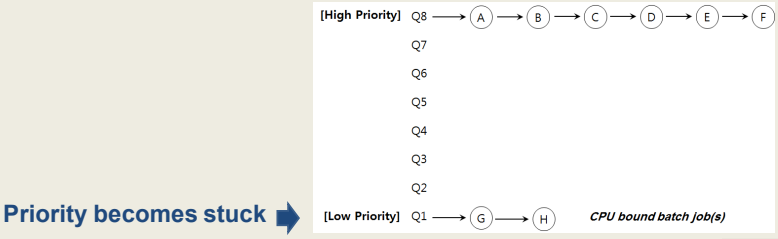
OBJECTIVES – 4/15

- Questions from 4/10
- Assignment 0
- C Tutorial - Pointers, Strings, Exec in C
- Chapter 6: Limited Direct Execution
- Chapter 7: Scheduling Introduction
  - Scheduling metrics
    - Turnaround time, Jain's Fairness Index, Response time
  - FIFO, SJF, STCF, **RR** schedulers
- Chapter 8: Multi-level Feedback Queue
  - MLFQ Scheduler
  - Job Starvation
  - **Gaming the Scheduler**
  - Examples

82

MLFQ: ISSUES - 2

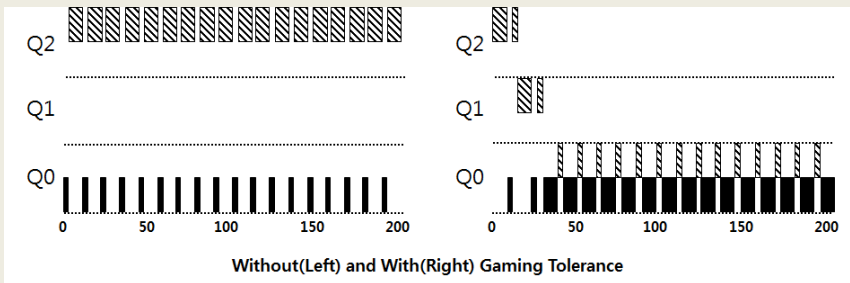
- Gaming the scheduler
  - Issue I/O operation at 99% completion of the time slice
  - Keeps job priority fixed – never lowered
- Job behavioral change
  - CPU/batch process becomes an interactive process



83

PREVENTING GAMING

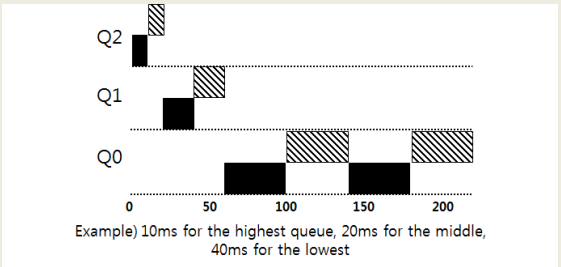
- Improved time accounting:
  - Track total job execution time in the queue
  - Each job receives a fixed time allotment
  - When allotment is exhausted, job priority is lowered



84

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?



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

85

OBJECTIVES – 4/15

- Questions from 4/10
- Assignment 0
- C Tutorial - Pointers, Strings, Exec in C
- Chapter 6: Limited Direct Execution
- Chapter 7: Scheduling Introduction
  - Scheduling metrics
    - Turnaround time, Jain's Fairness Index, Response time
  - FIFO, SJF, STCF, **RR** schedulers
- Chapter 8: Multi-level Feedback Queue
  - MLFQ Scheduler
  - Job Starvation
  - Gaming the Scheduler
  - **Examples**

86

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

87

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.

88

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.

89

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***

90

QUESTIONS

91