TCSS 422: OPERATING SYSTEMS

Intro to Schedulers II, Proportional Share Schedulers

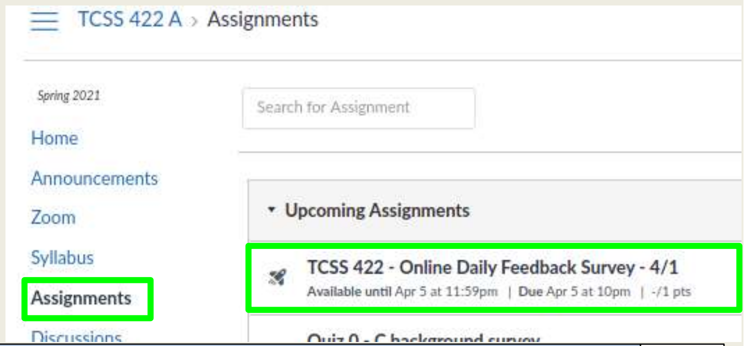
Wes J. Lloyd
School of Engineering and Technology
University of Washington - Tacoma

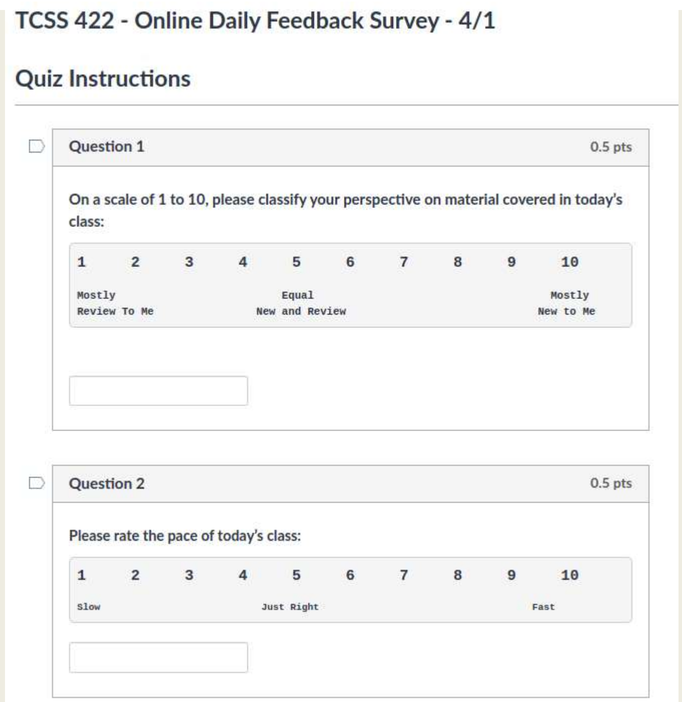
OBJECTIVES – 4/15

- Questions from 4/13
- Assignment 0
- C Tutorial - Pointers, Strings, Exec in C
- Chapter 7: Scheduling Introduction
  - RR scheduler
- Chapter 8: Multi-level Feedback Queue
  - MLFQ Scheduler
  - Job Starvation
  - Gaming the Scheduler
  - Examples
- Chapter 9: Proportional Share Schedulers

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





MATERIAL / PACE

- Please classify your perspective on material covered in today's class (52 respondents):
- 1-mostly review, 5-equal new/review, 10-mostly new
- **Average – 7.27 (↑ - previous 6.91)**

- Please rate the pace of today's class:
- 1-slow, 5-just right, 10-fast
- **Average – 5.52 (↓ - previous 5.65)**

FEEDBACK

- ***What is the purpose of calculating turnaround time and response time?***
  - Calculating these metrics helps us compare different CPU scheduling algorithms relative to scheduling a specific set of jobs
  - The idea is to find the best scheduling algorithm for a set of jobs
  - It is hard to find a scheduling algorithm that is good for ***ALL*** jobs
- ***Do programs usually output a sort of "projected time to completion" to facilitate easier sorting for fairness?***
  - No, often little information is available to suggest program runtime
  - Fairness is frequently evaluated after-the-fact
  - The percentage execution time may be given: A=52% B=32% C=16%
  - Or we must calculate the % time: A=10m 24s B=6m 24s C=3m 12s
- ***Is it common practice to break down different measures of fairness for resource allocation when designing programs?***
  - No. We calculate fairness to compare operating system algorithms used to share computing resources (CPU, disk, network)

FEEDBACK - 2

- ***What exactly does the fairness number represent? Best case is 1 and worst case is 1/n. Does that mean the share of the CPU?***
  - No, the share of the resource is the X_i values we use to calculate the Jain's fairness index score.
  - Perfect fairness always equals 1. This is when a resource is shared equally among a set of processes/users
  - Low values are always bad. If the number of processes is small, the value may not be that small
- ***Jain's fairness index: the math***
  - Consider JFI for A=52% B=32% C=16%

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

FEEDBACK - 3

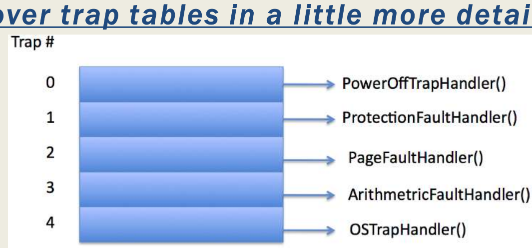
- ***If SJF (Shortest job first) scheduler is not realistic, why is it still being used?***
  - The textbook introduces some "pedagogical schedulers"
    - FIFO and Round-robin are actually legitimate schedulers
    - SJF and STCF require knowing how long a job will run in advance and this information is often not known
  - Each successive scheduler introduces new features and capabilities
  - We are building towards schedulers full-featured schedulers
    - Linux, for example, does not predict job runtime, but it does TRACK cumulative job runtime in making future scheduling decisions
- ***How would the implementation of a scheduler look? Both at a higher and lower level.***
  - Round-robin/FIFO can be simple. Involve a queue and job pointer

FEEDBACK - 2

- ***What are the advantages of using lower-level APIs such as open() compared to the specialized versions with additional features like fopen()? Is this similar to the control tradeoff? Introducing unnecessary overhead and the like?***
  - fopen() and other functions like it are provided largely out of convenience for developers
  - Specialized wrappers such as fopen() abstract additional functionality to make it more easily accessible for programmers
- ***With the use of standard out and standard error when EXEC with file redirection, I'm still not sure about the steps from L4.30***

FEEDBACK - 4

- ***Can we go over trap tables in a little more detail?***



  - **TRAP TABLE:**
    The x86 processor uses a table known as the interrupt descriptor table (IDT) to determine how to transfer control when a trap occurs. The x86 allows up to 256 different interrupt or exception entry points into the kernel, each with a different interrupt vector.
  - **TRAP HANDLERS:**
    Trap handlers are OS kernel functions that are pointed to by the trap table. These are "event handlers" that respond to various traps.

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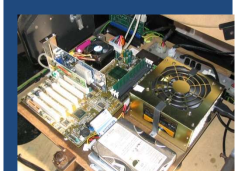
CHAPTER 7- SCHEDULING: INTRODUCTION



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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

P1	P2	P3	P4	P5	P1	P2	P4	P1

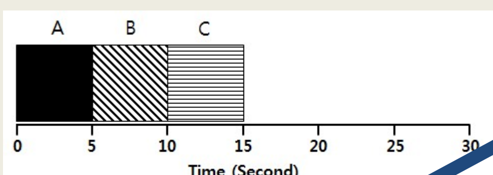
0 5 10 14 19 24 29 32 37 39

Scheduling Quantum = 5 seconds

RR EXAMPLE

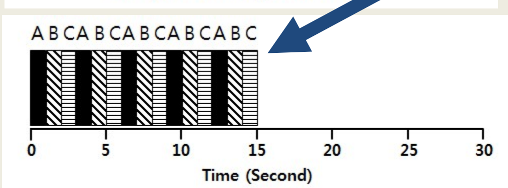
- ABC arrive at time=0, each run for 5 seconds

OVERHEAD not considered



SJF (Bad for Response Time)

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



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

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

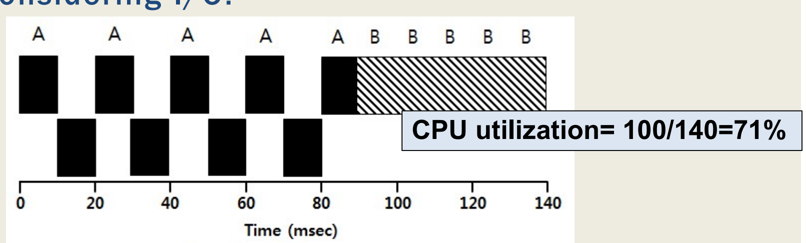
ROUND ROBIN: TRADEOFFS

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

SCHEDULING WITH I/O

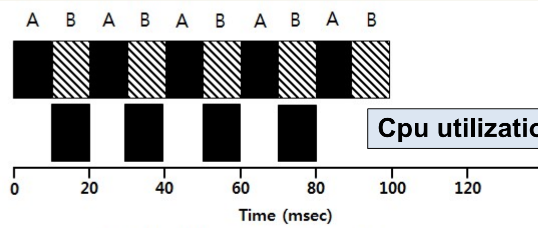
- STCF scheduler
  - A: CPU=50ms, I/O=40ms, 10ms intervals
  - B: CPU=50ms, I/O=0ms
  - Consider A as 10ms subjobs (CPU, then I/O)
- Without considering I/O:



Poor Use of Resources

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)



Cpu utilization = 100/100=100%

Overlap Allows Better Use of Resources

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**

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Total Results

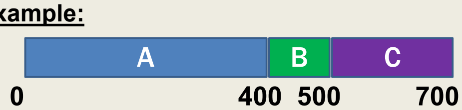
QUESTION: SCHEDULING FAIRNESS

- 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 <u>average response time (ART)</u> and <u>average turnaround time (ATT)</u> 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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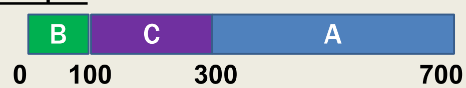
SCHEDULING METRICS

- 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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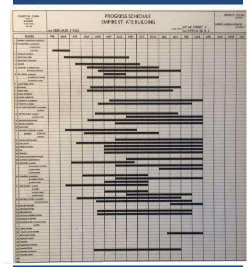

CHAPTER 8 – MULTI-LEVEL FEEDBACK QUEUE (MLFQ) SCHEDULER

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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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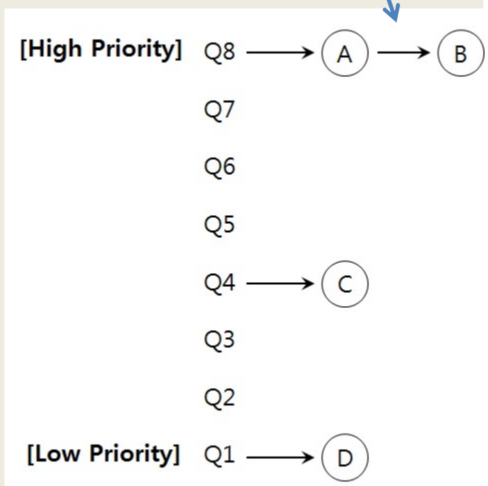
MLFQ - 2

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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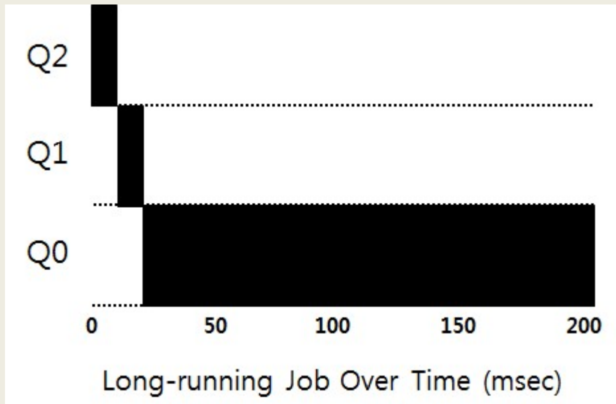
MLFQ: LONG RUNNING JOB

- Three-queue scheduler, time slice=10ms

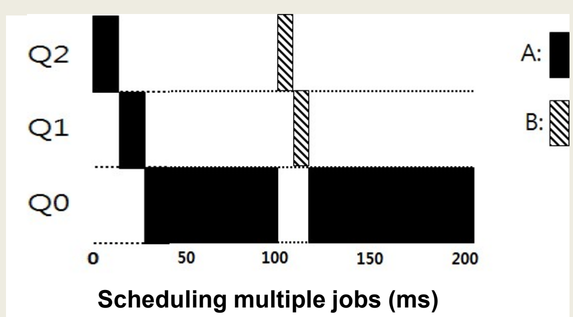
Priority



MLFQ: BATCH AND INTERACTIVE JOBS

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

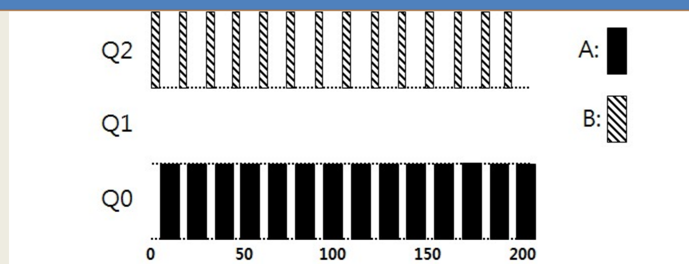
Priority



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



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

WE WILL RETURN AT 4:50PM

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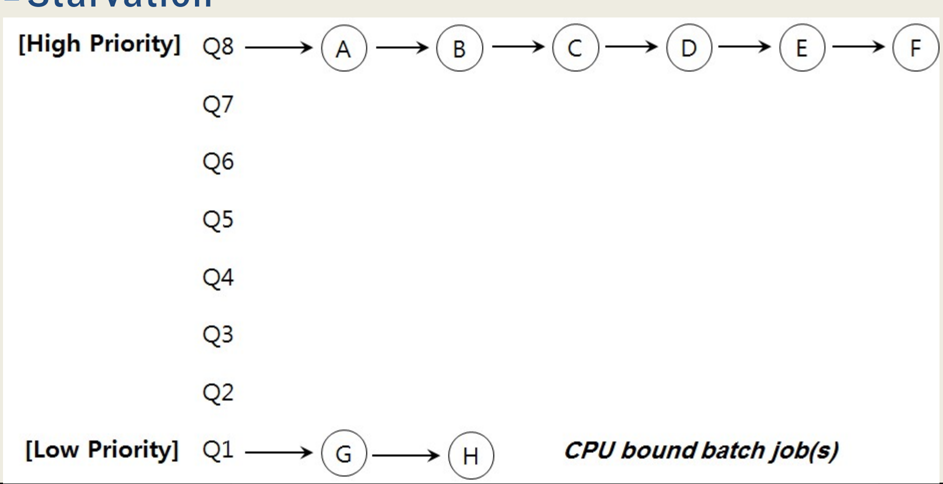
MLFQ: ISSUES

- Starvation



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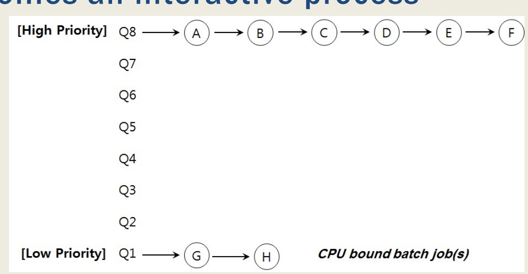
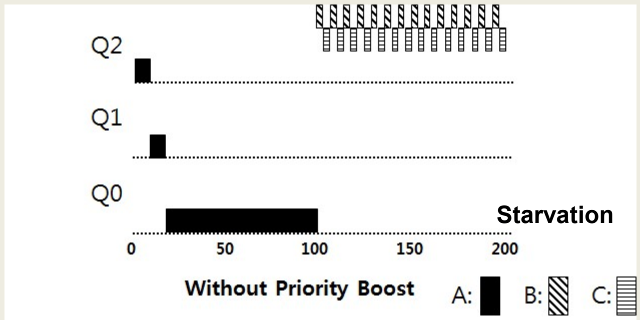
MLFQ: ISSUES - 2

- 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

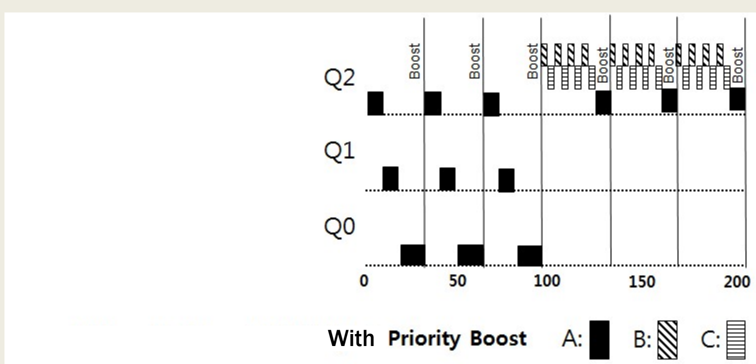
RESPONDING TO BEHAVIOR CHANGE



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

RESPONDING TO BEHAVIOR CHANGE - 2

- With priority boost
  - Prevents starvation

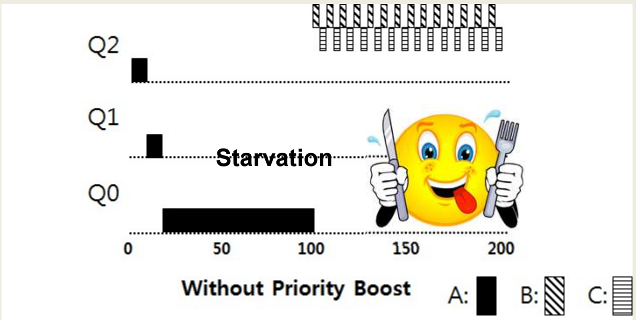


KEY TO UNDERSTANDING MLFQ – PB

- 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!!!

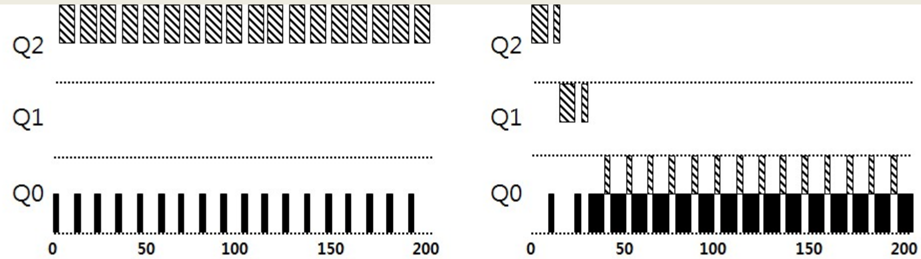
STARVATION EXAMPLE

- 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



PREVENTING GAMING

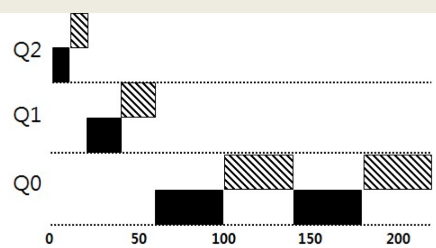
- Improved time accounting:
  - Track total job execution time in the queue
  - Each job receives a fixed time allotment
  - When allotment is exhausted, job priority is lowered



Without(Left) and With(Right) Gaming Tolerance

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

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

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.

HIGH |
MED |
LOW |
0

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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CHAPTER 9 - PROPORTIONAL SHARE SCHEDULER

OBJECTIVES – 4/15

- Chapter 9: Proportional Share Schedulers
  - Lottery scheduler
  - Ticket mechanisms
  - Stride scheduler
  - Linux Completely Fair Scheduler

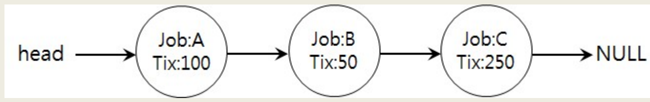
PROPORTIONAL SHARE SCHEDULER

- Also called fair-share scheduler
  or lottery scheduler
  - Guarantees each job receives some percentage of CPU time based on share of "tickets"
  - Each job receives an allotment of tickets
  - % of tickets corresponds to potential share of a resource
  - Can conceptually schedule any resource this way
    - CPU, disk I/O, memory

LOTTERY SCHEDULER

- Simple implementation
  - Just need a random number generator
    - Picks the winning ticket
  - Maintain a data structure of jobs and tickets (list)
  - Traverse list to find the owner of the ticket
  - Consider sorting the list for speed

LOTTERY SCHEDULER IMPLEMENTATION




```c
// counter: used to track if we've found the winner yet
int counter = 0;

// winner: use some call to a random number generator to
// get a value, between 0 and the total # of tickets
int winner = getrandom(0, totaltickets);

// current: use this to walk through the list of jobs
node_t *current = head;

// loop until the sum of ticket values is > the winner
while (current) {
        counter = counter + current->tickets;
        if (counter > winner)
                break; // found the winner
        current = current->next;
}
// 'current' is the winner: schedule it...
```


TICKET MECHANISMS

- Ticket currency / exchange
  - User allocates tickets in any desired way
  - OS converts user currency into global currency
- Example:
  - There are 200 global tickets assigned by the OS

User A → *500* (A's currency) to A1 → *50* (global currency)
→ *500* (A's currency) to A2 → *50* (global currency)

User B → *10* (B's currency) to B1 → *100* (global currency)

TICKET MECHANISMS - 2

- Ticket transfer
  - Temporarily hand off tickets to another process
- Ticket inflation
  - Process can temporarily raise or lower the number of tickets it owns
  - If a process needs more CPU time, it can boost tickets.

LOTTERY SCHEDULING

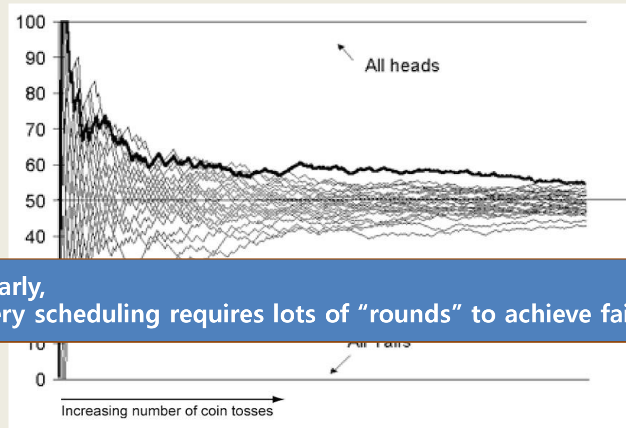
- Scheduler picks a winning ticket
  - Load the job with the winning ticket and run it
- Example:
  - Given 100 tickets in the pool
    - Job A has 75 tickets: 0 - 74
    - Job B has 25 tickets: 75 – 99

Scheduler's winning tickets:	63	85	70	39	76	17	29	41	36	39	10	99	68	83	63
Scheduled job:	A	B	A	A	B	A	A	A	A	A	A	B	A	B	A

- But what do we know about probability of a coin flip?

COIN FLIPPING

- Equality of distribution (fairness) requires a lot of flips!



Similarly,
Lottery scheduling requires lots of "rounds" to achieve fairness.

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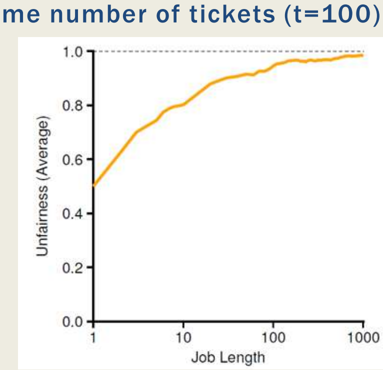
LOTTERY FAIRNESS

- With two jobs
  - Each with the same number of tickets (t=100)



When the job length is not very long,
average unfairness can be **quite severe**.

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LOTTERY SCHEDULING CHALLENGES

- What is the best approach to assign tickets to jobs?
  - Typical approach is to assume users know best
  - Users are provided with tickets, which they allocate as desired
- How should the OS automatically distribute tickets upon job arrival?
  - What do we know about incoming jobs a priori ?
  - Ticket assignment is really an open problem…

STRIDE SCHEDULER

- Addresses statistical probability issues with lottery scheduling
- Instead of guessing a random number to select a job, simply count…

STRIDE SCHEDULER - 2

- Jobs have a "stride" value
  - A stride value describes the counter pace when the job should give up the CPU
  - Stride value is <u>inverse in proportion</u> to the job's number of tickets (more tickets = smaller stride)
- Total system tickets = 10,000
  - Job A has 100 tickets → A_{stride} = 10000/100 = 100 stride
  - Job B has 50 tickets → B_{stride} = 10000/50 = 200 stride
  - Job C has 250 tickets → C_{stride} = 10000/250 = 40 stride
- Stride scheduler tracks "pass" values for each job (A, B, C)

STRIDE SCHEDULER - 3

- Basic algorithm:
  1. Stride scheduler picks job with the lowest pass value
  2. Scheduler increments job's pass value by its stride and starts running
  3. Stride scheduler increments a counter
  4. When counter exceeds pass value of current job, pick a new job (go to 1)
- <u>KEY:</u> When the counter reaches a job's "PASS" value, the scheduler <u>passes</u> on to the next job…

STRIDE SCHEDULER - EXAMPLE

- Stride values
  - Tickets = priority to select job
  - Stride is inverse to tickets
  - Lower stride = more chances to run (higher priority)

Priority

C stride = 40

A stride = 100

B stride = 200

STRIDE SCHEDULER EXAMPLE - 2

- Three-way tie: randomly pick job A (all pass values=0)
- Set A's pass value to A's stride = 100
- Increment counter until > 100
- Pick a new job: two-way tie

Tickets
C = 250
A = 100
B = 50

Pass(A) (stride=100)	Pass(B) (stride=200)	Pass(C) (stride=40)	Who Runs?
0	0	0	A
100	0	0	B
100	200	0	C
100	200	40	C
100	200	80	C
100	200	120	A
200	200	120	C
200	200	160	C
200	200	200	…

Initial job selection is random. All @ 0

C has the most tickets and receives a lot of opportunities to run…

STRIDE SCHEDULER EXAMPLE - 3

- We set A's counter (pass value) to A's stride = 100
- Next scheduling decision between B (pass=0) and C (pass=0)
  - Randomly choose B
- C has the lowest counter for next 3 rounds

Tickets
C = 250
A = 100
B = 50

Pass(A) (stride=100)	Pass(B) (stride=200)	Pass(C) (stride=40)	Who Runs?
0	0	0	A
100	0	0	B
100	200	0	C
100	200	40	C
100	200	80	C
100	200	120	A
200	200	120	C
200	200	160	C
200	200	200	…

C has the most tickets and is selected to run more often …

STRIDE SCHEDULER EXAMPLE - 4

- Job counters support determining which job to run next
- Over time jobs are scheduled to run based on their priority represented as their share of tickets…
- Tickets are analogous to job priority

Tickets
C = 250
A = 100
B = 50

Pass(A) (stride=100)	Pass(B) (stride=200)	Pass(C) (stride=40)	Who Runs?
0	0	0	A
100	0	0	B
100	200	0	C
100	200	40	C
100	200	80	C
100	200	120	A
200	200	120	C
200	200	160	C
200	200	200	…

LINUX: COMPLETELY FAIR SCHEDULER (CFS)

- Large Google datacenter study: *"Profiling a Warehouse-scale Computer"* (Kanev et al.)
- Monitored 20,000 servers over 3 years
- Found 20% of CPU time spent in the Linux kernel
- 5% of CPU time spent in the CPU scheduler!
- Study highlights importance for high performance OS kernels and CPU schedulers !

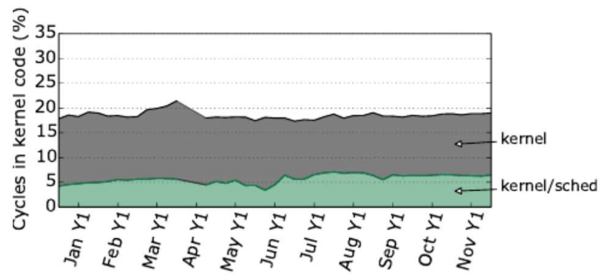


Figure 5: Kernel time, especially time spent in the scheduler, is a significant fraction of WSC cycles.

See: https://dl.acm.org/doi/pdf/10.1145/2749469.2750392

LINUX: COMPLETELY FAIR SCHEDULER (CFS)

- Loosely based on the stride scheduler
- CFS models system as a Perfect Multi-Tasking System
  - In perfect system every process of the same priority (class) receive exactly $1/n^{th}$ of the CPU time
- Each scheduling class has a runqueue
  - Groups process of same class
  - In class, scheduler picks task w/ lowest `vruntime` to run
  - Time slice varies based on how many jobs in shared runqueue
  - Minimum time slice prevents too many context switches (e.g. 3 ms)

COMPLETELY FAIR SCHEDULER - 2

- Every thread/process has a scheduling class (policy):
- Normal classes: SCHED_OTHER (TS), SCHED_IDLE, SCHED_BATCH
  - TS = Time Sharing
- Real-time classes: SCHED_FIFO (FF), SCHED_RR (RR)

- How to show scheduling class and priority:
- ```
  #class
  ps -elfc
  ```

- ```
  #priority (nice value)
  ps ax -o pid,ni,cls,pri,cmd
  ```


COMPLETELY FAIR SCHEDULER - 3

- Linux ≥ 2.6.23: Completely Fair Scheduler (CFS)
- Linux < 2.6.23: O(1) scheduler

- Linux maintains simple counter (vruntime) to track how long each thread/process has run
- CFS picks process with lowest vruntime to run next

- CFS adjusts timeslice based on # of proc waiting for the CPU
- Kernel parameters that specify CFS behavior:

```
$ sudo sysctl kernel.sched_latency_ns
kernel.sched_latency_ns = 24000000
$ sudo sysctl kernel.sched_min_granularity_ns
kernel.sched_min_granularity_ns = 3000000
$ sudo sysctl kernel.sched_wakeup_granularity_ns
kernel.sched_wakeup_granularity_ns = 4000000
```

COMPLETELY FAIR SCHEDULER - 4

- **Sched_min_granularity_ns** (3ms)
  - Time slice for a process: busy system (w/ full runqueue)
  - If system has idle capacity, time slice exceed the min as long as difference in **vruntime** between running process and process with lowest **vruntime** is less than **sched_wakeup_granularity_ns** (4ms)
- Scheduling time period is: total cycle time for iterating through a set of processes where each is allowed to run (like round robin)
- Example:
  sched_latency_ns (24ms)
  if (proc in runqueue < **sched_latency_ns**/**sched_min_granularity**)
  or
  sched_min_granularity * number of processes in runqueue

Ref: https://www.systutorials.com/sched_min_granularity_ns-sched_latency_ns-cfs-affect-timeslice-processes/

CFS TRADEOFF

- **HIGH** sched_min_granularity_ns (timeslice)
  sched_latency_ns
  sched_wakeup_granularity_ns

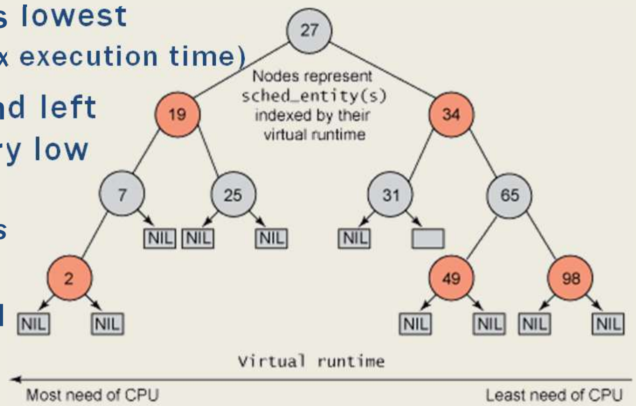
  reduced context switching → less overhead
  poor near-term fairness

- **LOW** sched_min_granularity_ns (timeslice)
  sched_latency_ns
  sched_wakreup_granularity_ns

  increased context switching → more overhead
  better near-term fairness

COMPLETELY FAIR SCHEDULER - 5

- Runqueues are stored using a linux red-black tree
  - Self balancing binary tree - nodes indexed by **`vruntime`**
- Leftmost node has lowest **`vruntime`** (approx execution time)
- Walking tree to find left most node has very low big O complexity: *~O(log N) for N nodes*
- Completed processes removed



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CFS: JOB PRIORITY

```
static const int prio_to_weight[40] = {
    /* -20 */ 88761, 71755, 56483, 46273, 36291,
    /* -15 */ 29154, 23254, 18705, 14949, 11916,
    /* -10 */  9548,  7620,  6100,  4904,  3906,
    /*  -5 */  3121,  2501,  1991,  1586,  1277,
    /*   0 */  1024,   820,   655,   526,   423,
    /*   5 */   335,   272,   215,   172,   137,
    /*  10 */   110,    87,    70,    56,    45,
    /*  15 */    36,    29,    23,    18,    15,
};
```

- Time slice: Linux ***"Nice value"***
  - Nice predates the CFS scheduler
  - Top shows nice values
  - Process command (nice & priority):
    `ps ax -o pid,ni,cmd,%cpu, pri`
- Nice Values: from -20 to 19
  - Lower is ***higher*** priority, default is 0
  - Vruntime is a weighted time measurement
  - Priority weights the calculation of vruntime within a runqueue to give high priority jobs a boost.
    - Influences job's position in rb-tree

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COMPLETELY FAIR SCHEDULER - 6

- CFS tracks cumulative job run time in `vruntime` variable
- The task on a given runqueue with the lowest `vruntime` is scheduled next
- `struct sched_entity` contains `vruntime` parameter
  - Describes process execution time in nanoseconds
  - Value is not pure runtime, is weighted based on job priority
  - Perfect scheduler → achieve equal `vruntime` for all processes of same priority
- Sleeping jobs: upon return reset vruntime to lowest value in system
  - Jobs with frequent short sleep ***SUFFER !!***
- Key takeaway: ***identifying the next job to schedule is really fast!***

COMPLETELY FAIR SCHEDULER - 7

- More information:
- Man page: "man sched" : Describes Linux scheduling API
- http://manpages.ubuntu.com/manpages/bionic/man7/sched.7.html
- https://www.kernel.org/doc/Documentation/scheduler/sched-design-CFS.txt
- https://en.wikipedia.org/wiki/Completely_Fair_Scheduler
- See paper: The Linux Scheduler – a Decade of Wasted Cores
- http://www.ece.ubc.ca/~sasha/papers/eurosys16-final29.pdf

QUESTIONS

QUESTIONS

TCSS 422

OFFICE HOURS

PLEASE SAY HELLO

OFFICE HOURS

HAVE STEPPED OUT

WILL RETURN SHORTLY