CS3281 / CS5281

Process Scheduling

CS3281 / CS5281

Spring 2025

**Some lecture slides borrowed and adapted from "Operating Systems: Three Easy Pieces"*

Tel (615) 343-7472 | Fax (615) 343-7440
1025 16th Avenue South Nashville, TN 37212
www.isis.vanderbilt.edu

VANDERBILT UNIVERSITY

Overview

- The scheduler is the part of the OS kernel responsible for deciding which process runs and for how long
- There are many types of scheduling algorithms
    - Which one is "best" depends on many things, such as the expected workload and metrics
- These slides discuss scheduling basics
    - Subsequent slides discuss particular types of schedulers, such as those in Linux

Scheduling

- A scheduling algorithm is responsible for deciding which process to run
- Some simple (impractical) scheduling algorithms (chapter 7 in your book):
  - First In First Out (FIFO): run each process to completion in the order they arrive
    - Problems: what if a process runs "indefinitely"? What if a long running process happens to arrive first?
  - Shortest Job First (SJF): select the process that will run for the shortest time
    - Problem: we don't know how long a process will run ahead of time!
  - Shortest Time-to-Completion First (STCF): *preempt* the currently running process if another process has a shorter time to completion
    - Problem: long running processes will be *starved* if short running processes keep arriving

Tel (615) 343-7472 | Fax (615) 343-7440
1025 16th Avenue South Nashville, TN 37212
www.isis.vanderbilt.edu

Scheduling Metrics

- Metrics can be used to measure how good a scheduler is
- Examples:
  - Turnaround time: Time of completion - Time of arrival
    - A scheduler with poor turnaround time might be bad for CPU bound processes
  - Response time: Time of first run - Time of arrival
    - A scheduler with a poor response time will feel “laggy” to interactive users
  - Throughput: Number of processes completed per unit time

What about I/O?

- All “interesting” programs do some I/O
- What should the scheduler do when a process is waiting for I/O?
  - Run another process instead! It’s a bad idea to have a process spin while waiting for I/O
- Example from the book:

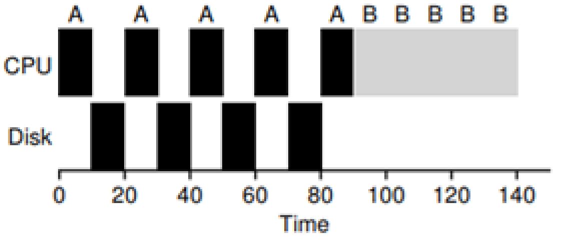


Figure 7.8: **Poor Use Of Resources**

vs

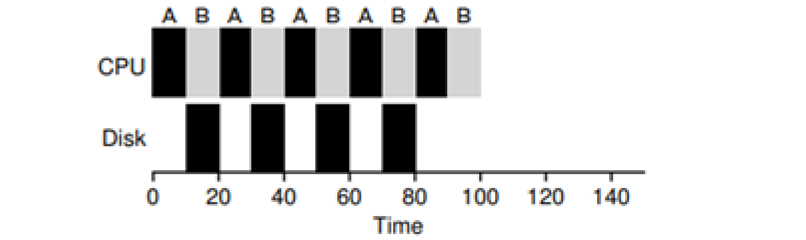


Figure 7.9: **Overlap Allows Better Use Of Resources**

Tel (615) 343-7472 | Fax (615) 343-7440
1025 16th Avenue South Nashville, TN 37212
www.isis.vanderbilt.edu

More Realistic Scheduling: Round-Robin

- Round-Robin (RR) scheduling: instead of running a process to completion, run a process for a *time slice* (or time *quantum*), *preempt* the process, and context switch to the next process in the run queue; do this repeatedly
  - In other words: everybody gets a turn eventually!
  - RR is used in many real-world schedulers
- What triggers the preemption of the currently running process?
  - Simple case: the periodic timer interrupt (whose rate is configurable)
    - Timer interrupt occurs
    - OS handles this interrupt by executing the timer interrupt handler
    - Time interrupt handler checks how long current process has been running
    - If current process has run longer than its allotted time slice, the scheduler is invoked
    - The scheduler saves the context of the current process and selects a new process to run

CPU Bound vs. I/O Bound

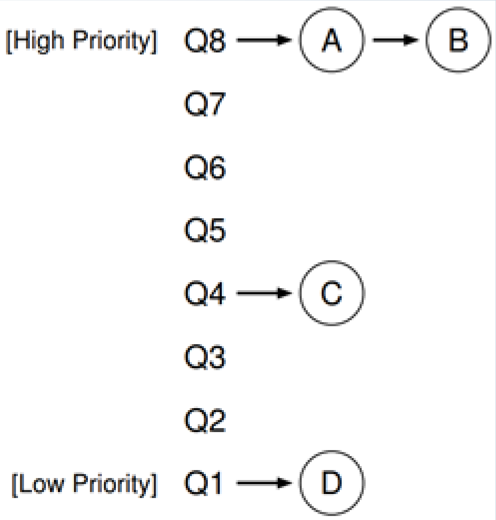
- Processes are often *CPU bound* or *I/O bound*
  - CPU bound: when they run, they use the CPU continuously
    - Examples: MATLAB simulations, training a machine learning model, video encoding
  - I/O bound: when they run, they spend most of their time waiting for I/O
    - Examples: text editors, powerpoint
- Processes can switch between being I/O bound and CPU bound (and vice versa)
  - Example: when you do a “spell check” on a document, the editor goes from being I/O bound to CPU bound
- Question: how can a scheduler let CPU bound processes use the CPU but also quickly switch to an I/O bound process when input or output arrives?
  - Something the Linux CFS (covered later) aims to address

Multi-Level Feedback Queues (MLFQ)

- MLFQ is a scheduling algorithm that tries to do two things:
  - Optimize turnaround time
    - This can be done by running shorter processes first, but we don't know how long a process will run!
  - Minimize response time
    - This makes the system feel responsive to interactive users
    - Round-robin is good for response time, but is bad for turnaround time
- MLFQ is cool because it addresses these two goals without knowing anything about the running times a priori

MLFQ Basic Rules

- MLFQ has:
  - A number of distinct queues, each at a different priority level
  - At any given time, a process that is ready to run is on a single queue
  - Processes with higher priority are run first; processes with equal priority are run RR
- Rule 1: priority(A) > priority(B) => A runs
- Rule 2: priority(A) == priority(B), A and B run in RR



Tel (615) 343-7472 | Fax (615) 343-7440
1025 16th Avenue South Nashville, TN 37212
www.isis.vanderbilt.edu

Changing Priority

- Rule 3: When process enters system, it is placed at highest priority (top queue)
- Rule 4a: If a process uses up an entire time allotment while running, its priority is reduced (it moves down one queue)
- Rule 4b: If a process gives up the CPU before its time allotment is up, it stays at the same priority level

Example of Moving through Queues

- Over time, a long running process will move to the bottom queue
- Example:

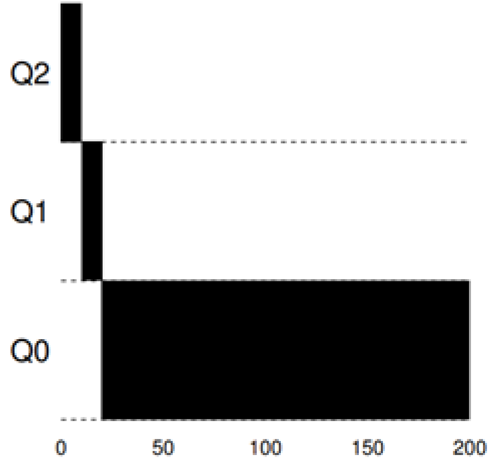


Figure 8.2: **Long-running Job Over Time**

Tel (615) 343-7472 | Fax (615) 343-7440
1025 16th Avenue South Nashville, TN 37212
www.isis.vanderbilt.edu

More Examples

- Figure 8.3: a long running process and short-running job
- Figure 8.4: a long running process and an I/O bound process

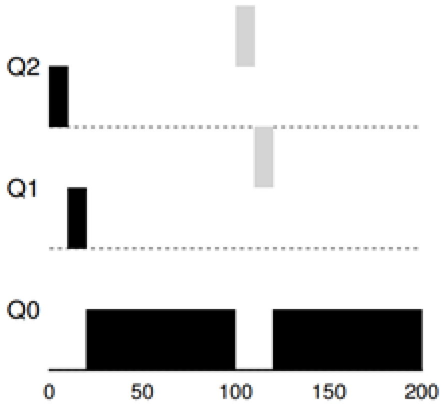


Figure 8.3: **Along Came An Interactive Job**

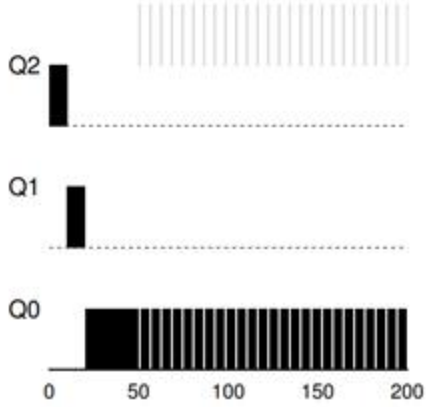


Figure 8.4: **A Mixed I/O-intensive and CPU-intensive Workload**

Tel (615) 343-7472 | Fax (615) 343-7440
1025 16th Avenue South Nashville, TN 37212
www.isis.vanderbilt.edu

Problems

- There are two problems with the design so far:
  - Processes have no way to move back up in priority
  - Processes can “game” the scheduler by giving up the CPU right before using the quantum

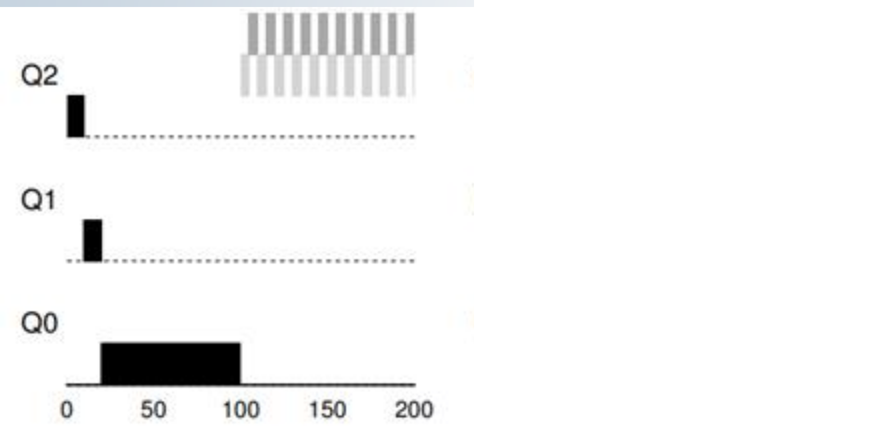


Figure 8.5: **Without (Left) and With (Right) Priority Boost**

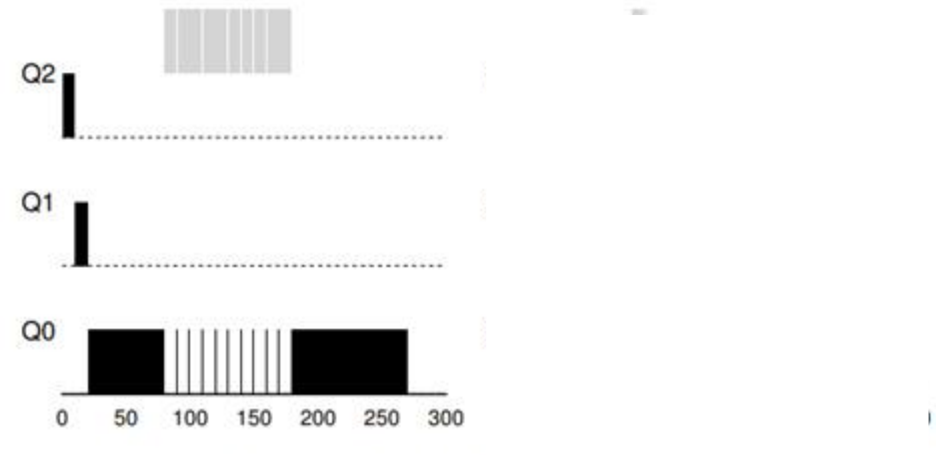


Figure 8.6: **Without (Left) and With (Right) Gaming Tolerance**

Tel (615) 343-7472 | Fax (615) 343-7440
1025 16th Avenue South Nashville, TN 37212
www.isis.vanderbilt.edu

VANDERBILT UNIVERSITY

Addressing the Problems

- We can keep processes from “gaming” the scheduler by moving them down a queue after they exhaust their cumulative time slice at a given level
- We can move processes up in priority periodically to keep them from starving
  - As an extension: we could “weight” processes so that some get to move up faster (but not too fast!)

Tel (615) 343-7472 | Fax (615) 343-7440
1025 16th Avenue South Nashville, TN 37212
www.isis.vanderbilt.edu

Addressing the Problems

Schedule these processes with FIFO, SJF, and RR algorithms

Assume the following for RR

- The time slice is 1 unit of time
- If two or more processes (re)enter a queue at the same time, the one with the lowest number is scheduled

Process	Runtime	Arrival time
P1	10	0
P2	1	3
P3	2	1
P4	1	2
P5	5	0

Summary of MFLQ Rules

- Rule 1: priority(A) > priority(B) => A runs
- Rule 2: priority(A) == priority(B), A and B run in RR
- Rule 3: when process enters system, it is placed at highest priority (top queue)
- Rule 4: once a process uses its allotment at a given level, its priority is reduced (it moves down a queue)
- Rule 5: after some time period *S*, move all the jobs in the system to the topmost queue

Multitasking: Preemptive Operating Systems

- Linux is a preemptive, multitasking OS
  - Preemptive: the scheduler decides when a process should stop and another should start
  - Multitasking: it can simultaneously interleave execution of more than one process
  - Windows, macOS, iOS, Android are also all multitasking, preemptive operating systems
- On a single-processor machine, this makes it seem like multiple processes are running concurrently
- On a multiprocessor (multicore) machine this allows multiple processes to run in parallel on different processors (cores)
- The *timeslice* (or quantum) is the amount of time a process runs before being preempted

Review: Preemption

- What triggers the preemption of the currently running process? Two things
- Case 1: returning from interrupt handler
    - Example: the timer interrupt occurs
    - OS handles this interrupt by executing the timer interrupt handler
    - Timer interrupt handler checks how long current process has been running
    - If current process has run longer than its allotted time slice, the scheduler is invoked
    - The scheduler saves the context of the current process and selects a new process to run
- Case 2: process makes a system call
    - Recall: process generates an intentional exception called a trap (e.g., `int 80h`)
    - OS executes a trap handler (to handle the system call)
    - When exiting the system call, the OS checks if it should invoke the scheduler
    - The scheduler, if run, checks for higher priority processes

High-Level Concept: Lottery Scheduling

- Simple idea: every so often, hold a lottery to determine which process should run next
  - Processes that should run more often get more *tickets*, and thus more chances to win the lottery
  - Described in chapter 9 in the book
- Example:
  - Two processes, A and B
  - 100 tickets total. A has 75, B has 25
  - Pick a random winning ticket to see who gets to run next
  - A should get the CPU ~75% of the time, B should get it ~25% of the time
- Need a good random number generator, a data structure for tickets, and the total number of tickets!

Completely Fair Scheduler Scenario

- The CFS in Linux is similar to lottery scheduling
- Consider the following scenario
  - Two tasks: a text editor (I/O bound) and a MATLAB simulation (CPU bound)
  - The text editor needs to respond to key presses quickly
  - MATLAB needs CPU time to perform a simulation
- In the ideal case:
  - Give a larger proportion of CPU time to text editor
    - But not because it needs it! Because we want it to have time the moment it needs it.
  - Allow the text editor to preempt MATLAB as soon as input is available (i.e., when a key is pressed)
    - This will make it responsive and give good interactive performance

Tel (615) 343-7472 | Fax (615) 343-7440
1025 16th Avenue South Nashville, TN 37212
www.isis.vanderbilt.edu

VANDERBILT UNIVERSITY

Completely Fair Scheduler Scenario (cont.)

- Suppose the text editor and MATLAB are the only two processes running
- Linux gives both processes a 50% "share" of the CPU
  - The text editor doesn't use anywhere close to its 50% share
  - MATLAB is free to use more than its 50% share
- When the text editor *does* need the CPU (i.e., when a key is pressed):
  - The interrupt handler (to handle the key press) notices that the text editor (1) needs to run, and (2) has used far less than its "fair-share", and thus schedules the text editor

Completely Fair Scheduler Scenario (cont.)

- Divides CPU time evenly among processes
- Instead of a “fixed” timeslice, CFS calculates how long each process should run as a function of the total number of runnable processes
  - Use the nice value to weight this proportion of processor a process receives
  - If all nice values are equal: all processes get an equal proportion of processor time
- Uses a simple counting technique known as virtual runtime (vruntime)
  - Lower vruntime => a process hasn’t had its “fair share”

Tel (615) 343-7472 | Fax (615) 343-7440
1025 16th Avenue South Nashville, TN 37212
www.isis.vanderbilt.edu

Virtual Runtime

- So how is the timeslice calculated?
  - Too low: increases "fairness" but also increases overhead (due to context switching)
  - Too high: decreases overhead but also decreases fairness
- Timeslice uses a "magic value" (empirically determined) called `sched_latency` (typical value = 48ms) to calculate the timeslice
  - Timeslice = sched_latency / # of processes
- Nice value: parameter of a process controllable by user
  - Goes from -20 to +19; default of 0;
    - Negative implies higher priority (you are "less nice")

Tel (615) 343-7472 | Fax (615) 343-7440
1025 16th Avenue South Nashville, TN 37212
www.isis.vanderbilt.edu

Timeslice

- Use the nice value to "weight" the timeslice

$$\texttt{time\_slice}_k = \frac{\texttt{weight}_k}{\sum_{n=0}^{n-1} \texttt{weight}_i} \cdot \texttt{sched\_latency} \qquad (9.1)$$

- Also scale the `vruntime`:

$$\texttt{vruntime}_i = \texttt{vruntime}_i + \frac{\texttt{weight}_0}{\texttt{weight}_i} \cdot \texttt{runtime}_i \qquad (9.2)$$

- Table of weights:

```
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,
};
```

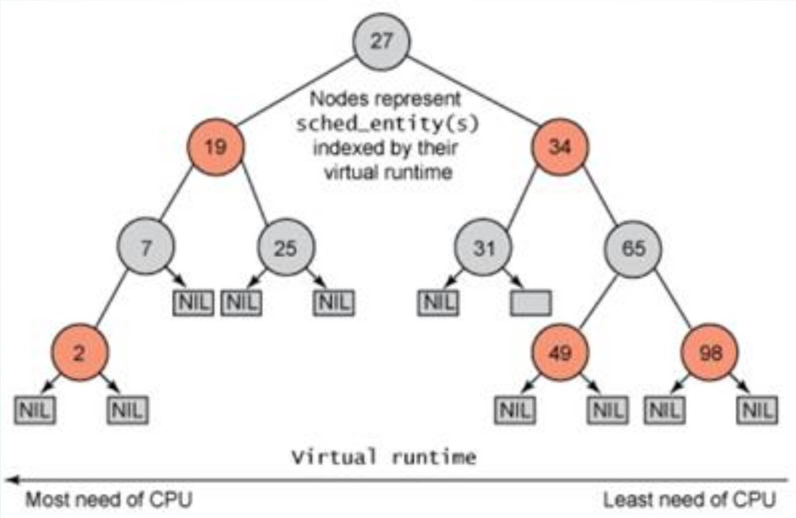
Tel (615) 343-7472 | Fax (615) 343-7440
1025 16th Avenue South Nashville, TN 37212
www.isis.vanderbilt.edu

Virtual Runtime (cont.)

- But what if there are too many processes?
  - Define a minimum timeslice value; never use timeslice lower than this
- But how do we give processes “priority”?
  - In CFS: give them a larger share of the CPU
- Nice value: parameter of a process controllable by user
  - Goes from -20 to +19; default of 0;
  - Negative implies higher priority (you are “less nice”)

Virtual Runtime (cont.)

- As a process runs, it accumulates vruntime
- When scheduler needs to pick a new process, it picks the process with the lowest vruntime



Tel (615) 343-7472 | Fax (615) 343-7440
1025 16th Avenue South Nashville, TN 37212
www.isis.vanderbilt.edu