CSE 120
Principles of Operating Systems

Spring 2016

Lecture 5: Scheduling

Administrivia

- Homework #1 due
- Homework #2 out

Scheduling Overview

- In discussing process management and synchronization, we talked about context switching among processes/threads on the ready queue
- But we have glossed over the details of exactly which thread is chosen from the ready queue
- Making this decision is called scheduling
- In this lecture, we'll look at:
  - Goals of scheduling
  - Starvation
  - Various well-known scheduling algorithms
  - Standard Unix scheduling algorithm

Multiprogramming

- In a multiprogramming system, we try to increase CPU utilization and job throughput by overlapping I/O and CPU activities
  - Doing this requires a combination of mechanisms and policy
- We have covered the mechanisms
  - Context switching, how and when it happens
  - Process queues and process states
- Now we'll look at the policies
  - Which process (thread) to run, for how long, etc.
- We'll refer to schedulable entities as jobs (standard usage) – could be processes, threads, people, etc.

Scheduling Goals

- Scheduling works at two levels in an operating system
  - To determine the multiprogramming level – the number of jobs loaded into primary memory
    - Moving jobs to/from memory is often called swapping
  - To decide what job to run next to guarantee “good service”
    - Good service could be one of many different criteria
- These decisions are known as long-term and short-term scheduling decisions, respectively
  - Long-term scheduling happens relatively infrequently
    - Significant overhead in swapping a process out to disk
  - Short-term scheduling happens relatively frequently
    - Want to minimize the overhead of scheduling
      - Fast context switches, fast queue manipulation

Scheduling

- The scheduler (aka dispatcher) is the module that manipulates the queues, moving jobs to and fro
- The scheduling algorithm determines which jobs are chosen to run next and what queues they wait on
- In general, the scheduler runs:
  - When a job switches from running to waiting
  - When an interrupt occurs (e.g., I/O completes)
  - When a job is created or terminated
- We'll discuss scheduling algorithms in two contexts
  - In preemptive systems the scheduler can interrupt a running job (involuntary context switch)
  - In non-preemptive systems, the scheduler waits for a running job to explicitly block (voluntary context switch)

Scheduling Goals

- Scheduling algorithms can have many different goals:
  - CPU utilization (%CPU)
  - Job throughput (# jobs/time)
  - Turnaround time $(T_{finish} - T_{start})$
  - Waiting time ($Avg(T_{wait})$: avg time spent on wait queues)
  - Response time ($Avg(T_{ready})$: avg time spent on ready queue)
- Batch systems
  - Strive for job throughput, turnaround time (supercomputers)
- Interactive systems
  - Strive to minimize response time for interactive jobs (PC)

Starvation

Starvation is a scheduling "non-goal":

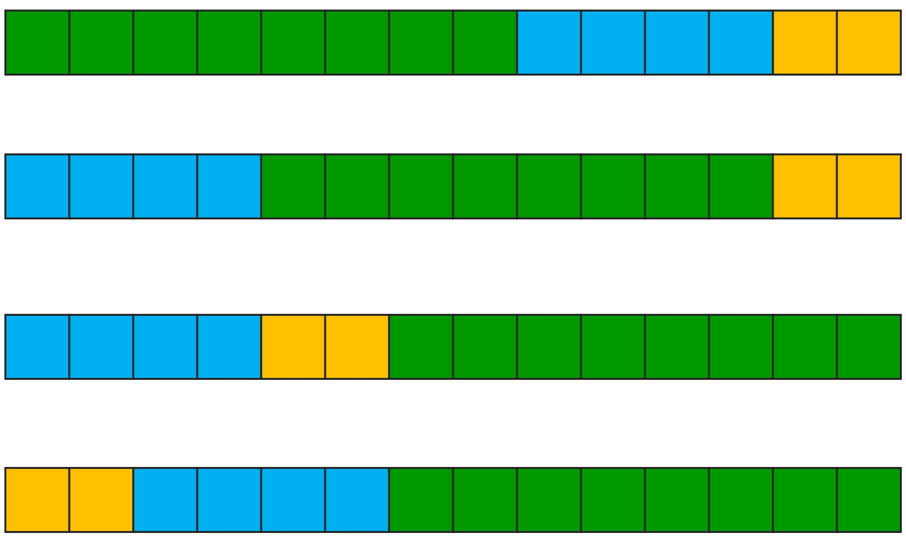
- Starvation is a situation where a process is prevented from making progress because some other process has the resource it requires
  - Resource could be the CPU, or a lock (recall readers/writers)
- Starvation usually a side effect of the sched. algorithm
  - A high priority process always prevents a low priority process from running on the CPU
  - One thread always beats another when acquiring a lock
- Starvation can be a side effect of synchronization
  - Constant supply of readers always blocks out writers

FCFS/FIFO

- First-come first-served (FCFS), first-in first-out (FIFO)
  - Jobs are scheduled in order of arrival to ready Q
  - “Real-world” scheduling of people in lines (e.g., supermarket)
  - Can be preemptive, or not.
  - Jobs treated equally, no starvation
- Problem
  - Average waiting time can be large if small jobs wait behind long ones (high turnaround time)
    - » You have a basket, but you’re stuck behind someone with a cart

Shortest Job First (SJF)

- Shortest Job First (SJF)
  - Choose the job with the smallest expected CPU burst
    - » Person with smallest number of items to buy
  - Provably optimal minimum average waiting time



AWT = (8 + (8+4)+(8+4+2))/3 = 11.33

AWT = (4 + (4+8)+(4+8+2))/3 = 10

AWT = (4+ (4+2)+(4+2+8))/3 = 8

AWT = (2 + (2+4)+(2+4+8))/3 = 7.33

Shortest Job First (SJF)

- Problems
  - Impossible to know size of CPU burst
    - » Like choosing person in line without looking inside basket/cart
  - How can you make a reasonable guess?
  - Can potentially starve
- Flavors
  - Can be either preemptive or non-preemptive
  - Preemptive SJF is called shortest remaining time first (SRTF)

Priority Scheduling

- Priority Scheduling
  - Choose next job based on priority
    - » Airline checkin for first class passengers
  - Can implement SJF, priority = 1/(expected CPU burst)
  - Also can be either preemptive or non-preemptive
- Problem
  - Starvation – low priority jobs can wait indefinitely
- Solution
  - "Age" processes
    - » Increase priority as a function of waiting time
    - » Decrease priority as a function of CPU consumption

Round Robin (RR)

- Round Robin
  - Excellent for timesharing
  - Ready queue is treated as a circular queue (FIFO)
  - Each job is given a time slice called a quantum
  - A job executes for the duration of the quantum, or until it blocks or is interrupted
  - No starvation
  - Can be preemptive or non-preemptive
- Problem
  - Context switches are frequent and need to be very fast

Combining Algorithms

- Scheduling algorithms can be combined
  - Have multiple queues
  - Use a different algorithm for each queue
  - Move processes among queues
- Example: Multiple-level feedback queues (MLFQ)
  - Multiple queues representing different job types
    - » Interactive, CPU-bound, batch, system, etc.
  - Queues have priorities, jobs on same queue scheduled RR
  - Jobs can move among queues based upon execution history
    - » Feedback: Switch from interactive to CPU-bound behavior

Unix Scheduler

- The canonical Unix scheduler uses a MLFQ
  - 3-4 classes spanning ~170 priority levels
    - Timesharing: first 60 priorities
    - System: next 40 priorities
    - Real-time: next 60 priorities
    - Interrupt: next 10 (Solaris)
- Priority scheduling across queues, RR within a queue
  - The process with the highest priority always runs
  - Processes with the same priority are scheduled RR
- Processes dynamically change priority
  - Increases over time if process blocks before end of quantum
  - Decreases over time if process uses entire quantum

Motivation of Unix Scheduler

- The idea behind the Unix scheduler is to reward interactive processes over CPU hogs
- Interactive processes (shell, editor, etc.) typically run using short CPU bursts
  - They do not finish quantum before waiting for more input
- Want to minimize response time
  - Time from keystroke (putting process on ready queue) to executing keystroke handler (process running)
  - Don’t want editor to wait until CPU hog finishes quantum
- This policy delays execution of CPU-bound jobs
  - But that’s ok

Scheduling Overhead

- Operating systems aim to minimize overhead
  - Context switching takes non-zero time, so it is pure overhead
  - Overhead includes context switch + choosing next process
- Modern time-sharing OSes (Unix, Windows, …) time-slice processes in ready list
  - A process runs for its quantum, OS context switches to another, next process runs, etc.
  - A CPU-bound process will use its entire quantum (e.g., 10ms)
  - An IO-bound process will use part (e.g., 1ms), then issue IO
  - The IO-bound process goes on a wait queue, the OS switches to the next process to run, the IO-bound process goes back on the ready list when the IO completes

Utilization

- CPU utilization is the fraction of time the system is doing useful work (e.g., not context switching or idle)
- If the system has
  - Quantum of 10ms + context-switch overhead of 0.1ms
  - 3 CPU-bound processes + round-robin scheduling
- In steady-state, time is spent as follows:
  - 10ms + 0.1ms + 10ms + 0.1ms + 10ms + 0.1ms
  - CPU utilization = time doing useful work / total time
  - CPU utilization = (3*10ms) / (3*10ms + 3*0.1ms) = 30/30.3
- If one process is IO-bound, it will not use full quantum
  - 10ms + 0.1ms + 10ms + 0.1ms + 1ms + 0.1ms
  - CPU util = (2*10 + 1) / (2*10 + 1 + 3*0.1) = 21/21.3

Scheduling Summary

- Scheduler (dispatcher) is the module that gets invoked when a context switch needs to happen
- Scheduling algorithm determines which process runs, where processes are placed on queues
- Many potential goals of scheduling algorithms
  - Utilization, throughput, wait time, response time, etc.
- Various algorithms to meet these goals
  - FCFS/FIFO, SJF, Priority, RR
- Can combine algorithms
  - Multiple-level feedback queues
  - Unix example

Thread Scheduling

- Discussed scheduling in the context of processes, but thread scheduling is analogous
- Process scheduling and thread scheduling are essentially the same for kernel supported threads
- User-level thread facilities have analogous user-level thread scheduler