Scheduling II

Today

- Proportional-share scheduling
- Multilevel-feedback queue
- Multiprocessor scheduling

Next Time

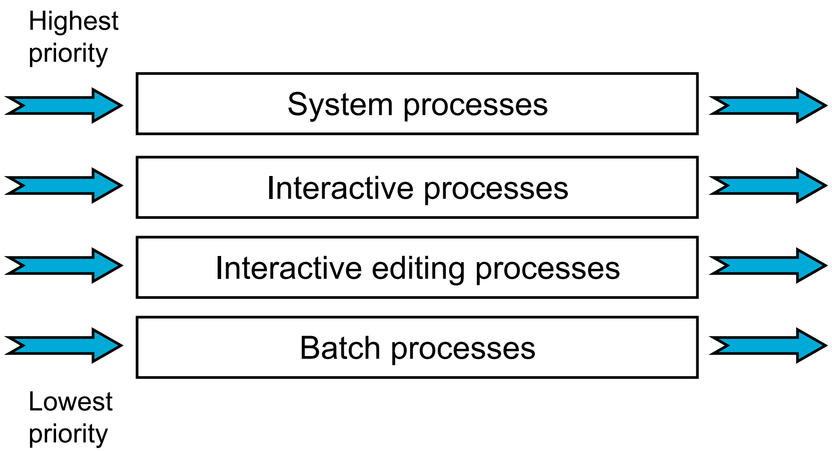
- Memory management

Scheduling with multiple goals

- What if you want both good turnaround time *and* responsiveness
- To optimize turnaround time, SJF
  - But you don't know how long a job will run for
- To improve responsiveness, Round Robin
  - Which is terrible for turnaround time

Multilevel queue

- Ready queue partitioned into separate queues
- Each queue has its own scheduling algorithm
- Now must schedule between the queues
  - Fixed priority scheduling; starvation?
  - Time slice – each queue gets a fraction of CPU time which it can schedule amongst its processes

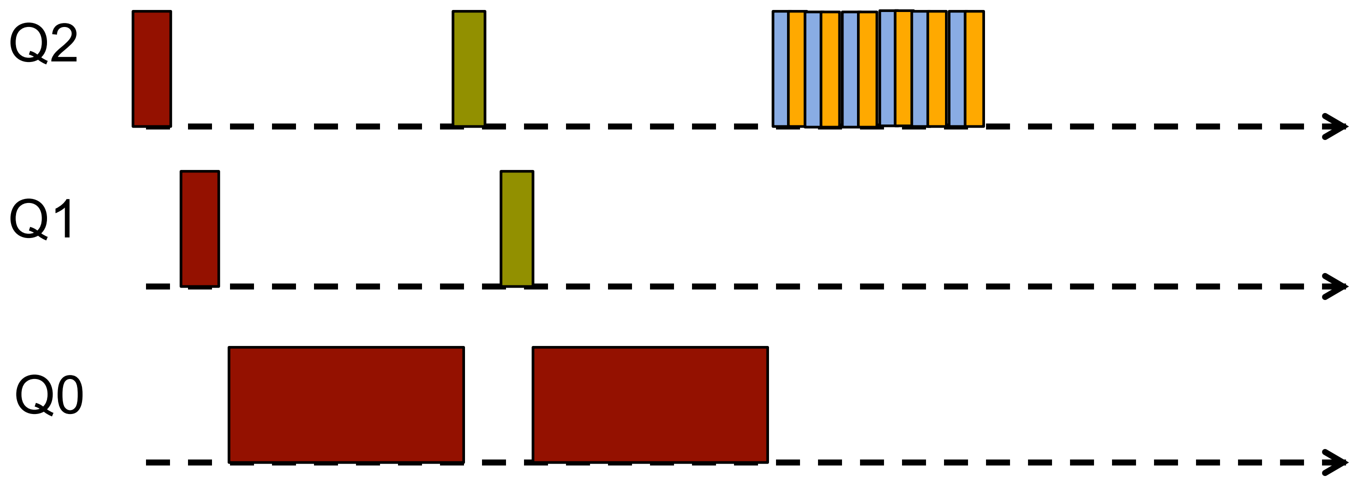


Multiple (feedback) queues …

- Rather than assigning processes to queues, move them around based on their behavior
  - Job enters at highest priority
  - If uses entire slice, it moves down (priority reduced)
  - If it gives up CPU before quantum ends, stays in place
- How MLFQ approximates SJF
  - Since it doesn't know if the job will be short, assumes so and gives it high priority
  - If it turns out to be short, it will run quickly and be done
  - Else, it will move to lower queues
    - And become more batch-like

MLFQ v1

- Two jobs: A, long-running CPU-intensive; B, short-running, interactive



- Some issues
  - Starvation again – if interactive jobs keep arriving ...
  - You can game the scheduler – issuing an I/O before your quantum is over and the job won’t move
  - What if the process changes behavior over time?

MLFQ v2

- Addressing starvation
  - Periodically boost priority; let's say every time period *S*
  - Now another problem is setting *S*
- CTSS – First MLFQ
  - IBM 7094 had space for 1 process in memory (switch = swap)
  - Priority classes: class *i* gets 2^i quantas
    - Scheduler first runs all processes in queue 0; if empty, all in queue 1, …
  - What about process with long start but interactive after that?
    - Carriage-return hit → promote process to top class on the assumption it will become interactive

MLFQ v2

- Easy to game

  Keep hitting that CR key!

- Preventing gaming
  - Better accounting, instead of forgetting how much of its time-slice a process has used
    - Track time used, independently of how many times it gave up the CPU
  - Once a process has used its allotment, it is demoted to next priority queue

Scheduling challenges

- Context
  - Multiplex scarce resources
  - Among concurrently executing clients
  - Servicing request of varying importance
- Priority scheduling
  - Absolute control, but crude
  - Often ad-hoc
  - Resource rights don’t vary smoothly
  - Unable to control service rates of tasks
  - No modular abstraction
- Proportional-share scheduling
  - The execution rate of processes is proportional to the relative share that they are allocated – *fairness*

Proportional-share scheduling

- Lottery scheduling – a modern example
  - Randomized resource allocation
  - Each process gets lottery tickets for resources (CPU time)
  - Scheduling – lottery, i.e. randomly pick a ticket
  - Probabilistically fair
- A basic run – A: 75 tickets; B: 15 tickets
  - Hold the lottery, random[0..99], in our case
  - If 0-74, run A, else run B

63	85	70	39	76	17	29	41	36	39	10	99	68	83	63
A	B	A	A	B	A	A	A	A	A	A	B	A	B	A

A: 11/5 ~73%

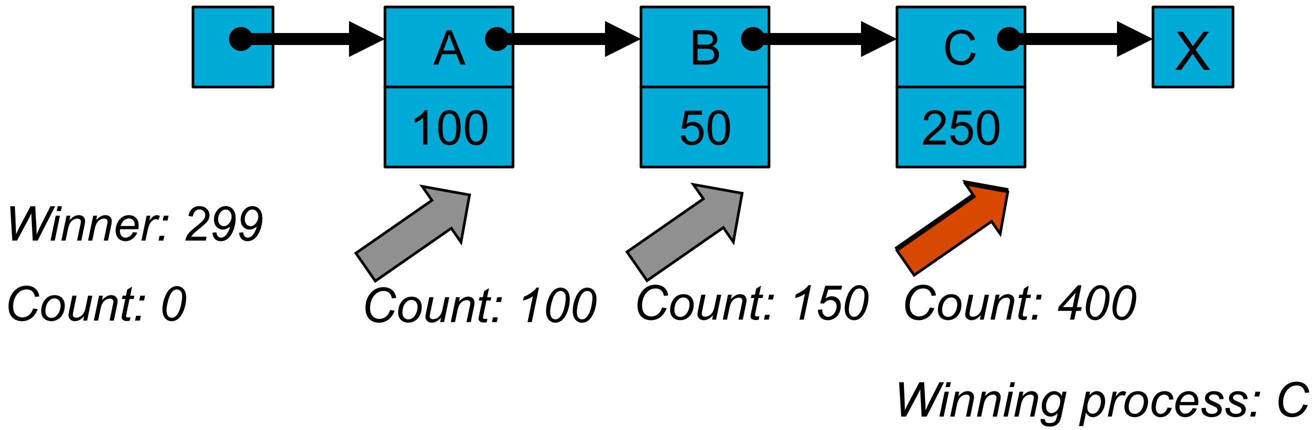
C. Waldspurger and W. Weihl, "Lottery scheduling: Flexible proportional-share resource management", In Proc. OSDI 1994.

Lottery scheduling

- CPU allocation and response time follow distributions with well-understood properties
  - Number of lotteries won by a process as a binomial distribution
    - Probability of winning is proportional to number of tickets t, $p = t/T$ (T is total tickets); after n draws, expected number of wins $E[w] = np$
  - Number of lotteries for a first win has a geometric distribution
    - A process avg response time is inversely proportional to ticket allocation
- Other features
  - No starvation
  - Fair with number of tickets varying dynamically
  - Responsive to changes on ticket allocation

Lottery scheduling

- Simple implementation
  - You just need a good random number generator
  - A list of processes with their tickets
  - Pick a winner, walk the list adding up tickets until count exceed winner – current process is the winning process



  - *Any easy way to optimize this?*

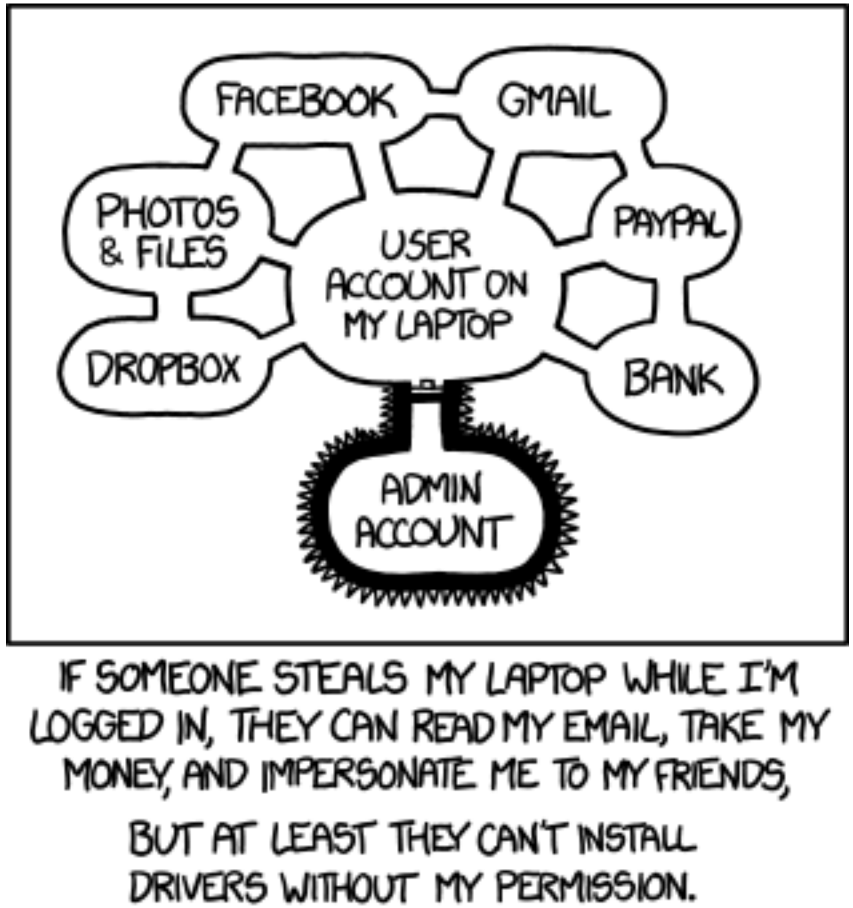
Lottery scheduling

- Some interesting features
  - Tickets can be used to insulate resource management policies of independent modules
  - Tickets transfer
    - Tickets can be treated as first class objects, so they can be transferred in messages
    - If you are blocked on someone else, give them your tickets
    - A client waiting on multiple clients, divide tickets among them
  - Ticket inflation/deflation is an alternative to transfer
    - A client can escalate its resource rights by creating more tickets
    - Only among mutually trusting clients

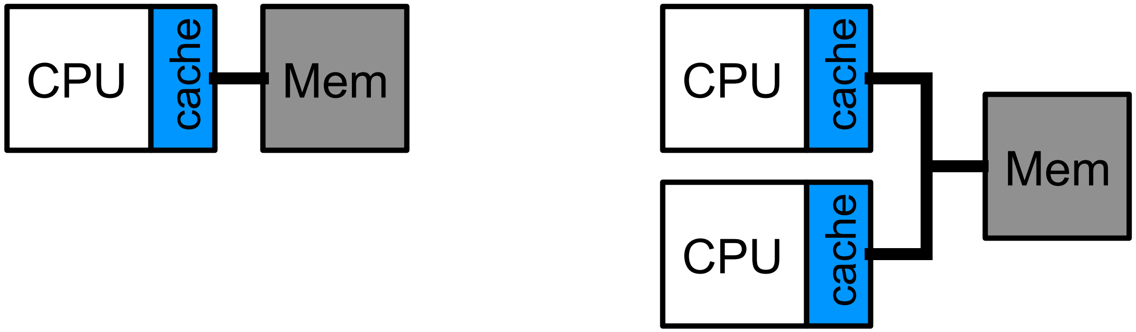
Lottery scheduling

- Some interesting features
  - Ticket currencies to isolate trust boundaries
    - A unique currency used to denominate tickets within trust boundaries
    - Each currency is backed by tickets denominated in more primitive currencies – defining an acyclic graph
    - Effects of inflation can be contained with a base currency, that is conserved, and an exchange rate
  - Compensation tickets if a process consume a fraction of its allocated resource (blocking before quantum expires)
    - Issue tickets to inflate values in proportion to unused resource until next quantum
    - Ensure everybody gets its share of the CPU
- But how do you assign tickets?
  - Assume the user knows (but that’s really a non-solution)

And now a short break …

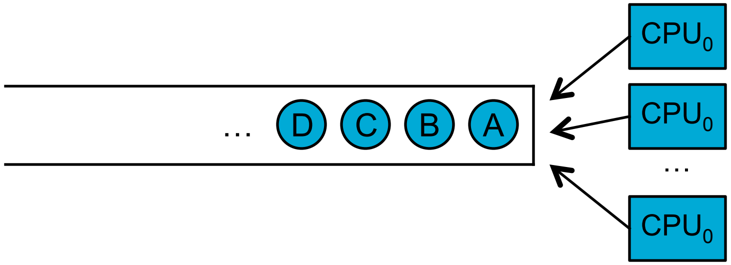


Multiple-processor scheduling



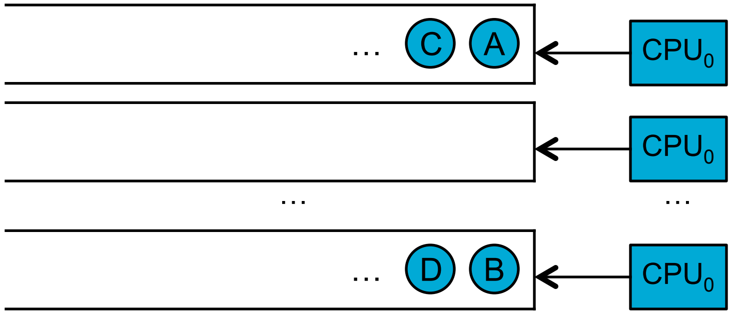
- Issues with multiprocessing – caches
  - Caches and locality (temporal and spatial)
  - Consistency, synchronization and affinity
- Scheduling complexity
  - From 1d to 2d: “Which process to run next?” ➔ “Which process to run *and* where?”
  - Are all process related or are they independent?
  - When re-scheduling a process, what should we do with the data cached in the previous run?

Multiple-processor scheduling



- Single-queue scheduling / time sharing
  - Reuse known framework; automatic load-balancing
  - Contention for scheduling data
  - Cache affinity?
    - Add some kind of affinity mechanism (e.g., a bitmask of CPUs allowed, like in Linux sched. 2.4 & 2.5)

Multiple-processor scheduling



- Multiple-queue scheduling / space sharing
  - Multiple queue, each with its own algorithm
  - Process comes into a queue (which one?) and is scheduled from there
  - Clearly more scalable – less contention for locks
  - But … load imbalance
    - Job migration? Push or pull

Some other algorithms

- Guaranteed scheduling - e.g. proportional to number of processes
  - Priority = amount used / amount promised
  - Lower ratio → higher priority
- Fair-Share scheduling
  - Schedule aware of ownership
    - If user 1 starts up 9 processes and user 2 starts up 1, user 1 will get 90% of the CPU
  - Owners get a % of CPU, processes are picked to enforce it
  - Divide user set into fair-share groups
  - Scheduling is done based on priority
    - Accounting for underlying priority, recent usage, recent group usage

Some other algorithms – Real-time

- Different categories
  - *Soft or Hard RT* – Important or critical?
  - Hard: not on time ~ not at all
  - Scheduling can be static or dynamic
- Schedulable real-time system
  - A RT system may have to respond to periodic (at regular intervals) or aperiodic (unpredictable) events
  - Given a set of *m* periodic events *i* each with period P_i and requiring C_i seconds of CPU, can the load be handle? *Schedulable*
    - An admission-control policy could reject/accept a new job depending on this

Solaris scheduling as an example

- Solaris is based on Unix System V Release 4 (SVR4)
  - As in all SVR4-based schedulers, two levels
    - Class-independent: dispatching and preempting (mechanisms)
    - Class-dependent: setting priorities (policy)
- Three scheduling classes or priority-class types
  - Real time – priorities 100-159
  - System – priorities 60-99
  - Time sharing – priorities 0-59
- When a process is created, it inherits its parent's priority class characteristics
  - i.e., priority class and global priority value
  - Most jobs will be running in the TS class

Solaris TS Scheduling Class - MLFQ

- Jobs begins at priority 29 (range 0-59)
- Priority is calculated from two proportional values
  - A kernel part and
  - A user provided part for backward compatibility (nice)
- Compute-bound jobs filter down to lower priorities
  - Process priority is lowered after it consumes its quantum
  - Schedule less frequently but for longer
- Interactive jobs move to higher priorities

Policy vs. mechanism

- Separate *what* is done from *how* it is done
  - Think of parent process with multiple children
  - Parent may knows relative importance of children (if, for example, each one has a different task)
- None of the algorithms presented takes the parent process input for scheduling
- Scheduling algorithm parameterized
  - Mechanism in the kernel
- Parameters filled in by user processes
  - Policy set by user process
  - Parent controls scheduling w/o doing it

Next time

- We have discussed sharing CPU to improve utilization and turnaround time
- For that to happen we also need to share memory
- We'll start with memory organization and basic management techniques (e.g. paging)