Process Scheduling

CSE 410, Spring 2009

Computer Systems

http://www.cs.washington.edu/410

Readings and References

- Reading
  - » *Operating System Concepts*
    - Chapter 5, Secs. 5.1-5.5
      - Skim math for cultural enrichment; we won't have time to go into scheduling theory

Scheduling

- In discussing processes and threads, we talked about context switching
  - » an interrupt occurs (device completion, timer, …)
  - » a thread causes an exception (a *trap* or a *fault*)
- We glossed over the choice of which thread is chosen to be run next
  - » "some thread from the ready queue"
- This decision is called scheduling
  - context switching is a mechanism inside the OS
  - scheduling is a policy

Scheduling Goals

- Keep the CPU(s) busy
- Maximize throughput (“requests” per second)
- Minimize latency
  - » Time between responses
  - » Time for entire “job”
- Favor some particular class (foreground window, interactive vs CPU-bound)
- Avoid jitter (video)
- Keep the airplane in the sky ☺
- Be fair (no starvation or inversion)
- THESE MAY CONFLICT

Classes of Schedulers

- Batch
  - » Throughput / utilization oriented
  - » Example: audit inter-bank funds transfers each night, Pixar rendering
- Interactive
  - » Response time oriented
- Hard Real Time
  - » Deadline driven
  - » Example: embedded systems (cars, airplanes, etc.)
- Soft Real Time
  - » Video, TIVO, etc.
- Parallel
  - » Speedup driven
  - » Example: "space-shared" use of a 1000-processor machine for large simulations
- Others…

We'll be talking primarily about interactive schedulers
(as does the text).

Multiple levels of scheduling decisions

- Long term
  - » Should a new “job” be “initiated,” or should it be held?
  - » typical of batch systems
  - » what might cause you to make a “hold” decision?
- Medium term
  - » Should a running program be temporarily marked as non-runnable (e.g., swapped out)?
- Short term
  - » Which thread should get the CPU next? For how long?
  - » Which I/O operation should be sent to the disk next?
  - » On a multiprocessor:
    - should we attempt to coordinate the running of threads from the same address space in some way?
    - should we worry about cache state (processor affinity)?

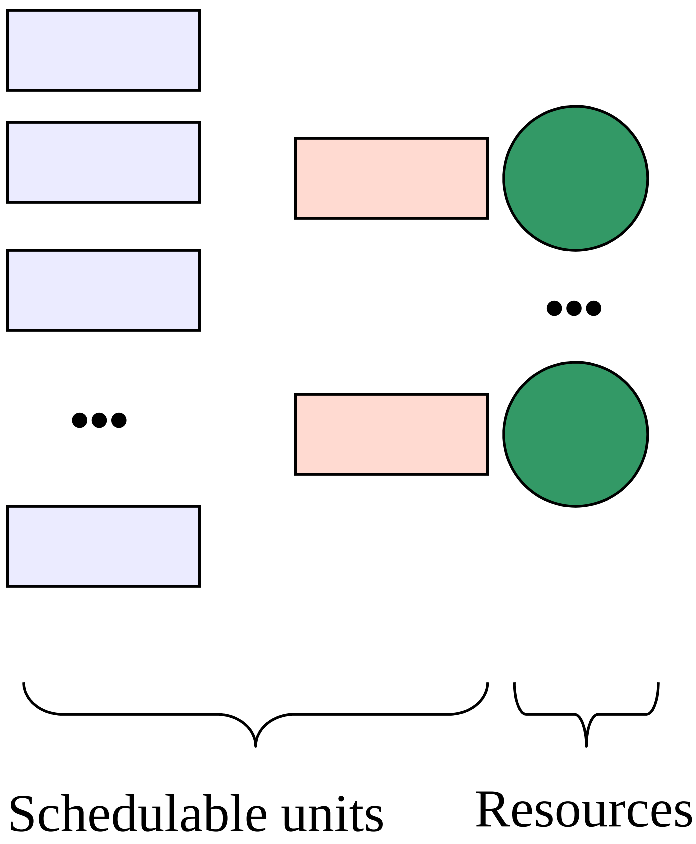
Scheduling Goals I: Performance

- Many possible metrics / performance goals (which sometimes conflict)
  - » maximize CPU utilization
  - » maximize throughput (requests completed/sec)
  - » minimize average response time (average time from submission of request to completion of response)
  - » minimize average waiting time (average time from submission of request to start of execution)
  - » minimize energy (joules per instruction) subject to some constraint (e.g., frames/second)

Scheduling Goals II: Fairness

- No single, compelling definition of "fair"
  - » How to measure fairness?
    - Equal CPU consumption? (over what time scale?)
  - » Fair per-user? per-process? per-thread?
  - » What if one thread is CPU bound and one is IO bound?
- Sometimes the goal is to be unfair:
  - » Explicitly favor some particular class of requests (priority system), but…
  - » avoid starvation (be sure everyone gets at least some service)

The basic situation



Scheduling:
- Who to assign each resource to
- When to re-evaluate your decisions

When to assign?

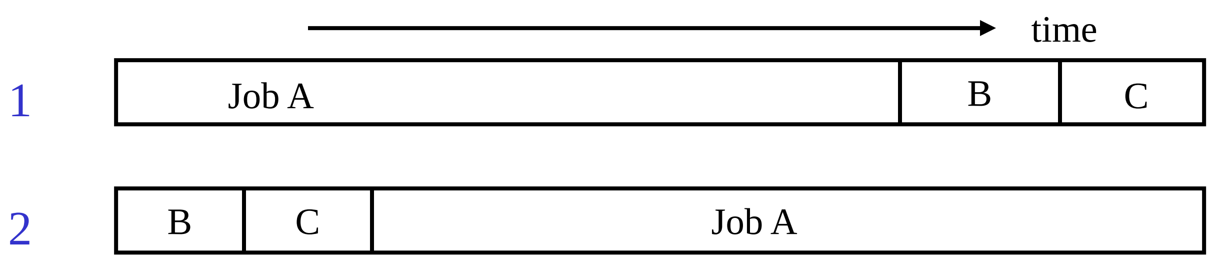
- Pre-emptive vs. non-preemptive schedulers
  - » Non-preemptive
    - once you give somebody the green light, they've got it until they relinquish it
      - an I/O operation
      - allocation of memory in a system without swapping
  - » Preemptive
    - you can re-visit a decision
      - setting the timer allows you to preempt the CPU from a thread even if it doesn't relinquish it voluntarily
      - in any modern system, if you mark a program as non-runable, its memory resources will eventually be re-allocated to others
    - Re-assignment always involves some overhead
      - Overhead doesn't contribute to the goal of any scheduler
- We'll assume "work conserving" policies
  - » Never leave a resource idle when someone wants it
    - Why even mention this? When might it be useful to do something else?

Algorithm #1: FCFS/FIFO

- First-come first-served / First-in first-out (FCFS/FIFO)
  - » schedule in the order that they arrive
  - » "real-world" scheduling of people in (single) lines
    - supermarkets, bank tellers, McD's, Starbucks …
      (sometimes we separate job classes – DMV)
  - » typically non-preemptive
    - no context switching at supermarket!
  - » jobs treated equally, no starvation
    - In what sense is this "fair"?

- Sounds perfect!
  - » in the real world, when does FCFS/FIFO work well?
    - even then, what's it's limitation?
  - » and when does it work badly?

FCFS/FIFO example



- Suppose the duration of A is 5, and the durations of B and C are each 1
  - » average response time for schedule 1 (assuming A, B, and C all arrive at about time 0) is (5+6+7)/3 = 18/3 = 6
  - » average response time for schedule 2 is (1+2+7)/3 = 10/3 = 3.3
  - » consider also "elongation factor" – a "perceptual" measure:
    - Schedule 1: A is 5/5, B is 6/1, C is 7/1 (worst is 7, ave is 4.7)
    - Schedule 2: A is 7/5, B is 1/1, C is 2/1 (worst is 2, ave is 1.5)

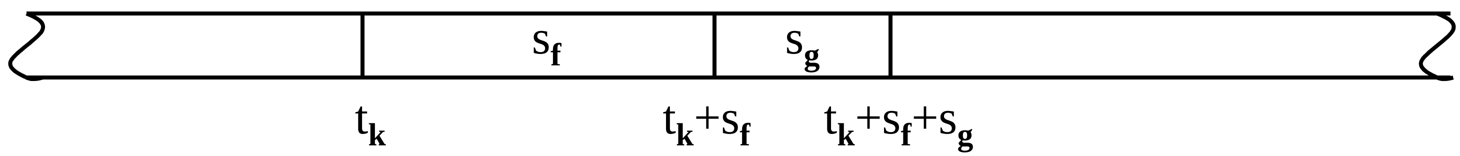
FCFS/FIFO drawbacks

- Average response time can be lousy
  - » small requests wait behind big ones
- May lead to poor utilization of other resources
  - » if you send me on my way, I can go keep another resource busy
  - » FCFS may result in poor overlap of CPU and I/O activity

Algorithm #2: SPT/SJF

- Shortest processing time first / Shortest job first (SPT/SJF)
  - » choose the request with the smallest service requirement
- *Provably optimal* with respect to average response time

SPT/SJF optimality



- In any schedule that is not SPT/SJF, there is some adjacent pair of requests f and g where the service time (duration) of f, s_f, exceeds that of g, s_g
- The total contribution to average response time of f and g is $2t_k+2s_f+s_g$
- If you interchange f and g, their total contribution will be $2t_k+2s_g+s_f$, which is smaller because $s_g < s_f$

SPT/SJF drawbacks

- It's non-preemptive
  - » So?
- … but there's a preemptive version – SRPT (Shortest Remaining Processing Time first) – that accommodates arrivals (rather than assuming all requests are initially available)
- Sounds perfect!
  - » what about starvation?
  - » can you know the processing time of a request?
  - » can you guess/approximate? How?

Algorithm #3: RR

- Round Robin scheduling (RR)
  - » ready queue is treated as a circular FIFO queue
  - » each request is given a time slice, called a quantum
    - request executes for duration of quantum, or until it blocks
      - what signifies the end of a quantum?
    - time-division multiplexing (time-slicing)
  - » great for timesharing
    - no starvation

- Sounds perfect!
  - » how is RR an improvement over FCFS?
  - » how is RR an improvement over SPT?
  - » how is RR an approximation to SPT?
  - » what are the warts?

RR drawbacks

- What if all jobs are exactly the same length?
  - » What would the pessimal schedule be?
- What do you set the quantum to be?
  - » no value is “correct”
    - if small, then context switch often, incurring high overhead
    - if large, then response time degrades
  - » treats all jobs equally
    - how might we fix this?

Algorithm #4: Priority

- Assign priorities to requests
  - » choose request with highest priority to run next
    - if tie, use another scheduling algorithm to break (e.g., RR)
  - » to implement SJF, priority = expected length of CPU burst

- Abstractly modeled (and usually implemented) as multiple "priority queues"
  - » put a ready request on the queue associated with its priority

- Sounds perfect!

Priority drawbacks

- How are you going to assign priorities?
- Starvation
  - » if there is an endless supply of high priority jobs, no low-priority job will ever run
- Solution: "age" threads over time
  - » increase priority as a function of accumulated wait time
  - » decrease priority as a function of accumulated processing time
  - » many ugly heuristics have been explored in this space

Combining algorithms

- In practice, any real system uses some sort of hybrid approach, with elements of FCFS, SPT, RR, and Priority

- Example: multi-level feedback queues (MLFQ)
  - » there is a hierarchy of queues
  - » there is a priority ordering among the queues
  - » new requests enter the highest priority queue
  - » each queue is scheduled RR
  - » queues have different quanta
  - » requests move between queues based on execution history

UNIX scheduling

- Canonical scheduler is pretty much MLFQ
  - » 3-4 classes spanning ~170 priority levels
    - timesharing: lowest 60 priorities
    - system: middle 40 priorities
    - real-time: highest 60 priorities
  - » priority scheduling across queues, RR within
    - thread with highest priority always run first
    - threads with same priority scheduled RR
  - » threads dynamically change priority
    - increases over time if thread blocks before end of quantum
    - decreases if thread uses entire quantum
- Goals:
  - » reward interactive behavior over CPU hogs
    - interactive jobs typically have short bursts of CPU

Summary

- Scheduling takes place at many levels
- It can make a huge difference in performance
  - » this difference increases with the variability in service requirements
- Multiple goals, sometimes (always?) conflicting
- There are many “pure” algorithms, most with some drawbacks in practice – FCFS, SPT, RR, Priority
- Real systems use hybrids
- Scheduling is still important, particularly in large-scale data centers – for reasons of both cost and energy