Review: Deadlock

- Starvation vs. Deadlock
  - Starvation: thread waits indefinitely
  - Deadlock: circular waiting for resources
  - Deadlock $\implies$ Starvation, but not other way around

- Four conditions for deadlocks
  - Mutual exclusion
    » Only one thread at a time can use a resource
  - Hold and wait
    » Thread holding at least one resource is waiting to acquire additional resources held by other threads
  - No preemption
    » Resources are released only voluntarily by the threads
  - Circular wait
    » There exists a set $\{T_1, \ldots, T_n\}$ of threads with a cyclic waiting pattern

Review: Resource Allocation Graph Examples

- Recall:
  - request edge - directed edge $T_i \rightarrow R_j$
  - assignment edge - directed edge $R_j \rightarrow T_i$

Review: Methods for Handling Deadlocks

- Allow system to enter deadlock and then recover
  - Requires deadlock detection algorithm
  - Some technique for selectively preemptioning resources and/or terminating tasks

- Ensure that system will never enter a deadlock
  - Need to monitor all lock acquisitions
  - Selectively deny those that might lead to deadlock

- Ignore the problem and pretend that deadlocks never occur in the system
  - used by most operating systems, including UNIX
Review: Train Example (Wormhole-Routed Network)

- **Circular dependency (Deadlock!)**
  - Each train wants to turn right
  - Blocked by other trains
  - Similar problem to multiprocessor networks
- **Fix?** Imagine grid extends in all four directions
  - Force ordering of channels (tracks)
    - Protocol: Always go east-west first, then north-south
  - Called "dimension ordering" (X then Y)

Review: Banker’s Algorithm for Preventing Deadlock

- **Monitor every request to see if it has the potential to lead to deadlock**
  - Every thread must state a "maximum" expected allocation ahead of time
  - Keeps system in a "SAFE" state ⇒ there always exists a sequence \{(T_1, T_2, ..., T_n)\} with
    - T_1 able to request all its remaining resources and finish, then T_2 able to request all its remaining resources and finish, etc.
  - Evaluate each request and grant if some ordering of threads is still deadlock free afterward
    - Technique: pretend each request is granted, then run deadlock detection algorithm, substituting
      \[ \text{Max}_{node} - \text{Alloc}_{node} \] for \[ \text{Request}_{node} \]
    - Grant request if result is deadlock free (conservative!)
  - Algorithm allows the sum of maximum resource needs of all current threads to be greater than total resources

Goals for Today

- **Tips for Programming in a Project Team**
- **Scheduling Policy goals**
- **Policy Options**
- **Implementation Considerations**

Note: Some slides and/or pictures in the following are adapted from slides ©2005 Silberschatz, Galvin, and Gagne. Many slides generated from my lecture notes by Kubiatowicz.

Tips for Programming in a Project Team

- **Big projects require more than one person (or long, long, long time)**
  - Big OS: thousands of person-years!
- **It’s very hard to make software project teams work correctly**
  - Doesn’t seem to be as true of big construction projects
    - Empire state building finished in one year: staging iron production thousands of miles away
    - Or the Hoover dam: built towns to hold workers
- **Is it OK to miss deadlines?**
  - We make it free (slip days)
- **Reality: they’re very expensive as time-to-market is one of the most important things!**

"You just have to get your synchronization right!"
**Big Projects**

- What is a big project?
  - Time/work estimation is hard
  - Programmers are eternal optimists (it will only take two days)
    - This is why we bug you about starting the project early
    - Had a grad student who used to say he just needed "10 minutes" to fix something. Two hours later...
  - Can a project be efficiently partitioned?
    - Partitionable task decreases in time as you add people
      - But, if you require communication:
        - Time reaches a minimum bound
        - With complex interactions, time increases!
    - Mythical person-month problem:
      - You estimate how long a project will take
      - Starts to fall behind, so you add more people
      - Project takes even more time!

---

**Techniques for Partitioning Tasks**

- Functional
  - Person A implements threads, Person B implements semaphores, Person C implements locks...
  - Problem: Lots of communication across APIs
    - If B changes the API, A may need to make changes
    - Story: Large airline company spent $200 million on a new scheduling and booking system. Two teams "working together." After two years, went to merge software. Failed! Interfaces had changed (documented, but no one noticed). Result: would cost another $200 million to fix.
  - Task
    - Person A designs, Person B writes code, Person C tests
    - May be difficult to find right balance, but can focus on each person's strengths (Theory vs systems hacker)
  - Mythical person-month problem:
    - You estimate how long a project will take
    - Starts to fall behind, so you add more people
    - Project takes even more time!

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**Communication**

- More people mean more communication
  - Changes have to be propagated to more people
  - Think about person writing code for most fundamental component of system: everyone depends on them!
- Miscommunication is common
  - "Index starts at 0? I thought you said 1!"
- Who makes decisions?
  - Individual decisions are fast but trouble
  - Group decisions take time
  - Centralized decisions require a big picture view (someone who can be the "system architect")
- Often designating someone as the system architect can be a good thing
  - Better not be clueless
  - Better have good people skills
  - Better let other people do work

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**Coordination**

- More people ⇒ no one can make all meetings!
  - They miss decisions and associated discussion
  - Example from earlier class: one person missed meetings and did something group had rejected
  - Why do we limit groups to 5 people?
    - You would never be able to schedule meetings
  - Why do we require 4 people minimum?
    - You need to experience groups to get ready for real world
- People have different work styles
  - Some people work in the morning, some at night
  - How do you decide when to meet or work together?
- What about project slippage?
  - It will happen, guaranteed!
  - Ex: phase 4, everyone busy but not talking. One person way behind. No one knew until very end - too late!
- Hard to add people to existing group
  - Members have already figured out how to work together
How to Make it Work?

- People are human. Get over it.
  - People will make mistakes, miss meetings, miss deadlines, etc. You need to live with it and adapt.
  - It is better to anticipate problems than clean up afterwards.
- Document, document, document
  - Why Document?
    » Expose decisions and communicate to others
    » Easier to spot mistakes early
    » Easier to estimate progress
  - What to document?
    » Everything (but don't overwhelm people or no one will read)
    » Standardize!
      » One programming format: variable naming conventions, tab indents, etc.
      » Comments (Requires, effects, modifies)—javadoc?

Suggested Documents for You to Maintain

- Project objectives: goals, constraints, and priorities
- Specifications: the manual plus performance specs
  - This should be the first document generated and the last one finished
- Meeting notes
  - Document all decisions
  - You can often cut & paste for the design documents
- Schedule: What is your anticipated timing?
  - This document is critical!
- Organizational Chart
  - Who is responsible for what task?

Use Software Tools

- Source revision control software (CVS)
  - Easy to go back and see history
  - Figure out where and why a bug got introduced
  - Communicates changes to everyone (use CVS’s features)
- Use automated testing tools
  - Write scripts for non-interactive software
  - Use "expect" for interactive software
  - Microsoft rebuild the Longhorn/Vista kernel every night with the day's changes. Everyone is running/testing the latest software
- Use E-mail and instant messaging consistently to leave a history trail

Test Continuously

- Integration tests all the time, not at 11pm on due date!
  - Write dummy stubs with simple functionality
    » Let's people test continuously, but more work
  - Schedule periodic integration tests
    » Get everyone in the same room, check out code, build, and test.
    » Don't wait until it is too late!
- Testing types:
  - Unit tests: check each module in isolation (use JUnit?)
  - Daemons: subject code to exceptional cases
  - Random testing: Subject code to random timing changes
- Test early, test later, test again
  - Tendency is to test once and forget; what if something changes in some other part of the code?
Administrivia

- Midterm I coming up in two weeks:
  - Wednesday, 3/8, TBA, Room TBA
  - 1 1/2 hour exam
  - Closed book, one page of hand-written notes (both sides)
- No class on day of Midterm
  - I will post extra office hours for people who have questions about the material (or life, whatever)
- Midterm Topics
  - Topics: Everything up to that Monday, 3/6
  - History, Concurrency, Multithreading, Synchronization, Protection/Address Spaces

CPU Scheduling

- Earlier, we talked about the life-cycle of a thread
  - Active threads work their way from Ready queue to Running to various waiting queues.
- Question: How is the OS to decide which of several tasks to take off a queue?
  - Obvious queue to worry about is ready queue
  - Others can be scheduled as well, however
- Scheduling: deciding which threads are given access to resources from moment to moment

Scheduling Assumptions

- CPU scheduling big area of research in early 70’s
- Many implicit assumptions for CPU scheduling:
  - One program per user
  - One thread per program
  - Programs are independent
- Clearly, these are unrealistic but they simplify the problem so it can be solved
  - For instance: is “fair” about fairness among users or programs?
  - If I run one compilation job and you run five, you get five times as much CPU on many operating systems
- The high-level goal: Dole out CPU time to optimize some desired parameters of system

Assumption: CPU Bursts

- Execution model: programs alternate between bursts of CPU and I/O
  - Program typically uses the CPU for some period of time, then does I/O, then uses CPU again
  - Each scheduling decision is about which job to give to the CPU for use by its next CPU burst
  - With timeslicing, thread may be forced to give up CPU before finishing current CPU burst
**Scheduling Policy Goals/Criteria**

- Minimize Response Time
  - Minimize elapsed time to do an operation (or job)
  - Response time is what the user sees:
    » Time to echo a keystroke in editor
    » Time to compile a program
  - Real-time Tasks: Must meet deadlines imposed by World

- Maximize Throughput
  - Maximize operations (or jobs) per second
  - Throughput related to response time, but not identical:
    » Minimizing response time will lead to more context switching than if you only maximized throughput
  - Two parts to maximizing throughput
    » Minimize overhead (for example, context-switching)
    » Efficient use of resources (CPU, disk, memory, etc)

- Fairness
  - Share CPU among users in some equitable way
  - Fairness is not minimizing average response time:
    » Better average response time by making system less fair

**First-Come, First-Served (FCFS) Scheduling**

- First-Come, First-Served (FCFS)
  - Also “First In, First Out” (FIFO) or “Run until done”
    » In early systems, FCFS meant one program scheduled until done (including I/O)
    » Now, means keep CPU until thread blocks

- Example:

<table>
<thead>
<tr>
<th>Process</th>
<th>Burst Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>P₁</td>
<td>24</td>
</tr>
<tr>
<td>P₂</td>
<td>3</td>
</tr>
<tr>
<td>P₃</td>
<td>3</td>
</tr>
</tbody>
</table>

- Suppose processes arrive in the order: P₁, P₂, P₃
- The Gantt Chart for the schedule is:

- Waiting time for P₁ = 0; P₂ = 24; P₃ = 27
- Average waiting time: \((0 + 24 + 27)/3 = 17\)
- Average Completion time: \((24 + 27 + 30)/3 = 27\)

- Convoy effect: short process behind long process

**FCFS Scheduling (Cont.)**

- Example continued:

<table>
<thead>
<tr>
<th>Process</th>
<th>Burst Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>P₁</td>
<td>6</td>
</tr>
<tr>
<td>P₂</td>
<td>0, P₂ = 0, P₃ = 3</td>
</tr>
<tr>
<td>P₃</td>
<td>3</td>
</tr>
</tbody>
</table>

- Waiting time for P₁ = 6; P₂ = 0; P₃ = 3
- Average waiting time: \((6 + 0 + 3)/3 = 3\)
- Average Completion time: \((3 + 6 + 30)/3 = 13\)

- In second case:
  - Average waiting time is much better (before it was 17)
  - Average completion time is better (before it was 27)

- FIFO Pros and Cons:
  - Simple (+)
    » Safeway: Getting milk, always stuck behind cart full of small items. Upside: get to read about space aliens!
  - Short jobs get stuck behind long ones (-)

**Round Robin (RR)**

- FCFS Scheme: Potentially bad for short jobs!
  - Depends on submit order
  - If you are first in line at supermarket with milk, you don't care who is behind you, on the other hand...

- Round Robin Scheme
  - Each process gets a small unit of CPU time (time quantum), usually 10-100 milliseconds
  - After quantum expires, the process is preempted and added to the end of the ready queue.
  - n processes in ready queue and time quantum is q ⇒
    » Each process gets \(1/n\) of the CPU time
    » In chunks of at most q time units
    » No process waits more than \((n-1)q\) time units

- Performance
  - q large ⇒ FCFS
  - q small ⇒ Interleaved (really small ⇒ hyperthreading?)
  - q must be large with respect to context switch, otherwise overhead is too high (all overhead)
Example of RR with Time Quantum = 20

- Example:

<table>
<thead>
<tr>
<th>Process</th>
<th>Burst Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>P₁</td>
<td>53</td>
</tr>
<tr>
<td>P₂</td>
<td>8</td>
</tr>
<tr>
<td>P₃</td>
<td>68</td>
</tr>
<tr>
<td>P₄</td>
<td>24</td>
</tr>
</tbody>
</table>

- The Gantt chart is:

```
   P₁  P₂  P₃  P₄  P₁  P₂  P₄  P₁  P₂  P₃
   0   20  28  48  88  108 112 125 145 153
```

- Waiting time for $P₁ = 112 - 88 = 24$
- Average waiting time = $112 / 4 = 28$
- Average completion time = $(125+28+153+112)/4 = 104$

• Thus, Round-Robin Pros and Cons:
  - Better for short jobs, Fair (+)
  - Context-switching time adds up for long jobs (-)

Round-Robin Discussion

- How do you choose time slice?
  - What if too big?
    - Response time suffers
  - What if infinite (-)?
    - Get back FIFO
  - What if time slice too small?
    - Throughput suffers!
- Actual choices of timeslice:
  - Initially, UNIX timeslice one second:
    - Worked ok when UNIX was used by one or two people.
    - What if three compilations going on? 3 seconds to echo each keystroke!
  - In practice, need to balance short-job performance and long-job throughput:
    - Typical time slice today is between 10ms – 100ms
    - Typical context-switching overhead is 0.1ms – 1ms
    - Roughly 1% overhead due to context-switching

Comparisons between FCFS and Round Robin

- Assuming zero-cost context-switching time, is RR always better than FCFS?
- Simple example: 10 jobs, each take 100s of CPU time
  - RR scheduler quantum of 1s
  - All jobs start at the same time
- Completion Times:

<table>
<thead>
<tr>
<th>Job #</th>
<th>FIFO</th>
<th>RR</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100</td>
<td>991</td>
</tr>
<tr>
<td>2</td>
<td>200</td>
<td>992</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>9</td>
<td>900</td>
<td>999</td>
</tr>
<tr>
<td>10</td>
<td>1000</td>
<td>1000</td>
</tr>
</tbody>
</table>

- Both RR and FCFS finish at the same time
- Average response time is much worse under RR!
  - Bad when all jobs same length
- Also: Cache state must be shared between all jobs with RR but can be devoted to each job with FIFO
- Total time for RR longer even for zero-cost switch!

Earlier Example with Different Time Quantum

<table>
<thead>
<tr>
<th>Quantum</th>
<th>P₁</th>
<th>P₂</th>
<th>P₃</th>
<th>P₄</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>85</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>32</td>
</tr>
<tr>
<td>5</td>
<td>80</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>32</td>
</tr>
<tr>
<td>10</td>
<td>72</td>
<td>20</td>
<td>85</td>
<td>20</td>
<td>66</td>
</tr>
</tbody>
</table>


Wait Time

<table>
<thead>
<tr>
<th>Quantum</th>
<th>P₁</th>
<th>P₂</th>
<th>P₃</th>
<th>P₄</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>68</td>
<td>145</td>
<td>0</td>
<td>121</td>
<td>83½</td>
</tr>
<tr>
<td>5</td>
<td>85</td>
<td>153</td>
<td>0</td>
<td>32</td>
<td>69½</td>
</tr>
<tr>
<td>10</td>
<td>85</td>
<td>153</td>
<td>0</td>
<td>32</td>
<td>69½</td>
</tr>
</tbody>
</table>

Completion Time

<table>
<thead>
<tr>
<th>Quantum</th>
<th>P₁</th>
<th>P₂</th>
<th>P₃</th>
<th>P₄</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>137</td>
<td>153</td>
<td>81</td>
<td>100</td>
<td>100½</td>
</tr>
<tr>
<td>5</td>
<td>135</td>
<td>153</td>
<td>82</td>
<td>99</td>
<td>99½</td>
</tr>
<tr>
<td>10</td>
<td>135</td>
<td>153</td>
<td>80</td>
<td>99</td>
<td>99½</td>
</tr>
</tbody>
</table>

What if we Knew the Future?

- Could we always mirror best FCFS?
- Shortest Job First (SJF):
  - Run whatever job has the least amount of computation to do
  - Sometimes called “Shortest Time to Completion First” (STCF)
- Shortest Remaining Time First (SRTF):
  - Preemptive version of SJF: if job arrives and has a shorter time to completion than the remaining time on the current job, immediately preempt CPU
  - Sometimes called “Shortest Remaining Time to Completion First” (SRTCF)
- These can be applied either to a whole program or the current CPU burst of each program
  - Idea is to get short jobs out of the system
  - Big effect on short jobs, only small effect on long ones
  - Result is better average response time

Discussion

- SJF/SRTF are the best you can do at minimizing average response time
  - Provably optimal (SJF among non-preemptive, SRTF among preemptive)
  - Since SRTF is always at least as good as SJF, focus on SRTF
- Comparison of SRTF with FCFS and RR
  - What if all jobs the same length?
    » SRTF becomes the same as FCFS (i.e. FCFS is best can do if all jobs the same length)
  - What if jobs have varying length?
    » SRTF (and RR): short jobs not stuck behind long ones

Example to illustrate benefits of SRTF

- Three jobs:
  - A, B: both CPU bound, run for week
  - C: I/O bound, loop 1ms CPU, 9ms disk I/O
  - If only one at a time, C uses 90% of the disk, A or B could use 100% of the CPU
- With FIFO:
  - Once A or B get in, keep CPU for two weeks
- What about RR or SRTF?
  - Easier to see with a timeline

SRTF Example continued:

- Disk Utilization: 9/201 ~ 4.5%
- Disk Utilization: ~90% but lots of wakeups!
SRTF Further discussion

- **Starvation**
  - SRTF can lead to starvation if many small jobs!
  - Large jobs never get to run
- **Somehow need to predict future**
  - How can we do this?
  - Some systems ask the user
    - When you submit a job, have to say how long it will take
    - To stop cheating, system kills job if takes too long
  - But: Even non-malicious users have trouble predicting runtime of their jobs
- **Bottom line, can’t really know how long job will take**
  - However, can use SRTF as a yardstick for measuring other policies
    - Optimal, so can’t do any better
  - **SRTF Pros & Cons**
    - Optimal (average response time) (+)
    - Hard to predict future (-)
    - Unfair (-)

Predicting the Length of the Next CPU Burst

- **Adaptive:** Changing policy based on past behavior
  - CPU scheduling, in virtual memory, in file systems, etc
  - Works because programs have predictable behavior
    - If program was I/O bound in past, likely in future
    - If computer behavior were random, wouldn’t help
- **Example:** SRTF with estimated burst length
  - Use an estimator function on previous bursts:
    - Let \( t_{n-1}, t_{n-2}, t_{n-3}, \ldots \) be previous CPU burst lengths.
    - Estimate next burst \( t_n = f(t_{n-1}, t_{n-2}, t_{n-3}, \ldots) \)
  - Function \( f \) could be one of many different time series estimation schemes (Kalman filters, etc)
  - For instance, exponential averaging:
    - \( t_n = \alpha t_{n-1} + (1-\alpha)t_{n-1} \)
      with \( 0 < \alpha \leq 1 \)

Multi-Level Feedback Scheduling

- **Another method for exploiting past behavior**
  - First used in CTSS
  - Multiple queues, each with different priority
    - Higher priority queues often considered “foreground” tasks
  - Each queue has its own scheduling algorithm
    - e.g. foreground - RR, background - FCFS
    - Sometimes multiple RR priorities with quantum increasing exponentially (highest:1ms, next:2ms, next: 4ms, etc)
- **Adjust each job’s priority as follows (details vary)**
  - Job starts in highest priority queue
  - If timeout expires, drop one level
  - If timeout doesn’t expire, push up one level (or to top)

Scheduling Details

- **Result approximates SRTF:**
  - CPU bound jobs drop like a rock
  - Short-running I/O bound jobs stay near top
- **Scheduling must be done between the queues**
  - **Fixed priority scheduling:**
    - serve all from highest priority, then next priority, etc.
  - **Time slice:**
    - each queue gets a certain amount of CPU time
    - e.g., 70% to highest, 20% next, 10% lowest
- **Countermeasure:** user action that can foil intent of the OS designer
  - For multilevel feedback, put in a bunch of meaningless I/O to keep job’s priority high
  - Of course, if everyone did this, wouldn’t work!
- **Example of Othello program:**
  - Playing against competitor, so key was to do computing at higher priority the competitors.
    - Put in printf’s, ran much faster!
What about Fairness?

- What about fairness?
  - Strict fixed-priority scheduling between queues is unfair (run highest, then next, etc):
    - long running jobs may never get CPU
    - In Multics, shut down machine, found 10-year-old job
  - Must give long-running jobs a fraction of the CPU even when there are shorter jobs to run
  - Tradeoff: fairness gained by hurting avg response time!

- How to implement fairness?
  - Could give each queue some fraction of the CPU
    - What if one long-running job and 100 short-running ones?
    - Like express lanes in a supermarket—sometimes express lanes get so long, get better service by going into one of the other lines
  - Could increase priority of jobs that don’t get service
    - What is done in UNIX
    - This is ad hoc—what rate should you increase priorities?
    - And, as system gets overloaded, no job gets CPU time, so everyone increases in priority ⇒ Interactive jobs suffer

Lottery Scheduling

- Yet another alternative: Lottery Scheduling
  - Give each job some number of lottery tickets
  - On each time slice, randomly pick a winning ticket
  - On average, CPU time is proportional to number of tickets given to each job
  - How to assign tickets?
    - To approximate SRTF, short running jobs get more, long running jobs get fewer
    - To avoid starvation, every job gets at least one ticket (everyone makes progress)
  - Advantage over strict priority scheduling: behaves gracefully as load changes
    - Adding or deleting a job affects all jobs proportionally, independent of how many tickets each job possesses

Lottery Scheduling Example

- Lottery Scheduling Example
  - Assume short jobs get 10 tickets, long jobs get 1 ticket

<table>
<thead>
<tr>
<th># short jobs/# long jobs</th>
<th>% of CPU each short job gets</th>
<th>% of CPU each long job gets</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/1</td>
<td>91%</td>
<td>9%</td>
</tr>
<tr>
<td>0/2</td>
<td>N/A</td>
<td>50%</td>
</tr>
<tr>
<td>2/0</td>
<td>50%</td>
<td>N/A</td>
</tr>
<tr>
<td>10/1</td>
<td>9.9%</td>
<td>0.99%</td>
</tr>
<tr>
<td>1/10</td>
<td>50%</td>
<td>5%</td>
</tr>
</tbody>
</table>

- What if too many short jobs to give reasonable response time?
  - In UNIX, if load average is 100, hard to make progress
  - One approach: log some user out

How to Evaluate a Scheduling algorithm?

- Deterministic modeling
  - takes a predetermined workload and compute the performance of each algorithm for that workload
- Queueing models
  - Mathematical approach for handling stochastic workloads
- Implementation/Simulation:
  - Build system which allows actual algorithms to be run against actual data. Most flexible/general.
A Final Word on Scheduling

- When do the details of the scheduling policy and fairness really matter?
  - When there aren’t enough resources to go around
- When should you simply buy a faster computer?
  - (Or network link, or expanded highway, or …)
  - One approach: Buy it when it will pay for itself in improved response time
    » Assuming you’re paying for worse response time in reduced productivity, customer angst, etc...
    » Might think that you should buy a faster X when X is utilized 100%, but usually, response time goes to infinity as utilization Þ 100%
- An interesting implication of this curve:
  - Most scheduling algorithms work fine in the “linear” portion of the load curve, fail otherwise
  - Argues for buying a faster X when hit “knee” of curve

Summary

- Suggestions for dealing with Project Partners
  - Start Early, Meet Often
  - Develop Good Organizational Plan, Document Everything, Use the right tools
  - Develop a Comprehensive Testing Plan
  - (Oh, and add 2 years to every deadline!)
- Scheduling: selecting a waiting process from the ready queue and allocating the CPU to it
- FCFS Scheduling:
  - Run threads to completion in order of submission
  - Pros: Simple
  - Cons: Short jobs get stuck behind long ones
- Round-Robin Scheduling:
  - Give each thread a small amount of CPU time when it executes; cycle between all ready threads
  - Pros: Better for short jobs
  - Cons: Poor when jobs are same length

Summary (2)

- Shortest Job First (SJF)/Shortest Remaining Time First (SRTF):
  - Run whatever job has the least amount of computation to do/least remaining amount of computation to do
  - Pros: Optimal (average response time)
  - Cons: Hard to predict future, Unfair
- Multi-Level Feedback Scheduling:
  - Multiple queues of different priorities
  - Automatic promotion/demotion of process priority in order to approximate SJF/SRTF
- Lottery Scheduling:
  - Give each thread a priority-dependent number of tokens (short tasks Þ more tokens)
  - Reserve a minimum number of tokens for every thread to ensure forward progress/fairness