BIOS and Scheduling

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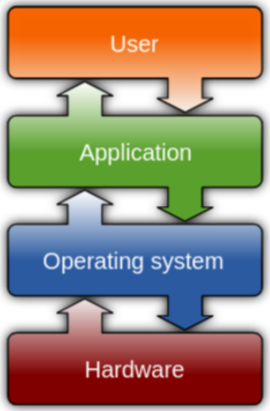
Summary

Hopefully from the material you've learnt:

- Why we need a scheduler
- What metrics we might use in scheduler decision making
- Why concepts like starvation are a problem
- What non-preemptive schedulers are
- What preemptive schedulers are

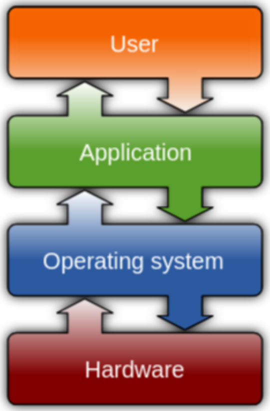
The Operating System

- The OS exists as a sort of middleware between applications and hardware
- It's not strictly necessary to run a computer, and some systems exist without an OS at all. And they run fast
- But the OS simplifies so much, and without it you really need to do everything from scratch, often in machine code (Boo)



An Aside - Layering

- We've seen this sort of thing already with language levels
- Layering is an important concept used repeatedly in Computer Science (and other places)
- It's a way of building on previous knowledge



Hardware and Software

- Worth setting out what we mean by these words
    - Hardware is physical machinery that takes signals to manipulate physical components, albeit small ones such as disk storage
    - Software is a collection of signals used to control that physical hardware
- Hardware performs a specific job that cannot be altered
- Software needs hardware to run on, but can alter how it uses that hardware

A CPU is Hardware

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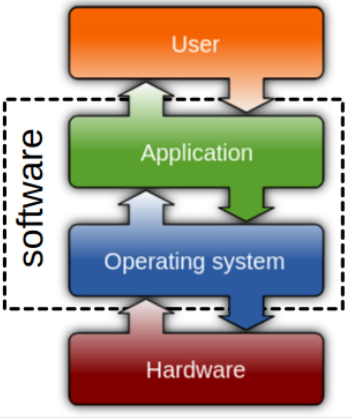
  - Software is a collection of signals used to control that physical hardware
- Hardware performs a specific job that cannot be altered
  - CPU, Screen, Lamp
- Software needs hardware to run on, but can alter how that hardware is used
  - Spotify, Minecraft, Windows

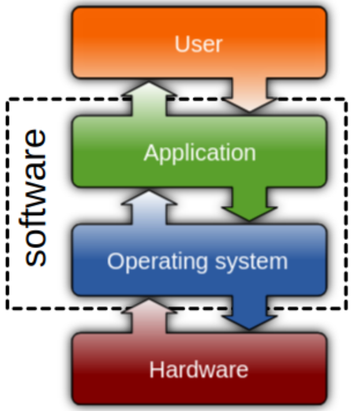
The OS Is All Just Software

- The OS is just software!
  - Note that some components are handled in dedicated hardware (cache, MMU, ALU, FPU, etc.)
  - But this is just because they are operations that have become standard enough that we can make dedicated hardware for them.
  - Originally many of these were software
- This makes it powerful, configurable, and slow(er than just machine code)



The OS Is All Just Software

- Consider everything we've covered so far
  - Caching, Processes, Floats, Memory Allocation, etc.
- These are all managed by software, even when they seem to depend on hardware
- And most of them are managed by the OS



Let's Consider Processes

- They're just a collection of (meaningful) data
  - Virtual Memory Space (stack, heap, code, etc.)
  - Execution Context (registers, etc.)
  - Plus some other things added by the OS to track each process (PID, parent, children etc.)
- There's nothing in hardware defining any of this, and the data that defines a process can just be saved to memory/disk just like any other file
- What makes it a meaningful process, is that the OS swaps out these saved collections of data on the fly

The Operating System

- It manages the complete runtime of the computer
- It's essentially *the* hard coded 'program' that starts everything else
- All those processes, memory accesses, etc etc...

But That's Not Enough

- The trouble with software is it only does anything when the computer is running
- E.g. powered up and already in a 'runnable' state
  - What does runnable even mean?

Where To Begin?

- Modern computers are large, complex beasts
- Operating Systems only complicate things by adding all their own layers
- We need some hardware to start things going
- Or at least start the ball rolling so the OS can set up the rest

BIOS

- Basic Input/Output Stream
- Performs a few functions that are outside our scope (Well, more outside our scope)
- The three important ones though are running basic setup, performing POST test, and handing off to the OS

The BIOS Chip

- After *seconds* of internet search, this is the best picture I could find, somehow
- The BIOS chip comes pre-installed
- Usually designed to work with a specific motherboard
- A motherboard being the main hardware component of most PCs, linking everything else together and hosting the CPU itself

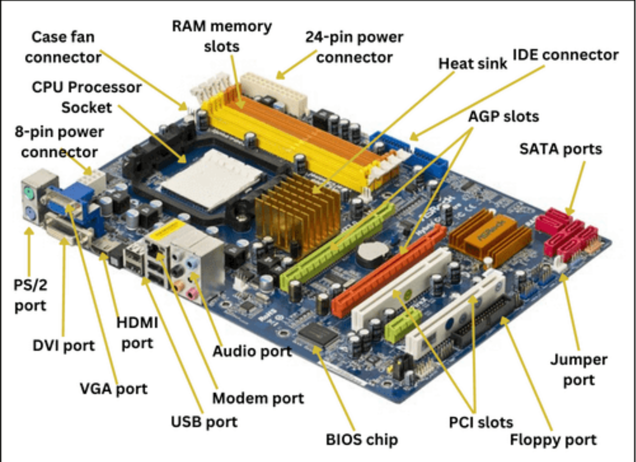
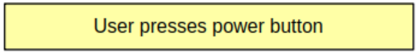
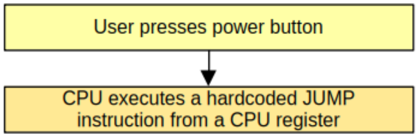


Fig: Main components of motherboard

Boot Sequence



Boot Sequence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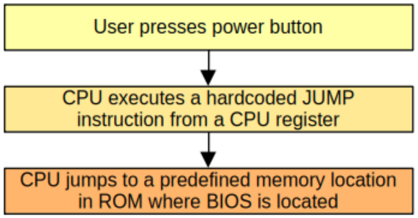
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CPU jumps to a predefined memory location in ROM where BIOS is located

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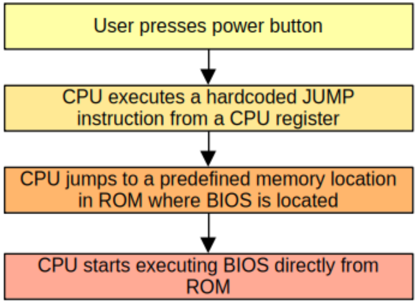
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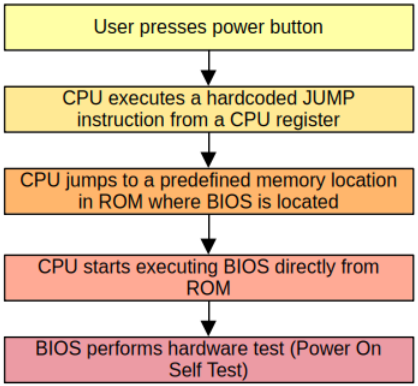
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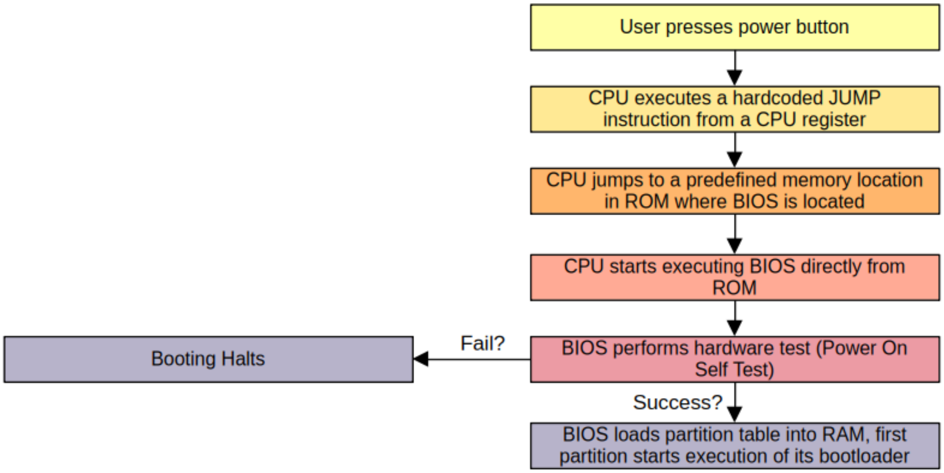
BIOS performs hardware test (Power On Self Test)

Power On Self Test

- Verifies integrity in BIOS code
- Verify basic hardware components (Registers, timers)
- Verify main memory (RAM)
- Initialise system buses
- Identify connected devices
- Plus other things buts its essentially verifying, identifying and sometime initialising

Boot Sequence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Fail?
Booting Halts
Success?
BIOS loads partition table into RAM, first partition starts execution of its bootloader

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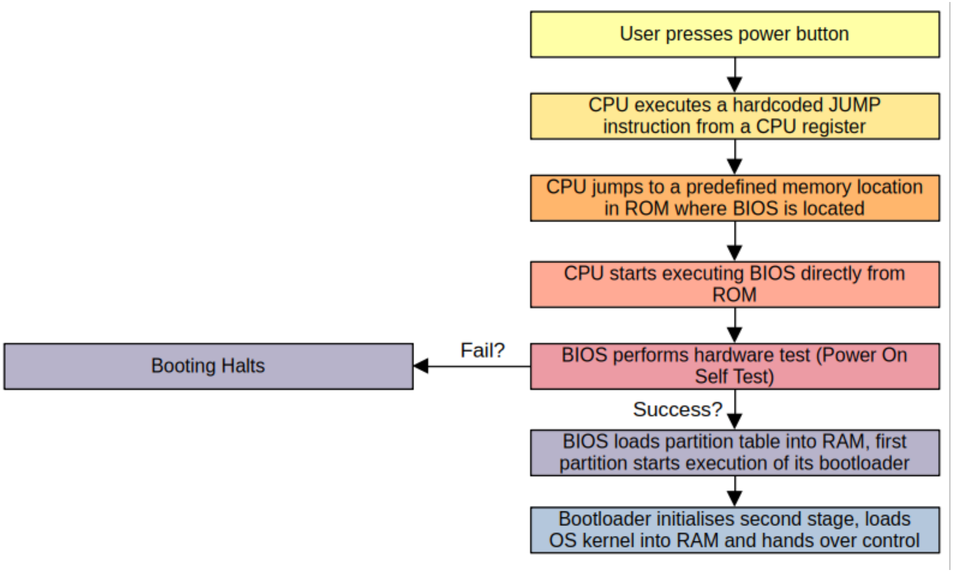
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Fail?
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Success?
BIOS loads partition table into RAM, first partition starts execution of its bootloader
Bootloader initialises second stage, loads OS kernel into RAM and hands over control

Bootloader

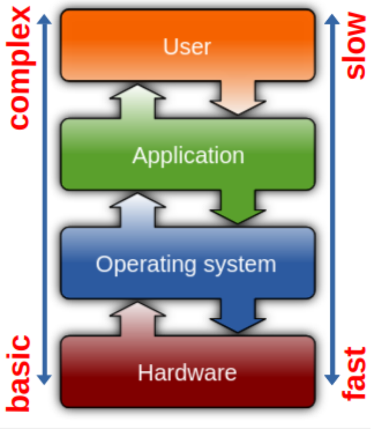
- Stored in non-volatile, read-only memory
- Initialises the different components if necessary, most notably the RAM
- Loads the OS kernel into RAM
- Then hands off control to that OS kernel which will handle everything from then on
- *This* is why a kernel isn't really a process, and the OS is just software

Why BIOS in Hardware?

- Most fast memory (SRAM and DRAM) is volatile
- We need to start somewhere
- We could just make all our memory out of non-volatile memory
    - But that's expensive

Why OS in software?

- Typically, the further up the layers we go, the less time efficient it is
- But also the further up we go, the more concept efficient it is
- Design is always about compromise, computer design is no different
- The OS can provide all sorts of powerful features allowing for concurrency, multi users, security, data management, pretty pictures



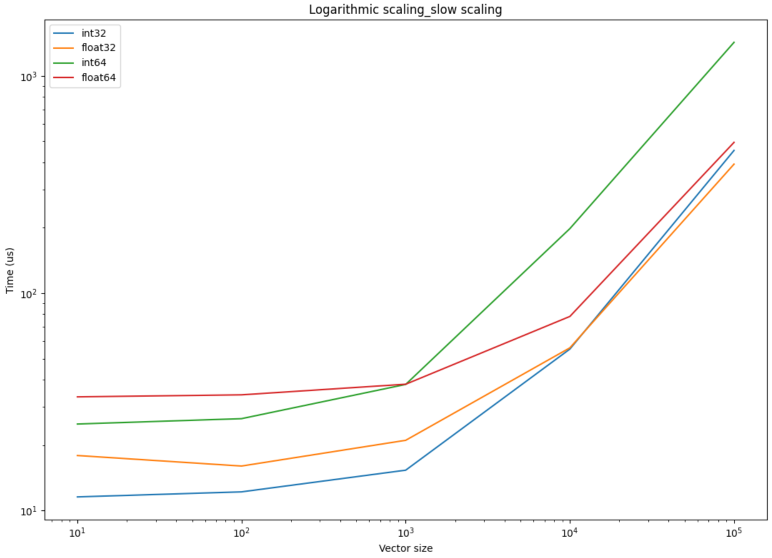
But Some Software Becomes Hardware

- MMU used to be just software lookup
- Cache always requires dedicated hardware, but more of it now and its better managed
- ALU/FPU used to be just regular CPU operations
- Implementing in hardware is quick!

Another Aside - Hardware vs Software

- Anything we can support directly in hardware will be *fast*
- Primarily this is down to pipelining of operations
- Can lead to some unintuitive results ...
- The following are some timing tests of large numbers of int and float operations

Another Aside - Hardware vs Software



Another Aside - Hardware vs Software

- For small problems ints are faster, as expected
- But as we get larger problems, floats actually become faster
- Each (probably) computed on dedicated hardware
  - ALU: Computes int and logic operations
  - FPU: Computes floating point operations
- We'll return to pipelining towards the end of the course...
- For now just see that implementing in hardware can make things *considerably* quicker

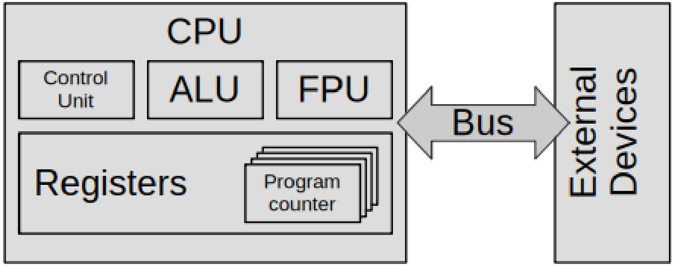
Could OS operations be implemented in hardware?

- No
- Hardware requires specifics to cemented to be worth the trouble
- We want to customise a lot of them OS operations (size of virtual memory, users, access to files)
- So we have to accept the overhead for these powerful features

The CPU

- A CPU is a dedicated piece of hardware for running software
- It has a few (ish) set of hard coded operations
  - Reading signals
  - Logical operations
- These are what machine code (and effectively Assembly) are expressing
- Software is just choosing what operation to perform in what order

The CPU



- It's a fundamental limit of a CPU that it can only ever do one thing at a time
- It's essentially just a fancy logic gate (this is a gross oversimplification)
- To run multiple processes, we need to context switch between them

The CPU

- If we don't do this well:

Starvation

One or more processes perpetually being denied the necessary resources to continue.

- This can manifest in a few ways
  - One or more processes will not progress at all
  - The CPU will compute unimportant tasks first
  - Hardware components will stop working
- Any of these are bad news, as presumably anything running has a reason to do so

Metric For Processes

- Once we've decided to decide between processes, we to decide on how we are going to decide between processes
  - How much memory they use
  - How long they take to complete
  - How much work they're actually doing
  - If it's a process that's important to the user
  - If it's a process that's important to the system
- The problem with most of these, is we only really know them once the process has already run.
  - Can estimate at runtime
  - But good estimation is often either accurate or computationally lightweight...
- This is a surprisingly complex topic, we're only going to broadly introduce here

Metric For Processes

- We need mechanisms to select processes that are simple, lightweight and meaningful
- Some of the following strategies will incorporate priority rankings, or time to completion
- Most will just use processes ID's to track that each process is getting some expected 'fair share' of computational resources.
  - Yes its crude, but it's also fast
  - And its usually good enough
  - In practice this whole lecture is somewhat of an oversimplification and many actual schedulers will use complex combinations of many of the following strategies and metrics

FIFO

- First In, First Out'
- Run each process, to completion, one after the other
- Perhaps the simplest scheduling strategy by far, no scheduling overhead except for the inevitable context switch once a process is complete and the maintenence of a process queue
- But if you've only a single core, you can only run a single process at a time
- What happens if task A is far too slow?

SJF

- Shortest Job First
- Variation of FIFO, sorted queue
- Still running each job to completion
- Some low overhead in maintaining a sorted list
- Gets *some* work done ASAP

Computation Time

- Consider three jobs:
  - A: Takes 10 minutes
  - B: Takes 1 minute
  - C: Takes 1 minute
- Now consider how each scheduler computes these:
  - FIFO: A->B->C, Mean completion time: $(10+11+12)/3 = 11$ minutes
  - SJF: B->C->A, Mean completion time: $(1+2+12)/3 = 5$ minutes
- We complete more work in a shorter time
- If all processes are queued at the same time, this is actually the optimal solution

STCF

- Shortest Time to Completion First
- Variation of FIFO, sorted queue
- Some low overhead in maintaining a sorted list
- Essentially the same as SJF, but we sort our process queue each time a job is added
- If a shorter job is added to the queue than the current one has left, context switch

Non-Preemptive Schedulers

- FIFO, SJF and STCF are all Non-Preemptive Schedulers
- They all run until a process has completed or it somehow gives up the processor
- This make it unfeasible to have a modern PC with multiple processes and programs running seemingly at once
- What happens if a process runs forever?
- But they are simple systems, and are still commonly used in many higher level scheduling
  - batch processing
  - thread pools
  - cloud services

Preemptive Schedulers

- We need to context switches because processes:
  - Can go on for a long time, even forever
  - Can need input from external devices or other processes
  - Can be scheduled at any time
  - Do not always know how many resources they will need ahead of time
- Note that even some non-preemptive schedulers still use context switches, but far more infrequently than what we're about to introduce

Round Robin

- The simplest form of preemptive scheduler
- Give each process a certain small period of computation
- Once one process has used up its small period, context switch to the next
- Don't reschedule a process until all others have had a period of computation
- Ensures some progress on everything ASAP
- Relatively low scheduling overhead, but high overhead for a lot of context switches
    - On most systems, context switch is 1μs or 1000 clock cycles
    - But perform enough and they add up
- This cost is constant (ish) so if we just give each process enough time to before the switch then it vanishes into the background.
    - Couldn't find any consensus on how long a typical scheduler gives each iteration but 100-250μs was mentioned reasonably often

Lottery Share

- Sort of similar to Round Robin
- But attempts to give all processes a proportional share of resources
- Assigns each process a number of 'tickets' proportional to the amount of work to be done
- Periodically, randomly pick a ticket, the owning process gets scheduled
  - If same processes drawn twice in a row, no context switching needed
  - Potential for starvation still exists, but there are ways around that
- Leads to probabilistic fairness in a reasonably sized system

The Benefits of Tickets

- Tickets have a lot of useful usability qualities for system administration
- Give users a set amount of tickets each, they can distribute them amongst their processes as needed
- If a process needs to wait for another process, it can lend it some of its own tickets to ensure it can progress
- Can also trivially manipulate ticket numbers for our own ends.
  - Privileging users by inflating their tickets
  - Increasing tickets of longer queued jobs should counter starvation

Stride

- In essence this is a non-random lottery
- Still give process tickets
- Scheduler calculates each processes `stride` inversely proportional to its ticket amount
- Each process start with a `pass` value of 0
- Update the `pass` value by the `stride` each time it runs
- Deterministically pick the process with the lowest `pass` to run
- Randomly select if two or more have the same `pass` value

Stride

- Lets imagine 3 Processes:
  - A = 100 tickets, 100 stride
  - B = 50 tickets, 200 stride
  - C = 250 tickets, 40 stride
- Here we've chosen 10000 as a value to divide the tickets by, but this is arbitrary. It doesn't affect the relationship

Pass(A)	Pass(B)	Pass(C)	Runs?	
0	0	0	A	<-Could also be B or C here
100	0	0	B	
100	200	0	C	
100	200	40	C	
100	200	80	C	
100	200	120	A	
200	200	120	C	
200	200	160	C	
200	200	200	A	<-Could also be B or C here

MLFQ

- Multi Level Feedback queue
- Assign each process a priority value
- Each priority values has an associated queue
- Higher priorities are computed before lower
- Within each queue use another scheduling system, usually some version of round robin.

Setting Priorities

- Sometimes done manually.
  - OS Processes prioritized
  - Hardware drivers
  - Network interactions
- Can also be automatic
  - Starting processes have the highest priority
    - Let everything start ASAP
    - Give opportunity to observe and learn
  - If a job willingly gives up CPU, keep priority the same
    - Probably hardware waiting for interaction
    - Keeps responses quick
  - If a job exceeds allocated computation time, decrement priority
    - Long running analysis that isn't waiting for anyone
    - Halting problem!

MLFQ

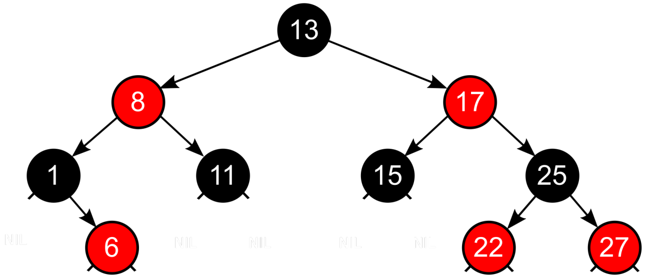
- Starvation is still an issue for lower priorities
  - Generally, long waiting processes have priorities increased
- Also, hardware processes remain high priority yet keep giving up the CPU meaning lots of spurious context switches
  - Allocate each process a 'computation time' across schedulings. Once exceeded, decrement priority
  - Computationally heavy processes will decrement quicker
- Do not need to give each priority queue the same computation allocation
  - After a time, higher priorities should be just the quick, hardware handling processes so give them each a small time allocation
  - Equally the lower you go, the longer running a process probably is, so it can be given a larger time allocation
  - As always, there's a balance to be struck here

CFS

- Completely Fair Schedular
- Used within Linux
- Effectively a weighted round robin system, plus additions
- Set a value, `sched_latency` to set how often (in theory) each process will be computed
- As we add more processes, they are divided equally across the `sched_latency`
- Set an additional value, `min_granularity` to ensure a minimum runtime per process
    - Ensures not too many context switches

CFS

- CFS intends to scale well. Modern systems frequently have thousands of processes
- Intuitively we can just keep a list/array
  - Picking off the next process is easy (if list is sorted)
  - But maintaining that sorting has O(n) complexity
- Better to use a tree, with O(log n) complexity for search, insert and delete



Scheduling

- Obviously this has been a broad overview
- Efficient scheduling is still very much an ongoing field
- By and large we treat it as a black box
- Modern OS's use preemptive scheduling to context switch regularly
- But many remote systems use cruder non-preemptive schedulers