CSE 451: Operating Systems
Winter 2015

Module 1
Course Introduction

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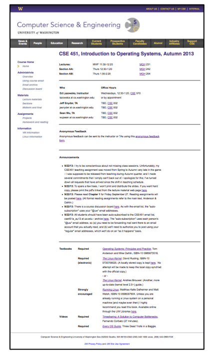
Today's agenda

- Administrivia
  - Course overview
    - course staff
    - general structure
    - the text(s)
    - policies
    - your to-do list
- OS overview
  - Trying to make sense of the topic

Course overview

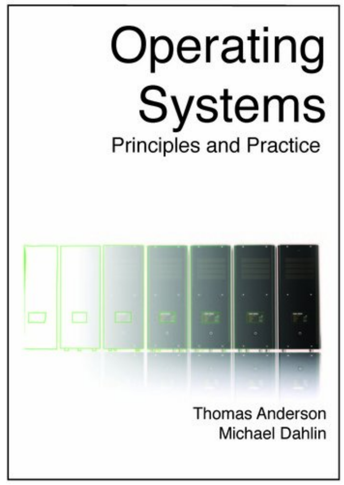


- Operationally, everything you need to know will be on the course web page:
  http://www.cs.washington.edu/451/
- Or on the course email and email archive:
  TBD
- Or on the course discussion board:
  TBD

But to tide you over for the next hour …

- Course staff
  - Mark Zbikowski
  - Gary Kimura
  - Michael Johnson
  - Ryan McMahon
- General Course Structure
  - Read the text prior to class (really important)
  - Homework exercises to motivate reading by non-saints
  - Sections will focus on projects
  - You're paying for interaction. We lecture for 40+ minutes and I expect YOU to ask questions. If you don’t, I will ask YOU questions.

- The text



- The text
  - Really outstanding – written by current experts
    - Allows you to actually figure out how things work
    - *Way* better (and way less expensive) than any alternative
  - ~~First~~ Second edition – *still* has typos
    - Try not to resent this; help the authors debug it
  - Think of it as helping you to understand, and dig deeper than, the lecture, section, and project material
- Other resources
  - Many online; some of them are essential
- Policies
  - Collaboration vs. cheating
  - Projects: late policy

- Projects
  - Project 0: a C warmup – individual assignment
  - Projects 1-3: significant OS "internals" projects to be done in teams of 2
    - Adding a system call
    - Building a thread package
    - Modifying the file system
  - You're likely to be happier if you form a team on your own than if we form one for you!
    - You'll need to do this over the weekend
    - Project 1 will begin next Friday
    - We'll ask for your input by Sunday night and create teams as needed

- Your to-do list …
  - Please read the entire course web thoroughly, *today*
  - Be sure you're on the cse451 email list, and check your email daily
    - You should have received email over the weekend!
    - Be sure your "@uw" email is being forwarded!
  - Please keep up with the reading
  - Homework 1 (reading) is posted on the web **now**
    - Due at **the start of class Friday**
  - Project 0 ("warmup") is posted on the web **now**
    - Will be discussed in section Thursday
    - Due at the end of the day **next Friday**
  - Begin coming up with a 2-person team for Projects 1-3

- Course registration
  – If you're going to drop, please do it soon!
  – If you want to get into the class, be sure you've registered with the advisors
    – *They run the show*
    – *I have a registration sheet here!*

More about 451

- This is really two "linked" classes:
  – A classroom/textbook part (mainly run by Mark)
  – A project part (mainly the TAs and Gary)
- In a perfect world, we would do this as a two-quarter sequence
  – The world isn't perfect … and CS majors have too many required courses as it is.
- By the end of the course, you'll see how it all fits together!
  – There will be a lot of work. Do not start projects late.
  – You'll learn a lot, and have a ton of fun
  – In the end, you'll understand much more deeply how computer systems work
- **"There is no magic"**

- In this class you will learn:
  - what are the major components of most OS's?
  - how are the components structured?
  - what are the most important (most common) interfaces?
  - what policies are typically used in an OS?
  - what algorithms are used to implement these policies?
- Philosophy
  - You may not ever build an OS
  - But as a computer scientist or computer engineer you need to understand the foundations
  - Most importantly, operating systems exemplify the sorts of engineering design tradeoffs that you'll need to make throughout your careers – compromises among and within cost, performance, functionality, complexity, schedule …
  - We want you will love this course!
  - We want you to remember it in 5 years as one that paid off!

What is an Operating System?

- Answers:
  - I don't know.
  - Nobody knows.
  - The book claims to know – read Chapter 1.
  - They're programs – big hairy programs
    - The Linux source you'll be compiling has over 1.7M lines of C
    - Windows has way, way more… NTFS for Windows 8 was over 800K itself.

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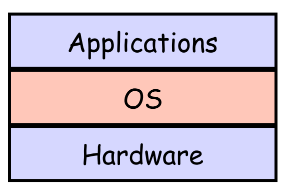
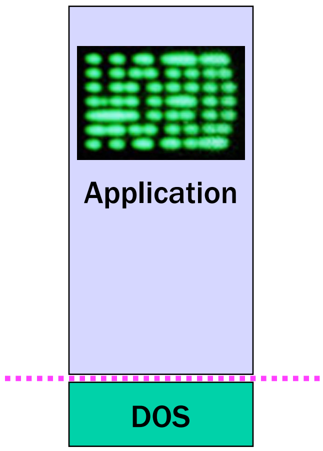
Okay. What are some goals of an OS?

The traditional picture



- "The OS is everything you don't need to write in order to run your application"
- This depiction invites you to think of the OS as a library; we'll see that
  - In some ways, it is:
    - all operations on I/O devices require OS calls (*syscalls)*
  - In other ways, it isn't:
    - you use the CPU/memory without OS calls
    - it intervenes without having been explicitly called

“Everything you don’t have to write”
What is Windows?



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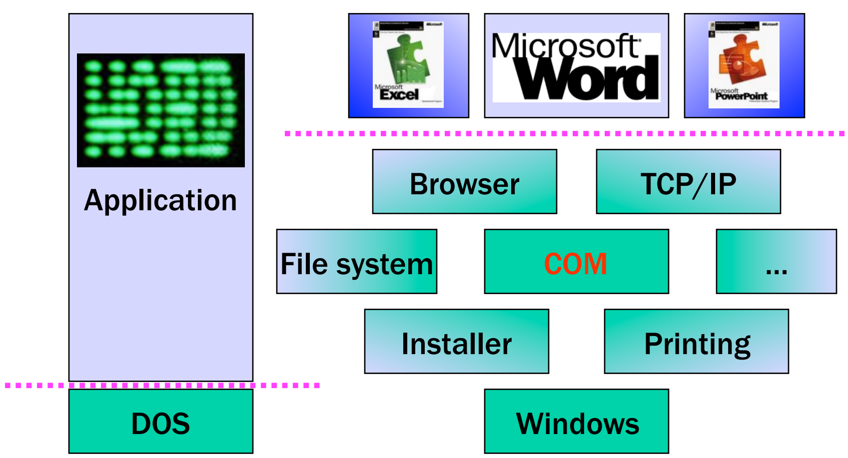
“Everything you don’t have to write”
What is Windows?



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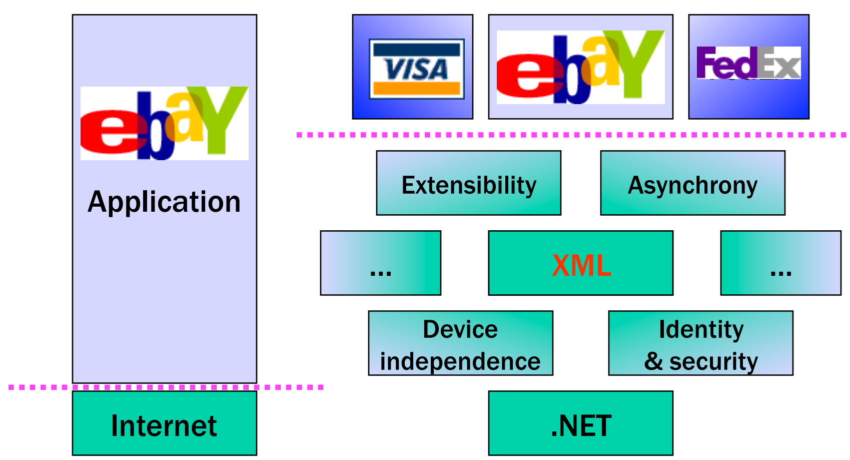
"Everything you don't have to write"
What is .NET?

"Everything you don't have to write"
What is .NET?



The OS and hardware

- An OS mediates programs' access to hardware resources (*sharing* and *protection*)
  - computation (CPU)
  - volatile storage (memory) and persistent storage (disk, etc.)
  - network communications (TCP/IP stacks, Ethernet cards, etc.)
  - input/output devices (keyboard, display, sound card, etc.)
- The OS abstracts hardware into logical resources and well-defined interfaces to those resources (*ease of use*)
  - processes (CPU, memory)
  - files (disk)
  - programs (sequences of instructions)
  - sockets (network)

The text says an OS is …

- A Referee
  - Mediates resource sharing
- An Illusionist
  - Masks hardware limitations
- Glue
  - Provides common services

Why bother with an OS?

- Application benefits
  - programming simplicity
    - see high-level abstractions (files) instead of low-level hardware details (device registers)
    - abstractions are reusable across many programs
  - portability (across machine configurations or architectures)
    - device independence: 3com card or Intel card?
- User benefits
  - safety
    - program "sees" its own virtual machine, thinks it "owns" the computer
    - OS protects programs from each other
    - OS fairly multiplexes resources across programs
  - efficiency (cost and speed)
    - share one computer across many users
    - concurrent execution of multiple programs

The major OS issues

- **structure**: how is the OS organized?
- **sharing**: how are resources shared across users?
- **naming**: how are resources named (by users, by programs)?
- **protection**: how is one user/program protected from another?
- **security**: how is the integrity of the OS and its resources ensured?
- **performance**: how do we make it all go fast?
- **availability**: can you always access the services you need?
- **reliability**: what happens if something goes wrong (either with hardware or with a program)?
- **extensibility**: can we add new features?
- **communication**: how do programs exchange information, including across a network?

More OS issues…

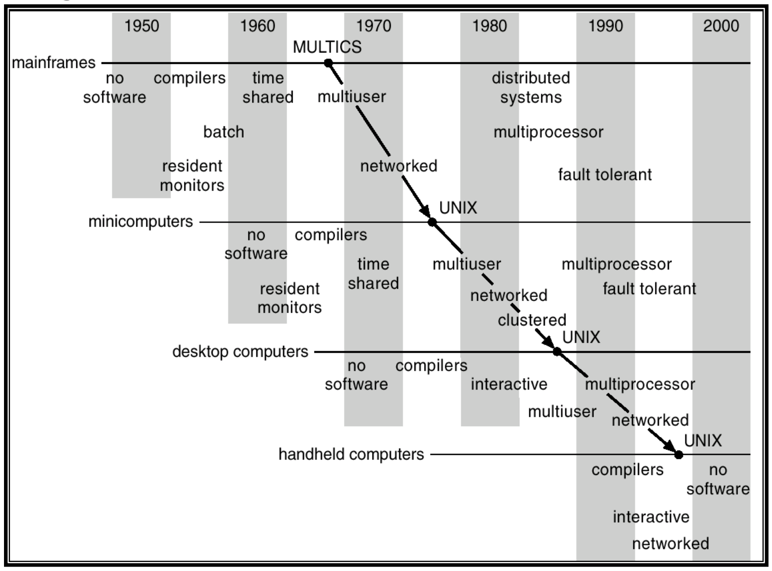
- **concurrency**: how are parallel activities (computation and I/O) created and controlled?
- **scale**: what happens as demands or resources increase?
- **persistence**: how do you make data last longer than program executions?
- **distribution**: how do multiple computers interact with each other?
- **accounting**: how do we keep track of resource usage, and perhaps charge for it?
- **auditing**: can we reconstruct who did what to whom?

There are tradeoffs – not right and wrong!

Hardware/Software Changes with Time

- 1960s: mainframe computers (IBM)
- 1970s: minicomputers (DEC)
- 1980s: microprocessors and workstations (SUN), local-area networking, the Internet
- 1990s: PCs (rise of Microsoft, Intel, Dell), the Web
- 2000s:
  - Internet Services / Clusters (Amazon)
  - General Cloud Computing (Google, Amazon, Microsoft)
  - Mobile/ubiquitous/embedded computing (iPod, iPhone, iPad, Android)
- 2010s: sensor networks, “data-intensive computing,” computers and the physical world (“pervasive computing”)
- 2020: it’s up to you!!

Progression of concepts and form factors



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Has it all been discovered?

- New challenges constantly arise
  - embedded computing (e.g., iPod)
  - sensor networks (very low power, memory, etc.)
  - peer-to-peer systems
  - ad hoc networking
  - scalable server farm design and management (e.g., Google)
  - software for utilizing huge clusters (e.g., MapReduce, Bigtable)
  - overlay networks (e.g., PlanetLab)
  - worm fingerprinting
  - finding bugs in system code (e.g., model checking)
- Old problems constantly re-define themselves
  - the evolution of smart phones recapitulated the evolution of PCs, which had recapitulated the evolution of minicomputers, which had recapitulated the evolution of mainframes
  - but the ubiquity of PCs re-defined the issues in protection and security, as phones are doing once again

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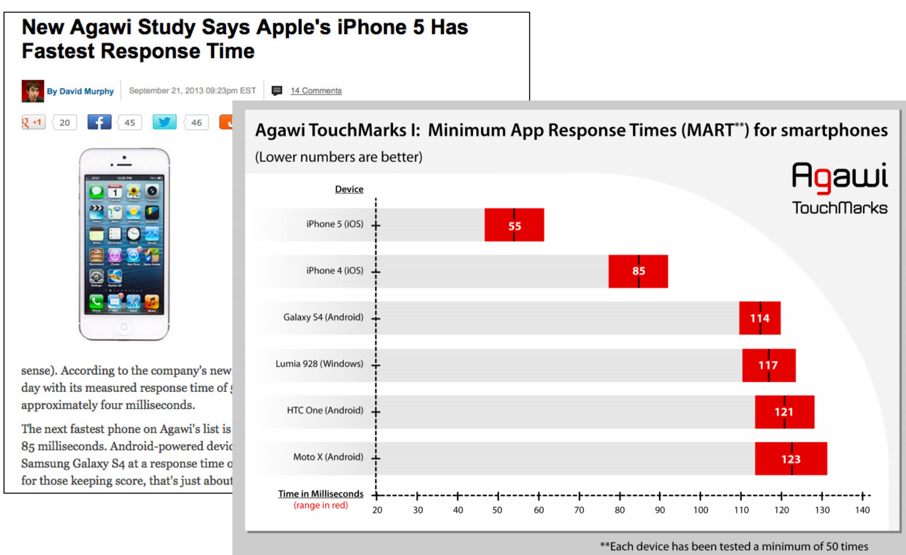
Protection and security as an example

- none
- OS from my program
- your program from my program
- my program from my program
- access by intruding individuals
- access by intruding programs
- denial of service
- distributed denial of service
- spoofing
- spam
- worms
- viruses
- stuff you download and run knowingly (bugs, trojan horses)
- stuff you download and run obliviously (cookies, spyware)

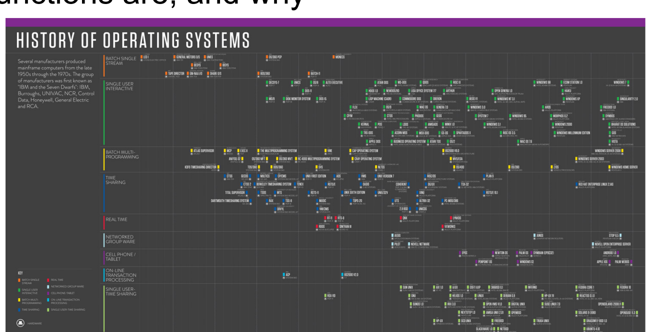
Performance as an example

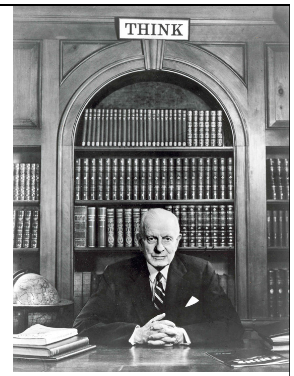


https://www.youtube.com/watch?v=vOvQCPLkPt4

An OS history lesson

- Operating systems are the result of a 60 year long evolutionary process.
- We'll follow a bit of their evolution
- That should help make clear what some of their functions are, and why

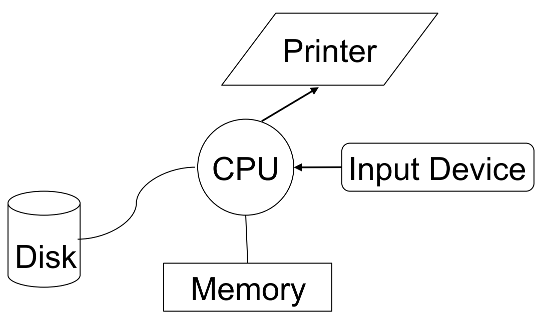




In the Beginning...

- 1943
  - T.J. Watson (created IBM):
    " I think there is a world market for maybe five computers."
- Fast forward … 1950
  - There are maybe 20 computers in the world
    - They were unbelievably expensive
    - Imagine this: machine time is more valuable than person time!
    - Ergo: *efficient use of the hardware is paramount*
  - Operating systems are born
    - They carry with them the vestiges of these ancient forces

The Primordial Computer



The OS as a linked library

- In the very beginning…
  - OS was just a library of code that you linked into your program; programs were loaded in their entirety into memory, and executed
    - “OS” had an “API” that let you control the disk, control the printer, etc.
  - Interfaces were literally switches and blinking lights
  - When you were done running your program, you’d leave and turn the computer over to the next person

- *Recapitulation: Paul Allen writing a bootstrap loader for the Altair as the plane was landing in New Mexico*

Asynchronous I/O

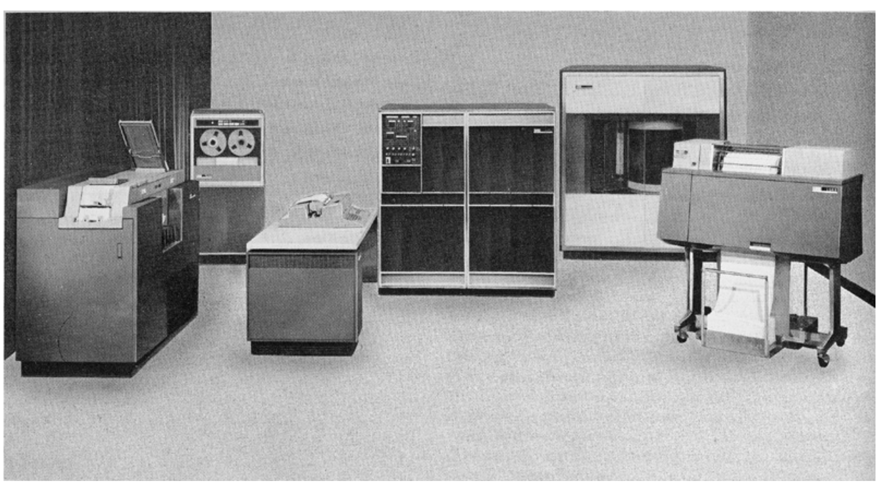
- The disk was really slow
- Add hardware so that the disk could operate without tying up the CPU
  - Disk controller
- Hotshot programmers could now write code that:
  - Starts an I/O
  - Goes off and does some computing
  - Checks if the I/O is done at some later time
- Upside
  - Helps increase (expensive) CPU utilization
- Downsides
  - It's hard to get right
  - The benefits are job specific

The OS as a "resident monitor"

- Everyone was using the same library of code
- Why not keep it in memory?

- While we're at it, make it capable of loading Program 4 while running Program 3 and printing the output of Program 2
  - SPOOLing – Simultaneous Peripheral Operations On-Line

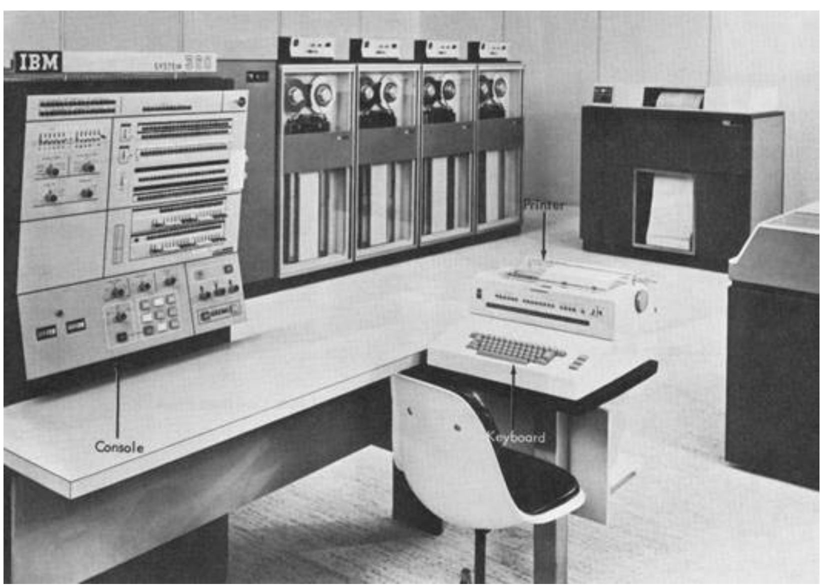
- What new requirements does this impose?



IBM 1401

Multiprogramming

- To further increase system utilization, multiprogramming OSs were invented
  - keeps multiple runnable jobs loaded in memory at once
  - overlaps I/O of one job with computing of another
    - while one job waits for I/O completion, another job uses the CPU
  - Can get rid of asynchronous I/O within individual jobs
    - Life of application programmer becomes simpler; only the OS programmer needs to deal with asynchronous events
  - How do we tell when devices are done?
    - Interrupts
    - Polling
  - What new requirements does this impose?



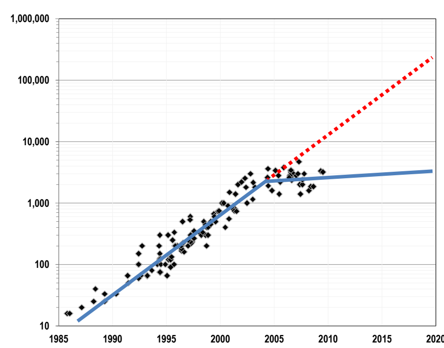
IBM System 360

(An aside on protection)

- Applications/programs/jobs execute directly on the CPU, but cannot touch anything except "their own memory" without OS intervention

(An aside on concurrency)

- Transistor density continues to increase (Moore's Law), but individual cores aren't getting faster – instead, we're getting more of them (the number doubles on roughly the old 18-month cycle)



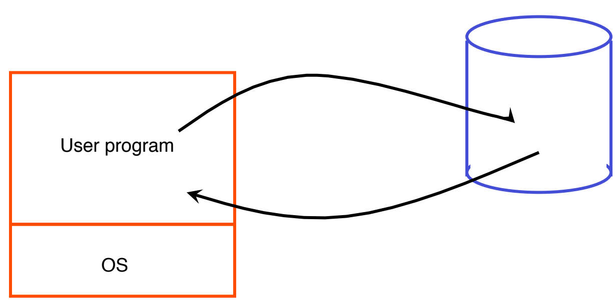
- The burden is on the programmer to use an ever increasing number of cores
- A lot of this course is about concurrency
  - It used to be a bit esoteric
  - It has now become one of the most important things you'll learn (in any of our courses)

Timesharing

- To support interactive use, create a timesharing OS:
  - multiple terminals into one machine
  - each user has illusion of entire machine to him/herself
  - optimize response time, perhaps at the cost of throughput
- Timeslicing
  - divide CPU equally among the users
  - if job is truly interactive (e.g., editor), then can jump between programs and users faster than users can generate load
  - permits users to interactively view, edit, debug running programs

- MIT CTSS system (operational 1961) was among the first timesharing systems
  - only one user memory-resident at a time (32KB memory!)
- MIT Multics system (operational 1968) was the first large timeshared system
  - nearly all OS concepts can be traced back to Multics!
  - “second system syndrome”

- CTSS as an illustration of architectural and OS functionality requirements



- In early 1980s, a *single* timeshared VAX-11/780 (like the one in the Allen Center atrium) ran computing for *all of* CSE.

- A typical VAX-11/780 was 1 MIPS (1 MHz) and had 1MB of RAM and 100MB of disk.
  - An Apple iPhone 5s (A7 processor) is 1.3GHz dual-core (x2600), has 2GB of RAM (x2000),64GB of flash (x640), a quad-core GPU (unheard of).

Parallel systems

- Some applications can be written as multiple parallel threads or processes
  - can speed up the execution by running multiple threads/ processes simultaneously on multiple CPUs [Burroughs D825, 1962]
  - need OS and language primitives for dividing program into multiple parallel activities
  - need OS primitives for fast communication among activities
    - degree of speedup dictated by communication/computation ratio
  - many flavors of parallel computers today
    - SMPs (symmetric multi-processors)
    - MPPs (massively parallel processors)
    - NOWs (networks of workstations)
    - Massive clusters (Google, Amazon.com, Microsoft)
    - Computational grid (SETI @home)

Personal computing

- Primary goal was to enable new kinds of applications
- Bit mapped display [Xerox Alto,1973]
  - new classes of applications
  - new input device (the mouse)
- Move computing near the display
  - why?
- Window systems
  - the display as a managed resource
- Local area networks [Ethernet]
  - why?
- Effect on OS?

Distributed OS

- Distributed systems to facilitate use of geographically distributed resources
  - workstations on a LAN
  - servers across the Internet
- Supports communications between programs
  - interprocess communication
    - message passing, shared memory
  - networking stacks
- Sharing of distributed resources (hardware, software)
  - load balancing, authentication and access control, …
- Speedup isn't the issue
  - access to diversity of resources is goal

Client/server computing

- Mail server/service
- File server/service
- Print server/service
- Compute server/service
- Game server/service
- Music server/service
- Web server/service
- etc.

Peer-to-peer (p2p) systems

- Napster
- Gnutella
  - example technical challenge: self-organizing overlay network
  - technical advantage of Gnutella?
  - er … legal advantage of Gnutella?

Embedded/mobile/pervasive computing

- Pervasive computing
  - cheap processors embedded everywhere
  - how many are on your body now? in your car?
  - cell phones, PDAs, network computers, …
- Often constrained hardware resources
  - slow processors
  - small amount of memory
  - no disk
  - often only one dedicated application
  - limited power
- But this is changing rapidly!
  - cf. specs of iPhone 5S earlier!

Ad hoc networking

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