CSE 451: Operating Systems
Spring 2013

Module 1
Course Introduction

Ed Lazowska
lazowska@cs.washington.edu
570 Allen Center

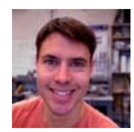
Today's agenda

- 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

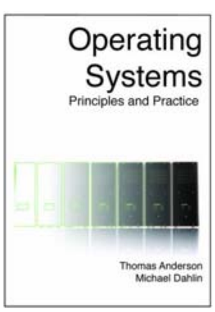
- Operationally, everything you need to know will be on the course web page:
  http://www.cs.washington.edu/451/
- Or on the course email and email archive:
  https://mailman1.u.washington.edu/mailman/private/cse451a_sp13/
- Or on the course discussion board:
  https://catalyst.uw.edu/gopost/board/lazowska/32506/

But to tide you over for the next hour …

- Course staff
  - Ed Lazowska
  - Elliott Brossard
  - Jim Youngquist
- General Course Structure
  - Read the text prior to class
  - Class doesn't aim to repeat the text
  - ~~Homework exercises to motivate reading by non-saints~~
  - Sections will focus on projects
  - You're paying for interaction

- The text



- The text
  - Really outstanding – written by current experts
    - Allows you to actually figure out how things work
  - Don't ignore it – read it and ask questions about it!
- 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 Wednesday
    - 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!
  - Please keep up with the reading
  - Homework 1 (reading) is posted on the web **now**
    - Due at **the start of class Wednesday**
  - Project 0 ("warmup") is posted on the web **now**
    - Will be discussed in section Thursday
    - Due at the end of the day *next* Wednesday
  - 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 me)
  - A project part (mainly run by the TA(s))
- In a perfect world, we would do this as a two-quarter sequence
  - The world isn't perfect …
- By the end of the course, you'll see how it all fits together!
  - There will be a lot of work
  - You'll learn a lot
  - 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 (common?) interfaces?
  - what policies are typically used in an OS?
  - what algorithms are used to implement 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

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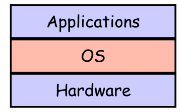
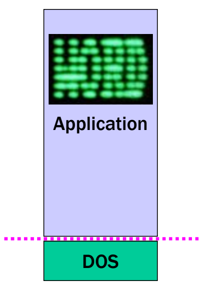
Okay. What are some goals of an OS?

The traditional picture

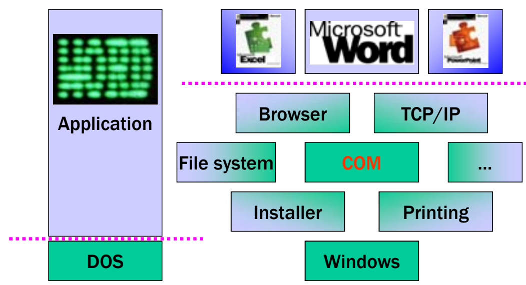


- "The OS is everything you don't need to write in order to run your application"
- This depiction invites you to think of the OS as a library; we'll see that
  - In some ways, it is:
    - all operations on I/O devices require OS calls (*syscalls*)
  - In other ways, it isn't:
    - you use the CPU/memory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

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

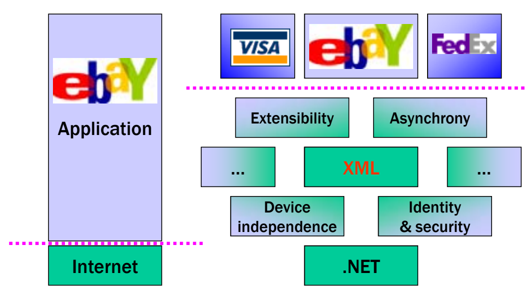


"Everything you don't have to write"
What is Windows?



"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
  - Mediate resource sharing
- An Illusionist
  - Mask hardware limitations
- Glue
  - Provide 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 or programs)?
- **security**: how is the integrity of the OS and its resources ensured?
- **protection**: how is one user/program protected from another?
- **performance**: how do we make it all go fast?
- **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…

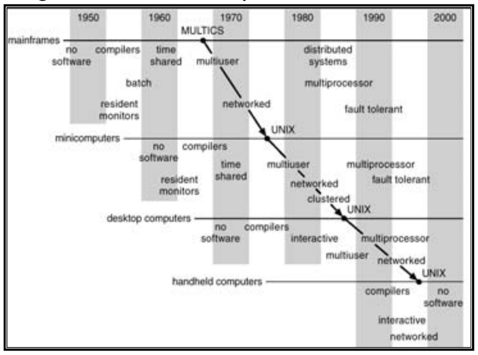
- **concurrency**: how are parallel activities (computation and I/O) created and controlled?
- **scale**: what happens as demands or resources increase?
- **persistence**: how do you make data last longer than program executions?
- **distribution**: how do multiple computers interact with each other?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

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
- 2020: it's up to you!!

Progression of concepts and form factors



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

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)

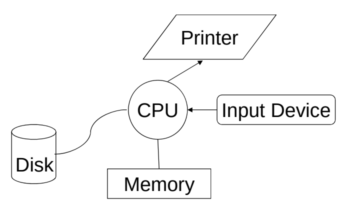
An OS history lesson

- Operating systems are the result of a 60 year long evolutionary process.
  - They were born out of need
- 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

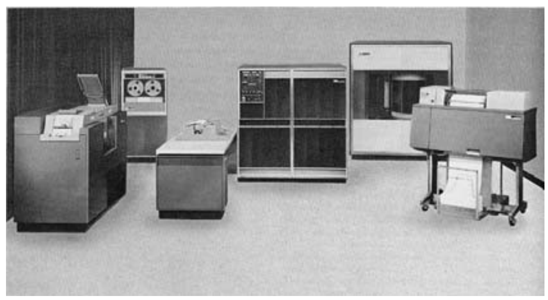
- The disk was really slow
- Add hardware so that the disk could operate without tying up the CPU
  - Disk controller
- Hotshot programmers could now write code that:
  - Starts an I/O
  - Goes off and does some computing
  - Checks if the I/O is done at some later time
- Upside
  - Helps increase (expensive) 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?

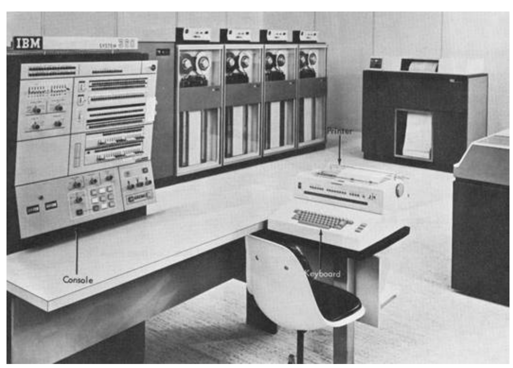


IBM 1401

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

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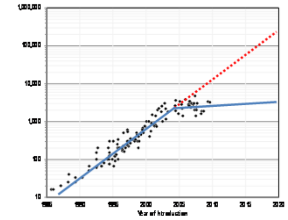
(An aside on concurrency)

- 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)



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- 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)

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Timesharing

- To support interactive use, create a timesharing OS:
  – multiple terminals into one machine
  – each user has illusion of entire machine to him/herself
  – <u>optimize response time</u>, 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

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- 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”

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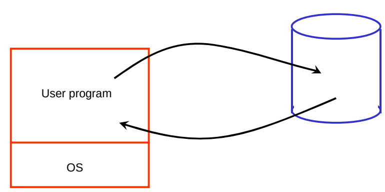
- CTSS as an illustration of architectural and OS functionality requirements



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- 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 5 (A6 processor) is 1.3GHz (x1300), has 1GB of RAM (x1000), and 64GB of flash (x640).

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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)

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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?

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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

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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.

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Peer-to-peer (p2p) systems

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

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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!

Ad hoc networking

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