CSE 451: Operating Systems
Spring 2004

Module 1
Course Introduction

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Today's agenda

- Administrivia
  - course overview
    - course staff
    - general structure
    - your to-do list
  - overloading
- OS overview
  - functional
    - resource mgmt, major issues
  - historical
    - batch systems, multiprogramming, time shared OS's
    - PCs, networked computers

Course overview

- Everything you need to know will be on the course web page:

  http://www.cs.washington.edu/education/courses/451/CurrentQtr

- But to tide you over for the next hour …
  - course staff
    - Brian Bershad (bershad@cs.washington.edu)
    - Kararyzna Wilamowska (kasiaw@cs.washington.edu)
    - Ilya Vladimirovich Maykov (uvmaykov@cs.washington.edu)
  - general structure
    - read the text prior to class
    - class will supplement rather than regurgitate the text
    - sections will focus on the project
    - we really want to encourage *discussion*, both in class and in section

– your to-do list …
  - please read the entire course web thoroughly, *today*
  - please get yourself on the cse451 email list, *today*, and check your email *daily*
  - homework 1 (reading + problems) is posted on the web now; due Friday
  - project 1 is posted on the web now and will be discussed in section on Thursday; due a week from Friday

Overloading

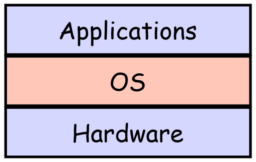
- If you're going to drop this course
  – please do it soon!
- If you want to get into this course
  – plan for the worst case
  – but, make sure you've filed a petition with the advisors

Required Background

- Processor fundamentals
- Compiler fundamentals
- Programming in C

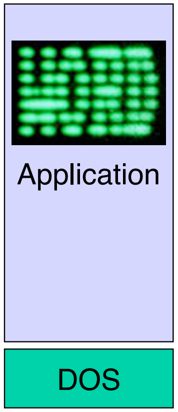
What is an Operating System?

- An operating system (OS) is:
  – a software layer to abstract away and manage details of hardware resources
  – a set of utilities to simplify application development

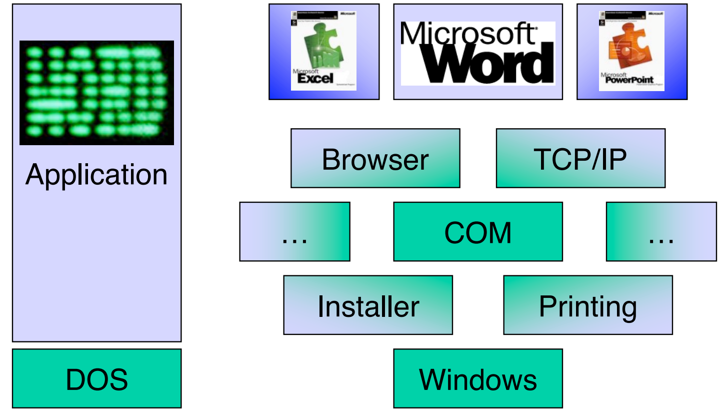


  – "all the code you didn't write" in order to implement your application

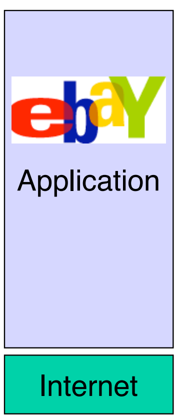
What is Windows?



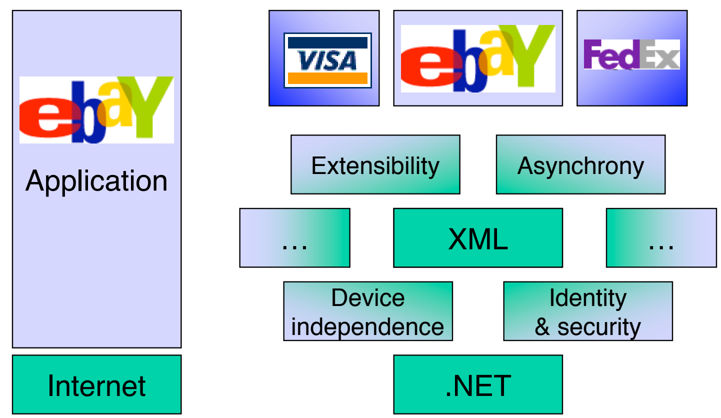
What is Windows?



What is .NET?



What is .NET?



The OS and hardware

- An OS mediates programs' access to hardware resources
  - 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
  - processes (CPU, memory)
  - files (disk)
    - programs (sequences of instructions)
  - sockets (network)

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" own virtual machine, thinks it owns 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?
- **manageability:** how do we adapt a system to a particular environment
  - "management is whatever you need to do that you can't write an algorithm for."

A Brief History of Computing

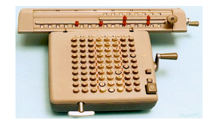
Inflection Point #0: 19th Century

- **Machines can do things faster than people**

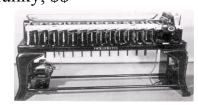
Business Number Crunching
Technology: 1880-1920

Adders
+ (and sometimes -)
mechanical devices
slow, clunky

Calculators
+-*/
mechanical devices
slow, clunky, $$



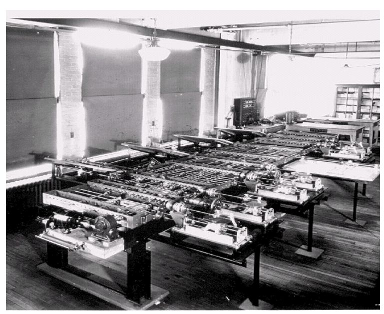
Tabulators
electronic and mechanical
popular in the insurance industry and w/employers
CTR



Automatic Calculators: “Bigger Must be Better”

The Bush Differential Analyzer

- Built in 1931
- Analog and Decimal
  - poor accuracy -- 1%
- Big & Slow
  - all mechanical
  - 100 tons
- Only one of them



In the very beginning…

- There was no OS and there was no program.
- Just levers, computation, and output (think Big Calculator)
- Problem: Really Hard to Use

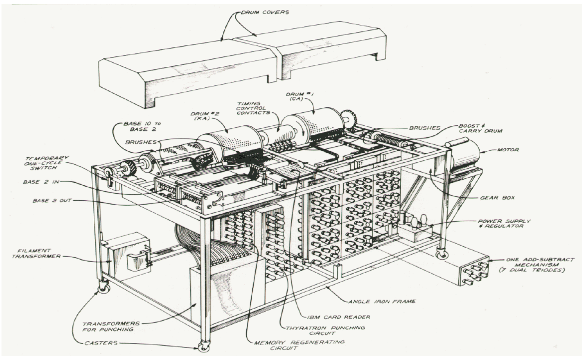
Iowa in 1937

John Vincent Atanasoff
(A math & physics guy)

In the treatment of many mathematical problems one requires the solution of systems of linear simultaneous algebraic equations.

- ***Curve fitting.***
- ***Method of least squares.***
- ***Vibration problems including the vibrational Raman effect.***
- ***Electrical circuit analysis.***
- ***Analysis of elastic structures.***
- ***Approximate solution of many problems of elasticity.***
- ***Approximate solution of problems of quantum mechanics.***
- ***Perturbation theories of mechanics, astronomy and the quantum theory.***

John Atanasoff Invents the First *Electronic* Calculator

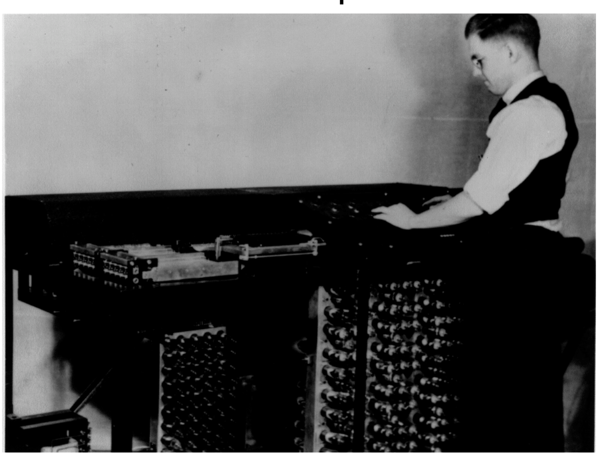


- 3kbits of RAM
- 30 calculations/minute

Key Technical Ideas

- Binary rather than decimal
- Vacuum tubes for logic rather than storage
- Inexpensive rotating capacitors for (cheap) temporary storage
- Punch cards for input/output

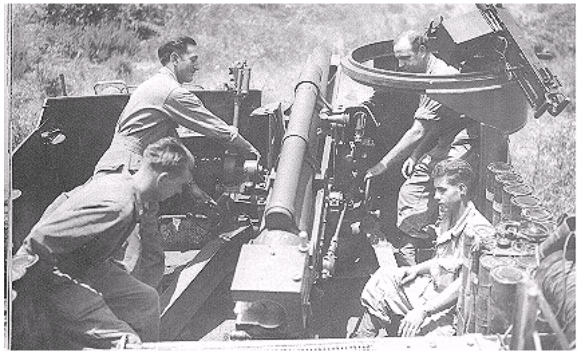
John Berry (Grad Student) With the ABC Computer



What Happened to Atanasoff ?

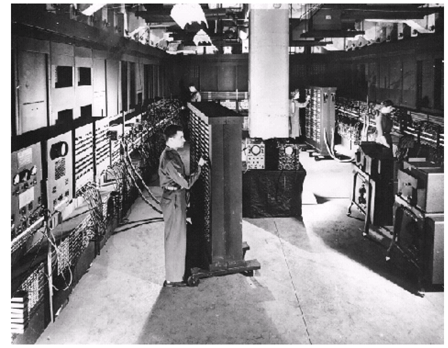
- In 1940, asks for 5K from Iowa Research Council to build a commercial-grade machine
  - he's turned down
- He meets John Mauchly
  - physicist from U Penn
- But forgets to have him sign the NDA
- WWII starts
  - By 1942, Atanasoff resigns from Iowa State to join the war effort

The First “Killer” App



- Projectile trajectories
- 5 days per trajectory using a mechanical calculator
- 30 minutes using BDA
  - not accurate enough
  - and still takes one month/table
- John Mauchly seized the opportunity

The ENIAC



Electronic Numerical Integrator and Computer

- Started in 1942
- Completed in 1945
- Key stats
  - $500K
  - 30 tons
  - 1800 square feet
  - 19000 vacuum tubes
  - 175 Kw/power
  - 5000 ops/second
- Followed 2 years later by EDVAC.
  - Stored Program

IPs Leading to EDVAC

- IP #1: Application of Dynamic RAM at any cost (Vacuum tubes)
  - Computers can now execute code against data
  - Could now have a “PROGRAM” that could be loaded quickly and run.
    - programs were loaded in their entirety into memory, and executed
  - OS was just a library of code that you linked into your program
  - By using the Hollerith Card (Old Technology Reapplied) (~1952) computers can run a *BATCH* of programs
    - Led to “Batch Processing Languages” which told OS about the programs
    - OS loaded the next job into memory from the card reader
      - job gets executed
      - output is printed, including a dump of memory (why?)
      - repeat…
- Problem:card readers and line printers were very slow
  - so CPU (most $$ part of system) was idle much of the time (wastes $$)

1947-1952: The UNIVAC

- E&M’s first commercial computer
  - used mag tape, courtesy of the Nazis
    - WWII was a Big Inflection Point
- $1M dev costs
  - Sold to Census Bureau for $150K
- The company was undercapitalized and needed cash to build
  - No problem finding customers.
  - They couldn’t deliver.

The UNIVAC Invented Spooling

- IP#3: Tapes, which are faster than mechanical readers and printers
  - Spool (Simultaneous Peripheral Operation On-Line)
    - while one job is executing, spool next job from card reader onto tape
      - slow card reader I/O is overlapped with CPU
- Problem: Tapes are sequential → can only run the "next" program.

IBM Invents The Disk in 1956

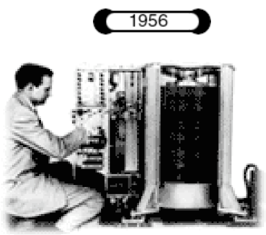
•IP#4: Disks, which allow Random Access to Storage

–Run multiple programs at "once" by swapping image to disk

•OS must choose which to run next when current ends, or performs I/O (eg, fetch data from disk)

•job scheduling. EARLY POLICY/MECHANISM SEPARATION EXAMPLE

–Problem: CPU still idle during I/O



First computer disk storage system. The 305 RAMAC (Random Access Method of Accounting and Control) could store five million characters (five megabytes) of data on 50 disks, each 24 inches in diameter. RAMAC's revolutionary recording head could go directly to any location on a disk surface without reading the information in between. This IBM innovation made it possible to use computers for airline reservations, automated banking, medical diagnosis, and space flights.

Multiprogramming by 1960

- IP#5: Big, Cheap Memory, to keep multiple programs in core at the same time
  - Again, to increase system utilization
  - keeps multiple runnable jobs loaded in memory at once
  - overlaps I/O of a job with computing of another
    - while one job waits for I/O completion, OS runs instructions from another job
  - to benefit, need asynchronous I/O devices
    - need some way to know when devices are done
      - interrupts
      - polling
  - goal: optimize system throughput
    - perhaps at the cost of response time…
  - Yielded the invention of the "PROCESS" – a program which is executing in memory
- Problem: Computer is NOT interactive

Timesharing by the mid-60s

- IP#6: Even cheaper memory, modems, and inexpensive CRTs, allowing multiple users to "interact" with the computer at the same time
  - 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 (why does this matter?)
  - MIT Multics system (mid-1960's) was the first large timeshared system (based on the CTSS for the IBM 7094 from 1961)
    - nearly all OS concepts can be traced back to Multics
    - UNIX is just a simpler MULTICS
      - Core of Mac OS X, Linux, etc.
- Problem: The computer ran faster at night

The Multics System

1968: Honeywell 645

1975: Honeywell 6180

Last one decommisioned in 2000

Personal and Distributed Computing by the 1970s

- IP#7: Plummeting cost of silicon and networking allows everyone to have their own computer
  - Memory was under a penny/bit
  - “Share everything but the time”
  - distributed systems using geographically distributed resources
    - workstations on a LAN
    - servers across the Internet
  - OS supports communications between jobs
    - interprocess communication
    - networking stacks
  - OS supports sharing of distributed resources (hardware, software)
    - load balancing, authentication and access control, …
  - speedup isn’t the issue
    - access to diversity of resources is goal
- Problem: there’s never a time that the machine runs faster

XEROX ALTO -- 1972

< $50K

First personal workstation First wide deployment of:
- Bit-map graphics
- Mouse
- WYSIWG editing

Hosted the invention of:
- Local-area networking
- Laser printing
- All of modern client / server distributed computing

Parallel Systems by the 80’s

- IP#8: High Speed Interconnects allow multiple processors to cooperate on a single program
  - 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
  - need OS and language primitives for dividing program into multiple parallel activities
  - need OS primitives for fast communication between activities
    - degree of speedup dictated by communication/computation ratio
  - many flavors of parallel computers
    - SMPs (symmetric multi-processors)
    - MPPs (massively parallel processors)
    - NOWs (networks of workstations)
    - computational grid (SETI @home)

Internet by the 90s

- IP#9: WEB, HTTP, TCP at Scale
  - TCP+HTTP+Web Browser has changed the way that the world looks at computing
  - BUT, there have been relatively few Operating System Advances to support this
    - The internet was functional by the 70s
  - Mostly, it's been a time of leveraging the last 50 years to deploy MASSIVELY SCALABLE SYSTEMS

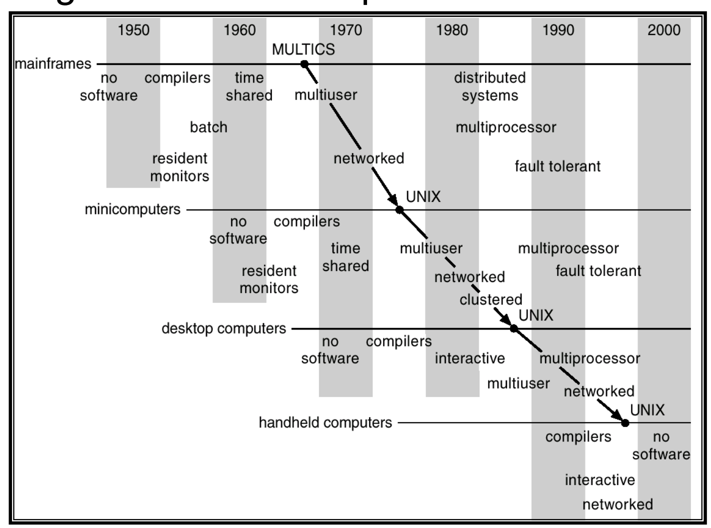
Ubiquitous Computing in the 21st Century

- IP#10: Massive miniaturization and integration of computers + Wireless
  - Ubiquitous computing
    - cheap processors embedded everywhere and anywhere
    - how many are on your body now? in your car?
    - cell phones, PDAs, network computers, …
  - Typically very constrained hardware resources
    - (relatively) slow processors
    - very small amount of memory (e.g. 8 MB)
    - no disk
  - OS researchers are working in this area today to understand what we'll be using tomorrow.

Embedded OS

- Pervasive computing
  - cheap processors embedded everywhere
  - how many are on your body now? in your car?
  - cell phones, PDAs, network computers, …
- Typically very constrained hardware resources
  - slow processors
  - very small amount of memory (e.g. 8 MB)
  - no disk
  - typically only one dedicated application

Progression of concepts and form factors



Multiple trends at work

- "Ontogeny recapitulates phylogeny"
  - Ernst Haeckel (1834-1919)
    - The evolution of any given OS tends to follow the evolution of OS technologies in general.
- "Those who cannot remember the past are condemned to repeat it"
  - George Santayana (1863-1952)
- But new problems arise, and old problems re-define themselves
  - The evolution of PCs 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

Protection and security as an example

- Protection is a very old OS concept
  - PhD theses still collecting dust from the 60s and 70s.
- What have we learned to protect?
  - OS & Devices from my program
    - ~1960: User/Supervisor Mode
  - Your program from my program
    - ~1962: Atlas (Virtual Memory)
    - ~1970: Multics
    - ~1978: Unix
    - ~1995: NT
  - OS from OS
    - ~1965: CP/370 & Virtual Machines
    - ~1971: Hydra & Capabilities/Objects
    - ~1985: Mach & Microkernels
    - ~1995: NT & Microkernels
    - ~2000: VMWARE & Virtual Machines
  - access by intruding individuals
    - ~1970: Multics

What are we not so good at (yet)?

- Unsolved, or poorly solved
  - 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 unknowingly (cookies, spyware)

Some Principles

1. It is a system
   - Good analogies found in real life systems
2. Technology changes *everything*
   - Look for the inflection points!
     - Stemming from, or leading to, the "killer app"
   - Generally, someone's trying to MAKE money or SAVE money by doing something differently
3. Priorities should not be mistaken for stupidity.
   - Choose 2 of [Soon, Good, Cheap.]
4. Things often left for "later"
   - Testability, Usability, Manageability, Security.

Rules - Continued

5. Code and Data are a matter of perspective.
6. MECHANISM and POLICY are generally separable
7. Simple solutions are generally better than complex ones.
   - "Simple and good enough" almost always more attractive than optimal.
   - Always consider the "Do nothing" option.
   - Static solutions are generally simpler than dynamic ones
8. In general, the future is unknowable, except in retrospect
   - It's a good bet though that it looks like the past
9. Laziness in the presence of uncertainty is generally rewarded
   - And punished in its absence
10. Often, all it takes is the the right level of indirection.
11. Space and time trade off
12. 2x rarely matters, 10x almost always does.
13. Scalability is hard, but rewarded in time.
14. Performance is easier than most other things

CSE 451

- In this class we 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 …