Cornell University

Introduction

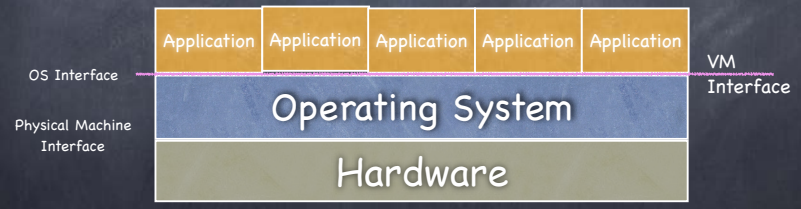
CS 4410

Meet the OS

- Software that manages a computer's resources
- Makes it easier to write the applications you want to write
- Makes you want to use the applications you wrote by running them efficiently

What is an OS?

- An Operating System implements a virtual machine whose interface is more convenient* that the raw hardware interface



* easier to use, simpler to code, more reliable, more secure…

"All the code you did not write"

OS wears many hats

- Referee
  - Manages shared resources: CPU, memory, disks, networks, displays, cameras…
- Illusionist
  - Look! Infinite memory! Your own private processor!
- Glue
  - Offers a set of common services (e.g., UI routines)
  - Separates apps from I/O devices

OS as Referee

Resource allocation

- Multiple concurrent tasks, how does OS decide who gets how much?

Isolation

- A faulty app should not disrupt other apps or OS

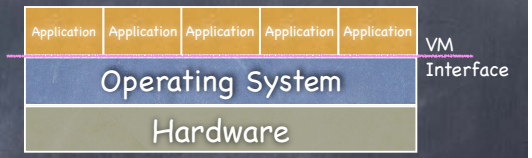
Communication/Coordination

- Apps need to coordinate and share state

OS as Illusionist

Appearance of resources not physically present

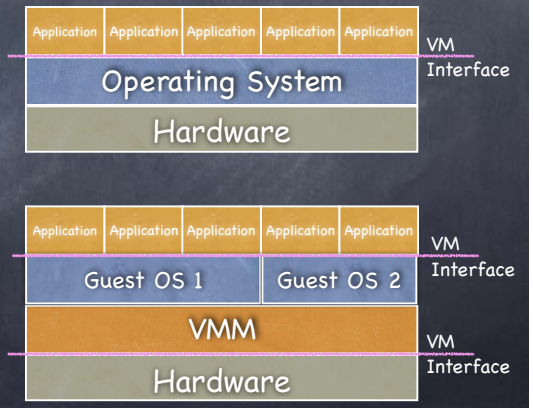
- Virtualization
  - Processor, memory, screen space, disk, network



OS as Illusionist

Appearance of resources not physically present

- Virtualization
  - Processor, memory, screen space, disk, network
  - The entire computer
    - Fooling the illusionist itself!
    - Eases debugging, portability, isolation



OS as Illusionist

Appearance of resources not physically present

- Atomic operations
  - HW guarantees atomicity at the word level…
    - What happens during concurrent updates to complex data structures?
    - What is a computer crashes while writing a file block?
  - At the hardware level, packets are lost
    - Reliable communication channels

OS as Glue

- Offers standard services to simplify app design and facilitate sharing
  - Send/Receive byte streams
  - Read/Write files
  - Pass messages
  - Share memory
  - UI
- Decouples HW and app development

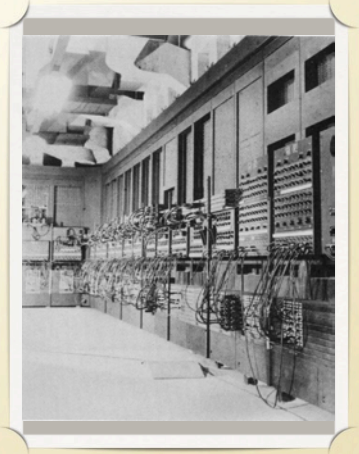
A Short History of Operating Systems

History of Operating Systems

- Phase 1: Hardware is expensive, humans are cheap
  - User at console: single-user systems
  - Batching systems
  - Multi-programming systems

Hand programmed machines (1945-1955)

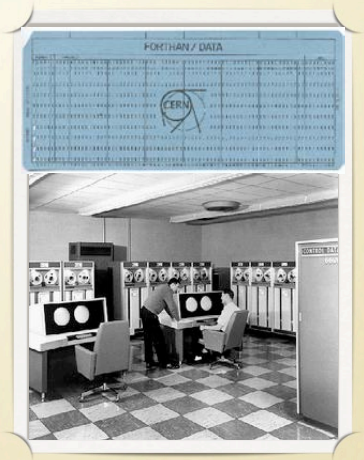
- Single user systems
- OS = loader + libraries of common subroutines
- Problem: low utilization of expensive components

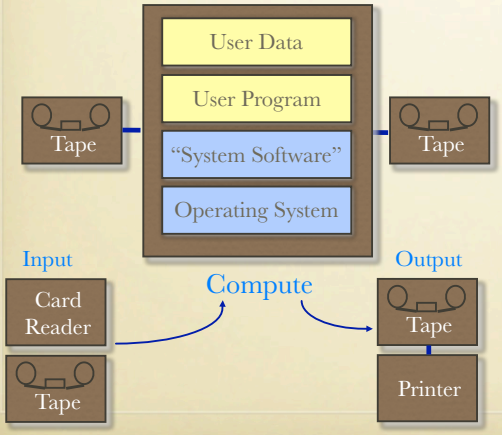


$$\frac{\textit{time device busy}}{\textit{observation interval}} = \%\ \textit{utilization}$$

Batch Processing (1955-1965)

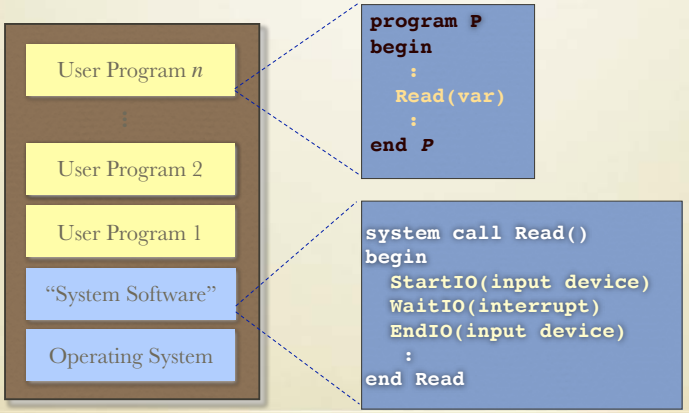
Operating system = loader + sequencer + output processor





Multiprogramming (1965-1980)

Keep several jobs in memory and multiplex CPU between jobs



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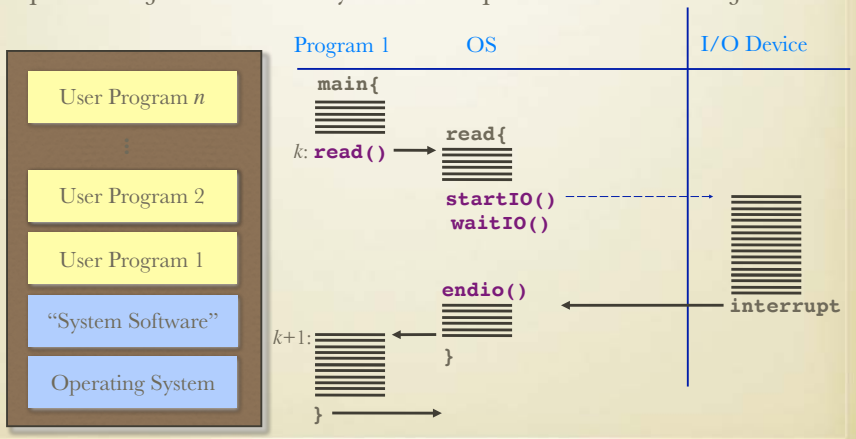

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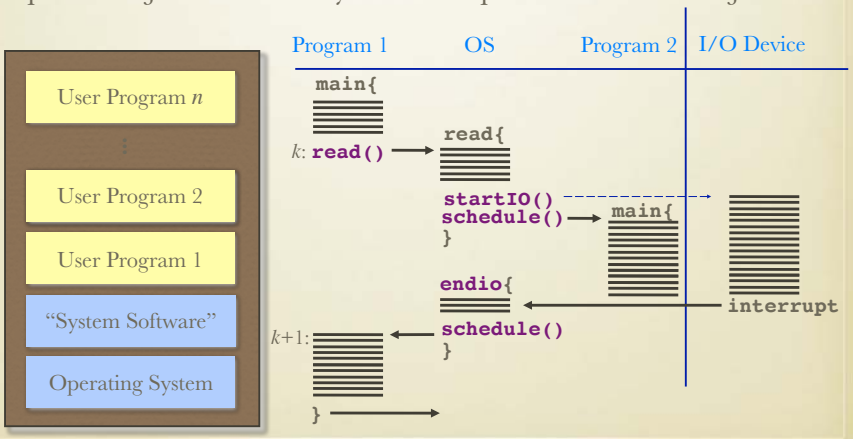

History of Operating Systems

- Phase 1: Hardware is expensive, humans are cheap
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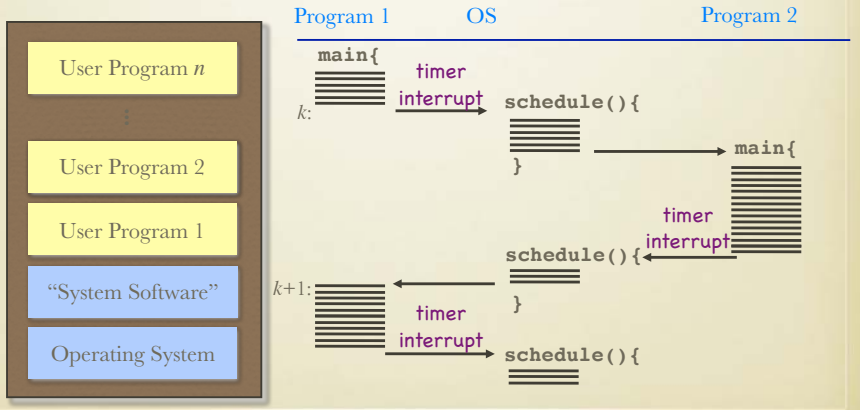
- Phase 2: Hardware is cheap, humans are expensive
  - Time sharing: Users use cheap terminals and share servers

Timesharing (1970-)

A timer interrupt is used to multiplex CPU between jobs



History of Operating Systems

- Phase 1: Hardware is expensive, humans are cheap
  - User at console: single-user systems
  - Batching systems
  - Multi-programming systems
- Phase 2: Hardware is cheap, humans are expensive
  - Time sharing: Users use cheap terminals and share servers
- Phase 3: Hardware is very cheap, humans are very expensive
  - Personal computing: One system per user
  - Distributed computing: many systems per user
  - Ubiquitous computing: LOTS of systems per users

Operating Systems for PCs

Personal computing systems

- Single user
- Utilization no longer a concern
- Emphasis on user interface and API
- Many services & features not present

Evolution

- Initially: OS as a simple service provider (simple libraries)
- Now: Multi-application systems with support for coordination

Why study Operating Systems?

- To learn how to manage complexity through appropriate abstractions
  - infinite CPU, infinite memory, files, locks, etc.
- To learn about design
  - performance vs. robustness, functionality vs. simplicity, HW vs. SW, etc.
- To learn how computers work
- Because OSs are everywhere!

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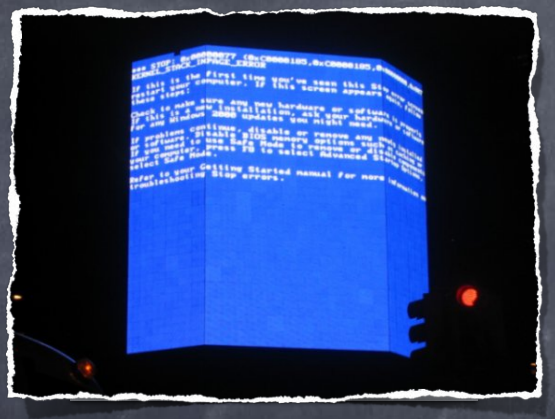


Where's the OS?
Las Vegas

Where's the OS?
New York

What will the course be like?

What kind of course?

- Top-down...
  - Start from first principles
  - Re-derive the design of components of a complex system
- ... & Bottom-up
  - Dissect existing systems, to learn
    - what tradeoffs they make
    - what patterns they use

Painting*

- Order
- Design
- Tension
- Balance
- Harmony

*Sondheim: Sunday in the Park with George

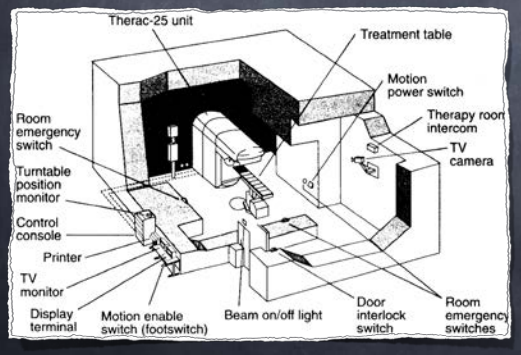
System building

- Reliability
- Availability
- Portability
- Efficiency
- Security

System building is hard!

Therac-25 [1982]

Computer-controlled radiation therapy machine



- Safety critical system with software interlocks
  - prevent machine from changing state because of state of another element
- Beam controlled entirely through a custom OS

Therac-25

- Old system used a hardware interlock
  - Lever either in the "electron-beam" or "x-ray" position
- New system was computer controlled.
  - A synchronization failure triggered when competent nurses used back arrow to change the data on the screen "too quickly"
  - Engineers reused software from older models
    - it was buggy, but hardware interlocks masked the bugs
  - The system noted a problem and halted X-beam, displaying "MALFUNCTION" followed by obscure error code 54
    - technician resumed treatment

Therac-25 Outcome

- Patients received over 100x the recommended dose of radiation
  - Three patients died of radiation overdose
  - Many cancer patients received inadequate treatment
- People died because a programmer could not write correct code for a concurrent system
- 37 Year Later…. Now what?

System building is hard

- We do not have the necessary technologies and know-how to build robust computer systems
- The world is increasingly dependent on computer systems
  - Connected, networked, interlinked
- There is huge demand for people who deeply understand and can build robust systems (most people don't and can't)

What's this course about?

Ostensibly, operating systems

- Architecting complex software
- Identifying needs and priorities
- Separating concerns
- Implementing artifacts with desired properties

In reality, software design principles

- OSes happen to illustrate organizational principles and design patterns

This is a Capstone Course. Get Ready!

What makes a good OS?

The right set of abstractions

A good abstraction:

- is portable and hides implementation details
- has an intuitive and easy-to-use interface
- can be installed many times
- is efficient and reasonably easy to implement

OS: a collection of abstractions

- Processes (abstract CPU and RAM)
- Files (abstract disks)
- Network endpoints (abstract NIC)
- Windows (abstract screens)
- ...

Think of them as objects with state and methods

Issues in OS Design

- Structure: how is the OS organized?
- Concurrency: how are parallel activities created and controlled?
- Sharing: how are resources shared?
- Naming: how are resources named by users?
- Protection: how are distrusting parties protected from each other?
- Security: how to authenticate, authorize, and ensure privacy?
- Performance: how to make it fast?

More Issues in OS Design

- Reliability: how do we deal with failures??
- Portability: how to write once, run anywhere?
- Extensibility: how do we add new features?
- Communication: how do we exchange information?
- Scale: what happens as demands increase?
- Persistence: how do we make information outlast the processes that created it?
- Accounting: who pays the bill and how do we control resource usage?