CS 422/522 Design & Implementation of Operating Systems

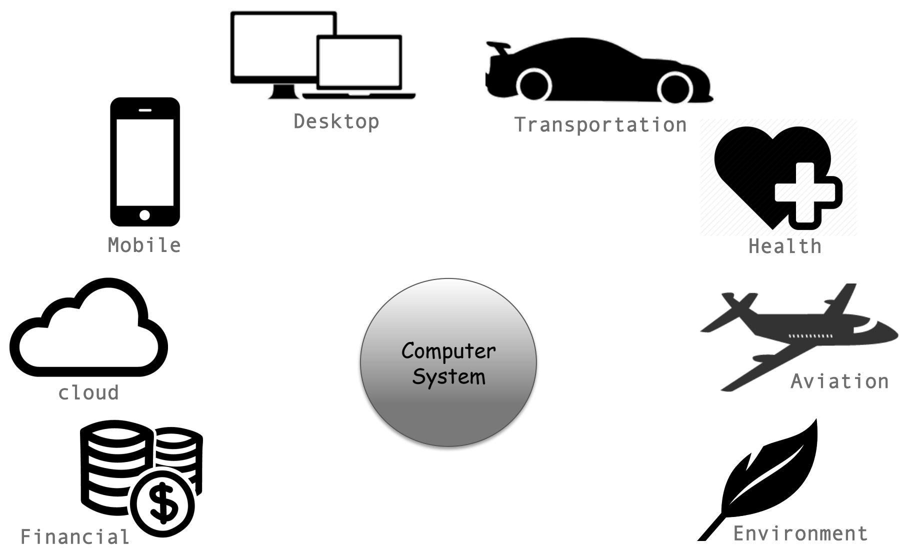
Lecture 1: Introduction

Zhong Shao
Dept. of Computer Science
Yale University

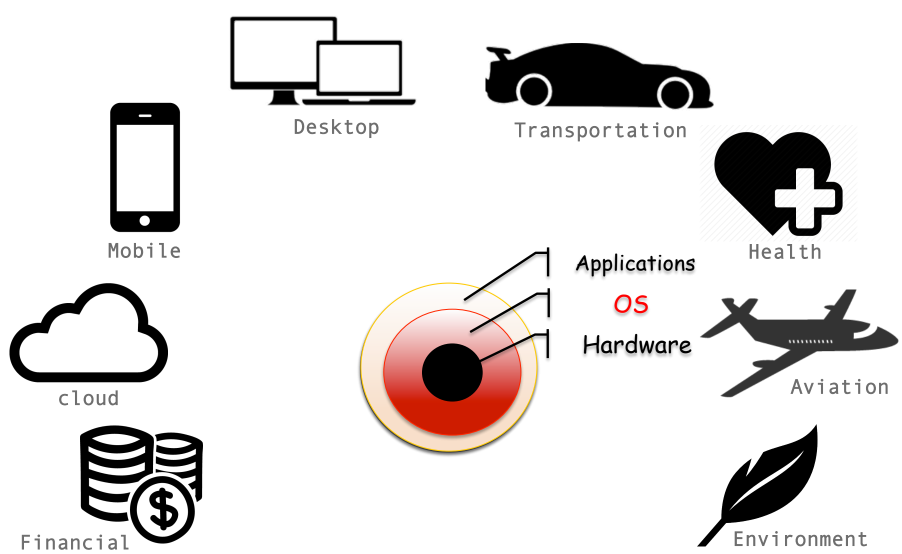
Today's lecture

- Why study operating systems ?
- What is an OS? What does an OS do?
- History of operating systems
- Principles of operating system design
- Course overview
  - course information
  - schedule, assignments, grading and policy
  - other organization issues
  - see web pages for more information

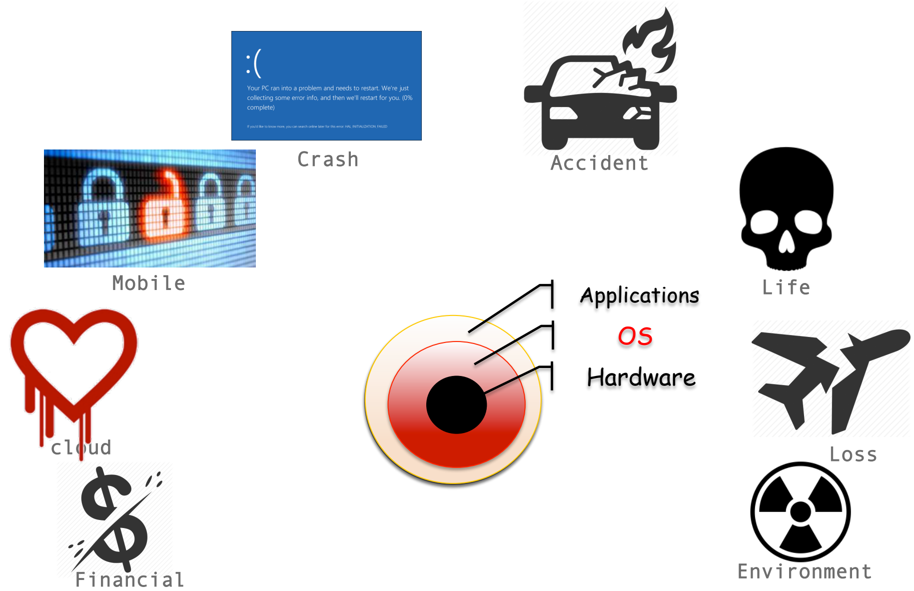
OS is pervasive



OS is pervasive



OS is pervasive & extremely important



OS is no longer for a single machine

Sean Everett Follow
Founder & CEO PROME Biologic Intelligence, EIR The Mission (acq. Humanizing Tech). Many startup...
Nov 16, 2016 · 9 min read

The New Battleground: Car Operating Systems

How Apple, Google, Samsung, Tesla, NVIDIA and BlackBerry are already competing behind the scenes

Recommended by Sean Everett (author)

Marius Slavescu
Nov 18, 2016 · 1 min read

Operating System: like BlackBerry's QNX, which Ford is using, but also Apple's CarOS and Android Auto extended to full OS. Currently folks are just running a fork of Ubuntu or the Ro...

The software running on the SDC should be standardized, in my opinion an open source base would be the right approach, similar with what we have in Android ecosystem.

This approach will ensure auto makers cooperation and allow everyone to contribute to the SDC ecosystem, and provide faster advanced, safe and consistent...

OS is no longer for a single machine

Harvard Business Review

TECHNOLOGY

Smart Cities Are Going to Be a Security Nightmare

by Todd Thibodeaux

In the fictional world of the video game *Watch Dogs*, you can play a hacktivist who takes over the central operating system of a futuristic, hyper-connected Chicago. With control over the city's security system, you can spy on residents using surveillance cameras, intercept phone calls, and cripple the city's critical infrastructure, unleashing a vicious cyberattack that brings the Windy City to its knees.

https://hbr.org/2017/04/smart-cities-are-going-to-be-a-security-nightmare

OS in media / movies & on reddit

- OS1 in HER https://www.youtube.com/watch?v=GV01B5kVsC0
- Hollywood OS http://wiki.c2.com/?HollywoodOs
- Social Network classroom scenes
  https://www.youtube.com/watch?v=-3Rt2_9d7Jg
- Should every CS major take operating systems?
  https://www.reddit.com/r/compsci/comments/50q019/should_every_cs_major_take_operating_systems/
- How a course in operating systems changed me?
  https://www.reddit.com/r/programming/comments/2n0nw5/how_a_course_in_operating_systems_changed_me/

Why study operating systems ?

- Understand how "computers" work under the hood
  - Magic for "infinite" CPUs, memory devices, network computing
  - Tradeoffs btw. performance & functionality, division of labor btw. HW & SW
  - Combine language, hardware, data structures, and algorithms
- Become a much better "programmer & architect" with a deeper level of "computational thinking" skills
- Help you make informed decisions
  - What "computers" to buy? should I upgrade the HW or the OS?
  - What's going on with new "computers"?
- Give you experience in hacking systems software

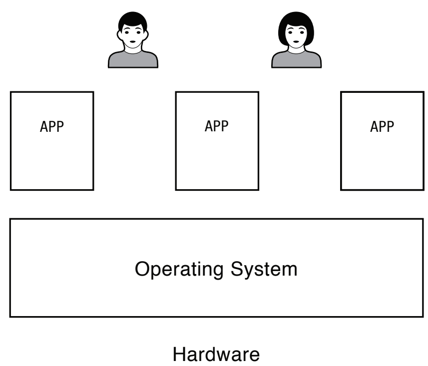
  "this system is so slow, can I do anything about it ?"

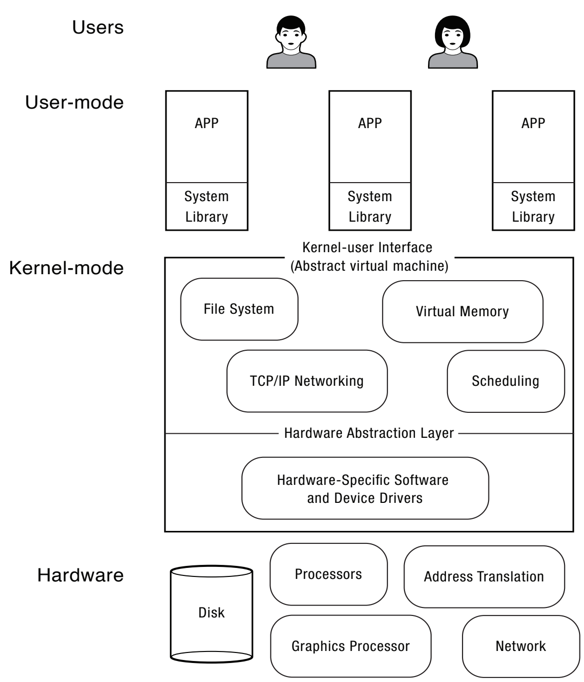
What's interesting?

- OS is a key part of a computer system
  - it makes our life better (or worse)
  - it is "magical" and we want to understand how
  - it has "power" and we want to have the power
- OS is complex
  - how many procedures does a key stroke invoke?
  - real OS is huge and insanely expensive to build
    - * Windows 8: many years, thousands of people. Still doesn't work well
- How to deal with complexity?
  - decomposition into many layers of abstraction
  - fail early, fail fast, and learn how to make things work

What is an OS?

Software to manage a computer's resources for its users & applications

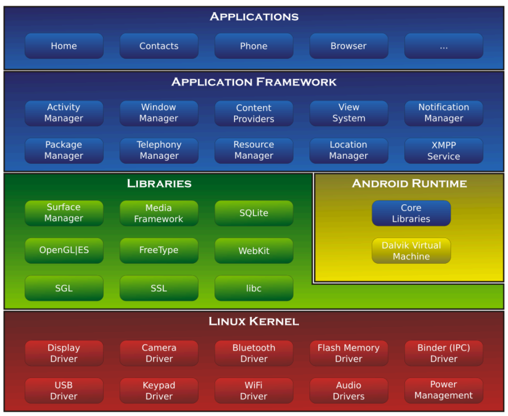


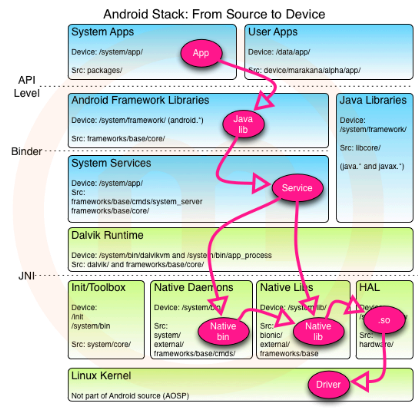


What is an OS?

Android architecture & system stack

From https://thenewcircle.com/s/post/1031/android_stack_source_to_device & http://en.wikipedia.org/wiki/Android_(operating_system)

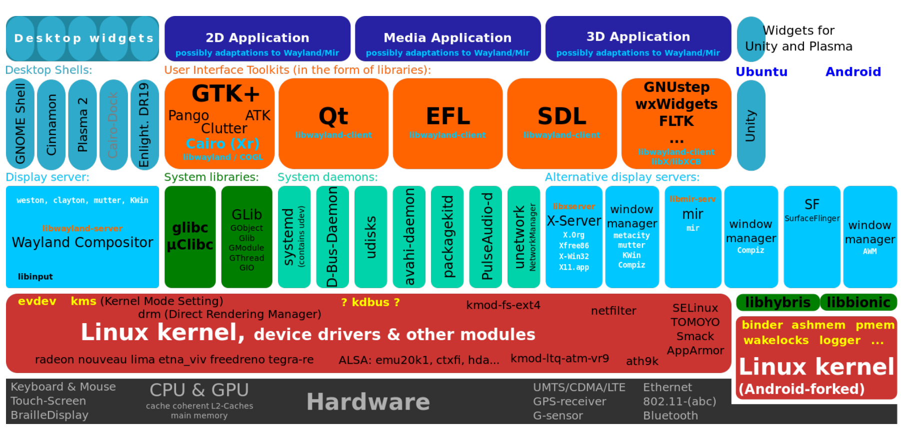




What is an OS?

Visible software components of the Linux desktop stack

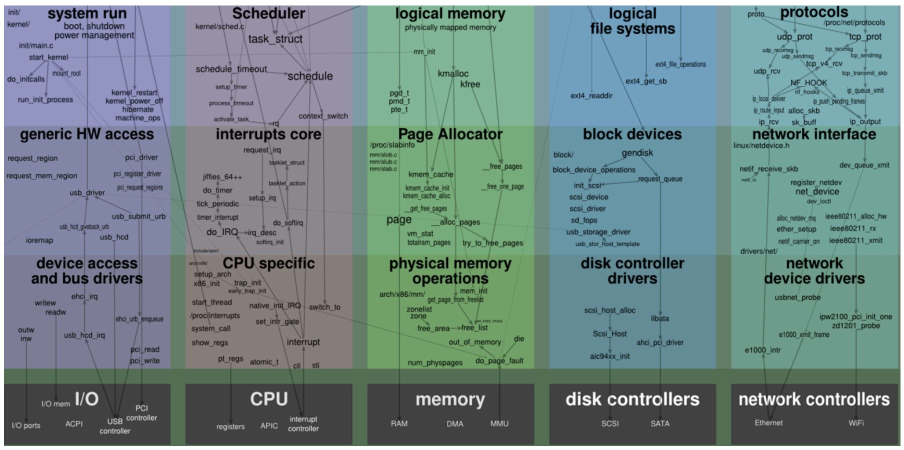
From http://en.wikipedia.org/wiki/Linux



What is an OS?

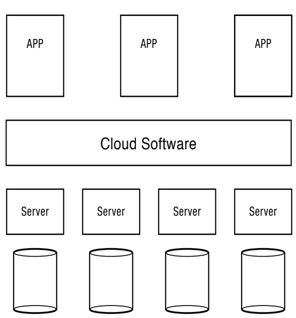
Linux Kernel Map: Kernel components are sorted into different stacks of abstraction layers based on their underlying HW devices

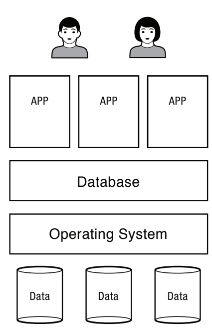
From http://www.makelinux.net/kernel_map/



What is an OS?

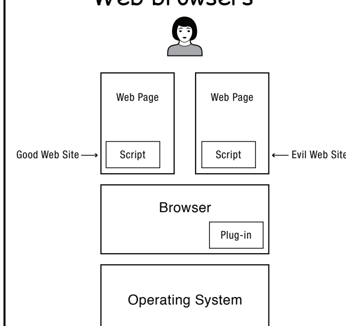
Cloud computing





Multi-user database systems

Web browsers



Other instances: multiplayer games, internet, social networking app, blockchain, …

Operating system roles

- Referee:
  - Resource allocation among users, applications
  - Isolation of different users, applications from each other
  - Communication between users, applications
- Illusionist
  - Each application appears to have the entire machine to itself
  - Infinite number of processors, (near) infinite amount of memory, reliable storage, reliable network transport
- Glue
  - Libraries, user interface widgets, …

Example: file systems

- Referee
  - Prevent users from accessing each other's files without permission
  - Even after a file is deleted and its space re-used
- Illusionist
  - Files can grow (nearly) arbitrarily large
  - Files persist even when the machine crashes in the middle of a save
- Glue
  - Named directories, printf, …

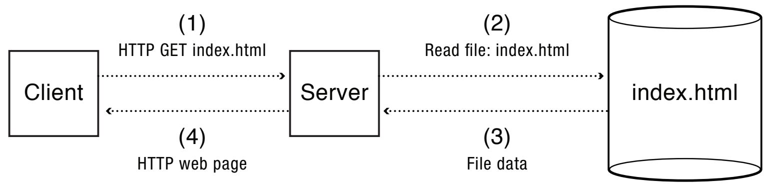
Question

- What (hardware, software) do you need to be able to run an untrustworthy application?

Question

- How should an operating system allocate processing time between competing uses?
  - Give the CPU to the first to arrive?
  - To the one that needs the least resources to complete? To the one that needs the most resources?

Example: web service



- How does the server manage many simultaneous client requests?
- How do we keep the client safe from spyware embedded in scripts on a web site?
- How to make updates to the web site so that clients always see a consistent view?

What does an OS do ?

- OS converts bare HW into nicer abstraction
  - **provide coordination**: allow multiple applications/users to work together in efficient and fair way (memory protection, concurrency, file systems, networking)
  - **provide standard libraries and services** (program execution, I/O operations, file system manipulations, communications, resource allocation and accounting)
- For each OS area, you ask
  - what is the hardware interface --- the physical reality ?
  - what is the application interface (API) --- the nicer abstraction?

Example of OS coordination: protection

Goal: isolate bad programs and people (security)

Solutions:

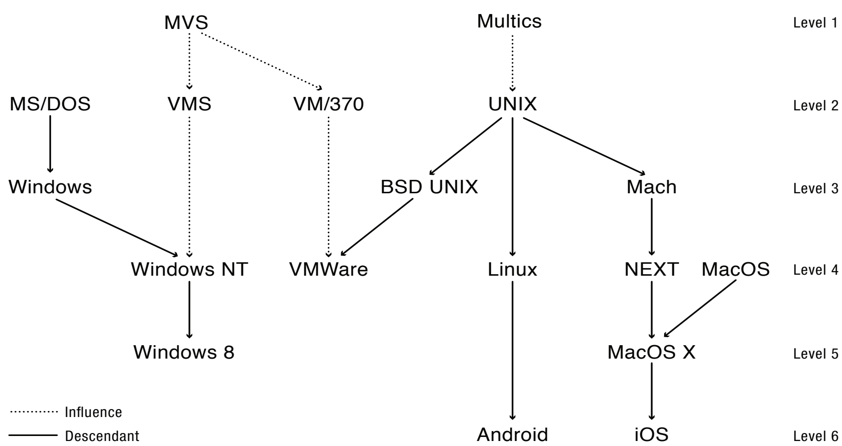
- CPU Preemption
  - give application something, can always take it away (via clock interrupts)
- Dual mode operation
  - when in the OS, can do anything (kernel-mode)
  - when in a user program, restricted to only touching that program's memory (user-mode)
- Interposition
  - OS between application and "stuff"
  - track all pieces that application allowed to use (in a table)
  - on every access, look in table to check that access legal
- Memory protection: address translation

Example: address translation

Restrict what a program can do by restricting what it can touch!

- Definitions:
  - Address space: all addresses a program can touch
  - Virtual address: addresses in process' address space
  - Physical address: address of real memory
  - Translation: map virtual to physical addresses
- Virtual memory
  - Translation done using per-process tables (page table)
  - done on every load and store, so uses hardware for speed
  - protection? If you don't want process to touch a piece of physical memory, don't put translation in table.

OS history



Challenges in writing OS

- Concurrent programming is hard
- Hard to use high-level programming languages
  - device drivers are inherently low-level
  - real-time requirement (garbage collection? probably not)
  - lack of debugging support (use simulation)
- Tension between functionality and performance
- Portability and backward compatibility
  - many APIs are already fixed (e.g., GUI, networking)
  - OS design tradeoffs change as HW changes !

Challenges in writing OS (cont'd)

- Reliability
  - Does the system do what it was designed to do?
- Availability
  - What portion of the time is the system working?
  - Mean Time To Failure (MTTF), Mean Time to Repair
- Security
  - Can the system be compromised by an attacker?
- Privacy
  - Data is accessible only to authorized users

Main techniques & design principles

- Keep things simple !
- Use abstraction
  - hide implementation complexity behind simple interface
- Use modularity
  - decompose system into isolated pieces
- But what about performance
  - find bottlenecks --- the 80-20 rule
  - use prediction and exploits locality (cache)
- What about security and reliability?

More research is necessary!

Course information

Required textbook:

Operating Systems: Principles & Practice (2nd Edition) by T. Anderson and M. Dahlin

information, assignments, & lecture notes are available on-line
we won't use much paper

Official URL: **http://flint.cs.yale.edu/cs422**

for help, go to the piazza site:

https://piazza.com/yale/fall2018/cpsc422522

Course information (cont'd)

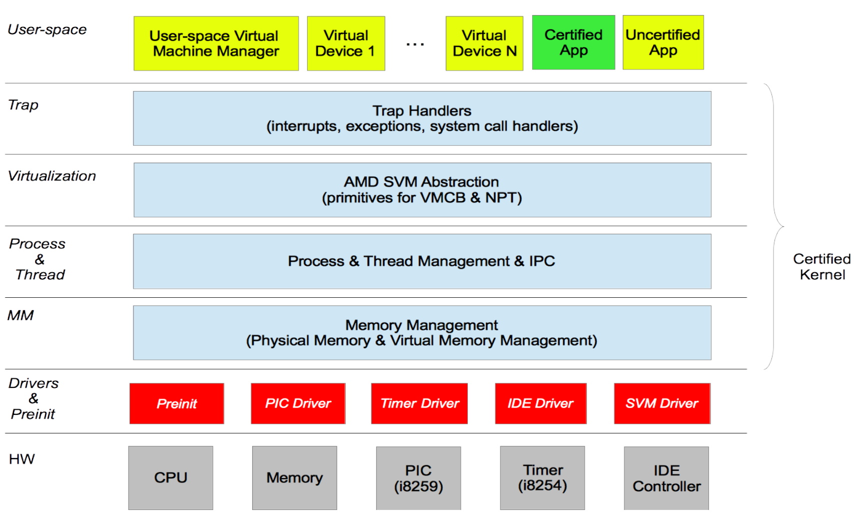
- **13 week lectures on OS fundamentals**
  - class participation is strongly recommended
- **Course requirements**
  - 70% on assignments (as1 – as6)
  - 30% closed-book, in-class midterm (Monday, November 5th)
- **Assignments (as1-as6) and course policies**
  - build a small but real OS kernel, bootable on real PCs.
  - extensive hacking (in C & x86 assembly) but highly rewarding
  - 2 persons / team (one person team is OK too).
  - 6 free late days (3 day late max per assignment).

Programming assignments

- Assignment topics (tentative)
  - Bootloader & physical memory management
  - Container and virtual memory management
  - Process management & trap handling
  - Multicore and preemption
  - File system
  - IPC, Shell, and Extensions
- How
  - Each assignment takes two weeks
  - Most assignments due Thursdays 11:59pm
- The Lab
  - Linux cluster in ZOO (3rd Floor of AKW or Room 111 at 17HH)
  - You can setup your own machine to do projects

Programming assignments (cont'd)

Based on mCertiKOS (Yale FLINT) & JOS (from MIT)



Programming assignments (cont'd)

- Break kernel interdependency by insisting on careful layer decomposition
- With the right methodology, every CS major should be able to write an OS kernel from scratch