CS 422/522 Design & Implementation of Operating Systems

Lecture 1: Introduction

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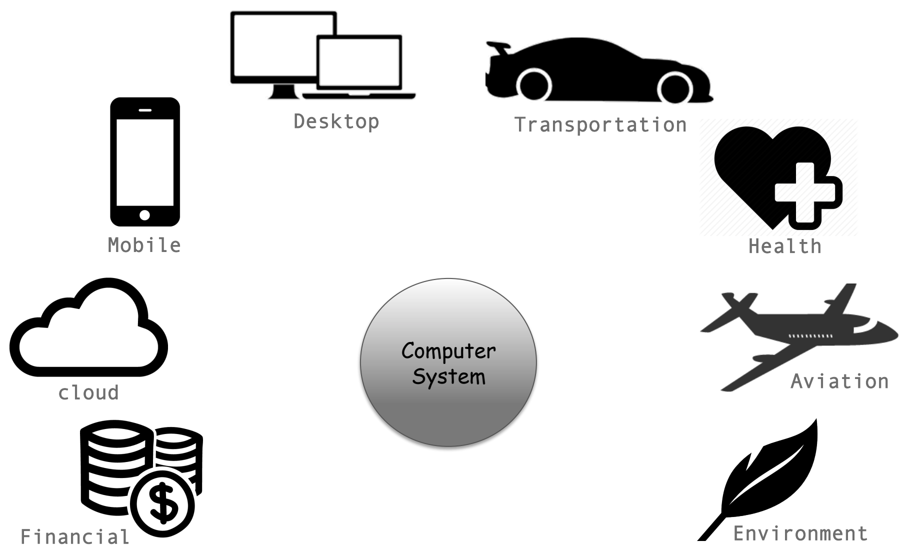
Acknowledgement: some slides are taken from previous versions of the CS422/522 lectures taught by Prof. Bryan Ford and Dr. David Wolinsky, and also from the official set of slides accompanying the OSPP textbook by Anderson and Dahlin.

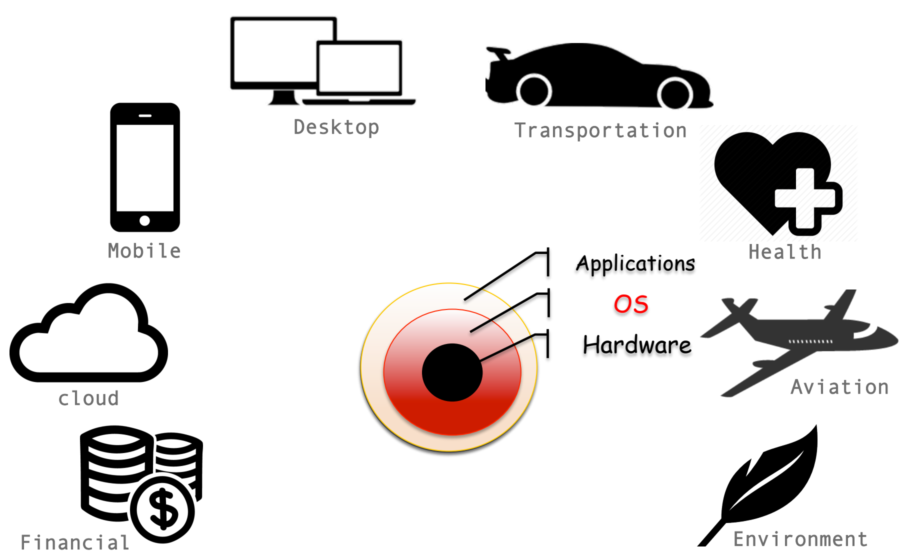
Today's lecture

- 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

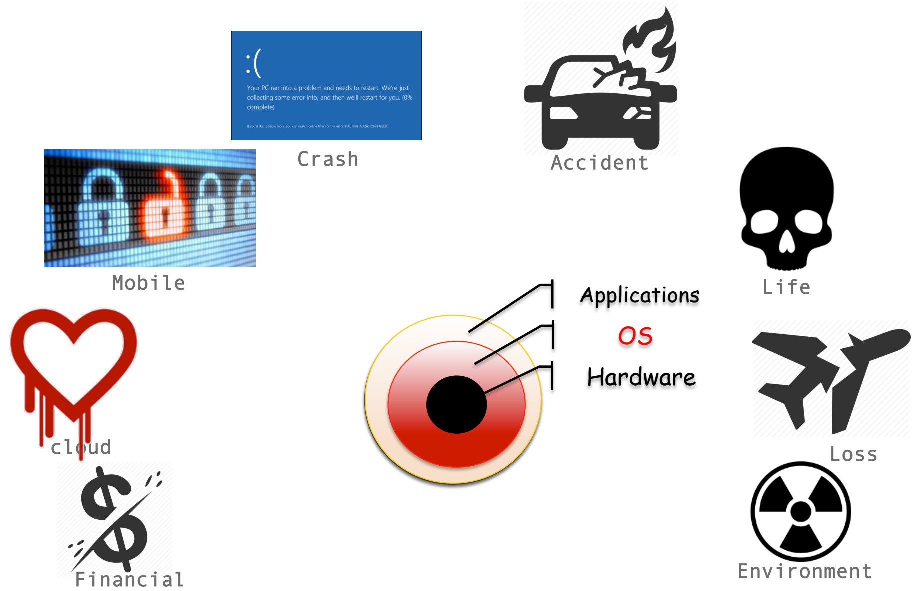
OS is pervasive



OS is pervasive



OS is pervasive & extremely important



Why study operating systems ?

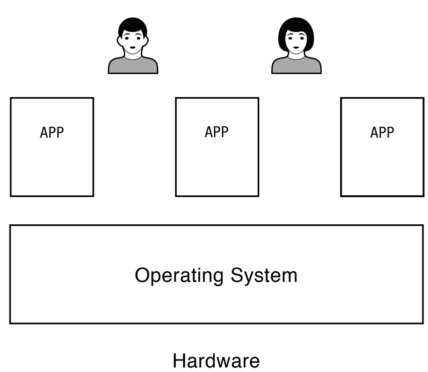
- Understand how "computers" work under the hood
  - Magic for "infinite" CPUs, memory devices, network computing
  - Tradeoffs btw. performance & functionality, division of labor btw. HW & SW
  - Combine language, hardware, data structures, and algorithms
- Help you make informed decisions
  - What "computer" to buy? should I upgrade the HW or the OS?
  - What's going on with my PC, especially when I have to install something?
  - Linux vs Mac OS X vs Windows 10 …, what should I bet on?
- Give you experience in hacking systems software
  "this system is so slow, can I do anything about it ?"

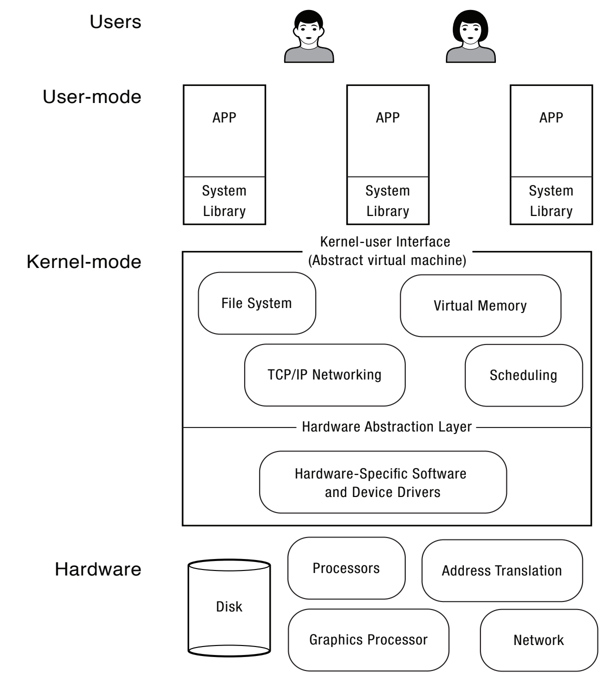
What's interesting?

- 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

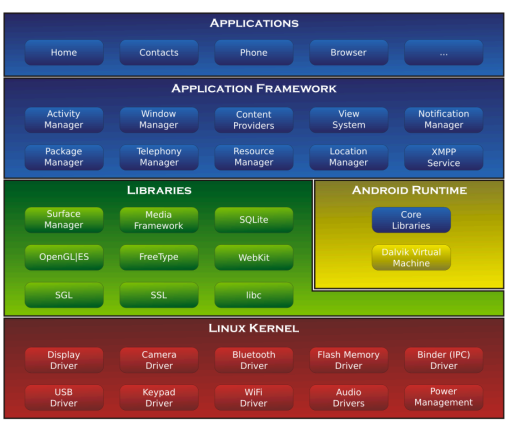


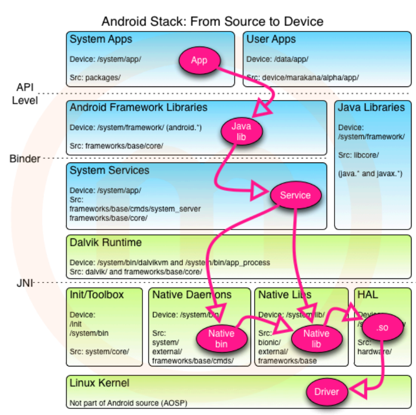


What is an OS?

Android architecture & system stack

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

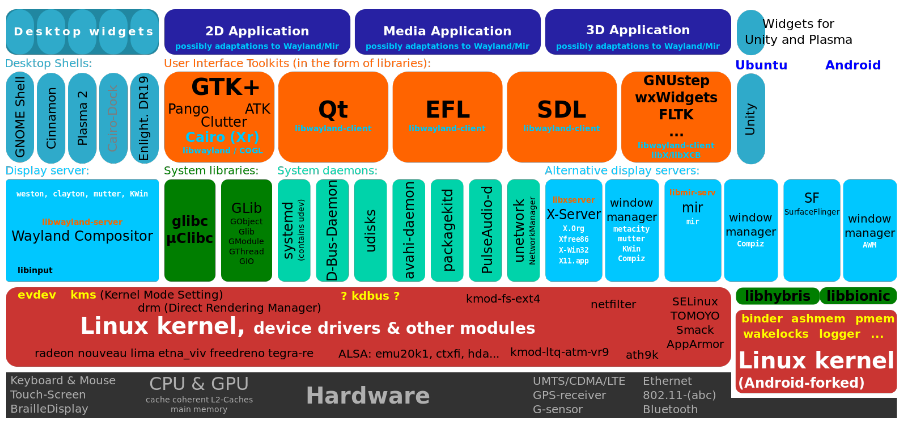




What is an OS?

Visible software components of the Linux desktop stack

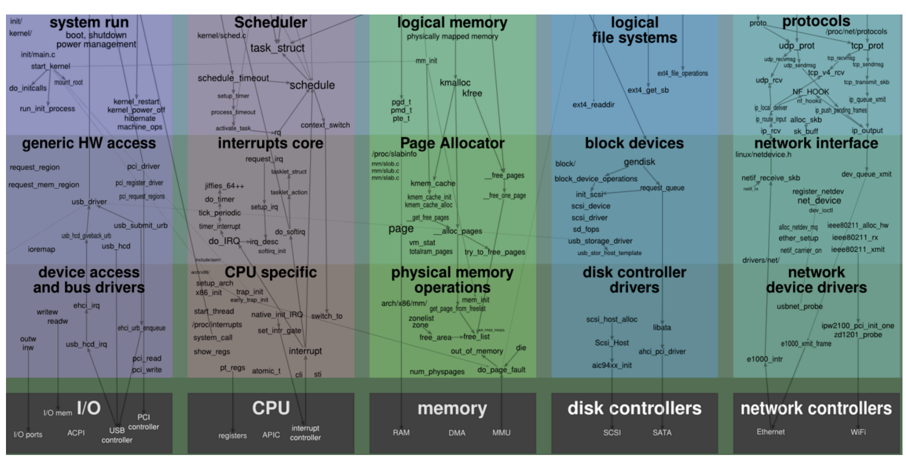
From http://en.wikipedia.org/wiki/Linux



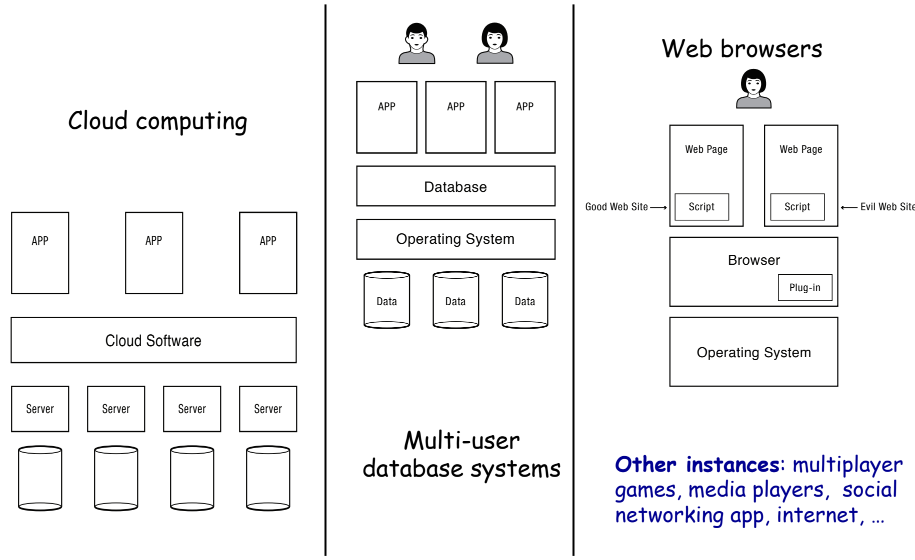
What is an OS?

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?



Other instances: multiplayer games, media players, social networking app, internet, …

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, …

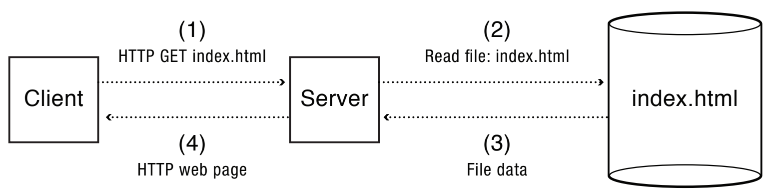
Question

- 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:

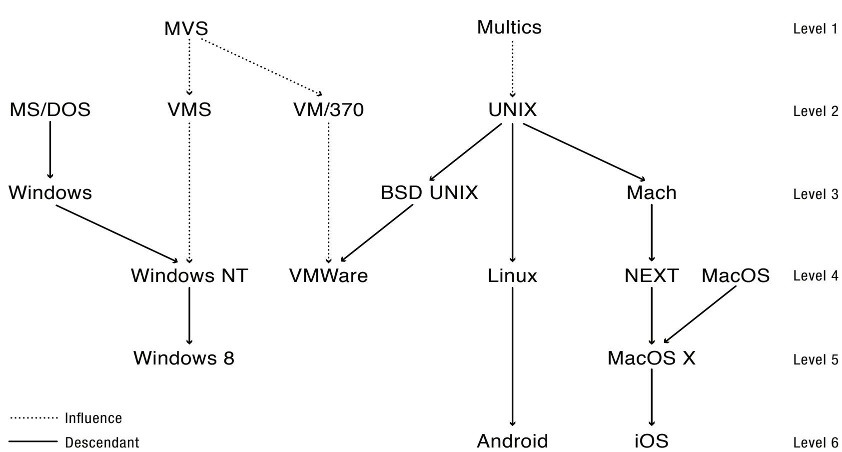
- CPU Preemption
  - give application something, can always take it away (via clock interrupts)
- Dual mode operation
  - when in the OS, can do anything (kernel-mode)
  - when in a user program, restricted to only touching that program's memory (user-mode)
- Interposition
  - OS between application 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 !

Challengs 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/fall2016/cpsc422522

Course information (cont'd)

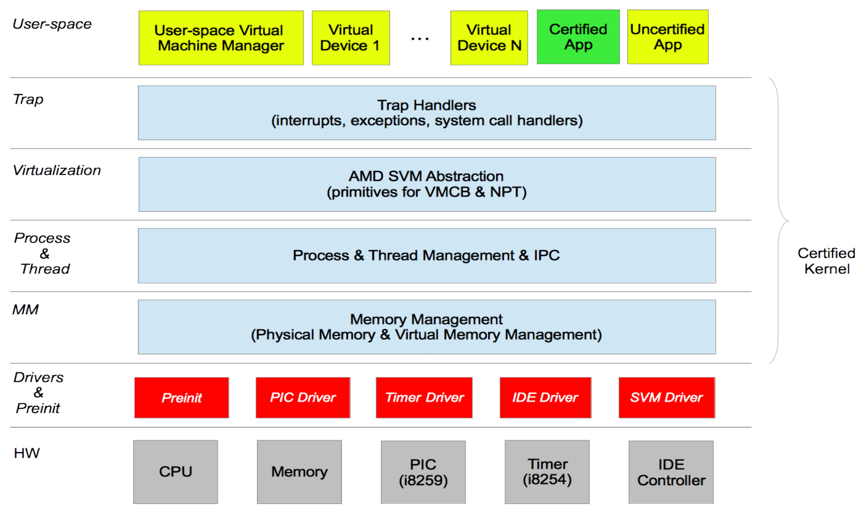
- **13 week lectures on OS fundamentals**
  - class participation is strongly recommended
- **Course requirements**
  - 70% on assignments (as1 – as6)
  - 25% open-book, in-class midterm (Thursday, November 17th)
  - 5% class participation
- **Assignments (as1-as6) and course policies**
  - build a small 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).
  - 5 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 Tuesdays 11:59pm
- The Lab
  - Linux cluster in ZOO
  - 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