CS2106
Introduction to OS

Lecture 1

Overview

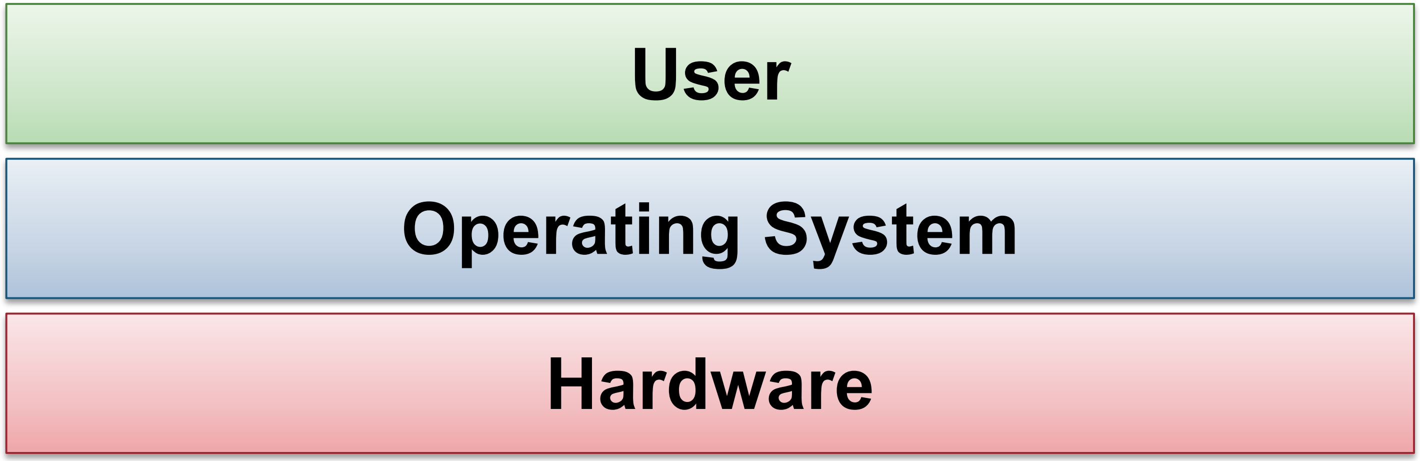
- **Operating Systems basic concepts:**
  - What is OS?
  - Brief History
    - Motivation for OS
  - Overview of Modern OSes
- **Operating System Structures**
  - OS components
  - Types of kernels
- **Virtual Machines**

What is OS?

- Incorrect/Incomplete definition:
  - It is the desktop when you boot up your PC
  - The "thing" that stores your games
  - Windows! (or Mac!) (or Linux!)

- One simple definition:
  - A **program** that acts as an **intermediary** between a **computer user** and the **computer hardware**
  - OS manages hardware and software resources and provides essential services to other programs

Illustration: What is an OS?



User

Operating System

Hardware

- A simplified view:
  - Will be refined as we move along
- The most general version:
  - Hardware (not only a computer!)
  - User (can be application programs or an actual person!)

Example of Common OS

- On Computer:
  - Windows 10/9/8/XP
  - Mac OS X
  - Linux distros: Ubuntu, Redhat, CentOS, Debian
  - Solaris

- On Smartphone:
  - iOS, Android, Windows Mobile

- Other hardware with OS:
  - Game console: PS4, Xbox, Wii U, PSP vista, …
  - Home appliance: Blueray/DVD Player, Mio TV console, …

To invent the future, you must understand the past

BRIEF HISTORY OF OS

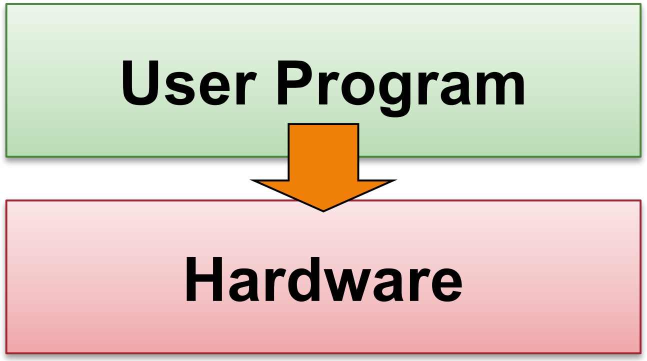
Brief History of OS

- Essentially, OS evolves with:
  - Computer hardware
  - User application and usage pattern

- The "first" computers:
  - **E**lectronic **N**umerical Integrator **A**nd **C**omputer (**ENIAC**)
    - 1945
    - Program controlled by cables and switches
  - Harvard Mark I:
    - 1944
    - Program controlled by punched paper tape

OS for the first computers

- OS Type:
  - **NO** OS



- Programs directly interact with hardware
  - Reprogram by changing **physical** configuration of hardware

- **Advantage:**
  - Minimal overhead

- **Disadvantages:**
  - Not portable, inflexible
  - Inefficient use of computer resources!

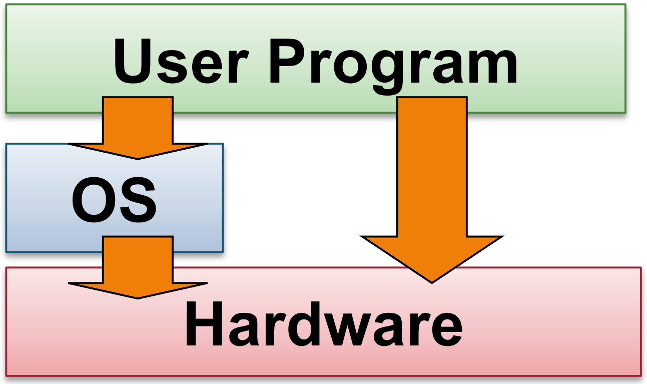
Mainframes: The "Big Iron"

- Commonly used by large corporations in 60s, 70s

- Common features:
  - No interactive interface
  - Accept programs in the form of:
    - Paper tape, magnetic tape, punch card
  - Support batch processing only
  - Very costly
    - Usually "rented" instead of owned
- Example:
  - IBM 360
    - Cost: 5 billion USD in 1964 to develop, 130K to buy

OS for Mainframes

- OS Type:
  - **Batch** OS



- Batch OS:
  - Execute user program (a.k.a. ***job***) one at a time
    - Load job from storage media, execute, collect result
- User Job:
  - Still interact with hardware directly
  - With additional information for the OS
    - Resource required
    - Job specification

OS for Mainframes: Improvements

- Simple batch processing is inefficient:
  - CPU idle when perform I/O

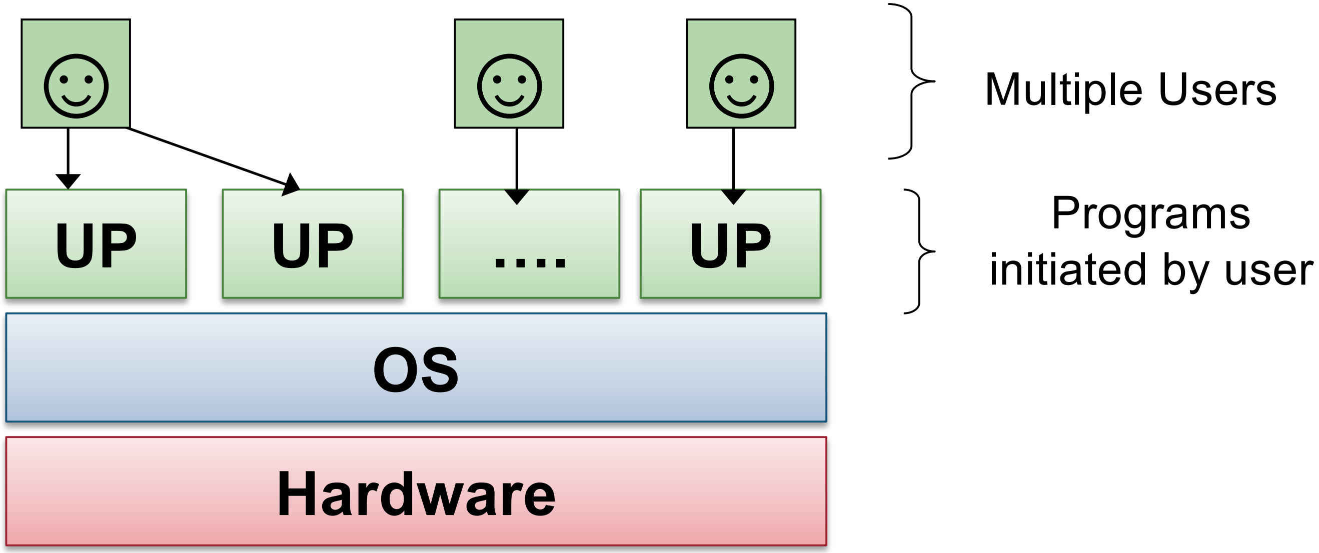
- One possible improvement:
  - Multiprogramming:
    - Loads multiple jobs and runs other jobs when I/O needs to be done
    - Overlaps computation with I/O

- Another OS development in 1970s:
  - Time-Sharing OS

Time-Sharing OS

- Features:
  - Allow multiple users to interact with machine using terminals (***teletypes***)
  - User job scheduling
    - Illusion of Concurrency
  - Memory management
- Famous Examples:
  - CTSS developed at MIT 1960s
  - Multics (1970s)
    - Considered as the *parent of Unix*
  - Pushed the state of art in virtual memory, security
- Similar to Unix servers today, but more primitive

Time-sharing OS: Illustration



- OS manages the sharing of:
  - CPU time, memory and storage

- ***Virtualization*** of hardware:
  - Each program executes ***as if*** it has all the resources to itself

Minicomputer and Unix

- Minicomputer follows the mainframe:
  - A "mini" version of mainframe:
    - Smaller and cheaper
  - Example:
    - Digital Equipment Corp (DEC) PDP-11
- Famous OS:
  - Unix
    - Developed by AT&T employees, including Ken Thompson, Dennis Ritchie, Douglas McIlroy, and Joe Ossanna
    - Ken Thompson and Dennis Ritchie
      - Invented the C programming language as well!!

Personal Computer

- Apple II PC:
  - First successfully produced mass home computer
  - Designed by Steve Wozniak (alone!)

- IBM PC:
  - The first generic PC
  - PC becoming truly a collection of commodity hardware components
  - Leads to dominance of Microsoft OS in PCs: MSDOS then Windows

OS on Personal Computer

- Machine (can be) dedicated to user, not timeshared between multiple users
  - Give rise to **personal OS**

- Several Models:
  - Windows model:
    - Single user at a time but possibly more than 1 user can access
    - Dedicated machine
  - Unix model:
    - One user at the workstation but other users can access remotely
    - General time-sharing model

Why do we need OS?

MOTIVATION FOR OPERATING SYSTEMS

Motivation for OS: Abstraction

- Large variation in hardware configurations

- Example (Hard disk):
  - Different capacity (500MB, 320GB, 1.5TB, etc)
  - Different capabilities:
    - Rotation per minutes (RPM)
    - Access (read/write) speed
    - Etc

- However, hardware in the same category has well defined and common functionality
  - Example (hard disk): store and retrieve information

Motivation for OS: **Abstraction**

- Operating System serves as an **abstraction**:
  - Hide the different low-level details
  - Present the common high-level functionality to users
- Users can perform essential tasks **through** operating system
  - No need to worry about low-level details
- Provides:
  - Efficiency and portability

Motivation for OS: **Resource Allocator**

- Program execution requires multiple resources:
  - CPU, memory, I/O devices etc

- For better utilization of resources, multiple programs should be allowed to execute simultaneously

- OS is a **resource allocator**
  - Manages all resources
    - CPU, Memory, Input/Output devices
  - Arbitrate potentially conflicting requests
    - for **efficient** and **fair** resource use

Motivation for OS: **Control Program**

- Program can misuse the computer:
  - Accidentally: due to coding bugs
  - Maliciously: virus, malware etc

- Multiple users can share the computer:
  - Tricky to ensure separate user space

- OS is a **control program**
  - Controls execution of programs
    - Prevent errors and improper use of the computer
    - Provides security and protection

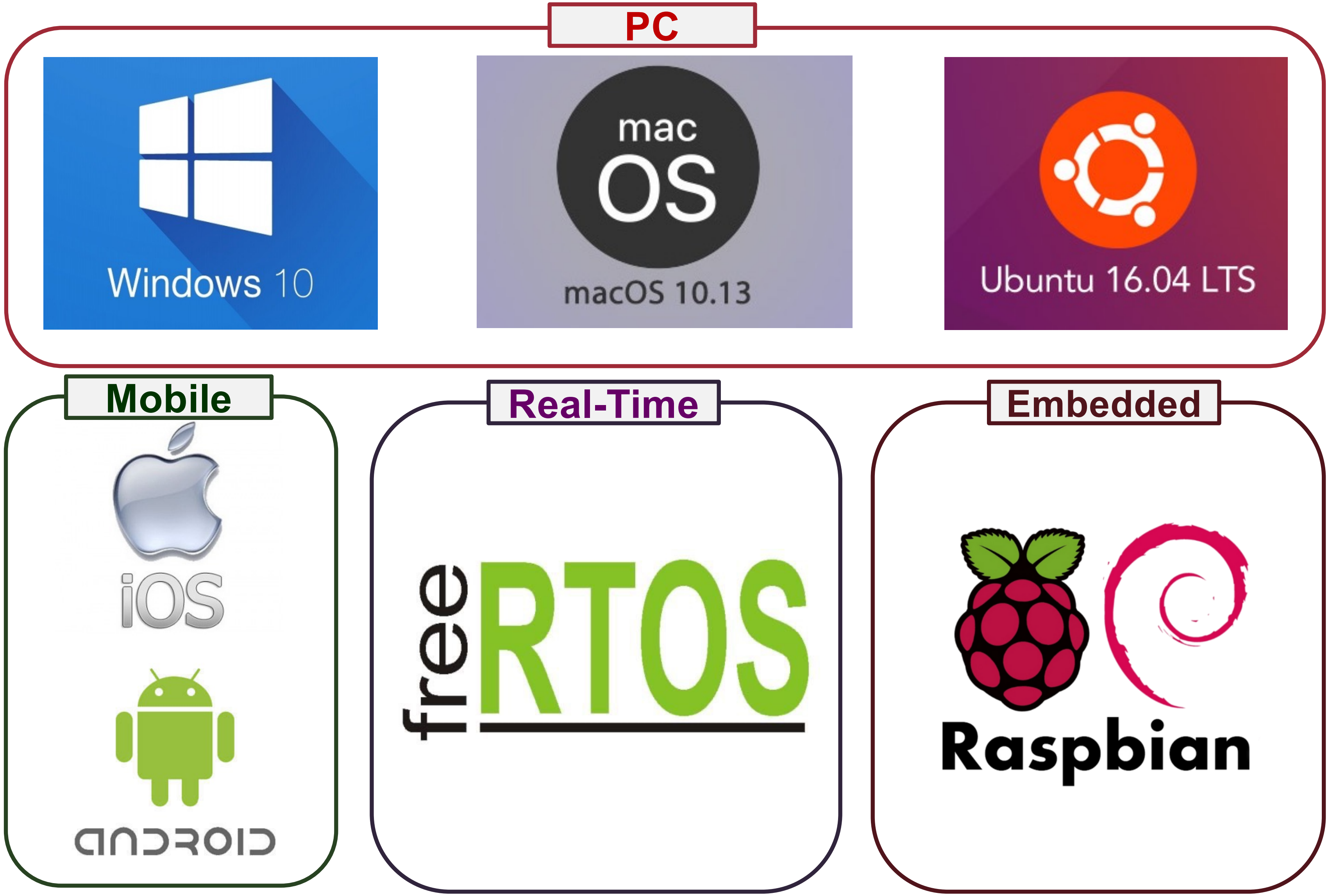
Motivation for OS: **Summary**

- Manage resources and coordination
  - process synchronization, resource sharing
- Simplify programming
  - abstraction of hardware, convenient services
- Enforce usage policies
- Security and protection
- User Program Portability:
  - Across different hardware
- Efficiency
  - Sophisticated implementations
  - Optimized for particular usage and hardware

The families of modern OS

OVERVIEW OF MODERN OS

Modern OS: Overview



PC

Mobile

Real-Time

Embedded

Common Architecture for OS

OS STRUCTURE

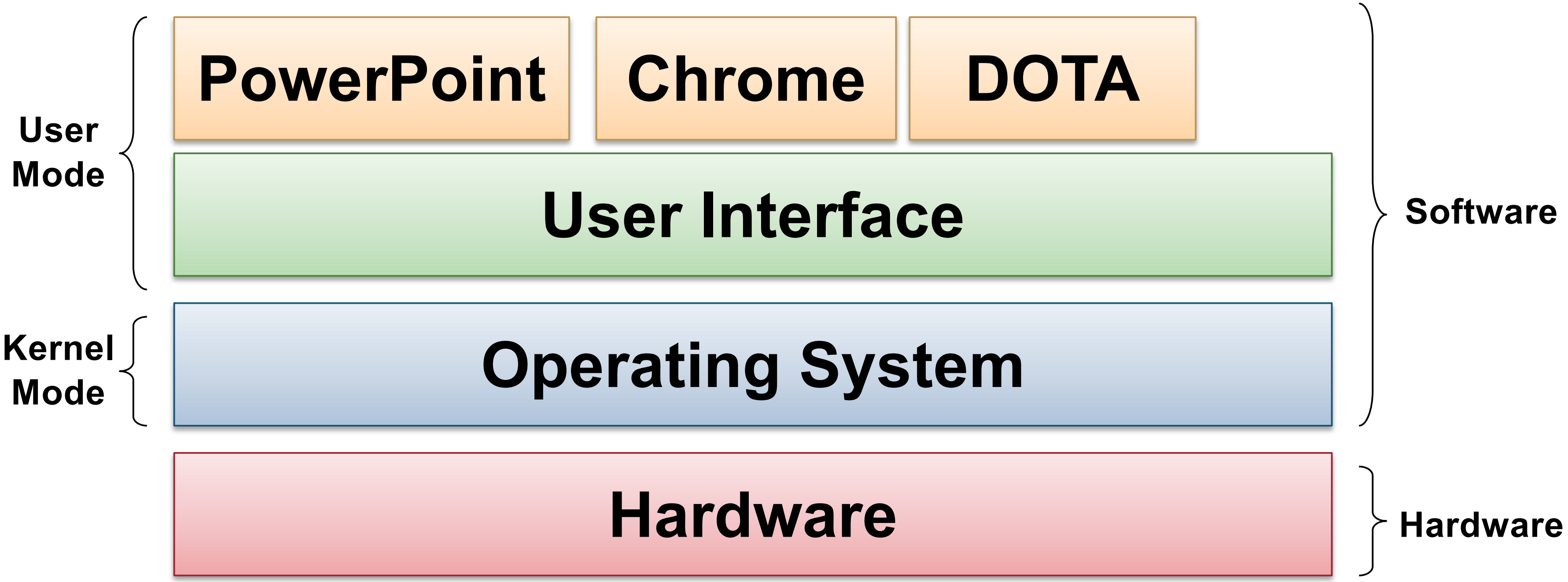
Operating System Structures

- We have identified the major capabilities of an OS
  - i.e., the *specification* of the OS

- Let us now consider:
  - The best way to provides these capabilities
  - i.e., the *implementations* of the OS

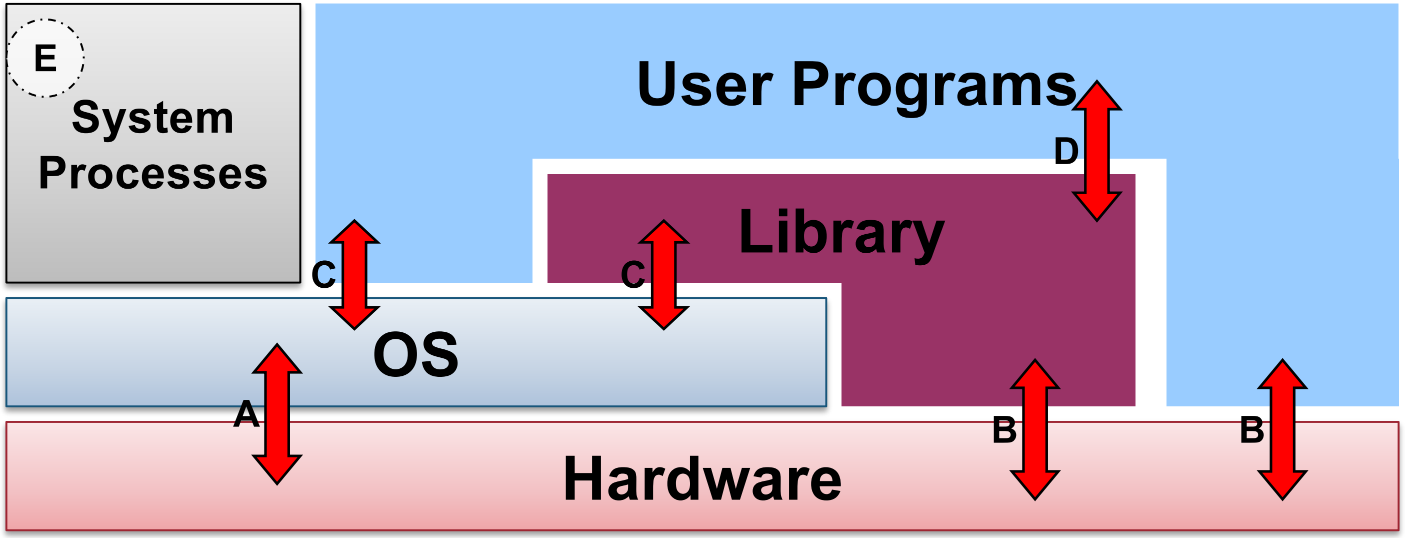
- Operating system structure:
  - *Organization* of the various components
  - Important factors:
    - Flexibility
    - Robustness
    - Maintainability

Illustration: High level view of OS



- Operating System is essentially a software
  - Runs in ***kernel mode***: Have complete access to all hardware resources
- Other software executes in ***user mode***
  - With limited (or controlled) access to hardware resources

Illustration: Generic OS Components



- **A**: OS executing machine instructions
- **B**: normal machine instructions executed (program/library code)
- **C**: calling OS using ***system call interface***
- **D**: user program calls library code
- **E**: system processes
  - Provide high level services, usually part of OS

OS as a Program

- OS is also known as the **kernel**
  - Just another program with some special features
    - Deals with hardware issues
    - Provides system call interface
    - Special code for interrupt handlers, device drivers

- Kernel code has to be different than normal programs:
  - no use of system call in kernel code
  - can’t use normal libraries
  - no normal I/O

- Consider this:
  - Normal programs use OS: what does OS use? ☺

Implementing Operating System

- **Programming Language:**
  - Historically in assembly/machine code
  - Now in ***HLLs***:
    - Especially C/C++
  - Heavily hardware architecture dependent

- **Common code organization:**
  1. Machine independent HLL
  2. Machine dependent HLL
  3. Machine dependent assembly code

- **Challenges:**
  - "No one else" to rely on for nice services
  - Debugging is hard
  - Complexity
  - Enormous Codebase

OS Structures

- Several ways to structure an OS:
  - **Monolithic**
  - **Microkernel**
  - Layered
  - Client-Server
  - Exokernel
  - Split kernel
  - etc

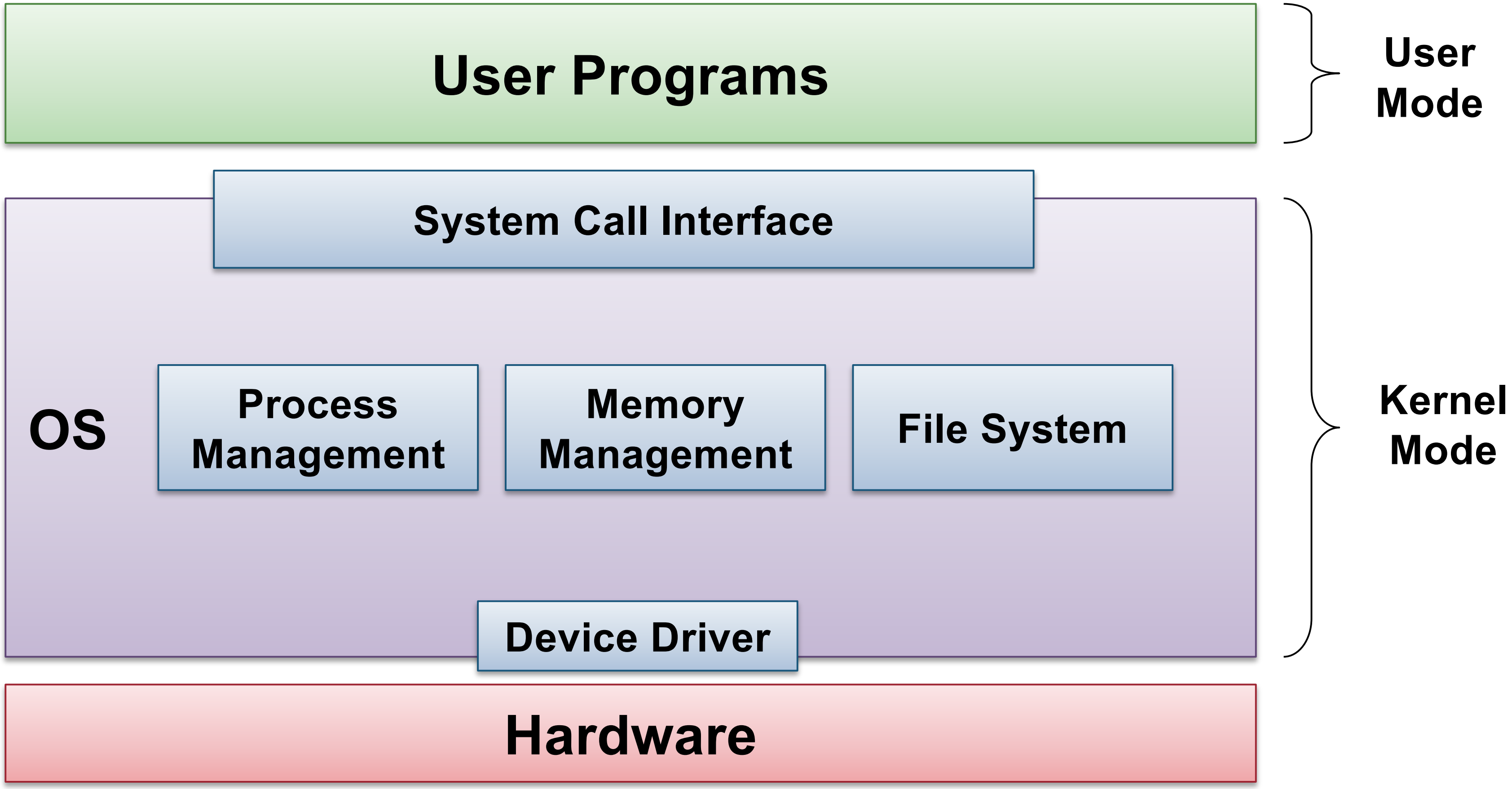
- We will cover the first two in details:
  - They represent the whole range of possibilities
  - Most other approaches are variant or improvement

Monolithic OS

- Kernel is:
  - One **BIG** special program
    - Various services and components are integral part
  - Good SE principles is still possible with:
    - modularization
    - separation of interfaces and implementation
- This is the traditional approach taken by:
  - Most Unix variants, Windows NT/XP

- **Advantages:**
  - Well understood
  - Good performance
- **Disadvantages:**
  - Highly coupled components
  - Usually devolved into very complicated internal structure

Monolithic Kernel Illustration



Generic Architecture of Monolithic OS Components

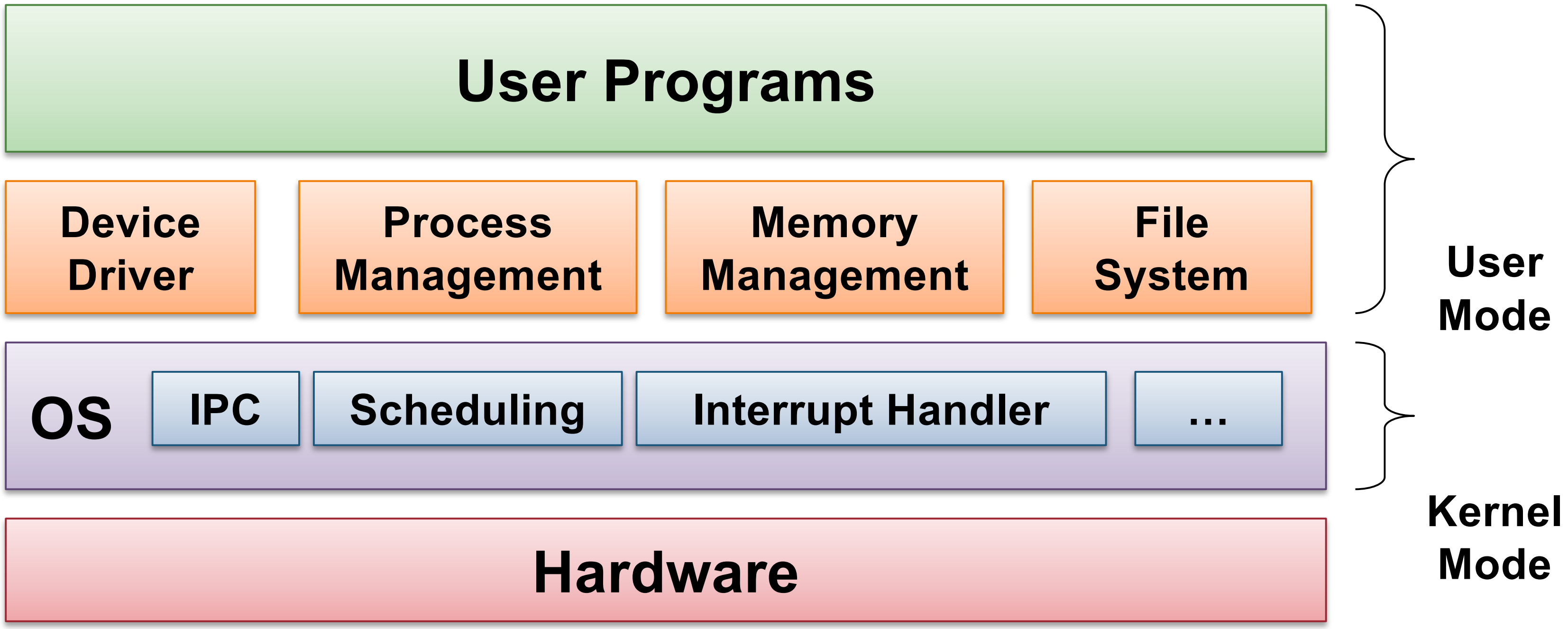
Microkernel OS

- Kernel is:
  - Very small and clean
  - Only provides basic and essential facilities:
    - Inter-Process Communication (IPC)
    - Address space management
    - Thread management
    - etc
- Higher level services:
  - Built on top of the basic facilities
  - Run as server process ***outside*** of the OS
  - Use IPC to communicate

- Advantages:
  - Kernel is generally more robust and more extendible
  - Better isolation and protection between kernel and high level services

- Disadvantages:
  - Lower Performance

Microkernel Components



Generic Architecture of Microkernel OS Components

Other Operating System Structure

- Layered Systems:
  - Generalization of monolithic system
  - Organize the components into hierarchy of layers
    - Upper layers make use of the lower layers
    - Lowest layer is the hardware
    - Highest layer is the user interface
- Client-Server Model
  - Variation of microkernel
  - Two classes of processes:
    - Client process request service from server process
    - Server Process built on top of the microkernel
    - Client and Server process can be on separate machine!

Ways of running OSes

VIRTUAL MACHINES

Motivation: Why Virtual Machines

- Operating system assumes total control of the hardware:
  - What if we want to run several OSes on the same hardware at the same time?

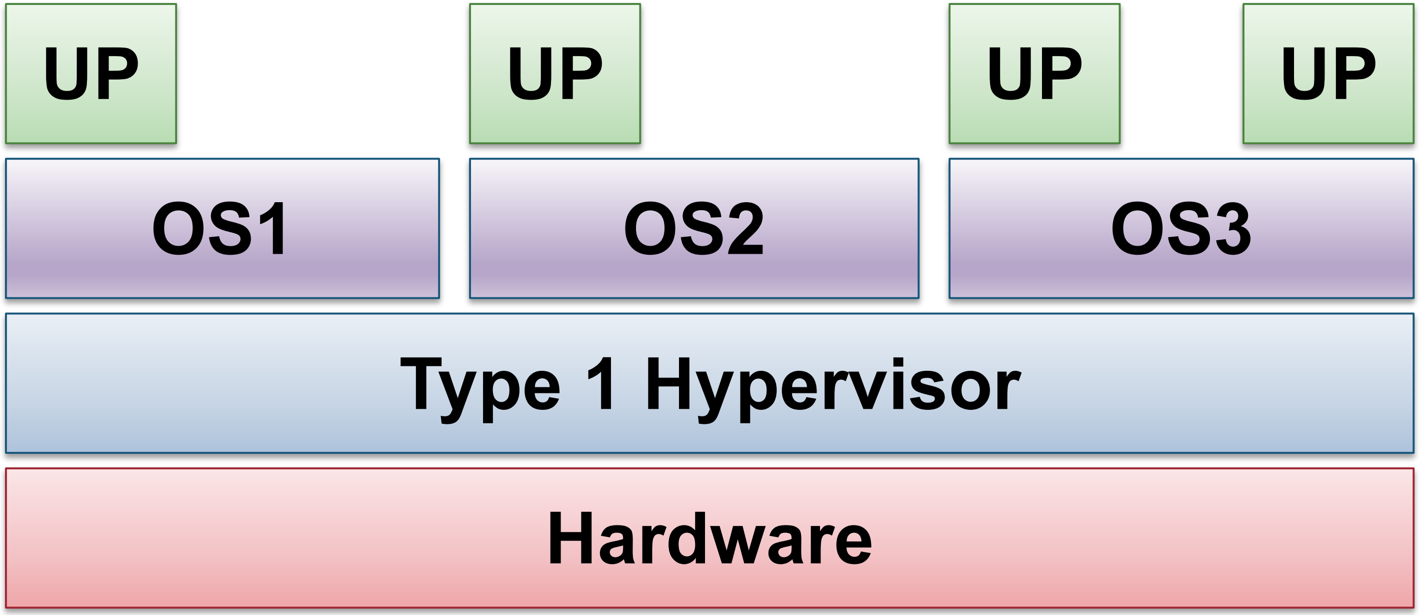
- Operating system is hard to debug / monitor:
  - How do we observe the working of the OS?
  - How do we test a potentially destructive implementation?

Definition: Virtual Machine

- Virtual Machine:
  - A software emulation of hardware
  - **Virtualization** of underlying hardware
    - Illusion of complete hardware to level above: memory, CPU, hard disk etc…
  - Normal (primitive) operating system can then run on top of the virtual machine

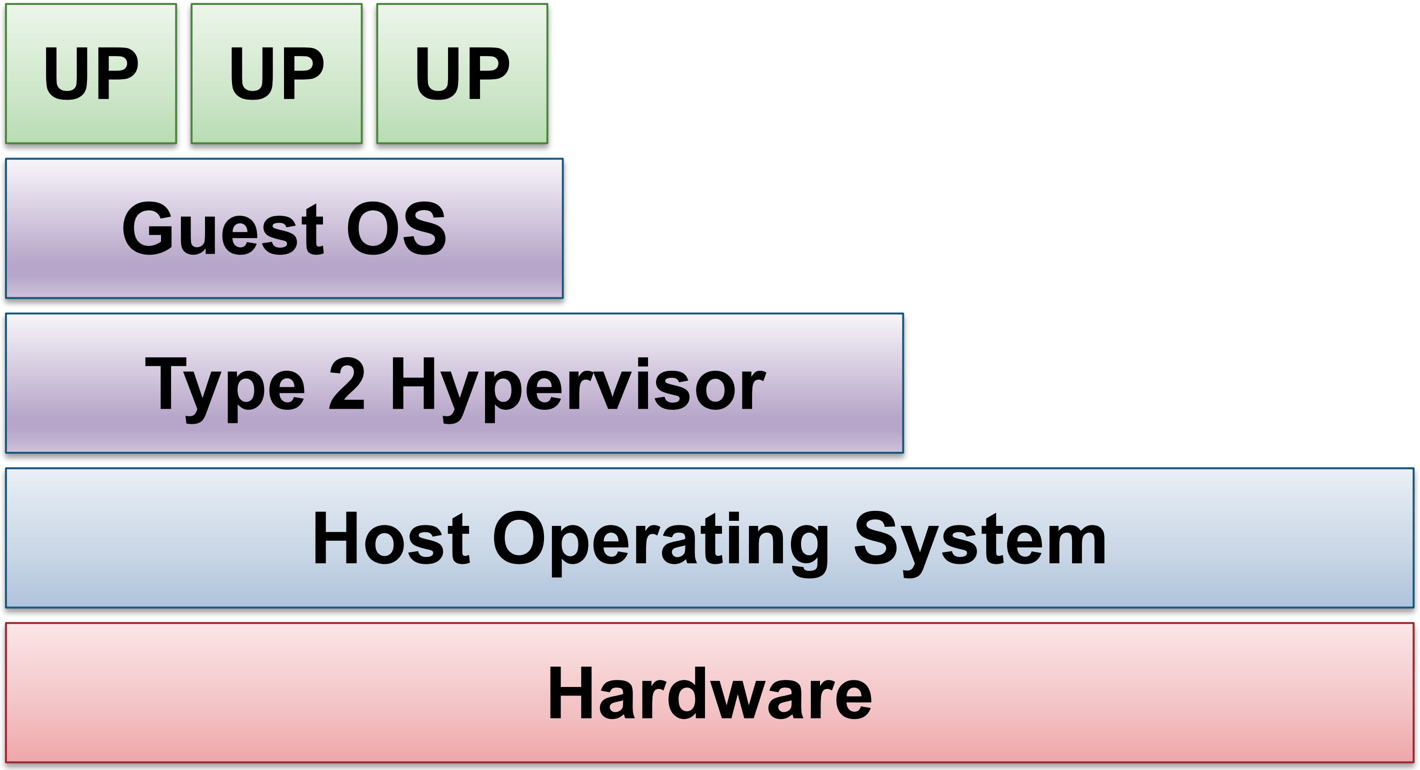
- Also known as **Hypervisor**
  - Two classes of implementations shown next

Type 1 Hypervisor



- Type 1 hypervisor:
  - Provides individual *virtual machines* to guest OSes
  - eg. IBM VM/370

Type 2 Hypervisor



- Type 2 hypervisor OS
  - Runs in host OS
  - Guest OS runs inside Virtual Machine
  - e.g. VMware

Summary

- Definition of Operating System
- Roles of Operating System
- Common Operating System families
- Operating System structure

Reference

- Modern Operating System (4th Edition)
  - By Andrew S.Tanenbaum
  - Published by Pearson

- Operating System Concepts (9th Edition)
  - By Abraham Silberschatz, Peter Baer Galvin & Greg Gagne
  - Published by McGraw Hill

FYI: MODERN OS FAMILY

(AS OF 2016)

Modern OS: An Overview

- Several dominant desktop OSes:
  - Microsoft Windows family
  - Unix and its variants
  - Mac OS family

- Specialized OSes:
  - Real-time OS
  - Embedded System OS
  - Mobile OS
  - Distributed OS

Microsoft OS Family

- 16-bit:
  - MS-DOS (various versions, v1.0 in 1985)
  - Windows 1.X – 3.X, Windows 9X, Windows ME (2000)
- 32-bit:
  - Windows NT (32-bit, v3.1 in 1994)
  - Windows 2000, XP, 2003, Vista, 7, 8, 10 (2015)
- 64-bit:
  - Windows XP (2005), Vista, 7, 8, 10 (2015)
- Mostly on PC (Intel Processors) platforms
- Proprietary
  - some sources available under conditions
- Complex architecture, internals info not widely available

Microsoft OS: Complexity

- Win NT 3.1: (shipped 1993)
  - Dev Team Size: 200
  - 6 Millions LOC (Line of Code)
  - Complete build time is 5 hours on ~486/50

- Win 2000: (shipped 1999)
  - Dev Team Size: 1400
  - 29 Millions LOC (about 50Gb of disk space)
  - Complete build time: 8 hours on 4-way PIII Xeon 550 with 50Gb disk and 512k RAM

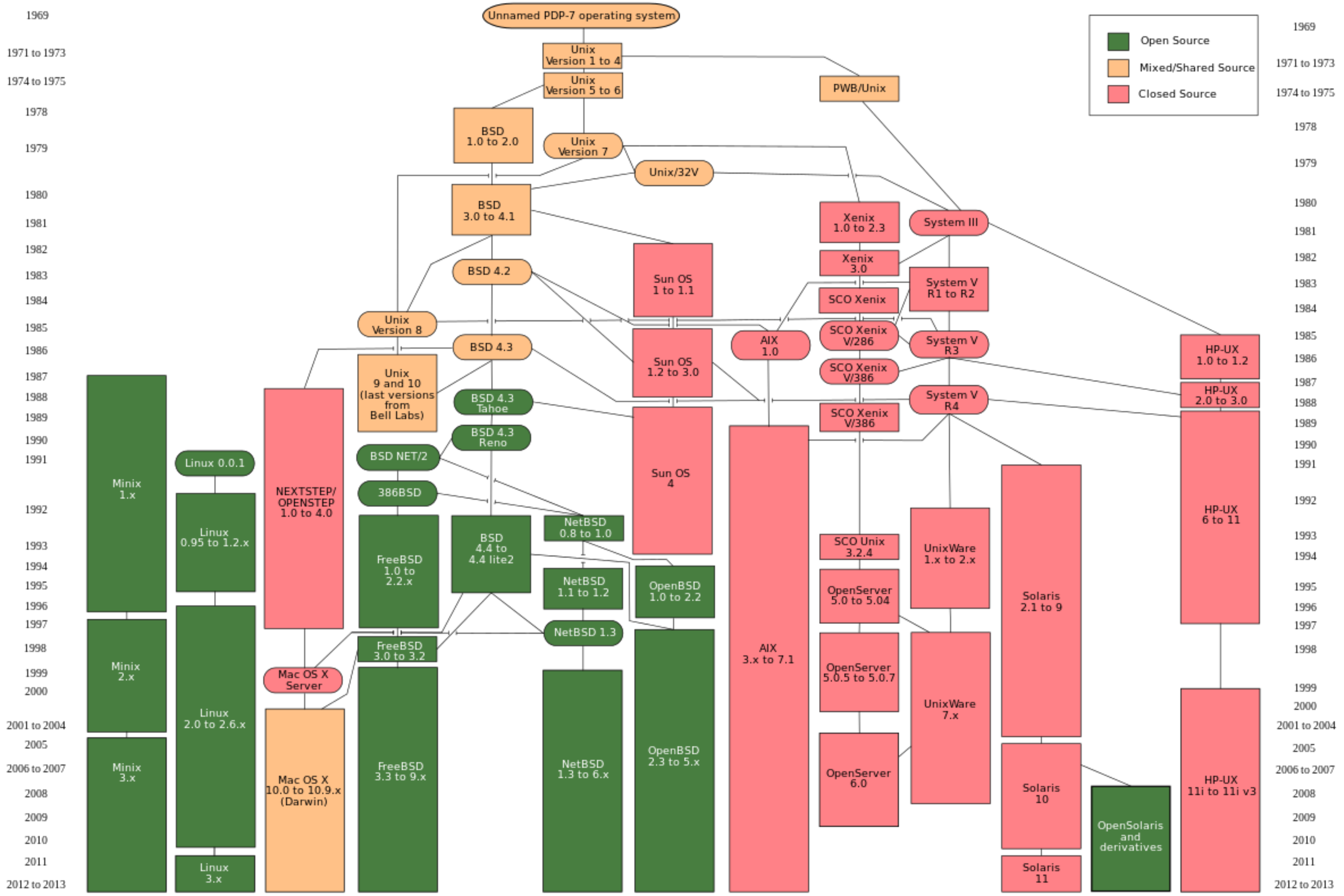
- Windows 7: (shipped 2009)
  - Dev Team Size: ~2500 (split into 25 teams of ~100)
  - ~40 Millions LOC

Unix and its Variants

- Many Unix Variants:
  - Unix System V versions
  - Berkeley System Distribution (BSD)
  - Sun Solaris
  - SGI IRIX, IBM AIX, Digital Unix, HP-UX, ...
  - Linux
  - MacOS X (BSD + Mach + Apple)

- Programming Interface (API) mostly the same, fundamentals are same but small differences exist
- Simple architecture, internals well understood, good documentation, research papers
- Linux + BSD open source
- Non-proprietary, POSIX standards
- Implementations on many processors architectures:
  - x86, powerpc, m68k, mips, arm, sparc, alpha, ...

Unix Variants: Rough timeline



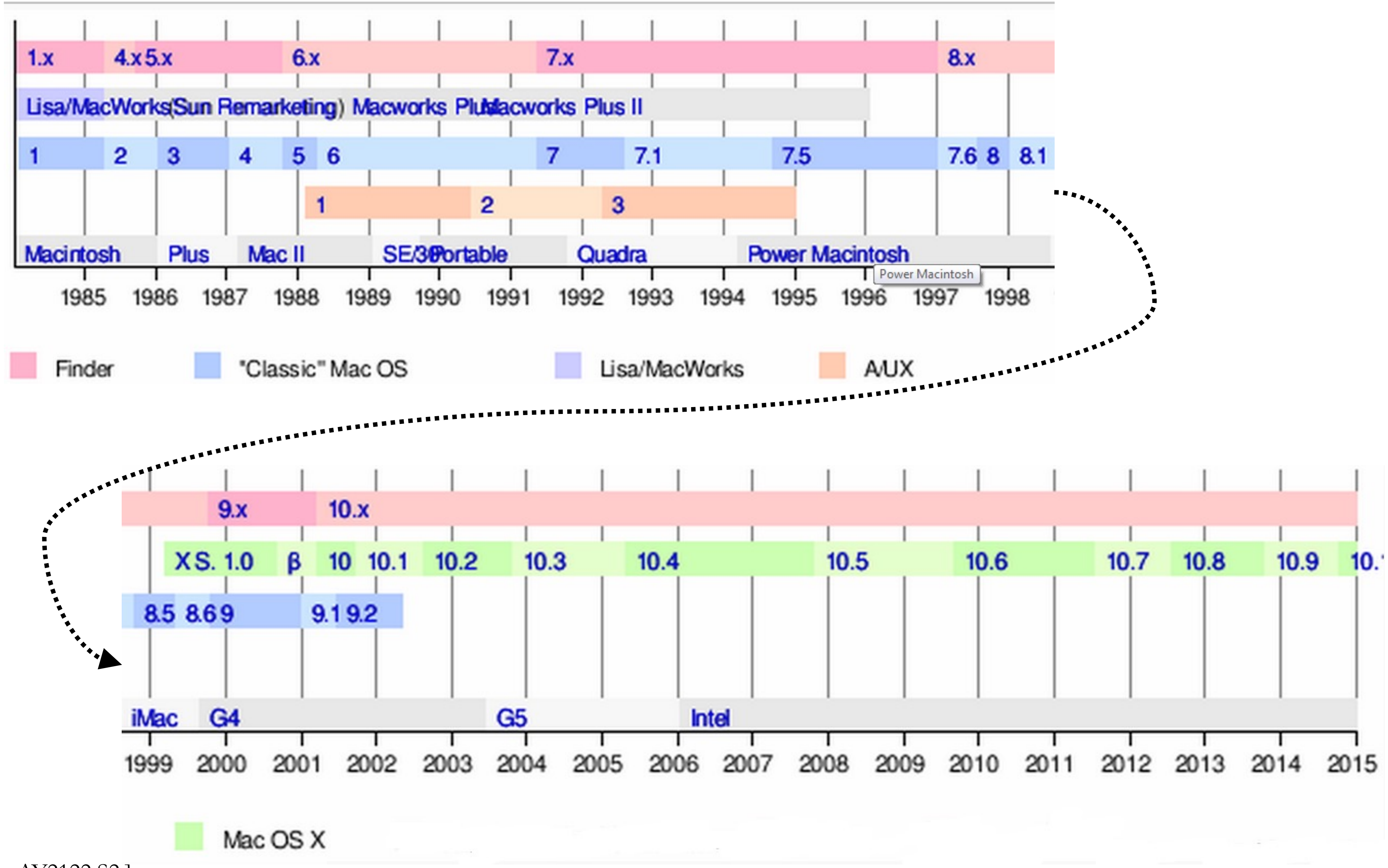
"Unix history-simple" by Eraserhead1, Infinity0, Sav_vas - Levenez Unix History Diagram, Information on the history of IBM's AIX on ibm.com

Linux Distributions (Distros)

- Most popular form of linux OS
  - E.g. Ubuntu, Fedora, SuSe, BSD, Debian, CentOS, etc

- Essentially a software collection with:
  - Linux kernel
  - Common software:
    - Desktop management, browser, media player etc
  - Development tools/libraries
    - gnu libraries, compilers etc
  - Device drivers
  - Package manager

Mackintosh OS Timeline



Characteristics of Modern PC OS

- Multitasking:
  - Concurrent execution of programs
    - On multiple cores
- Multi/single user:
  - Unix usually multi-user
  - Windows usually single-user at a time
- Wide range of computer hardware:
  - Single PC/notebook
  - Shared memory systems with 10-100s of processors
  - Machine clusters with 100-1000s of processors
  - Distributed computing on Internet with >10K machines

Real Time OS

- OS for computer systems with time constraints:
  - periodicity, deadlines

- Examples:
  - **Critical Systems**: aircraft flight system, nuclear power plant, radar system
  - **Consumer appliances**: mobile phones, mp3, video players

- **Hard real time**:
  - Timing requirements **must** be respected, eg. control system
- **Soft real time**:
  - Some timing constraints can be missed

- May need **formally verified systems**

Embedded OS

- OS for specialized devices and appliances

- Examples:
  - (Older) Smartphones, microwave oven, car, smart cards, game consoles, etc

- Special consideration required for:
  - power usage, real-time requirement and memory limitations

- Usually:
  - Not general purpose: cannot run any application
  - Cannot be modified: Mostly stored in Read-Only Memory (ROM)

Mobile OS

- OS for smartphones, tablets, PDAs, or other mobile devices

- Examples:
  - Android, iOS, Windows Phone, etc.

- Characteristics:
  - Essentially a customized version of PC OS
  - Common features: Touchscreen, Cellular, (Video) Camera, etc…

Distributed OS

- OS for computers/processors connected using network
  - Loosely or Tightly coupled

- Loosely coupled:
  - Autonomous nodes, network may be wide area
  - Communication is asynchronous
  - Reliability issues:
    - communication may not be reliable, nodes may fail
  - Resources are distributed
    - eg., distributed filesystem, P2P storage

- Tightly coupled:
  - Specialized node (e.g., Computing nodes) that shares other resources (e.g. Memory / Harddisk etc), nodes in close proximity
  - Examples:
    - Tembusu2 cluster compute nodes:
      - ~100 Intel Xeon nodes running CentOS