# CS2106
# Introduction to OS

Lecture 1 Introduction

# Overview

- **Operating Systems basic concepts:**
  - What is OS?
  - Brief History
    - Motivation for OS
  - Overview of modern OSes

- **Operating System Structures**
  - OS components
  - Types of kernel

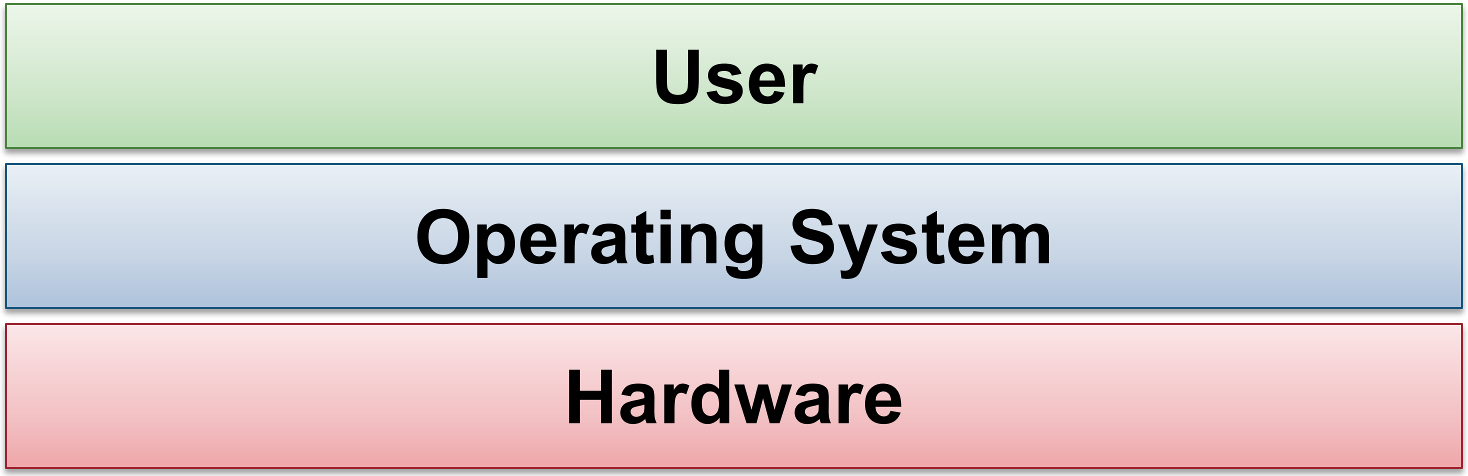
- **Virtual Machines**

# What is an 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**
  - **Wikipedia:** An operating system (OS) is system software that manages computer hardware, software resources, and provides common services for computer programs.

# Illustration: What is an OS?



- A simplified view:
  - Will be refined as we move along

- The most general version:
  - Hardware (not only computer!)
  - User (can be application programs or actual person!)

# Example of Common OS

- On Computer:
  - Windows 11/10/8/XP
  - Mac OS X
  - Linux distros: Ubuntu, Redhat, Debian, Fedora, CentOS
  - Solaris, FreeBSD

- On Smartphone:
  - iOS, Android

- Other hardware with OS:
  - Game console: PS5, Xbox, Nintendo Switch, …
  - Home appliance: Smart TV, Smart Watch, …

To invent the future, you must understand the past

# BRIEF HISTORY OF OS

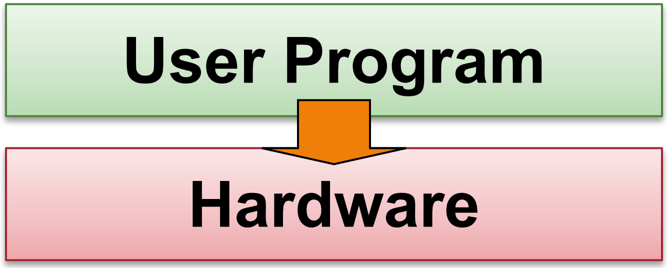
# Brief History of OS

- 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
- **Disadvantage:**
  - Not portable
  - Inefficient use of computer!

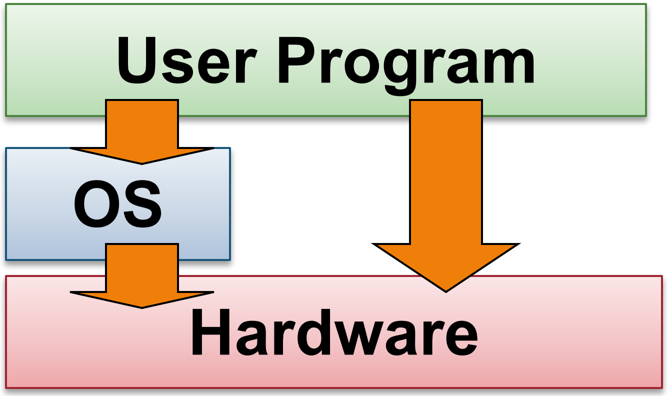
# Mainframes: The "Big Iron"

- 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 US dollars in 1964 to develop
    - Cost 130k US dollar in 1965 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 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

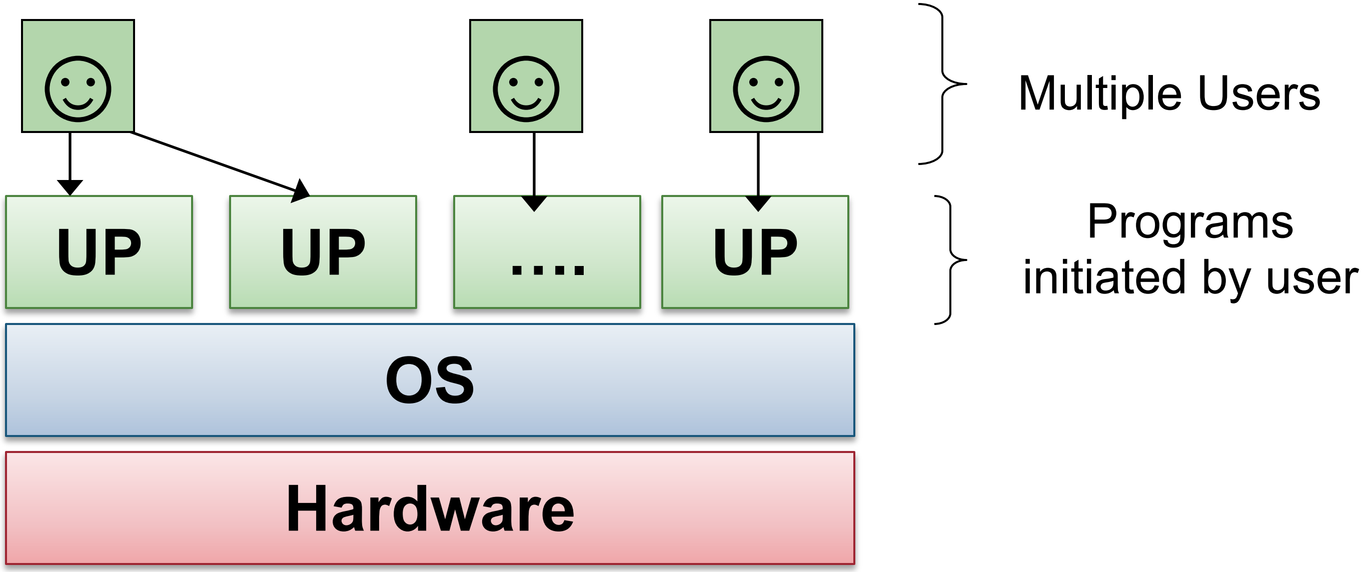
- One possible Improvements:
  - Multiprogramming:
    - Loads multiple jobs and runs other jobs when I/O needs to be done
    - Overlaps computation with I/O

- Another development of OS during this period (70s):
  - 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

# Personal Computer

- Apple II PC (1977):
  - First successfully produced mass home computer
  - Designed by Steve Wozniak (alone!)

- IBM PC (1981):
  - The first generic PC
  - PC becoming a collection of **commodity** hardware components
  - Leads to dominance of Microsoft OSes on PCs: MSDOS (1981) then Windows (1985)

# 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?

# MOTIVATIONS OF OS

# 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
    - ...

- 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 user

- The user can then perform essential tasks **through** operating system
  - No need to concern with low-level details

- Provides:
  - Efficiency, programmability, 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, I/O 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 isolation among users

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

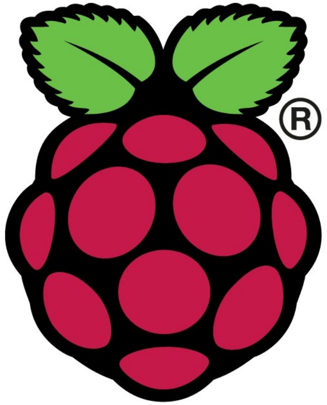
# Modern OS: Overview

Desktop

Mobile

Real-Time

Embedded



Common Architecture for OS

# OS STRUCTURE

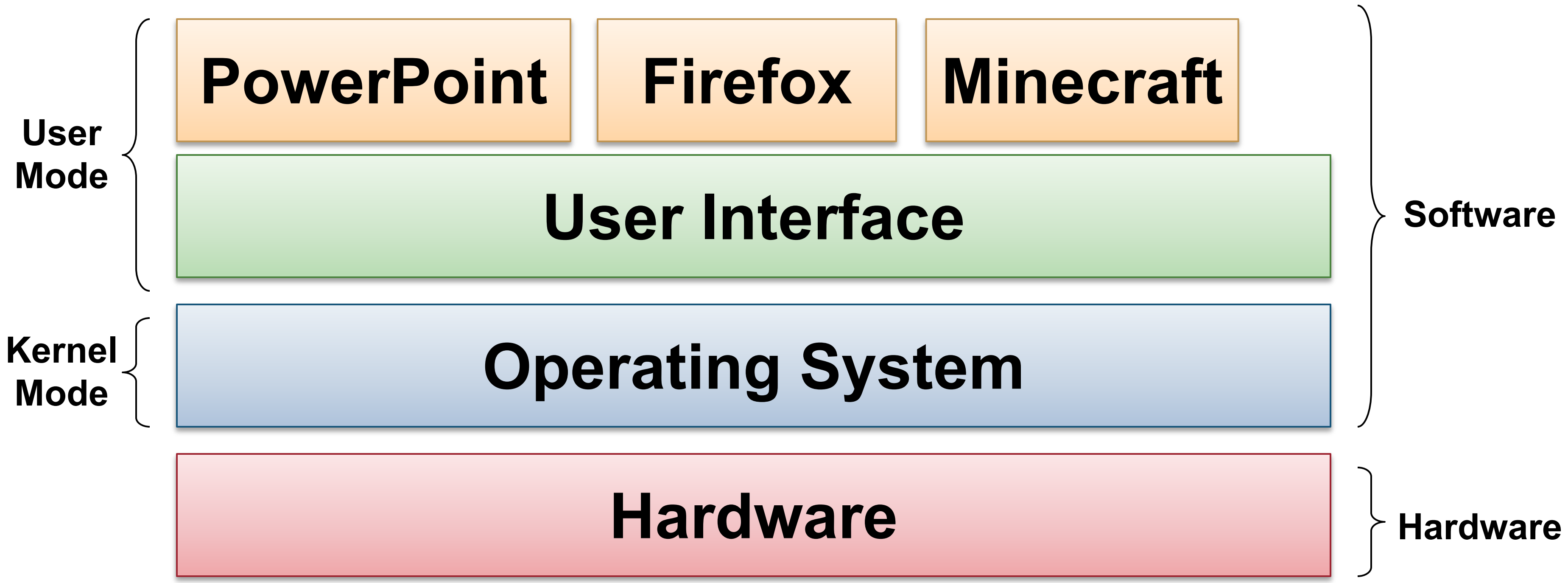
# Operating System Structures

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

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

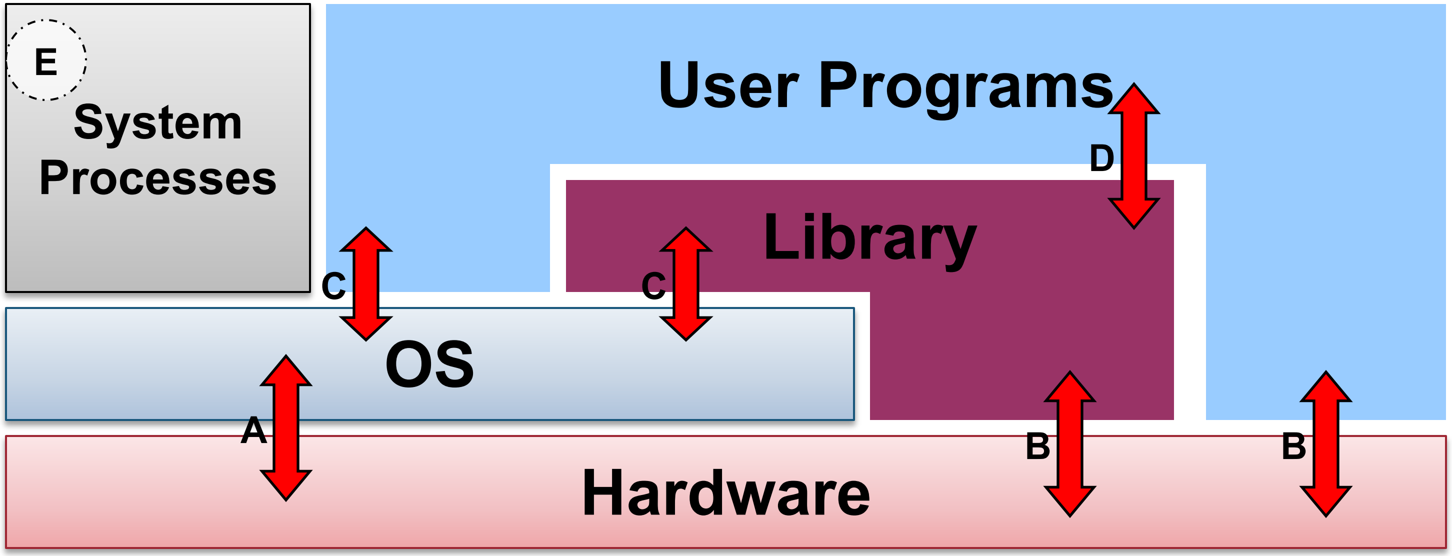
- Operating system structure:
  - *Organization* of the various components
  - Important factors:
    - Flexibility
    - Robustness
    - Maintainability
    - Performance

# Illustration: High-level view of OS



- Operating System is essentially a software
  - Runs in ***kernel mode***: direct 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

- A critical part of an OS is 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:
  - Can’t use system calls 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
  - Hybrid
  - ...

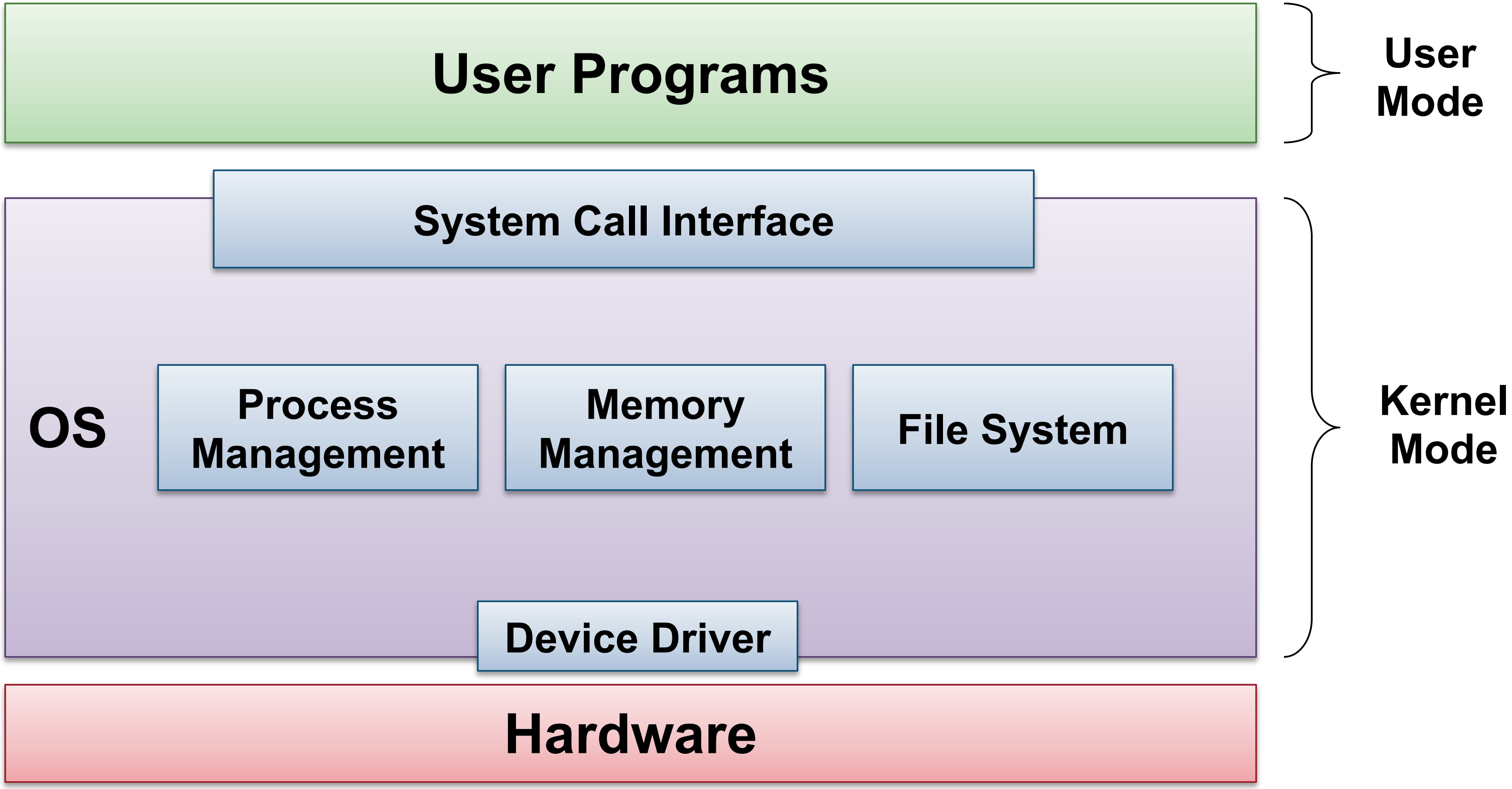
- We will cover the first two in details:
  - They represent the whole range of possibilities
  - Most other approaches are variant or improvement

# Monolithic OS

- Kernel is:
  - One **BIG** special program
    - Various services and components are integral part
  - Good software engineering principles are still possible with:
    - Modularization
    - Separation of interfaces and implementation
- This is the traditional approach taken by:
  - Most Unix variants, DOS, Windows 9x

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

# Monolithic Kernel Illustration



Generic Architecture of Monolithic OS Components

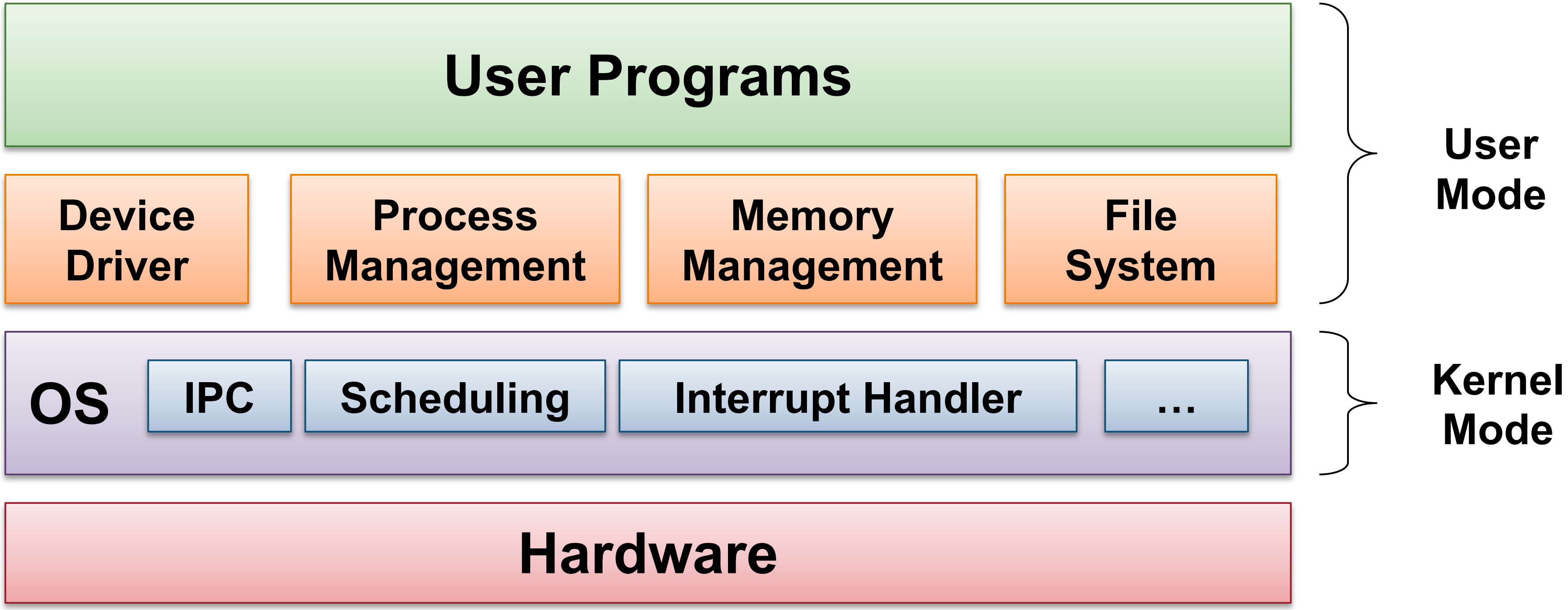
# Microkernel OS

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

- Advantages:
  - Kernel is generally more robust and more extensible
  - 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

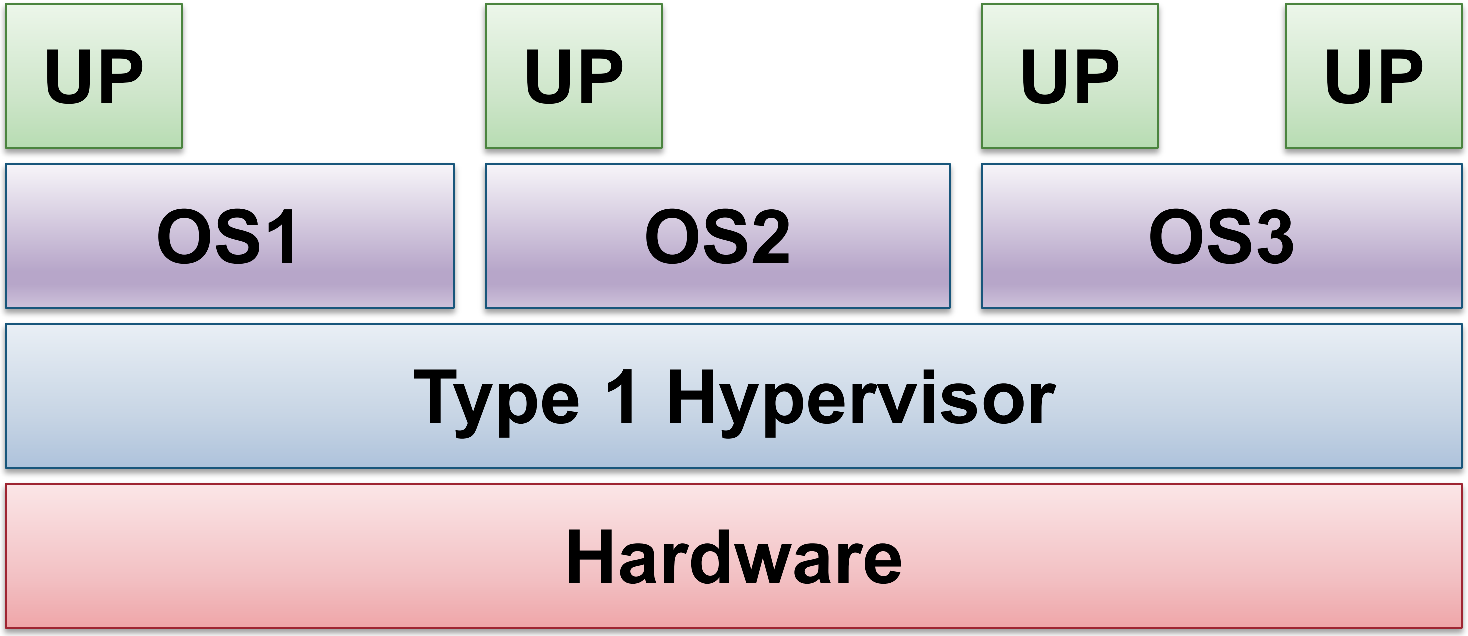
# Motivation: Why Virtual Machines

- OS assumes total control of the hardware:
  - What if we want to run several OSes on the same hardware at the same time?
  - Cloud computing (Infrastructure as a Service)
- OS 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

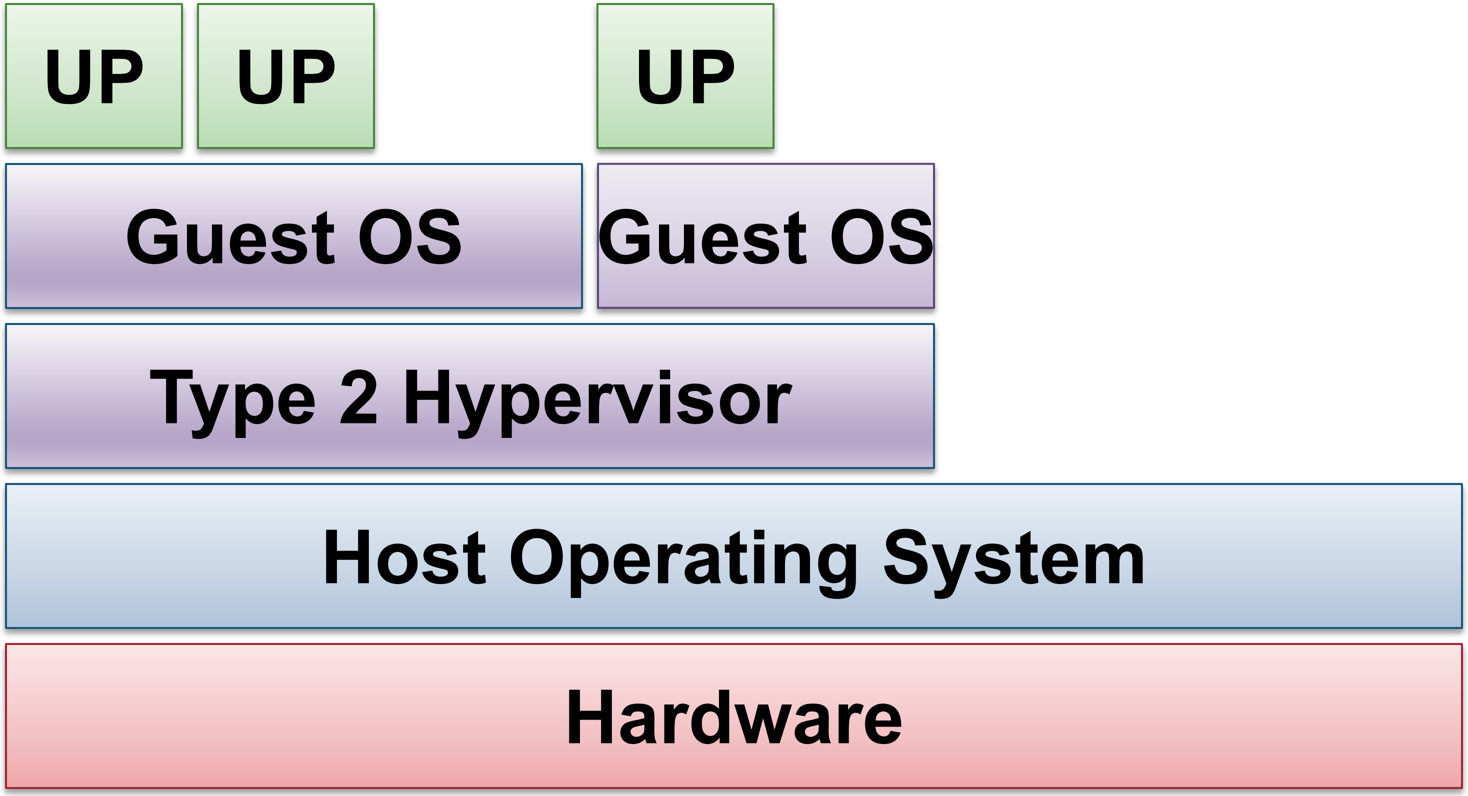
- Virtual Machine:
  - A software emulation of hardware
  - **Virtualization** of underlying hardware
    - Illusion of complete hardware to level above: memory, CPU, hard disk, …
  - Normal (primitive) operating system can then run on top of the virtual machine
- Created and managed by **Hypervisor**
  - Also known as **Virtual Machine Monitor (VMM)**
  - Two classes of implementations shown next

# Type 1 Hypervisor



- Type 1 hypervisor:
  - AKA bare-metal hypervisor
  - Provides individual *virtual machines* to guest OSes
  - E.g., IBM VM/370, VMware ESXi

# Type 2 Hypervisor



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

# 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 (8th Edition)
  - By Abraham Silberschatz, Peter Baer Galvin & Greg Gagne
  - Published by McGraw Hill