



Operating System Concepts

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Syllabus

- ▶ **Lecturer:** Che-Wei Chang (張哲維)
- ▶ **Lecture Hours:** Wednesday 9:10 am – 12:00 pm
- ▶ **Office Hours:** Thursday 4:00 pm – 5:30 pm
- ▶ **Classroom:** C0108R
- ▶ **Textbook:** Silberschatz, Galvin, and Gagne, “Operating System Principles,” 9th Edition, John Wiley & Sons
- ▶ **Website:** <https://icechewei.github.io/webpage/teaching.html>
- ▶ **Grading:**
 - Quiz and Attendance: 20%
 - Homework and Project: 30%
 - Midterm: 25%
 - Final: 25%



Teaching Assistants

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Rules

- ▶ **Closed Book Examinations**
 - All books and papers should be collected into your backpacks
- ▶ **Some Quizzes**
 - The announcement is not always provided
- ▶ **No Grade Adjustment**
 - Some bonus might be provided in the project and exams

Contents



1. Introduction
2. System Structures
3. Process Concept
4. Multithreaded Programming
5. Process Scheduling
6. Synchronization
7. Deadlocks
8. Memory-Management Strategies
9. Virtual-Memory Management
10. File System
11. Implementing File Systems
12. Secondary-Storage Systems





Chapter 1. Introduction

Objectives

- ▶ To describe the basic organization of computer systems
- ▶ To provide a grand tour of the major components of operating systems
- ▶ To give an overview of the many types of computing environments
- ▶ To explore several open-source operating systems





Overview

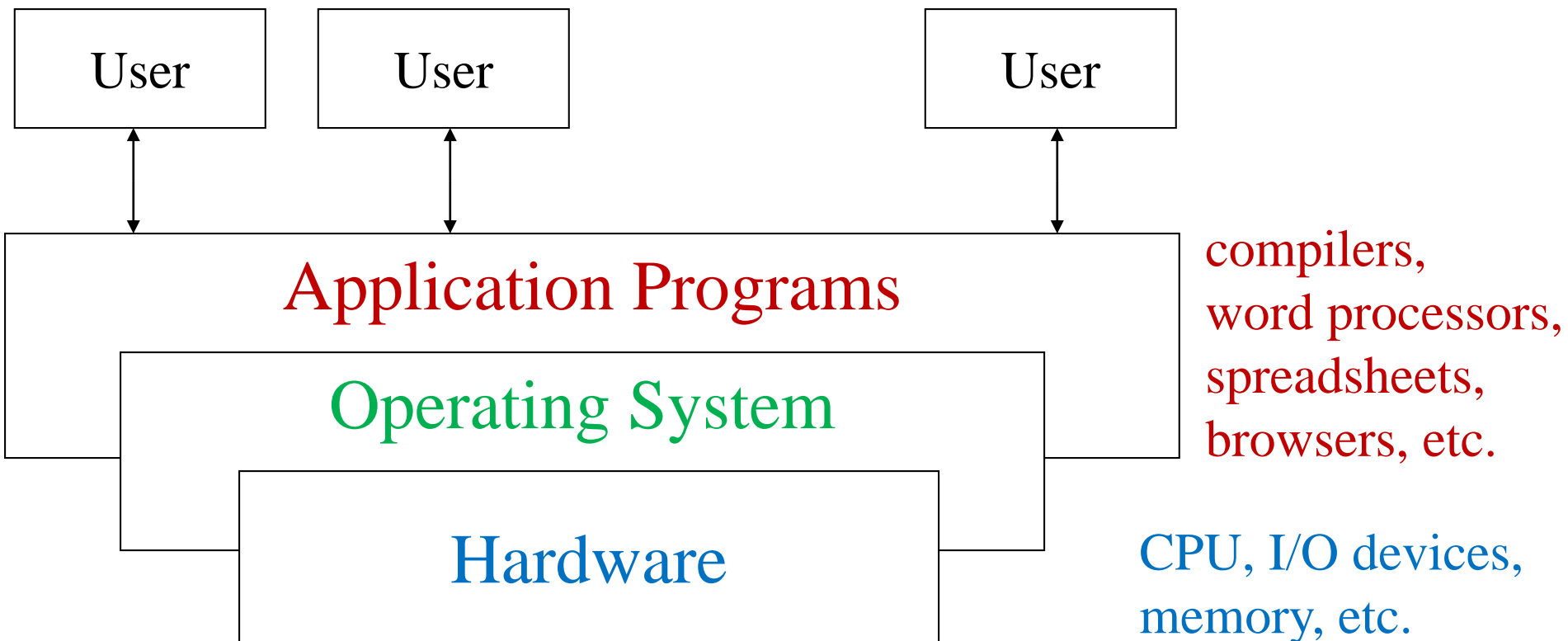
Introduction

- ▶ What is an Operating System?
 - A basis for application programs
 - An intermediary between users and hardware

- ▶ Amazing Variety
 - Super computers, enterprise servers, personal computers (PCs), handheld computers, embedded systems, wearable devices
 - Convenient vs Efficient



Computer System Components



- ▶ OS – a government/environment provider

User View

- ▶ The user view of the computer varies by the interface being used
- ▶ Examples:
 - Personal computer → Ease of use
 - Mainframe or minicomputer → maximization of resource utilization
 - Efficiency and fair share
 - Handheld computer → individual usability
 - Embedded computer without user view → run without user intervention



System View

- ▶ A Resource Allocator
 - CPU time, Memory Space, File Storage, I/O Devices, Shared Code, Data Structures, and more
- ▶ A Control Program
 - Control execution of user programs
 - Prevent errors and misuse
- ▶ OS Definition – US Department of Justice against Microsoft in 1998 (Netscape Navigator)
 - The stuff shipped by vendors as an OS
 - Internet Explorer → No
 - Microsoft Windows → Yes
 - Run at all time



System Goals

- ▶ Two Conflicting Goals:
 - Convenient for the user
 - Efficient operation of the computer system
- ▶ We should
 - recognize the influences of operating systems and computer architecture on each other
 - and learn why and how OS's are by tracing their evolution and predicting what they will become
 - Cray-2: a super computer in 1985 with 3.9 GFLOPS
 - GFLOPS: Giga FLoating-point Operations Per Second
 - Ryzen 9 3950X : an AMD desktop processor in 2019 (Q4) with 170.56 GFLOPS

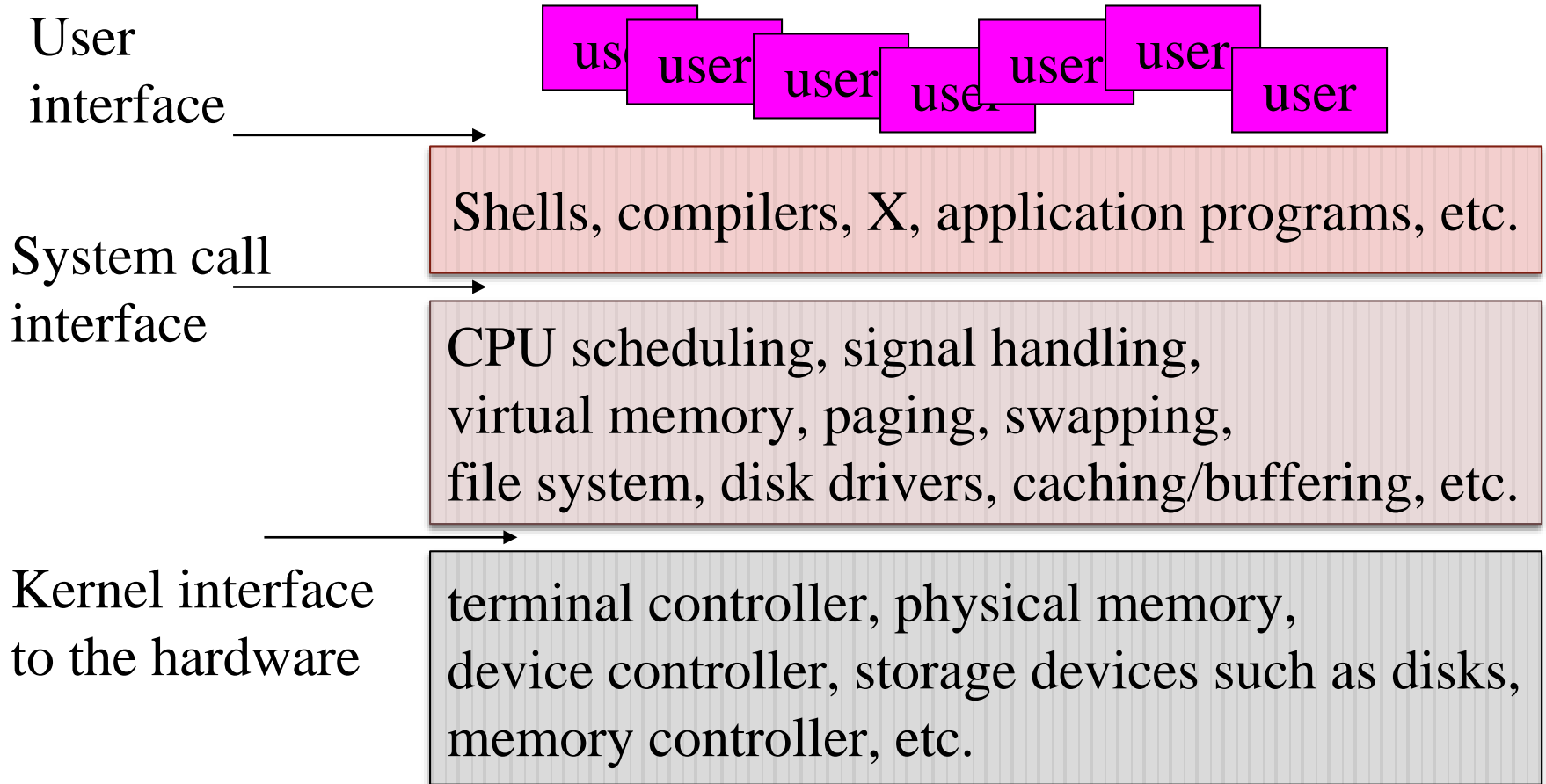
Source:

<https://en.wikipedia.org/wiki/Supercomputer>

https://setiathome.berkeley.edu/cpu_list.php



UNIX Architecture



UNIX

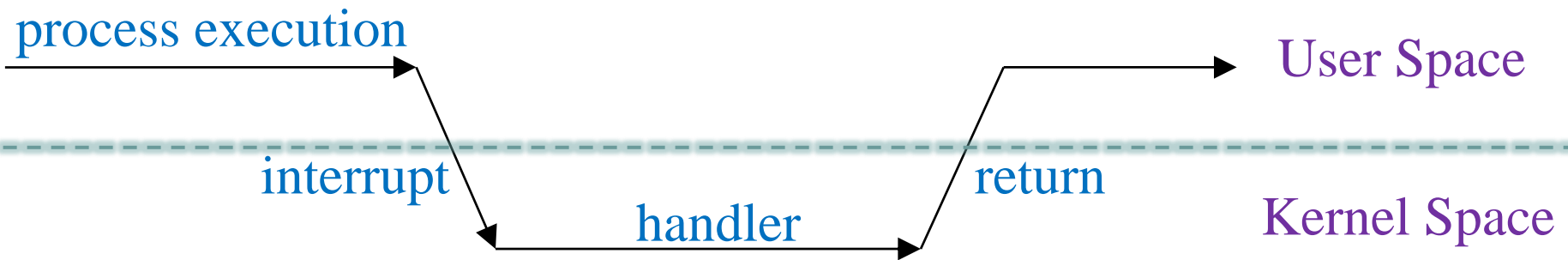
Computer Startup

- ▶ **Bootstrap program** is loaded at power-up or reboot
 - Typically stored in ROM or EPROM, generally known as firmware
 - Initializes all aspects of system
 - Loads operating system kernel and starts execution
 - BIOS: basic input output system
 - UEFI: unified extensible firmware interface
- ▶ **Operating system** runs initial program to initialize system processes, e.g., various daemons, login processes, after the kernel has been bootstrapped



Interrupt

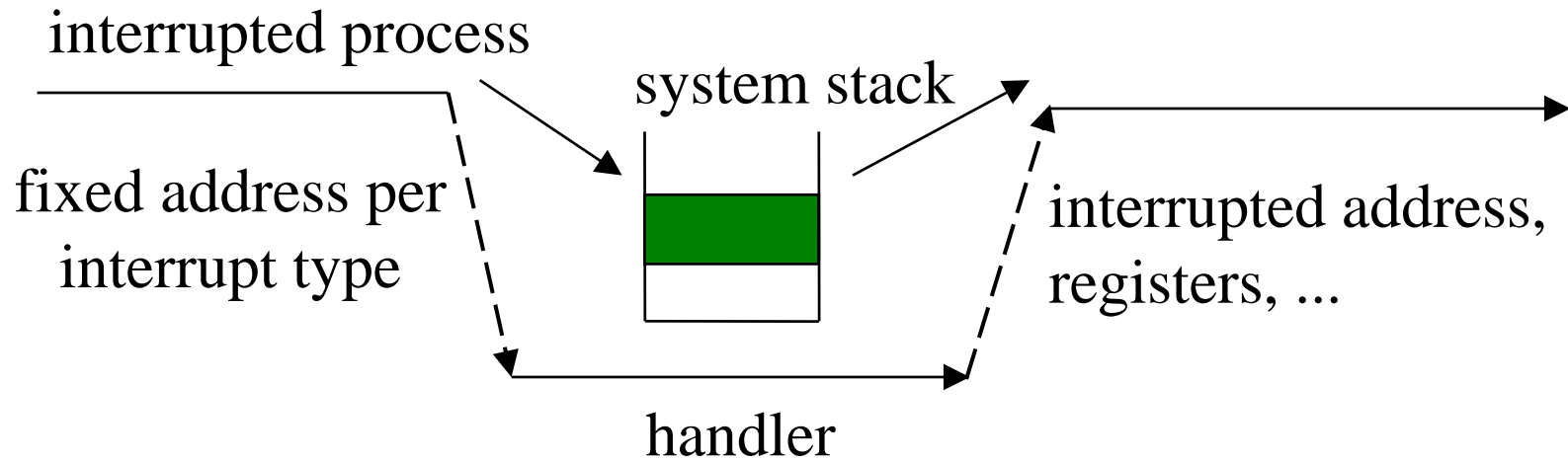
- ▶ **Hardware interrupts**: services requests of I/O devices
- ▶ **Software interrupts**: signals, invalid memory access, division by zero, **system calls**, etc



- ▶ Procedures: generic handler or interrupt vector (MS-DOS, UNIX)



Interrupt Handling Procedure (1 / 2)

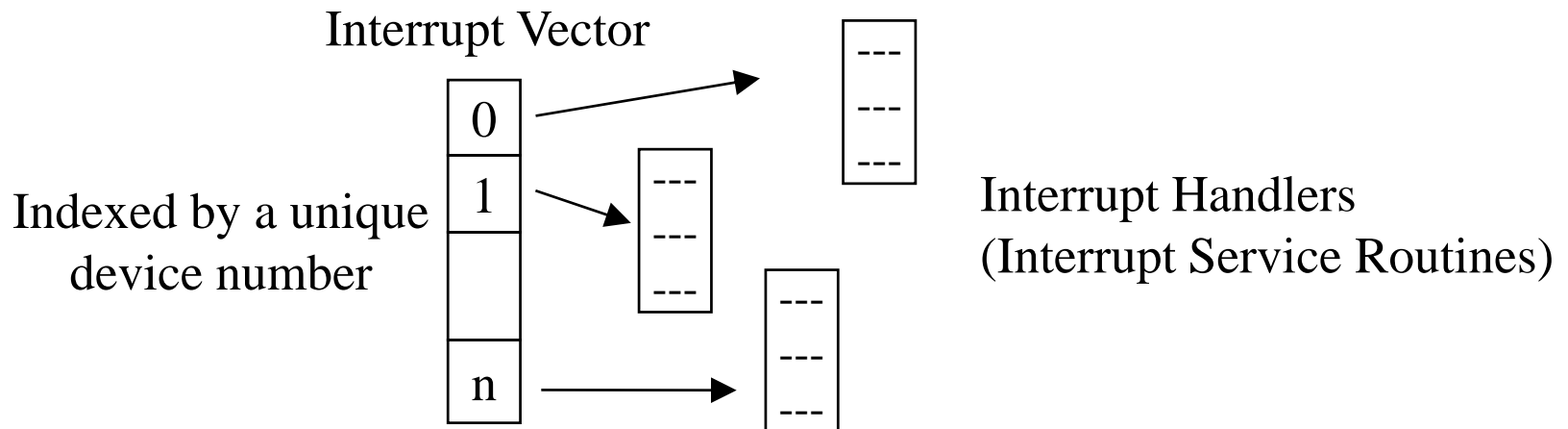


- ▶ Saving of the address of the interrupted instruction
 - By fixed locations or stacks
- ▶ Interrupt disabling or enabling issues
 - Might lose some interrupts?
 - ➔ prioritized interrupts masking

Interrupt Handling Procedure (2/2)

▶ Interrupt Handling

- Save interrupt information
- OS determine the interrupt type
- Call the corresponding handlers
- Return to the interrupted job by the restoring important information (e.g., saved return address and program counter)

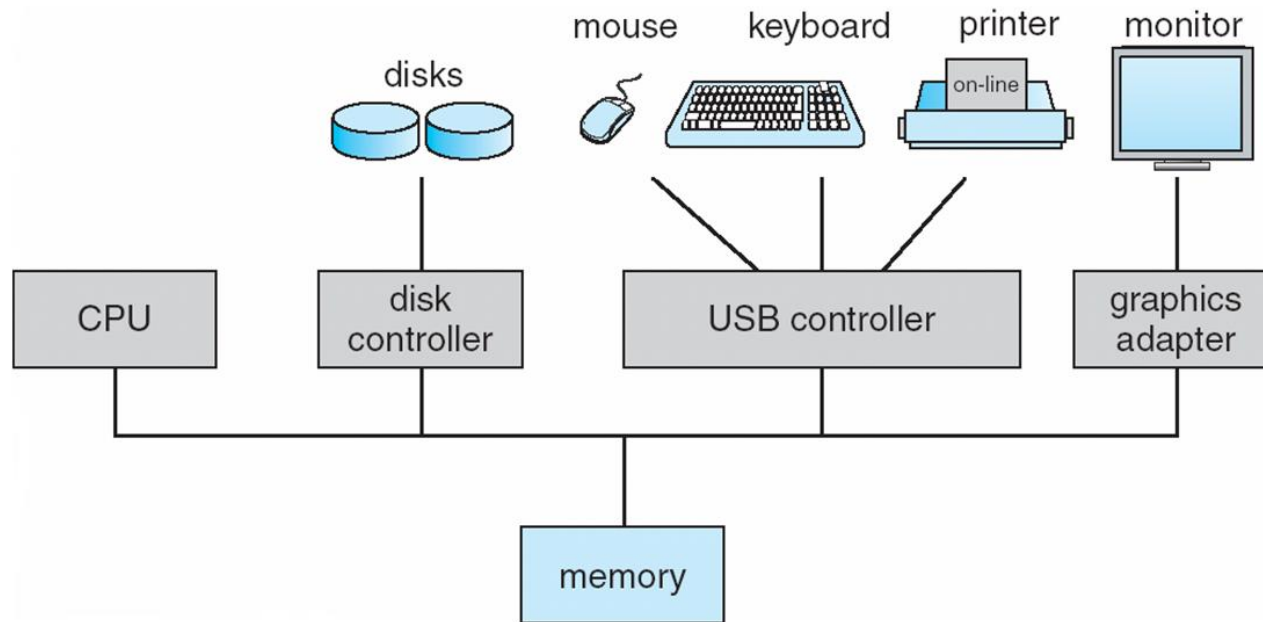




Computer Systems

Computer System Organization

- ▶ One or more CPUs for computing
- ▶ Memory and storage devices for keeping data
- ▶ Peripheral devices for I/O operations



Computer Processors

- ▶ Some systems use a single general-purpose processor
 - Most systems have special-purpose processors as well
- ▶ Multiprocessors systems are growing in use and importance
 - Tightly coupled: have more than one processor in close communication sharing computer bus, clock, and sometimes memory and peripheral devices
 - Loosely coupled: otherwise



Multiprocessor Systems

- ▶ Symmetric Multiprocessing
 - Each processor runs an identical copy of the OS
 - All processors are the same in user and system views
- ▶ Asymmetric Multiprocessing
 - Master-and-slave framework
 - Commonly seen in extremely large systems
 - Hardware and software make a difference



Parallel Systems

- ▶ Tightly-coupled multiprocessor systems are also known as parallel systems
- ▶ Advantages:
 - Increased throughput
 - Economy of scale
 - Increased reliability– graceful degradation and fault tolerance
- ▶ Trends
 - Multiple cores over single chip
 - Cores in a chip can even share cache
 - Hyper-threading processors
 - More than one programs can be executed on a core



Clustered Systems

- ▶ Loosely-coupled multiprocessor systems are also known as clustered systems
 - Computers which share storage and are closely linked via LAN networking
 - Processors do not share memory or a clock
- ▶ Advantages:
 - High availability
 - Performance improvement
- ▶ Some clusters are for high-performance computing
 - Applications must be written to use parallelization
- ▶ Some clusters have distributed lock manager
 - Conflicting operations must be avoided



Memory Management

- ▶ Memory: a large array of words or bytes, where each has its own address
- ▶ OS must keep several programs in memory to improve CPU utilization and user response time
- ▶ Management algorithms depend on the hardware support
- ▶ Services
 - Memory usage and availability
 - Decision of memory assignment
 - Memory allocation and deallocation



Secondary Storage Management

- ▶ Goal:
 - On-line storage medium for programs & data
 - Backup of main memory
- ▶ Services for Disk Management
 - Free-space management
 - Storage allocation, e.g., continuous allocation
 - Read/write request scheduling, e.g., first-come-first-serve



Tertiary Storage Management

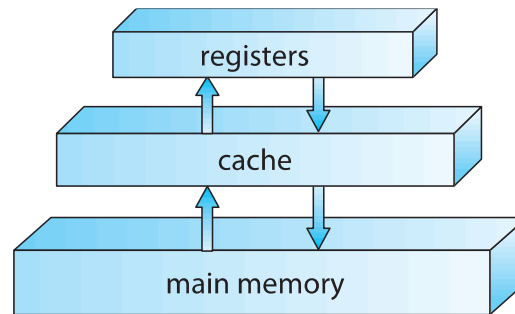
- ▶ Goals:
 - Backups of disk data, seldom-used data, and long-term archival storage
- ▶ Examples:
 - Magnetic tape drives and their tapes, CD & DVD drives and platters
- ▶ Services – OS Supports or Applications' Duty
 - Device mounting and unmounting
 - Exclusive allocation and freeing
 - Data transfers from tertiary devices to secondary storage devices



Storage-Device Hierarchy

Primary Storage

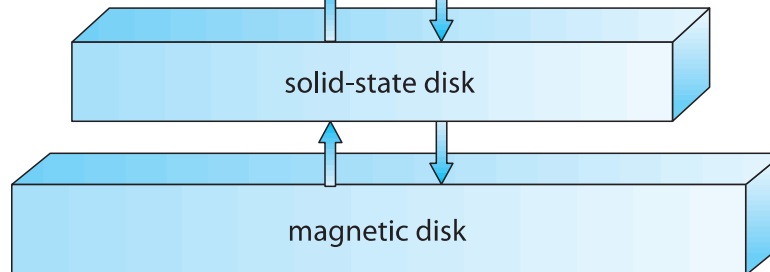
- volatile storage



- Access time: a cycle
- Access time: several cycles
- Access time: many cycles

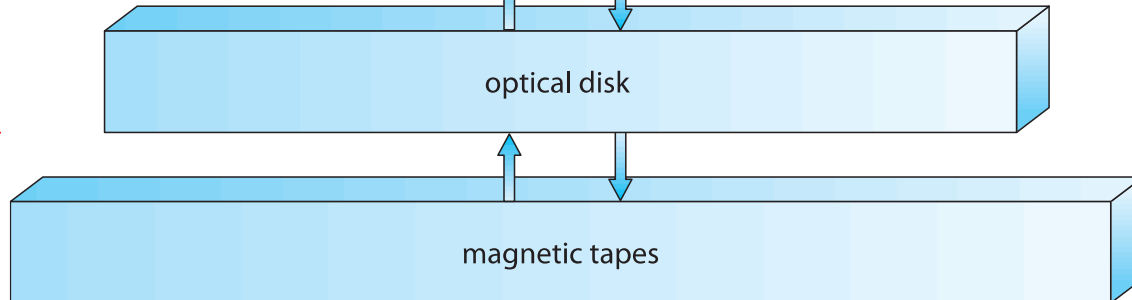
Secondary Storage

- nonvolatile storage



Tertiary Storage

- removable media



I/O Devices

- ▶ Device drivers are used by OS to drive the device controllers
- ▶ Character Devices
 - Sequential access
 - Examples might include printers, scanners, sound boards
 - The same device may have both block and character oriented interfaces
- ▶ Block Devices
 - Block size is from 512B to 4KB
 - For example, disks are commonly implemented as block devices

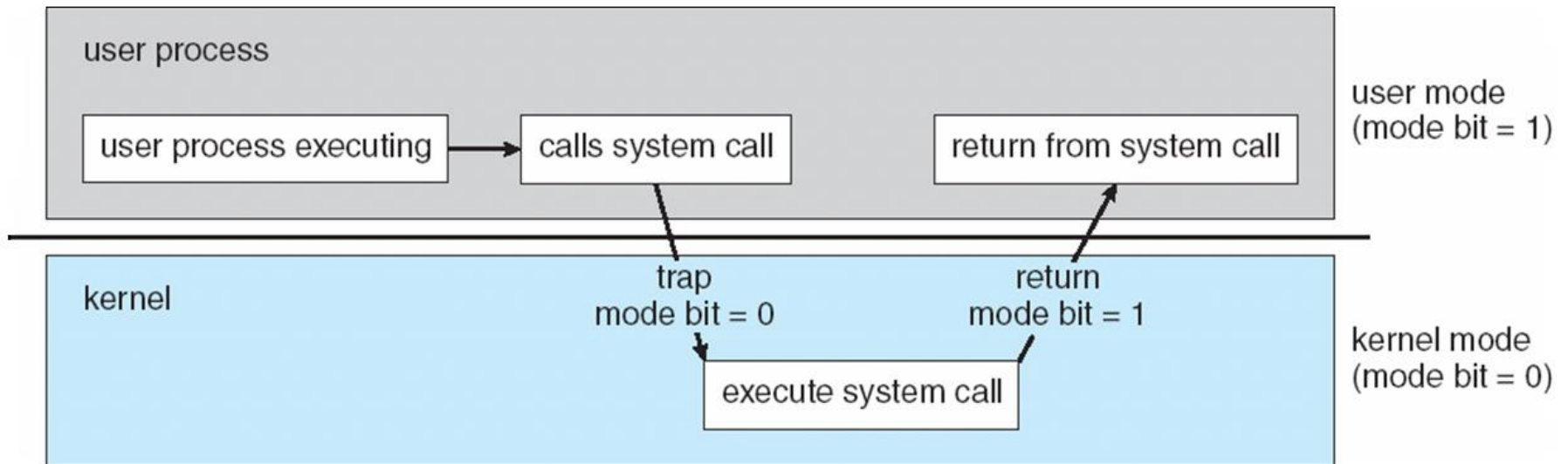


Hardware Protection

- ▶ Dual-mode operation allows OS to protect itself and other system components
 - User mode and kernel mode
 - Mode bit provided by hardware
 - Provides ability to distinguish when system is running user code or kernel code
 - Some instructions designated as privileged, only executable in kernel mode
 - System call changes the current mode to kernel mode, return from call resets it to user mode
- ▶ Increasingly CPUs support multi-mode operations
 - For example, virtual machine manager (VMM) mode



Transition Between User and Kernel Modes





Operating-System Operations

Process Management

- ▶ **A process is a program in execution**
 - A program is a passive entity
 - A process is an active entity
- ▶ Process needs resources to accomplish its task
 - CPU, memory, I/O, files
 - Initialization data
- ▶ Process termination requires to reclaim any reusable resources
- ▶ Typically system has many processes, some users, some operating system running concurrently on one or more CPUs



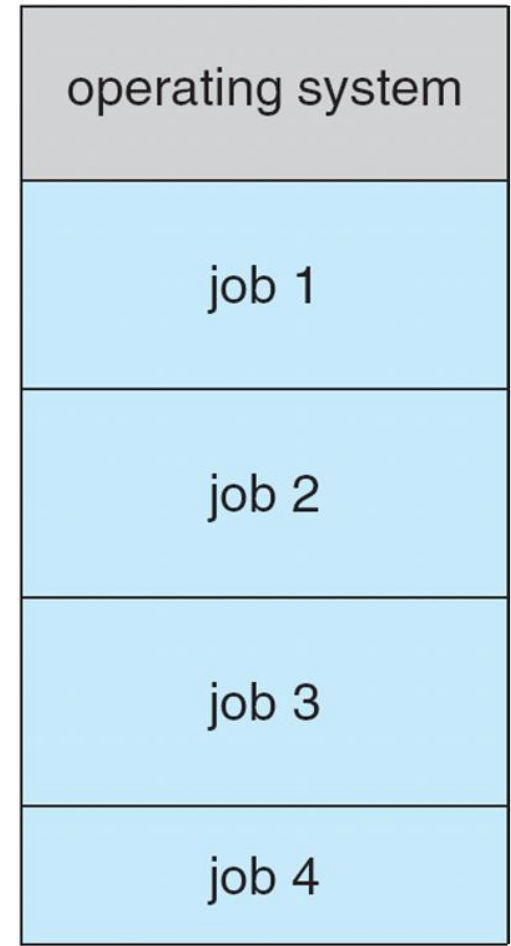
Process Management Activities

- ▶ Creating and deleting both user and system processes
- ▶ Suspending and resuming processes
- ▶ Providing mechanisms for process synchronization
- ▶ Providing mechanisms for process communication
- ▶ Providing mechanisms for deadlock handling



Multiprogramming

- ▶ Multiprogramming is needed for efficiency
 - Single user cannot keep CPU and I/O devices busy at all times
 - Multiprogramming organizes jobs (code and data) so CPU always has one to execute
 - A subset of total jobs in system is kept in memory via **job scheduling**
 - One job selected and run via **CPU scheduling**
 - When a job has to wait (for I/O for example), OS switches to another job



Timesharing

- ▶ Timesharing (multitasking) is a logical extension of multiprogramming
 - CPU switches jobs so frequently
 - Users can interact with each job while it is running
 - Timesharing creates interactive computing
- ▶ Each user has at least one program executing in memory
 - A program executing in memory → a process is created
- ▶ If several processes ready to run at the same time
 - Pick a process to run on CPU → CPU scheduling
- ▶ If processes don't fit in memory,
 - Swapper moves them in and out of memory → job scheduling
- ▶ Virtual memory allows execution of processes not completely in memory



Caching (1 / 2)

▶ Caching

- Information is copied to a faster storage system on a temporary basis
- Assumption: Data or binaries will be used again soon
 - Programmable registers, instruction cache, etc.

▶ Cache Management

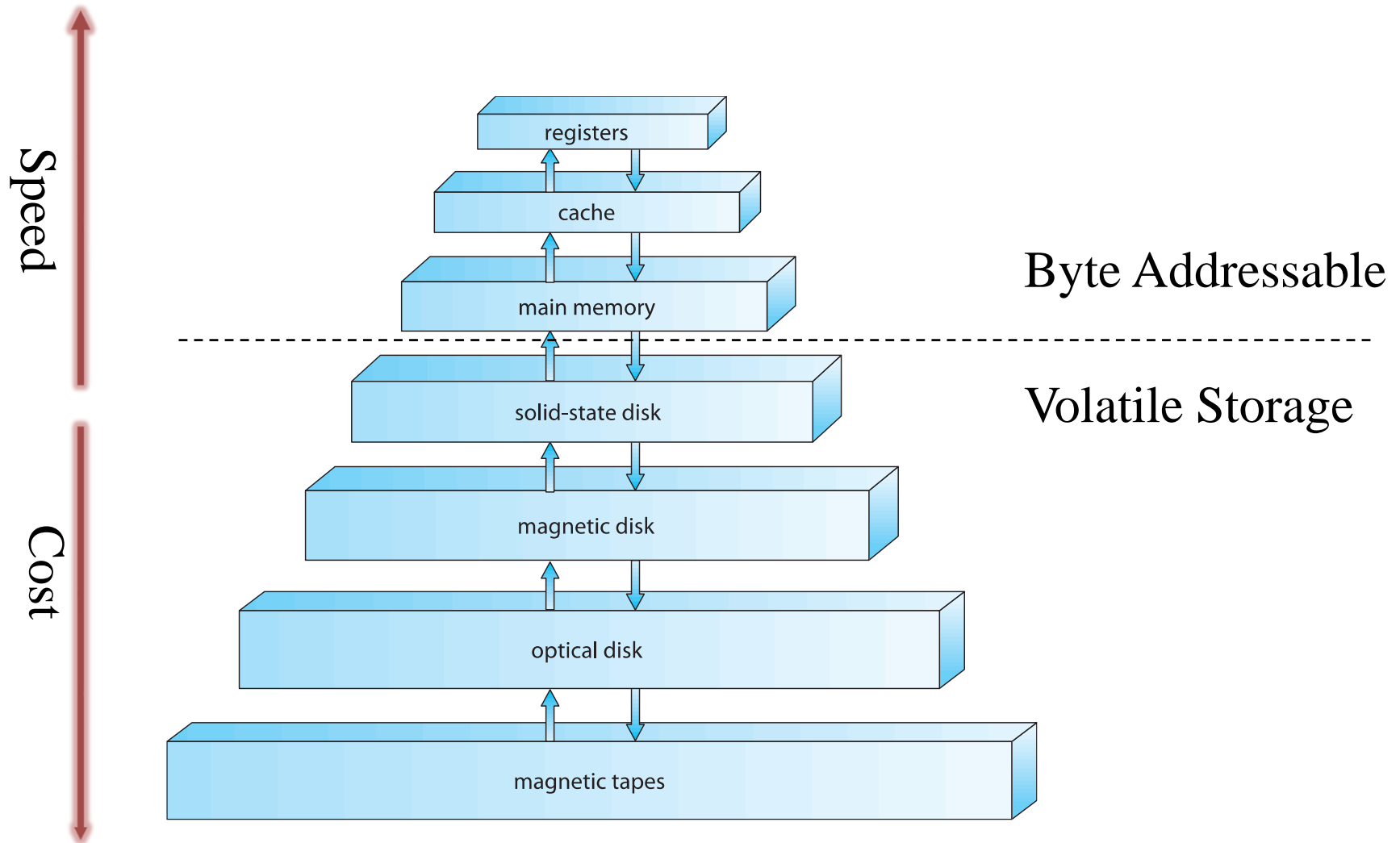
- Cache size and the replacement policy

▶ Movement of Information Between Hierarchy

- Hardware design & operating system control

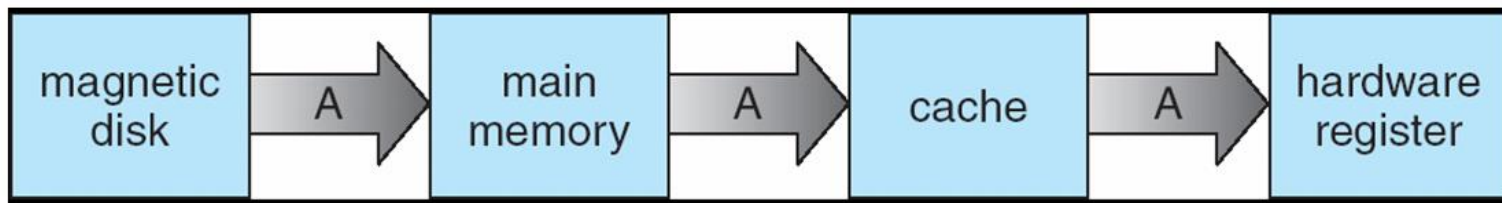


Caching (2/2)



Migration of Integer A from Disk to Register

- ▶ Multitasking environments must be careful to use most recent value, no matter where it is stored in the storage hierarchy



- ▶ Multiprocessor environment must provide **cache coherency** in hardware such that all CPUs have the most recent value in their cache
- ▶ Distributed environment situation even more complex
 - Several copies of a datum can exist

File-System Management

- ▶ Goal:
 - A uniform logical view of information storage
 - Each medium controlled by a device
 - Magnetic tapes, magnetic disks, optical disks, etc.
- ▶ OS provides a logical storage unit: File
 - Formats:
 - Free form or being formatted rigidly
 - General Views:
 - A sequence of bits, bytes, lines, records



File Management Activities

- ▶ Creating and deleting files and directories
- ▶ Primitives to manipulate files and directories
- ▶ Mapping files onto secondary storage
- ▶ Backup files onto stable (non-volatile) storage media



I/O System Management

- ▶ Goal:
 - Hide the peculiarities of specific hardware devices from users
- ▶ Components of an I/O System
 - A buffering, caching, and spooling system
 - A general device-driver interface
 - Device drivers



Protection and Security (1 / 2)

- ▶ Goal
 - Resources are only allowed to be accessed by authorized processes
- ▶ Definitions:
 - Protection – any mechanism for controlling the access of processes or users to the resources defined by the computer system
 - Security – Defense of a system from external and internal attacks, e.g., viruses, denial of services, etc



Protection and Security (2 / 2)

- ▶ Protected Resources
 - Files, CPU, memory space, etc
- ▶ Protection Services
 - Detection & controlling mechanisms
 - Specification mechanisms
- ▶ Distinguishing of Users
 - User names and ID's
 - Group names and GID's
 - Privilege Escalating, e.g., Setuid in Unix
 - To gain extra permissions for an activity





Advanced Topics

Distributed Systems (1 / 2)

- ▶ Definition: Loosely-Coupled Systems – processors do not share memory or a clock
- ▶ Advantages or Reasons
 - Resource sharing: computation power, peripheral devices, specialized hardware
 - Computation speedup: distribute the computation among various sites – load sharing
 - Reliability: redundancy → reliability



Distributed Systems (2 / 2)

- ▶ Distributed systems depend on networking for their functionality
- ▶ Networks vary by the protocols used
 - TCP/IP, ATM, etc.
- ▶ Types – different distance
 - Local-area network (LAN)
 - Wide-area network (WAN)
 - Metropolitan-area network (MAN)
 - Small-area network – distance of few feet
- ▶ Media – copper wires, fiber strands, ...



Real-Time Embedded Systems (1 / 2)

- ▶ Embedded Computers— Most Prevalent Form of Computers
 - Have a wide variety ranged from car engines to VCR's
 - Tend to have specific tasks and almost always run real-time operating systems
- ▶ Definition:
 - A real-time system is a computer system where a timely response by the computer to external stimulation is vital!



Real-Time Embedded Systems

(2/2)

- ▶ Hard real-time system: The system has failed if a timing constraint, e.g. deadline, is not met
 - All delays in the system must be bounded
 - Many advanced features are absent
- ▶ Soft real-time system: Missing a timing constraint is serious but does not necessarily result in a failure
 - A critical task has a higher priority
 - Supported in most commercial OS
- ▶ Real-time means **on-time** instead of **fast**



Computing Environments— Mobile Devices

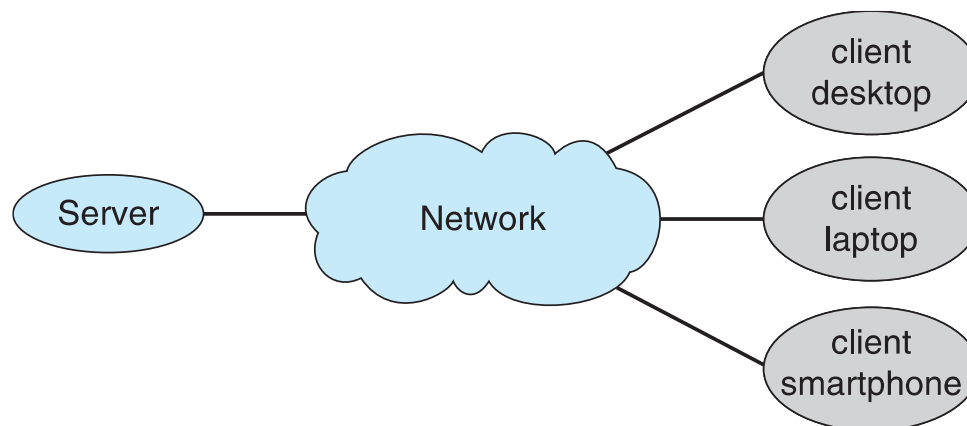
- ▶ Target devices: handheld smartphones, tablets, ...
- ▶ Extra features: GPS, gyroscope, ...
- ▶ New types of Application: augmented reality, ...
- ▶ Use IEEE 802.11 wireless, or cellular data networks for connectivity
- ▶ Leaders are Apple iOS and Google Android



Computing Environments— Client–Server

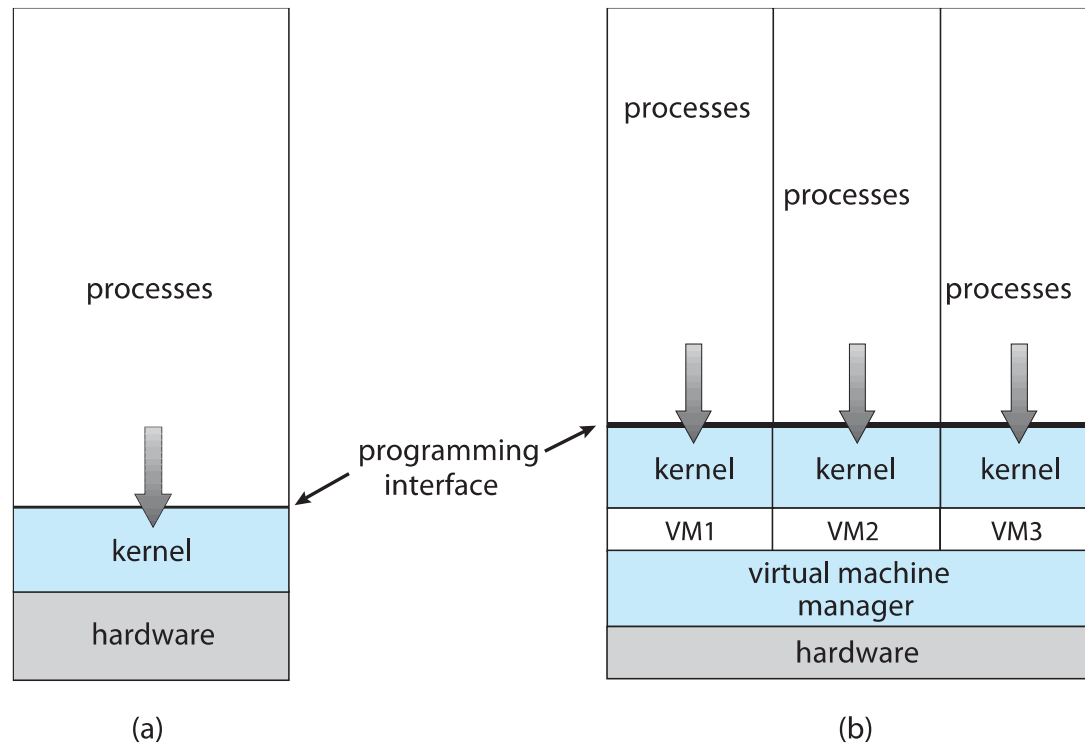
▶ Client-Server Systems

- Trend:
 - The functionality of clients is improved in the past decades
- Categories:
 - Compute-server systems
 - File-server systems



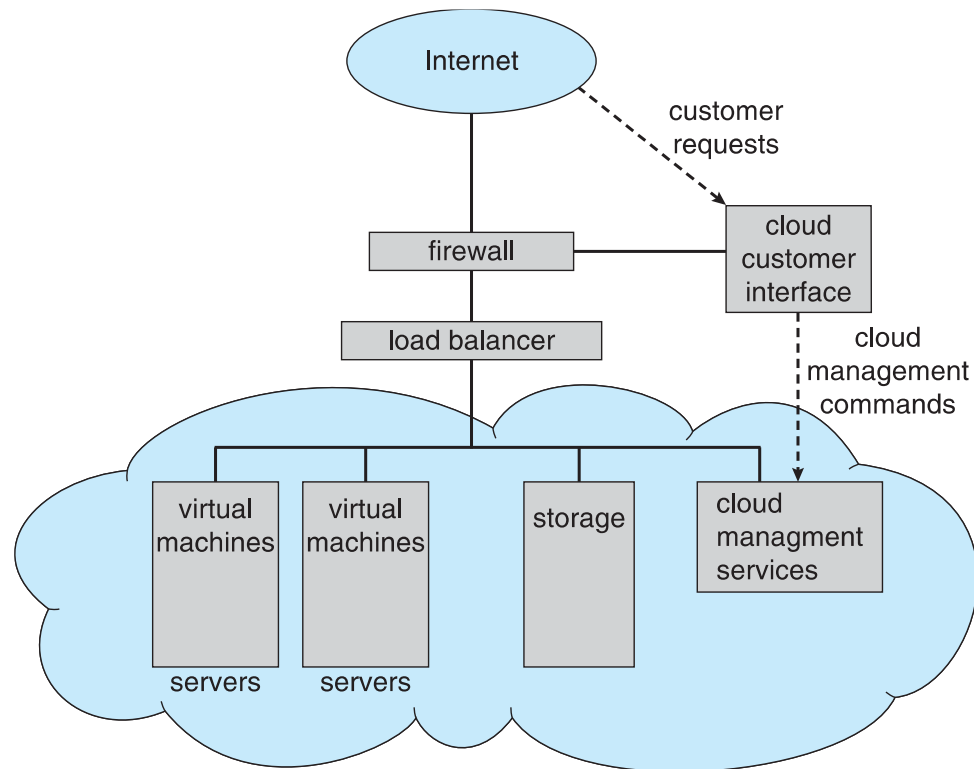
Computing Environments— Virtualization

- ▶ Use cases involve laptops and desktops running multiple OSES for exploration or compatibility



Computing Environments— Cloud Computing

- ▶ Cloud computing environments are composed of traditional OSeS, plus virtualization tools plus cloud management tools





We will go through the details in the following lectures!