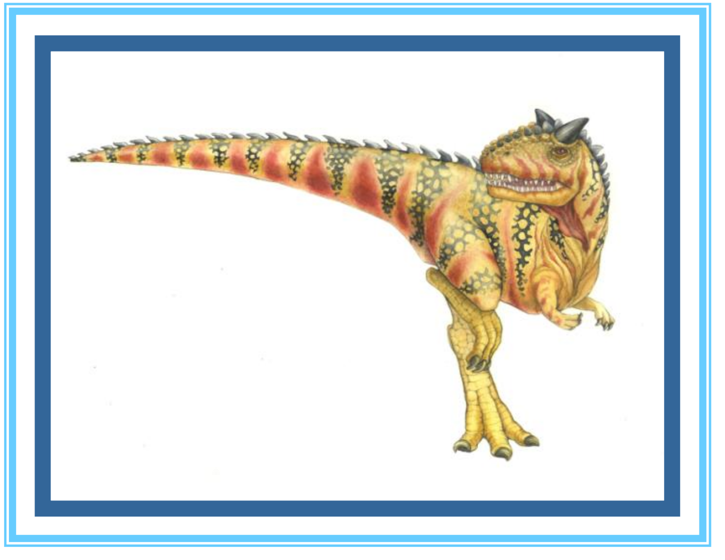
Chapter 1: Introduction



Chapter 1: Introduction

- What Operating Systems Do
- Computer-System Organization
- Computer-System Architecture
- Operating-System Structure
- Operating-System Operations
  - Process Management
  - Memory Management
  - Storage Management
  - Protection and Security
- Computing Environments
- Open-Source Operating Systems

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

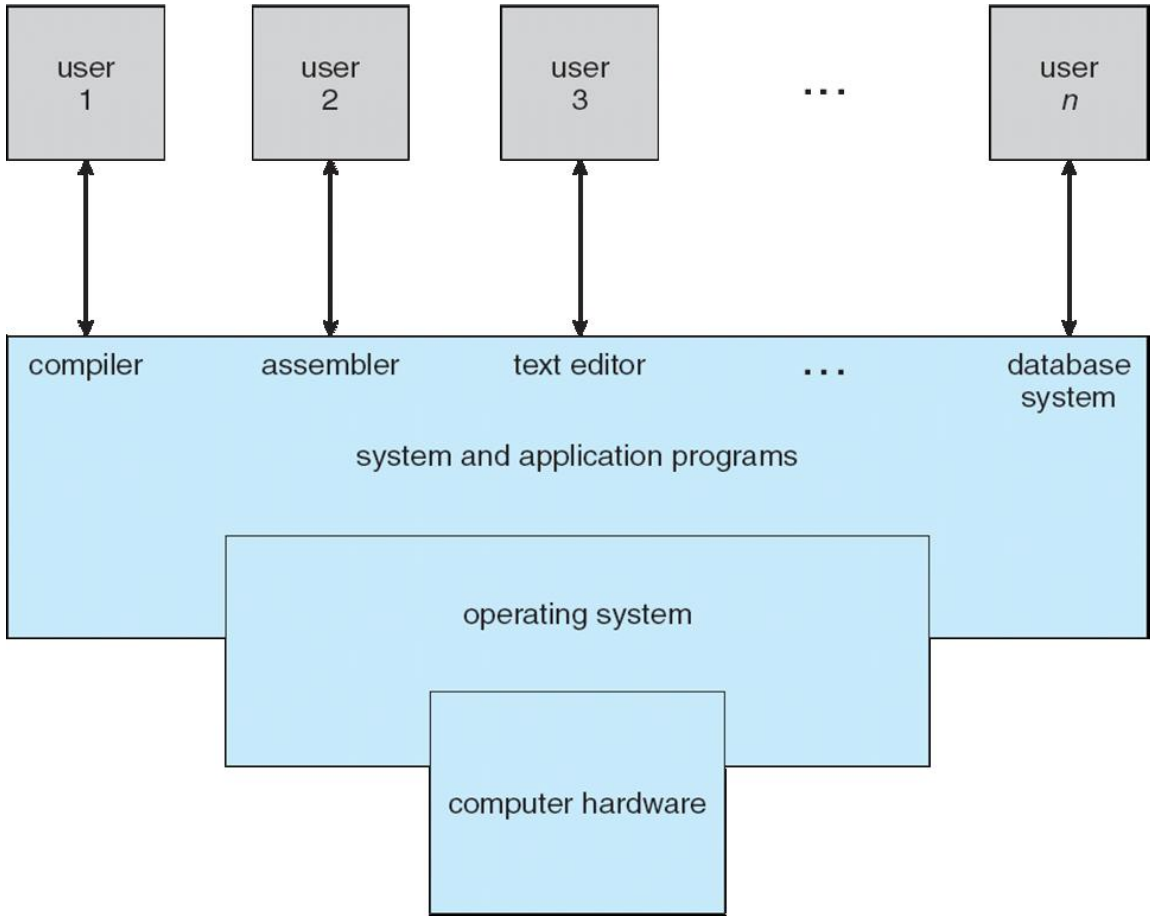
What is an Operating System?

- A program that acts as an intermediary between a user of a computer and the computer hardware
- Operating system goals:
  - Execute user programs and make solving user problems easier
  - Make the computer system **convenient** to use
  - Use the computer hardware in an **efficient** manner

Computer System Structure

- Computer system can be divided into four components:
  - **Hardware** – provides basic computing resources
    - CPU, memory, I/O devices
  - **Operating system**
    - Controls and coordinates use of hardware among various applications and users
  - **Application programs** – define the ways in which the system resources are used to solve the computing problems of the users
    - Word processors, compilers, web browsers, database systems, video games
  - **Users**
    - People, machines, other computers

Four Components of a Computer System



What Operating Systems Do

User View

- Depends on the point of view
- Users want convenience, **ease of use**
  - Don't care about **resource utilization**
- But shared computer such as **mainframe** or **minicomputer** must keep all users happy
- Users of dedicate systems such as **workstations** have dedicated resources but frequently use shared resources from **servers**
- Handheld computers are resource poor, optimized for usability and battery life
- Some computers have little or no user interface, such as embedded computers in devices and automobiles

What Operating Systems Do

System View

- OS is a **resource allocator**
  - Manages all resources (CPU time, memory space, file-storage space, I/O devices, … …)
  - Decides between conflicting requests for efficient and fair resource use
- OS is a **control program**
  - Controls execution of programs to prevent errors and improper use of the computer

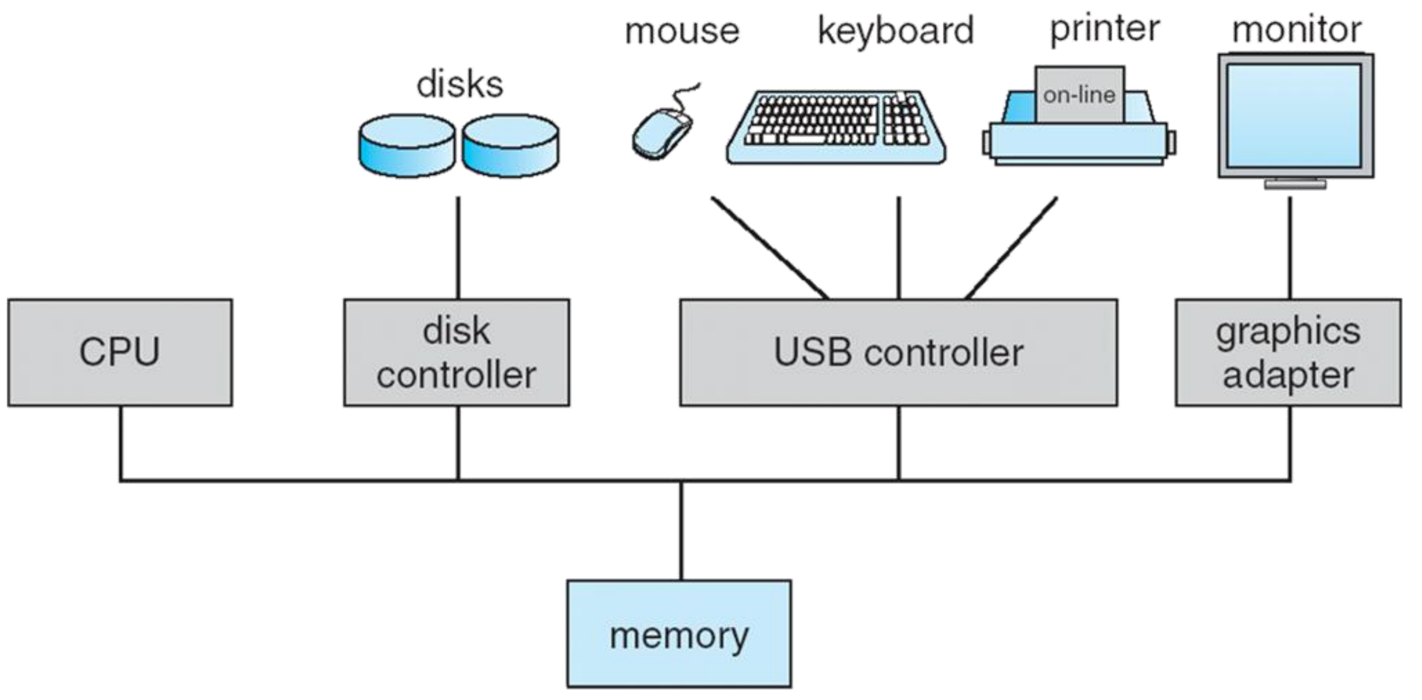
Operating System Definition

- No universally accepted definition of what is part of the operating system
- "**Everything a vendor ships when you order an operating system**" is good approximation
  - But varies wildly
- "**The one program running at all times on the computer**" is the **kernel**.
  - Everything else is either a system program (ships with the operating system) or an application program.

Computer Startup

- **Bootstrap program** is loaded when a computer is powered up or rebooted
  - Typically stored in ROM or EPROM, generally known as **firmware**
  - Initializes all aspects of system
    - CPU registers, device controllers, and memory contents
  - Loads operating system kernel and starts execution

Computer-System Organization



- One or more CPUs, device controllers connect through common bus providing access to shared memory
- CPUs and device controllers can execute in parallel, competing for memory cycles

Computer-System Operation

- I/O devices and the CPU can execute concurrently
- Each device controller is in charge of a particular device type
- Each device controller has a local buffer
- CPU moves data from/to main memory to/from local buffers
- I/O is from the device to local buffer of controller
- Device controller informs CPU that it has finished its operation by causing an interrupt

Common Functions of Interrupts

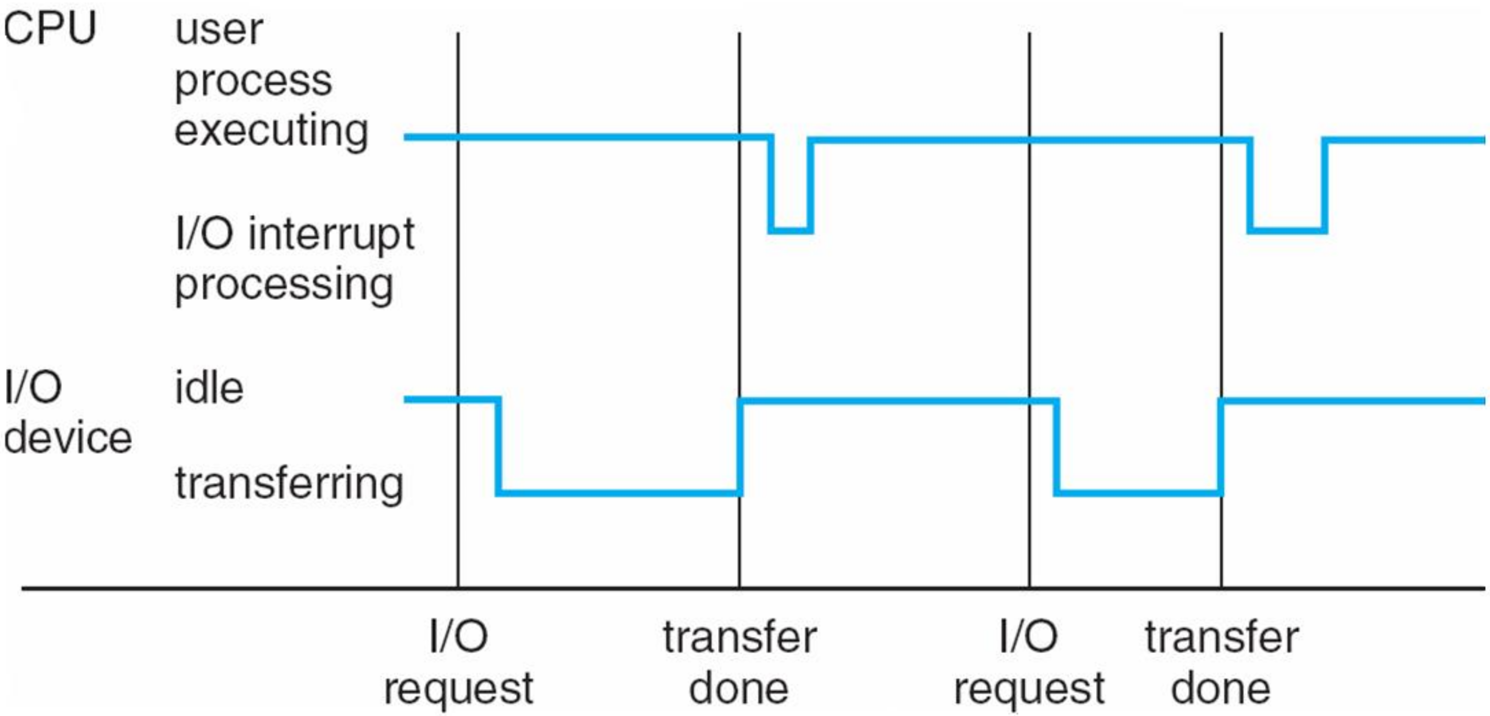
- Interrupt transfers control to the appropriate interrupt service routine, through the **interrupt vector**, which contains the addresses of all the service routines
- Interrupt architecture must save the address of the interrupted instruction
- A **trap** or **exception** is a software-generated interrupt caused either by an error or a user request

→ An operating system is **interrupt driven**

Interrupt Handling

- The operating system preserves the state of the CPU by storing registers and the program counter
- Determines which type of interrupt has occurred:
  - **polling**
  - **vectored** interrupt system
- Separate segments of code determine what action should be taken for each type of interrupts

Interrupt Timeline



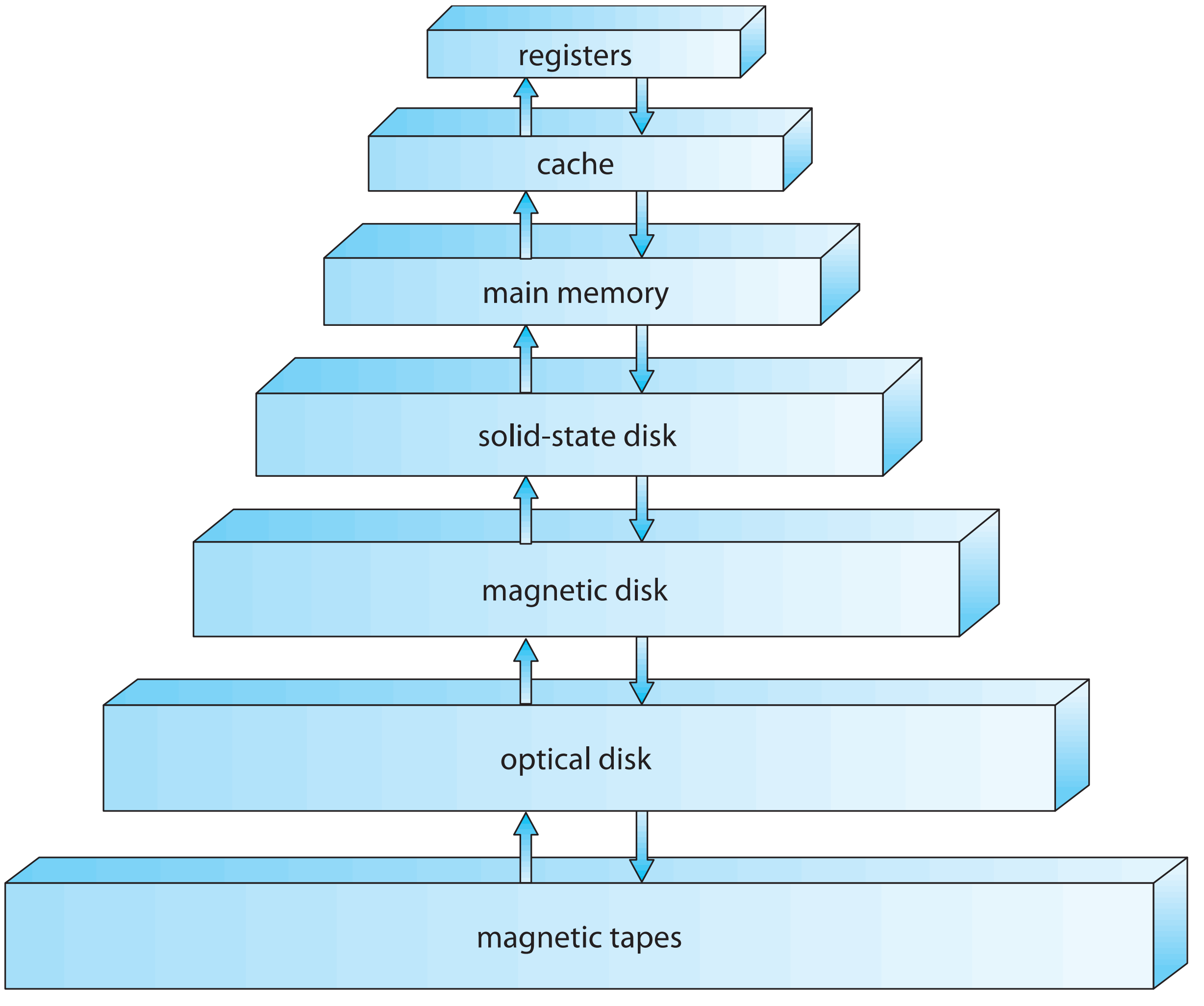
Storage Structure

- **Main memory** – only large storage media that the CPU can access directly
  - **Random access**
  - Typically **volatile**
- **Secondary storage** – extension of main memory that provides large **nonvolatile** storage capacity
  - **Magnetic disks** – rigid metal or glass platters covered with magnetic recording material
    - Disk surface is logically divided into **tracks**, which are subdivided into **sectors**
    - The **disk controller** determines the logical interaction between the device and the computer
  - **Solid-state disks** – faster than magnetic disks
    - Various technologies
    - Becoming more popular

Storage Hierarchy

- Storage systems organized in hierarchy
  - Speed
  - Cost
  - Volatility
- **Caching** – copying information into faster storage system
  - Main memory can be viewed as a cache for secondary storage
- **Device Driver** for each device controller to manage I/O
  - Provides interface between controller and kernel

Storage-Device Hierarchy



Caching

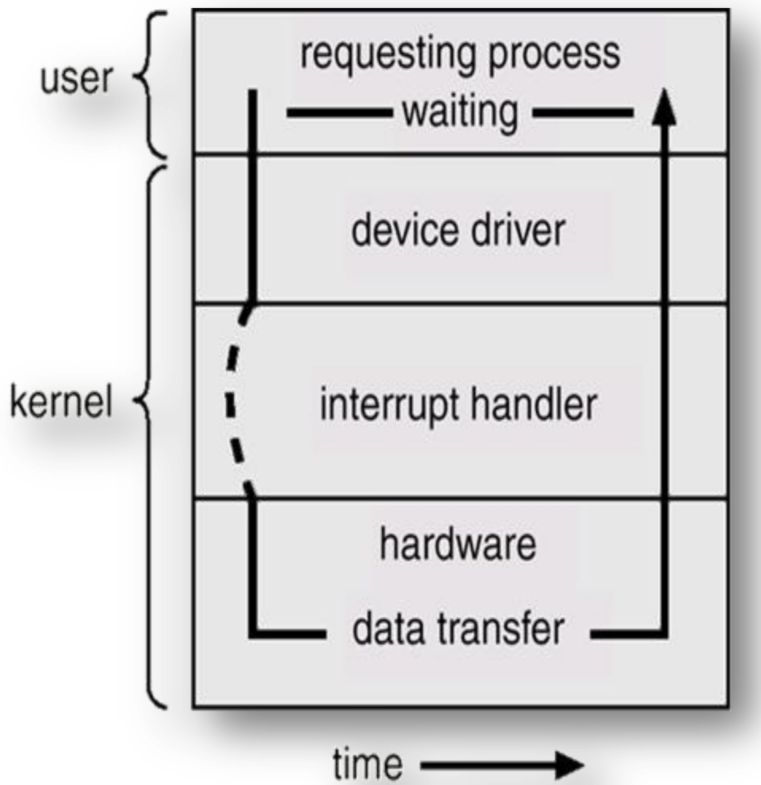
- Important principle, performed at many levels in a computer (in H/W, OS, S/W)
- Information in use copied from slower to faster storage temporarily
- Faster storage (cache) checked first to determine if information is there
  - If it is, information used directly from the cache (fast)
  - If not, data copied to cache and used there
- Cache smaller than storage being cached
  - Cache management important design problem
  - Cache size and replacement policy

I/O Structure

- After I/O starts, control returns to user program only upon I/O completion
  - Wait instruction idles the CPU until the next interrupt
  - Wait loop (contention for memory access)
  - At most one I/O request is outstanding at a time, no simultaneous I/O processing
- After I/O starts, control returns to user program without waiting for I/O completion
  - **System call** – request to the OS to allow user to wait for I/O completion
  - **Device-status table** contains entry for each I/O device indicating its type, address, and state
  - OS indexes into I/O device table to determine device status and to modify table entry to include interrupt

Two I/O Methods

Synchronous	Asynchronous



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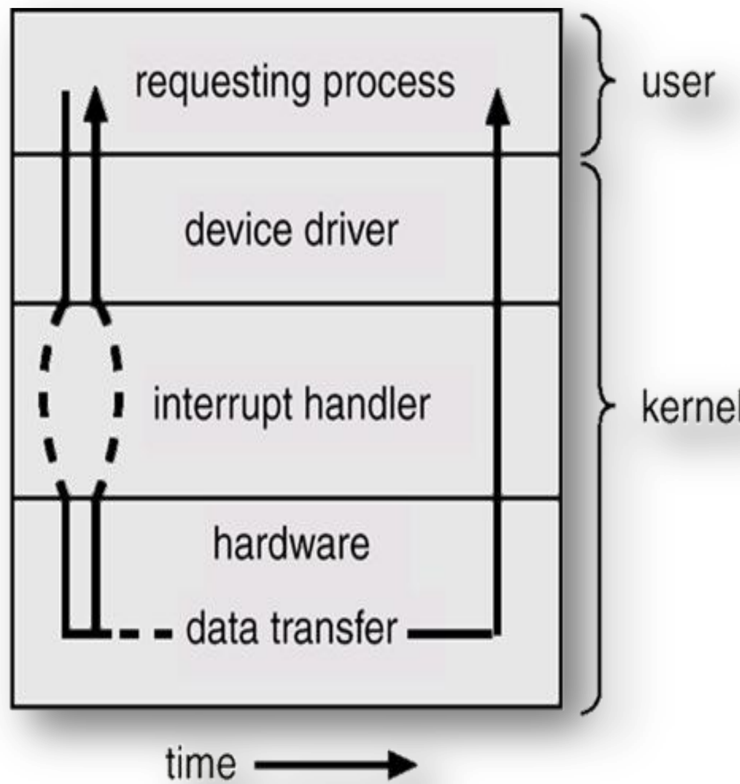

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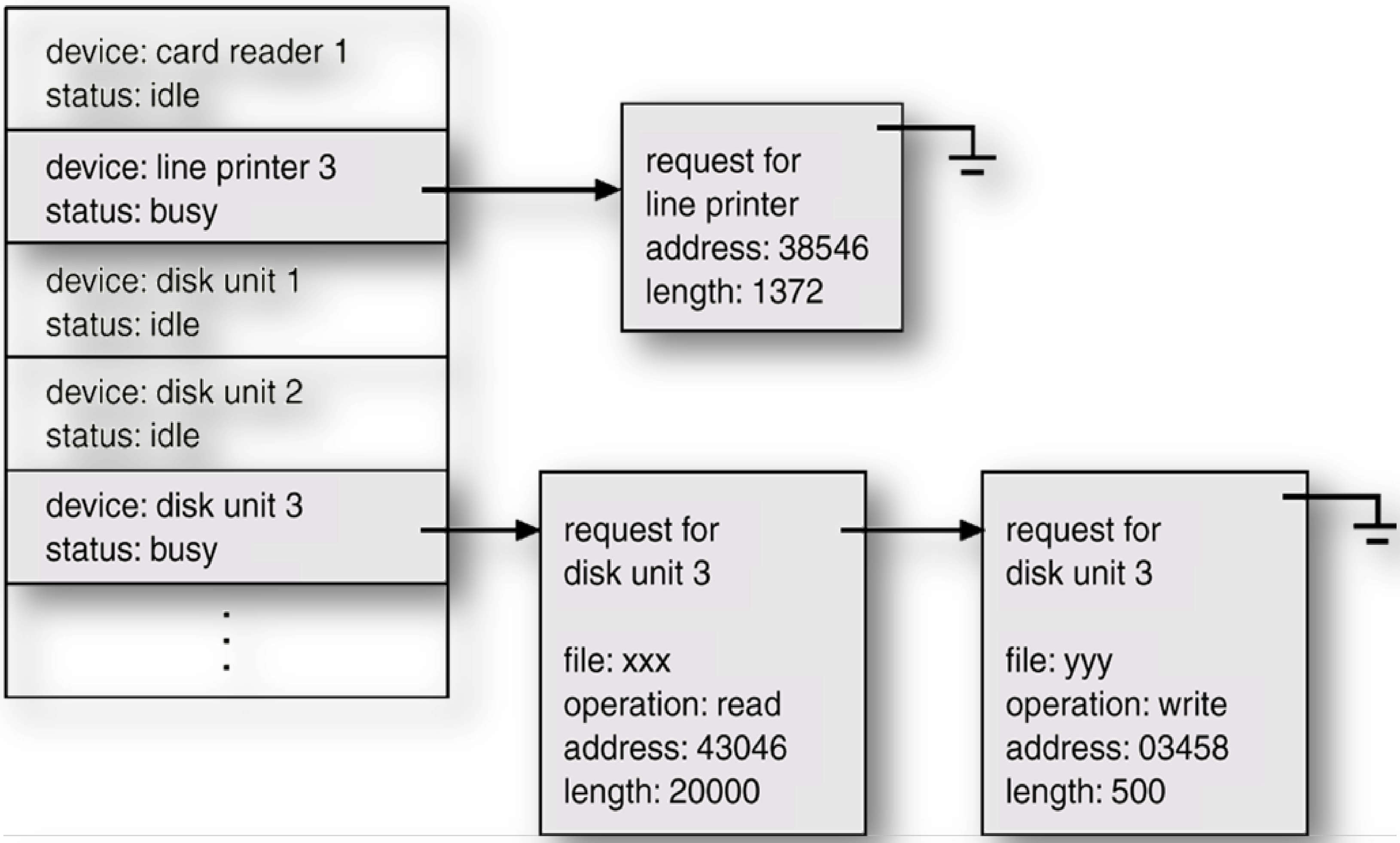
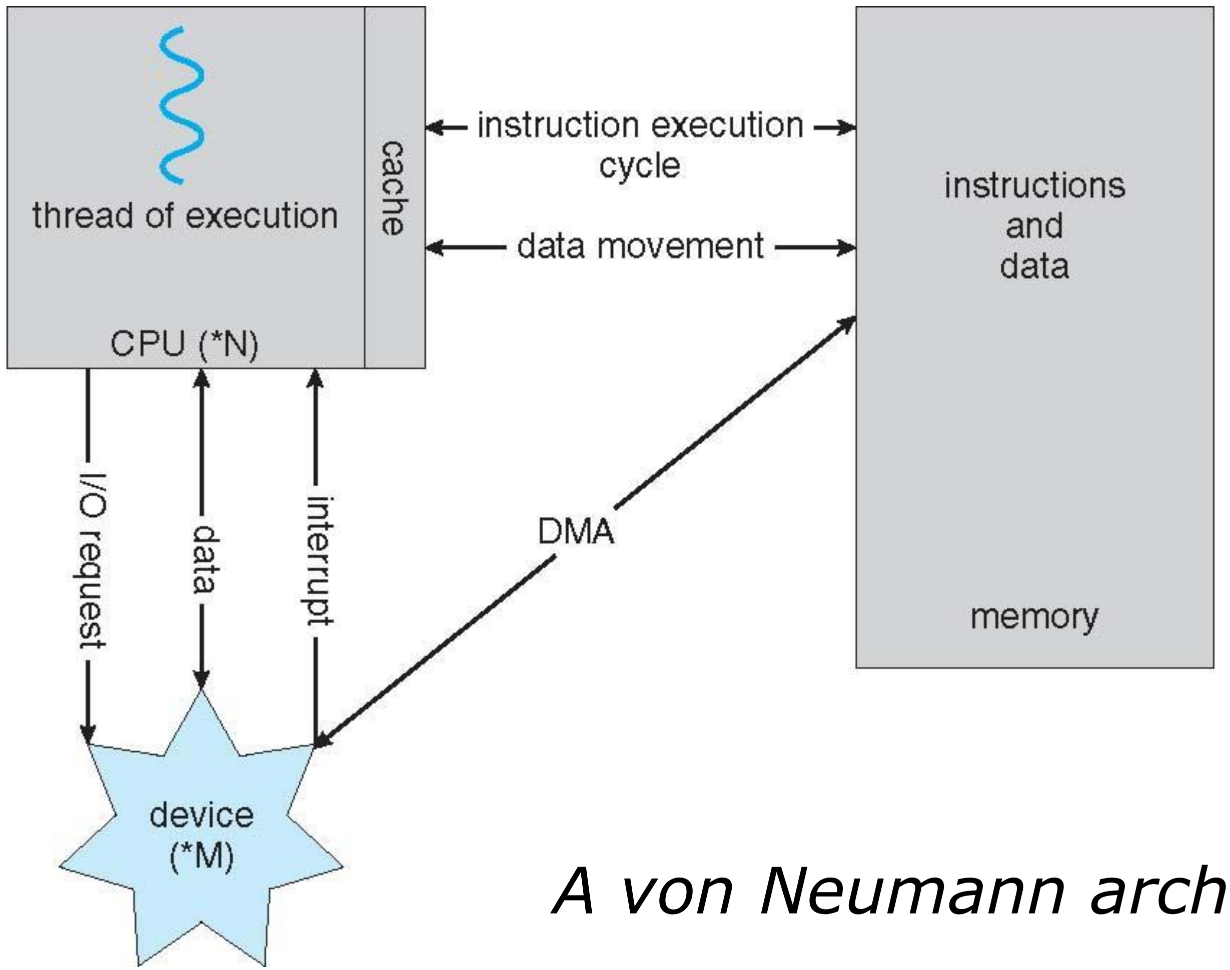
Device-Status Table



Direct Memory Access Structure

- Used for high-speed I/O devices able to transmit information at close to memory speeds
- Device controller transfers blocks of data from buffer storage directly to main memory without CPU intervention
- Only one interrupt is generated per block, rather than the one interrupt per byte

How a Modern Computer Works

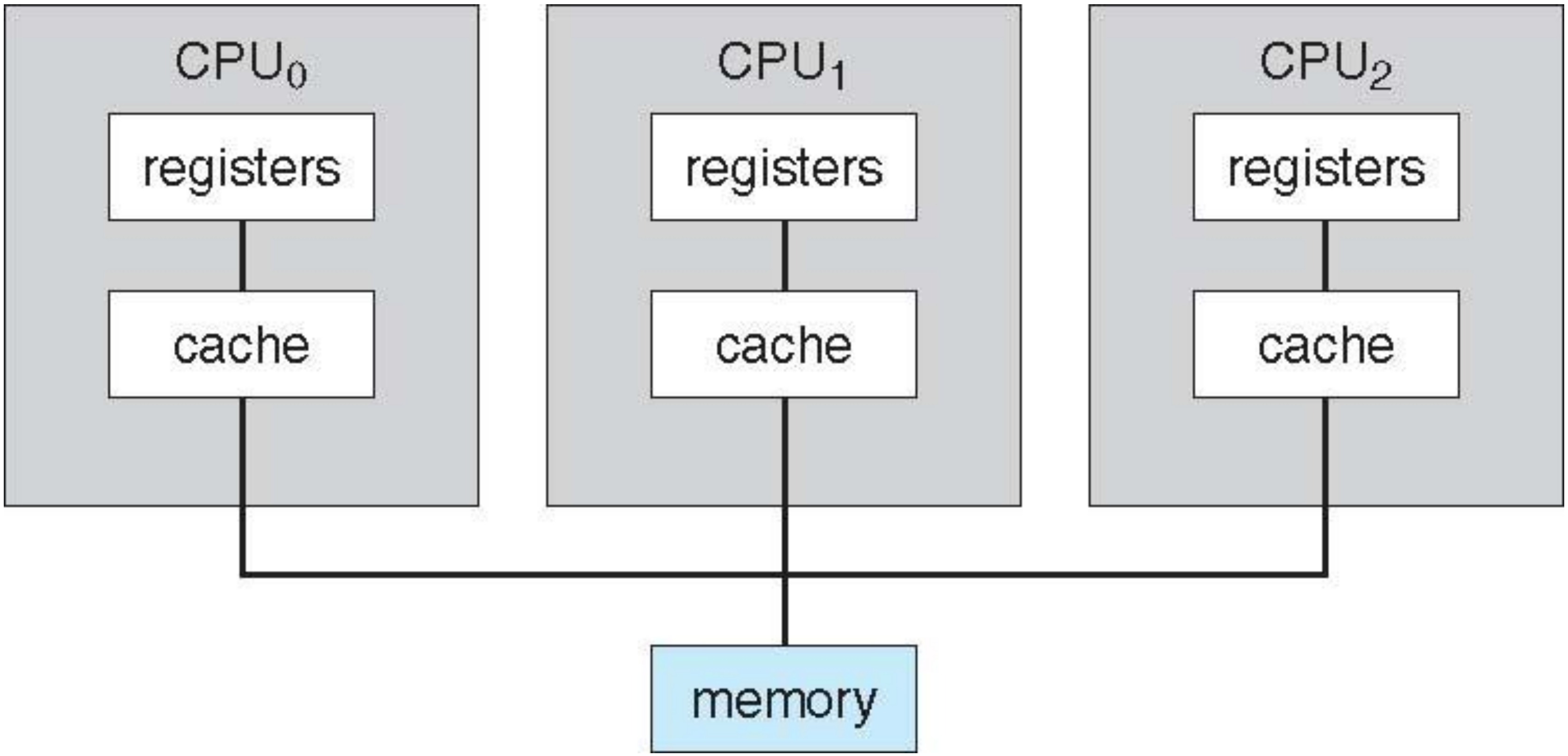


A von Neumann architecture

Computer-System Architecture

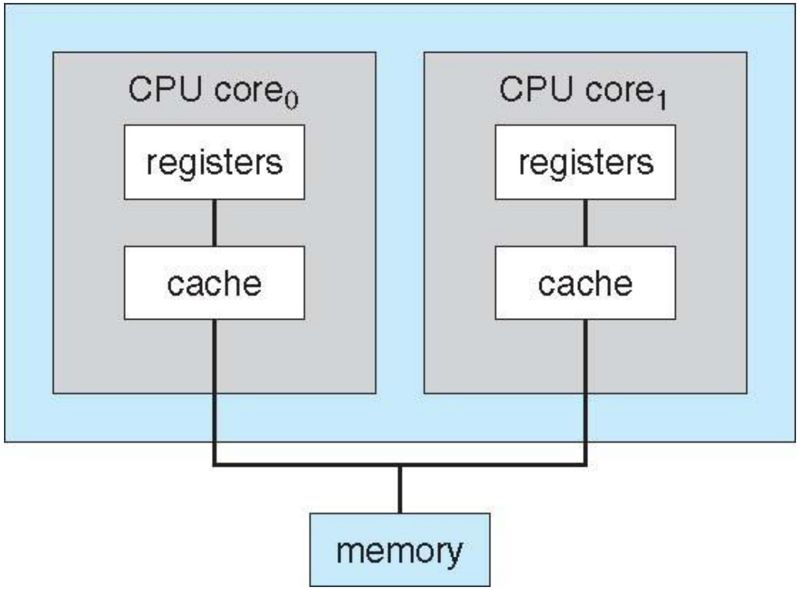
- Most systems use a single general-purpose processor (PDAs through mainframes)
  - Almost all have special-purpose processors as well
- **Multiprocessors** systems growing in use and importance
  - Also known as **parallel** or **multicore** systems
  - Advantages include:
    1. Increased throughput
    2. Economy of scale
    3. Increased reliability – graceful degradation or fault tolerance
  - Two types:
    1. **Asymmetric** Multiprocessing
    2. **Symmetric** Multiprocessing

Symmetric Multiprocessing Architecture



A Dual-Core Design

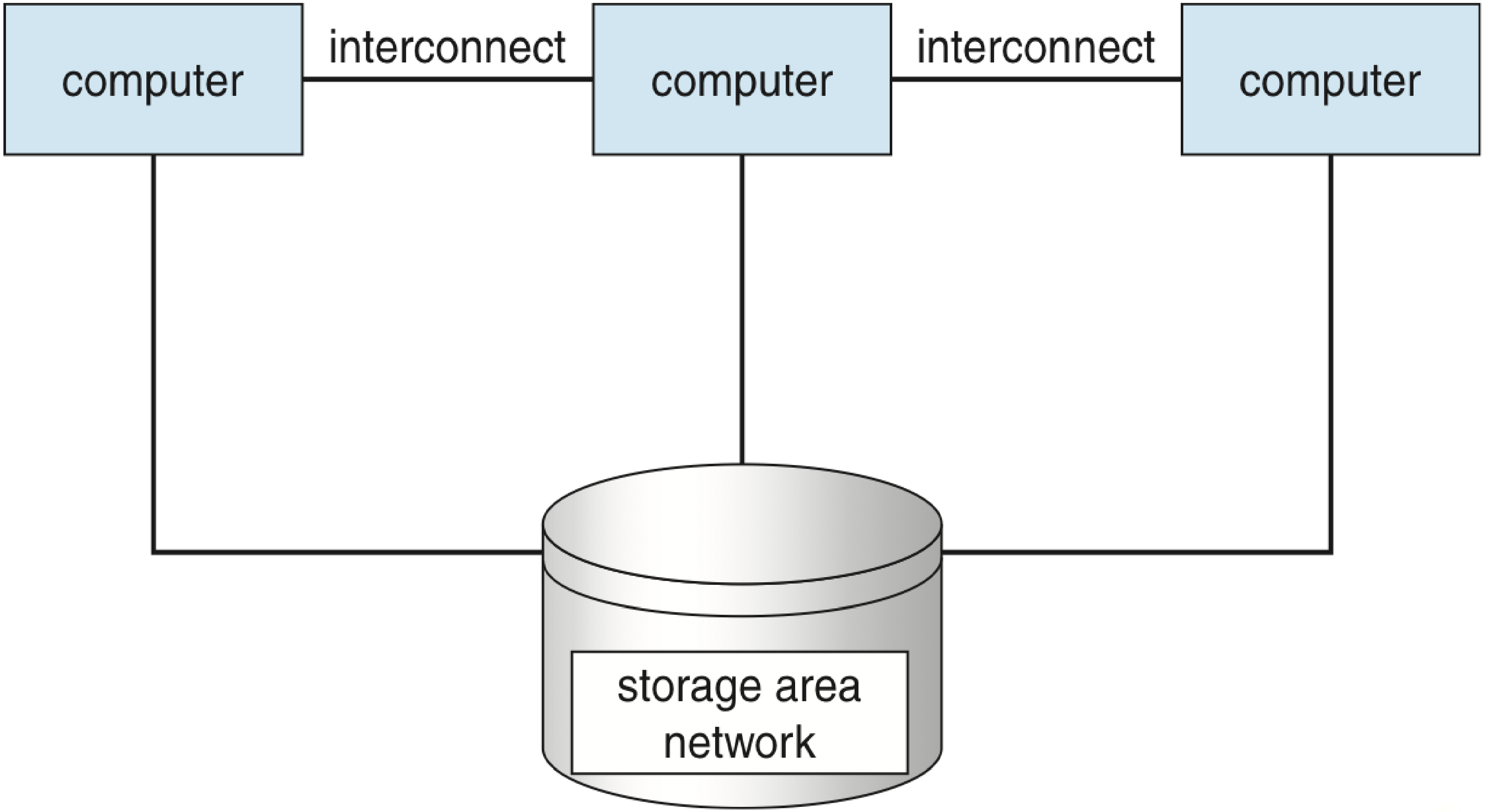
- **UMA** (uniform memory access) vs. **NUMA** (non-uniform memory access) architecture variations
- Multiple chips with single cores vs. multiple **cores** on a single chip
- Systems containing all chips vs. **blade servers**
  - Chassis holding multiple independent multiprocessor systems



Clustered Systems

- Like multiprocessor systems, but multiple systems working together
  - Usually sharing storage via a **storage-area network (SAN)**
  - Provides a **high-availability** service which survives failures
    - **Asymmetric clustering** has one machine in hot-standby mode
    - **Symmetric clustering** has multiple nodes running applications, monitoring each other
  - Some clusters are for **high-performance computing (HPC)**
    - Applications must be written to use **parallelization**
  - Some have **distributed lock manager** (**DLM**) to avoid conflicting operations

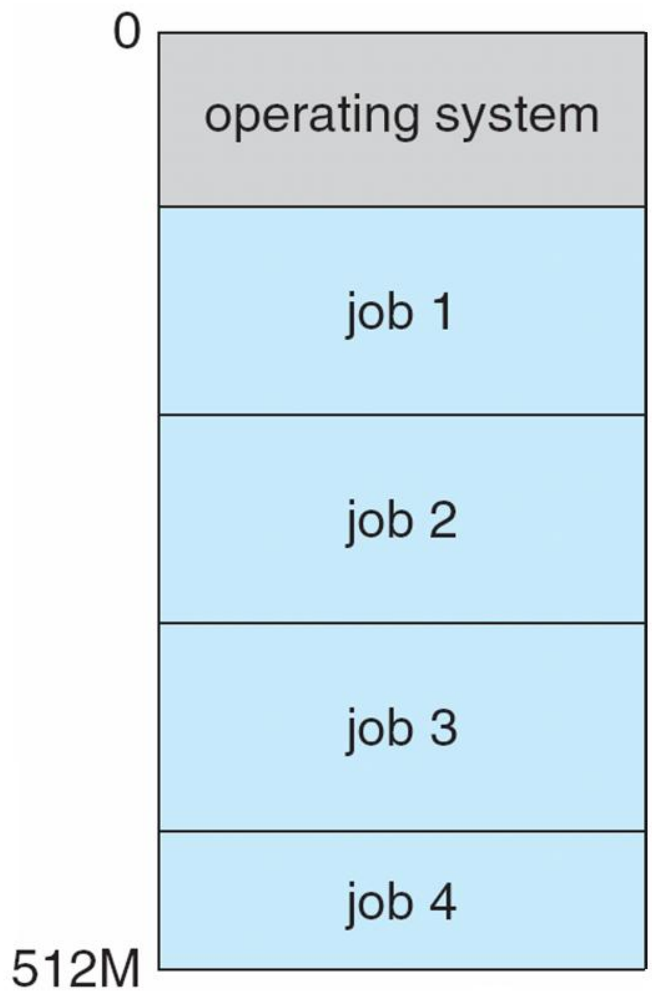
Clustered Systems



Operating System Structure

- **Multiprogramming** 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 the system is kept in memory
  - A jobs set is selected from a pool via **job scheduling**
  - When a job has to wait (for I/O for example), OS switches to another job

Memory Layout for Multiprogrammed System



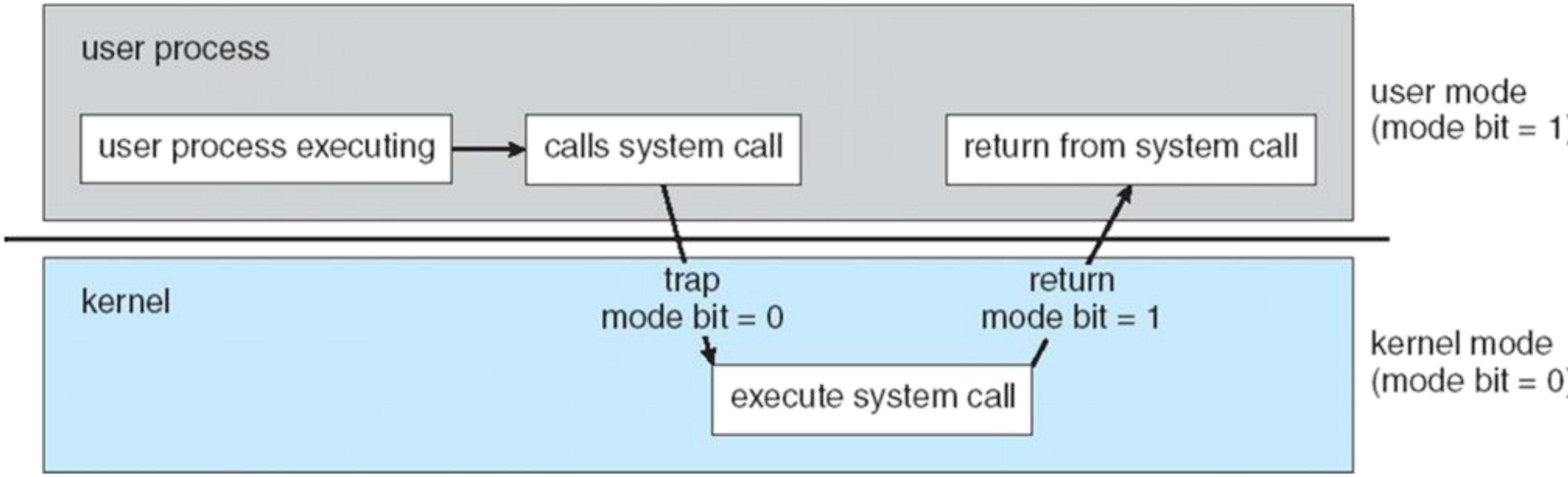
Operating System Structure

- **Timesharing** (**multitasking**) is a logical extension to multiprogramming
  - The CPU switches jobs so frequently that users can interact with each job while it is running, creating **interactive** computing
  - **Response time** should be short (typically < 1 second)
  - Each user has at least one program executing in memory ⇨ **process**
  - If several jobs ready to run at the same time ⇨ **CPU scheduling**
  - If processes don't fit in memory, **swapping** moves them in and out to run
  - **Virtual memory** allows execution of processes not completely in memory

Operating-System Operations

- **Interrupt driven** by hardware
- Software error or request creates **exception** or **trap**
  - Division by zero, request for operating system service
  - Other process problems include infinite loop, processes modifying each other or the operating system
- **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 mode to kernel, return from call resets it to user
- Increasingly CPUs support multi-mode operations
  - i.e. **virtual machine manager** (**VMM**) mode for guest **VMs**

Transition from User to Kernel Mode



- **Timer** to prevent infinite loop / process hogging resources
  - Set interrupt after specific period (fixed or variable)
  - Operating system initializes and decrements counter
  - When counter reaches zero generate an interrupt
  - Set up before scheduling process to regain control or terminate program that exceeds agreed time

Process Management

- A **process** is a program in execution.
  - It is a unit of work within the system
  - Program is a **passive entity**, process is an **active entity**
- Process needs resources to accomplish its task
  - CPU, memory, I/O, files
  - Initialization data
- Process termination requires reclaim of any reusable resources

Process Management

- Single-threaded process has one **program counter** specifying location of next instruction to execute
  - Process executes instructions sequentially, one at a time, until completion
- Multi-threaded process has one program counter per thread
- Typically a system has many processes running concurrently on one or more CPUs
  - Some user processes and others system processes
  - Concurrency by multiplexing the CPUs among the processes / threads

Process Management Activities

- The operating system is responsible for the following activities in connection with process management:
  - Creating and deleting both user and system processes
  - Scheduling processes and threads on the CPUs
  - Suspending and resuming processes
  - Providing mechanisms for process synchronization
  - Providing mechanisms for process communication
  - Providing mechanisms for deadlock handling

Memory Management

- All data in memory before and after processing
- All instructions in memory in order to execute
- Memory management allows keeping several programs in memory
  - To improve CPU utilization and speed computer's response to users
- Memory management activities
  - Keeping track of which parts of memory are currently being used and by whom
  - Deciding which processes (or parts thereof) and data to move into and out of memory
  - Allocating and deallocating memory space as needed

Storage Management

- OS provides uniform, logical view of information storage
  - Abstracts physical properties to logical storage unit - **file**
  - Each medium is controlled by device (i.e., disk or tape drive)
    - Varying properties include access speed, capacity, data-transfer rate, access method (sequential or random)
- **File-System management**
  - Files usually organized into directories
  - Access control on most systems to determine who can access what
  - OS activities include
    - Creating and deleting files and directories
    - Supporting primitives to manipulate files and directories
    - Mapping files onto secondary storage
    - Backup files onto stable (non-volatile) storage media

Mass-Storage Management

- Usually disks used to store data that does not fit in main memory or data that must be kept for a "long" period of time
- Proper management is of central importance
- Entire speed of computer operation hinges on disk subsystem and its algorithms
- OS activities
  - Free-space management
  - Storage allocation
  - Disk scheduling
- Some storage need not be fast
  - **Tertiary storage** includes optical storage, magnetic tape
  - Still must be managed – by OS or applications
  - Varies between WORM and RW

Cache Management

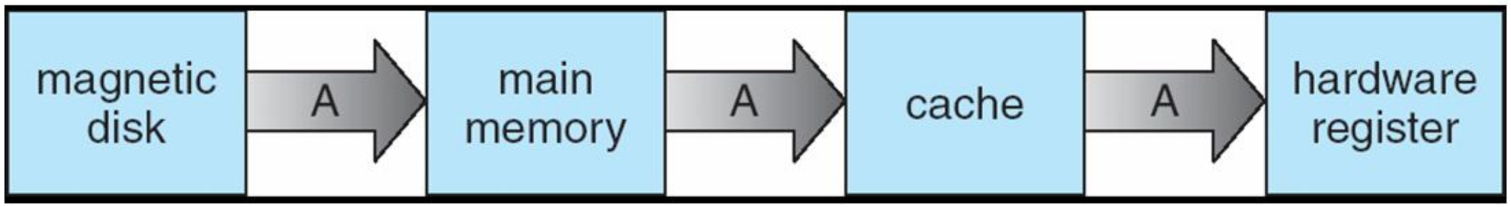
- Movement of information between various levels of storage hierarchy can be explicit or implicit

Level	1	2	3	4	5
Name	registers	cache	main memory	solid state disk	magnetic disk
Typical size	< 1 KB	< 16MB	< 64GB	< 1 TB	< 10 TB
Implementation technology	custom memory with multiple ports CMOS	on-chip or off-chip CMOS SRAM	CMOS SRAM	flash memory	magnetic disk
Access time (ns)	0.25 - 0.5	0.5 - 25	80 - 250	25,000 - 50,000	5,000,000
Bandwidth (MB/sec)	20,000 - 100,000	5,000 - 10,000	1,000 - 5,000	500	20 - 150
Managed by	compiler	hardware	operating system	operating system	operating system
Backed by	cache	main memory	disk	disk	disk or tape

- Careful selection of cache size and replacement policy can result in greatly increased performance

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)

I/O Subsystem

- One purpose of OS is to hide individuality of hardware devices from the user
- I/O subsystem responsible for
  - Memory management of I/O including
    - **buffering** - storing data temporarily while it is being transferred
    - **caching** - storing parts of data in faster storage for performance
    - **spooling** - overlapping of output of one job with input of other jobs
  - General device-driver interface
  - Drivers for specific hardware devices

Protection and Security

- **Protection** – any mechanism for controlling access of processes or users to resources defined by the OS
- **Security** – defense of the system against internal and external attacks
  - Huge range, including denial-of-service, worms, viruses, identity theft, theft of service
- Systems generally first distinguish among users, to determine who can do what
  - User identities (**user IDs**, security IDs) include name and associated number, one per user
  - User ID then associated with all files, processes of that user to determine access control
  - Group identifier (**group ID**) allows set of users to be defined and controls managed, then also associated with each process, file
  - **Privilege escalation** allows user to change to effective ID with more rights

Computing Environments - Traditional

- Stand-alone general purpose machines
- But indistinct as most systems interconnect with others (i.e. the Internet)
- **Portals** provide web access to internal systems
- **Network computers** (**thin clients**) are like Web terminals - more security or easier maintenance
- Mobile computers interconnect via **wireless networks**
- Networking becoming ubiquitous - even home systems use **firewalls** to protect home computers from Internet attacks

Computing Environments - Mobile

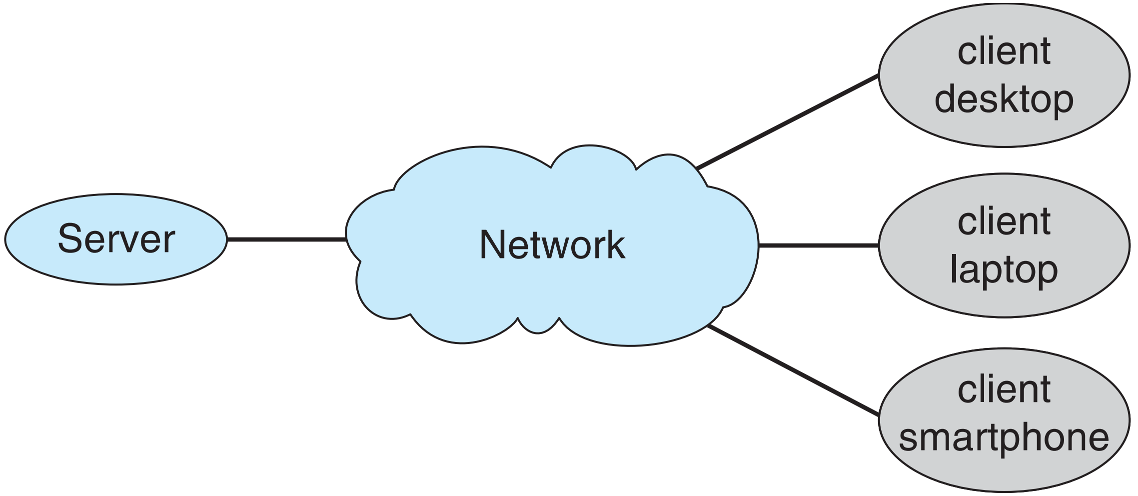
- Handheld smart phones, tablet computers, etc
- What is the functional difference between them and a "traditional" laptop?
- Extra feature – more OS features (GPS, gyroscope, taking photos, and recording videos)
- Allows new types of apps like ***augmented reality***
- Use IEEE 802.11 wireless, or cellular data networks for connectivity
- Leaders are **Apple iOS** and **Google Android**

Computing Environments – Distributed

- Collection of separate, possibly heterogeneous, systems networked together
  - **Network** is a communications path, **TCP/IP** most common
    - **Local Area Network** (**LAN**)
    - **Wide Area Network** (**WAN**)
    - **Metropolitan Area Network** (**MAN**)
    - **Personal Area Network** (**PAN**)
- **Network Operating System** provides features (as file sharing) between systems across network
  - Communication scheme allows systems to exchange messages
  - Impression of a single system

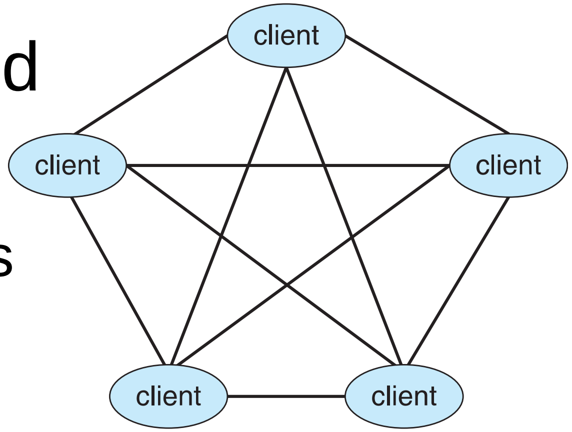
Computing Environments – Client-Server

- Client-Server Computing
  - Dumb terminals supplanted by smart PCs
  - Many systems now **servers**, responding to requests generated by **clients**
    - **Compute-server system** provides an interface to client to request services (i.e., database)
    - **File-server system** provides interface for clients to store and retrieve files



Computing Environments - Peer-to-Peer

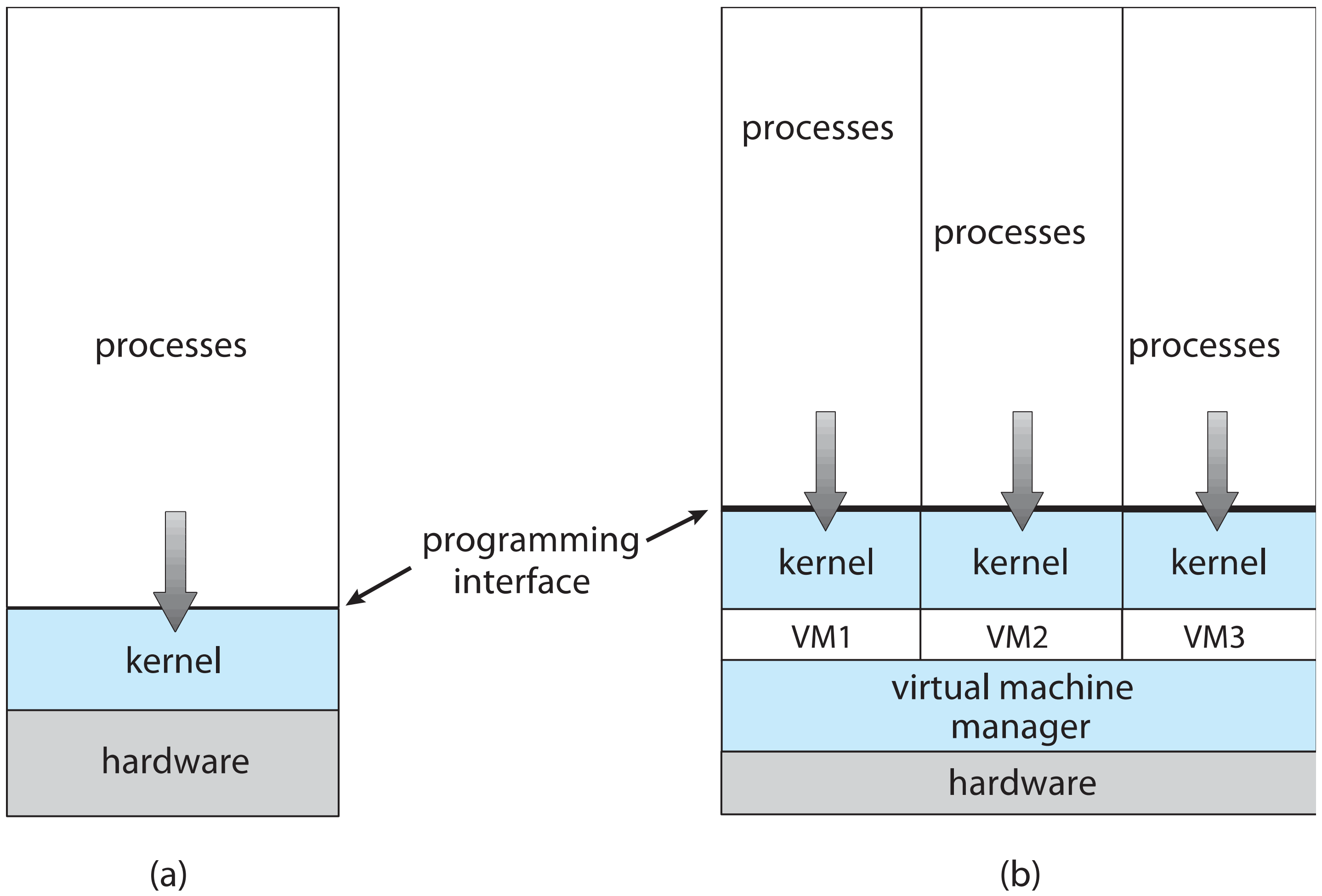
- Another model of distributed system
- P2P does not distinguish clients and servers
  - Instead all nodes are considered peers
  - May each act as client, server or both
  - Node must join P2P network
    - Registers its service with central lookup service on network, or
    - Broadcast request for service and respond to requests for service via **discovery protocol**
  - Examples include Napster and Gnutella, **Voice over IP** (**VoIP**) such as Skype



Computing Environments - Virtualization

- Allows operating systems to run as applications within other OSs
  - Vast and growing industry
- **Emulation** used when source CPU type different from target CPU type (i.e. PowerPC to Intel x86)
  - Generally slowest method
  - When computer language not compiled to native code – **Interpretation**
- **Virtualization** – OS natively compiled for CPU, running **guest** OSs also natively compiled
  - Consider VMware running WinXP guests, each running applications, all on native WinXP **host** OS
  - **VMM** provides virtualization services

Computing Environments - Virtualization



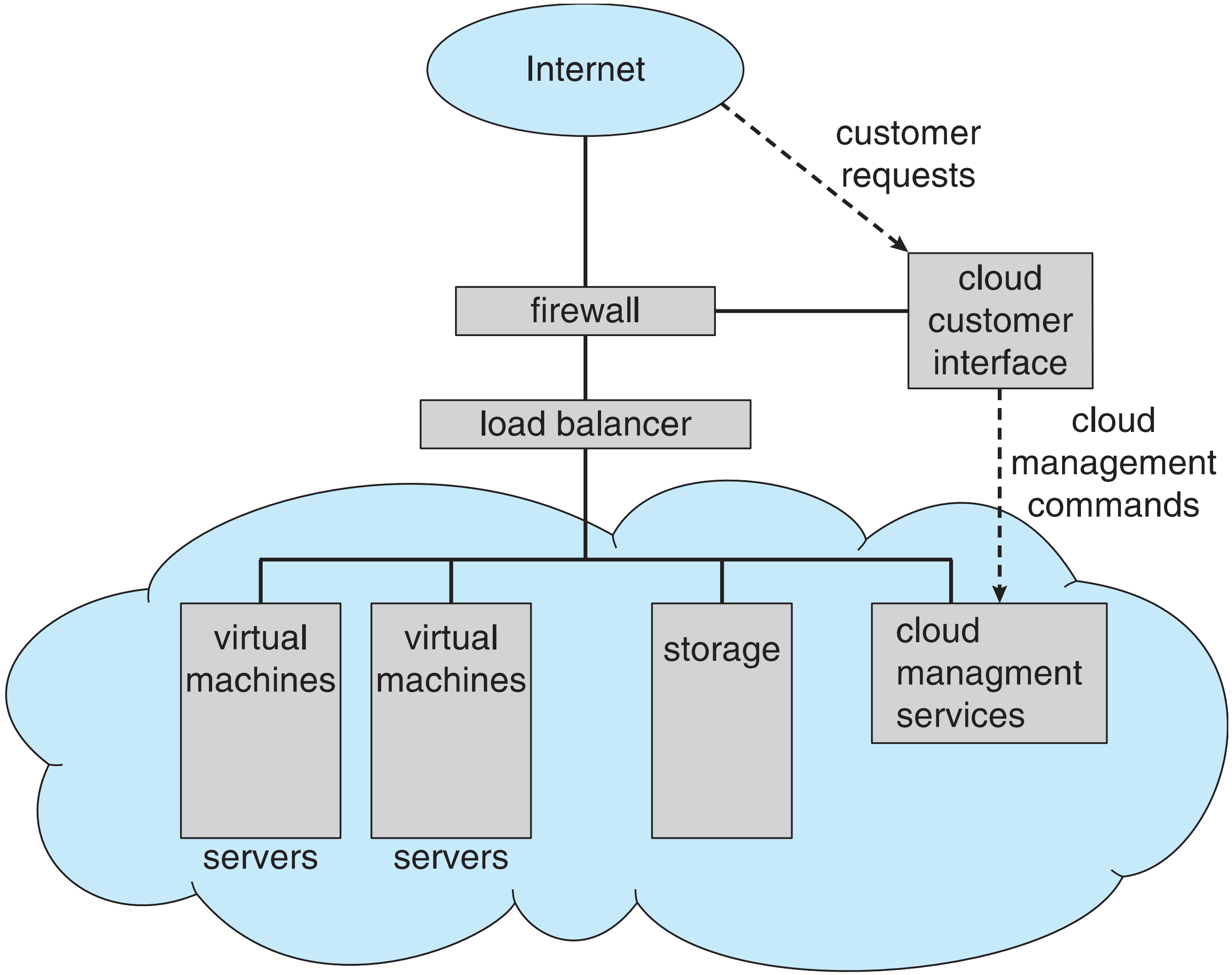
Computing Environments - Virtualization

- Use cases involve laptops and desktops running multiple OSs for exploration or compatibility
  - Apple laptop running Mac OS X host, Windows as a guest
  - Developing apps for multiple OSs without having multiple systems
  - QA testing applications without having multiple systems
  - Executing and managing compute environments within data centers
- VMMs can run natively, in which case they are also the host

Computing Environments – Cloud Computing

- Delivers computing, storage, even apps as a service across a network
- Logical extension of virtualization as based on virtualization
  - Amazon **EC2** has thousands of servers, millions of VMs, PBs of storage available across the Internet, pay based on usage
- Cloud compute environments composed of usual OSs plus VMMs and cloud management tools
  - Internet connectivity requires security like firewalls
  - Load balancers spread traffic across multiple applications

Computing Environments – Cloud Computing



Computing Environments – Cloud Computing

- Many types
  - **Public cloud** – available via Internet to anyone willing to pay
  - **Private cloud** – run by a company for the company's own use
  - **Hybrid cloud** – includes both public and private cloud components
  - Software as a Service (**SaaS**) – one or more applications available via the Internet (i.e. word processor)
  - Platform as a Service (**PaaS**) – software stack ready for application use via the Internet (i.e a database server)
  - Infrastructure as a Service (**IaaS**) – servers or storage available over Internet (i.e. storage available for backup)

Computing Environments – Real-Time Embedded Systems

- Real-time embedded systems most prevalent form of computers
  - Vary considerable, special purpose, limited purpose OS, **real-time OS**
  - Usually have little or no user interface
- Many other special computing environments as well
  - Some have OSs, some perform tasks without an OS
- Real-time OS has well-defined fixed time constraints
  - Processing **must** be done within constraint
  - Correct operation only if constraints met

Open-Source Operating Systems

- Operating systems made available in source-code format rather than just binary **closed-source**
- Counter to the **copy protection** and **Digital Rights Management (DRM)** movement
- Started by **Free Software Foundation (FSF)**, which has “copyleft” **GNU Public License (GPL)**
- Examples include **GNU/Linux** and **BSD UNIX** (including core of **Mac OS X**), and many more
- Can use VMM like VMware Player (Free on Windows), Virtualbox (open source and free on many platforms)
  - Use to run guest operating systems for exploration

End of Chapter 1