

Chapter 1: Introduction

Quick overview of the entire computer system: Many slides will be skim quickly.

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
- Kernel Data Structures
- 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

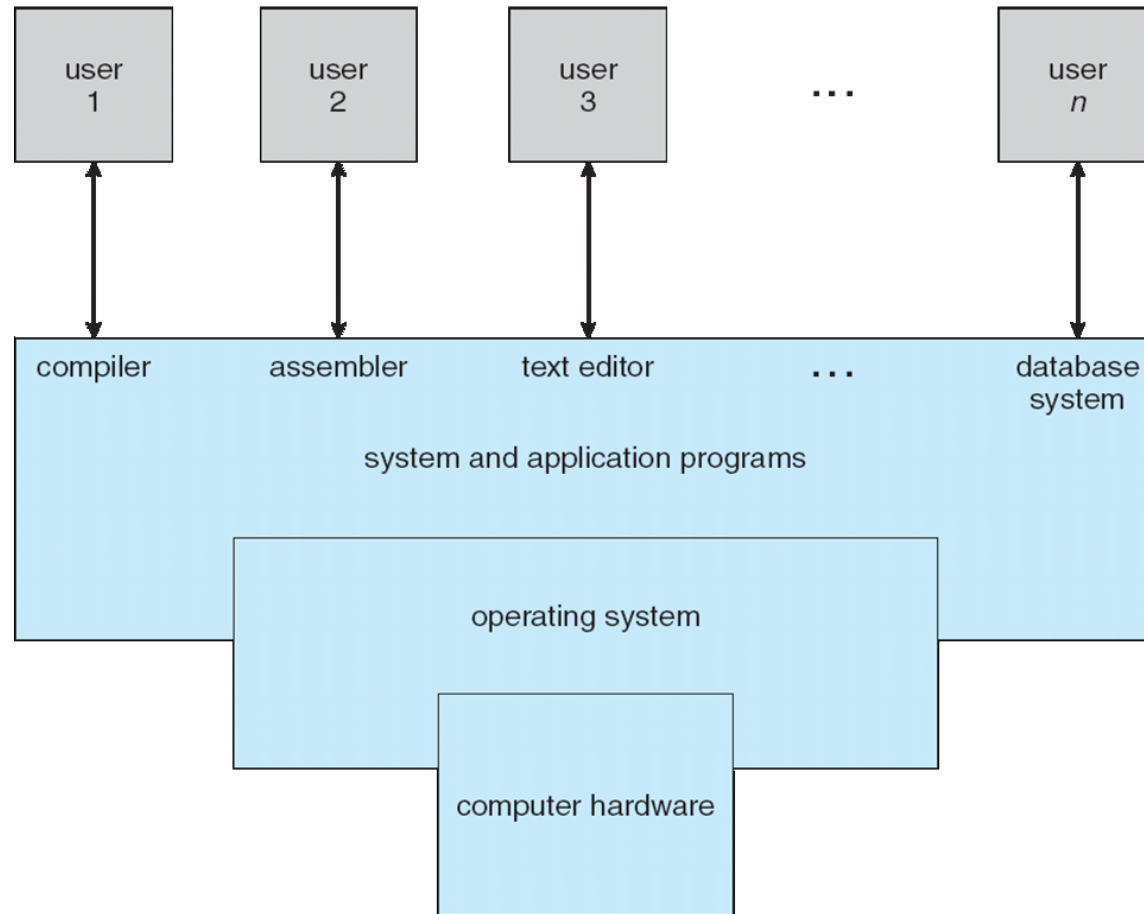
What is an Operating System?

- 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

- Depends on the point of view
- Users want convenience, **ease of use** and **good performance**
 - Don't care about **resource utilization**
- But shared computer such as **mainframe** or **minicomputer** must keep all users happy
- Users of dedicated 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

Operating System Definition

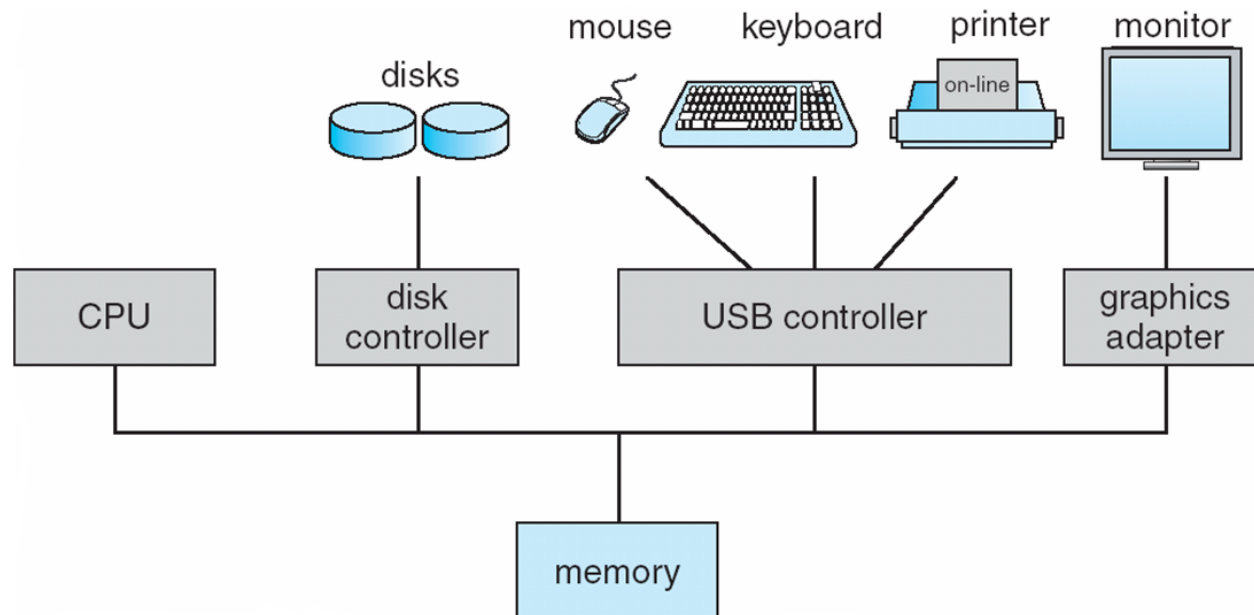
- OS is a **resource allocator**
 - Manages all resources
 - Decides between conflicting requests for efficient and fair resource use
- OS is a **control program**
 - Controls execution of programs to prevent errors and improper use of the computer

Operating System Definition (Cont.)

- No universally accepted definition
- “Everything a vendor ships when you order an operating system” is a 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 System Organization

- Computer-system operation
 - One or more CPUs, device controllers connect through common bus providing access to shared memory
 - Concurrent execution of CPUs and devices competing for memory cycles



Computer-System Operation

- I/O devices and the CPU can execute concurrently/in parallel
- Each device controller is in charge of a particular device type, e.g., USB controller, SATA controller, etc.
- 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**

I/O Structure

- After I/O starts, control returns to another 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 another user program without waiting for I/O completion
 - **System call** – request to the OS to allow user program 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

Storage Definitions and Notation Review

The basic unit of computer storage is the **bit**. A bit can contain one of two values, 0 and 1. All other storage in a computer is based on collections of bits. Given enough bits, it is amazing how many things a computer can represent: numbers, letters, images, movies, sounds, documents, and programs, to name a few. A **byte** is 8 bits, and on most computers it is the smallest convenient chunk of storage. For example, most computers don't have an instruction to move a bit but do have one to move a byte. A less common term is **word**, which is a given computer architecture's native unit of data. A word is made up of one or more bytes. For example, a computer that has 64-bit registers and 64-bit memory addressing typically has 64-bit (8-byte) words. A computer executes many operations in its native word size rather than a byte at a time.

Computer storage, along with most computer throughput, is generally measured and manipulated in bytes and collections of bytes.

A **kilobyte**, or **KB**, is $1,024$ bytes

a **megabyte**, or **MB**, is $1,024^2$ bytes

a **gigabyte**, or **GB**, is $1,024^3$ bytes

a **terabyte**, or **TB**, is $1,024^4$ bytes

a **petabyte**, or **PB**, is $1,024^5$ bytes

Computer manufacturers often round off these numbers and say that a megabyte is 1 million bytes and a gigabyte is 1 billion bytes. Networking measurements are an exception to this general rule; they are given in bits (because networks move data a bit at a time).

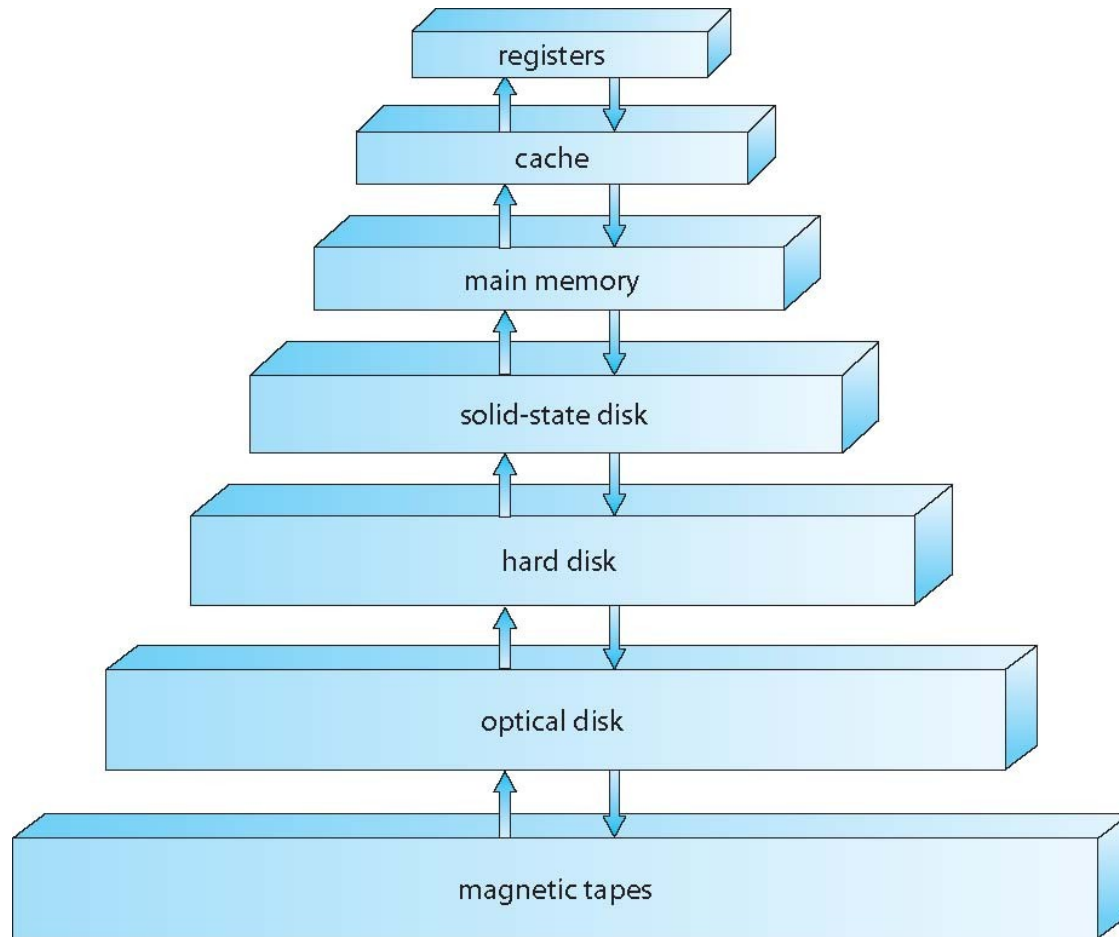
Storage Structure

- 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
- Hard 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 hard disks, nonvolatile
 - 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 uniform interface between controller and kernel

Storage-Device Hierarchy



Caching

- Important principle, performed at many levels in a computer (in hardware, operating system, other softwares)
- 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

Direct Memory Access Structure

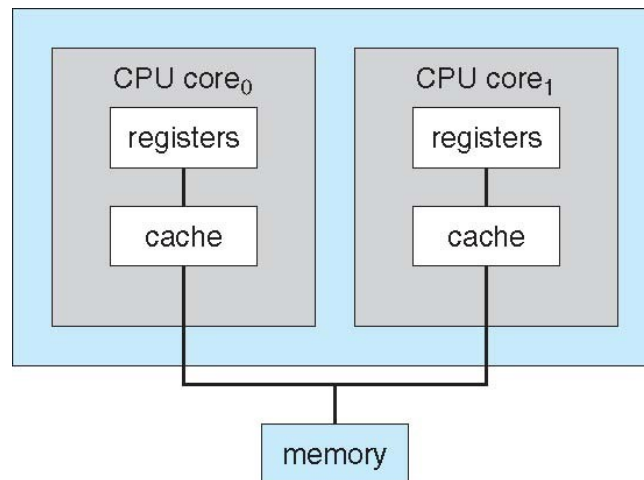
- Used for high-speed I/O devices able to transmit information at close to memory speeds
- Device controller transfers blocks of data from buffer storage directly to main memory without CPU intervention
- Only one interrupt is generated per block, rather than the one interrupt per byte

Computer-System Architecture

- Most systems use a single general-purpose processor
 - Most systems have special-purpose processors as well
- **Multiprocessors** systems growing in use and importance -multiple CPUs
 - Also known as **parallel systems**, **tightly-coupled systems**
 - Advantages include:
 1. **Increased throughput**
 2. **Economy of scale**
 3. **Increased reliability** – graceful degradation or fault tolerance
 - Two strategies:
 1. **Asymmetric Multiprocessing** – each processor is assigned a specific task.
 2. **Symmetric Multiprocessing** – each processor performs all tasks

A Dual-Core Design

- Multi-chip and **multicore**
- Systems containing all chips
 - Chassis containing multiple separate 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

Operating System Structure

- **Multiprogramming (Batch system)** 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
 - One job selected and run via **job scheduling**
 - When it has to wait (for I/O for example), OS switches to another job
- **Timesharing (multitasking)** is logical extension in which CPU switches jobs so frequently that users can interact with each job while it is running, creating **interactive** computing
 - **Response time** should be < 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

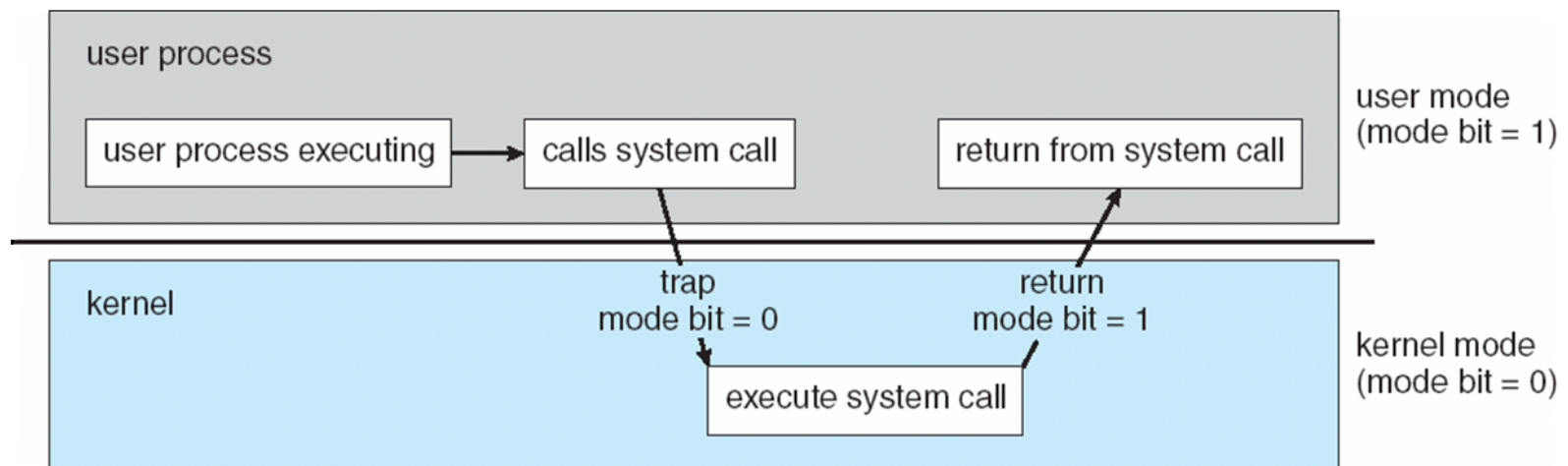
- **Interrupt driven** (hardware and software) – CPU flag
 - Hardware interrupt by one of the devices
 - Software interrupt (**exception** or **trap**):
 - ▶ Software error (e.g., division by zero, memory access error)
 - ▶ Request for operating system service
 - ▶ Other process problems include infinite loop, processes modifying each other or the operating system

Operating-System Operations (cont.)

- **Dual-mode** operation allows OS to protect itself and other system components
 - **User mode** and **kernel mode**
 - **Mode bit** provided by hardware – CPU flag
 - ▶ 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
 - Timer is set to interrupt the computer after some time period
 - Keep a counter that is decremented by the physical clock.
 - Operating system set the counter (privileged instruction)
 - When counter zero generate an interrupt
 - Set up before scheduling process to regain control or terminate program that exceeds allotted time



I/O Protection

- User process may accidentally or purposefully attempt to disrupt normal operation via illegal I/O instructions
 - All I/O instructions defined to be privileged
 - I/O must be performed via system calls
 - ▶ Memory-mapped and I/O port memory locations must be protected too

Process Management

Skim the remaining slides in lab. Questions on them will be addressed during the next lab period.

- 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
- 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 system has many processes, some user, some operating system running concurrently on one or more CPUs
 - 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
- Suspending and resuming processes
- Providing mechanisms for process synchronization
- Providing mechanisms for process communication
- Providing mechanisms for deadlock handling

Memory Management

- To execute a program all (or part) of the instructions must be in memory
- All (or part) of the data that is needed by the program must be in memory.
- Memory management determines what is in memory and when
 - Optimizing CPU utilization and computer 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

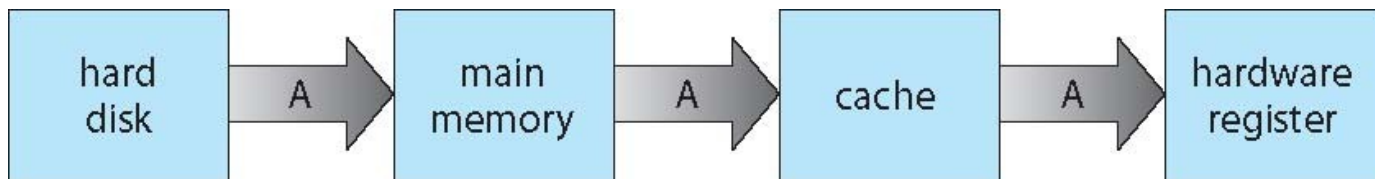
- OS provides uniform, logical view of information storage
 - Abstracts physical properties to logical storage unit - **file**
 - Each medium is controlled by device (i.e., disk drive, tape drive)
 - ▶ Varying properties include access speed, capacity, data-transfer rate, access method (sequential or random)
- Abstraction: OS hides/masks the complexity of the device layer
- 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
 - ▶ 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 (write-once, read-many-times) and RW (read-write)

Migration of data “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



Note where data is stored in the computer.

- 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
 - Various solutions covered in Chapter 17 (beyond our scope)

I/O Subsystem

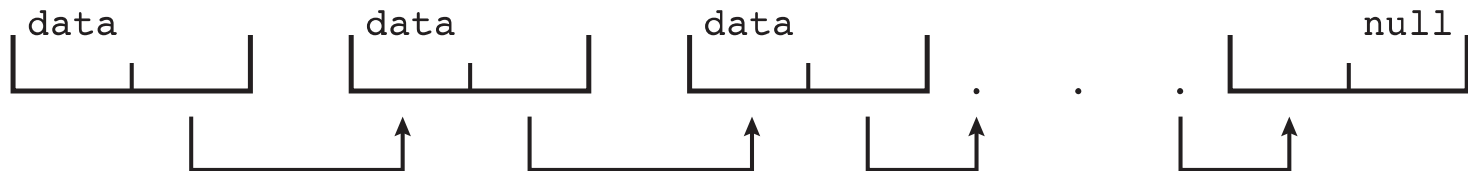
- One purpose of OS is to hide peculiarities of hardware devices from the user Abstraction
- I/O subsystem responsible for
 - Memory management of I/O including **buffering** (storing data temporarily while it is being transferred), **caching** (storing parts of data in faster storage for performance),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

Protection and Security

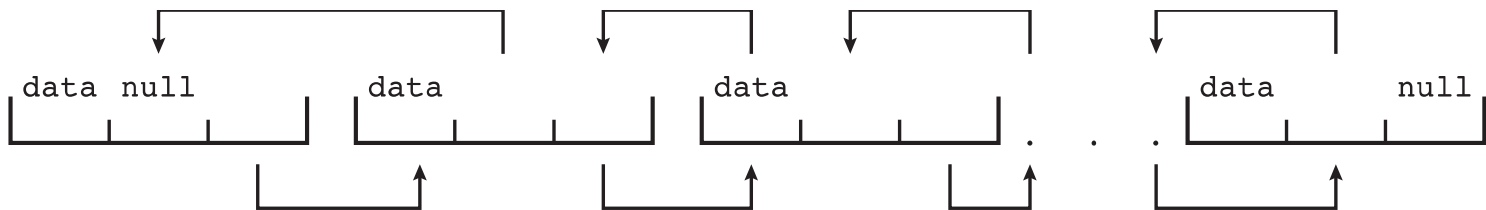
- **Protection** – any mechanism for controlling access of processes or users to resources defined by the OS
- **Security** – defense of the system against internal and external attacks
 - Huge range, including denial-of-service, worms, viruses, identity theft, theft of service
- Systems generally first 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

Kernel Data Structures

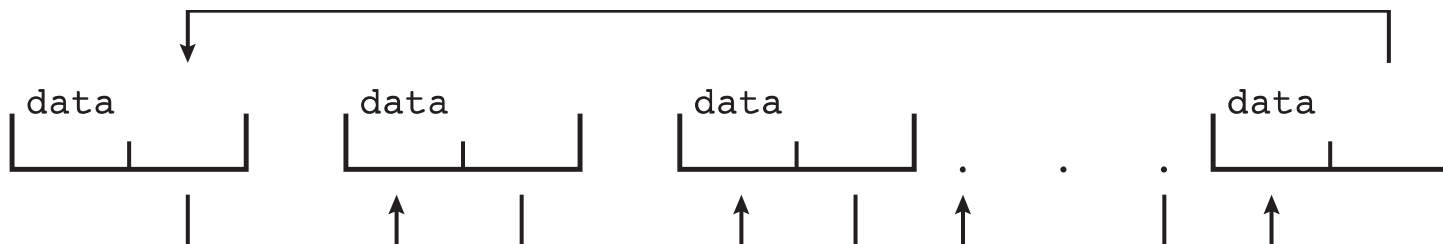
- Many similar to standard programming data structures
- ***Singly linked list***



- ***Doubly linked list***



- ***Circular linked list***

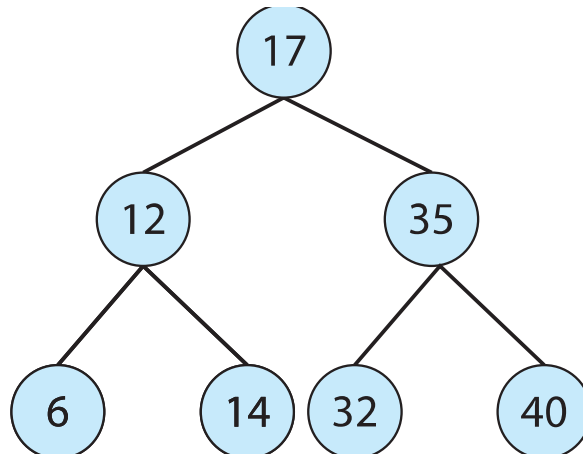


Kernel Data Structures

- **Binary search tree**

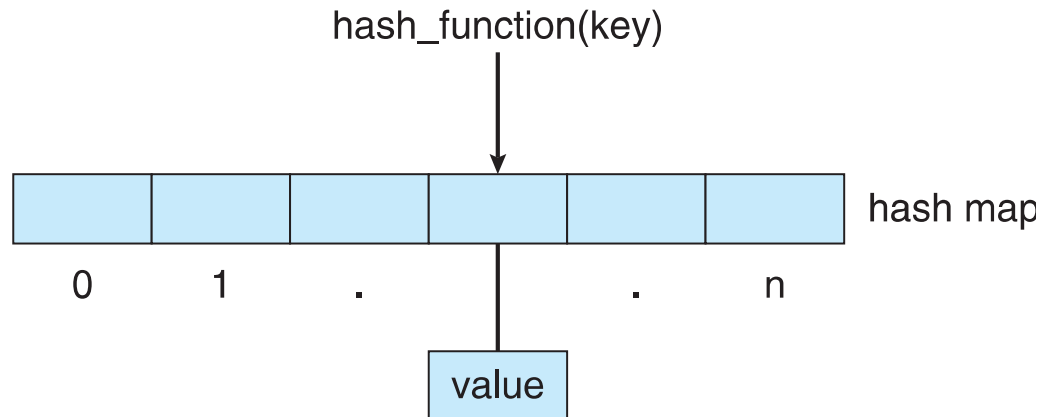
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- Search performance is $O(n)$
- **Balanced binary search tree** is $O(\lg n)$



Kernel Data Structures

- **Hash function** can create a **hash map**



- **Bitmap** – string of n binary digits representing the status of n items
- Linux data structures defined in
include files `<linux/list.h>`, `<linux/kfifo.h>`,
`<linux/rbtree.h>`

Computing Environments - Traditional

- Stand-alone general purpose machines
- But blurred 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
- 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 smartphones, tablets, etc
- What is the functional difference between them and a “traditional” laptop?
- Extra feature – more OS features (GPS, gyroscope)
- 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**

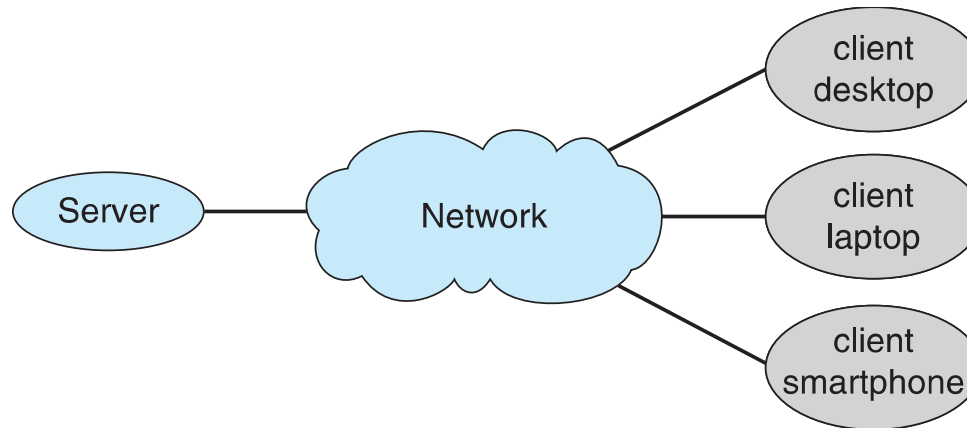
Computing Environments – Distributed

- Distributed computing
 - 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 between systems across network
 - ▶ Communication scheme allows systems to exchange messages
 - ▶ Illusion of a single system

Computing Environments – Client-Server

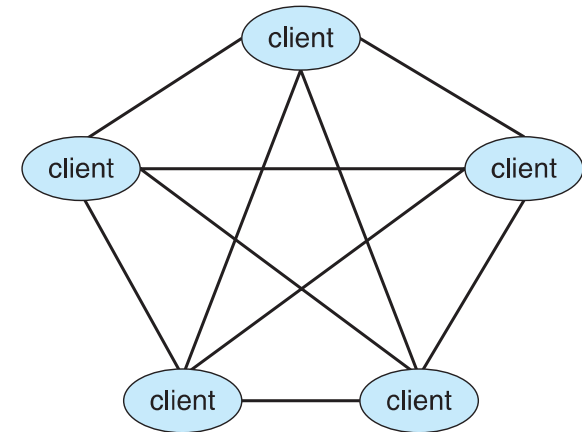
■ Client-Server Computing

- 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



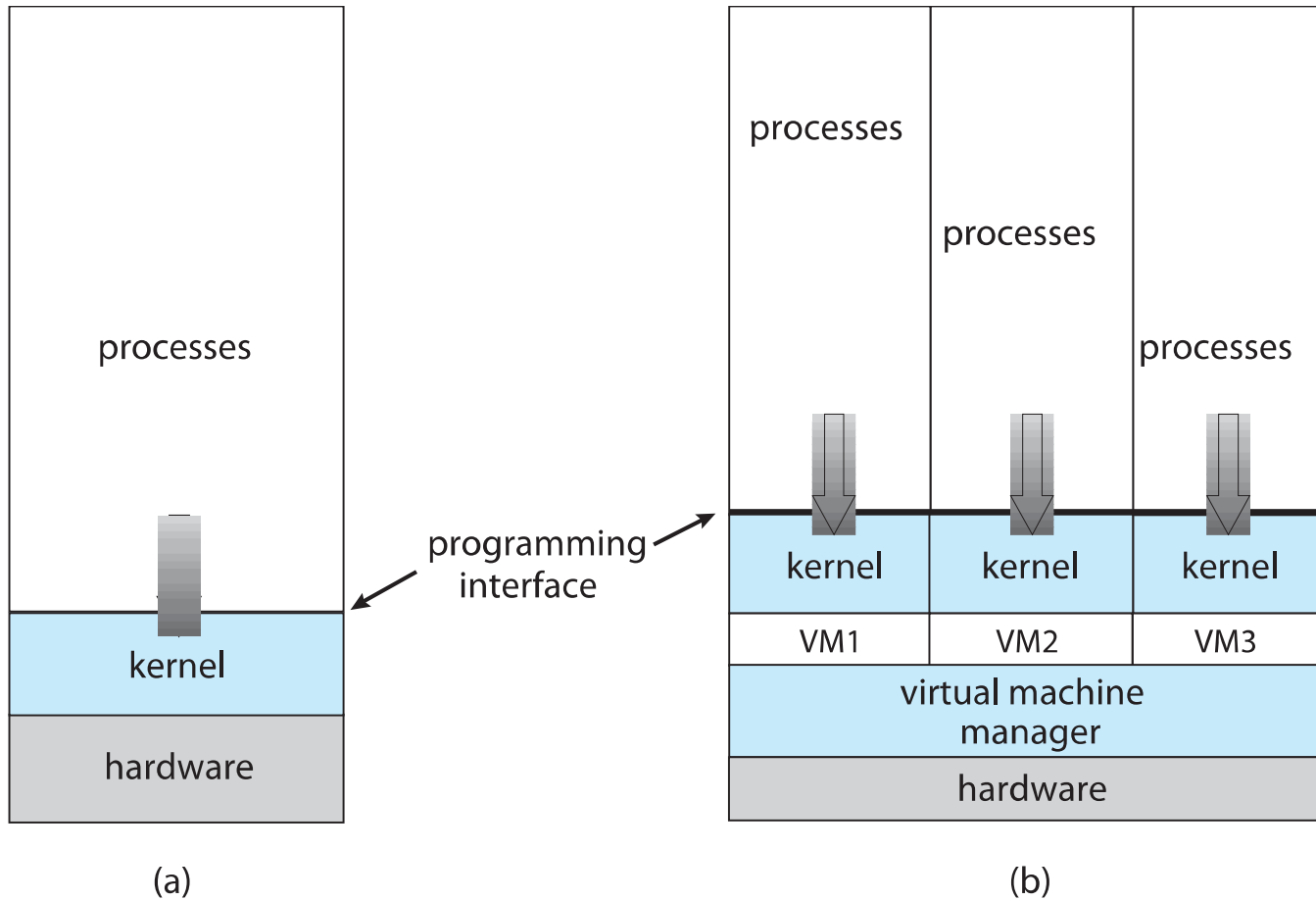
Computing Environments - Virtualization

- Allows operating systems to run applications within other OSes
 - Vast and growing industry
- **Emulation** used when source CPU type different from target 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** OSes also natively compiled
 - Consider VMware running WinXP guests, each running applications, all on native WinXP **host** OS
 - **VMM** (virtual machine Manager) provides virtualization services

Computing Environments - Virtualization

- Use cases involve laptops and desktops running multiple OSES for exploration or compatibility
 - Apple laptop running Mac OS X host, Windows as a guest
 - Developing apps for multiple OSES without having multiple systems
 - QA testing applications without having multiple systems
 - Executing and managing compute environments within data centers
- VMM can run natively, in which case they are also the host
 - There is no general purpose host then (VMware ESX and Citrix XenServer)

Computing Environments - Virtualization

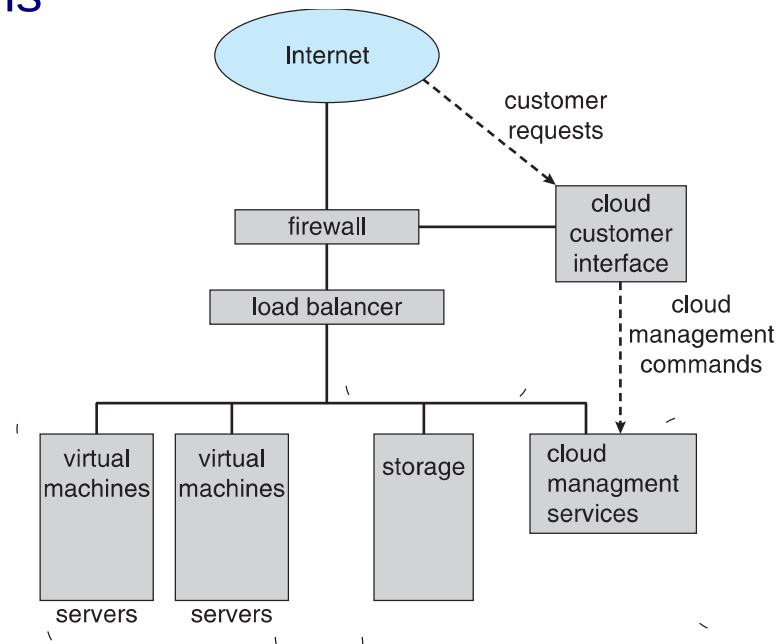


Computing Environments – Cloud Computing

- Delivers computing, storage, even apps as a service across a network
- Logical extension of virtualization because it uses virtualization as the base for it functionality.
 - Amazon **EC2** has thousands of servers, millions of virtual machines, petabytes of storage available across the Internet, pay based on usage
- 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 use)

Computing Environments – Cloud Computing

- Cloud computing environments composed of traditional OSe, plus VMMs, plus cloud management tools
 - Internet connectivity requires security like firewalls
 - Load balancers spread traffic across multiple applications



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**
 - Use expanding
- Many other special computing environments as well
 - Some have OSes, 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 - <http://www.virtualbox.com>)
 - Use to run guest operating systems for exploration

End of Chapter 1