Introduction to Operating Systems

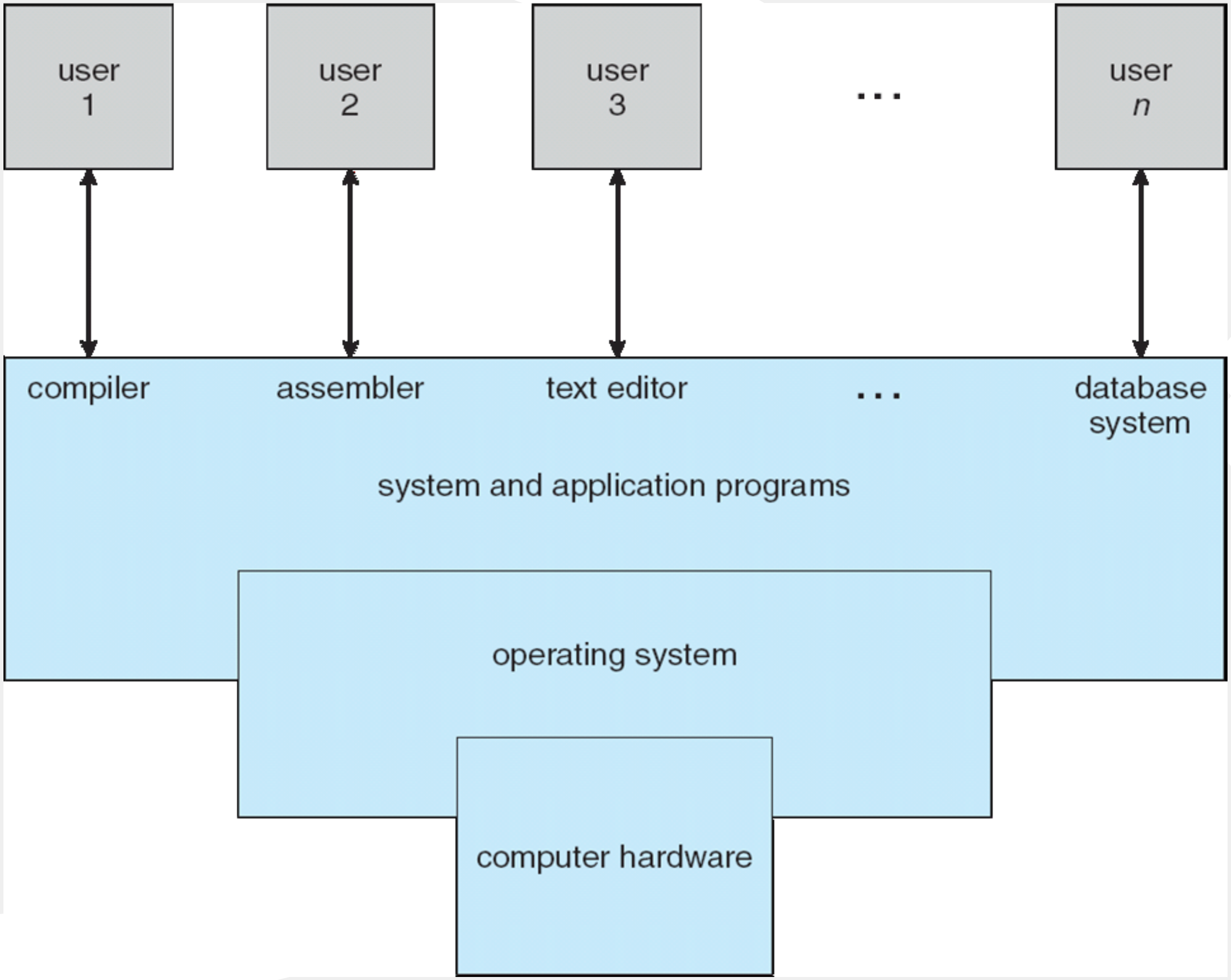
What is an Operating System?

- 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?

- 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 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 could have real-time requirements

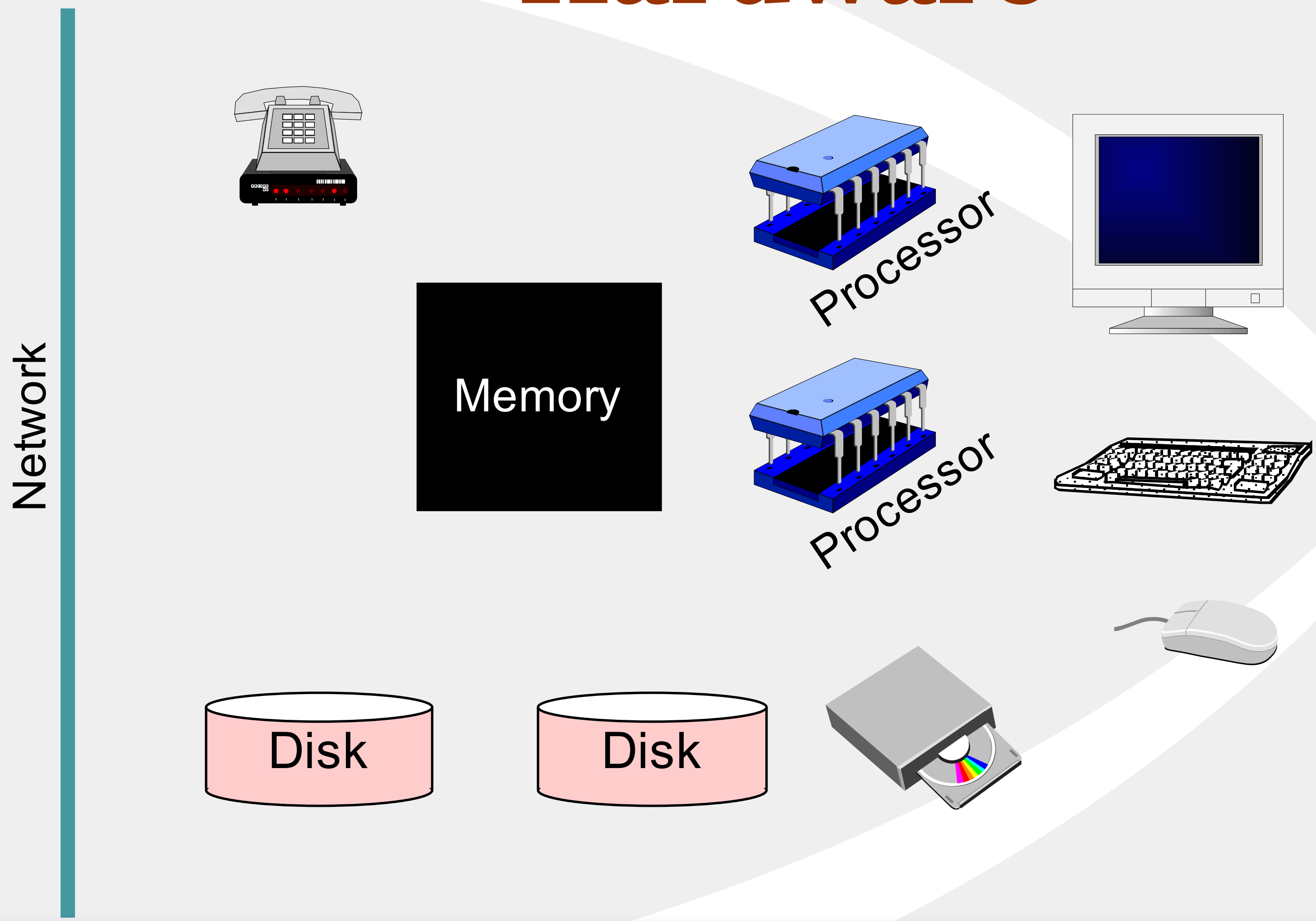
So What are the Major OS Functions?

- Control access and provide interfaces
  - To the OS and devices attached to the system
  - Provide interfaces for human-machine and machine-machine transactions
- Manage resources (Resource Allocator)
  - Mediate resource usage among different tasks
  - Implement policies

So What are the Major OS Functions?

- Provide abstractions
  - Hide the peculiarities of the hardware.
  - Example: device independent I/O
- Consume resources*
  - OS runs on the system that is being managed… so it is going to consume resources!

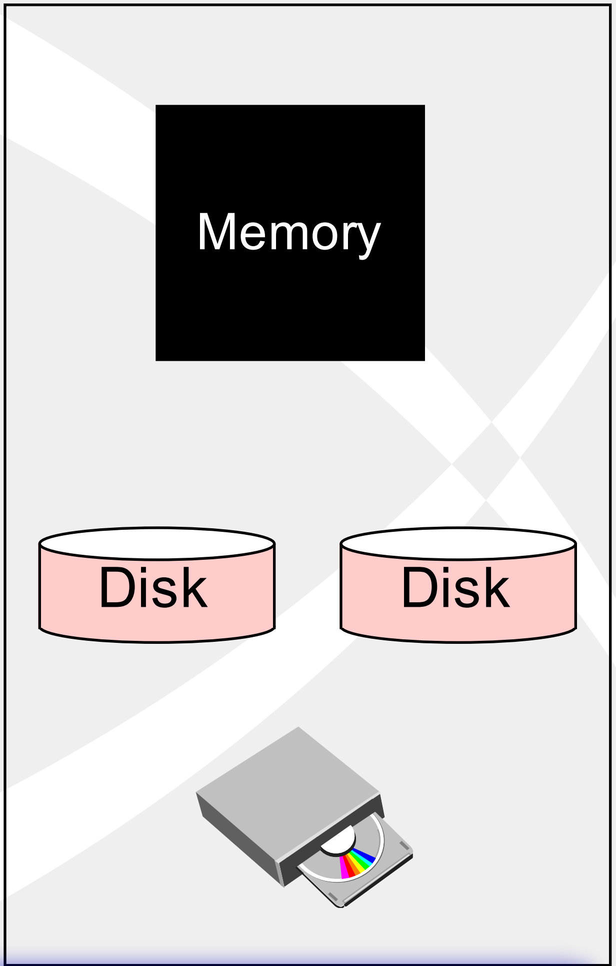
Hardware



Operating System needs to give an easy-to-use abstraction over a complicated collection of hardware components

Files

How does OS manage persistent storage (e.g., disks)?

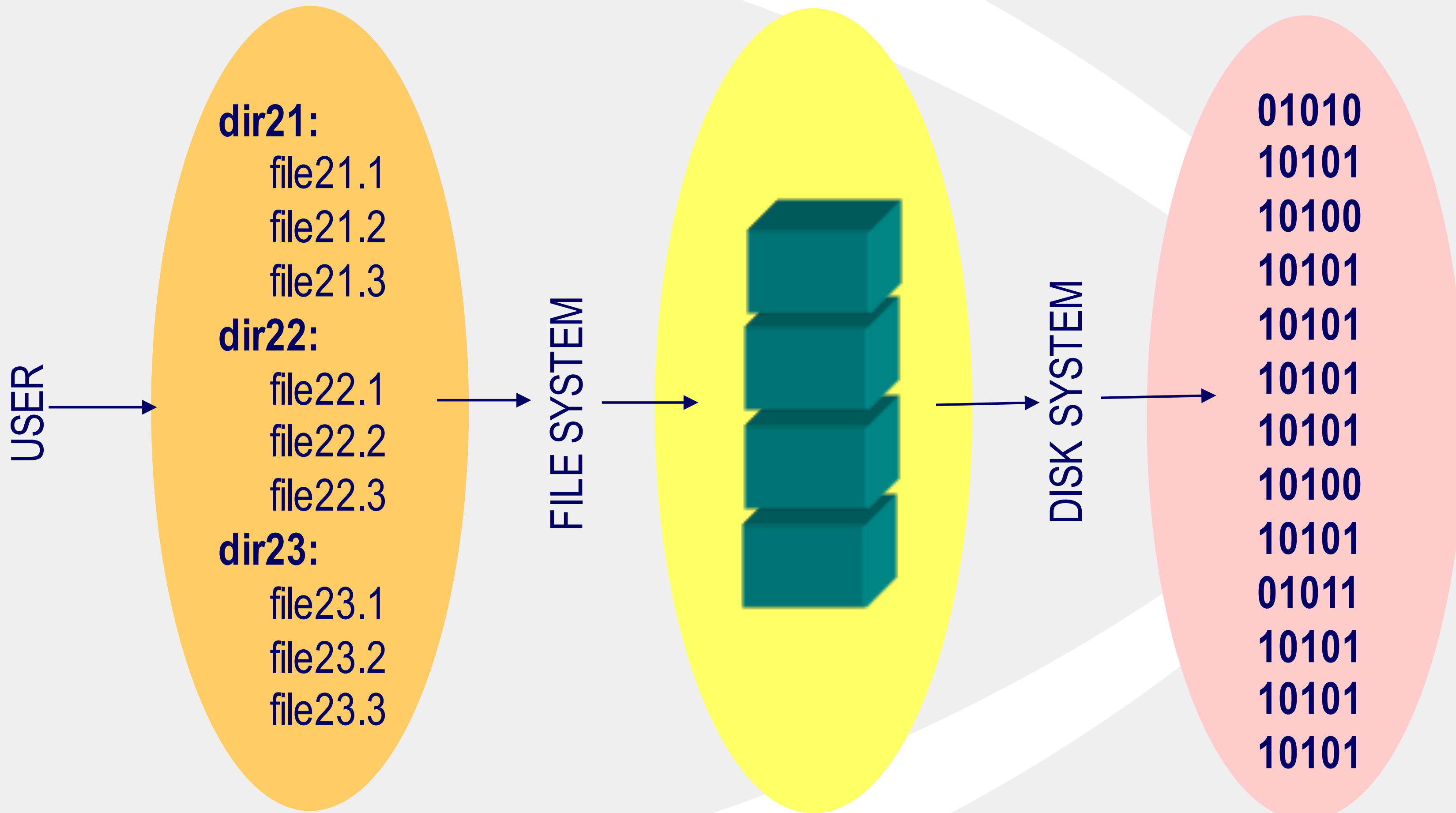


OSes use the File concept to give a familiar way of managing the persistent storage

Storage Management: In Words

- 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)
- 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

Storage Management: In Pictures

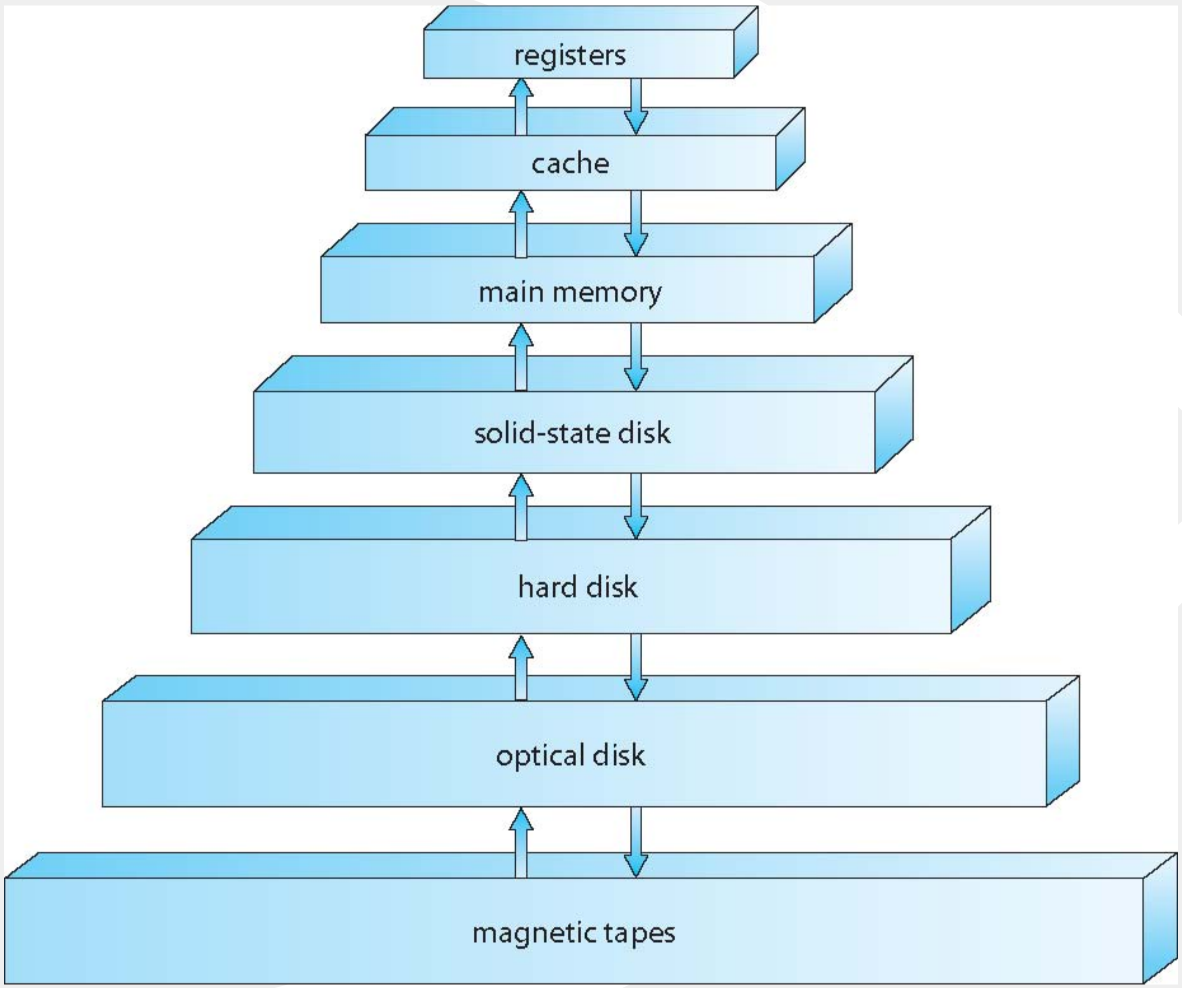


File system based view – content visible as files and directories

Block based view content considered as blocks of data

Physical view – all data just a stream of bits

Storage-Device Hierarchy



Storage Hierarchy

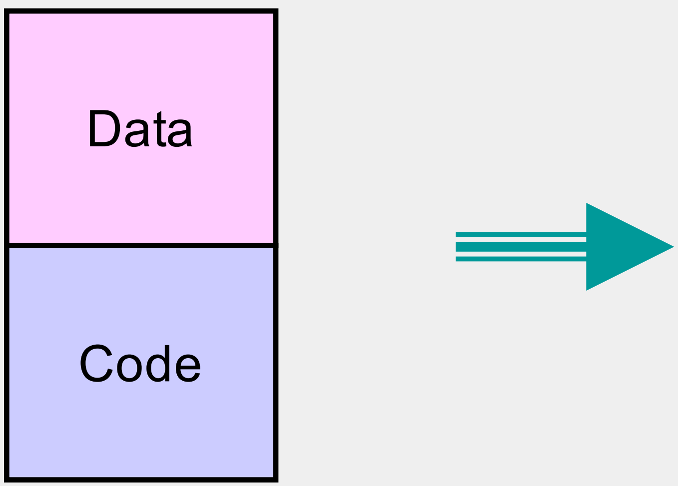
- Storage systems organized in hierarchy
  - Speed
  - Cost
  - Volatility
- **Caching** – copying information into faster storage system; main memory can be viewed as a cache for secondary storage
- **Device Driver** for each device controller to manage I/O
  - Provides uniform interface between controller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

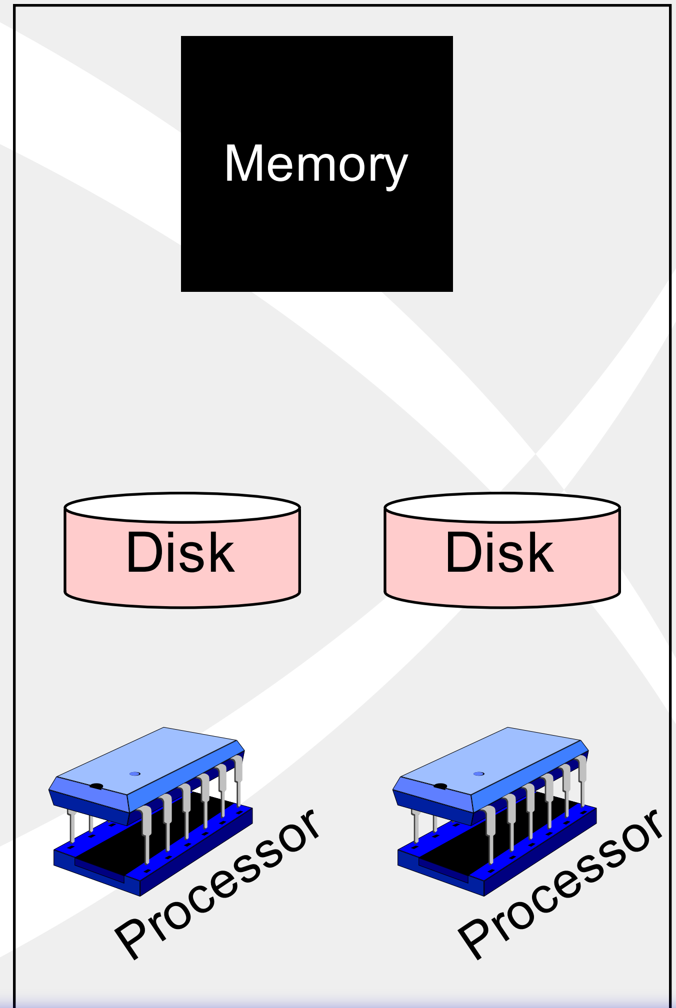
Storage Structure

- 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

Programs

How to load a program?





Programs are made up of Code & Data
Need to load both into memory and make the Code run

Process Management

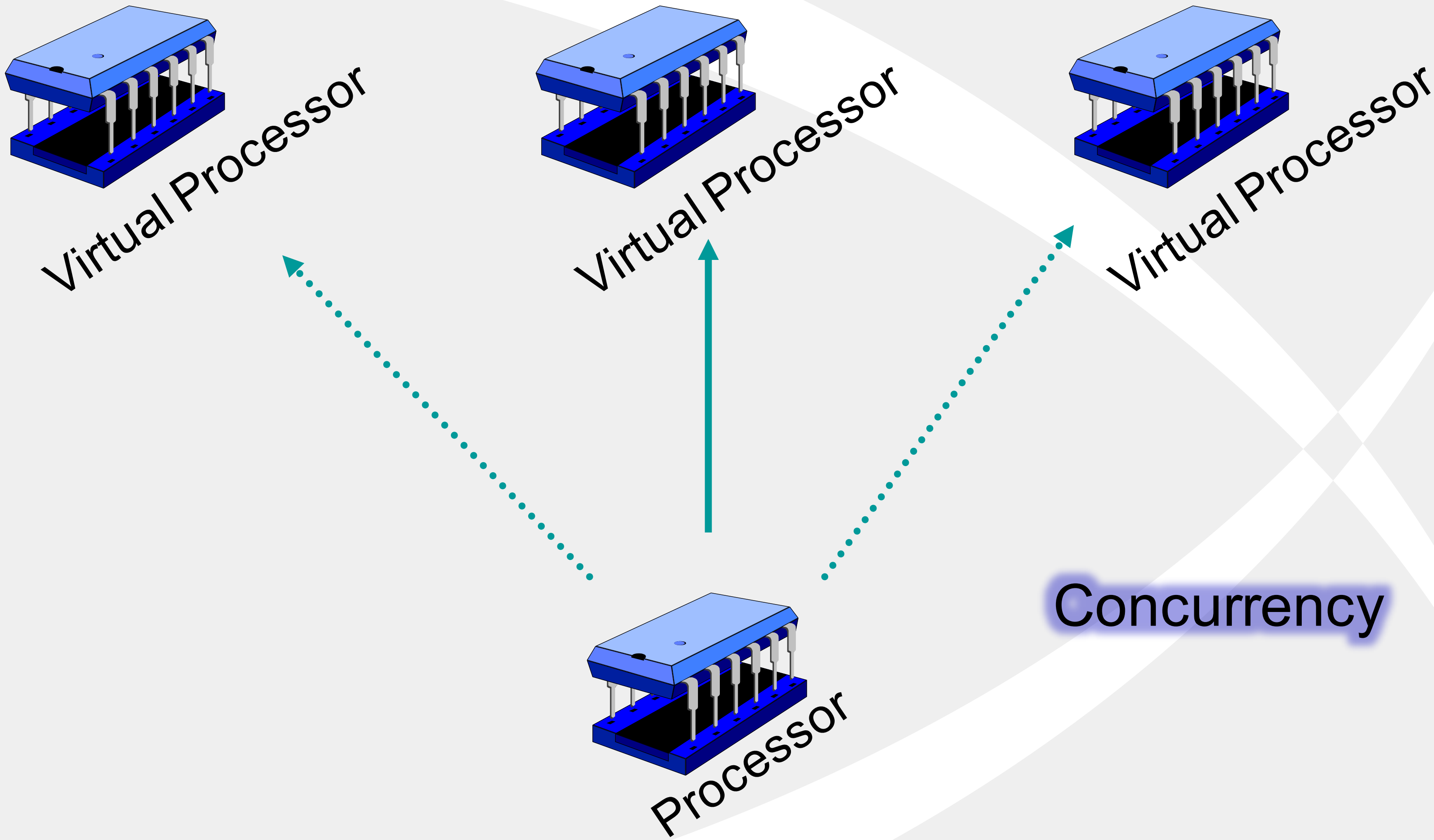
- A process is a program in execution. It is a unit of work within the system. Program is a ***passive entity***, process is an ***active entity***.
- Process needs resources to accomplish its task
  - CPU, memory, I/O, files
  - Initialization data
- Process termination requires reclaim of any reusable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

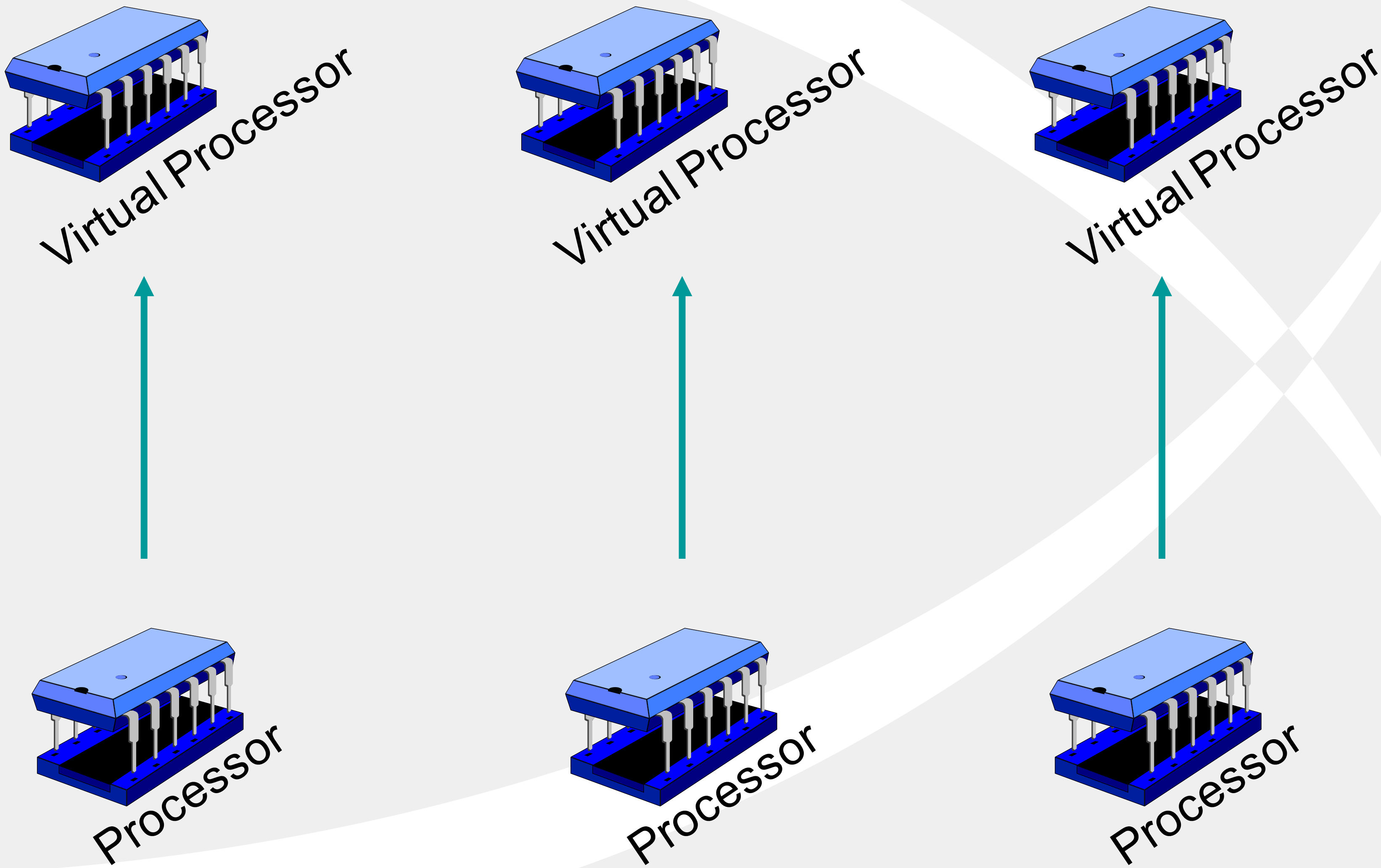
- Creating and deleting both user and system processes
- Suspending and resuming processes
- Providing mechanisms for process synchronization
- Providing mechanisms for process communication
- Providing mechanisms for deadlock handling

Concurrency

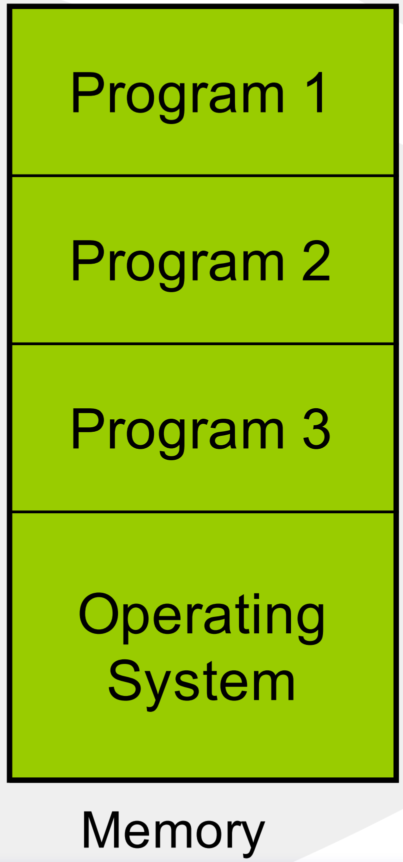


With multiple processes, we can think of each process getting a virtual processor

Parallelism



Memory Sharing



OS needs to share the memory among all the processes that are active so that a process does not corrupt memory belonging to another process

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

Operating System Definition

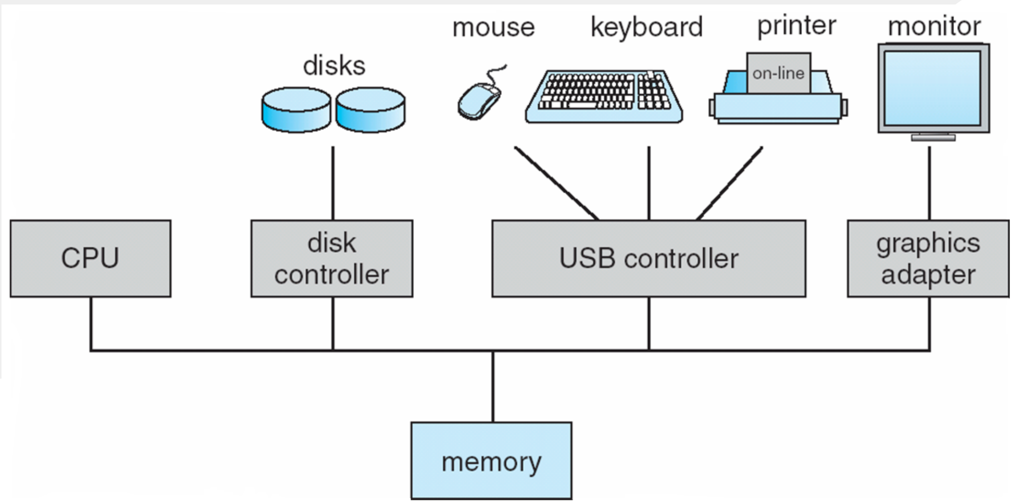
- No universally accepted definition
- “Everything a vendor ships when you order an operating system” is a good approximation
  - But varies wildly
- “The one program running at all times on the computer” is the **kernel**.
- Everything else is either
  - a system program (ships with the operating system)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

Computer 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

Computer System Org.

- 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



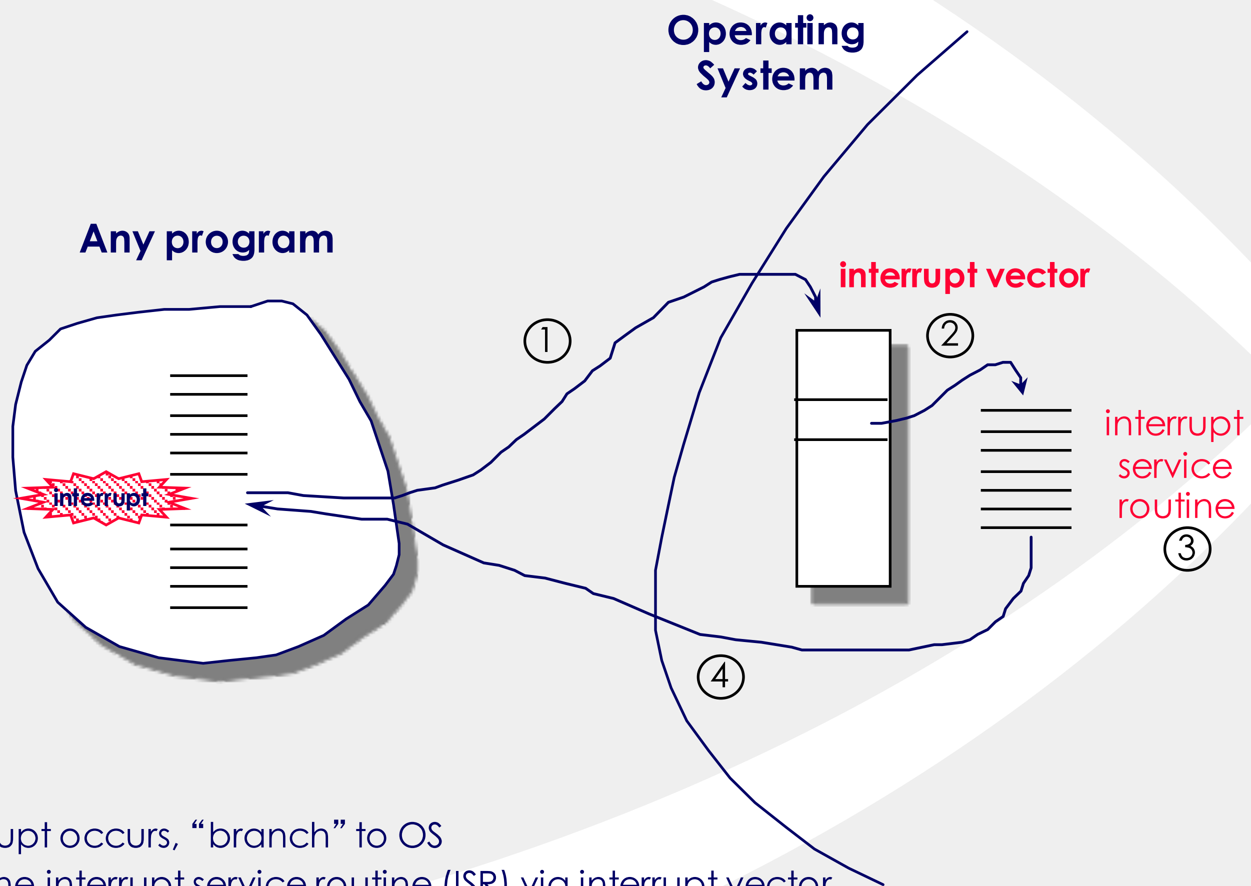
Computer-System Operation

- I/O devices and the CPU can execute concurrently
- 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

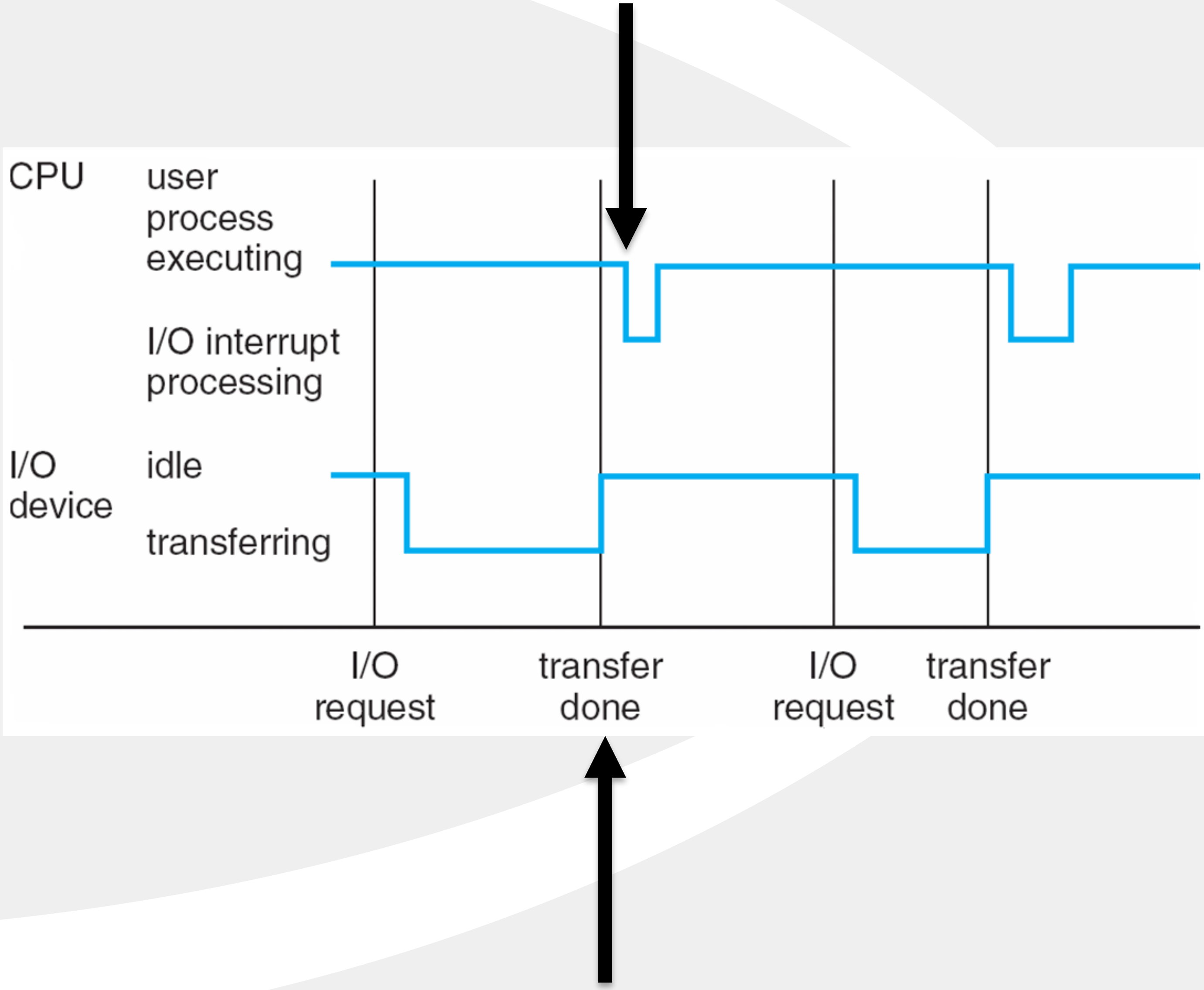
- Interrupt transfers control to the interrupt service routine generally, through the **interrupt vector**, which contains the addresses of all the service routines
- Interrupt architecture must save the address of the interrupted instruction
- A **trap** or **exception** is a software-generated interrupt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

Interrupt Servicing: In Picture

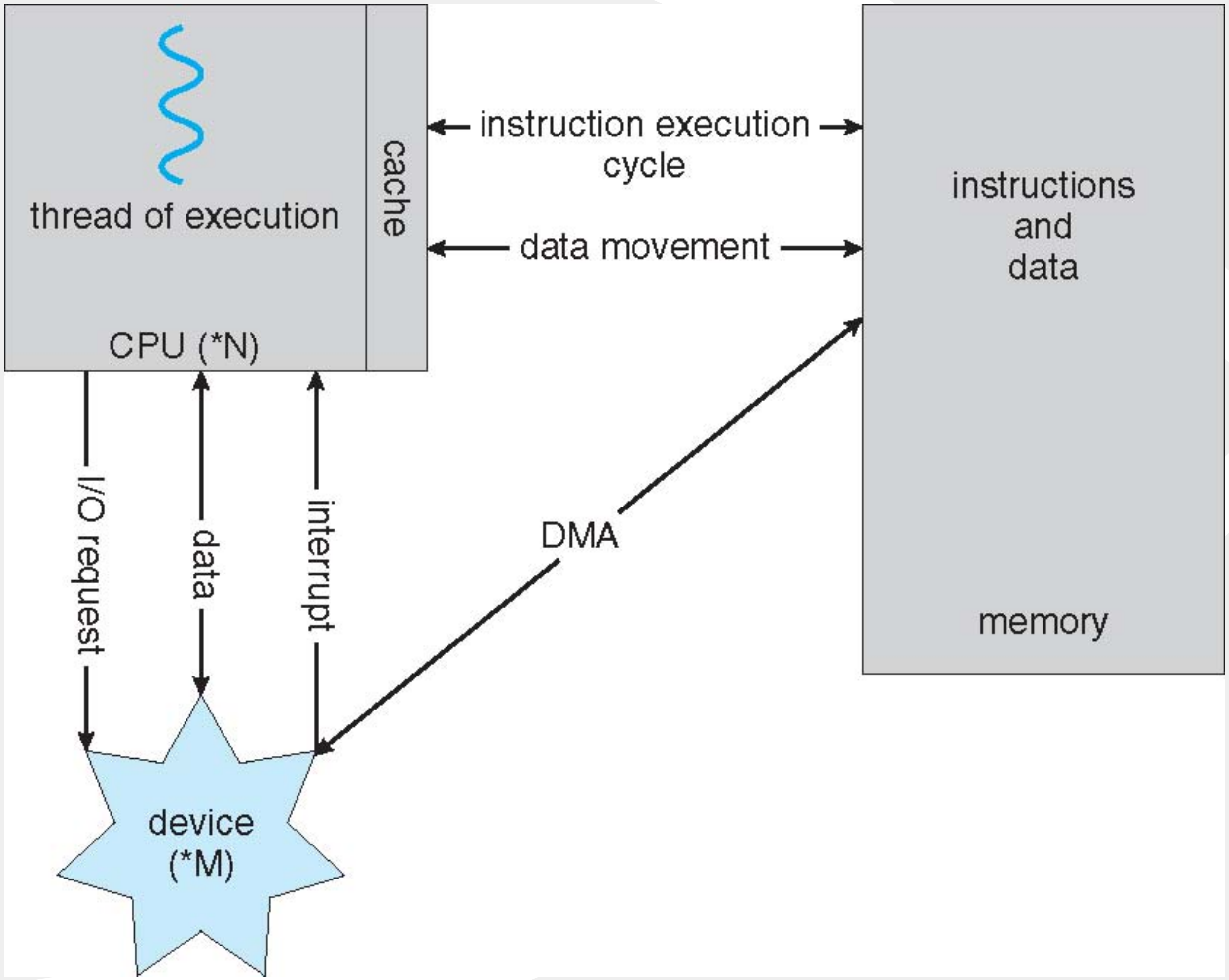


1. An interrupt occurs, "branch" to OS
2. Locate the interrupt service routine (ISR) via interrupt vector
3. Execute the ISR
4. Return to interrupted program

Interrupt Timeline



How a Modern Computer Works

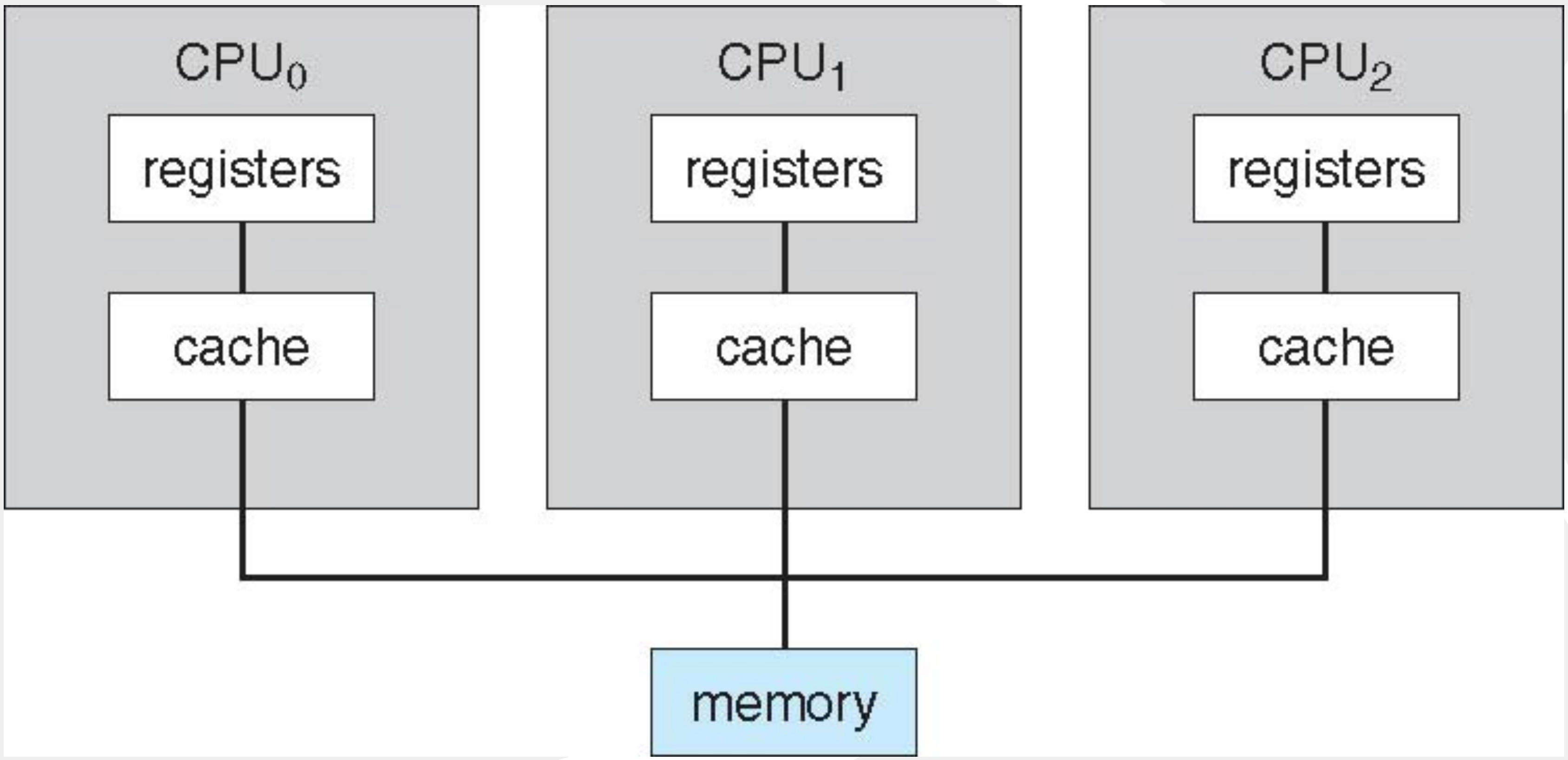


A von Neumann architecture

Computer-System Arch.

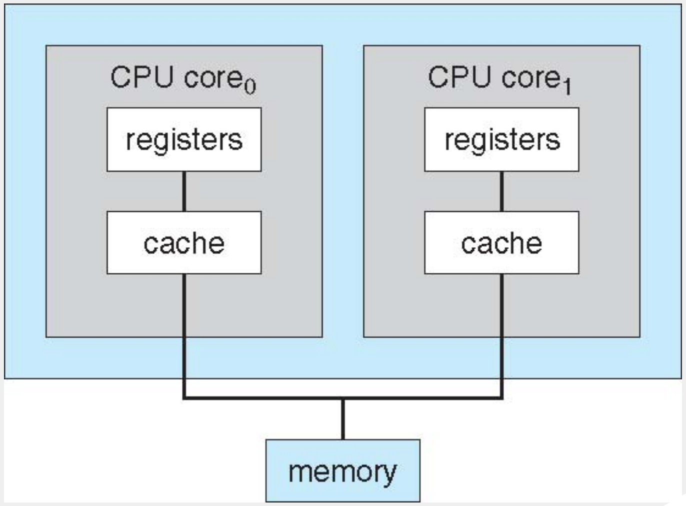
- Started migrating from single processors to multiprocessors (multi-cores are common)
- **Special purpose processors** are also heavily used (e.g., GPUs)
  - Also known as **parallel systems**, **tightly-coupled systems**
  - Advantages include:
    1. **Increased throughput**
    2. **Economy of scale**
    3. **Increased reliability** – graceful degradation or fault tolerance
  - Two types:
    1. **Asymmetric Multiprocessing** – each processor is assigned a specie task.
    2. **Symmetric Multiprocessing** – each processor performs all tasks

Symmetric Multiprocessing Architecture



A Dual-Core Design

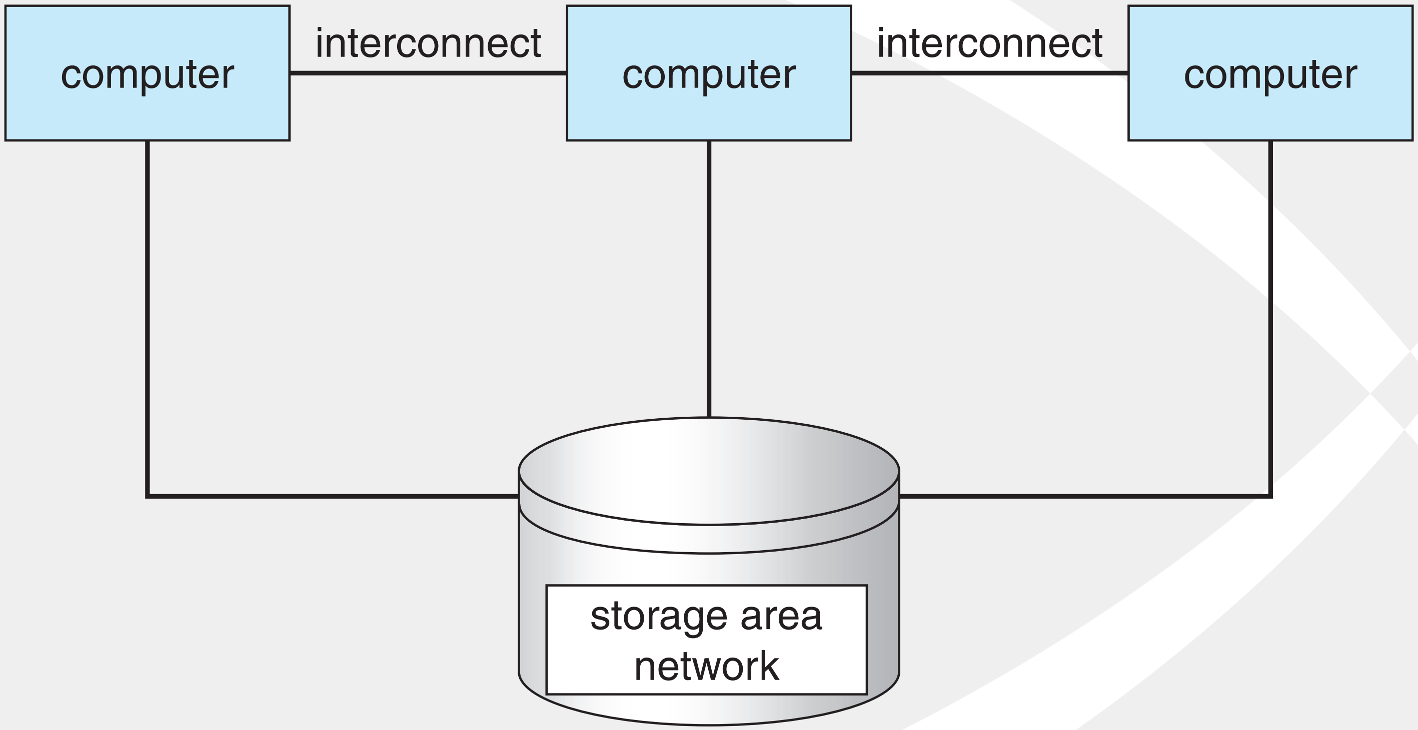
- Multi-chip and **multicore**
- Systems containing all chips
  - Chassis containing multiple separate systems



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

Clustered Systems



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

Operating System Structure

- **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

OS Operations

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

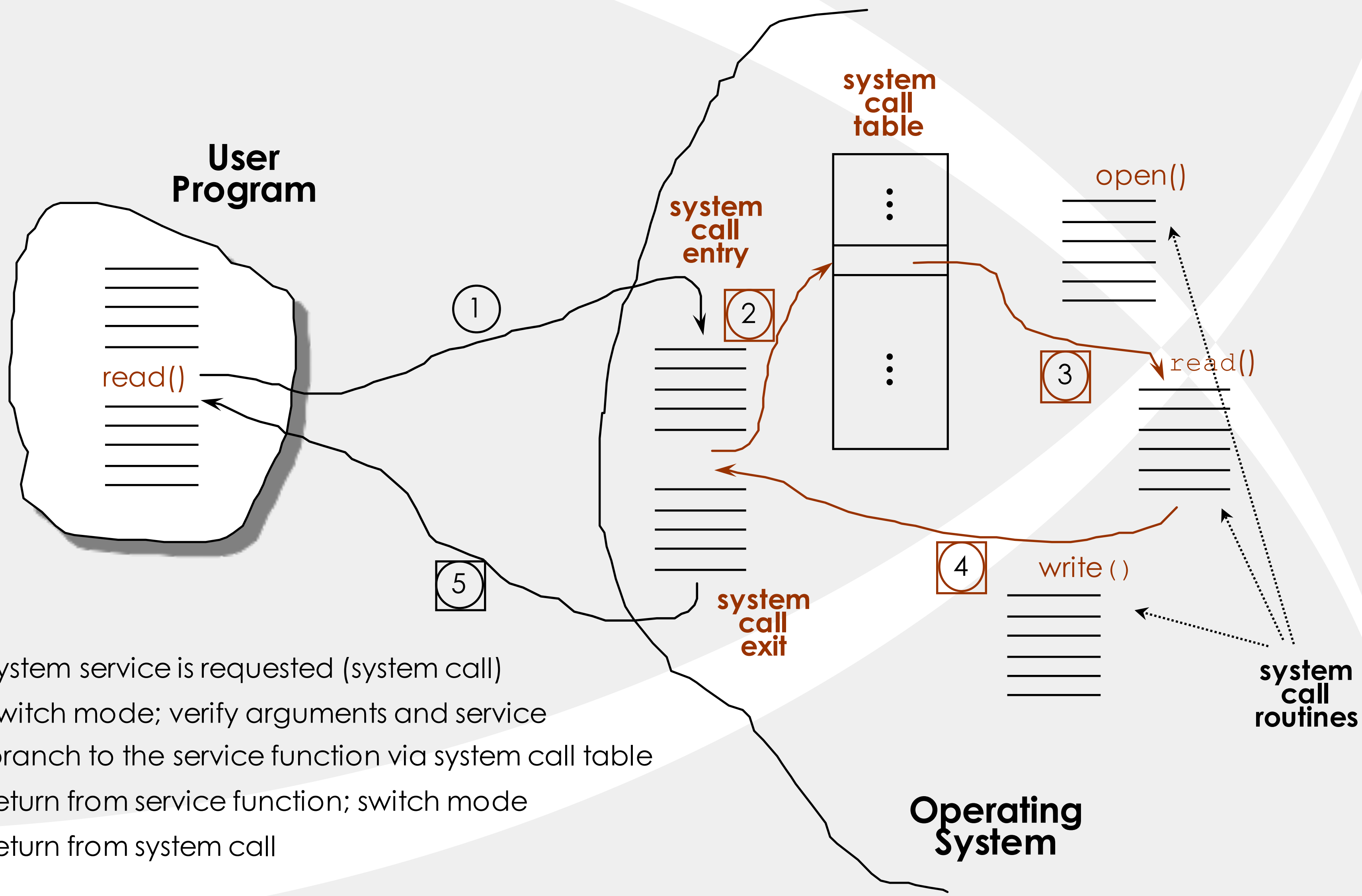
OS Operations (cont.)

- **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**

User to Kernel Mode Transition

- 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

How system call is processed?



1. system service is requested (system call)
2. switch mode; verify arguments and service
3. branch to the service function via system call table
4. return from service function; switch mode
5. return from system call

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 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 – 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

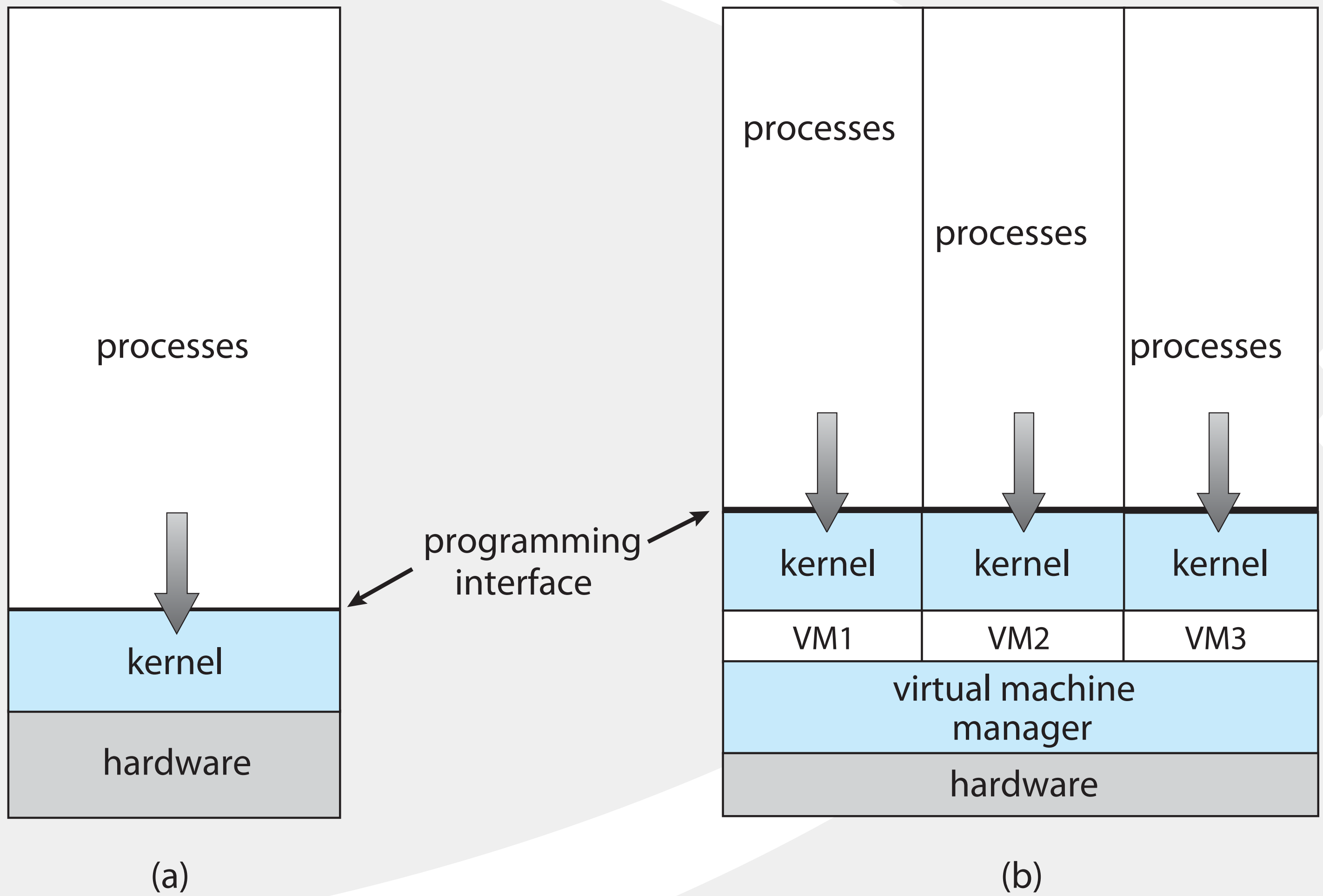
Computing Environments - Virtualization

- 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

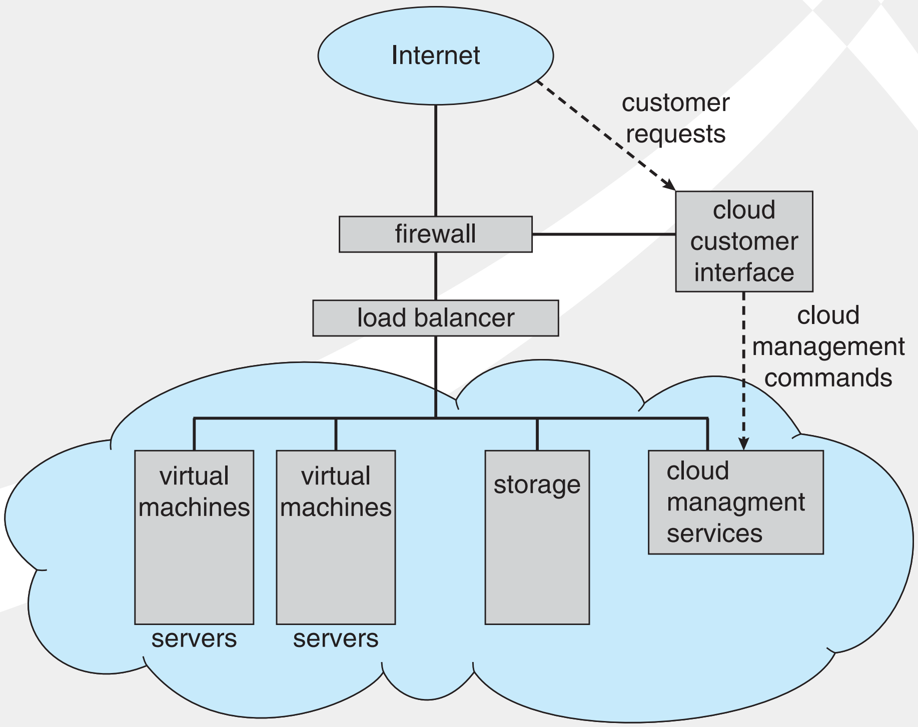


Computing Environments – Cloud Computing

- 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 OSes, 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