OPERATING SYSTEMS

Introduction and Basic Concepts

Why study Operating Systems?

- OS, and its internals, largely influences general functioning, including security and performance.
- Importance of OS choice in an organization is higher and higher. Trend to strategic decision.
- Knowledge fundamental to develop applications when good performance is desired and to understand causes of many problems.

Understanding OS

- Which OS takes advantage better of a given system capabilities?
- Does the OS support all the devices I intend to connect to the computer? If not, what can I do?
- Is it secure enough for the environment it will be integrated in?
- Will my applications run «smoothly» on the chosen OS? How will my concrete workload adapt to the platform?

To make the right choice

- Is it easy to find admins for this OS? Is administration an *obscure* task needing ultra-specialized personnel?
- What support does the OS have? Which is the update publishing rate?
- Besides cost, what future expectations does it have?

Protect your investment

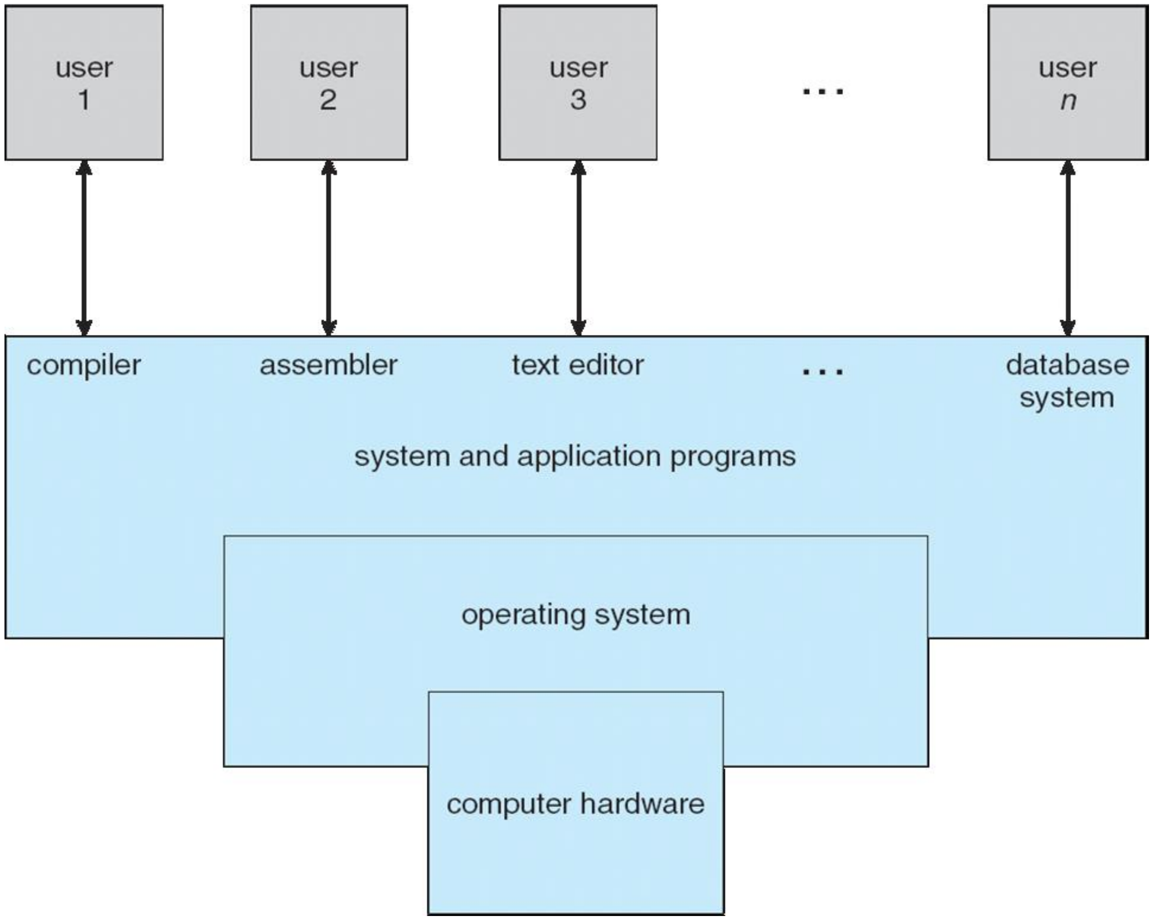
To develop high performance software

- Software needs OS services for may tasks.
  - What services does the OS offer and how do I invoke them?
- To take advantage of new architectures multithreading is essential.
  - How do I develop a multithreaded application for my OS?

An engineer must be

OPERATING SYSTEM AGNOSTIC

Four Components of a Computer System

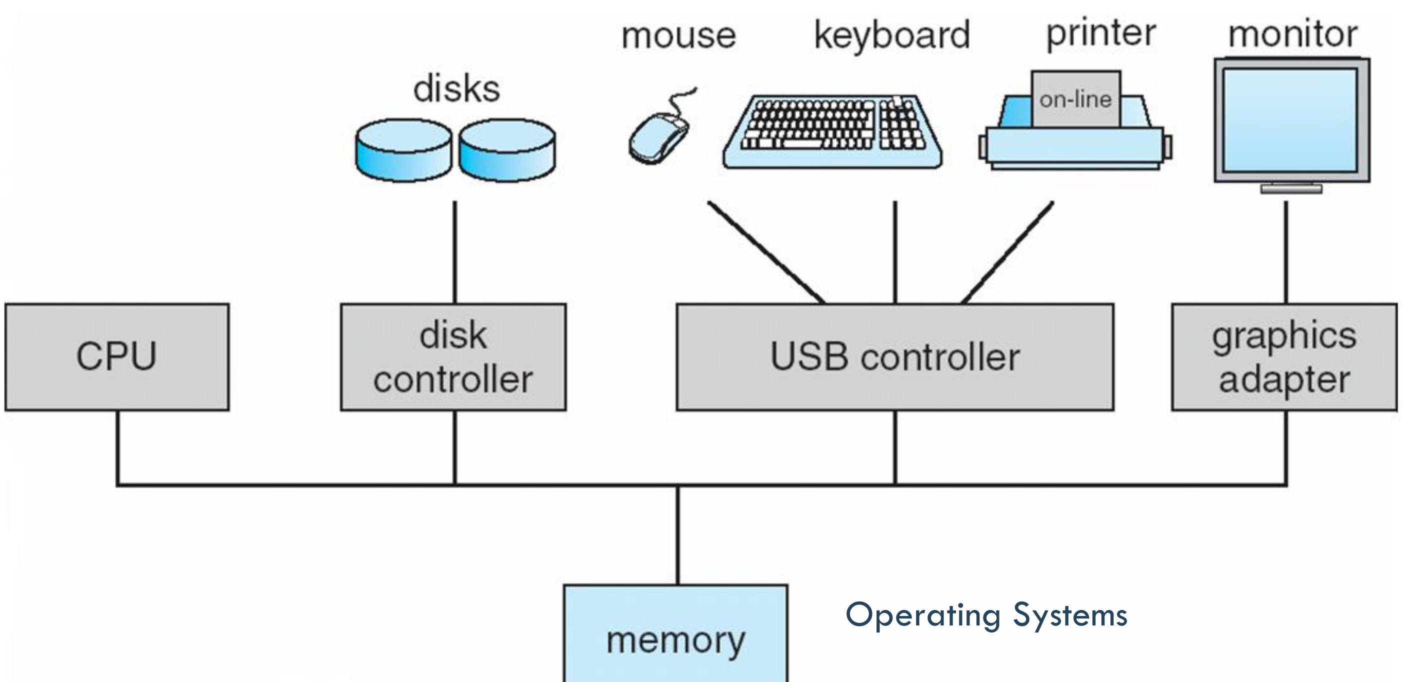


Computer System Structure

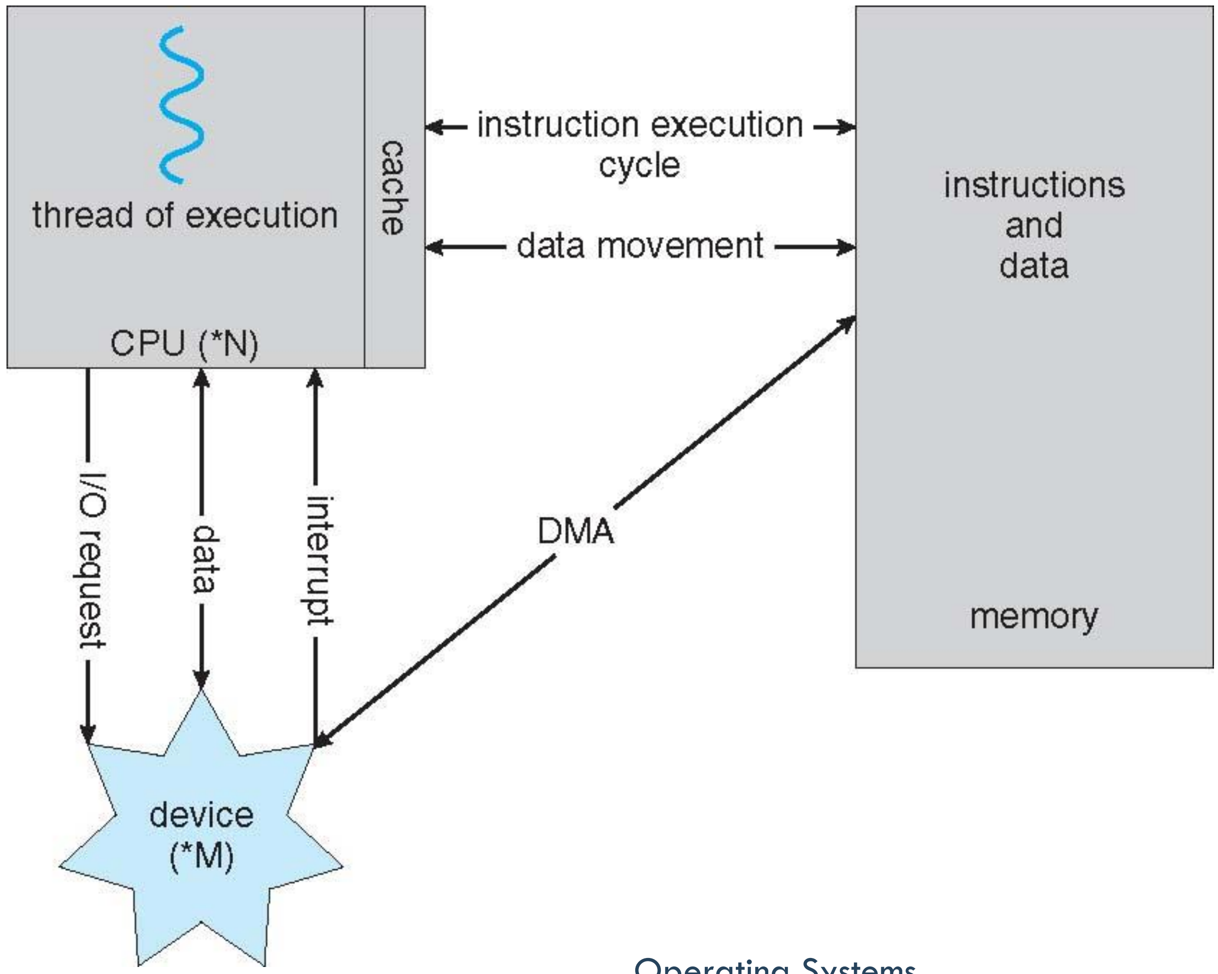
- Computer system can be divided into four components
  - Hardware – provides basic computing resources
    - CPU, memory, I/O devices
  - Operating system
    - Controls and coordinates use of hardware among various applications and users
  - Application programs – define the ways in which the system 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

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



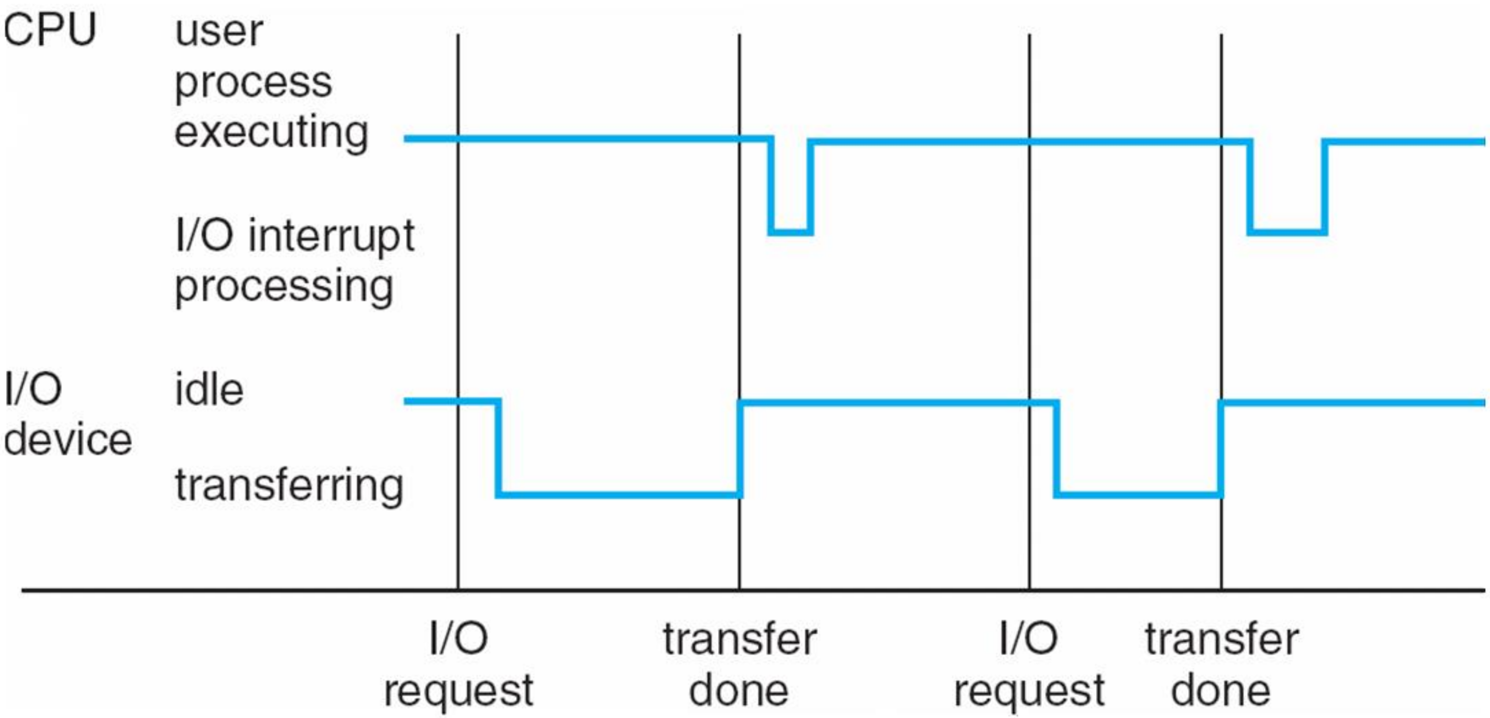
How a Computer Works



Computer-System Operation

- I/O devices and the CPU can be executed **concurrently**
- Each device controller oversees 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 controller's local buffer
- Device controller notifies CPU that has finished its operation by causing an ***interrupt***

Interrupt timeline



Common Functions of Interrupts

- An operating system is **interrupt driven**
- 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
- Incoming interrupts are *disabled* while another interrupt is being processed to prevent a *lost interrupt*
- A ***trap*** (also called **software interrupt**) is a software-generated interrupt caused either by an error or a user request

Interrupt Handling

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

I/O Structure

- **System call** – request to the operating system

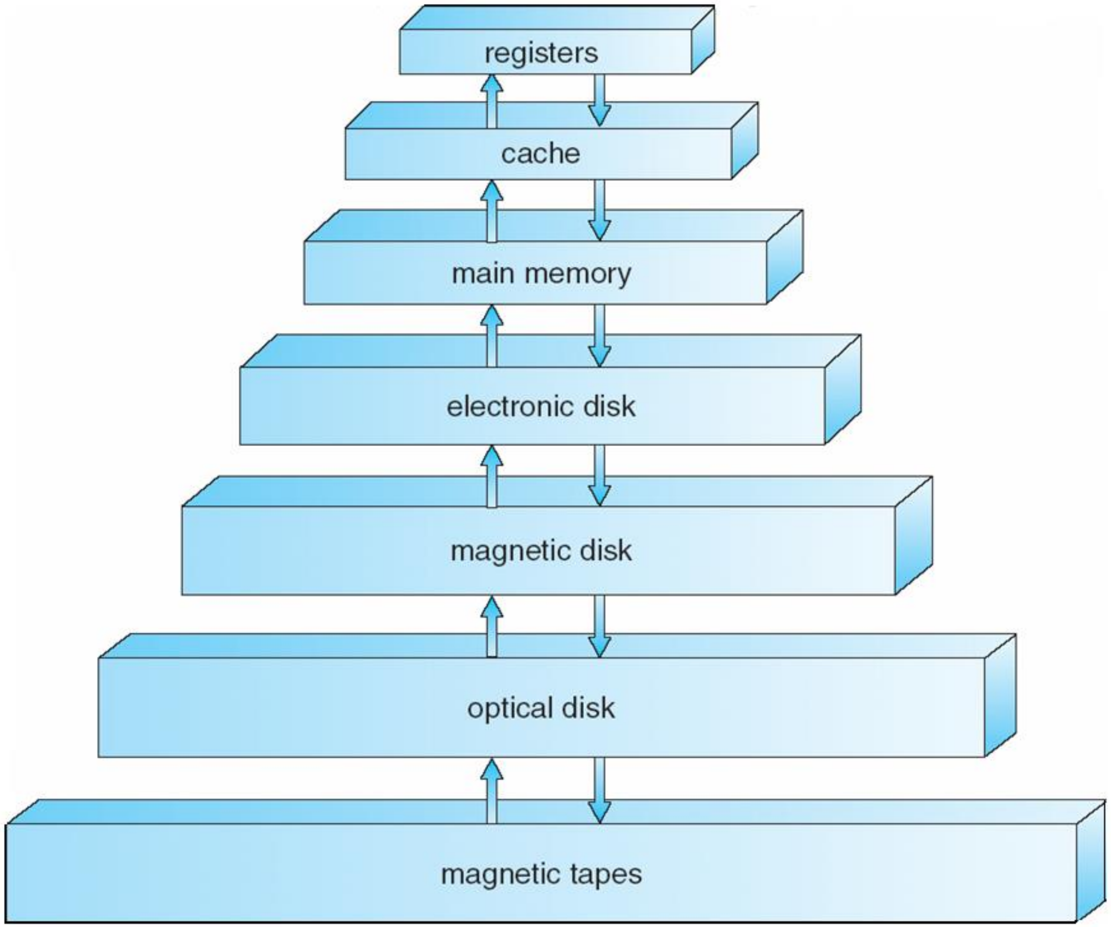
- After I/O starts (by means of a system call), control returns to user program only upon I/O completion
  - Wait instruction idles the CPU until the next interrupt
  - Wait loop (contention for memory access)
  - Only one I/O request is outstanding at a time, no simultaneous I/O is allowed

- **Device-status table** contains entry for each I/O device indicating its type, address, and state
  - Operating system indexes into I/O device table to determine device status and to modify table entry to include interrupt

Direct Memory Access

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

Storage-Device Hierarchy



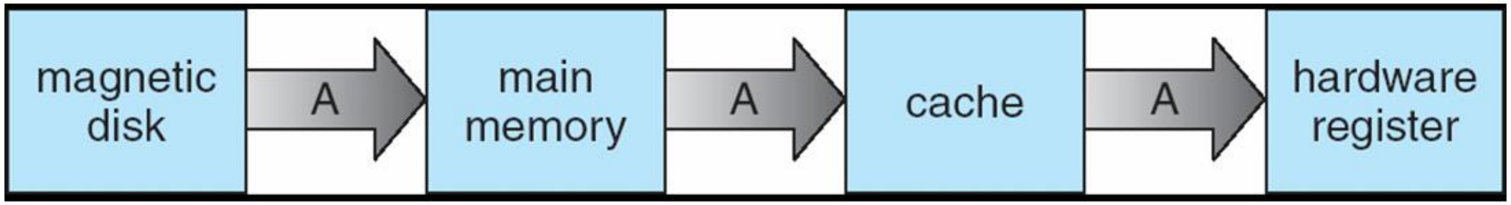
Performance of Various Levels of Storage

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

Level	1	2	3	4
Name	registers	cache	main memory	disk storage
Typical size	< 1 KB	> 16 MB	> 16 GB	> 100 GB
Implementation technology	custom memory with multiple ports, CMOS	on-chip or off-chip CMOS SRAM	CMOS DRAM	magnetic disk
Access time (ns)	0.25 – 0.5	0.5 – 25	80 – 250	5,000.000
Bandwidth (MB/sec)	20,000 – 100,000	5000 – 10,000	1000 – 5000	20 – 150
Managed by	compiler	hardware	operating system	operating system
Backed by	cache	main memory	disk	CD or tape

Migration of Integer A from Disk to Register

- **Multitasking environments**: several processes/threads sharing data.
  - Must provide the last recent changed value, no matter where it is stored in the storage hierarchy



- Cache coherency ensured that the most recent value is accessed
  - Hardware support

Storage Structure

- Main memory: large storage are that the CPU can directly access
- 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

Storage Hierarchy

- Storage systems hierarchically organized
  - Speed
  - Cost
  - Volatility
- **Caching** – copying information into faster storage system
  - main memory can be viewed as a last *cache* for secondary storage

Caching

- Important principle, performed at many levels in a computer (in hardware, operating system, software)
- Information in use copied from slower to faster storage temporarily
- Faster storage (cache) accessed first:
  - If present, 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

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

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 the programs execution to prevent errors and improper use of the computer

Operating System Definition (Cont)

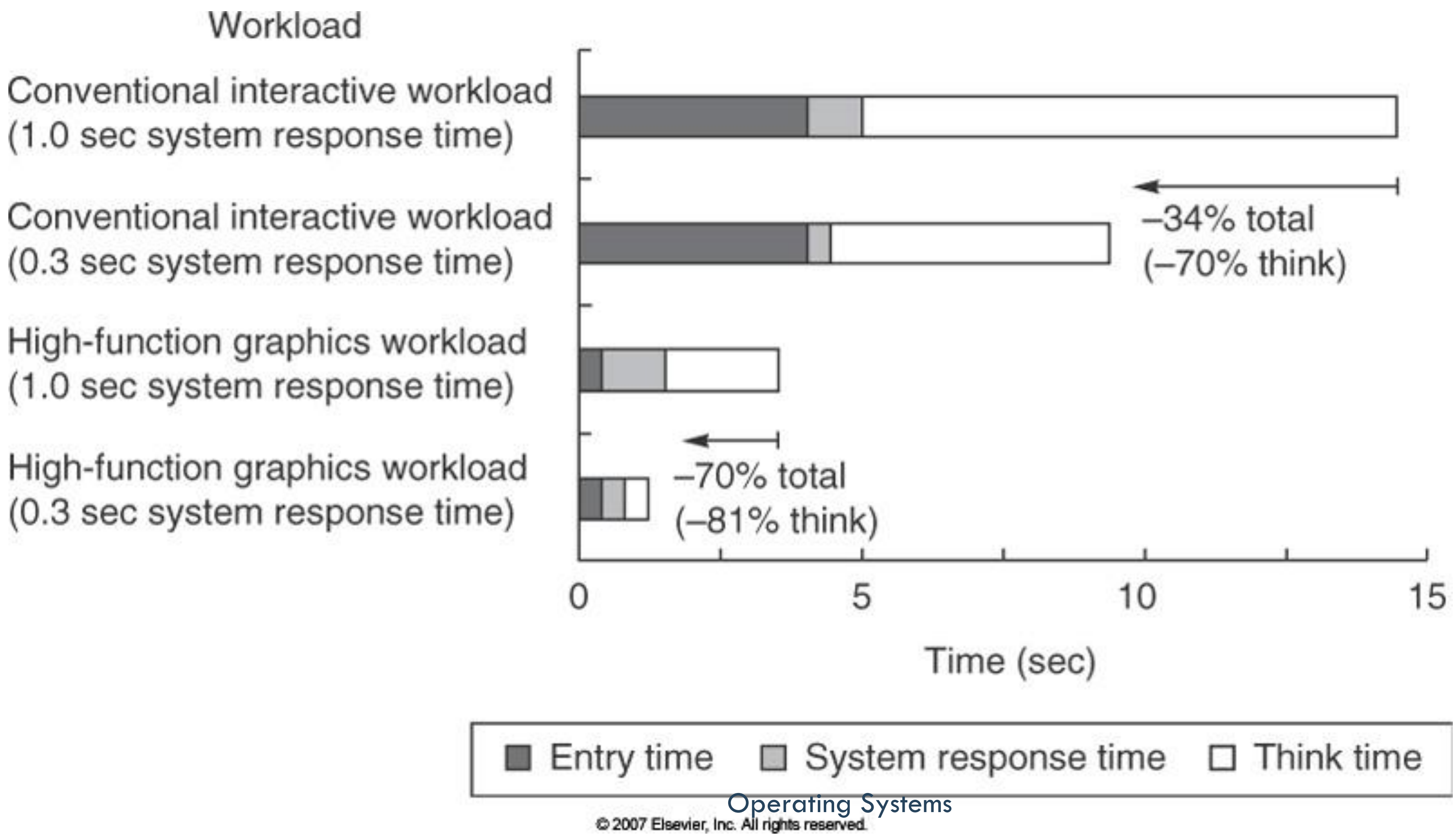
- No universally accepted definition
- *"Everything a vendor ships when you order an operating system"* is good approximation
  - But varies wildly
- *"The program running at all the time on the computer" is the **kernel**. Everything else is either a system program (ships with the operating system)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

Operating System Structure

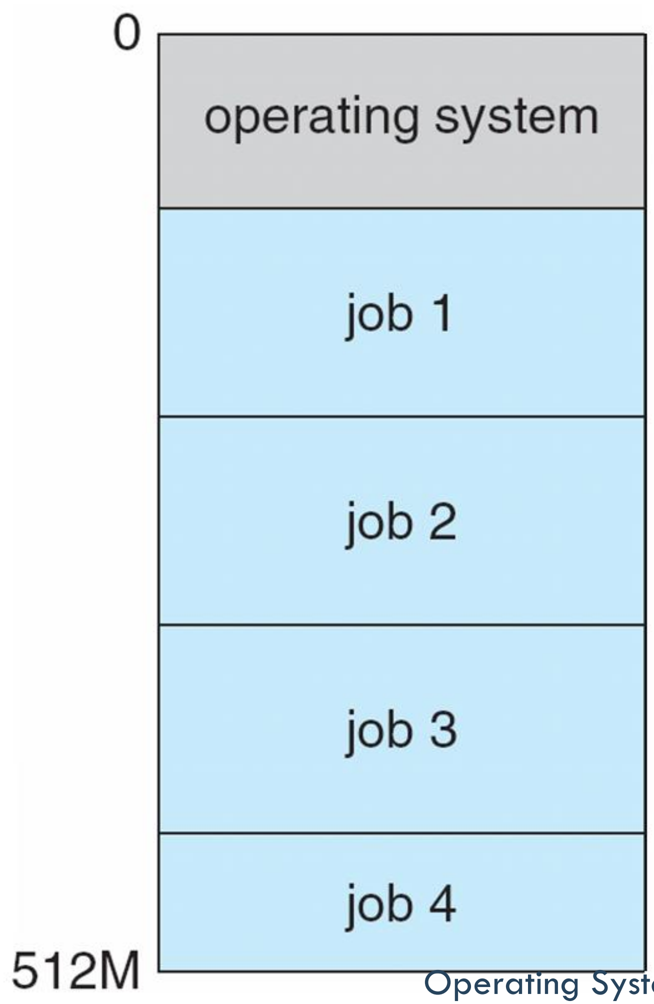
- **Multiprogramming** needed for efficiency
  - Single program cannot keep CPU and I/O devices busy at all times
  - Multiprogramming organizes jobs (code and data) so CPU always has a program to execute
  - A subset of total jobs in system is kept in memory
  - One job selected and run via **job scheduling**
  - 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 from memory
  - **Virtual memory** allows execution of processes not completely in memory

Response time



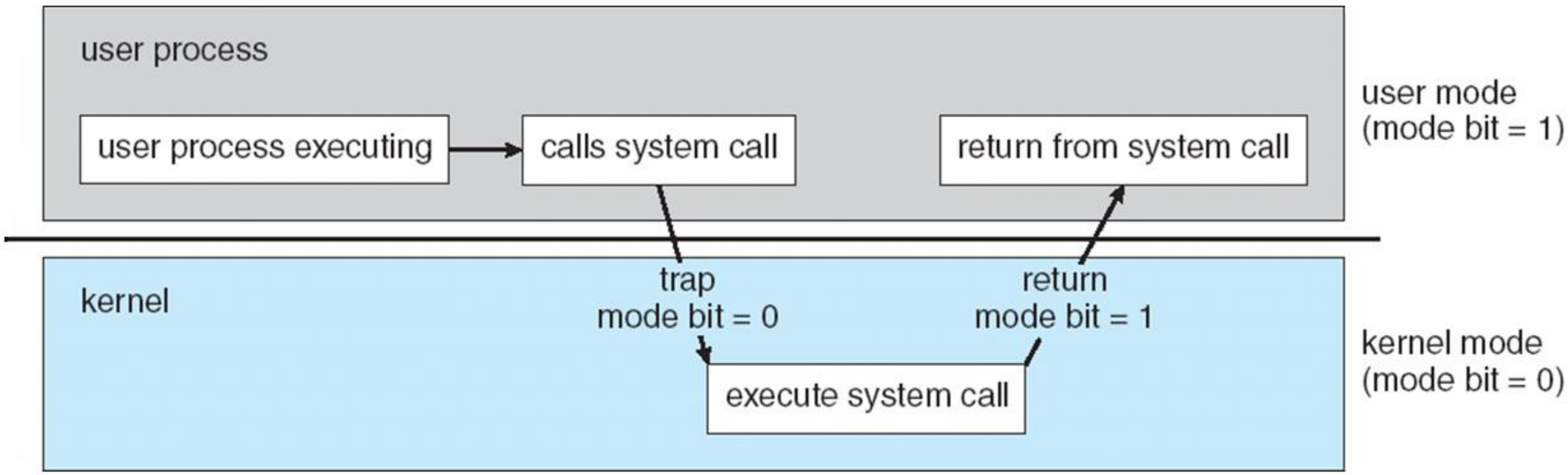
Memory Layout for Multiprogrammed Systems



Operating-System Operations

- Interrupt driven by hardware
  - Software error or requests creates **exceptions** or **traps**
    - Division by zero, request for operating system service
  - Other process problems include deadlocks, 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

Transition from User to Kernel Mode



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, a system has many processes, some users, 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

- All data in memory used by the programs
- All instructions in memory ready to execute
- 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)

- **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
    - Backing up files onto stable (non-volatile) storage media

Mass-Storage Management

- 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 needs not be fast
  - Tertiary storage includes optical storage, magnetic tape
  - Still must be managed
  - Varies between WORM (write-once, read-many-times) and RW (read-write)

I/O Subsystem

- One purpose of OS is to hide peculiarities 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 (the overlapping of output of one job with input of other jobs)
  - General device-driver interface
  - Drivers for specific hardware devices

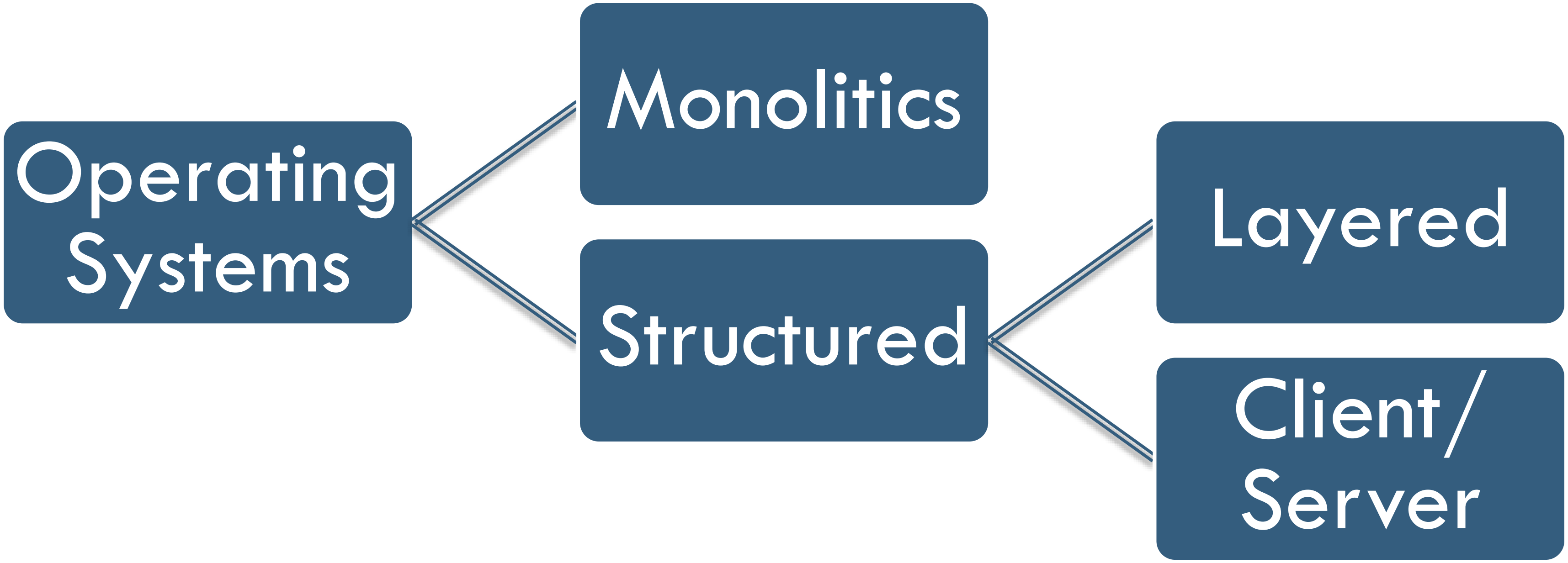
Protection and Security

- **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

Conceptual structure

- Execution modes:
  - **User mode**: executes user processes.
  - **Kernel mode**: executes the OS kernel.
- Processes and OS use separate memory spaces.
- When a process needs a service, it requests it to the OS through a system call.
  - The Operating System enters execution to perform requested function.

Structure

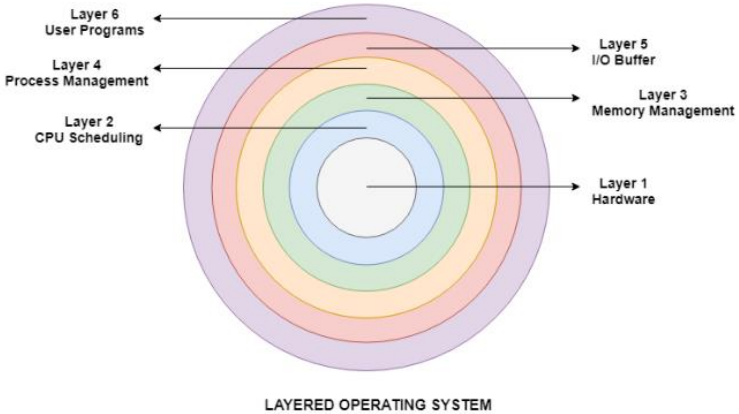

Operating Systems
Monolitics
Structured
Layered
Client/
Server

Monolitic OS

- No clear or well defined structure.
- All the OS code linked into a single executable running in kernel mode.
  - Single address space.
  - No data hiding among modules.
- More efficient at the cost of very complex development and maintenance.
- Examples:
  - All OS until ’80, including UNIX.
  - MS-DOS y current UNIX variants: Solaris, Linux, AIX, HP-UX,...

Layered OS

- Organization as a set of layers with clear and well defined interfaces.
- Each layer on top of lower layer.
- Advantages:
  - Modularity.
  - Data hiding.
  - Better development and debugging.



- Less efficient due to need to cross many layers to perform an operation.
- Difficult to distribute OS functions into layers.
- Examples:
  - Windows NT
  - THE
  - OS/2

Client/Server approach

- Most services as user processes with a small amount of functionality into a **microkernel.**
- Advantages:
  - Very flexible. Each server can be developed and debugged in isolation.
  - Easily extensible to a distributed model
- Drawbacks:
  - Overhead in services execution.
- Examples:
  - Minix y Amoeba (Tanenbaum)
  - Mac OS and Windows NT.
    - Services executed in kernel space for performance reasons.

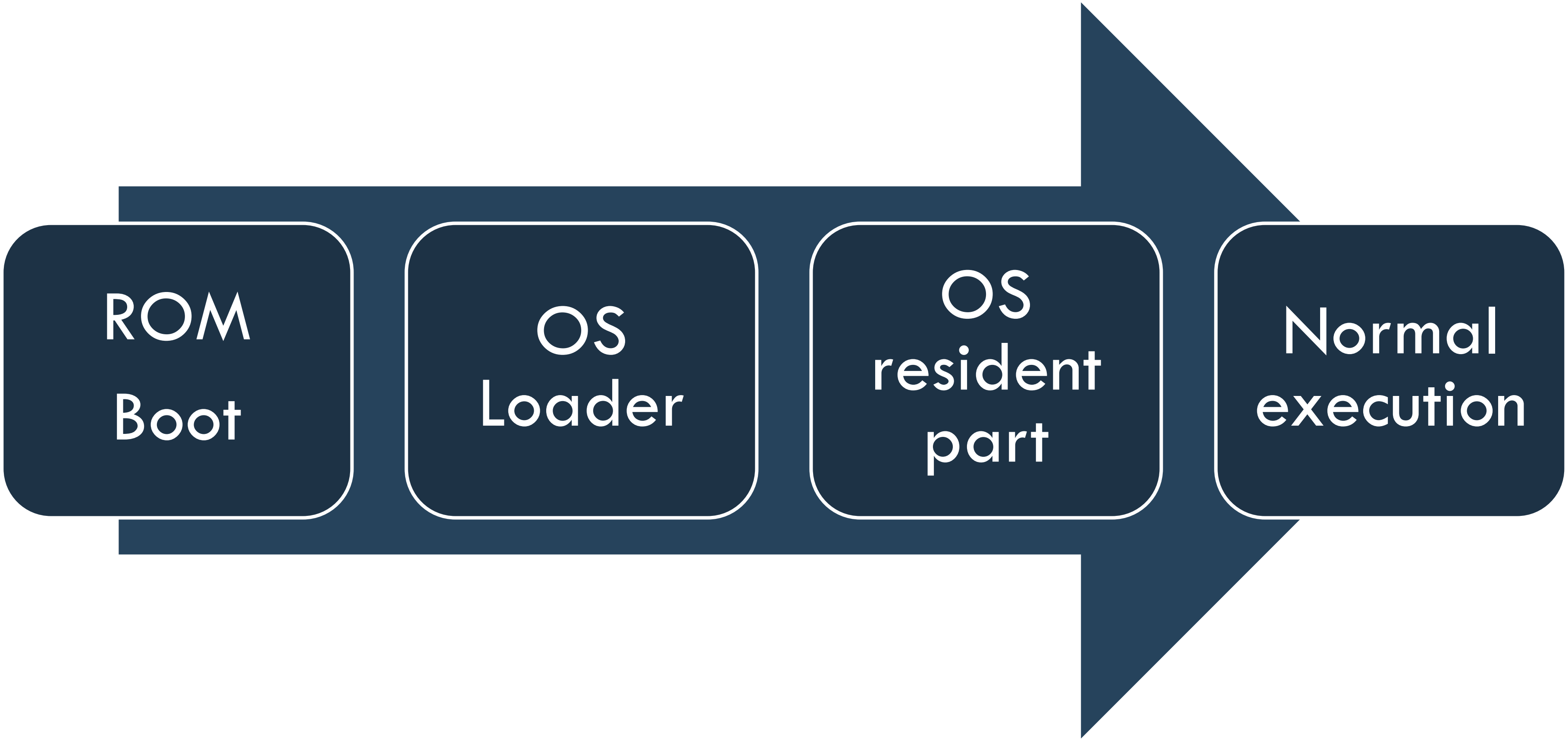
Classifications

- Number of processes:
  - Single-Task.
  - Multitaks.
- Interaction Mode:
  - Interactive.
  - Batch.
- Number of users:
  - Monouser.
  - Multiuser.
- Number of processors:
  - Monoprocessor.
  - Multiprocessor.
- Trheading:
  - *Monothread.*
  - *Multithread.*
- uses:
  - Client.
  - Server.
  - Embedded.
  - Real-Time.

OS startup

- OS starts up whe computer is switched on.
  - Initially in secondary storage.
  - How does it come to main memory?
  - How does it start execution after being loaded?

Phases



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

ROM boot

- RESET signal loads predefined values in registers.
  - PC: boot address in room boot.

- Start running ROM boot:
  - System hardware test.
  - Load into memory the OS loader.

OS loader

- Program loader is in disk boot sector.
- Responsible for loading the rest of the OS.
- Verifies the magic word in boot sector.

Generating the OS

- OS designed for a complete class of machines with several variants of configurations and many supported devices.
- Need to generate OS copy based on characteristics of specific machine configuration.
- Generation performed during initial installation.

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