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OPERATING SYSTEM CONCEPTS

Chapter 2. Operating-System Structures

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Warm-up

Some History

- 1st Gen, **vacuum tube** (1945-1955) — mainframe: Libraries
  - "OS": a set of libraries of commonly-used functions.
  - One program ran at a time, as controlled by a human operator.
    - » Batch system with a human operator.
- 2nd Gen, **transistor** (1955-1965) — beyond Libraries: + Protection
  - Now suppose a bus replacing the operator.
  - What if an application read from / write to anywhere on disk?
    - » System call + Dual mode
- 3rd Gen, **integrated circuit** (1965-1980) — minicomputer: + Long-term Scheduling
  - Multiprogramming
    - » Batch system with an operating system
- 4th Gen, **large-scale integration** (1980-now) — personal computer (PC): + Short-term Scheduling
  - Timesharing

Objectives

- To describe the services an operating system provides to users, processes, and other systems.
- To discuss the various ways of structuring an operating system.
- To explain how operating systems are installed and customized and how they boot.

Operating System Services

*Functions Helpful to the **User***

- **User interface** — Almost all operating systems have a user interface (UI).
  - Varies between Command-Line (CLI), Graphics User Interface (GUI), Batch.
- **Program execution** — The system must be able to load a program into memory and to run that program, end execution, either normally or abnormally (indicating error).
- **I/O operations** — A running program may require I/O, which may involve a file or an I/O device.
- **File-system manipulation** — The file system is of particular interest. Programs need to read and write files and directories, create and delete them, search them, list file Information, permission management.
- **Communications** — Processes may exchange information, on the same computer or between computers over a network.
- **Error detection** — OS needs to be constantly aware of possible errors.

Operating System Services

*Functions Ensuring Efficient Operation of the **System***

- **Resource allocation** — When multiple users or multiple jobs running concurrently, resources must be allocated to each of them.
  - Many types of resources — CPU cycles, main memory, file storage, I/O devices.
- **Accounting** — To keep track of which users use how much and what kinds of computer resources.
- **Protection** and **security** — The owners of information stored in a multiuser or networked computer system may want to control use of that information, concurrent processes should not interfere with each other.
  - **Protection** involves ensuring that all access to system resources is controlled.
  - **Security** of the system from outsiders requires user authentication, extends to defending external I/O devices from invalid access attempts.

User Operating System Interface

Command Line Interfaces

- Command line interface (CLI) or command interpreter allows direct command entry.
  - Sometimes implemented in kernel, sometimes by systems program.
  - Sometimes multiple flavors implemented — shells.
  - Primarily fetches a command from user and executes it.
  - Sometimes commands built-in, sometimes just names of programs.
    - » If the latter, adding new features doesn't require shell modification.

User Operating System Interface

Graphical User Interfaces

- User-friendly desktop metaphor interface.
  - Usually mouse, keyboard, and monitor.
  - Icons represent files, programs, actions, etc.
  - Various mouse buttons over objects in the interface cause various actions (provide information, options, execute function, open directory (known as a folder).
  - Invented at Xerox PARC.
- Many systems now include both CLI and GUI interfaces.
  - Microsoft Windows is GUI with CLI “command” shell.
  - Apple Mac OS X is “Aqua” GUI interface with UNIX kernel underneath and shells available.
  - Unix and Linux have CLI with optional GUI interfaces (CDE, KDE, GNOME).

User Operating System Interface

Touchscreen Interfaces

- Touchscreen devices require new interfaces.
  - Mouse not possible or not desired.
  - Actions and selection based on gestures.
  - Virtual keyboard for text entry.
- Voice commands.

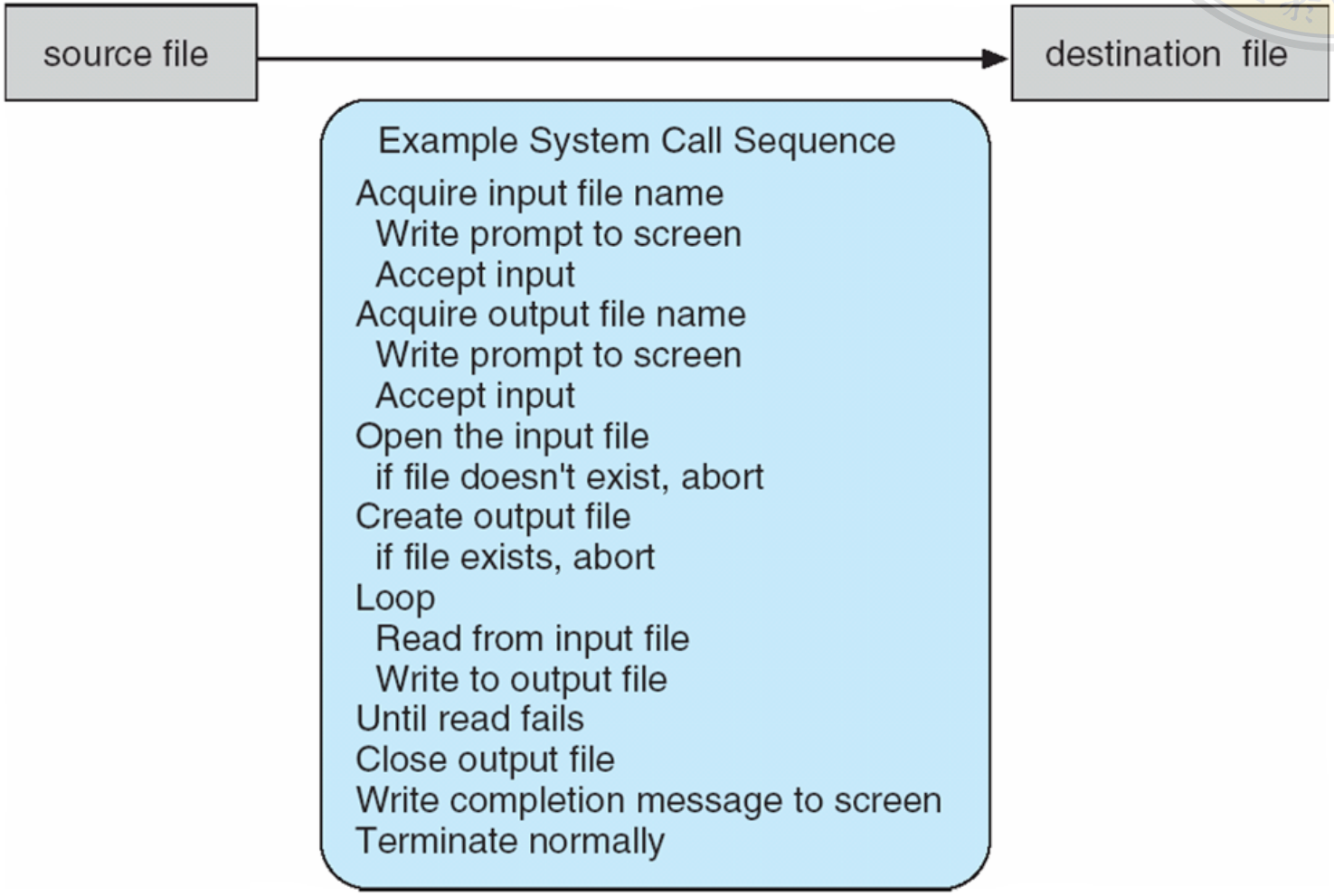
System Calls

- Programming interface to the services provided by the OS.
- Typically written in a high-level language (C or C++).
- Mostly accessed by programs via a high-level Application Programming Interface (API) rather than direct system call use.
- Three most common APIs
  - Win32 API for Windows
  - POSIX API for POSIX-based systems (including virtually all versions of UNIX, Linux, and Mac OS X)
  - Java API for the Java virtual machine (JVM)
- Why do users use procedure calls / APIs rather than system calls?
  - Program portability.
  - System calls are more detailed and difficult to work with.

System Calls

Example of System Calls

System call sequence to copy the contents of one file to another file



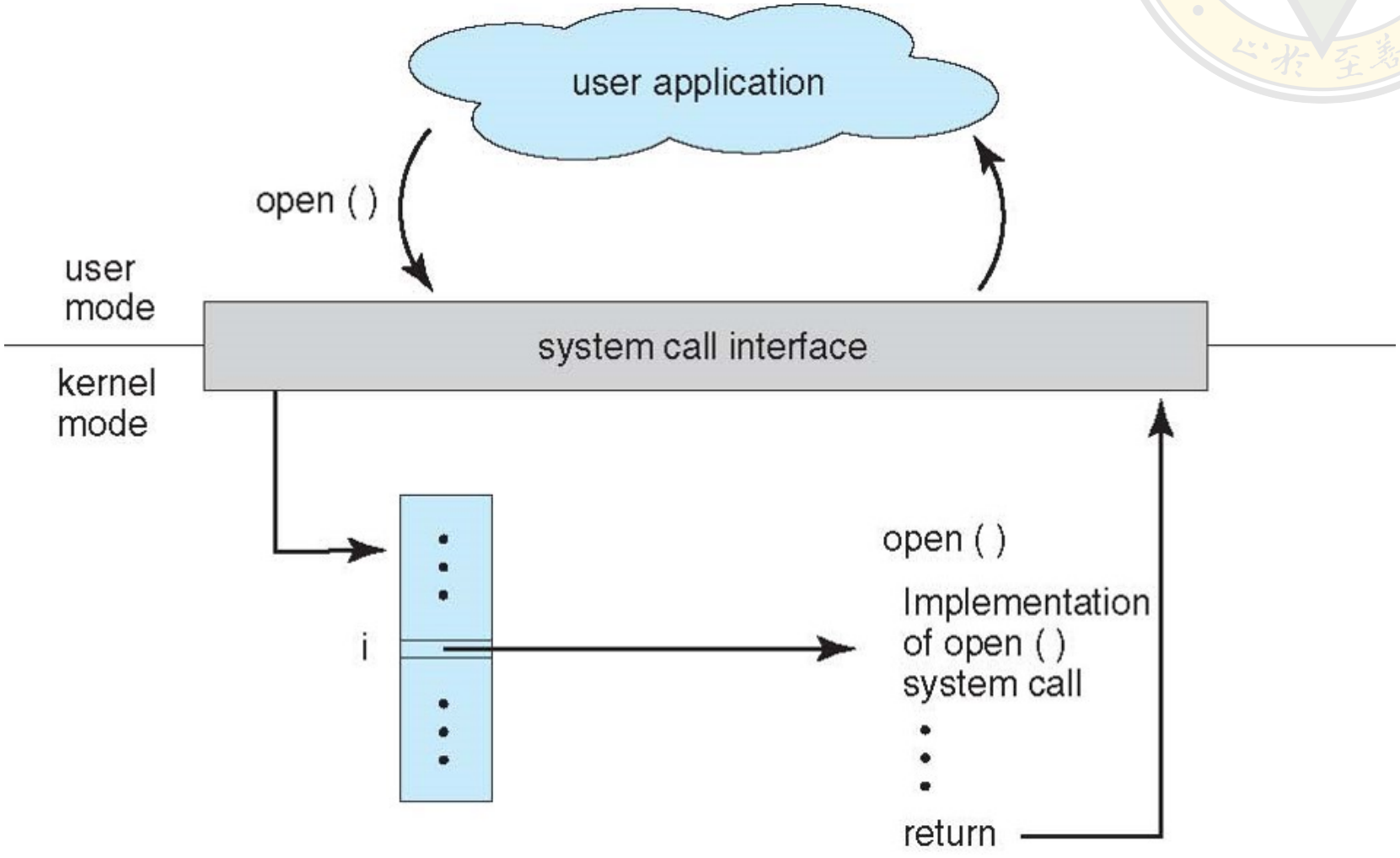
System Calls

System Call Implementation

- Typically, a **number** associated with each system call.
  - **System-call interface** maintains a table indexed according to these numbers.
- The system call interface invokes the intended system call in OS kernel and returns status of the system call and any return values.
- The caller need know nothing about how the system call is implemented.
  - Just needs to obey API and understand what OS will do as a result call.
  - Most details of OS interface hidden from programmer by API.
    - » Managed by run-time support library (set of functions built into libraries included with compiler).

System Calls

API — System Call — OS Relationship



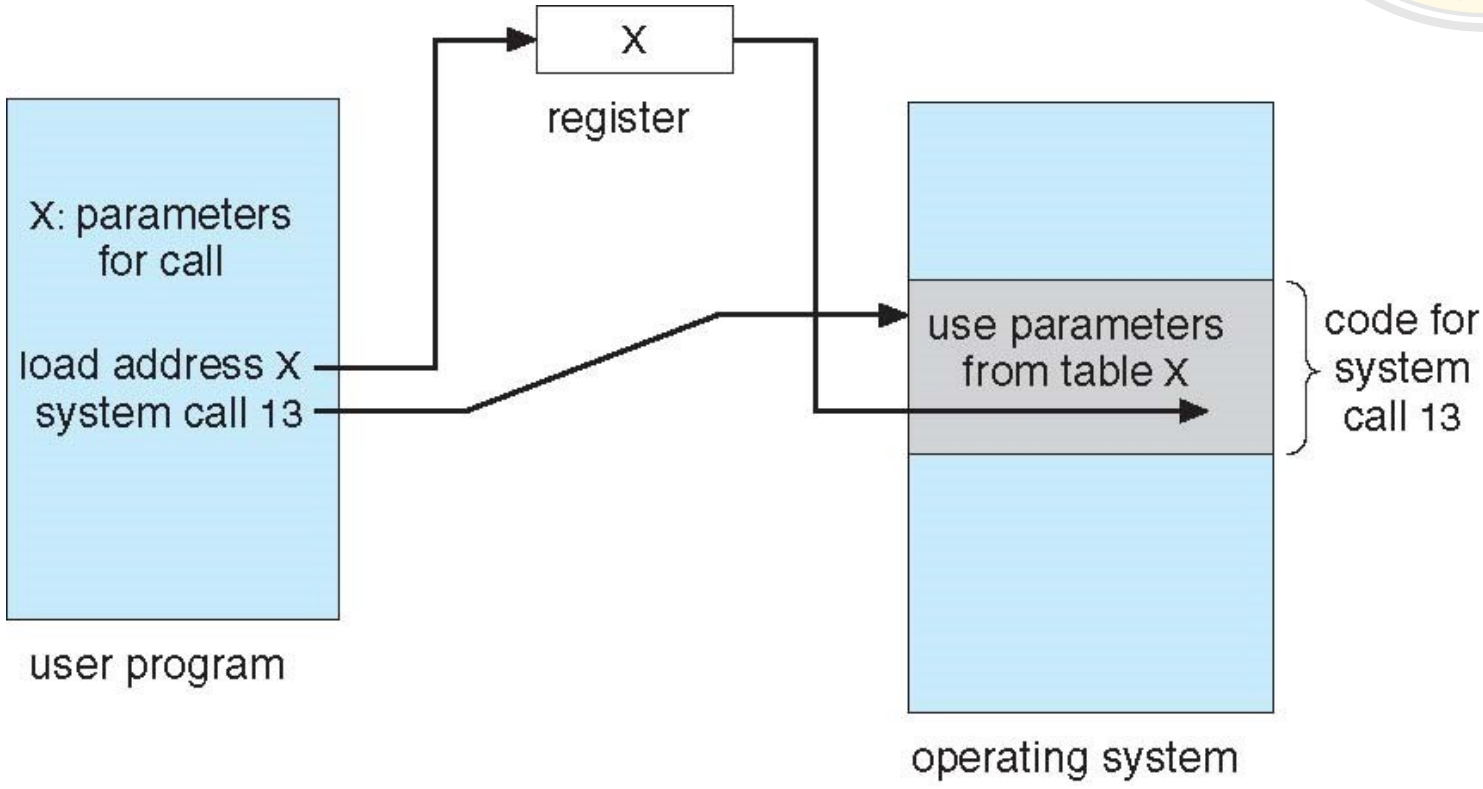
System Calls

System Call Parameter Passing

- Often, more information is required than simply identity of desired system call.
  - Exact type and amount of information vary according to OS and call.
- Three general methods used to pass parameters to the OS.
  1. Simplest: pass the parameters in registers.
     - » In some cases, may be more parameters than registers.
  2. Parameters stored in a block, or table, in memory, and address of block passed as a parameter in a register.
     - » This approach taken by Linux and Solaris.
  3. Parameters placed, or pushed, onto the stack by the program and popped off the stack by the operating system.
  - Block and stack methods do not limit the number or length of parameters being passed.

System Calls

Parameter Passing via Table



System Calls

Motivating System Call

- What should a user process do to perform a privileged operation?
  - **System Calls**
- How to execute a system call?
  - **Trap**, **trap-handler** and **return-from-trap**
- In a trap, which code to run inside the OS?
  - **Trap table** –> **trap-handler**.
- When return-from-trap, how to restore context?
  - Kernel stack for each process.

System Calls

What Happens When the Computer System is Booting?

OS @boot (kernel mode)	**Hardware**
initialize *trap table*	
	remember addresses of ...
	system call handler
	timer handler
	illegal instruction handler
start interrupt timer	
	start timer; interrupt after *X* ms

System Calls

What Happens When the Computer System is Running?

OS @run (kernel mode)	**Hardware**	**Program (user mode)**
to start process *A*:		
return-from-trap (into *A*)		
	move to *user mode*	
		process *A* runs:
		fetch instruction
		execute instruction
		...
		call *system-call*(), via *api trap* into OS
	system call interface	
	move to *kernel mode*	
	jump to *system call handler*	
handle the *trap* (*system call*)		
return-from-trap (into *A*)		
		...

Types of System Calls

Process Control

- create process, terminate process
- end, abort
- load, execute
- get process attributes, set process attributes
- wait for time
- wait event, signal event
- allocate and free memory
- dump memory if error
- debugger for determining bugs, single step execution
- locks for managing access to shared data between processes

Types of System Calls

File Management

- create file, delete file
- open, close file
- read, write, reposition
- get and set file attributes

Types of System Calls

Device Management

- request device, release device
- read, write, reposition
- get device attributes, set device attributes
- logically attach or detach devices

Types of System Calls

Information Maintenance

- get time or date, set time or date
- get system data, set system data
- get and set process, file, or device attributes

Types of System Calls

Communications

- create, delete communication connection
- send, receive messages if message passing model to host name or process name
  - from client to server
- Shared-memory model create and gain access to memory regions
- transfer status information
- attach and detach remote devices

Types of System Calls

Protection

- control access to resources
- get and set permissions
- allow and deny user access

Operating System Design and Implementation

Policy & Mechanism

- Important principle to separate
  - **Policy**: What will be done?
  - **Mechanism**: How to do it?
- Mechanisms determine how to do something, policies decide what will be done.
- The separation of policy from mechanism is a very important principle, it allows maximum flexibility if policy decisions are to be changed later (example — timer).
- Specifying and designing an OS is highly creative task of software engineering.

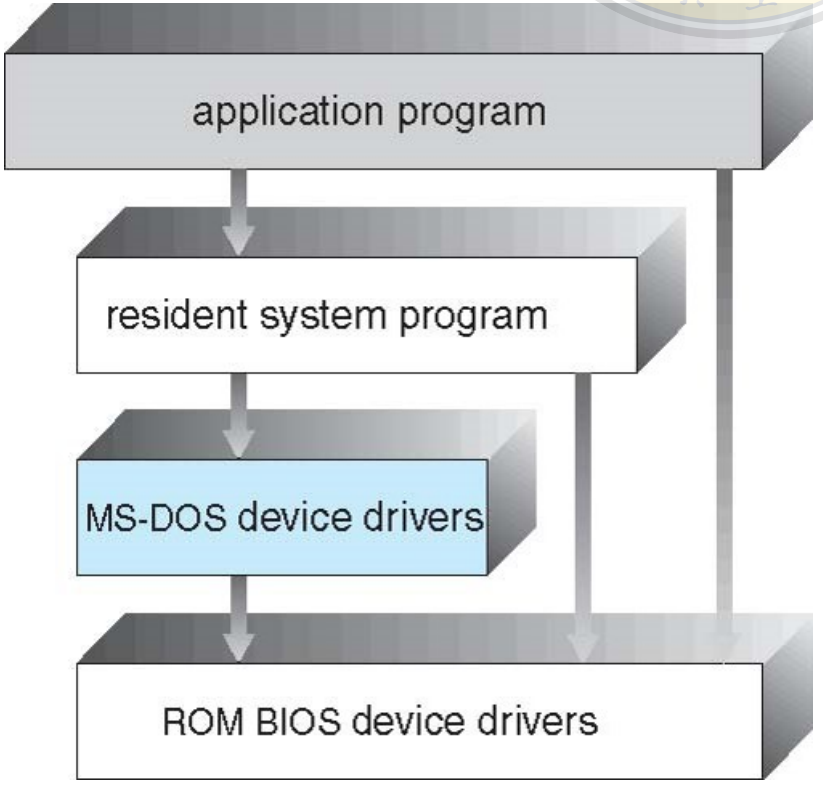
Operating System Structure

- General-purpose OS is very large program
- Various ways to structure ones
  - Simple structure — MS-DOS
  - More complex — UNIX
  - Layered — an abstraction
  - Microkernel — Mach
  - Modules — Linux
  - Hybrid

Operating System Structure

Simple Structure — MS-DOS

- MS-DOS — written to provide the most functionality in the least space.
  - Not divided into modules.
  - Although MS-DOS has some structure, its interfaces and levels of functionality are not well separated.



Operating System Structure

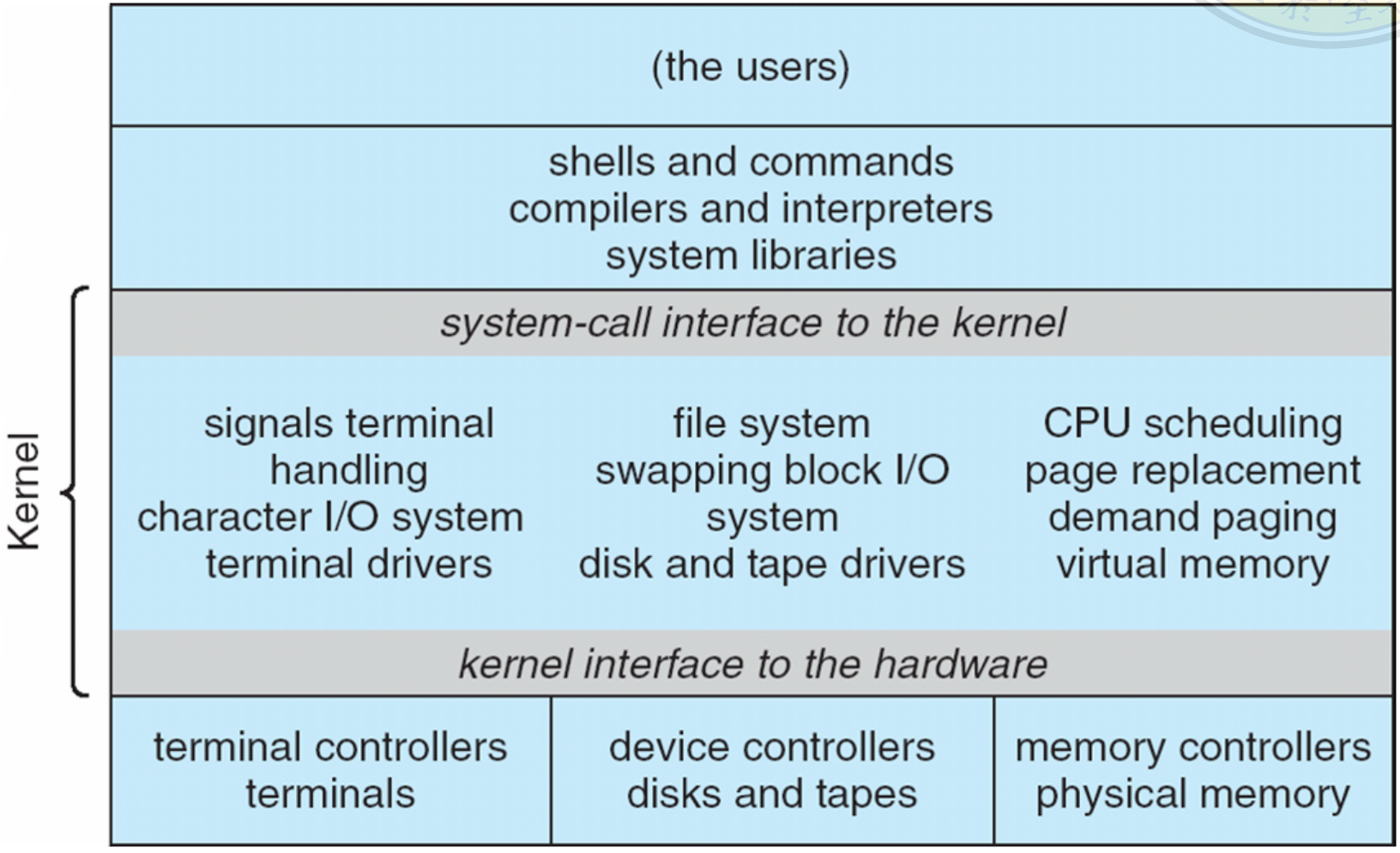
Non Simple Structure — UNIX

- UNIX — limited by hardware functionality, the original UNIX operating system had limited structuring.
- The UNIX OS consists of two separable parts.
  - Systems programs
  - The kernel
    - » Consists of everything below the system-call interface and above the physical hardware.
    - » Provides the file system, CPU scheduling, memory management, and other operating-system functions; a large number of functions for one level.

Operating System Structure

Non Simple Structure — UNIX (contd.)

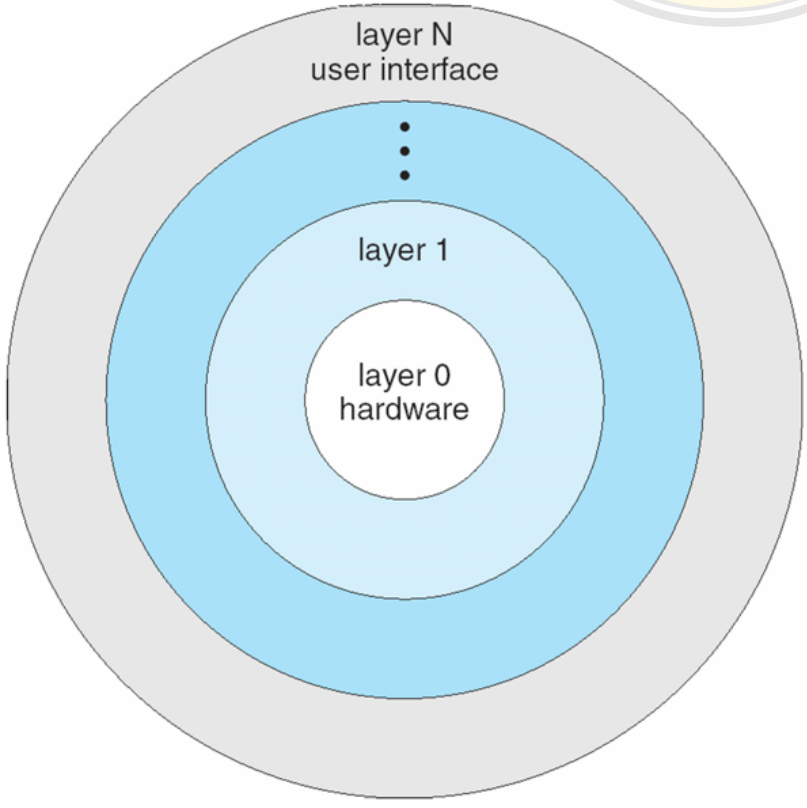
Beyond Simple but not fully layered



Operating System Structure

Layered Approach

- The operating system is divided into a number of layers (levels), each built on top of lower layers. The bottom layer (layer 0), is the hardware; the highest (layer N) is the user interface.
- With modularity, layers are selected such that each uses functions (operations) and services of only lower-level layers



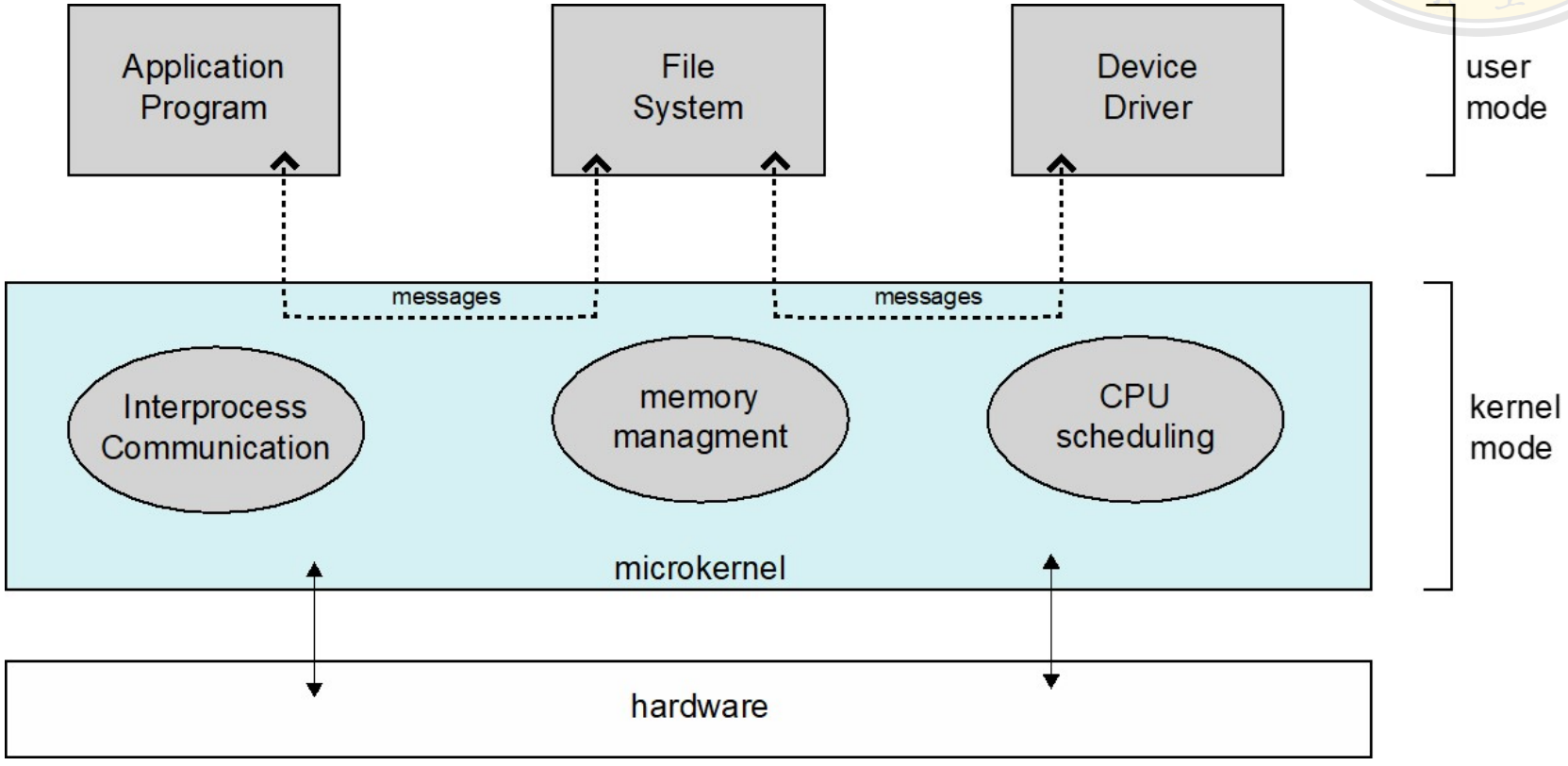
Operating System Structure

Microkernel System Structure

- Moves as much from the kernel into user space.
- Mach example of microkernel.
  - Mac OS X kernel (Darwin) partly based on Mach.
- Communication takes place between user modules using message passing.
- Benefits:
  - Easier to extend a microkernel.
  - Easier to port the operating system to new architectures.
  - More reliable (less code is running in kernel mode).
  - More secure.
- Detriments:
  - Performance overhead of user space to kernel space communication.

Operating System Structure

Microkernel System Structure (contd.)



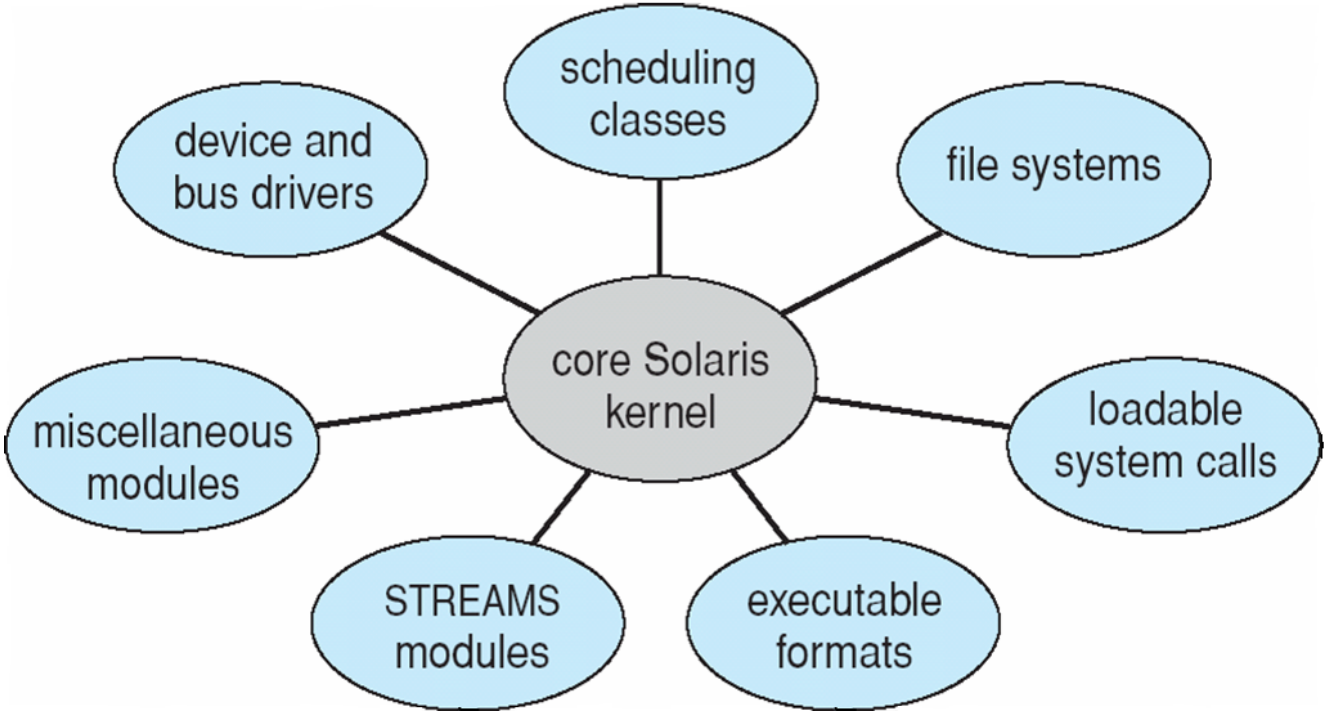
Operating System Structure

Modules

- Many modern operating systems implement loadable kernel modules.
  - Uses object-oriented approach.
  - Each core component is separate.
  - Each talks to the others over known interfaces.
  - Each is loadable as needed within the kernel.
- Overall, similar to layers but with more flexible.
  - Linux, Solaris, etc

Operating System Structure

Modules (contd.)



Operating System Structure

Hybrid Systems

- Most modern operating systems are actually not one pure model.
  - Hybrid combines multiple approaches to address performance, security, usability needs.
  - Linux and Solaris kernels in kernel address space, so monolithic, plus modular for dynamic loading of functionality.
  - Windows mostly monolithic, plus microkernel for different subsystem personalities.
  - Apple Mac OS X hybrid, layered, Aqua UI plus Cocoa programming environment.

Operating System Structure

Recent Trends

- Library Operating System
  —— Madhavapeddy, Anil, et al. "Unikernels: Library operating systems for the cloud." ACM SIGARCH Computer Architecture News 41.1 (2013): 461-472.
- Exokernel
  —— Engler, Dawson R., M. Frans Kaashoek, and James O'Toole Jr. "Exokernel: An operating system architecture for application-level resource management." ACM SIGOPS Operating Systems Review 29.5 (1995): 251-266.
- Multikernel
  —— Baumann, Andrew, et al. "The multikernel: a new OS architecture for scalable multicore systems." Proceedings of the ACM SIGOPS 22nd symposium on Operating systems principles. 2009.
- Splitkernel
  —— Shan, Yizhou, et al. "Legoos: A disseminated, distributed OS for hardware resource disaggregation." 13th USENIX Symposium on Operating Systems Design and Implementation (OSDI 18). 2018.