IF2230
Introduction to Operating Systems
OS Structure

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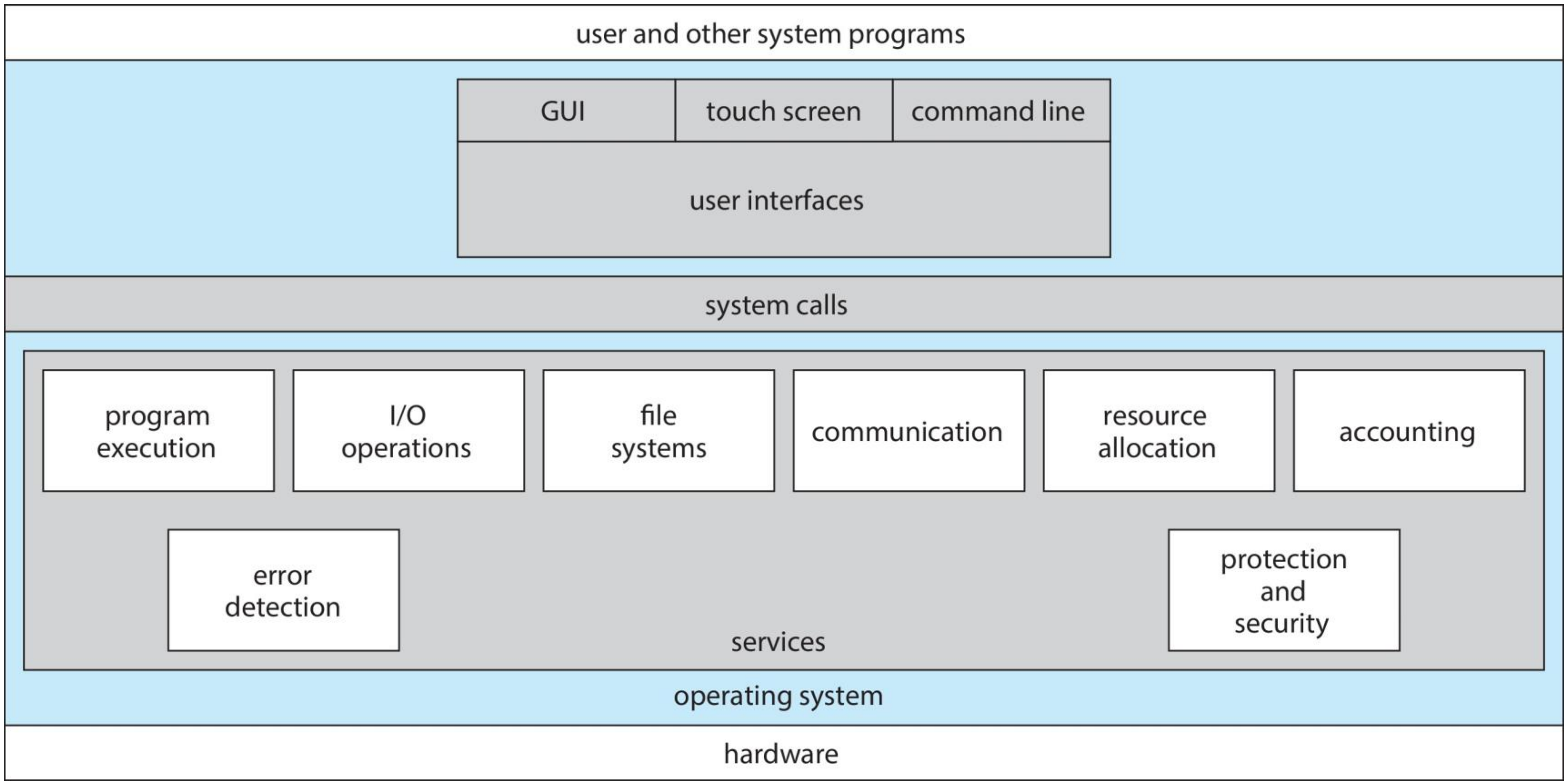
Operating Systems Services



Operating system services (i)

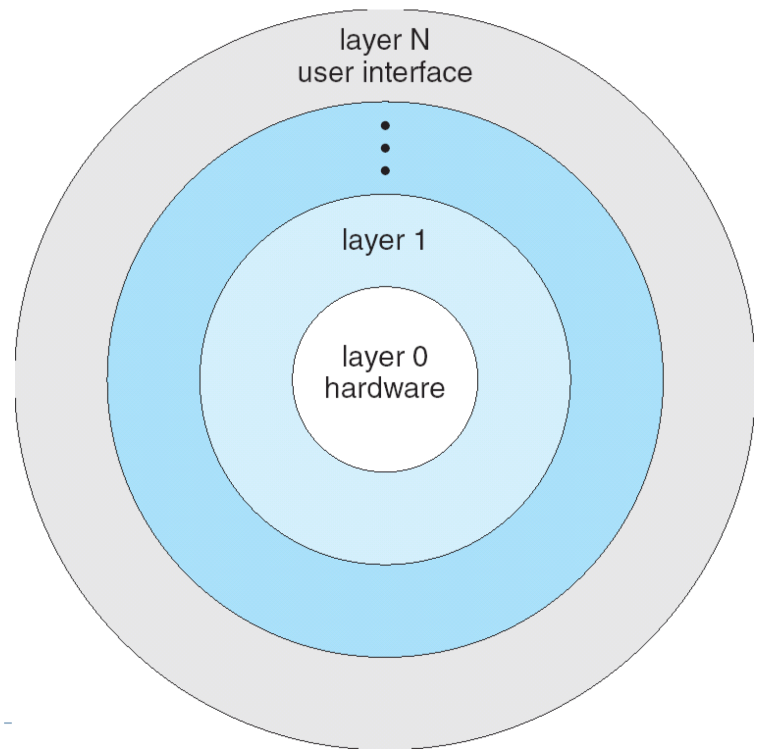
- An operating system provides *services*:
  - Program execution
    - Load programs into memory, run/suspend/halt programs, handle/display errors
  - I/O operations
    - Seamlessly interact with I/O devices, including disks, networks connection, etc.
  - Filesystem manipulation
    - Read/write/traverse filesystem directories, read/write files, enforce permissions, search for files

Operating system services (ii)

- Other operating system *services*:
  - Inter-Process Communications (IPC)
    - Processes exchange information via shared memory, message passing, sockets, pipes, files, etc.
    - Often spans multiple computers and networks
  - Error detection and recovery
    - Detect errors in CPU, memory, I/O devices, processes, network connections, etc.
    - Recover from errors gracefully,
      ensuring correct and consistent operations

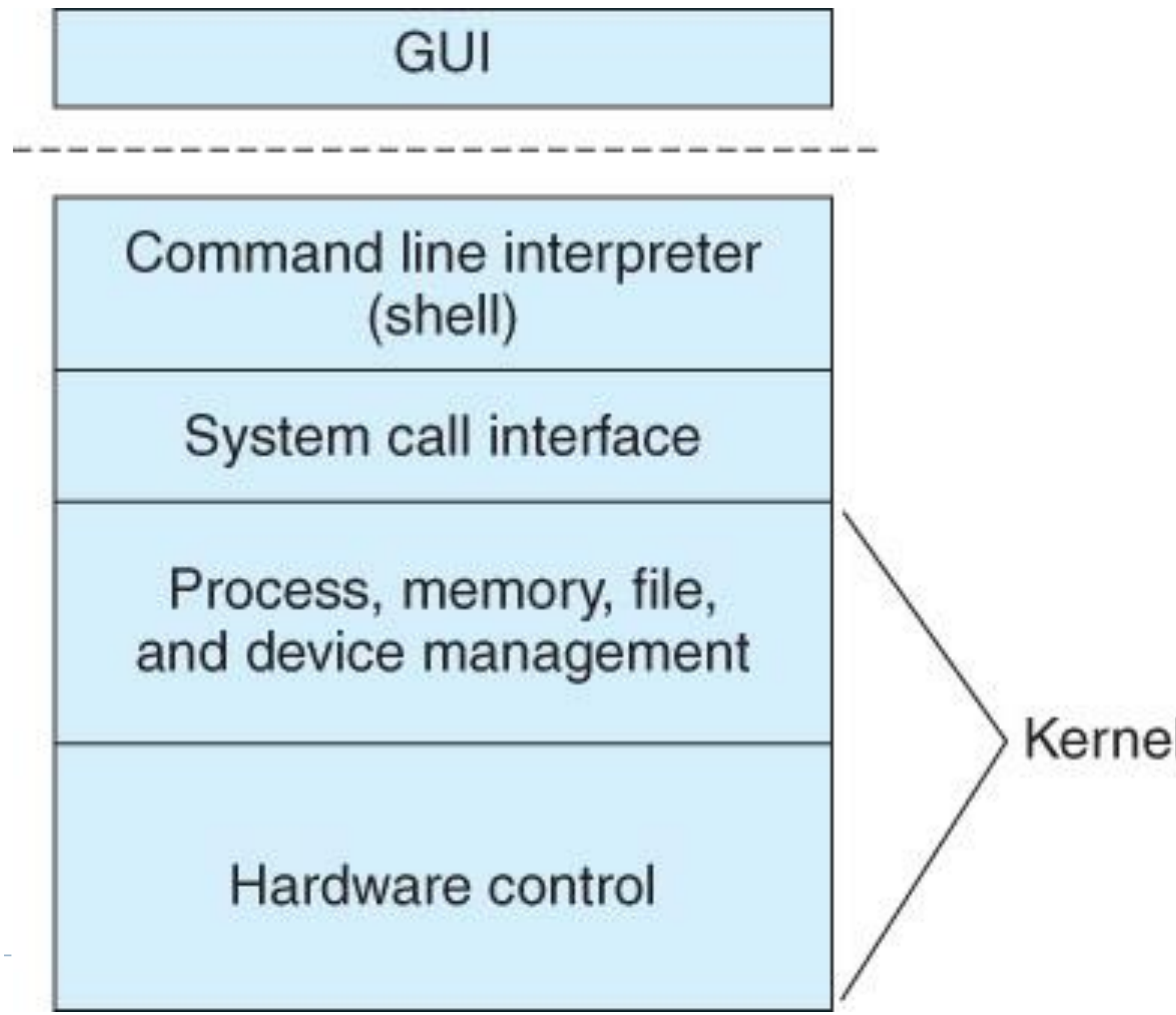
Operating system structure (i)

- Using a *layered* approach, the operating system is divided into **N** *levels* or *layers*
  - Layer 0 is the hardware
  - Layer 1 is often the *kernel*
  - Layer **N** is the top-level user interface (GUI)
  - Each layer uses functions and services of the layer (or layers) beneath it



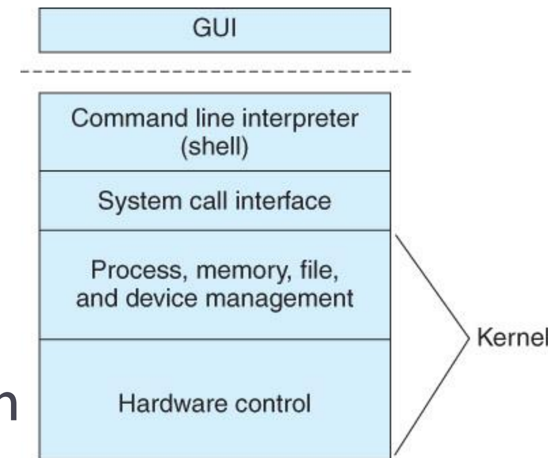
Operating system structure (ii)

- Also view as a *stack* of services

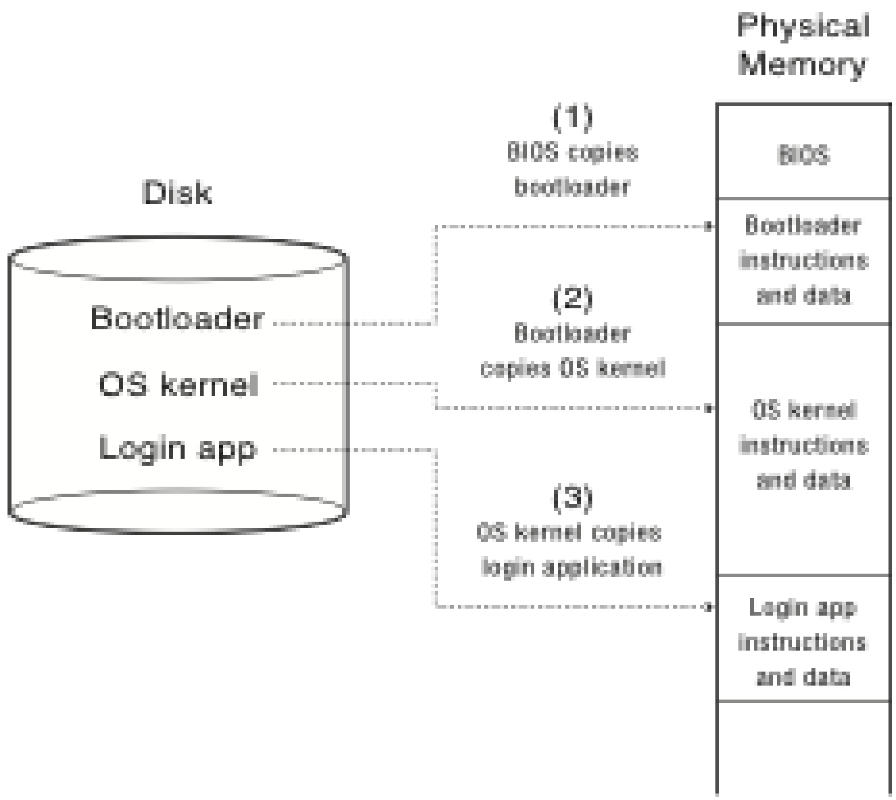


Operating system kernel

- The core program running in an operating system is called the *kernel*
  - When a computer is switched on, a *bootstrap program* executes from ROM
  - The bootstrap program initializes the system operating system kernel and starts its execution



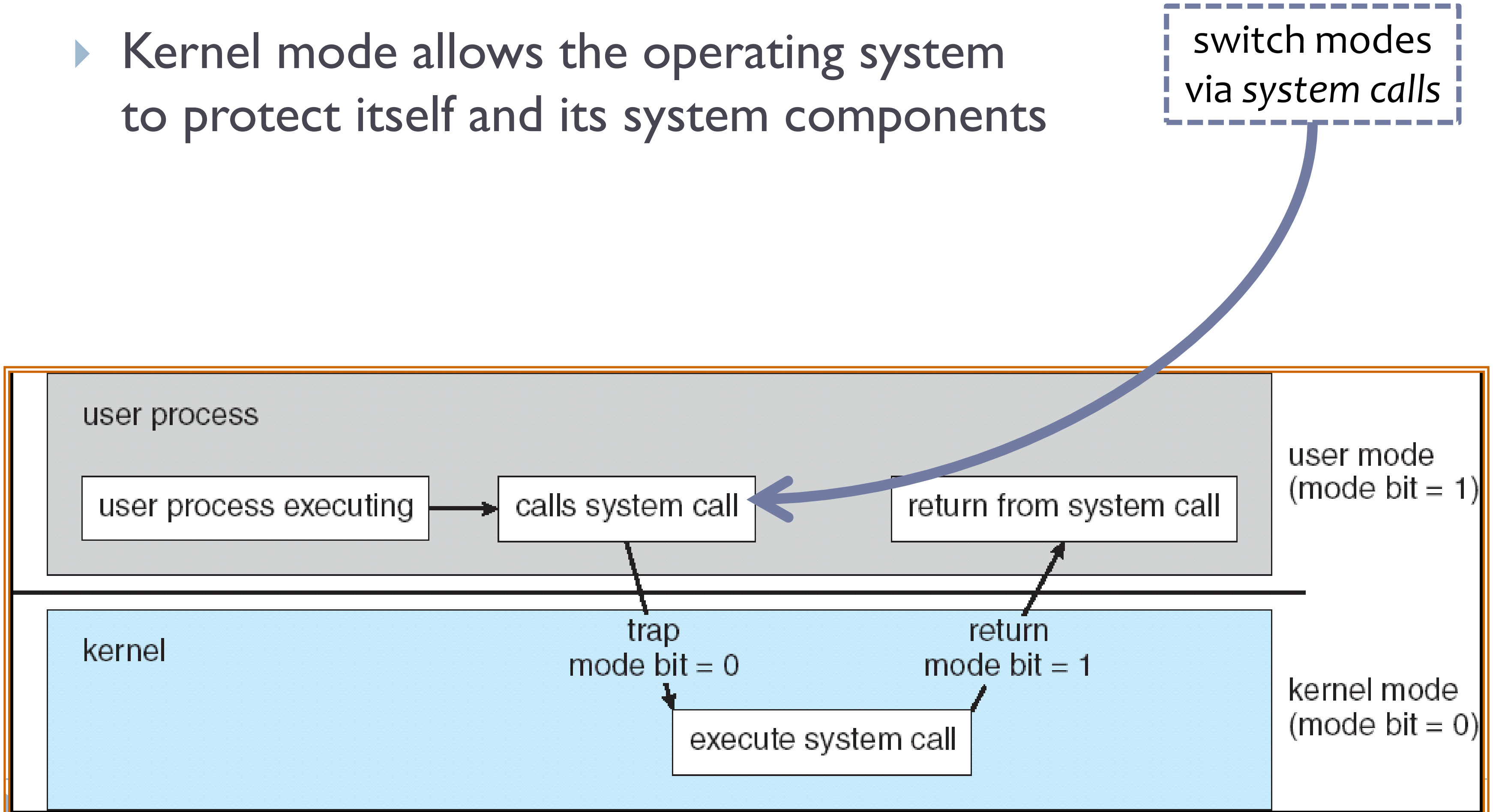
Booting



Physical Memory
Disk
Bootloader
OS kernel
Login app
(1)
BIOS copies bootloader
(2)
Bootloader copies OS kernel
(3)
OS kernel copies login application
BIOS
Bootloader instructions and data
OS kernel instructions and data
Login app instructions and data

User and kernel modes (i)

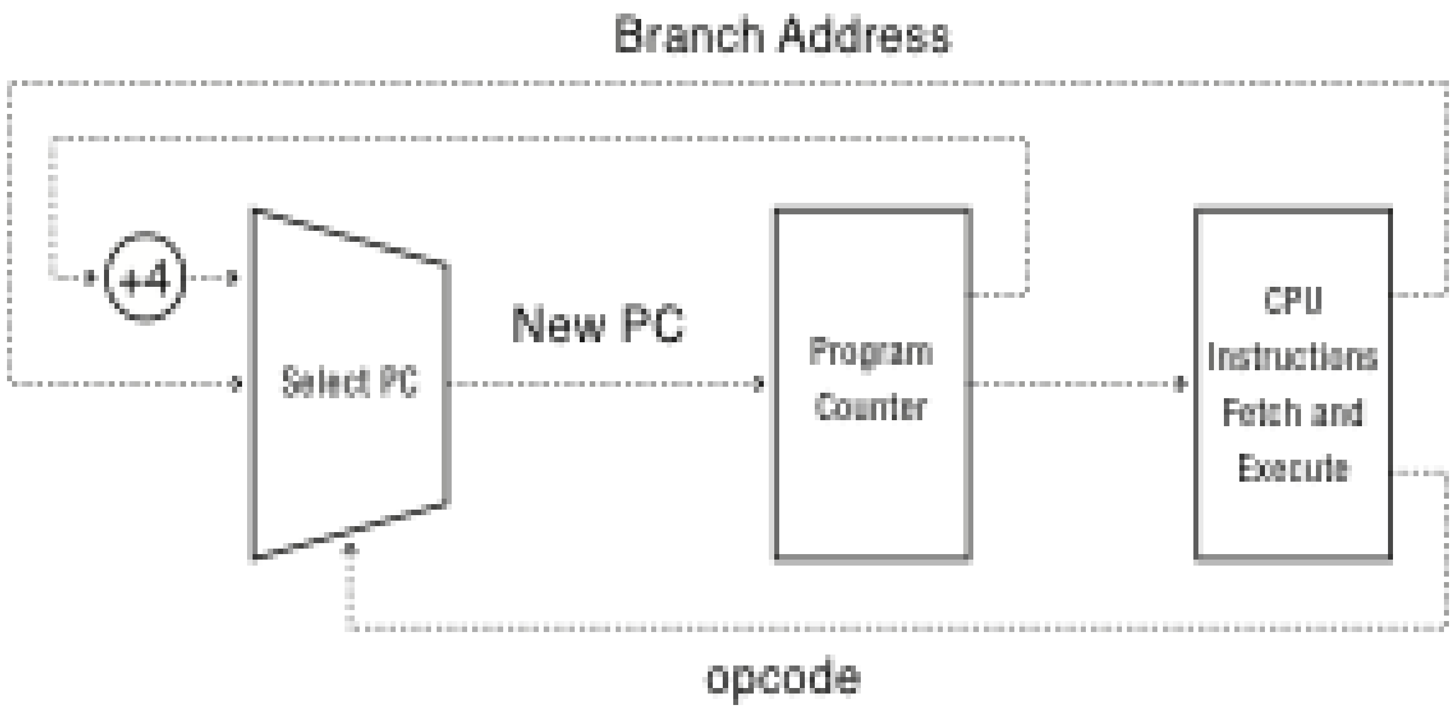
- Program instructions run either in *user mode* or in *kernel mode*
  - Kernel mode allows the operating system to protect itself and its system components



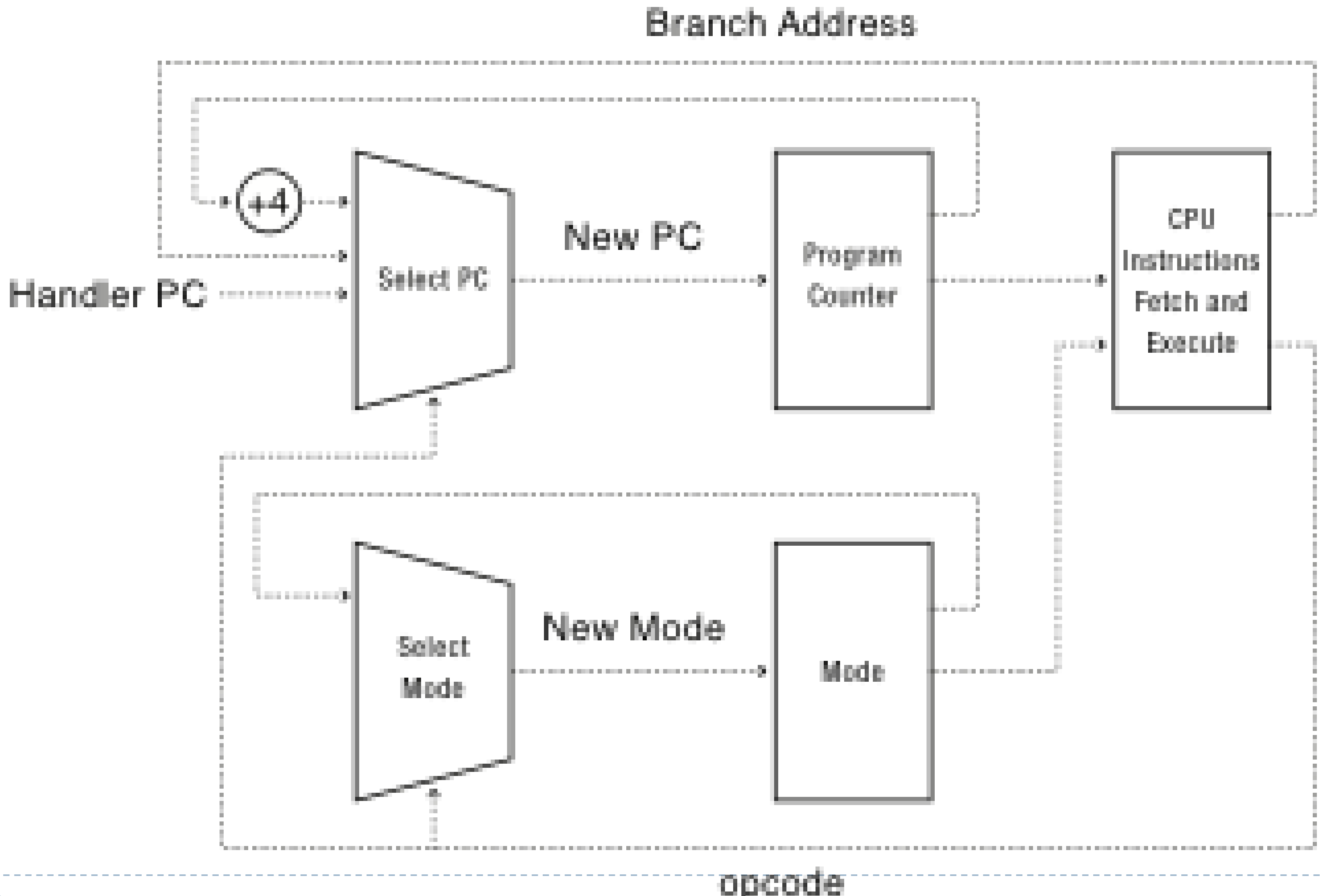
Hardware Support: Dual-Mode Operation

- Kernel mode
  - Execution with the full privileges of the hardware
  - Read/write to any memory, access any I/O device, read/write any disk sector, send/read any packet
- User mode
  - Limited privileges
  - Only those granted by the operating system kernel
- On the x86, mode stored in EFLAGS register
- On the MIPS, mode in the status register

A Model of a CPU



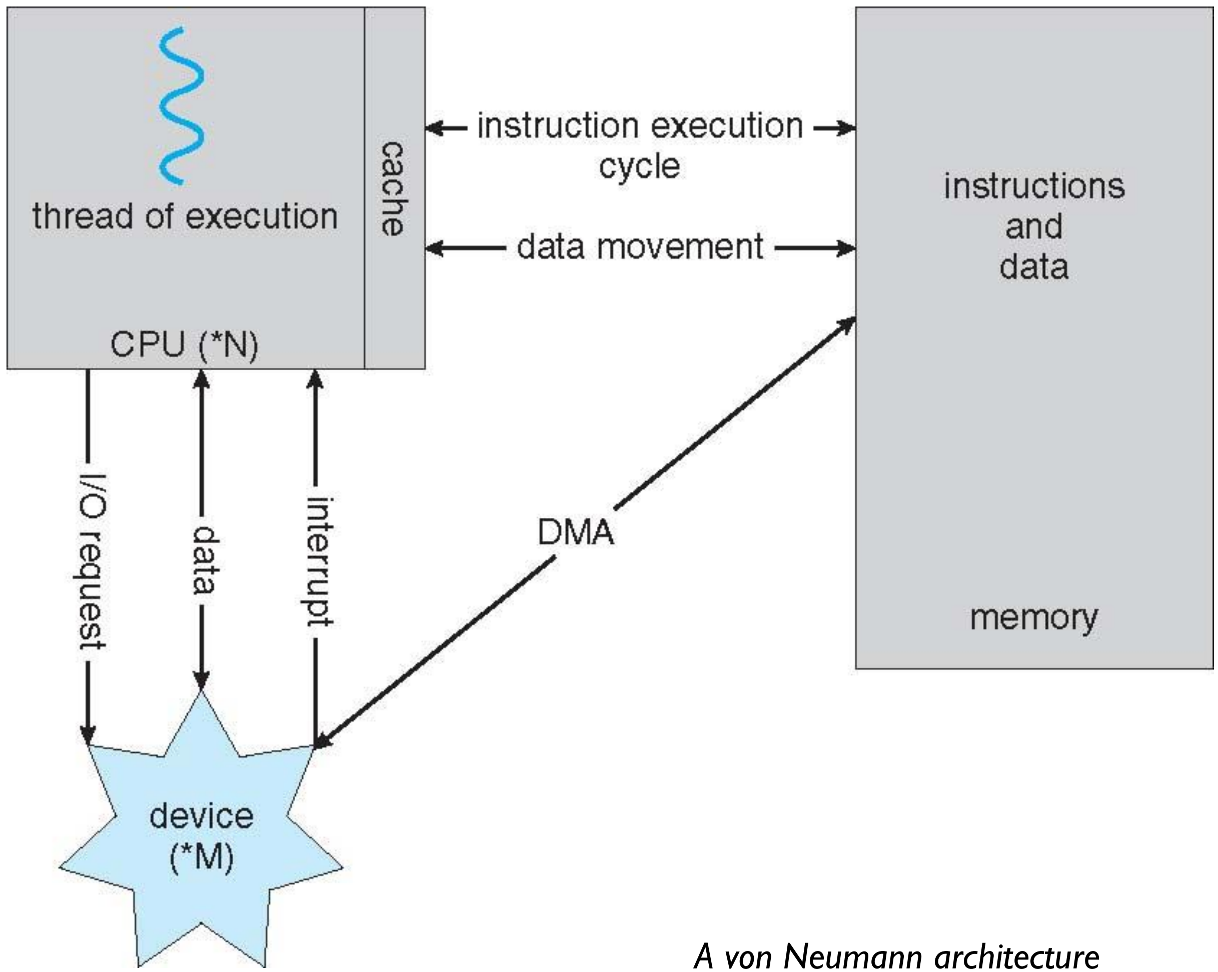
A CPU with Dual-Mode Operation



Hardware Support: Dual-Mode Operation

- Privileged instructions
  - Available to kernel
  - Not available to user code
- Limits on memory accesses
  - To prevent user code from overwriting the kernel
- Timer
  - To regain control from a user program in a loop
- Safe way to switch from user mode to kernel mode, and vice versa

How a Modern Computer Works



A von Neumann architecture

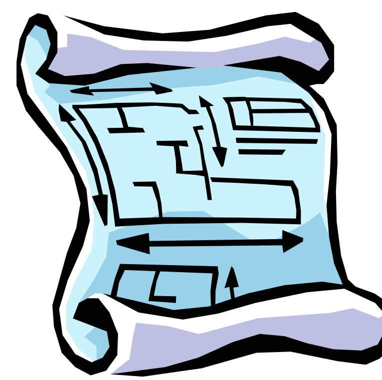
User and kernel modes (ii)

- Kernel gives control to a user process, but may set a timer to ensure a process does not run beyond its allotted time
  - To avoid infinite loops, memory leaks, memory hogs, etc.
  - Not always effective in practice…
    - Can you stop a runaway process before your computer crashes?

Aaaaaaaugghhhh!
I'm going to take
this computer and…

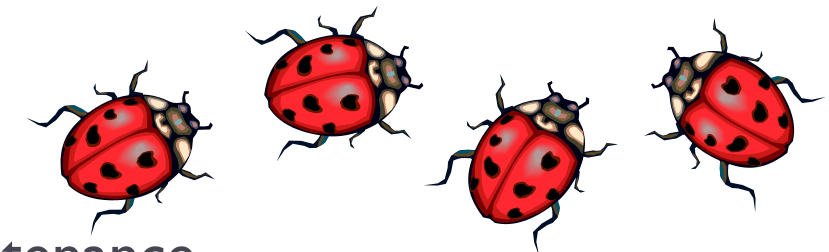
System calls via APIs (i)

- OS services are available via *system calls*
  - System calls are made via an interface called an *Application Program Interface* (*API*)
  - Common operating system APIs:
    - Win32 API for Windows
    - POSIX API for POSIX-based systems, including UNIX, Linux, Mac OS X
    - Java API for Java Virtual Machine
    - C/C++ Standard Library



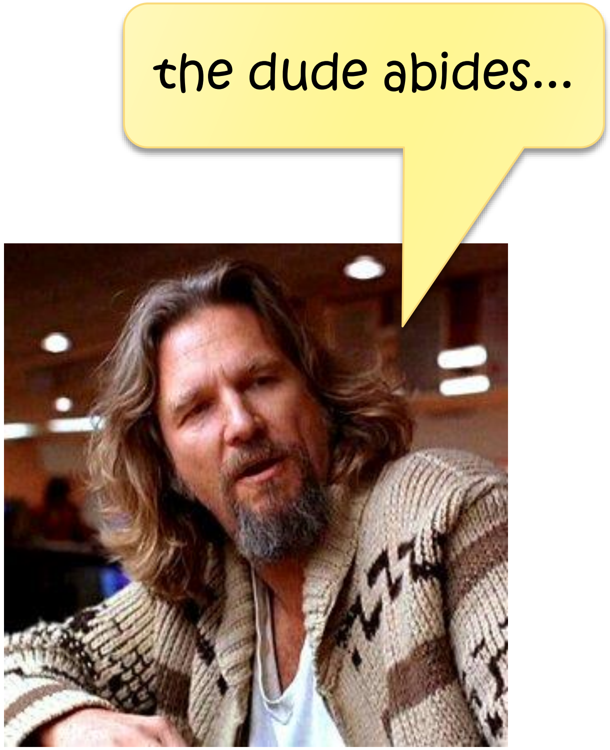
System calls via APIs (ii)

- Types of system calls include:
  - Process control (e.g. start/suspend/stop a process)
    - Debugging information, too
  - File management
  - Device management
  - Information retrieval and maintenance
    - Current date/time, number of current users, OS version, amount of free memory, process information, etc.
  - Communications (e.g. IPC, network)

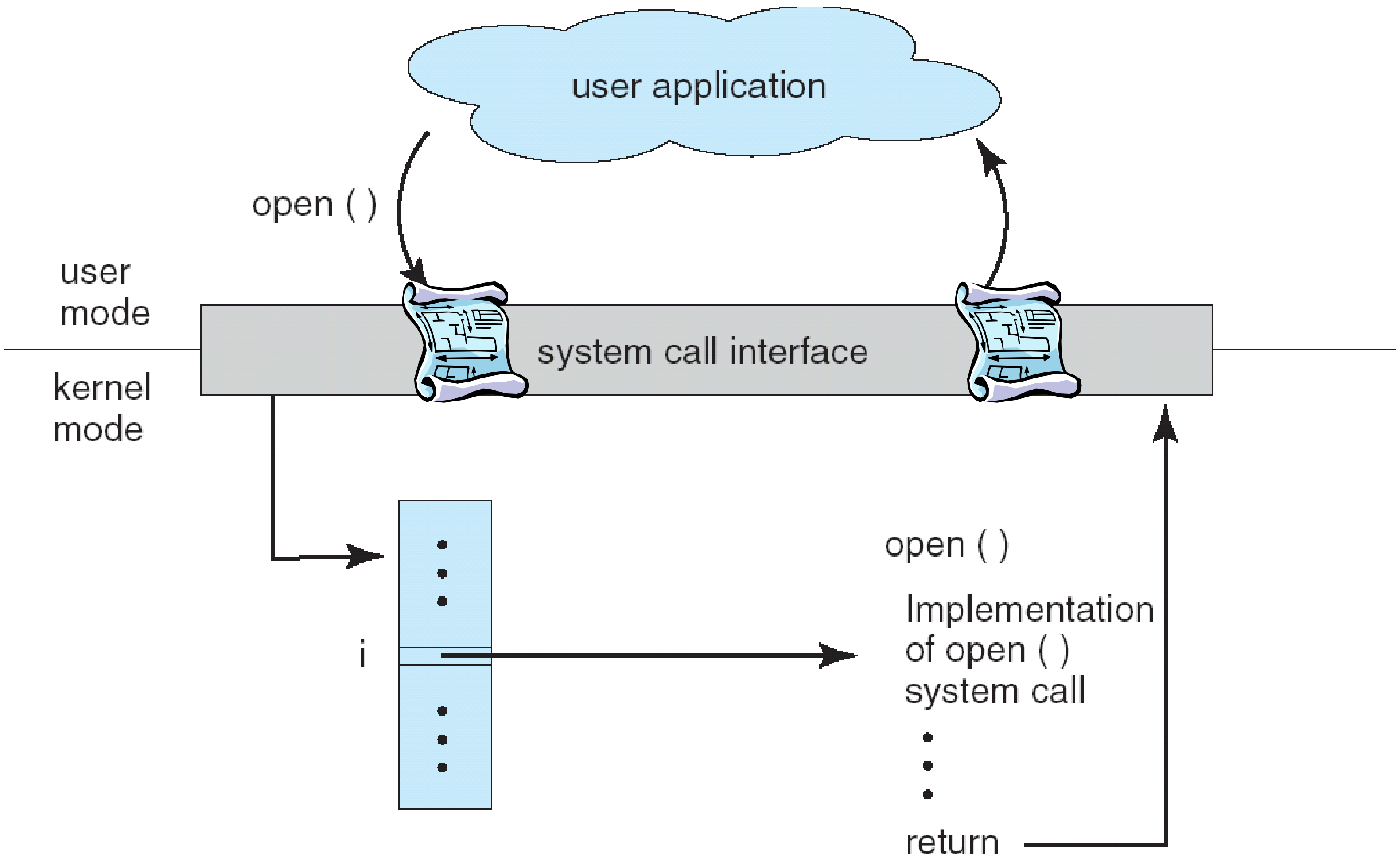


System calls via APIs (iii)

- An API *hides the implementation details* of the underlying operating system
  - Programmers just need to *abide* by the *API specifications*
  - How do we *change* the API or the operating system services that it offers?



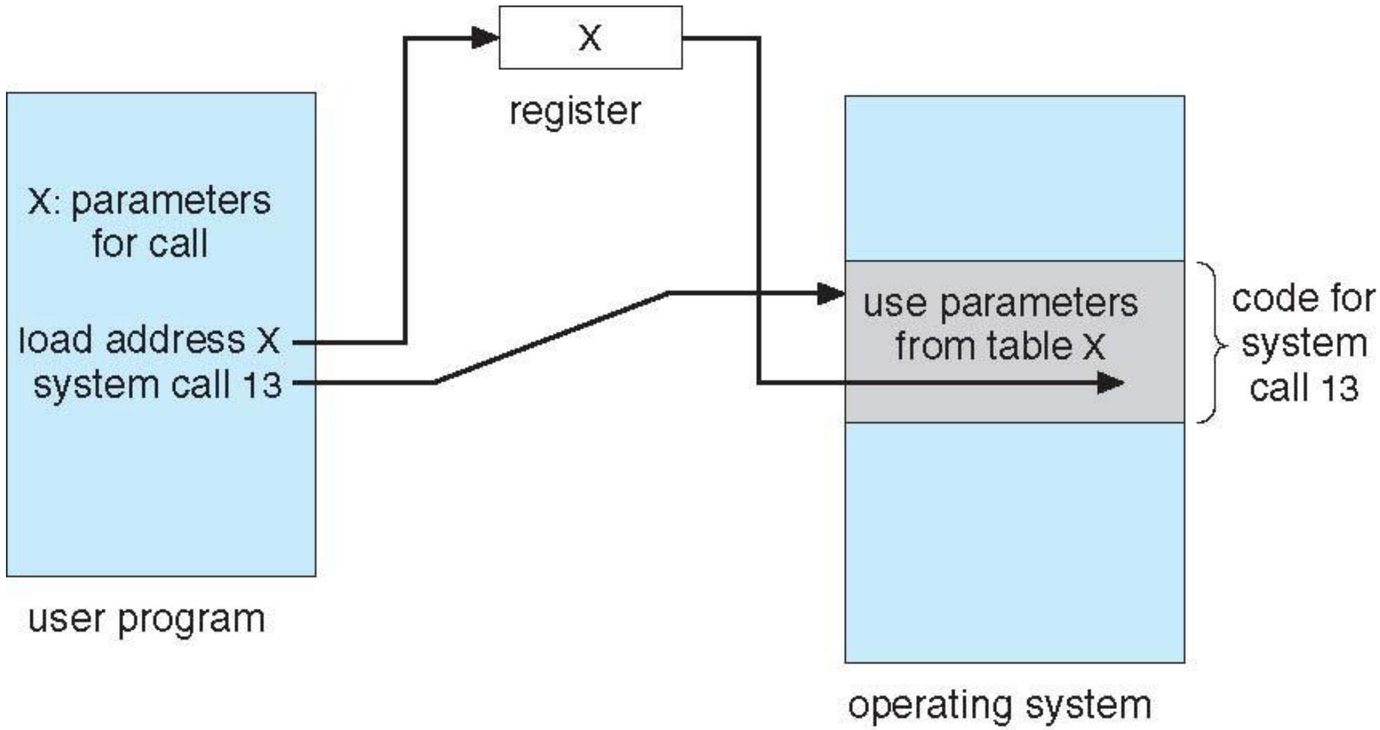
System calls via APIs (iv)



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
  - Simplest: pass the parameters in registers
    - In some cases, may be more parameters than registers
  - 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
  - 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

Parameter Passing via Table



Types of System Calls

- Process control
  - end, abort
  - load, execute
  - create process, terminate process
  - 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

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

Types of System Calls (Cont.)

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

- 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 (Cont.)

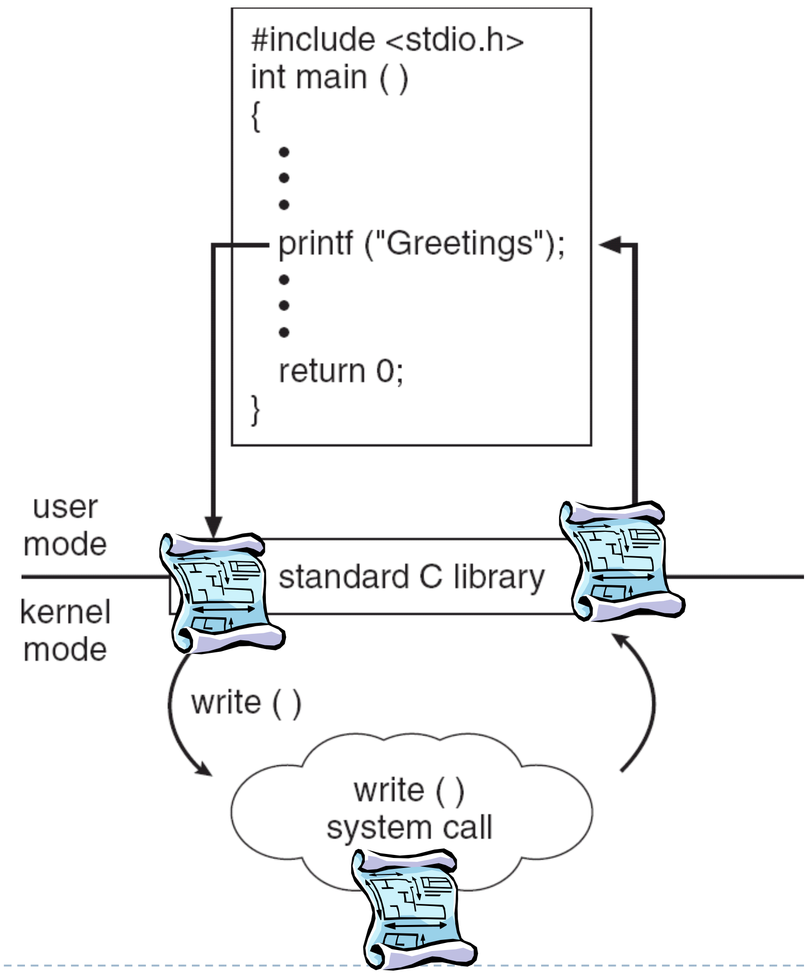
- Protection
  - Control access to resources
  - Get and set permissions
  - Allow and deny user access

Examples of Windows and Unix System Calls

	Windows	Unix
Process Control	CreateProcess()	fork()
	ExitProcess()	exit()
	WaitForSingleObject()	wait()
File Manipulation	CreateFile()	open()
	ReadFile()	read()
	WriteFile()	write()
	CloseHandle()	close()
Device Manipulation	SetConsoleMode()	ioctl()
	ReadConsole()	read()
	WriteConsole()	write()
Information Maintenance	GetCurrentProcessID()	getpid()
	SetTimer()	alarm()
	Sleep()	sleep()
Communication	CreatePipe()	pipe()
	CreateFileMapping()	shmget()
	MapViewOfFile()	mmap()
Protection	SetFileSecurity()	chmod()
	InitlializeSecurityDescriptor()	umask()
	SetSecurityDescriptorGroup()	chown()

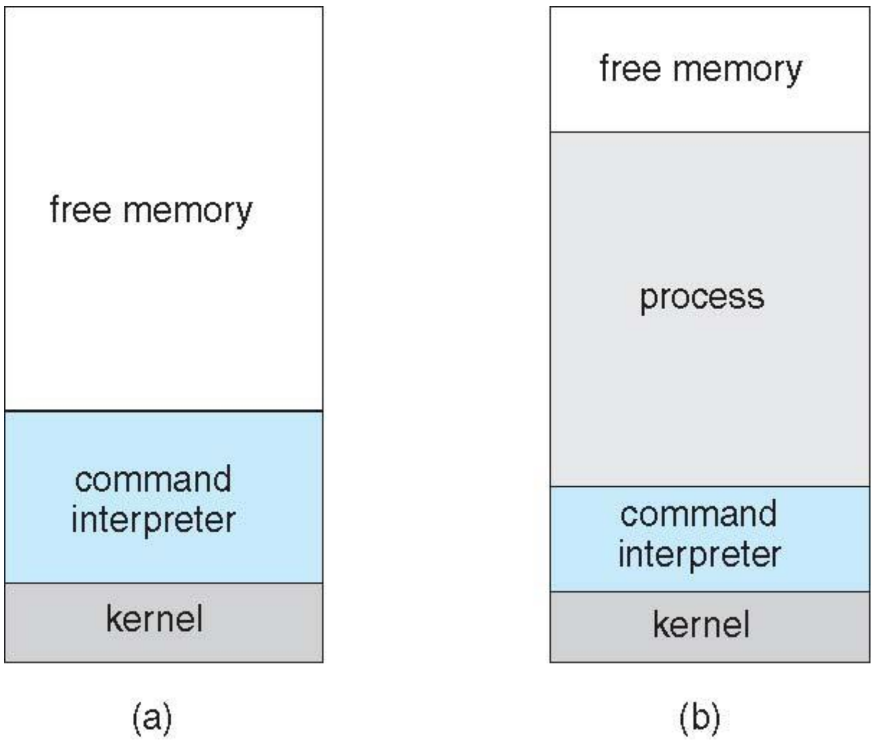
System calls via APIs (v)

- Example using the printf() function from C
- One API may call another, which may in turn call another, and so on...



Example: MS-DOS

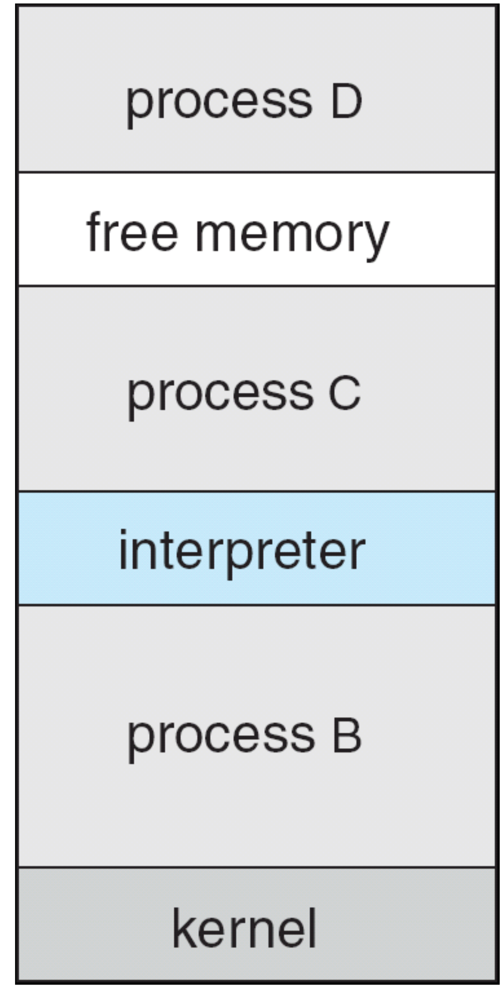
- Single-tasking
- Shell invoked when system booted
- Simple method to run program
  - No process created
- Single memory space
- Loads program into memory, overwriting all but the kernel
- Program exit -> shell reloaded



(a) At system startup (b) running a program

Example: FreeBSD

- Unix variant
- Multitasking
- User login -> invoke user's choice of shell
- Shell executes fork() system call to create process
  - Executes exec() to load program into process
  - Shell waits for process to terminate or continues with user commands
- Process exits with code of 0 – no error or > 0 – error code



System Programs

- System programs provide a convenient environment for program development and execution. They can be divided into:
  - File manipulation
  - Status information sometimes stored in a File modification
  - Programming language support
  - Program loading and execution
  - Communications
  - Background services
  - Application programs
- Most users' view of the operation system is defined by system programs, not the actual system calls

System Programs

- Provide a convenient environment for program development and execution
  - Some of them are simply user interfaces to system calls; others are considerably more complex
- **File management -** Create, delete, copy, rename, print, dump, list, and generally manipulate files and directories
- **Status information**
  - Some ask the system for info - date, time, amount of available memory, disk space, number of users
  - Others provide detailed performance, logging, and debugging information
  - Typically, these programs format and print the output to the terminal or other output devices
  - Some systems implement a **registry** - used to store and retrieve configuration information

System Programs (Cont.)

- **File modification**
  - Text editors to create and modify files
  - Special commands to search contents of files or perform transformations of the text
- **Programming-language support** - Compilers, assemblers, debuggers and interpreters sometimes provided
- **Program loading and execution-** Absolute loaders, relocatable loaders, linkage editors, and overlay-loaders, debugging systems for higher-level and machine language
- **Communications** - Provide the mechanism for creating virtual connections among processes, users, and computer systems
  - Allow users to send messages to one another's screens, browse web pages, send electronic-mail messages, log in remotely, transfer files from one machine to another

System Programs (Cont.)

- **Background Services**
  - Launch at boot time
    - Some for system startup, then terminate
    - Some from system boot to shutdown
  - Provide facilities like disk checking, process scheduling, error logging, printing
  - Run in user context not kernel context
  - Known as **services**, **subsystems**, **daemons**
- **Application programs**
  - Don't pertain to system
  - Run by users
  - Not typically considered part of OS
  - Launched by command line, mouse click, finger poke

Operating System Design and Implementation

- Design and Implementation of OS not "solvable", but some approaches have proven successful
- Internal structure of different Operating Systems can vary widely
- Start by defining goals and specifications
- Affected by choice of hardware, type of system
- **User** goals and **System** goals
  - User goals – operating system should be convenient to use, easy to learn, reliable, safe, and fast
  - System goals – operating system should be easy to design, implement, and maintain, as well as flexible, reliable, error-free, and efficient

Operating System Design and Implementation (Cont.)

- 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

- Specifying and designing OS is highly creative task of **software engineering**

Implementation

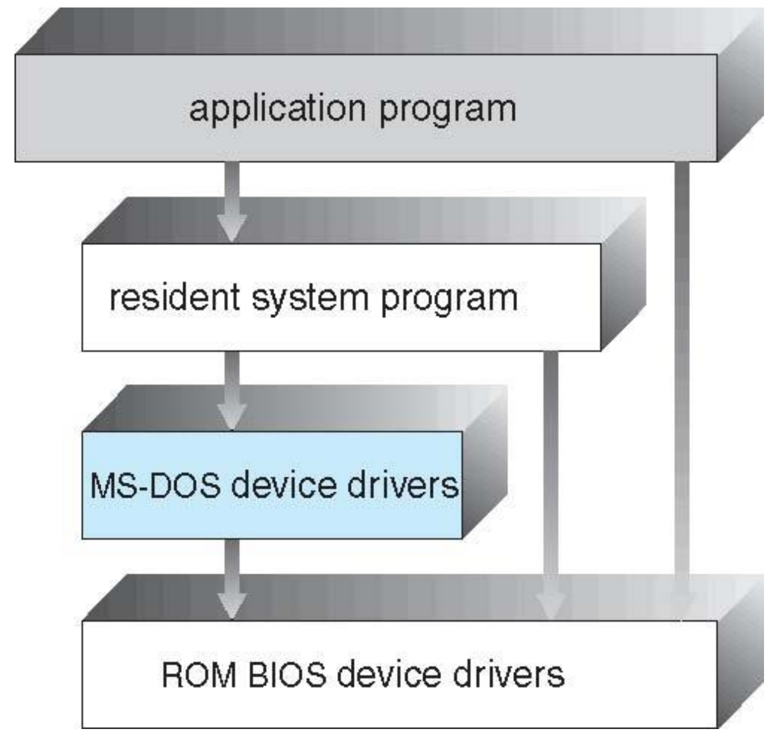
- Much variation
  - Early OSes in assembly language
  - Then system programming languages like Algol, PL/1
  - Now C, C++
- Actually usually a mix of languages
  - Lowest levels in assembly
  - Main body in C
  - Systems programs in C, C++, scripting languages like PERL, Python, shell scripts
- More high-level language easier to **port** to other hardware
  - But slower
- **Emulation** can allow an OS to run on non-native hardware

Operating System Structure

- General-purpose OS is very large program
- Various ways to structure one as follows

Simple Structure

- I.e. 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

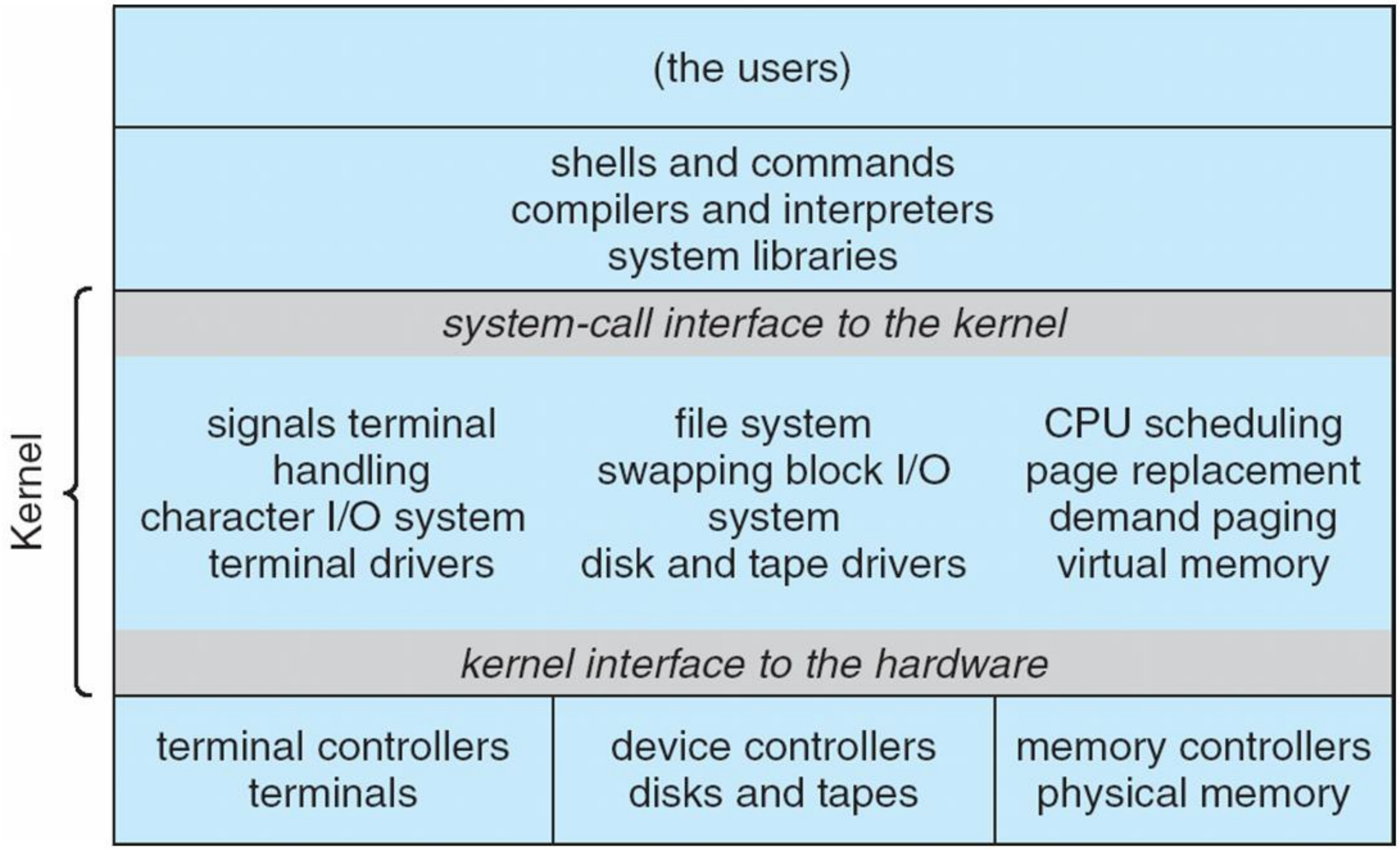


UNIX

- 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

Traditional UNIX System Structure

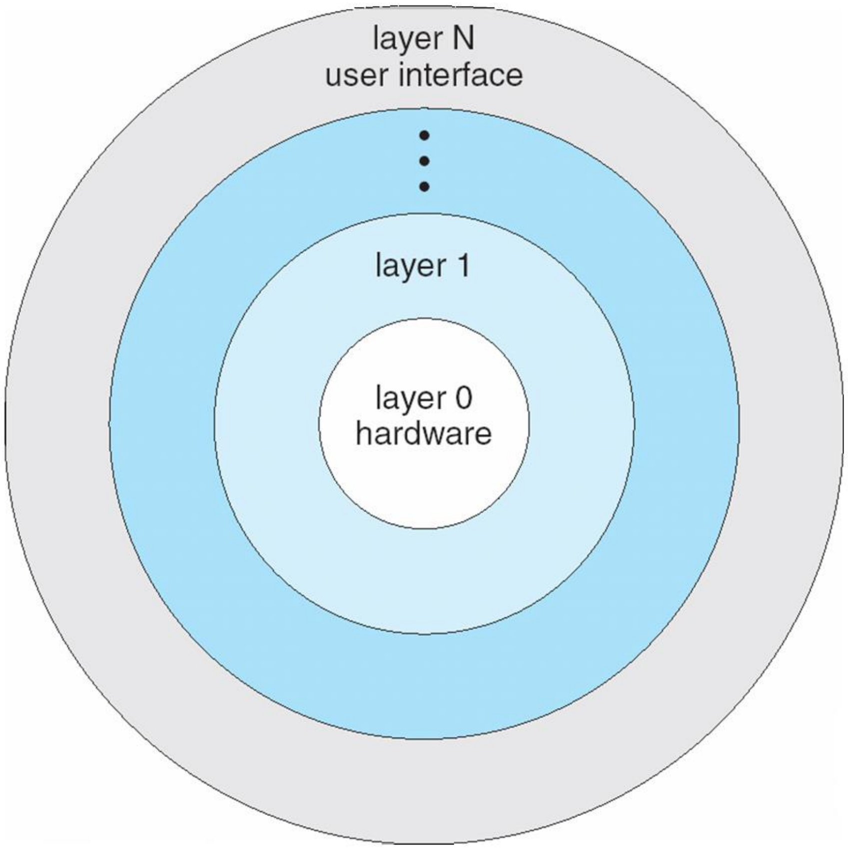
Beyond simple but not fully layered



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.

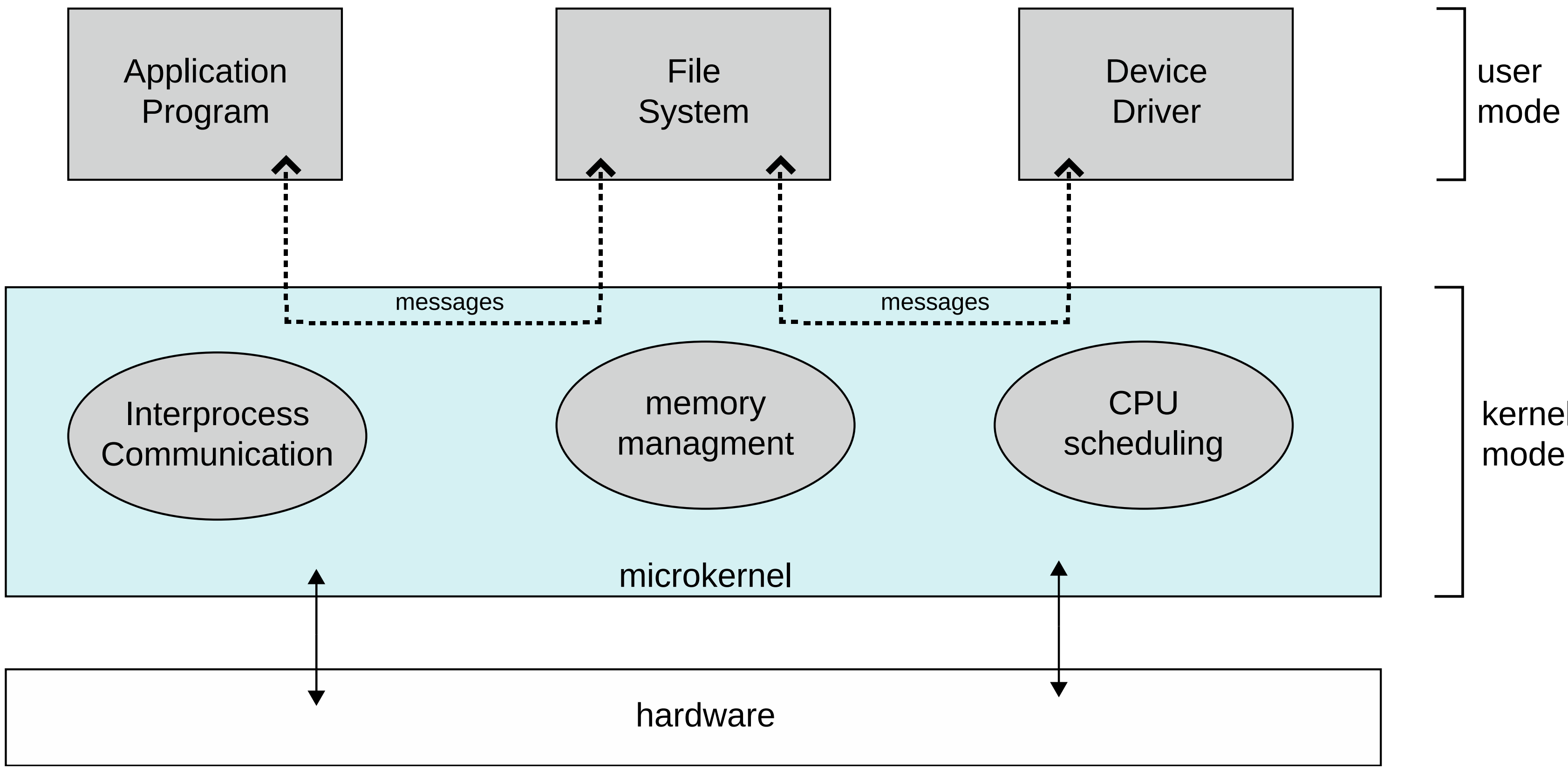
- With modularity, layers are selected such that each uses functions (operations) and services of only lower-level layers



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

Microkernel System Structure

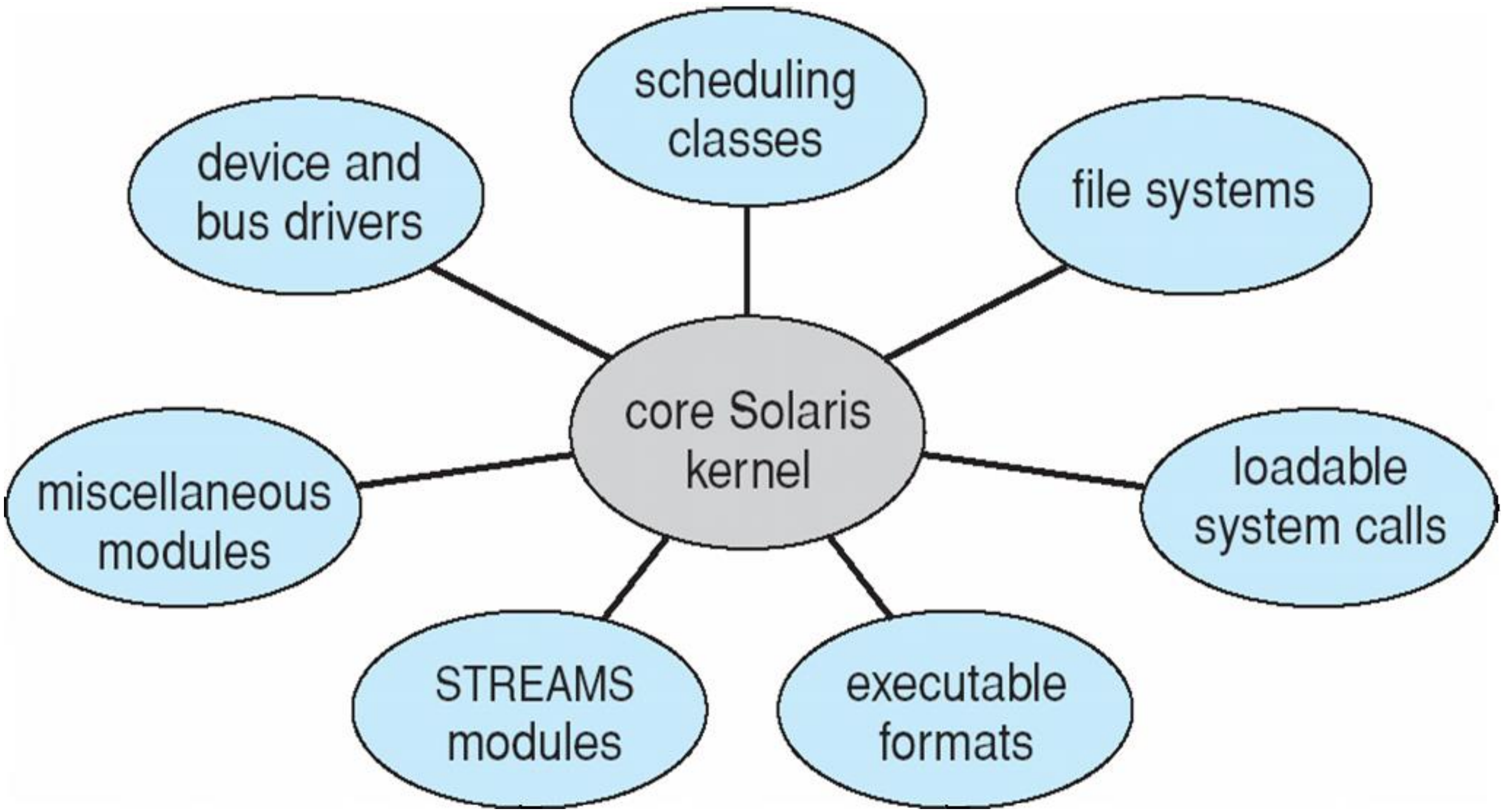


Modules

- Most 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

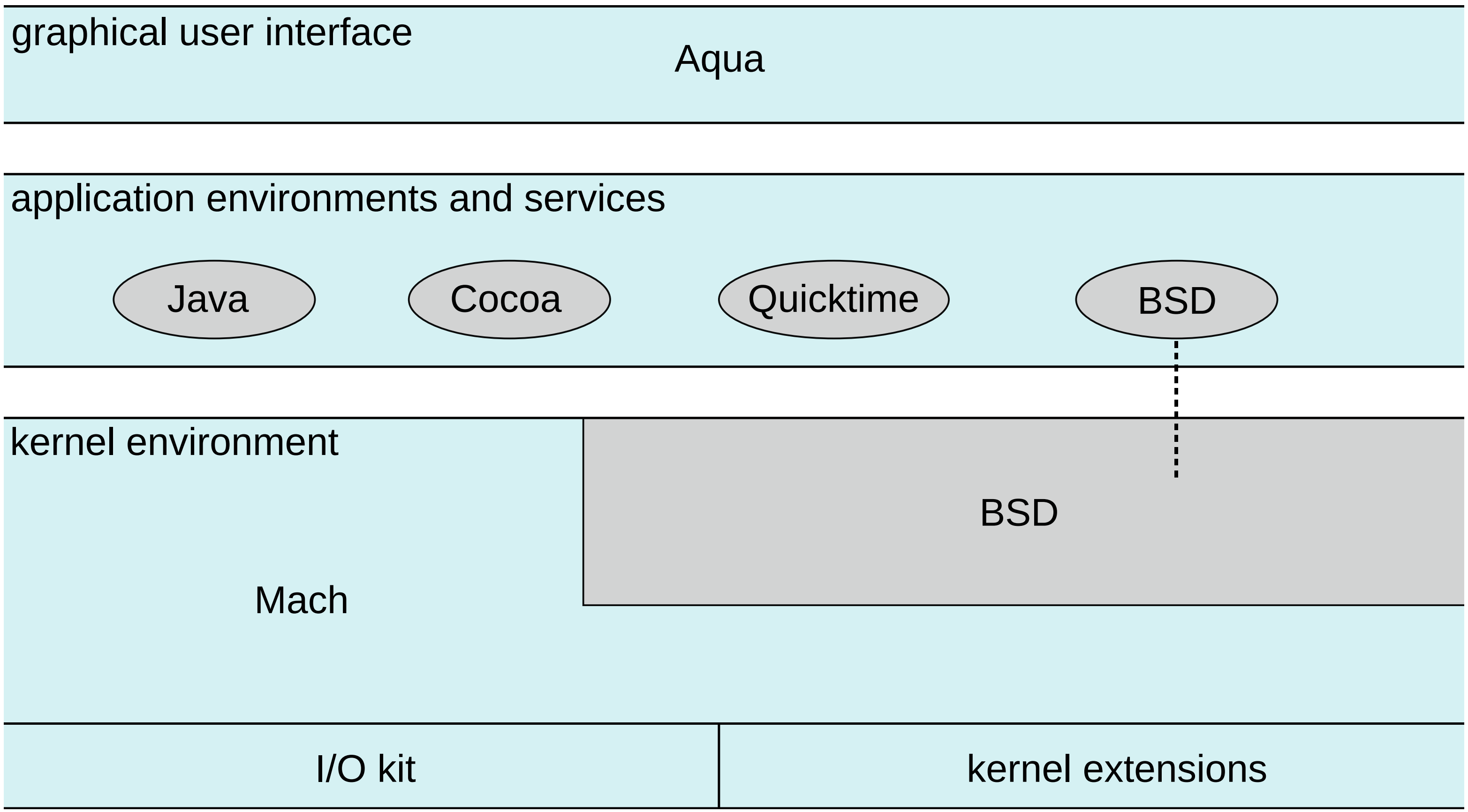
Solaris Modular Approach



Hybrid Systems

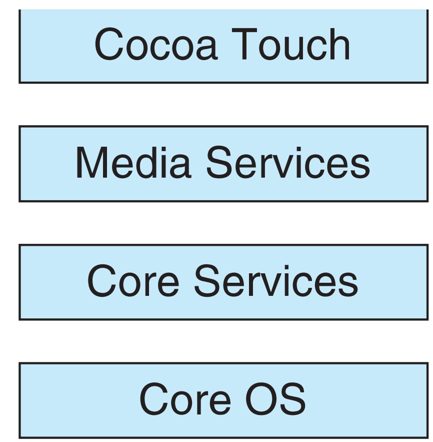
- Most modern operating systems actually not one pure model
  - Hybrid combines multiple approaches to address performance, security, usability needs
  - Linux and Solaris kernels in kernel address space, so monolithic, plus modular for dynamic loading of functionality
  - Windows mostly monolithic, plus microkernel for different subsystem ***personalities***
- Apple Mac OS X hybrid, layered, **Aqua** UI plus **Cocoa** programming environment
  - Below is kernel consisting of Mach microkernel and BSD Unix parts, plus I/O kit and dynamically loadable modules (called **kernel extensions**)

Mac OS X Structure



iOS

- Apple mobile OS for ***iPhone***, ***iPad***
  - Structured on Mac OS X, added functionality
  - Does not run OS X applications natively
    - Also runs on different CPU architecture (ARM vs. Intel)
  - **Cocoa Touch** Objective-C API for developing apps
  - **Media services** layer for graphics, audio, video
  - **Core services** provides cloud computing, databases
  - Core operating system, based on Mac OS X kernel



Android

- Developed by Open Handset Alliance (mostly Google)
  - Open Source
- Similar stack to IOS
- Based on Linux kernel but modified
  - Provides process, memory, device-driver management
  - Adds power management
- Runtime environment includes core set of libraries and Dalvik virtual machine
  - Apps developed in Java plus Android API
    - Java class files compiled to Java bytecode then translated to executable than runs in Dalvik VM
- Libraries include frameworks for web browser (webkit), database (SQLite), multimedia, smaller libc

Android Architecture