Operating Systems

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Chapter 2
Operating System Structures

Objectives

- Operating System Services
  - User Operating System Interface
  - System Calls
- Operating System Structure
- Operating System Design and Implementation
- MISC: Debugging, Generation & System Boot

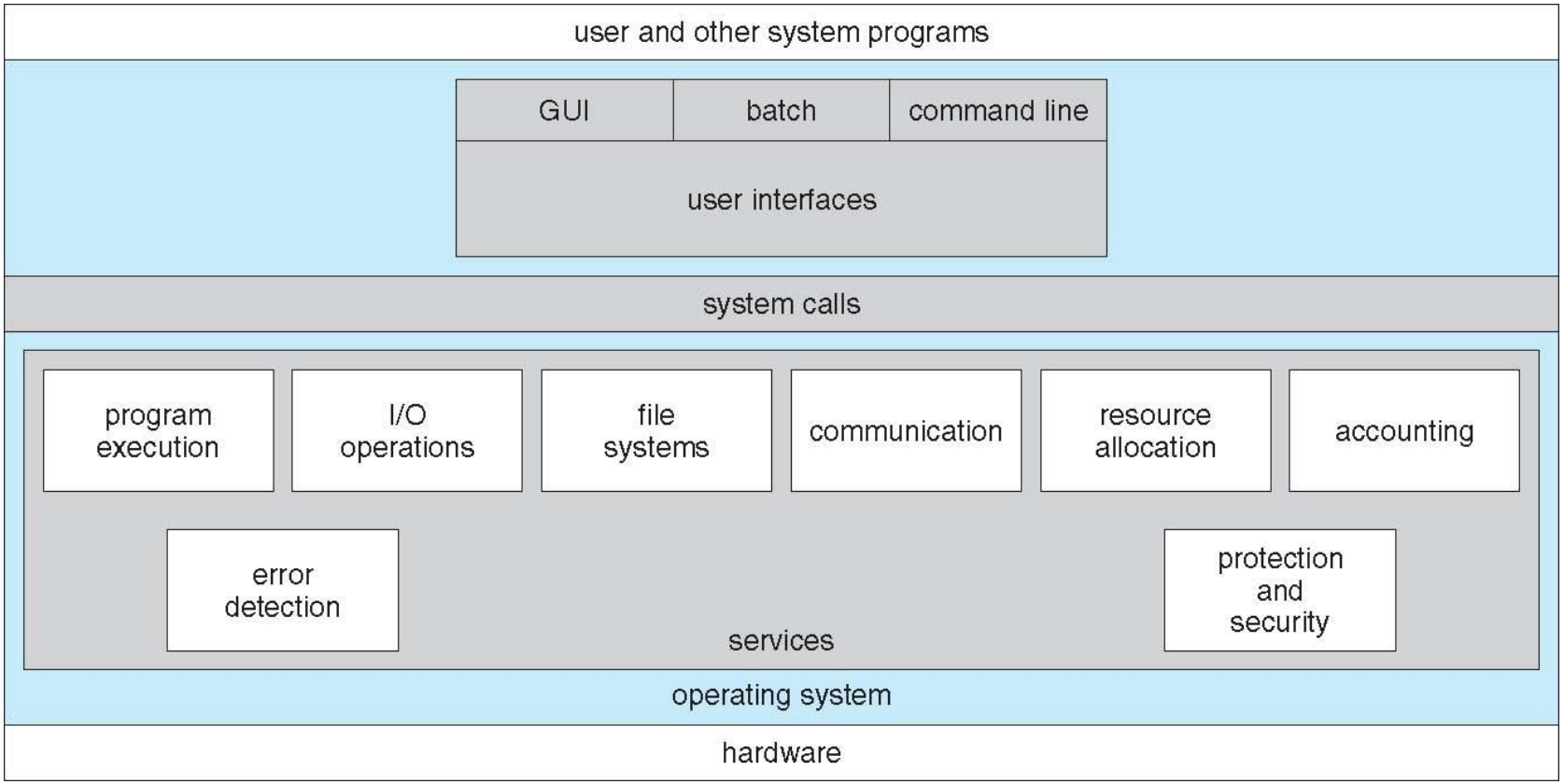
Operating System Services

Services Overview, User Interface

Operating System Services

- Operating systems provide
  - an environment for execution of programs and
  - services to programs and users
- Services may differ from one OS to another
- What are the common classes?
  - Convenience of the user
  - Efficiency of the system

Overview of Operating System Services



OS Services for Helping Users

- **Program execution**
  - Load a program into memory
  - Run the program
  - End execution
    - either normally or
    - abnormally (indicating error)

OS Services for Helping Users

- **I/O operations** - A running program may require I/O, which may involve a file or an I/O device
  - Common I/Os: read, write, etc.
  - Special functions: recording CD/DVD

- Notes: Users usually cannot control I/O devices directly, so OS provides a mean to do I/O
  - Mainly for efficiency and protection

OS Services for Helping Users

- **File-system manipulation** - The file system is of particular interest
  - OS provides a variety of file systems

- Major services
  - read and write files and directories
  - create and delete files and directories
  - search for a given file
  - list file Information
  - permission management: allow/deny access

OS Services for Helping Users

- **Communications**: information exchange between processes
  - Processes on the same computer
  - Processes between computers over a network

- Implementations
  - Shared memory
    - Two or more processes read/write to a shared section of mem.
  - Message passing
    - Packets of information are moved between processes by OS

OS Services for Helping Users

- **Error detection** – OS needs to be constantly aware of possible errors
- Error types
  - CPU
  - memory hardware: memory error, power failure, etc.
  - I/O devices: parity error, connection failure, etc.
  - user program: arithmetic overflow, access illegal mem.
- Error handling
  - Ensure correct and consistent computing
  - Halt the system, terminate an error-causing process etc.

OS Services for Ensuring Efficiency

- Systems with multiple users can gain efficiency by sharing the computer resources
- **Resource allocation**
  - Resources must be allocated to each user/job
  - Resource types - CPU cycles, main memory, file storage, I/O devices
  - Special allocation code may be required, e.g., CPU scheduling routines depend on
    - Speed of the CPU, jobs, number of registers, etc.

OS Services for Ensuring Efficiency

- **Accounting -** To keep track of
  - which users use how much and what kinds of resources
- Usage
  - Accounting for billing users
  - Accumulating usage statistics, can be used for
    - Reconfiguration of the system
    - Improvement of the efficiency

OS Services for Ensuring Efficiency

- **Protection and security**
  - Concurrent processes should not interfere w/ each other
  - Control the use of computer
- **Protection**
  - Ensure that all access to system resources is controlled
- **Security**
  - User authentication by password to gain access
  - Extends to defending external I/O devices from invalid access attempts

OS Services for Helping Users

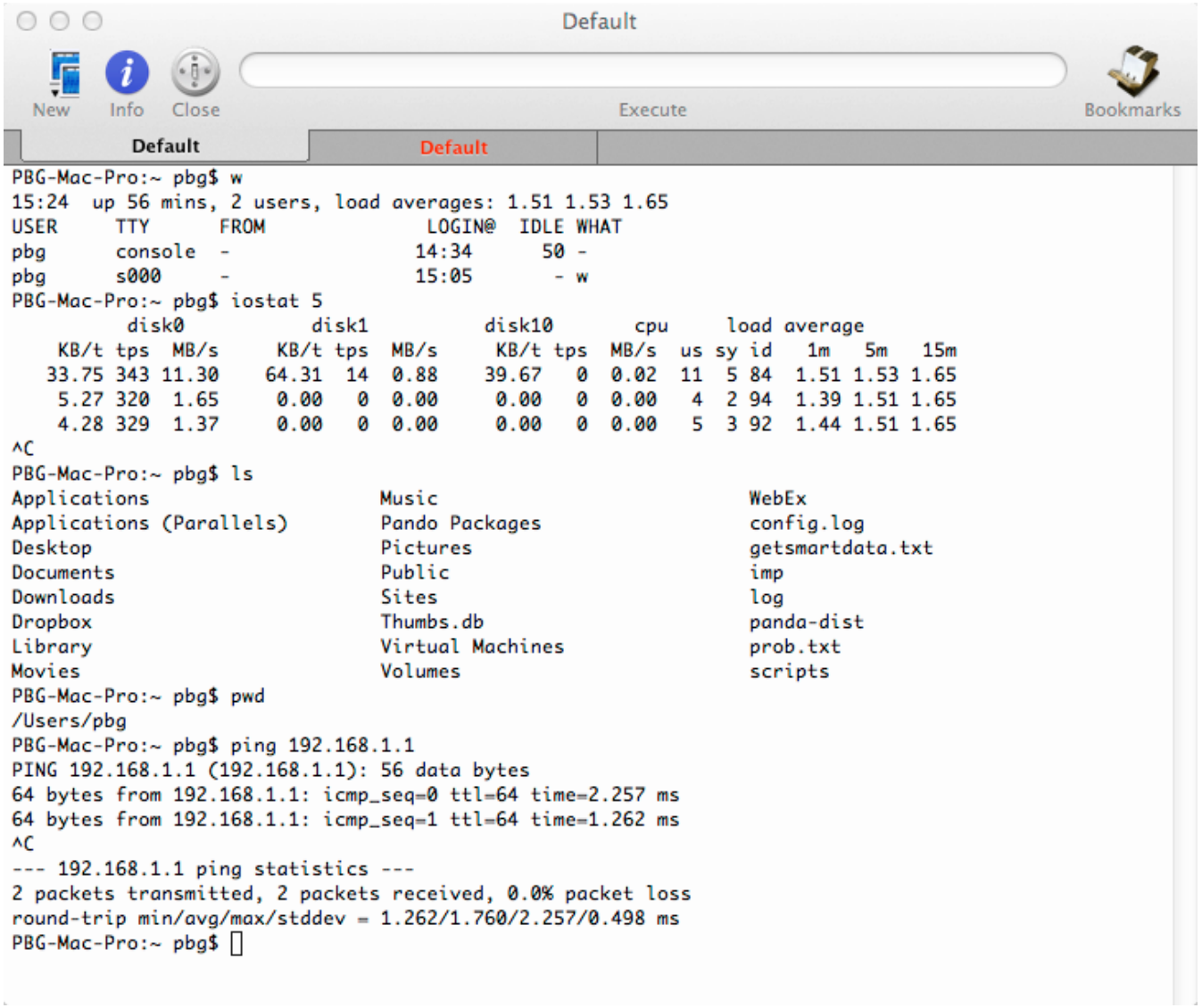
- **User interface** - Almost all operating systems have a user interface (**UI**).
  - Three forms
    - **Command-Line** (**CLI**)
      - Shell command
    - **Batch**
      - Shell script
    - **Graphics User Interface** (**GUI**)
      - Windows system

User Operating System Interface - CLI

- Command line interface or command interpreter
  - Allows direct command entry
  - Included in the kernel or treated as a special program

- Sometimes multiple flavors implemented – **shells**
  - Linux: multiple shells (C shell, Korn Shell etc.)
  - Third-party shell or free user-written shell
  - Most shells provide similar functionality (personal preference)

Bourne Shell Command Interpreter



User Operating System Interface - CLI

- Main function of CLI
  - Get and execute the next user-specified command
  - Many commands manipulate files
- Two ways of implementing commands
  - The command interpreter itself contains the code
    - Jump to a section of its code & make appropriate system call
    - Number of commands determines the size of CLI
  - Implements commands through system program (UNIX)
    - CLI does not understand the command
    - Use the command to identify a file to be loaded into memory and executed
    - Exp: rm file.txt (search for file rm, load into memory and exe w/ file.txt)
    - Add new commands easily

User Operating System Interface - GUI

- User-friendly graphical user interface
  - Mouse-based window-and-menu system (desktop metaphor)
  - **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 in early 1970s
- 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
  - Unix and Linux have CLI with optional GUI interfaces (CDE, KDE, GNOME)

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

Choices of Interfaces

- Personal preference
- CLI: more efficient, easier for repetitive tasks
  - System administrator
  - Power users who have deep knowledge of a system
  - Shell scripts
- GUI: user-friendly
- The design and implementation of user interface is not a direct function of the OS

System Call

Usage, Implementation, Types

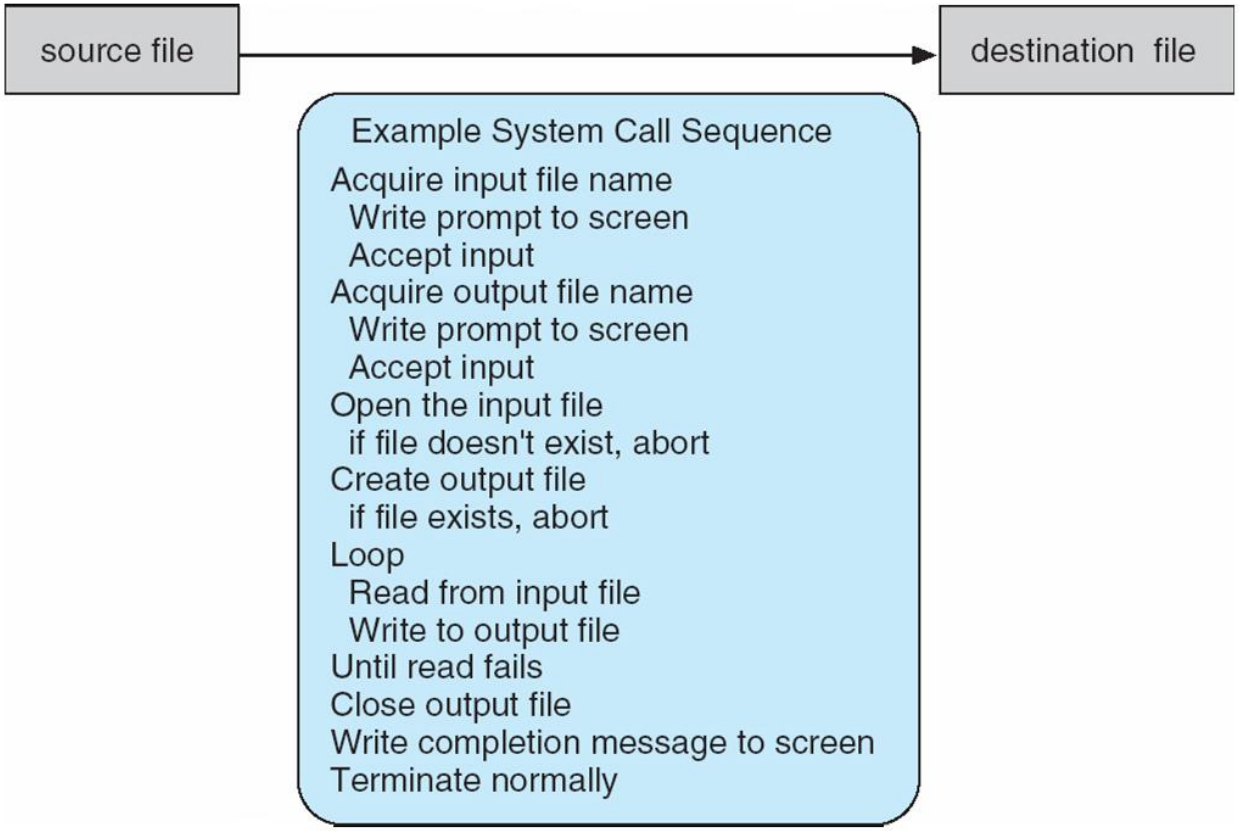
System Calls

- Programming interface to the services provided by the OS
- Implementation language
  - Typically written in a high-level language (C or C++)
  - Certain low-level tasks (direct hardware access) are written using assembly language

- Example of using system call
  - Read data from a file and copy to another file
  - open()+ read() + write()?

Example of System Calls

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



System Call

- Simple programs may make heavy use of the OS
  - A system executes thousands of system calls per second
  - Not user-friendly
- Each OS has its own name for each system call
  - This course/textbook uses generic examples

System Call

- How to use?
  - Mostly accessed by programs via a high-level **API** rather than direct system call use

- Why prefer API rather than invoking system call?
  - Easy of use
    - Simple programs may make heavy use of the OS
  - Program portability
    - Compile and run on any system that supports the same API

API

- **Application Programming Interface (API)**
  - A set of functions that are available to application programmers

EXAMPLE OF STANDARD API

As an example of a standard API, consider the `read()` function that is available in UNIX and Linux systems. The API for this function is obtained from the `man` page by invoking the command

```
man read
```

on the command line. A description of this API appears below:

```
#include <unistd.h>

ssize_t     read(int fd, void *buf, size_t count)
```

return value — function name — parameters

A program that uses the `read()` function must include the `unistd.h` header file, as this file defines the `ssize_t` and `size_t` data types (among other things). The parameters passed to `read()` are as follows:

- `int fd`—the file descriptor to be read
- `void *buf`—a buffer where the data will be read into
- `size_t count`—the maximum number of bytes to be read into the buffer

On a successful read, the number of bytes read is returned. A return value of 0 indicates end of file. If an error occurs, `read()` returns −1.

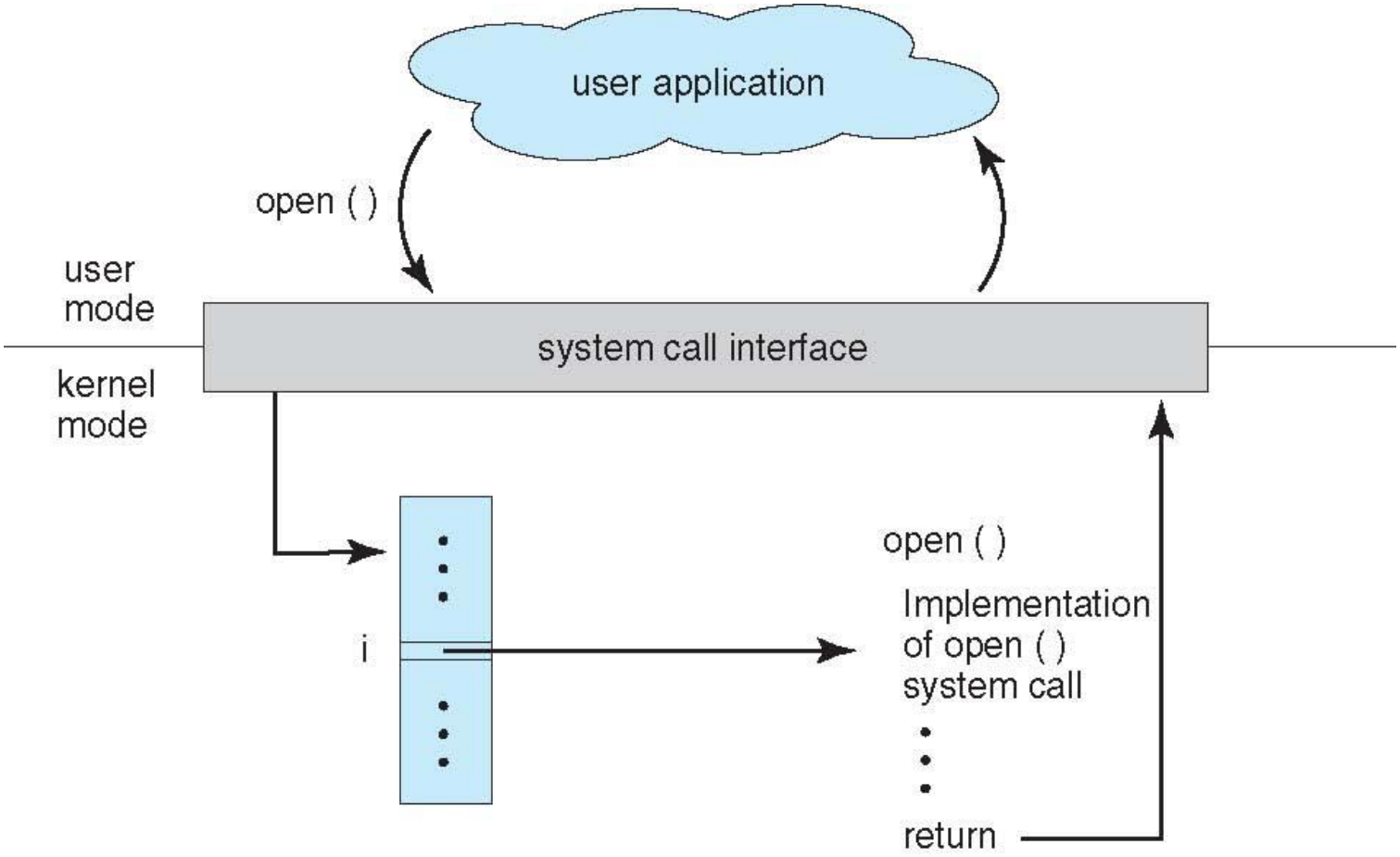
API

- **Application Programming Interface (API)**
  - A set of functions that are available to application programmers
- 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)
- How to use API?
  - Via a library of code provided by OS
  - Libc: UNIX/LINUX with C language

System Call Implementation

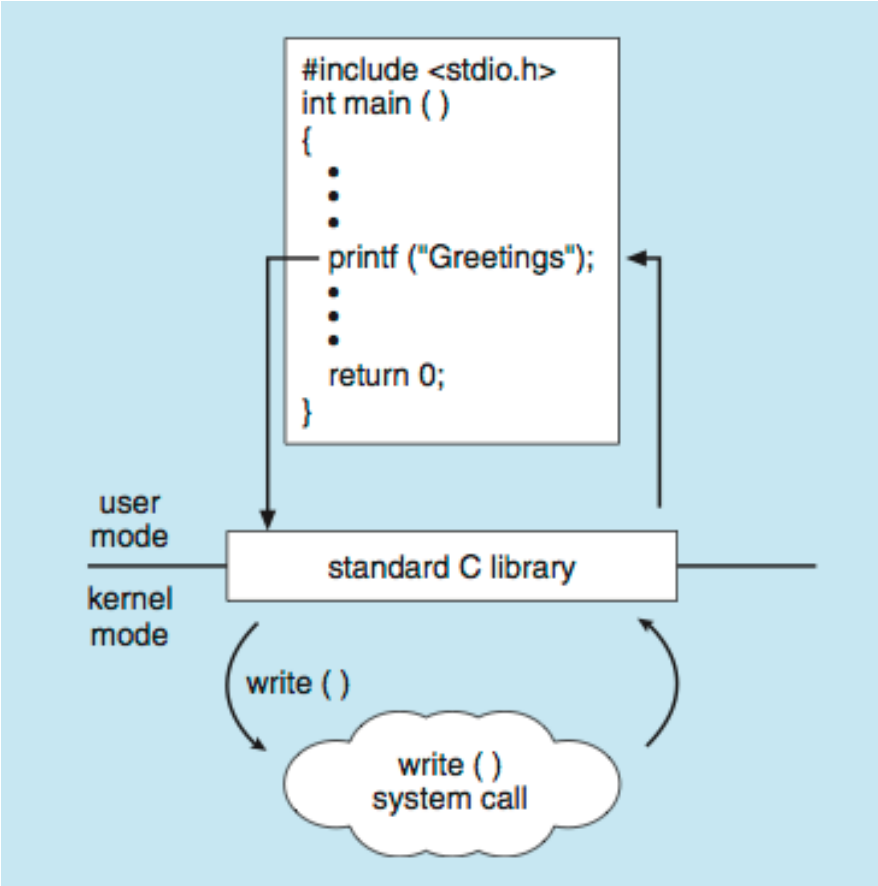
- Who invokes system call: System call interface
  - Provided by the run-time support system, which is
  - a set of functions built into libraries within a compiler
- How?
  - intercepts function calls in the API
  - invokes necessary system calls
- Implementation
  - Typically, a number associated with each system call
  - System-call interface maintains a table indexed according to the numbers

API – System Call – OS Relationship



Standard C Library Example

- C program invoking `printf()` library call, which calls `write()` system call



Implementation Benefits

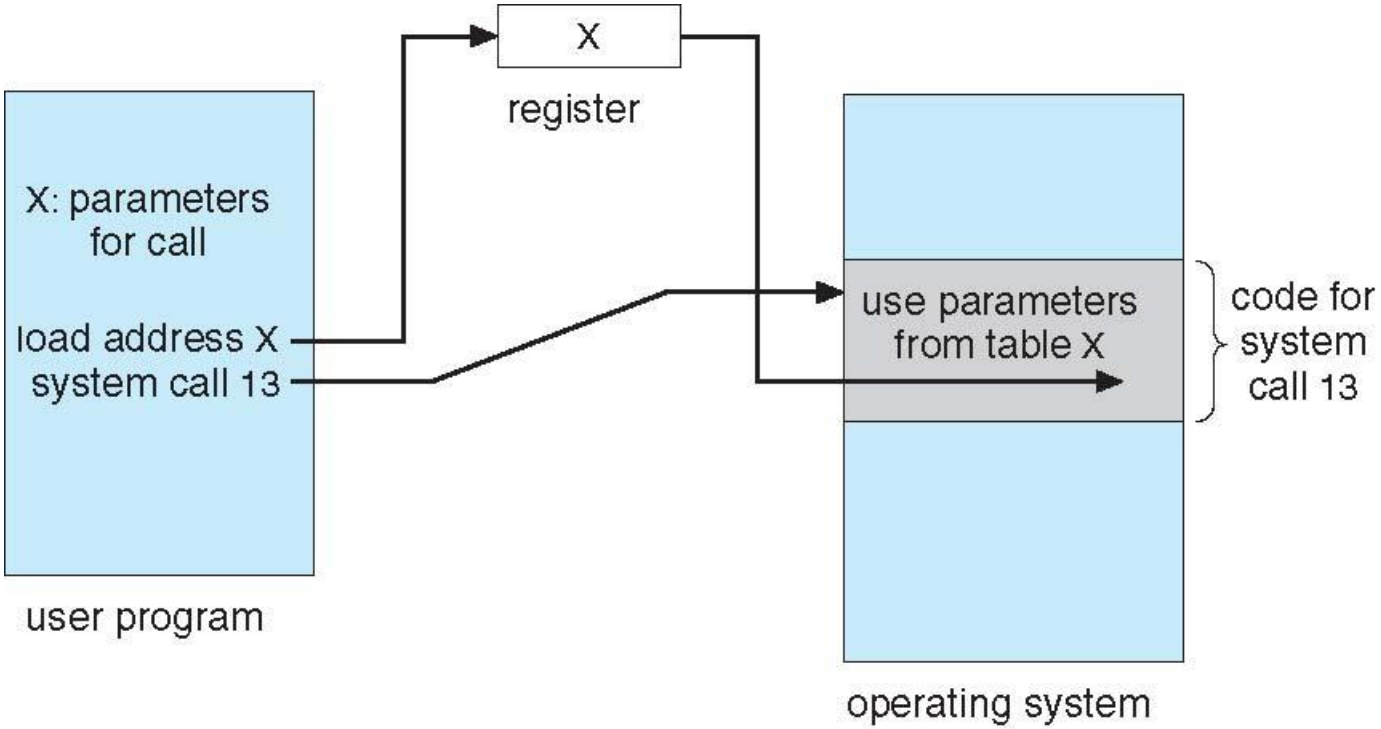
- The caller needs to know nothing about
  - how the system call is implemented
  - what it does during execution
  - Just needs to obey API and understand what OS will do as a result call

- Most details of OS interface are hidden from programmer by API
  - Managed by run-time support library

System Call Parameter Passing

- More information is required than simply the identity of desired system call
  - Parameters: file, address and length of buffer
- Three methods to pass parameters to the OS
  - Simplest: pass the parameters in registers
    - In some cases, may be more parameters than registers
  - Table-based
    - 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
  - Stack-based
    - Parameters are placed, or **pushed**, onto the **stack** by the program and **popped** off the stack by the operating system

Parameter Passing via Table



Types of System Calls

- Six major categories
  - Process control
  - File manipulation
  - Device manipulation
  - Information maintenance
  - Communications
  - Protection

Types of System Calls

- Process control
  - `end(), abort()`
    - Halt a running program normally or abnormally
    - Transfer control to invoking command interpreter
    - Memory dump & & error message
      - Written to disk and examined by debugger
      - Respond to error: alert window (GUI system) or terminate the entire job (batch system)
    - Error level: normal termination (level 0)

Types of System Calls

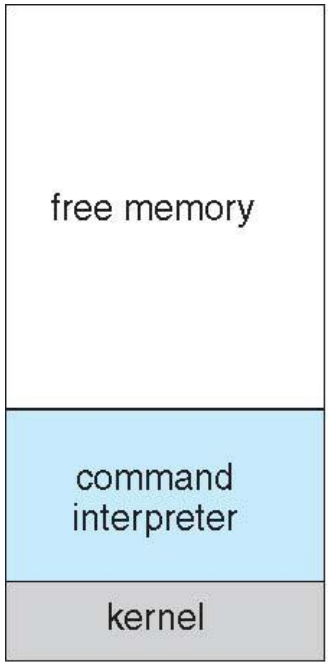
- Process control
  - `end(), abort()`
  - `load(), execute()`
    - Where to return?
      - Return to existing program: save mem. image
      - Both programs continue concurrently: multiprogram
  - `create_process(), terminate_process()`
  - `get_process_attributes(), set_process_attributes()`
    - Job's priority, maximum allowable execution time, etc

Types of System Calls

- Process control
  - `end(), abort()`
  - `load(), execute()`
  - `create_process(), terminate_process()`
  - `get_process_attributes(), set_process_attributes()`
  - `wait_time()`
  - `wait_event(), signal_event()`
  - `acquire_lock(), release_lock()`

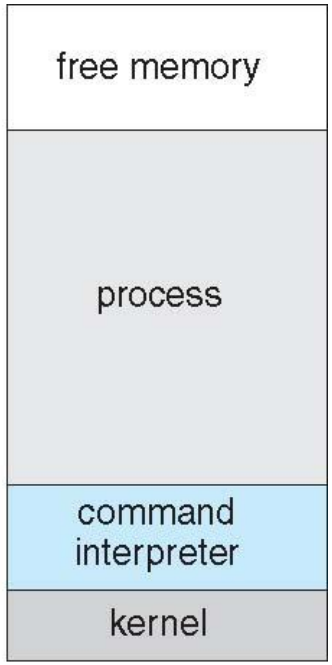
Example of Process Control: MS-DOS

- 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

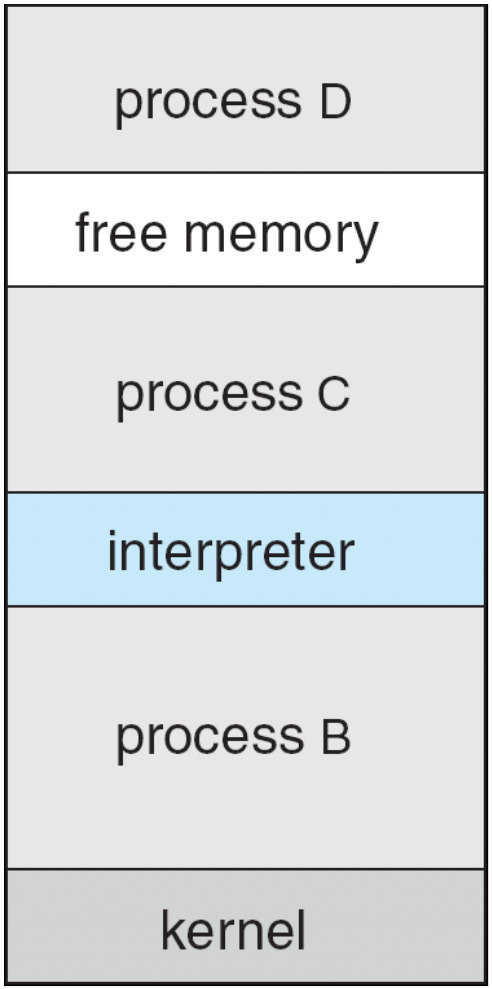


(b)

running a program

Example of Process Control: 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 = 0 – no error
  - code > 0 – error code



Types of System Calls

- File management
  - create file, delete file
  - open, close file
  - read, write, reposition
  - get and set file attributes
- Device management: physical/virtual devices
  - 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
    - Num. of current users, os version, amount of free mem. & disk
  - Debugging
    - Dump memory
    - Single-step execution
    - Time profile: timer interrupt
      - The amount of time that the program executes at a particular location

Types of System Calls

- Communications
  - Message-passing model
    - Host name, IP, process name
    - `Get_hostid(), get_processid(), open_connection(), close_connection(), accept_connection(), read_message(), write_message()`
    - Useful for exchanging smaller amounts of data
  - Shared-memory model
    - Remove the normal restriction of preventing one process from accessing another process's memory
    - Create and gain access to shared mem. region
      - `shared_memory_create(), shared_memory_attach()`
    - Threads: memory is shared by default
    - Efficient and convenient, having protection and synchronization issues

Types of System Calls

- Protection
  - Control access to resources
  - All computer systems must be concerned
  - Permission setting
    - `get_permission(), set_permission()`
  - Allow/deny access to certain resources
    - `allow_user(), deny_user()`

Examples of Windows and Unix System Calls

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

https://www.kernel.org/doc/man-pages/
http://man7.org/linux/man-pages/

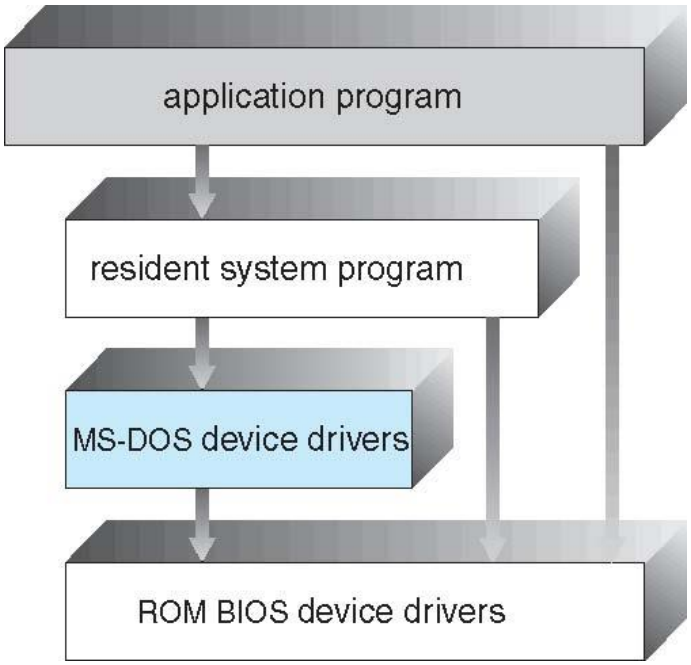
Operating System Structures

Operating System Structure

- General-purpose OS is a very large program
- Various ways to structure ones
  - Simple structure – MS-DOS
  - Monolithic-- UNIX
  - Layered – an abstraction
  - Microkernel –Mach
  - Modules
  - Hybrid system – most OSes

Simple Structure -- MS-DOS

- MS-DOS – written to provide the most functionality in the least space
  - Do not have well-defined structures
  - Not divided into modules
  - Its interfaces and levels of functionality are not well separated
    - Application programs can access basic I/O routines
    - Vulnerable to errant programs
    - Limited by hardware

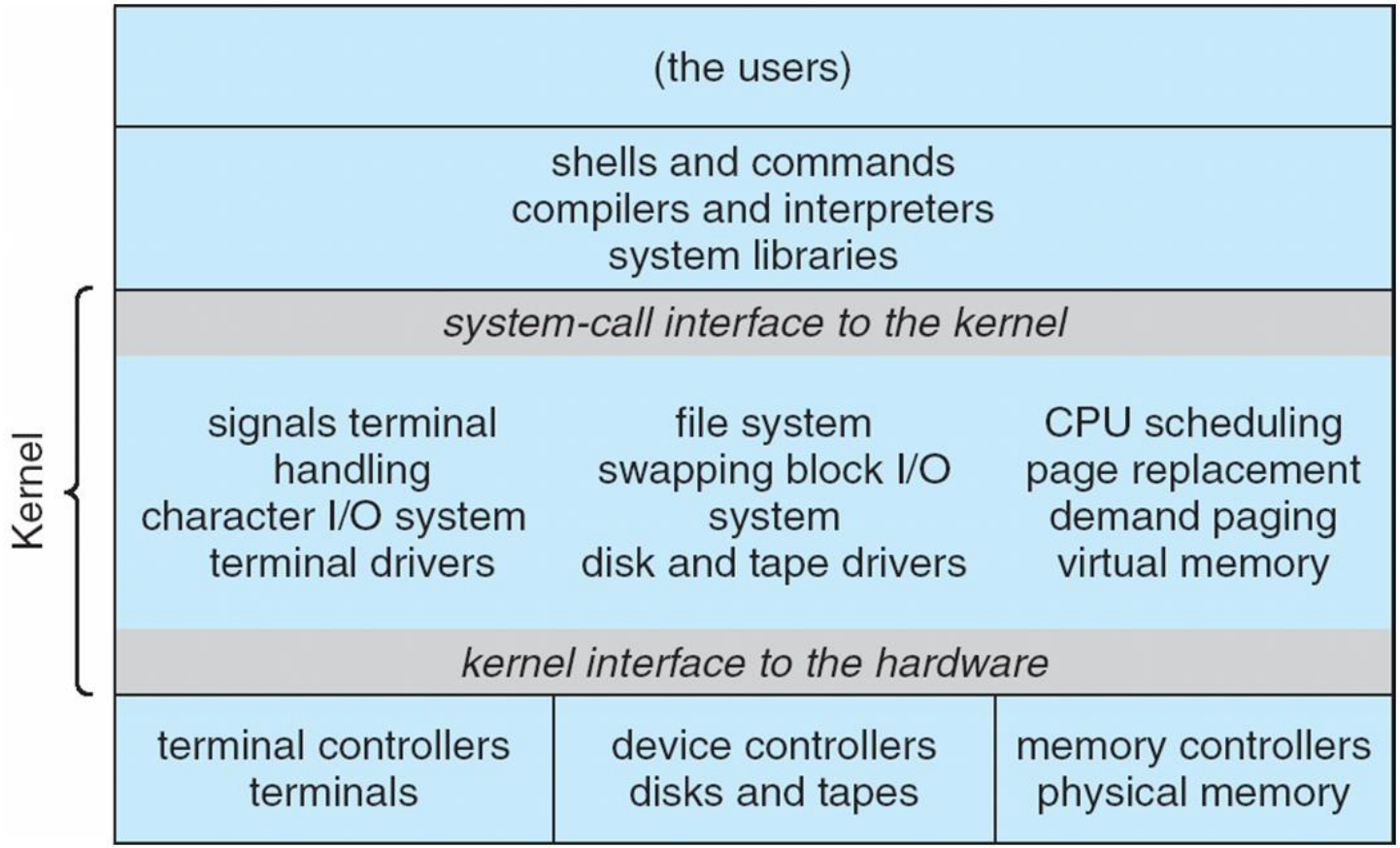


Monolithic Structure -- UNIX

- UNIX
  - The original UNIX operating system had limited structuring, it consists of two separable parts
    - Systems programs
    - The kernel
      - Consists of everything below the system-call interface and above the physical hardware
      - A series of interfaces and device drivers
  - Monolithic structure: combine all functionality in one level
    - File system, CPU scheduling, memory management, and other operating-system functions
    - Difficult to implement and maintain
    - Performance advantage

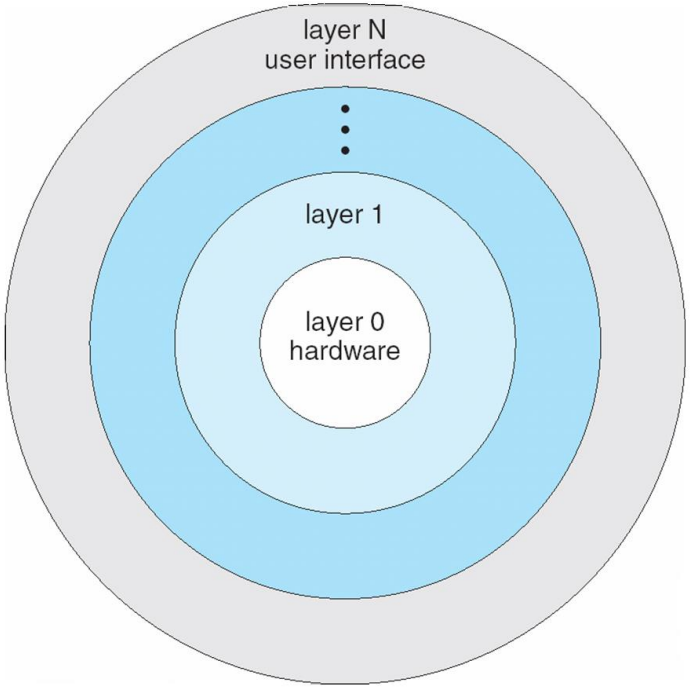
Traditional UNIX System Structure

- Beyond simple but not fully layered



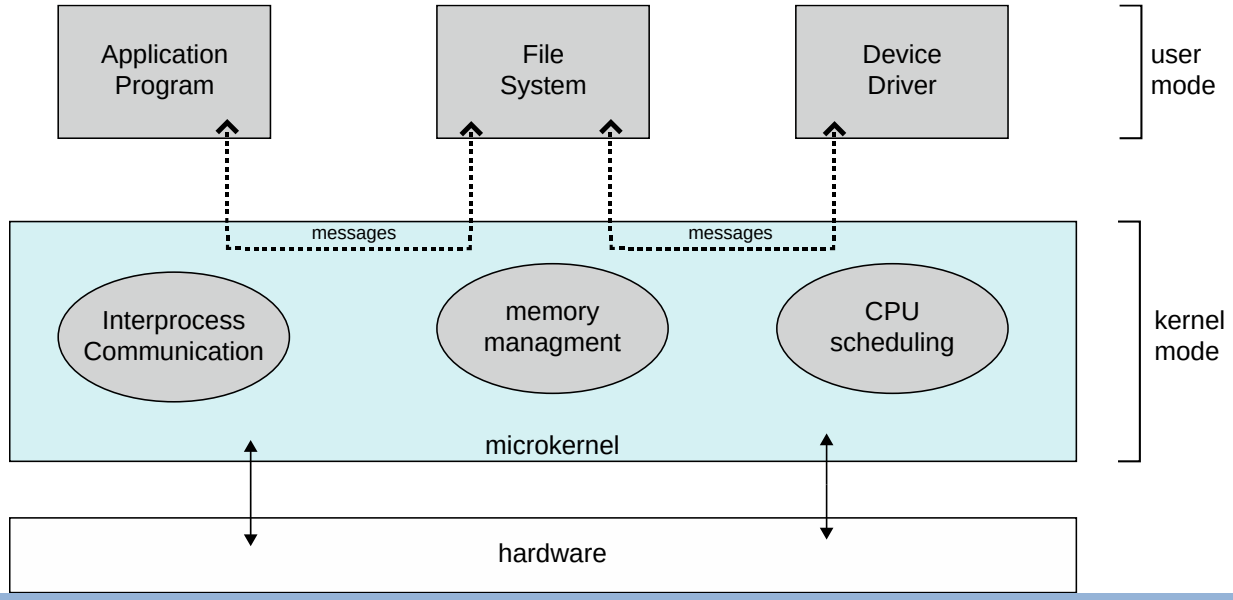
Layered Approach

- The operating system is divided into a number of layers (levels), each built on top of lower layers
  - The bottom layer (0), is the hardware; the highest layer (N) is the user interface
- Implementation
  - Each layer is an implementation of an abstract object made up of data and operations
- Advantages
  - Simple to construct and debug
  - Hides the existence of DS, Ops, hardware from upper layers
- Challenges
  - How to define various layers?
  - Efficiency problem
    - I/O->memory manage->CPU scheduling->hardware



Microkernel System Structure

- Moves as much from the kernel into user space as possible
  - Provides minimal process, memory management and communication
  - **Mach:** example of **microkernel** (developed by CMU in mid-1980s)
    - Mac OS X kernel (**Darwin**) partly based on Mach
- Main function
  - Communication between client program and services (also in user space)
  - Provided through **message passing**



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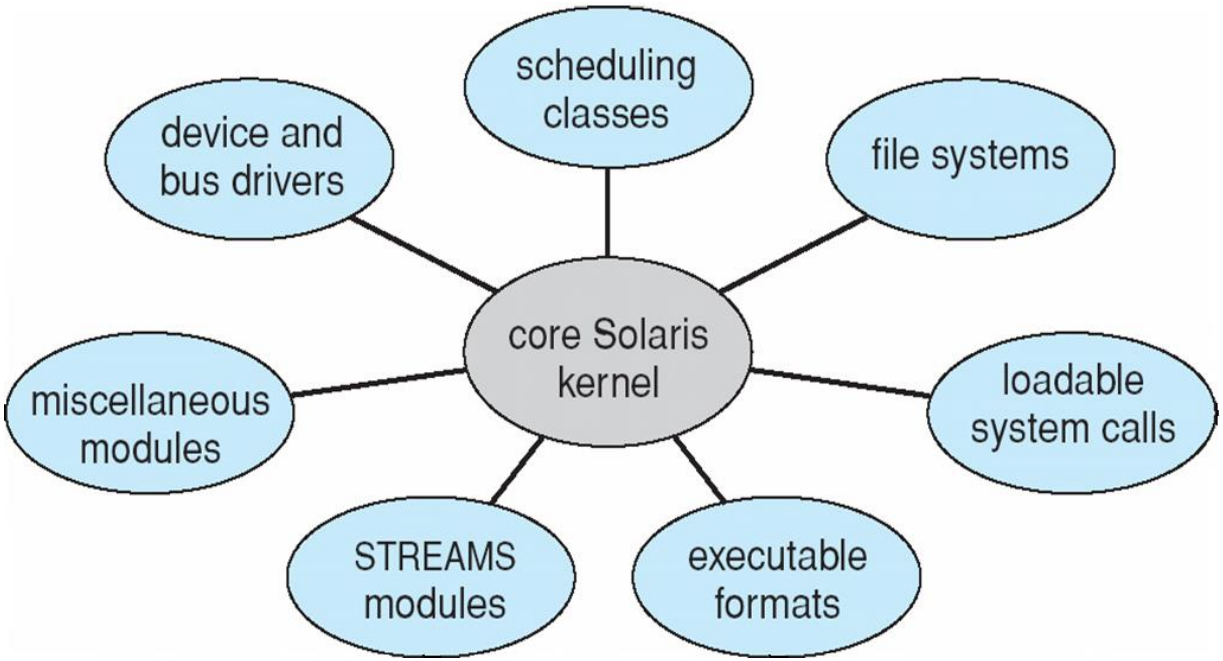
- Benefits
  - Easier to extend a microkernel: add services to user space, no changes to kernel
  - Easier to port the operating system to new architectures
  - More reliable & more secure(less code is running in kernel mode)
- Detriments
  - Performance overhead of user space to kernel space communication

Modules

- Many modern operating systems implement **loadable kernel modules**
  - The Kernel has a set of core components
  - Links in additional services via modules (boot time or run time)
  - Common in most modern OSes



Modules

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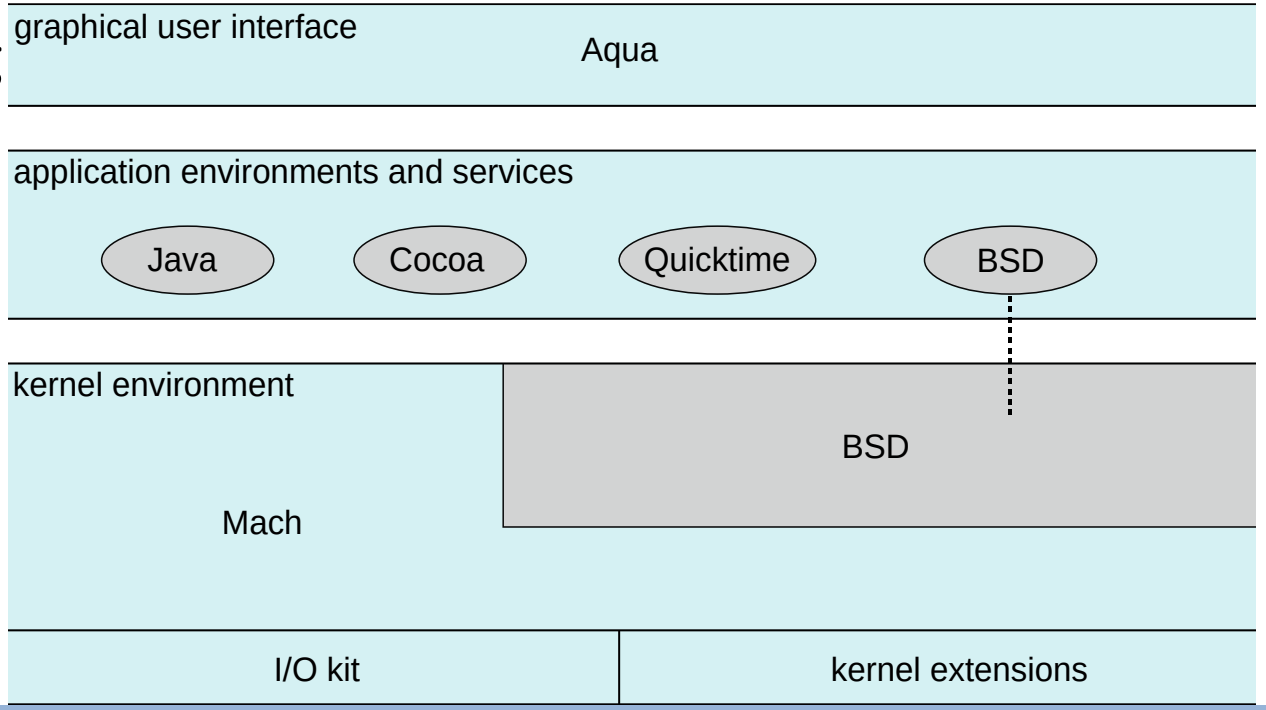
  - The Kernel has a set of core components
  - Links in additional services via modules (boot time or run time)
  - Common in most modern OSes
- Similar to layered system
  - Any module can call any other model
  - More flexible
- Similar to the microkernel
  - Primary module has only core functions
  - No need to invoke message passing
  - More efficient

Hybrid Systems

- Most modern operating systems combine different structures, resulting in hybrid systems
  - Why? Address performance, security, usability needs
- Examples
  - Linux kernel
    - Monolithic: single address space (for efficient performance)
    - Modular: dynamic loading of functionality
  - Windows
    - Mostly monolithic, plus microkernel for different subsystem personalities (running in user-mode), also support loadable kernel module
  - Apple Mac OS X
    - Mach microkernel, BSD Unix parts, plus I/O kit and dynamically loadable modules (called **kernel extensions**)

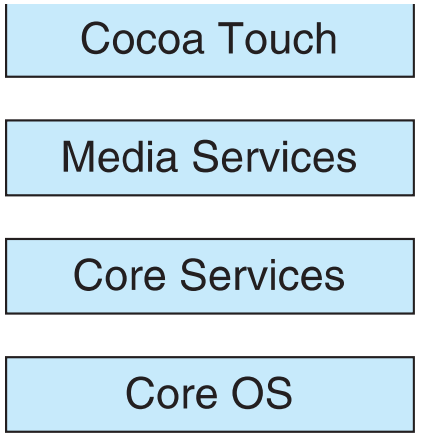
Mac OS X Structure

- Layered system: user interface + application environment & services + kernel (Mach+BSD UNIX)
- Mach Microkernel
  - Memory management
  - inter-process communication
  - Thread scheduling
- BSD UNIX
  - CLI
  - POSIX API
  - Networking
  - File system



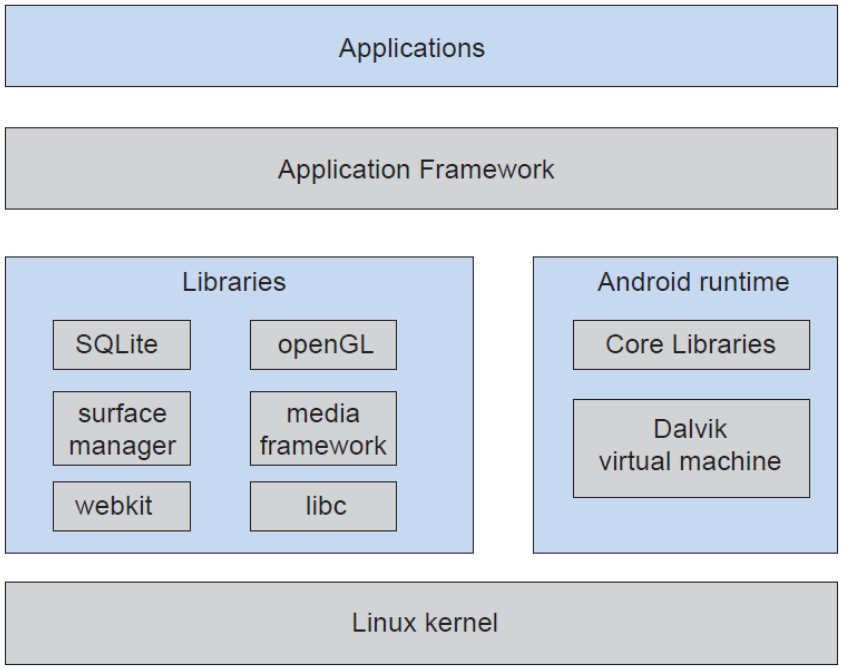
iOS

- 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)
- Structure
  - **Cocoa Touch** is 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)
  - Similar stack to IOS
  - Open Source
- Based on Linux kernel
  - Provides process, memory, device-driver management
- Optimization
  - Adds power management



Operating System Design and Implementation

Operating System Design and Implementation

- Design and Implementation of OS not “solvable”, but some approaches have proven successful
- First problem: Design goals and specifications
  - Affected by choice of hardware, type of system (batch, time-sharing, single/multiple users, distributed, real-time, etc)
  - User goals
    - Convenient to use, easy to learn, reliable, safe, and fast
  - System goals
    - Easy to design, implement, and maintain, as well as flexible, reliable, error-free, and efficient
  - No unique solution to the problem of defining the requirements

Operating System Design and Implementation

- Important principle to separate
  - **Mechanism**: ***How*** to do it?
  - **Policy**: ***What*** will be done?
- Examples
  - Timer mechanism (for CPU protection)
    - Policy decision: How long the timer is to be set?
  - Priority mechanism (in job scheduling)
    - Policy: I/O-intensive programs have higher priority than CPU-intensive ones or vice versa
- Benefits: maximum flexibility
  - Change policy without changing mechanism

OS Implementation

- Much variation
  - Early OSes in assembly language
  - Now C, C++
- Actually usually a mix of languages
  - Main body in C
  - Lowest levels in assembly
  - Systems programs in C, C++, scripting languages
- Pros and cons
  - Code can be written faster, easier to understand/debug
  - More high-level language, easier to **port** to other hardware
  - Slower & increased storage requirement

Implementation

- Performance?
  - Major performance improvements: better data structures and algorithms
  - How about developing excellent assembly-language code in OS implementation?
    - Modern compiler is well optimized
    - A small amount of the code is critical to performance, easy to do specialized optimization
      - Interrupt handler
      - I/O manager
      - Memory manager
      - CPU scheduler

MISC

Debugging, Generation, Booting

Operating-System Debugging

- Failure analysis
  - **log files**: written with error information when process fails
  - **core dump**: a capture of the memory of the processes
  - **crash dump**: memory state when OS crashes
- Performance tuning
  - ***Trace listings*** of system behavior
  - **Interactive tools**: top displays resource usage of processes

- Kernighan's Law
  - "Debugging is twice as hard as writing the code in the first place. Therefore, if you write the code as cleverly as possible, you are, by definition, not smart enough to debug it."

Operating System Generation

- Operating systems are designed to run on any of a class of machines
  - The system must be configured or generated for each specific computer site
- **SYSGEN** program obtains information concerning the specific configuration of the hardware system
  - Read from file, ask the operator or probe
  - Generation methods
    - Modify source code and completely recompile
    - Select modules from precompiled library and link together

System Boot

- System booting on most computer systems
  - Bootstrap program (residing in ROM) locates the kernel, loads it into memory, and starts it
    - ROM needs no initialization, cannot be easily infected by virus
    - Diagnostics to determine machine state
    - Initialization: CPU registers, device controllers, memory
  - Some use two-step process: a simple bootstrap loader fetches a more complex bootstrap program, which loads kernel (large OSes)
  - Some store the entire OS in ROM (Mobile OS)
- Common bootstrap loader allows selection of kernel from multiple disks, versions, kernel options (**GRUB**)

Summary

- Operating system services
- System calls
  - Relationship between system call and API
- Operating system structures
  - Modular is important
  - Generally adopt a hybrid approach
- Design principles
  - Separate policy from mechanism

Summary of Part I (Ch1 & Ch2)

- OS Overview
  - OS Functionality
  - Multiprogramming & Multitasking
- OS Operations
  - Dual Mode & System Call
- OS Components
  - Process Management
  - Memory Management
  - Storage Management
- Computing Environment

- Ch2 OS Structure
  - Operating system services
  - System calls
  - Operating system structures
  - Design principles
- Process management
  - Concept, scheduling, operation, communication, synchronization
- Memory management
  - Main memory, virtual mem
- Storage management
  - Storage, FS, I/O

End of Chapter 2