

# Chapter 2: Operating-System Structures

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Operating System Services

User Operating System Interface

System Calls

Types of System Calls

System Programs

Operating System Design and Implementation

Operating System Structure

Operating System Debugging

Operating System Generation

System Boot





# Objectives

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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

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Operating systems provide an environment for execution of programs and services to programs and users

One set of operating-system services provides functions that are 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





# Operating System Services (Cont.)

One set of operating-system services provides functions that are helpful to the user (Cont.):

**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

- ▶ Communications may be via **shared memory** or **through message passing** (packets moved by the OS)

**Error detection** – OS needs to be constantly aware of possible errors

- ▶ May occur in the CPU and memory **hardware**, in I/O devices, in user program
- ▶ For each type of error, OS should take the appropriate action to ensure correct and consistent computing
- ▶ Debugging facilities can greatly enhance the user's and programmer's abilities to efficiently use the system





# Operating System Services (Cont.)

Another set of OS functions exists for ensuring **the efficient operation of the system itself** via resource sharing

**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

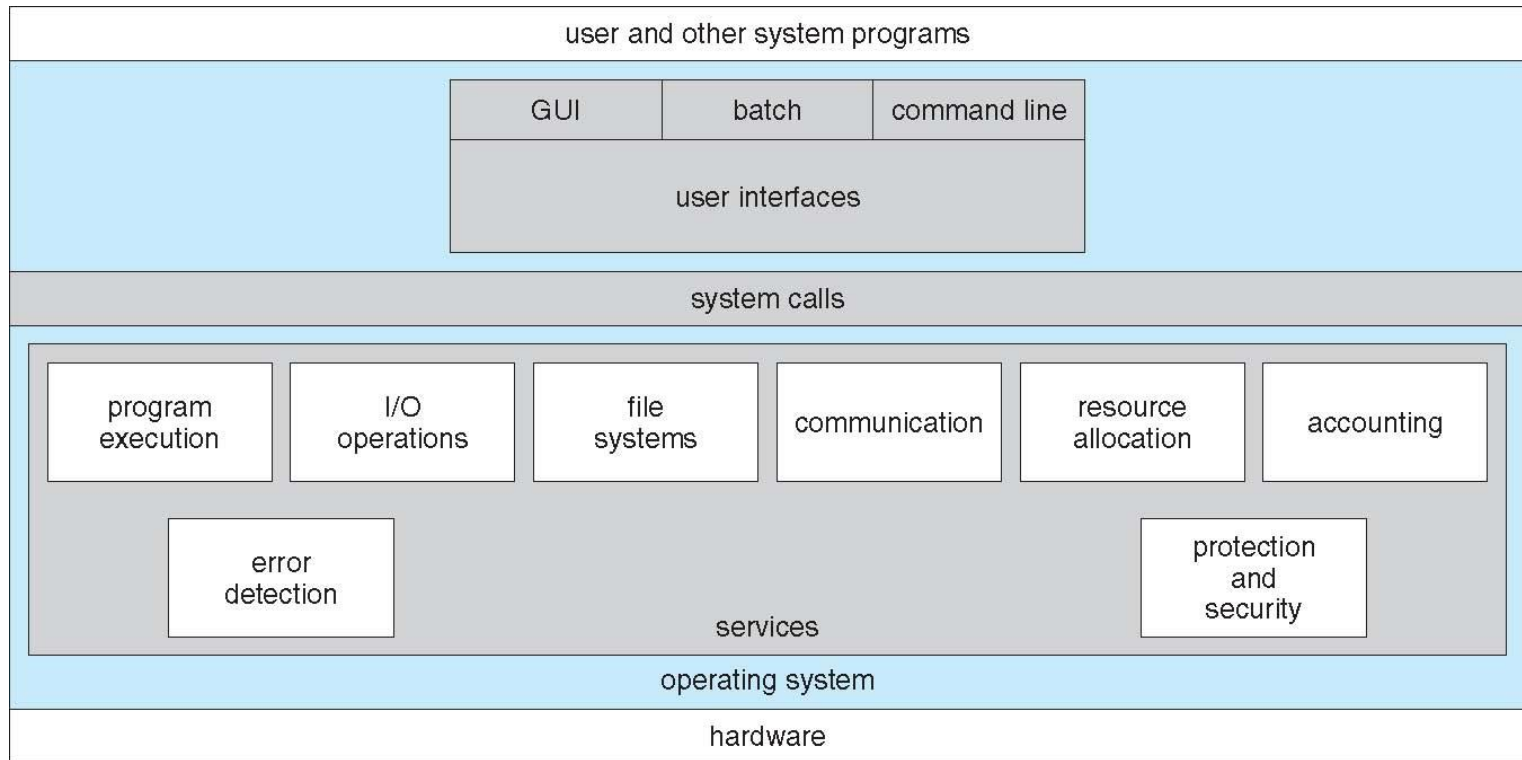
**Protection and security** - The owners of information stored in a multiuser or networked computer system may want to control use of that information, concurrent processes should not interfere with each other

- ▶ **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





# A View of Operating System Services





# User Operating System Interface - CLI

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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







# Bourne Shell Command Interpreter

```

PBG-Mac-Pro:~ pbg$ w
15:24 up 56 mins, 2 users, load averages: 1.51 1.53 1.65
USER      TTY      FROM          LOGIN@  IDLE WHAT
pbg       console -              14:34    50 -
pbg       s000    -              15:05    - w
PBG-Mac-Pro:~ pbg$ iostat 5
            disk0            disk1            disk10            cpu            load average
      KB/t tps  MB/s      KB/t tps  MB/s      KB/t tps  MB/s  us sy id  1m  5m  15m
      33.75 343 11.30      64.31 14  0.88      39.67 0  0.02  11 5 84  1.51 1.53 1.65
      5.27 320  1.65        0.00 0  0.00        0.00 0  0.00   4 2 94  1.39 1.51 1.65
      4.28 329  1.37        0.00 0  0.00        0.00 0  0.00   5 3 92  1.44 1.51 1.65
^C
PBG-Mac-Pro:~ pbg$ ls
Applications          Music                  WebEx
Applications (Parallels)  Pando Packages        config.log
Desktop                Pictures               getsmartdata.txt
Documents              Public                 imp
Downloads              Sites                  log
Dropbox                Thumbs.db              panda-dist
Library                Virtual Machines       prob.txt
Movies                 Volumes                scripts
PBG-Mac-Pro:~ pbg$ pwd
/Users/pbg
PBG-Mac-Pro:~ pbg$ ping 192.168.1.1
PING 192.168.1.1 (192.168.1.1): 56 data bytes
64 bytes from 192.168.1.1: icmp_seq=0 ttl=64 time=2.257 ms
64 bytes from 192.168.1.1: icmp_seq=1 ttl=64 time=1.262 ms
^C
--- 192.168.1.1 ping statistics ---
2 packets transmitted, 2 packets received, 0.0% packet loss
round-trip min/avg/max/stddev = 1.262/1.760/2.257/0.498 ms
PBG-Mac-Pro:~ pbg$
```





# User Operating System Interface - GUI

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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

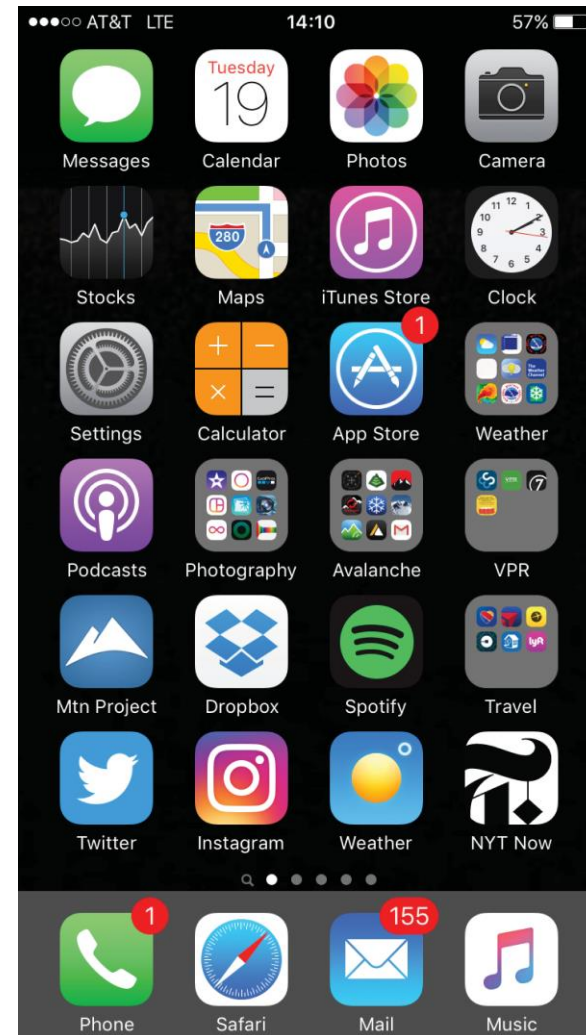
Unix and Linux have CLI with optional GUI interfaces (CDE, KDE, GNOME)





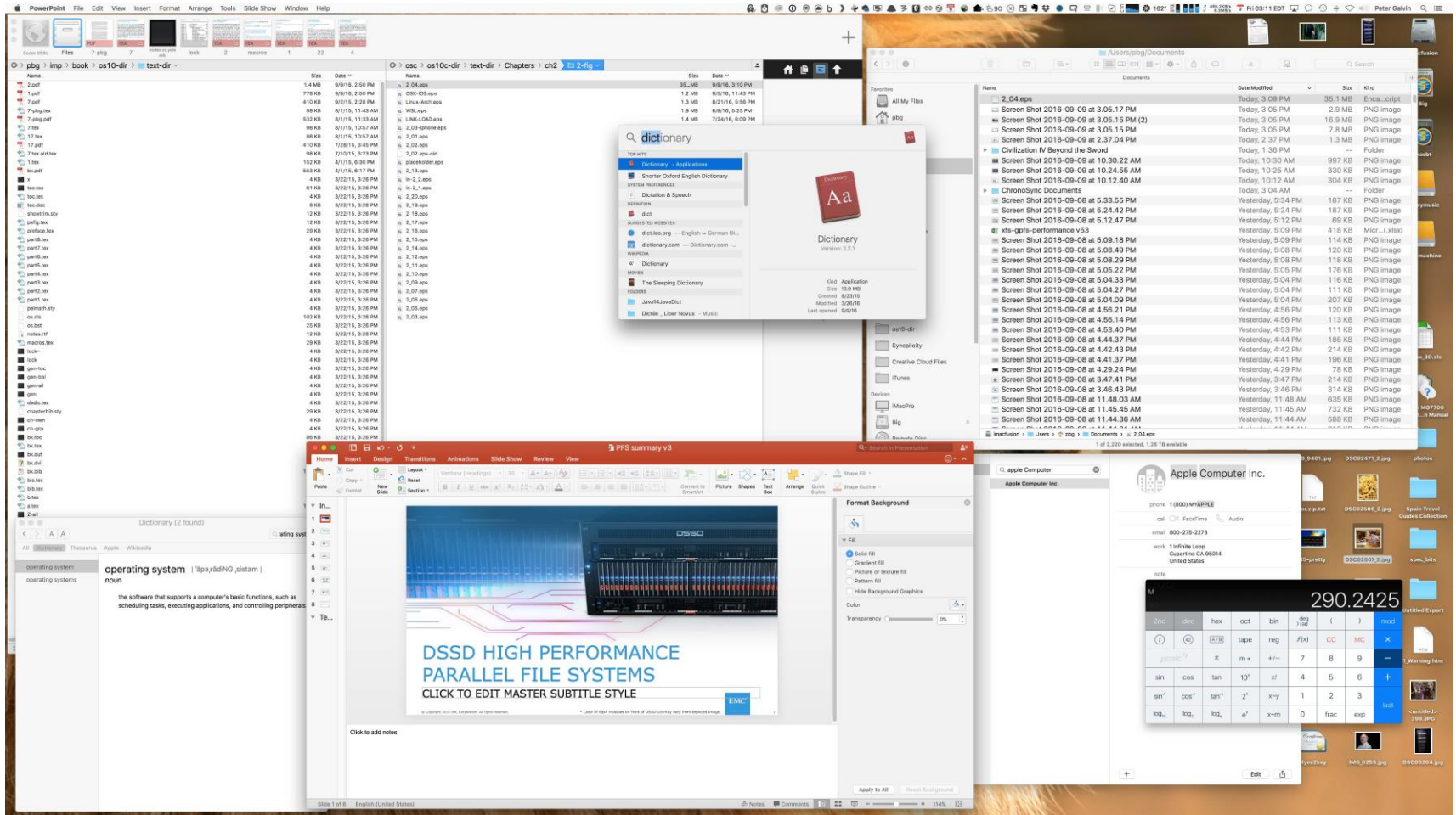
# Touchscreen Interfaces

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





# The Mac OS X GUI





# System Calls

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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 are Win32 API for Windows, POSIX API for POSIX-based systems (including virtually all versions of UNIX, Linux, and Mac OS X), and Java API for the Java virtual machine (JVM)

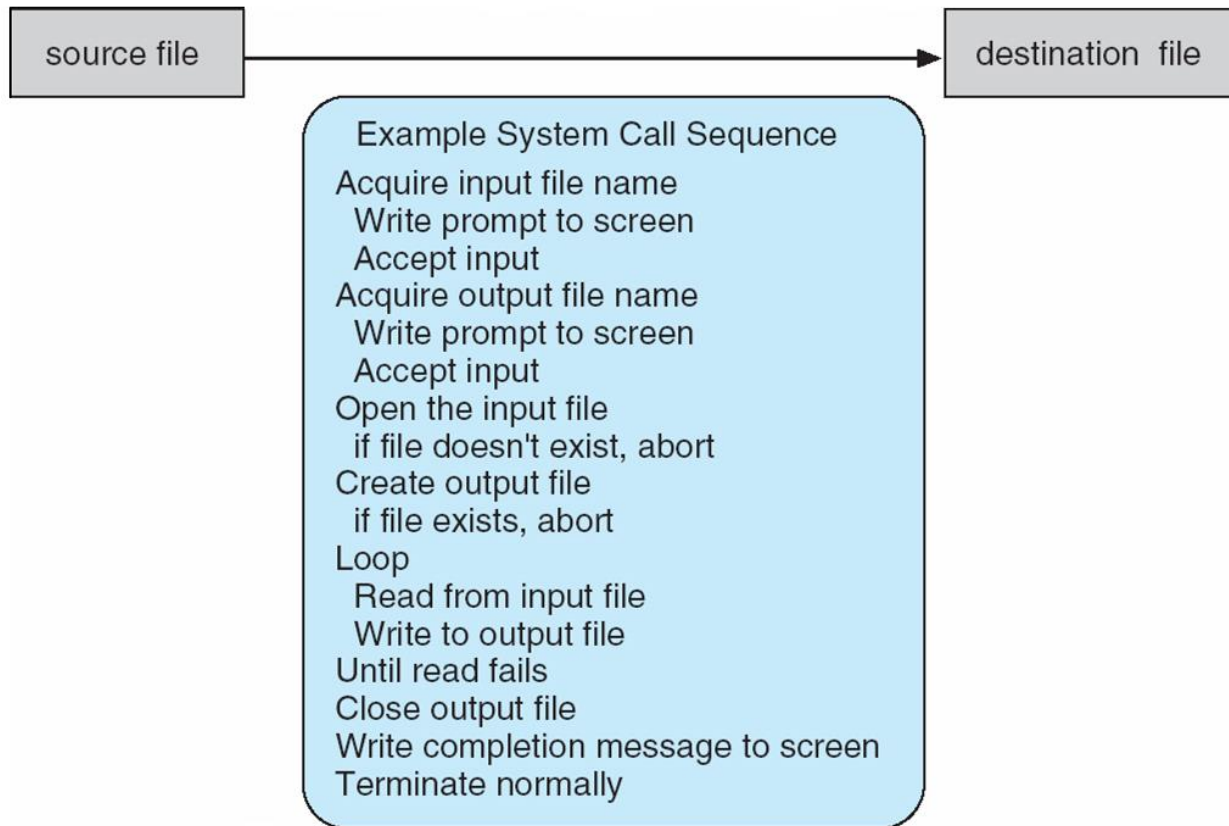
Note that the system-call names used throughout this text are generic





# Example of System Calls

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







# Example of Standard API

## 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)
```

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`.





# System Call Implementation

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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

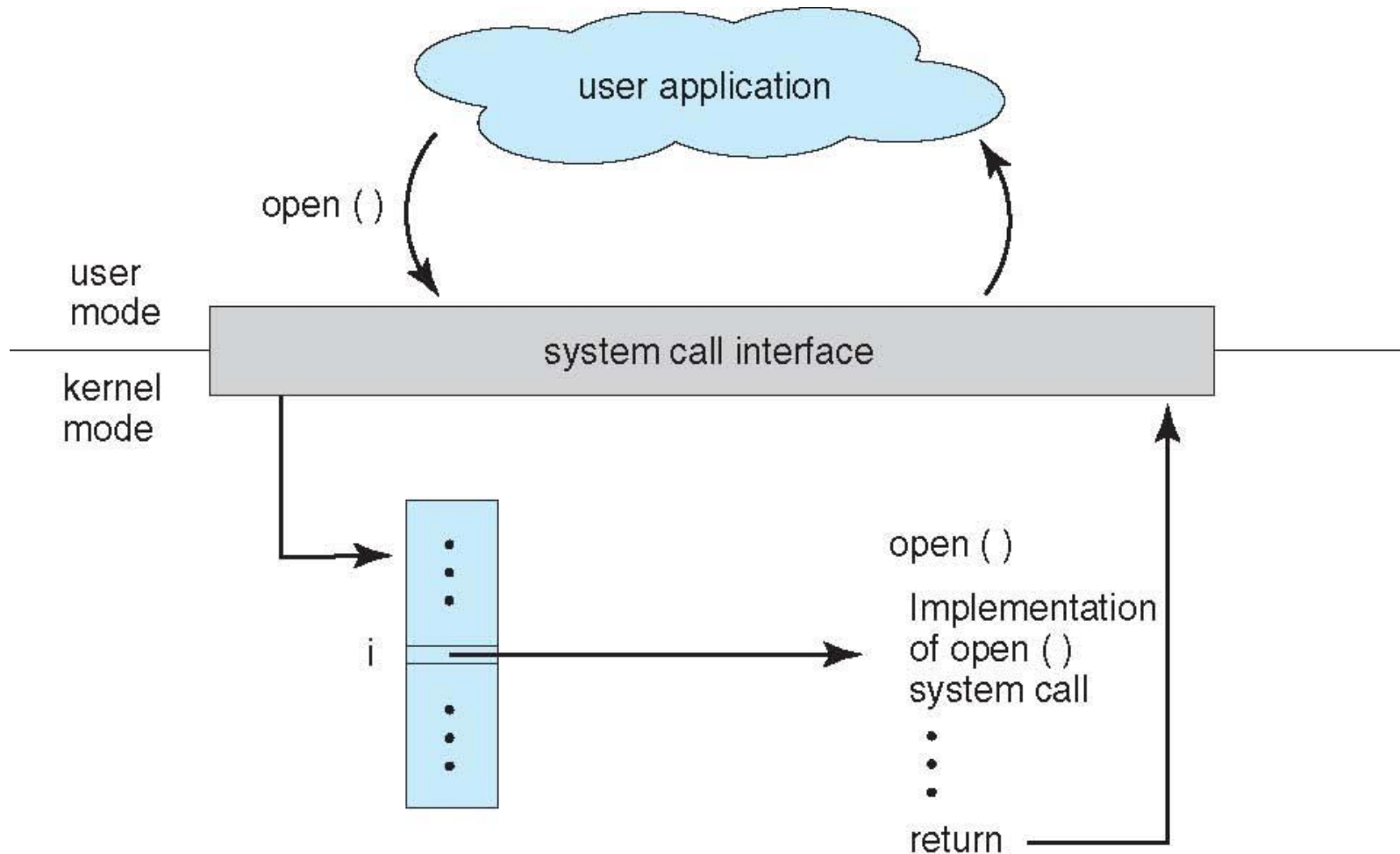
- ▶ Managed by run-time support library (set of functions built into libraries included with compiler)







# API – System Call – OS Relationship





# System Call Parameter Passing

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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

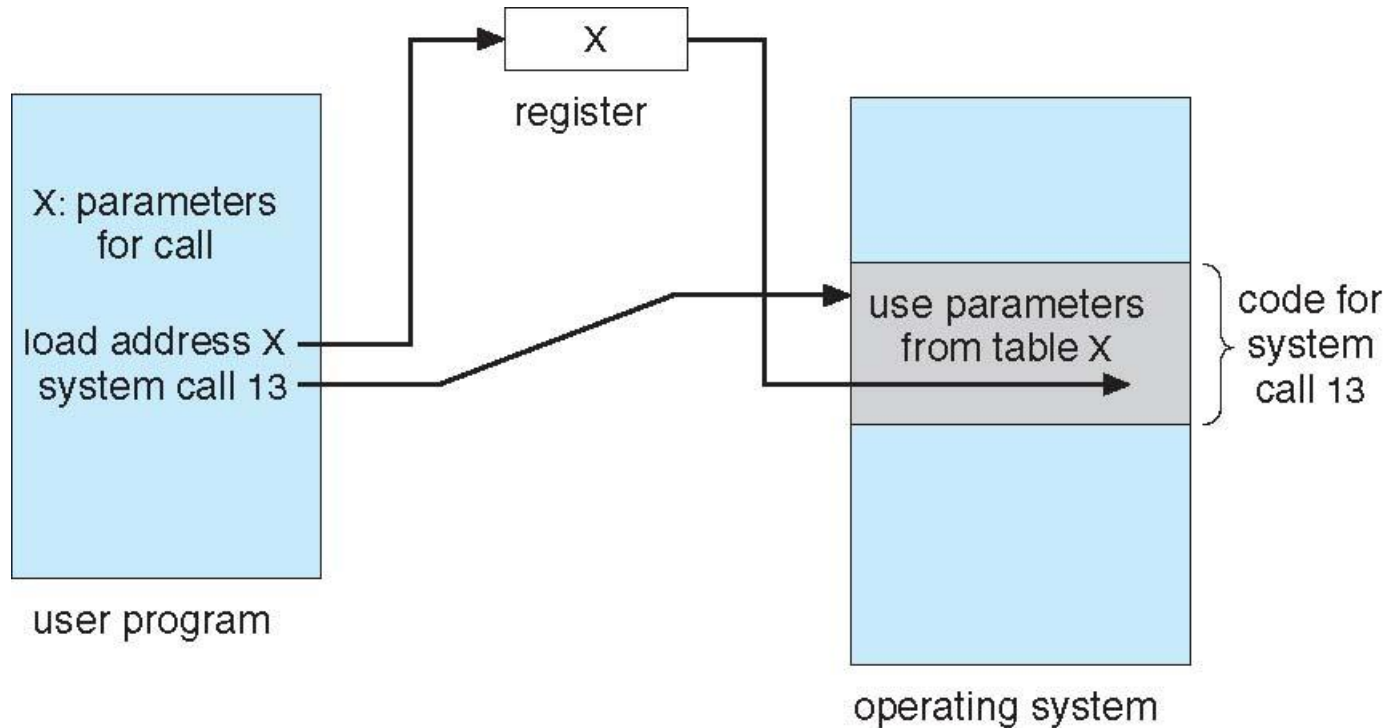
Parameters placed, or **pushed**, onto the **stack** by the program and **popped** off the stack by the operating system

Block and stack methods do not limit the number or length of parameters being passed





# Parameter Passing via Table





# Types of System Calls

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## 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

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## 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.)

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## 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.)

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## 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() 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() InitializeSecurityDescriptor() SetSecurityDescriptorGroup()	chmod() umask() chown()

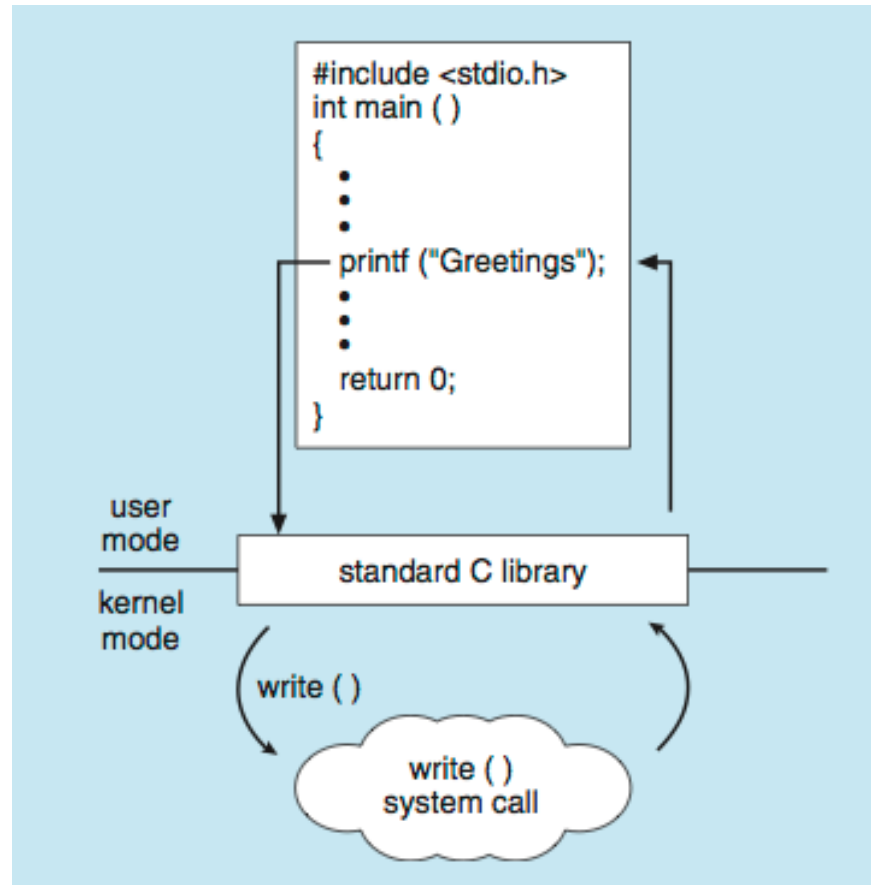






# Standard C Library Example

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





# Example: MS-DOS

Single-tasking

Shell invoked when system booted

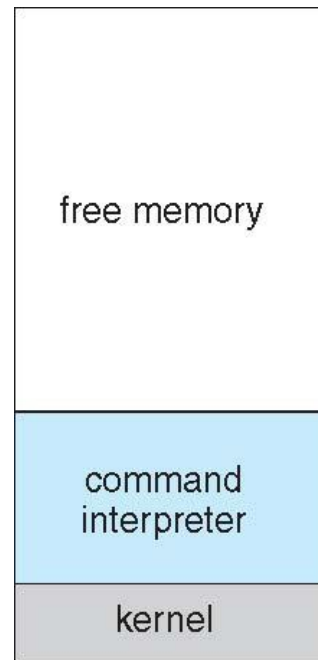
Simple method to run program

No process created

Single memory space

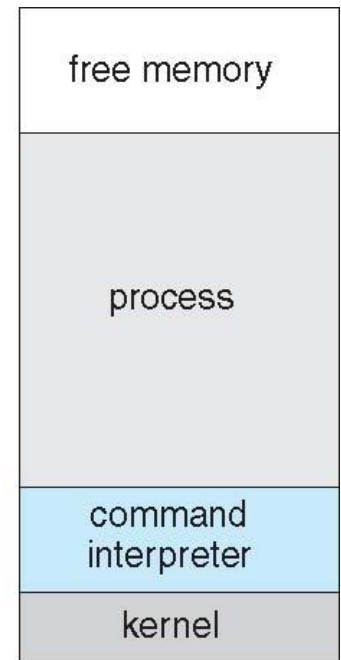
Loads program into memory, overwriting all but the kernel

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

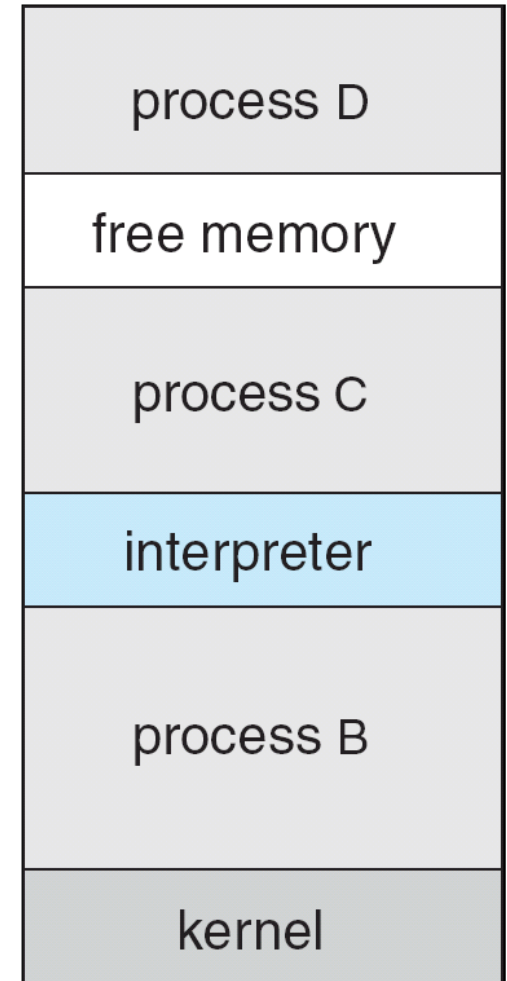
Executes `exec()` to load program into process

Shell waits for process to terminate or continues with user commands

Process exits with:

code = 0 – no error

code > 0 – error code





# System Programs

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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

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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.)

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## 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.)

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## 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

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Design and Implementation of OS not “solvable”, but some approaches have proven successful

Internal structure of different Operating Systems can vary widely

Start the design by defining goals and specifications

Affected by choice of hardware, type of system

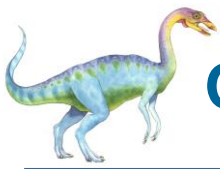
## User goals and System goals

**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.)

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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**





# Implementation

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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

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General-purpose OS is very large program

Various ways to structure ones

Simple structure – MS-DOS

More complex -- UNIX

Layered – an abstraction

Microkernel -Mach



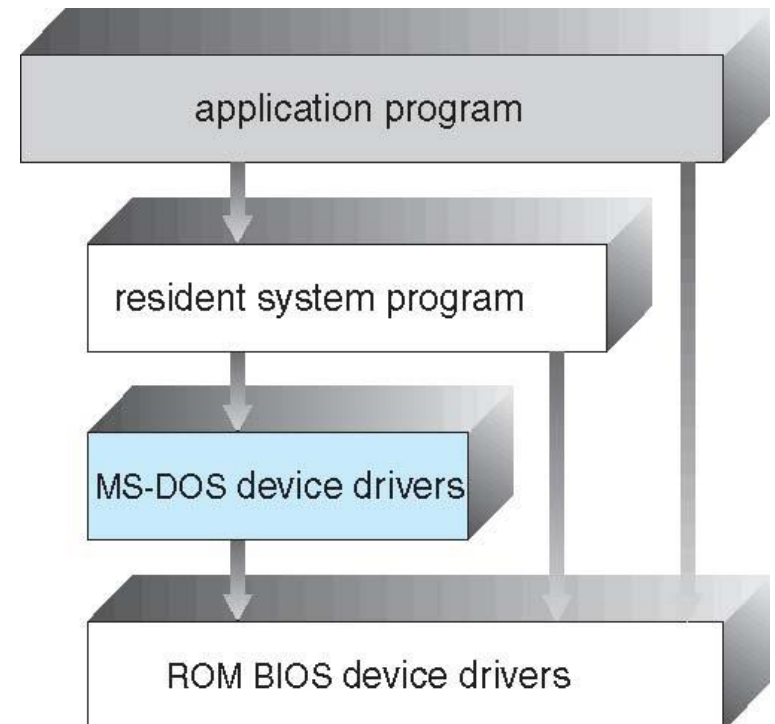


# Simple Structure -- MS-DOS

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





# Non Simple Structure -- UNIX

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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

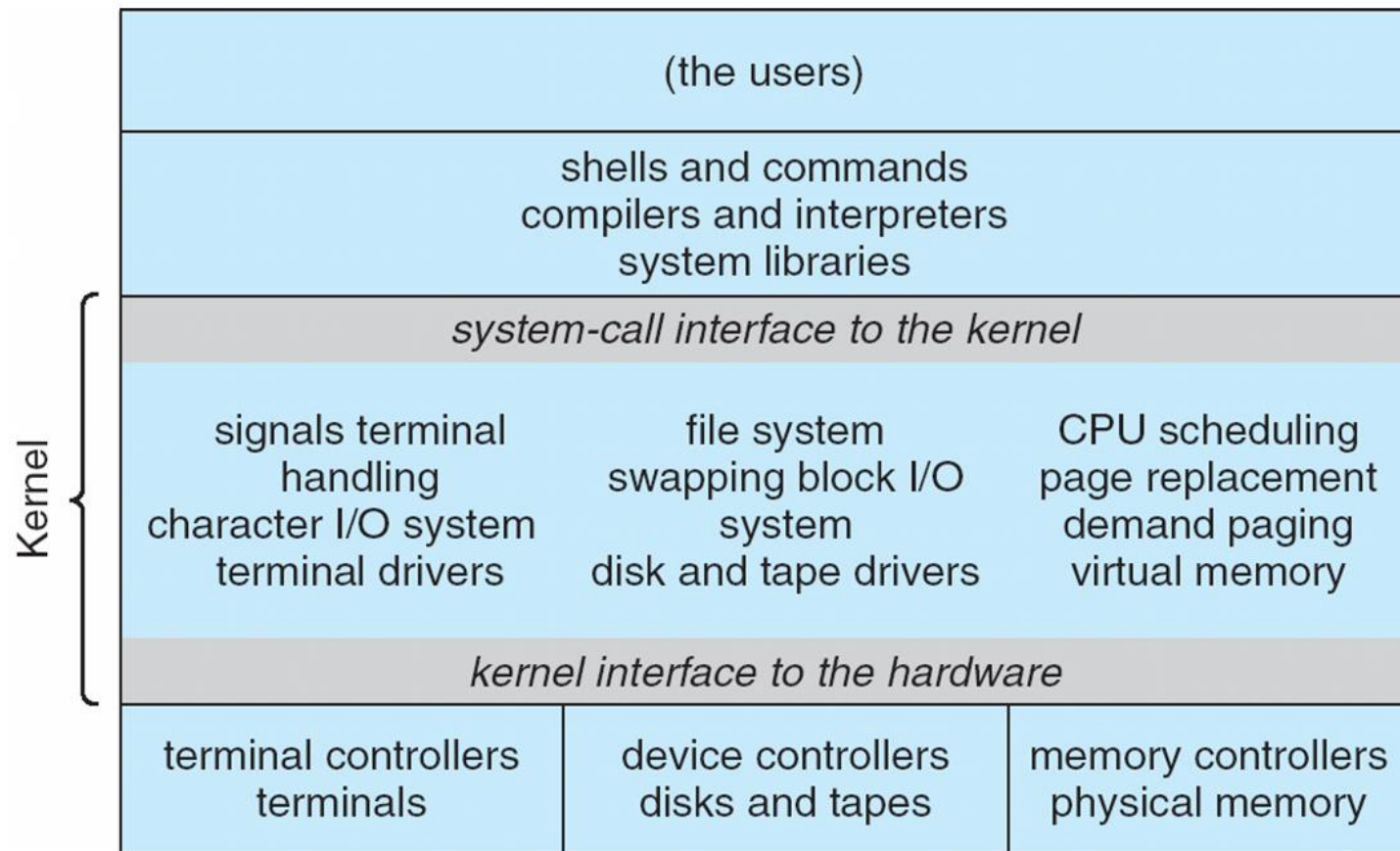
- ▶ Consists of everything below the system-call interface and above the physical hardware
- ▶ Provides the file system, CPU scheduling, memory management, and other operating-system functions; a large number of functions for one level





# Traditional UNIX System Structure

Beyond simple but not fully layered

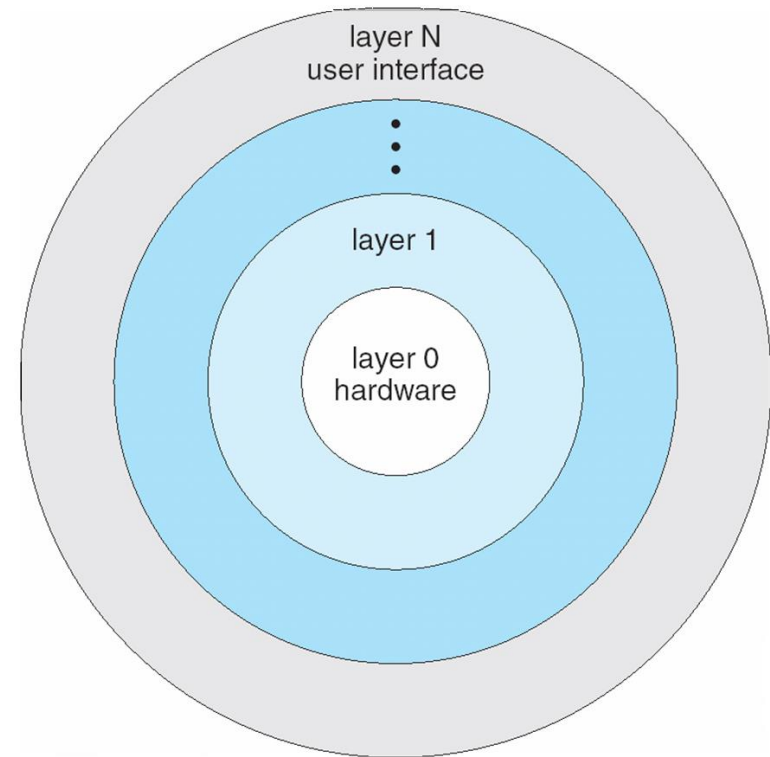




# Layered Approach

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

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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:

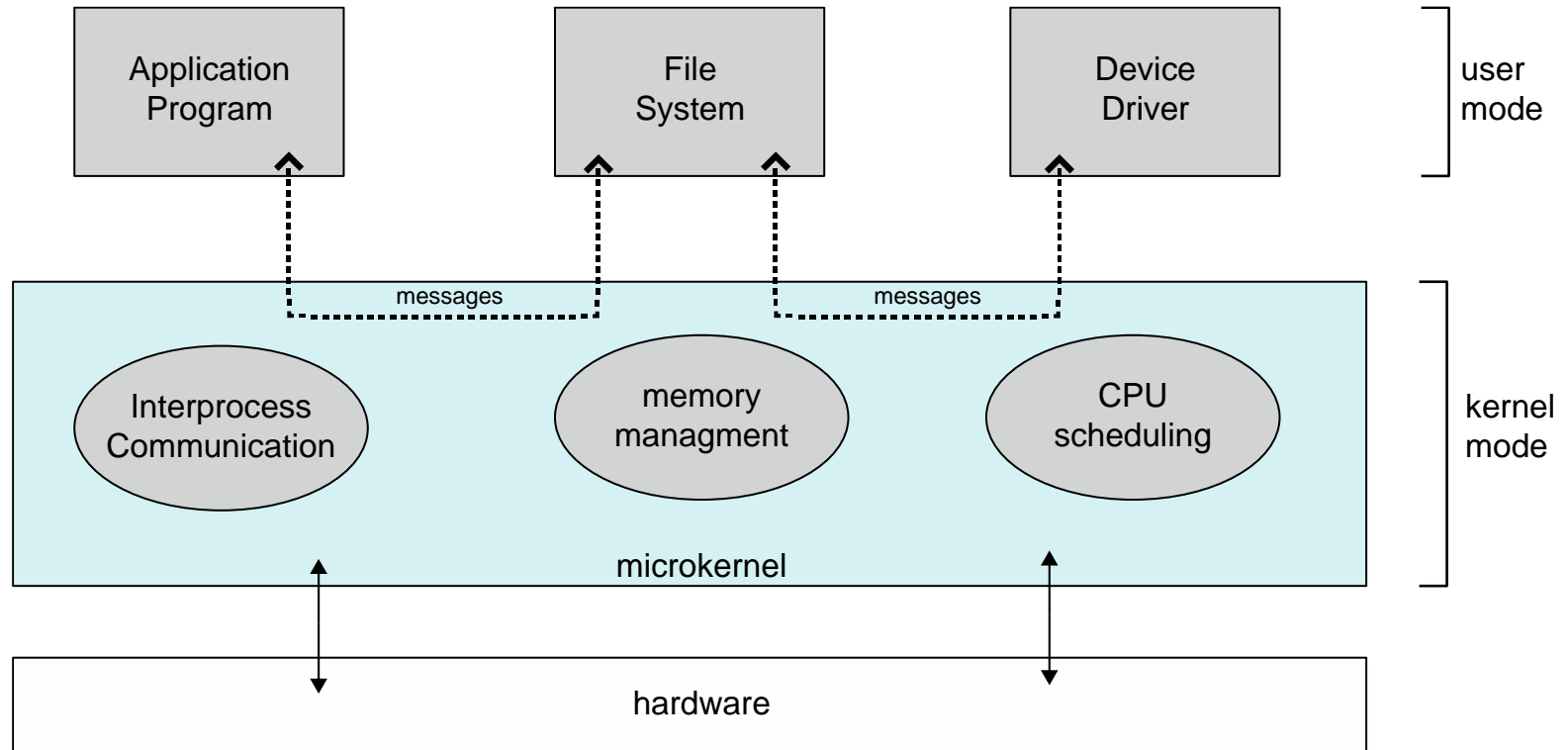
- Performance overhead of user space to kernel space communication







# Microkernel System Structure





# Modules

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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

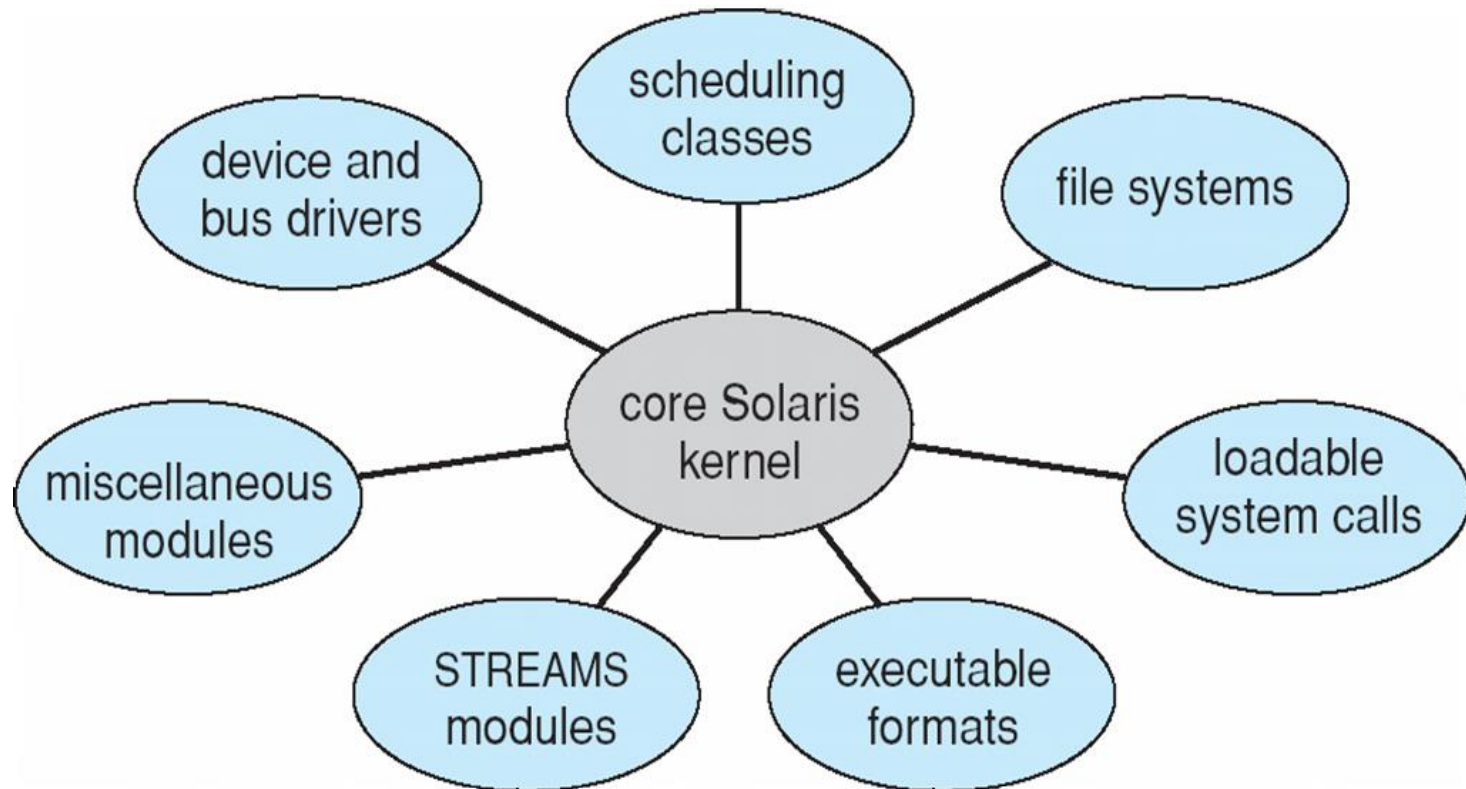
Overall, similar to layers but with more flexible

- Linux, Solaris, etc





# Solaris Modular Approach





# Hybrid Systems

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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***

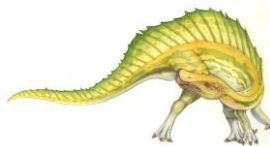
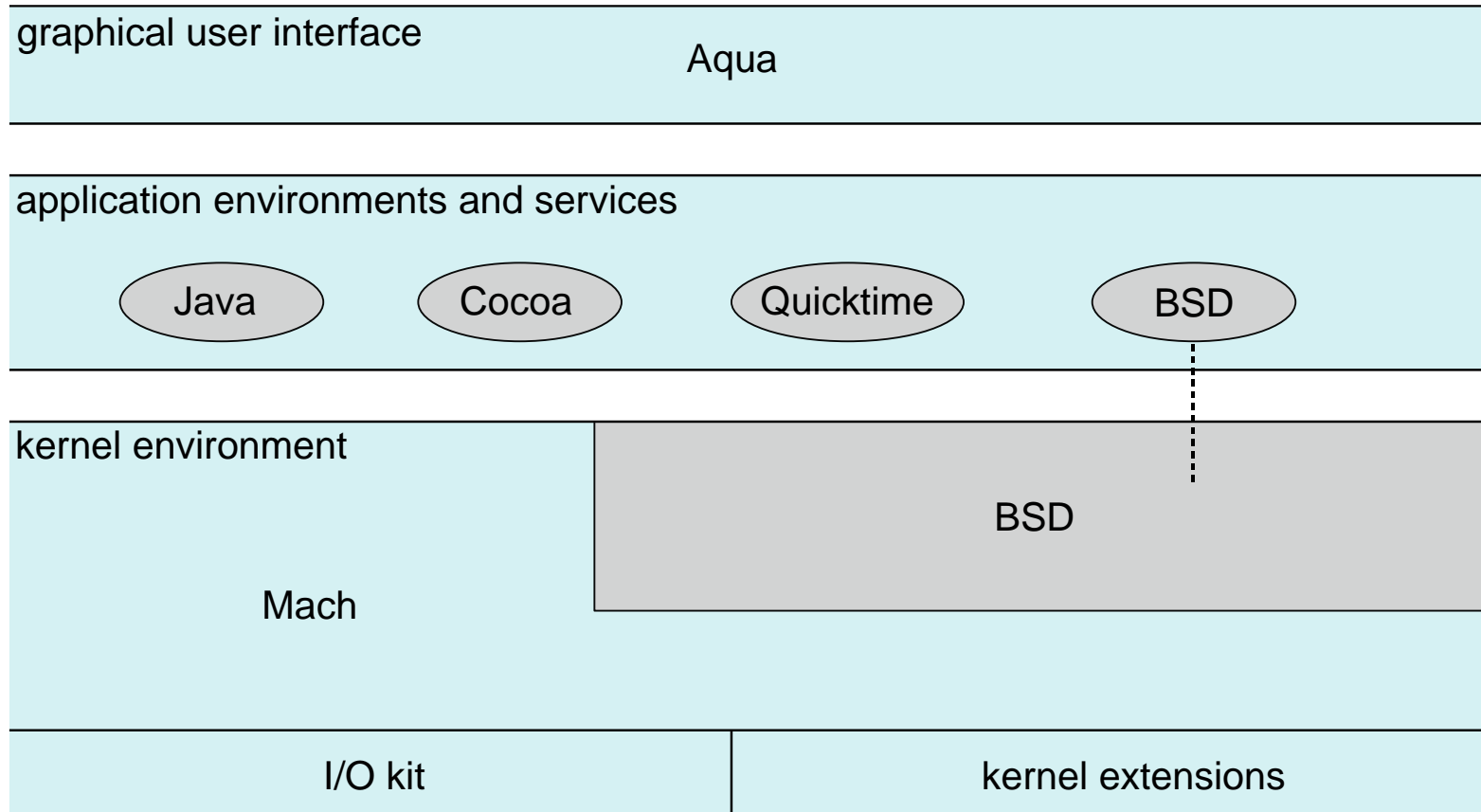
Apple Mac OS X hybrid, layered, **Aqua** UI plus **Cocoa** programming environment

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

Cocoa Touch

Media Services

Core Services

Core OS





# Android

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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

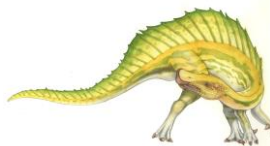
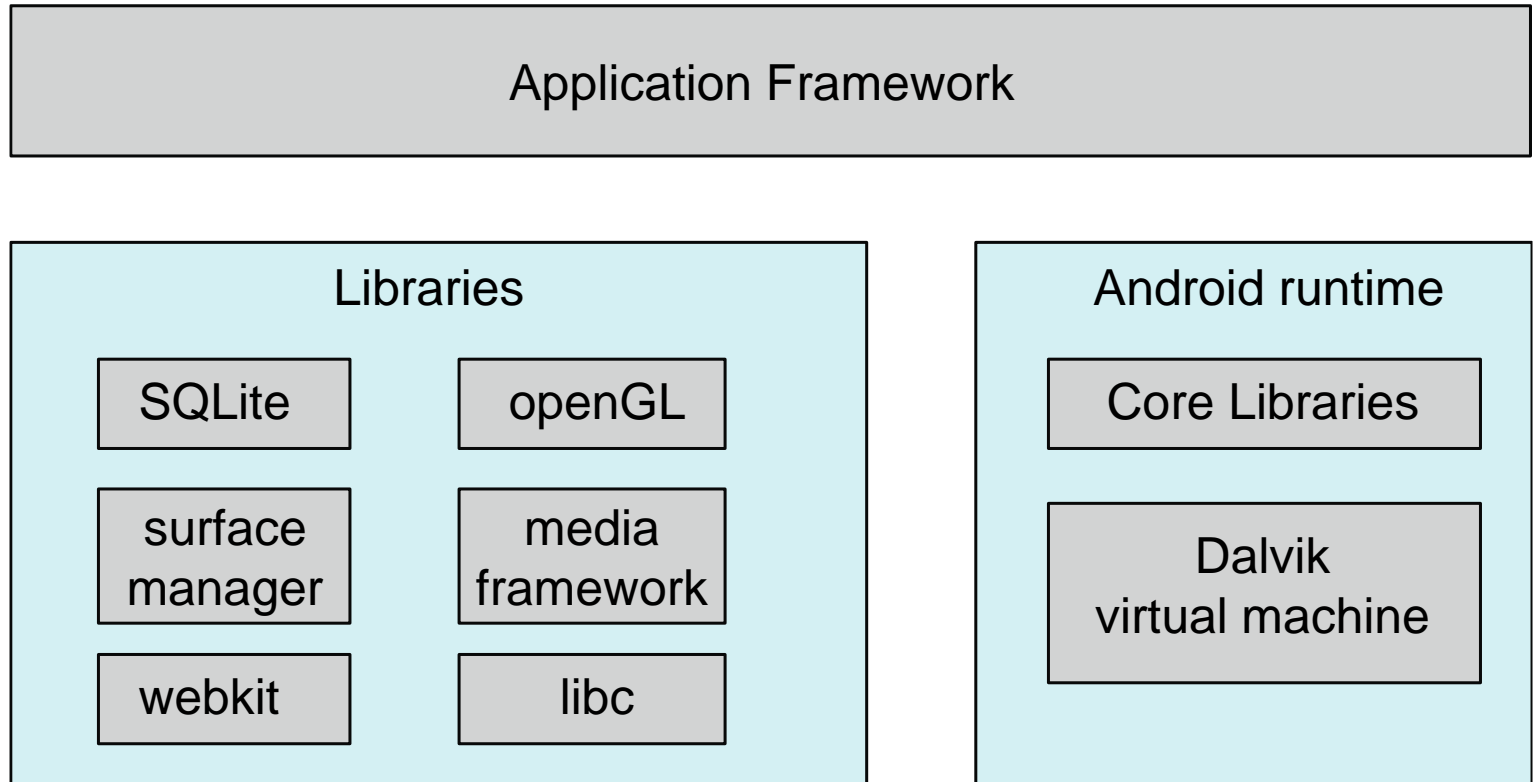
- ▶ Java class files compiled to Java bytecode then translated to executable then runs in Dalvik VM

Libraries include frameworks for web browser (webkit), database (SQLite), multimedia, smaller libc





# Android Architecture







# Operating-System Debugging

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**Debugging** is finding and fixing errors, or **bugs**

OS generate **log files** containing error information

Failure of an application can generate **core dump** file capturing memory of the process

Operating system failure can generate **crash dump** file containing kernel memory

Beyond crashes, performance tuning can optimize system performance

Sometimes using ***trace listings*** of activities, recorded for analysis

**Profiling** is periodic sampling of instruction pointer to look for statistical trends

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."



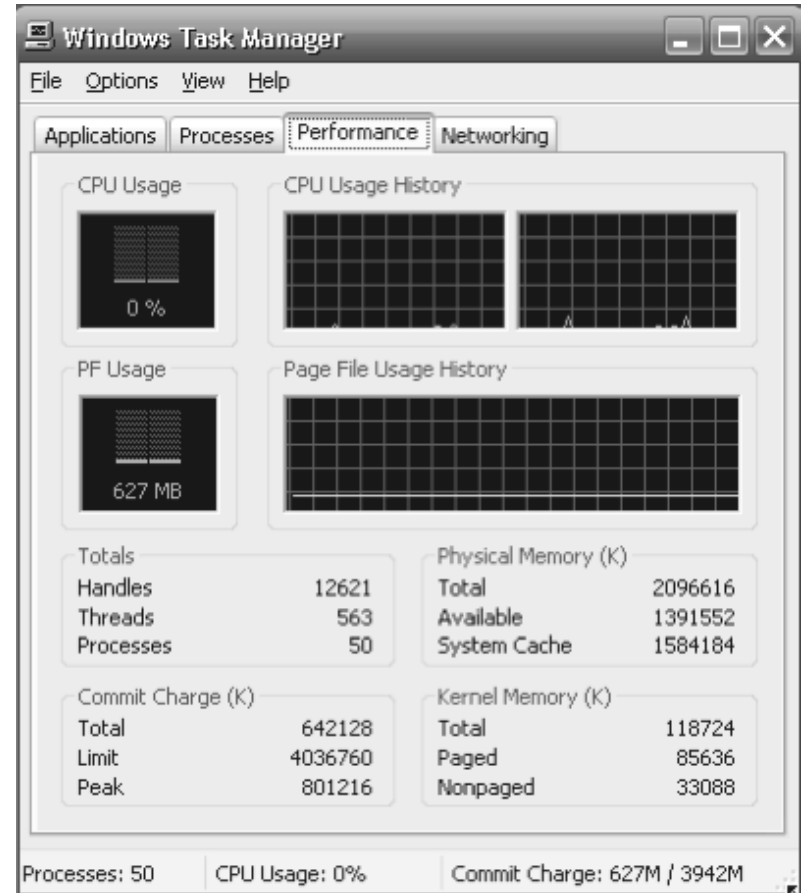


# Performance Tuning

Improve performance by removing bottlenecks

OS must provide means of computing and displaying measures of system behavior

For example, “top” program or Windows Task Manager





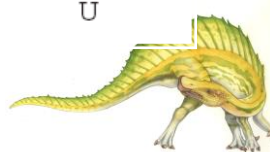
# DTrace

DTrace tool in Solaris, FreeBSD, Mac OS X allows live instrumentation on production systems

**Probes** fire when code is executed within a **provider**, capturing state data and sending it to **consumers** of those probes

Example of following XEventsQueued system call move from libc library to kernel and back

```
# ./all.d 'pgrep xclock' XEventsQueued
dtrace: script './all.d' matched 52377 probes
CPU FUNCTION
0 -> XEventsQueued U
0 -> _XEventsQueued U
0 -> _X11TransBytesReadable U
0 <- _X11TransBytesReadable U
0 -> _X11TransSocketBytesReadable U
0 <- _X11TransSocketBytesreadable U
0 -> ioctl U
0 -> ioctl K
0 -> getf K
0 -> set_active_fd K
0 <- set_active_fd K
0 <- getf K
0 -> get_udatamodel K
0 <- get_udatamodel K
...
0 -> releasef K
0 -> clear_active_fd K
0 <- clear_active_fd K
0 -> cv_broadcast K
0 <- cv_broadcast K
0 <- releasef K
0 <- ioctl K
0 <- ioctl U
0 <- _XEventsQueued U
0 <- XEventsQueued U
```





# Dtrace (Cont.)

DTrace code to record  
amount of time each  
process with UserID 101 is  
in running mode (on CPU)  
in nanoseconds

```
sched:::on-cpu
uid == 101
{
    self->ts = timestamp;
}

sched:::off-cpu
self->ts
{
    @time[execname] = sum(timestamp - self->ts);
    self->ts = 0;
}
```

```
# dtrace -s sched.d
dtrace: script 'sched.d' matched 6 probes
^C
```

gnome-settings-d	142354
gnome-vfs-daemon	158243
dsdm	189804
wnck-applet	200030
gnome-panel	277864
clock-applet	374916
mapping-daemon	385475
xscreensaver	514177
metacity	539281
Xorg	2579646
gnome-terminal	5007269
mixer_applet2	7388447
java	10769137

**Figure 2.21** Output of the D code.





# Operating System Generation

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- n Operating systems are designed to run on any of a class of machines; the system must be configured for each specific computer site
- n **SYSGEN** program obtains information concerning the specific configuration of the hardware system
  - | Used to build system-specific compiled kernel or system-tuned
  - | Can generate more efficient code than one general kernel





# System Boot

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When power initialized on system, execution starts at a fixed memory location

Firmware ROM used to hold initial boot code

Operating system must be made available to hardware so hardware can start it

Small piece of code – **bootstrap loader**, stored in **ROM** or **EEPROM** locates the kernel, loads it into memory, and starts it

Sometimes two-step process where **boot block** at fixed location loaded by ROM code, which loads bootstrap loader from disk

Common bootstrap loader, **GRUB**, allows selection of kernel from multiple disks, versions, kernel options

Kernel loads and system is then **running**



# End of Chapter 2

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