Operating Systems:
Lecture 2

Operating System Structures

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Chapter 2: Operating-System Structures

- Operating System Services
- User Operating System Interface
- System Calls
- Types of System Calls
- System Programs
- Operating System Design and Implementation
- Operating System Structure
- Virtual Machines
- Operating System Generation
- System Boot

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

- 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.
  - File-system manipulation
    - **The file system is of particular interest. Obviously, programs need to read and write files and directories, create and delete them, search them, list file Information, permission management**

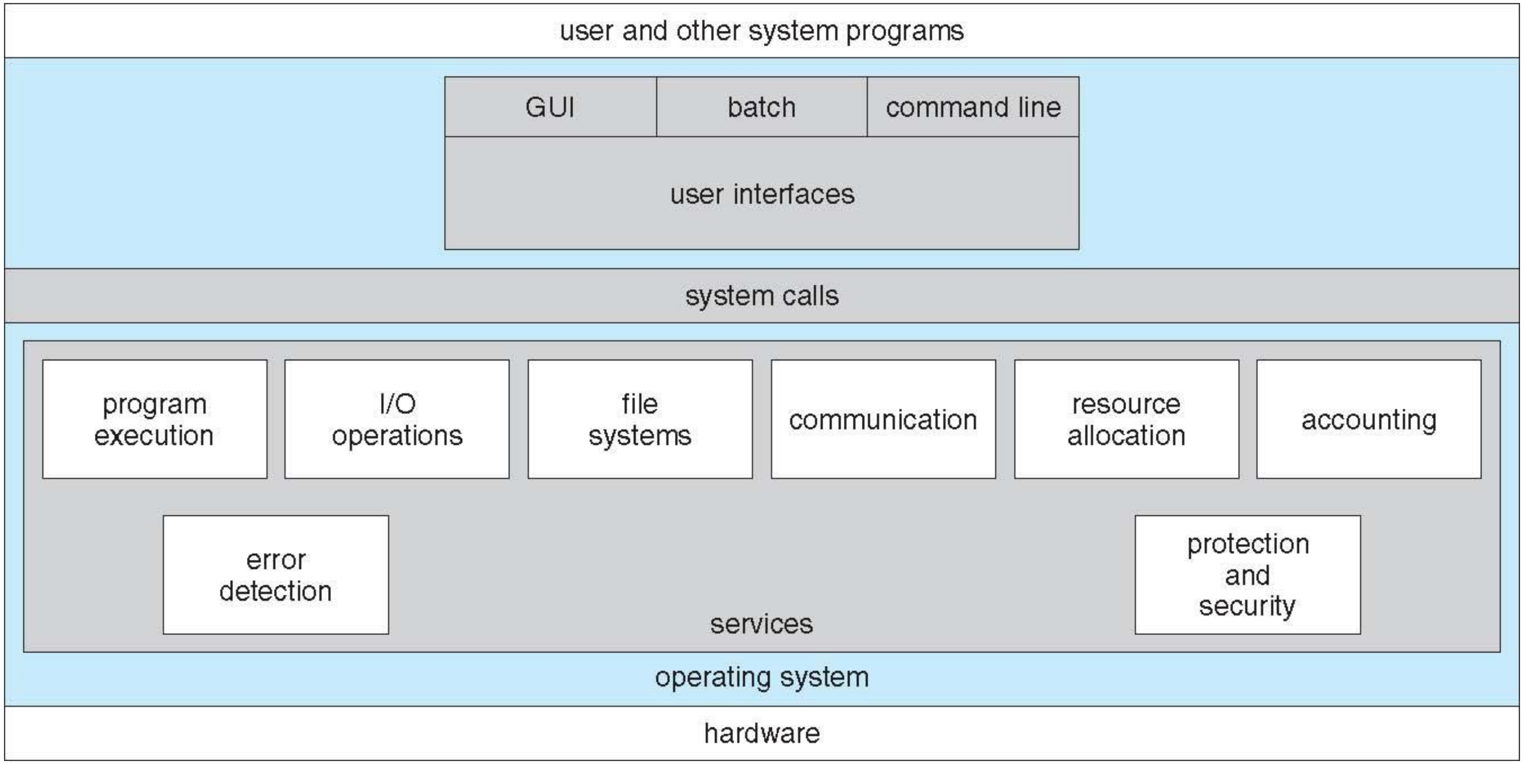
Operating System Services (Cont.)

- One set of operating-system services provides functions that are helpful to the user (Cont.):
  - 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 - Some (such as CPU cycles, main memory, and file storage) may have special allocation code, others (such as I/O devices) may have general request and release code.**
  - **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 multi-user 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

- CLI 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

- 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 as "Aqua" GUI interface with UNIX kernel underneath and shells available
  - 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

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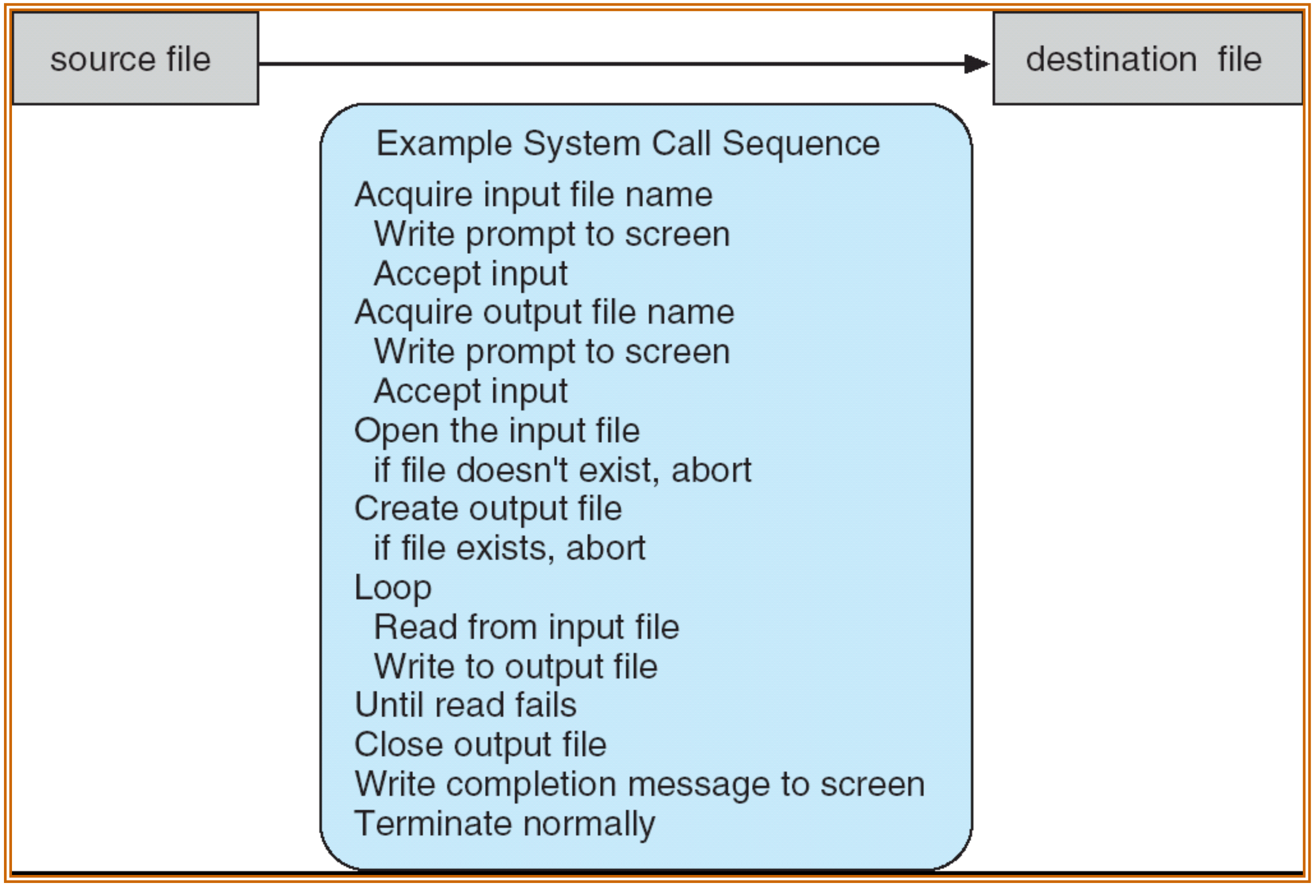
The Mac OS X GUI

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 Program 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)
- Why use APIs rather than system calls?
- Note that the system-call names used throughout this text are generic

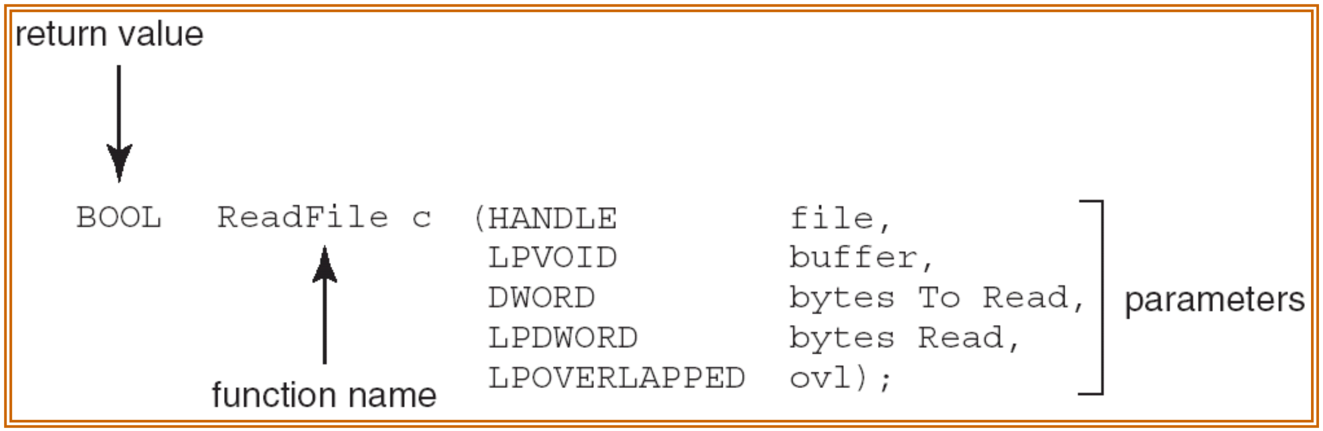
Example of System Calls

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



Example of Standard API

- Consider the ReadFile() function in the Win32 API
  – A function for reading from a file



- A description of the parameters passed to ReadFile()
  – HANDLE file—the file to be read
  – LPVOID buffer—a buffer where the data will be read into and written from
  – DWORD bytesToRead—the number of bytes to be read into the buffer
  – LPDWORD bytesRead—the number of bytes read during the last read
  – LPOVERLAPPED ovl—indicates if overlapped I/O is being used

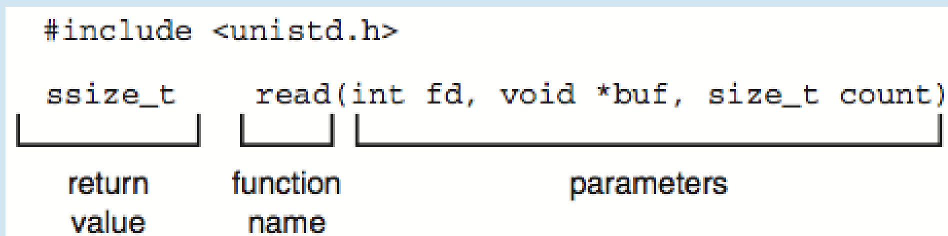
Example of Standard API

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:



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:

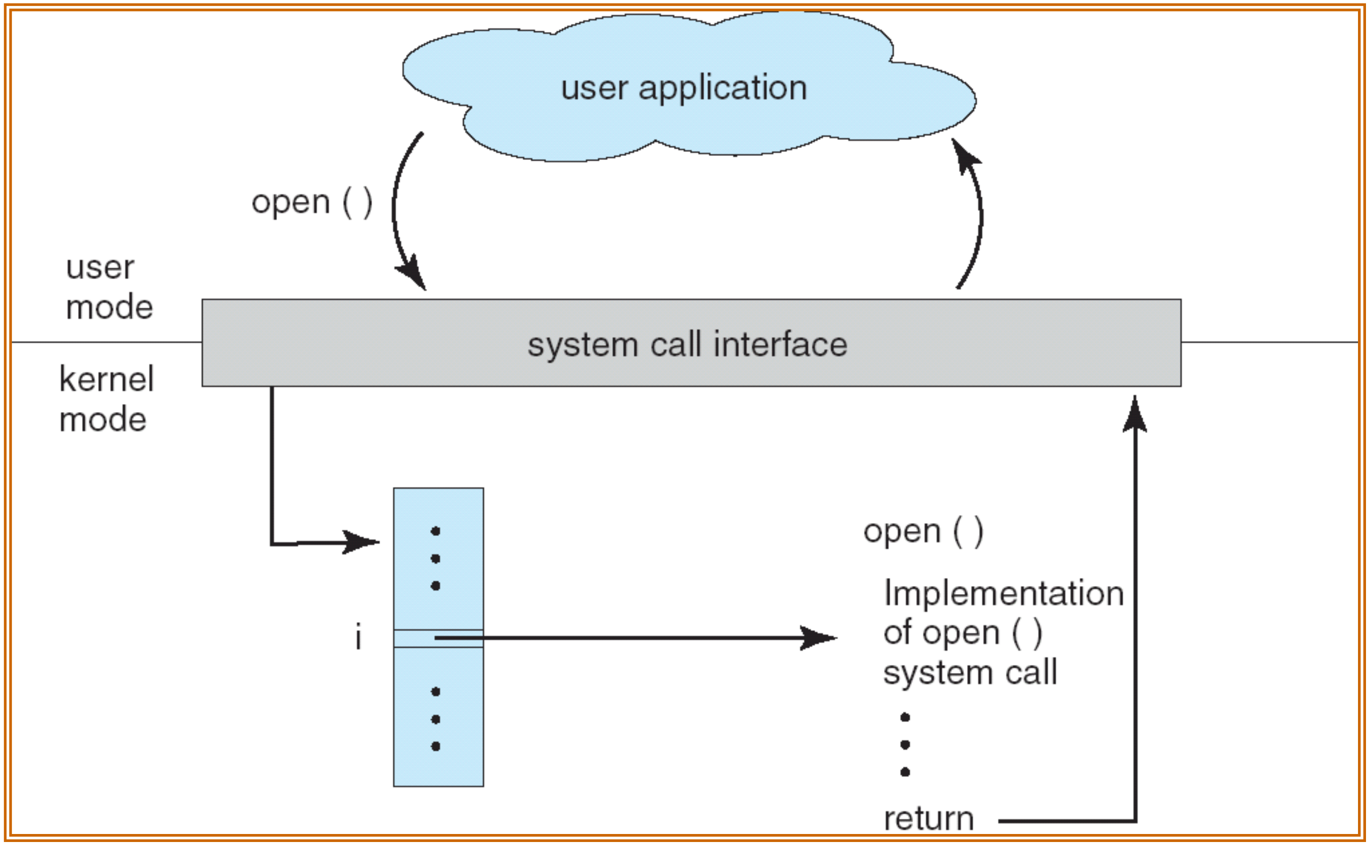
- `int fd`—the file descriptor to be read
- `void *buf`—a buffer where the data will be read into
- `size_t count`—the maximum number of bytes to be read into the buffer

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

- Typically, a number associated with each system call
  - ***System-call interface*** maintains a table indexed according to these numbers
- The system call interface invokes intended system call in OS kernel and returns status of the system call and any return values
- The caller need to 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

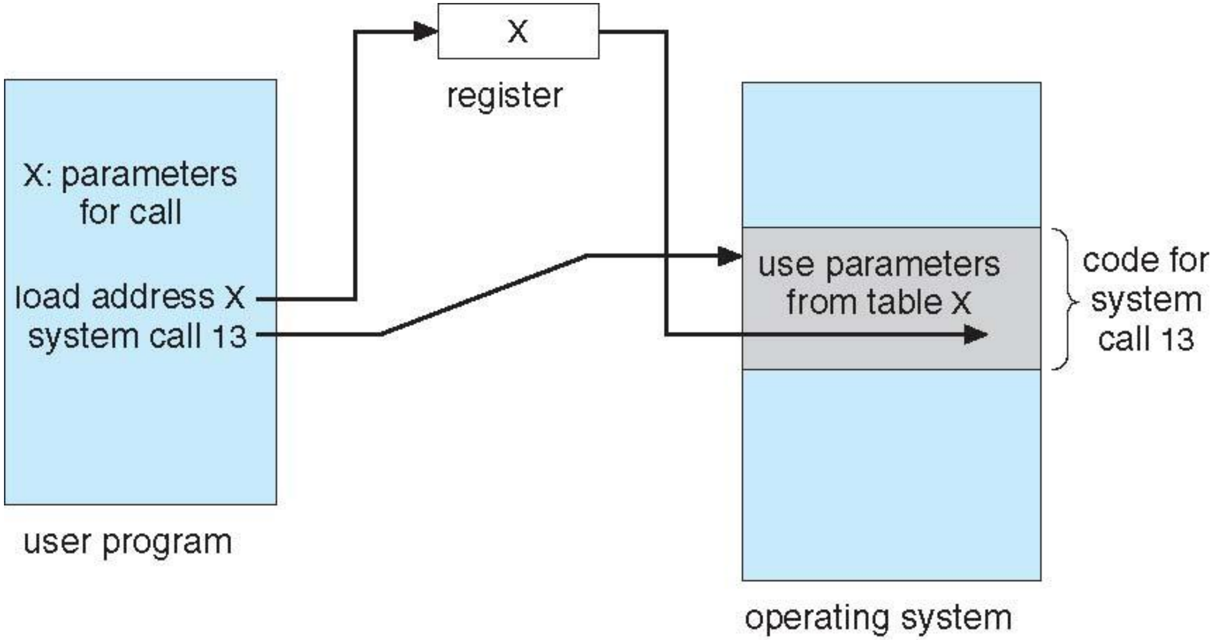


System Call Parameter Passing

- 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
  - 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

- 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.)

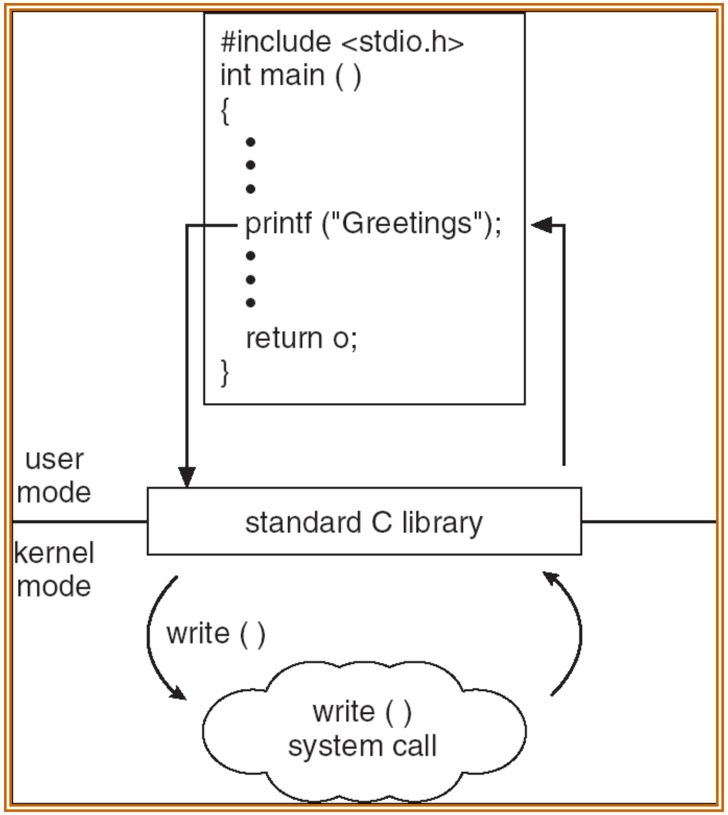
- Protection
  - Control access to resources
  - Get and set permissions
  - Allow and deny user access

Examples of Windows and Unix System Calls

	Windows	Unix
Process Control	CreateProcess() 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()

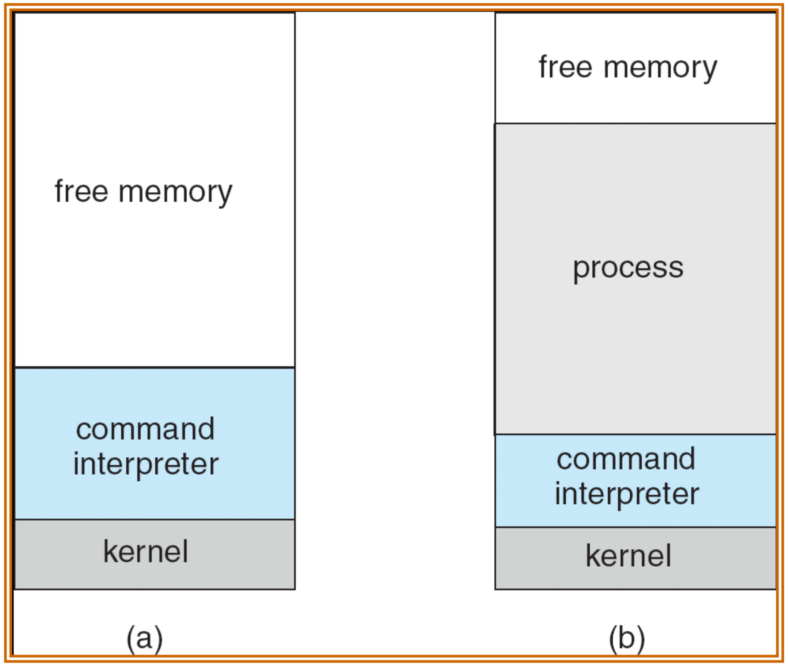
Standard C Library Example

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



MS-DOS execution

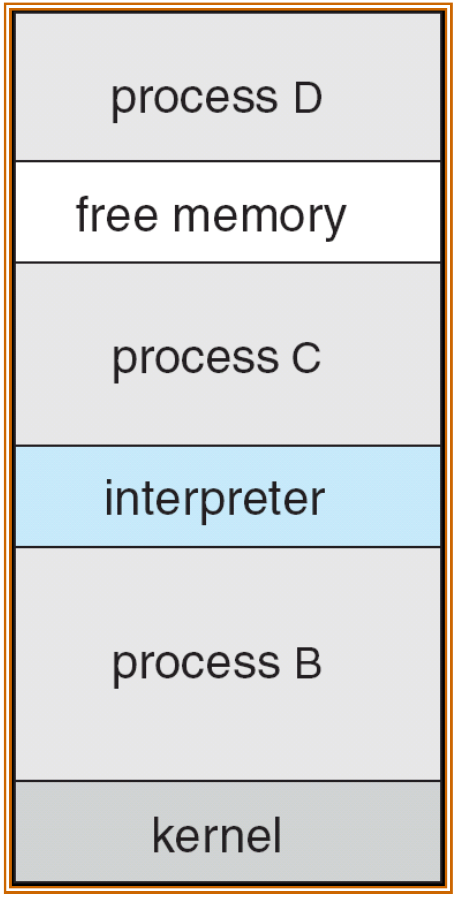
- Single-tasking
- Shell invoked when system booted
- Simple method to run program
  - No process created
- Single memory space
- Loads program into memory, overwriting all but the kernel
- Program exit -> shell reloaded



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

FreeBSD Running Multiple Programs

- 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

- System programs provide a convenient environment for program development and execution. They can be divided into:
  - File manipulation
  - Status information
  - File modification
  - Programming language support
  - Program loading and execution
  - Communications
  - Application programs

- Most users' view of the operating 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'd)

- 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 an OS is highly creative task of **software engineering**

Implementation

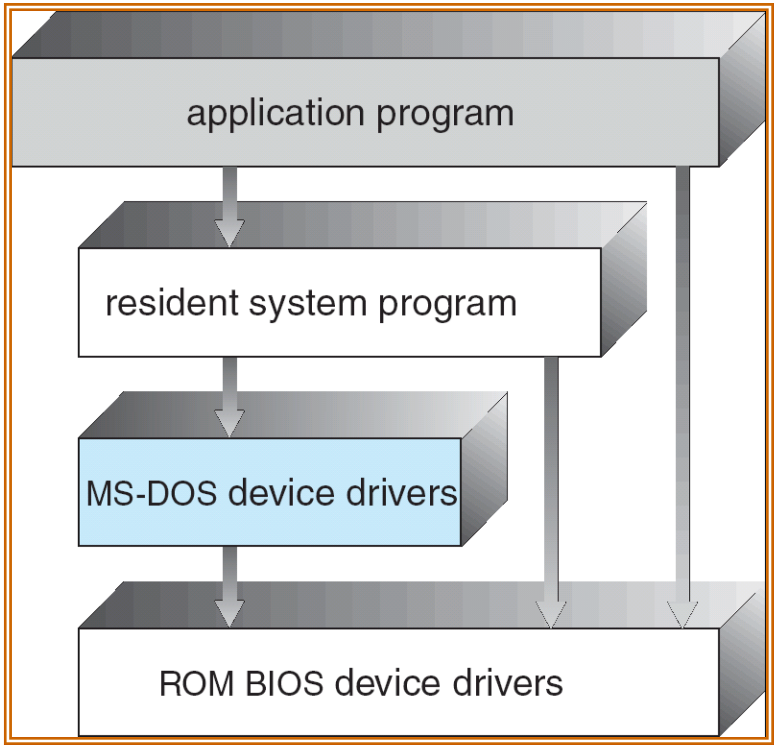
- Much variation
  - Early OSes in assembly language
  - Then system programming languages like Algol, PL/1
  - Now C, C++
- Usually a mix of languages
  - Lowest levels in assembly
  - Main body in C
  - Systems programs in C, C++, scripting languages like PERL, Python, shell scripts
- More high-level 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 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



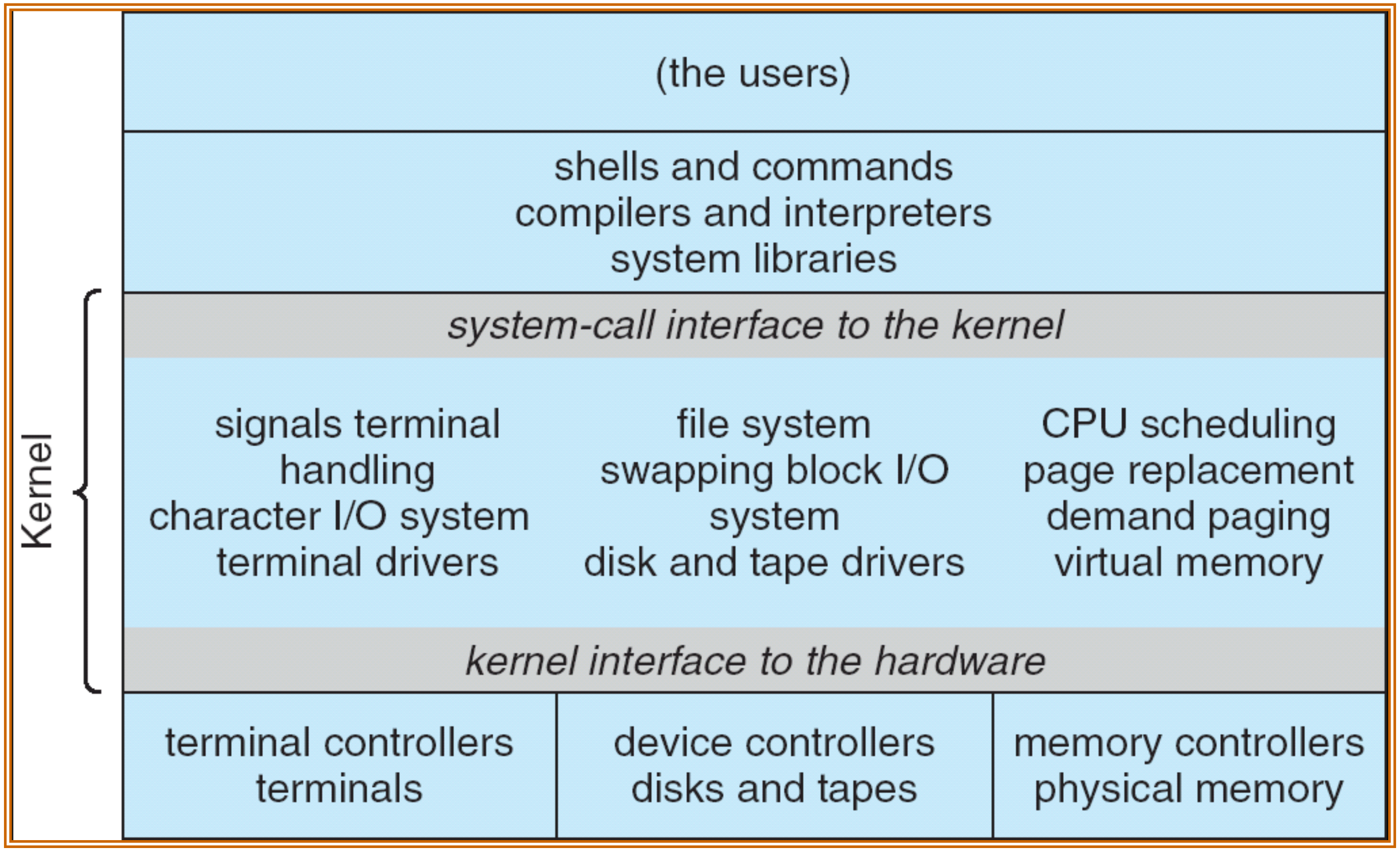
Non-Simple Structure -- UNIX

- 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; many functions for one level**

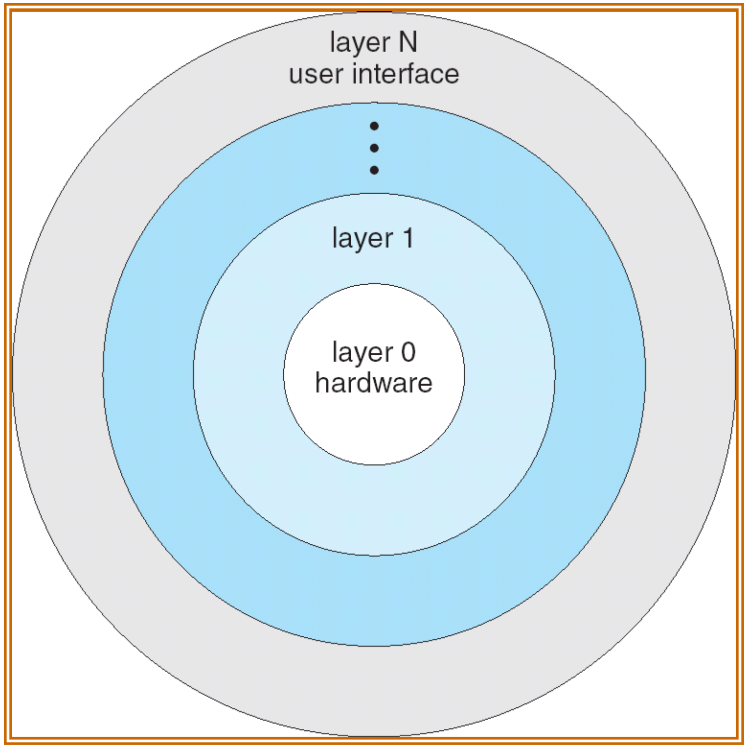
UNIX System Structure

Beyond simple but not fully layered



Layered Approach

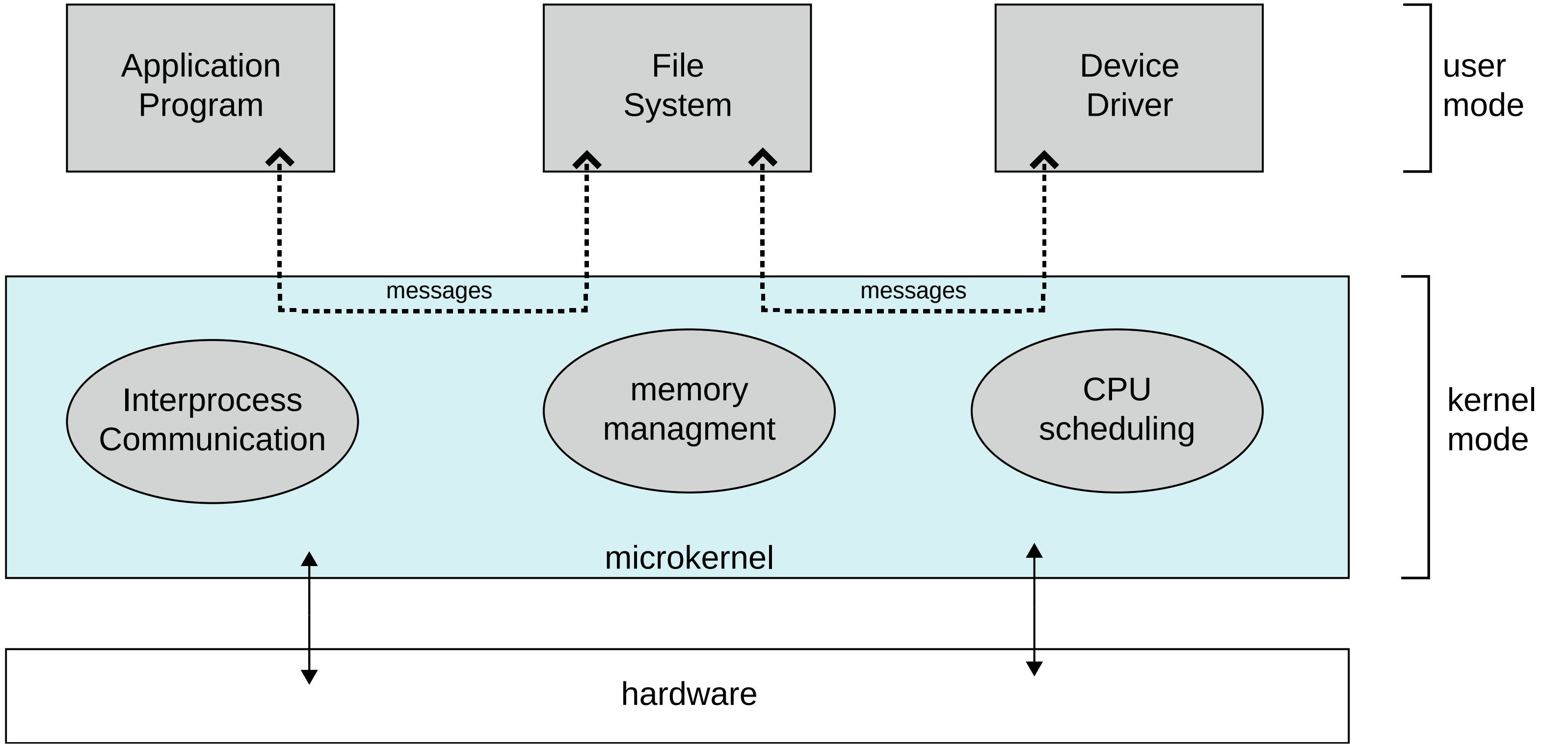
- The operating system is divided into several layers (levels), each built on top of lower layers
- The bottom layer (layer 0), is the hardware; the highest (layer N) is the user interface
- With modularity, layers are selected such that each uses functions (operations) and services of only lower-level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

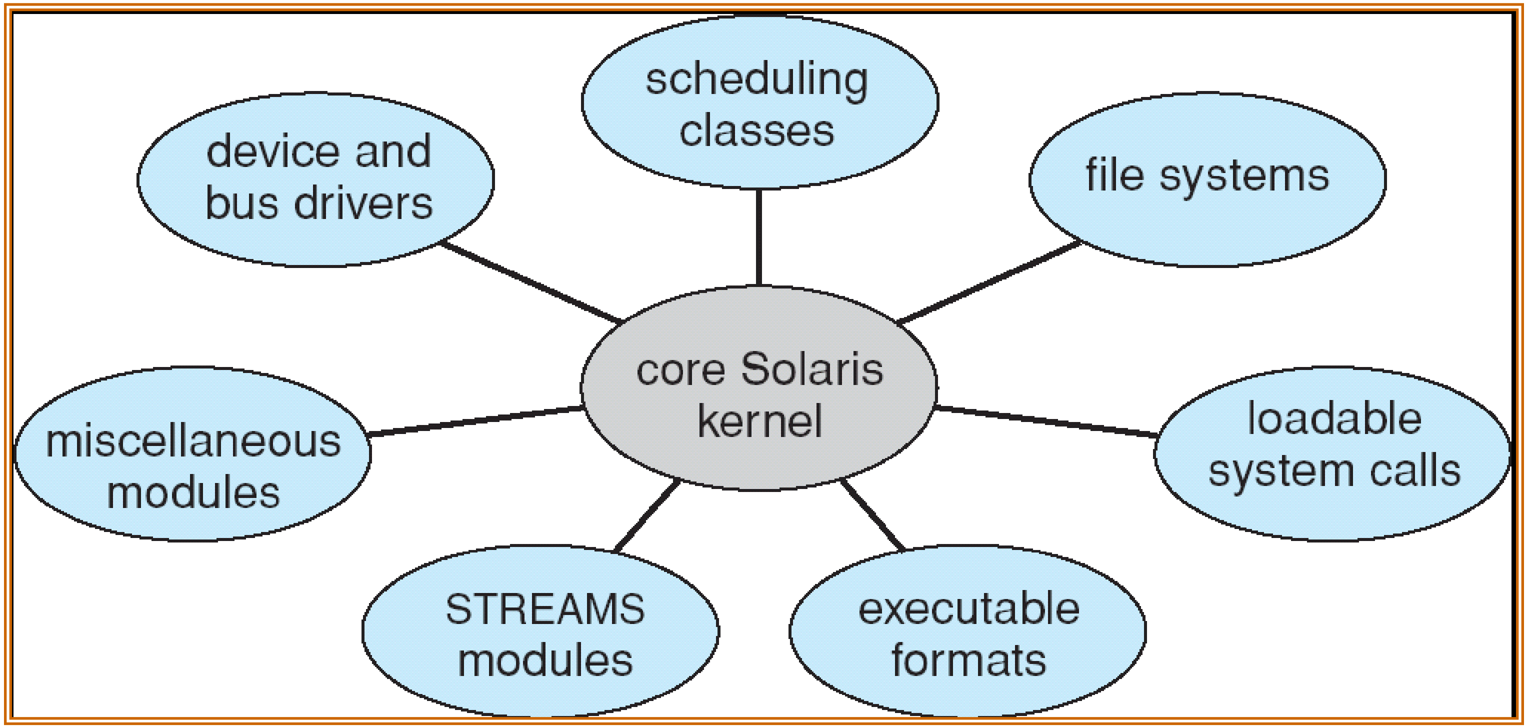
Microkernel System Structure



Modules

- 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 approach*** but with more flexible
  - Linux, Solaris, etc

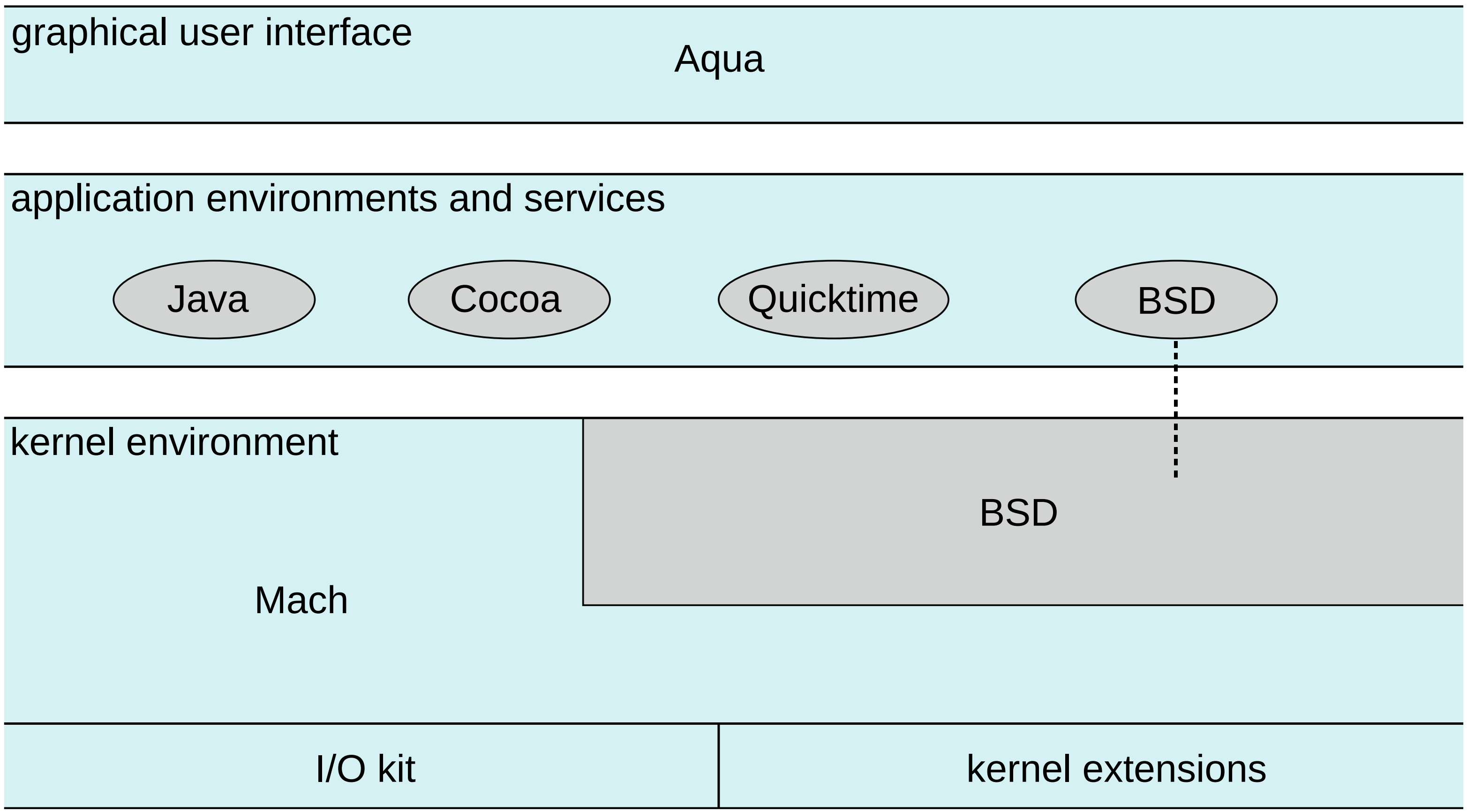
Solaris Modular Approach



Hybrid Systems

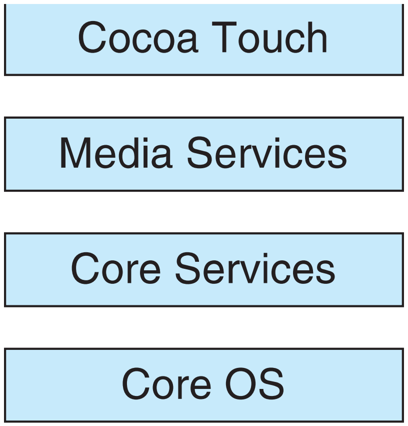
- Most modern operating systems are not one pure model
  - Hybrid combines multiple approaches to address performance, security, usability needs
  - Linux and Solaris kernels in kernel address space, so monolithic, plus modular for dynamic loading of functionality
  - Windows mostly monolithic, plus 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

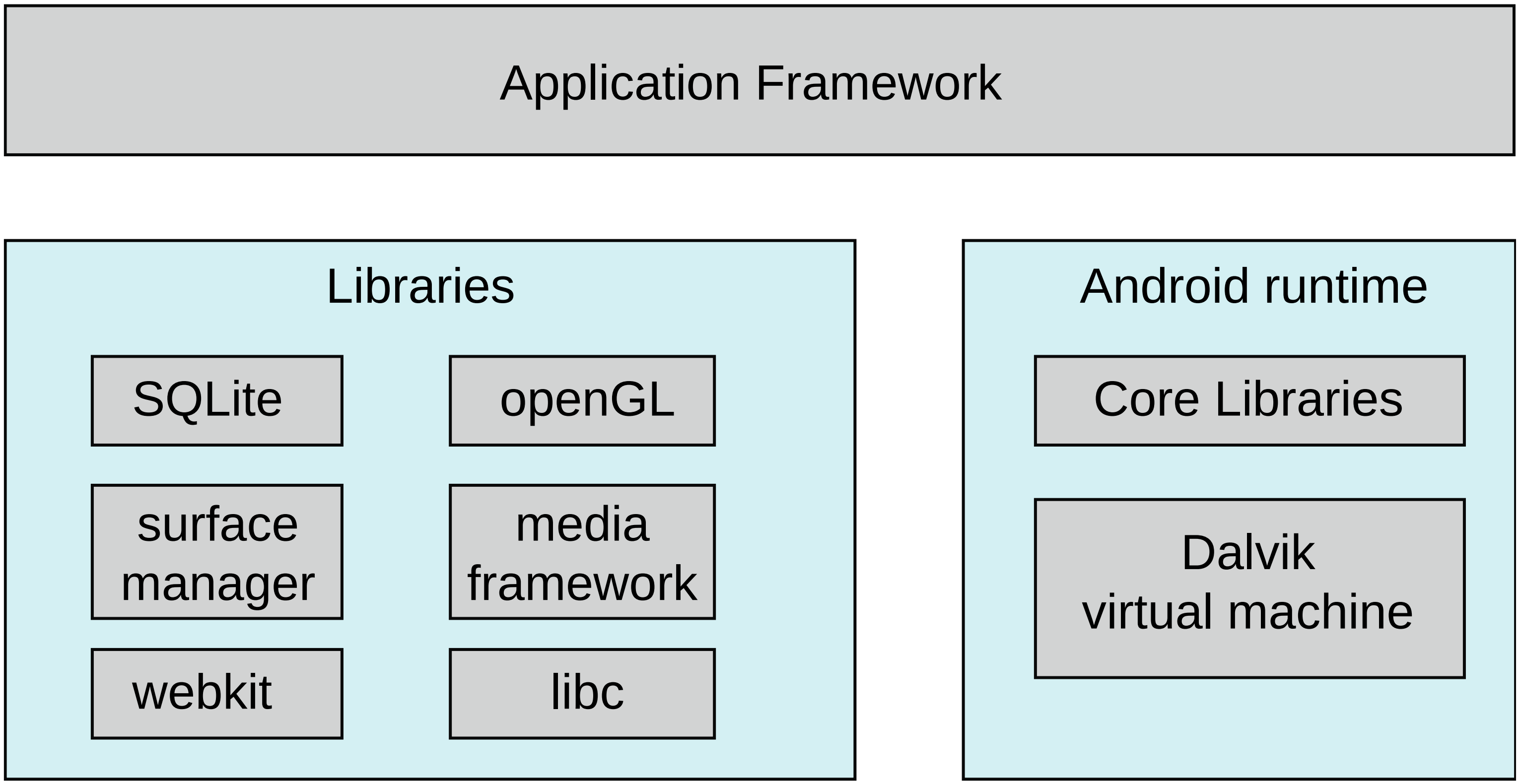
- Apple mobile OS for ***iPhone***, ***iPad***
  - Structured on Mac OS X, added functionality
  - Does not run OS X applications natively
    - **Also runs on different CPU architecture (ARM vs. Intel)**
  - **Cocoa Touch** Objective-C API for developing apps
  - **Media services** layer for graphics, 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



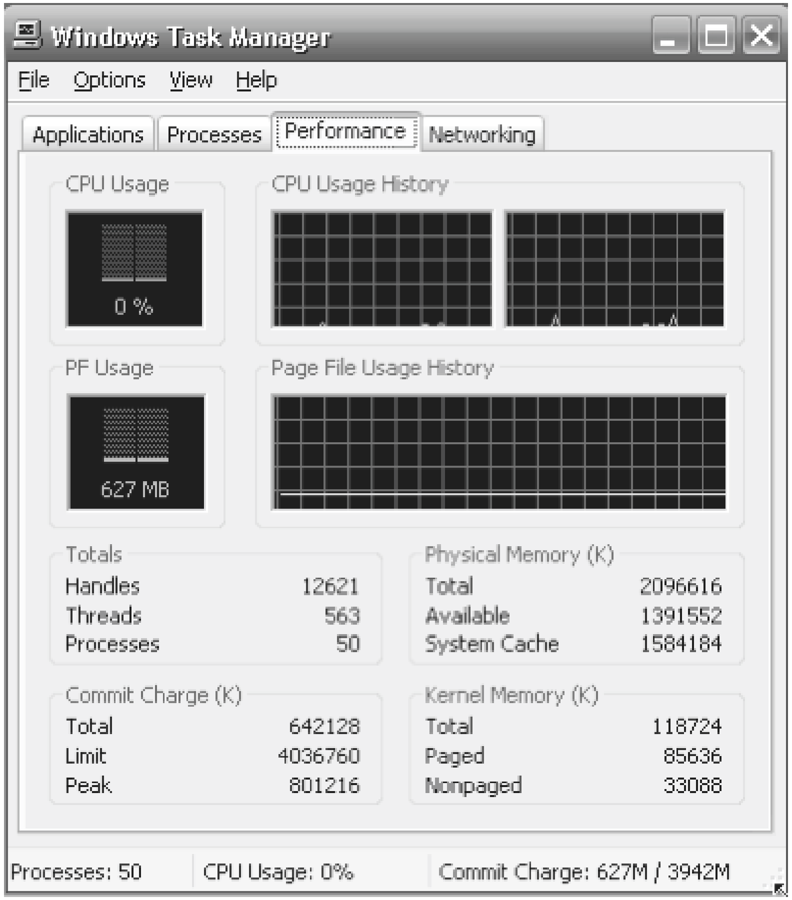
Operating-System Debugging

- **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

Operating systems are designed to run on any of a class of machines; the system must be configured for each specific computer site

SYSGEN program obtains information concerning the specific configuration of the hardware system

- Used to build system-specific compiled kernel or system-tuned
- Can general more efficient code than one general kernel

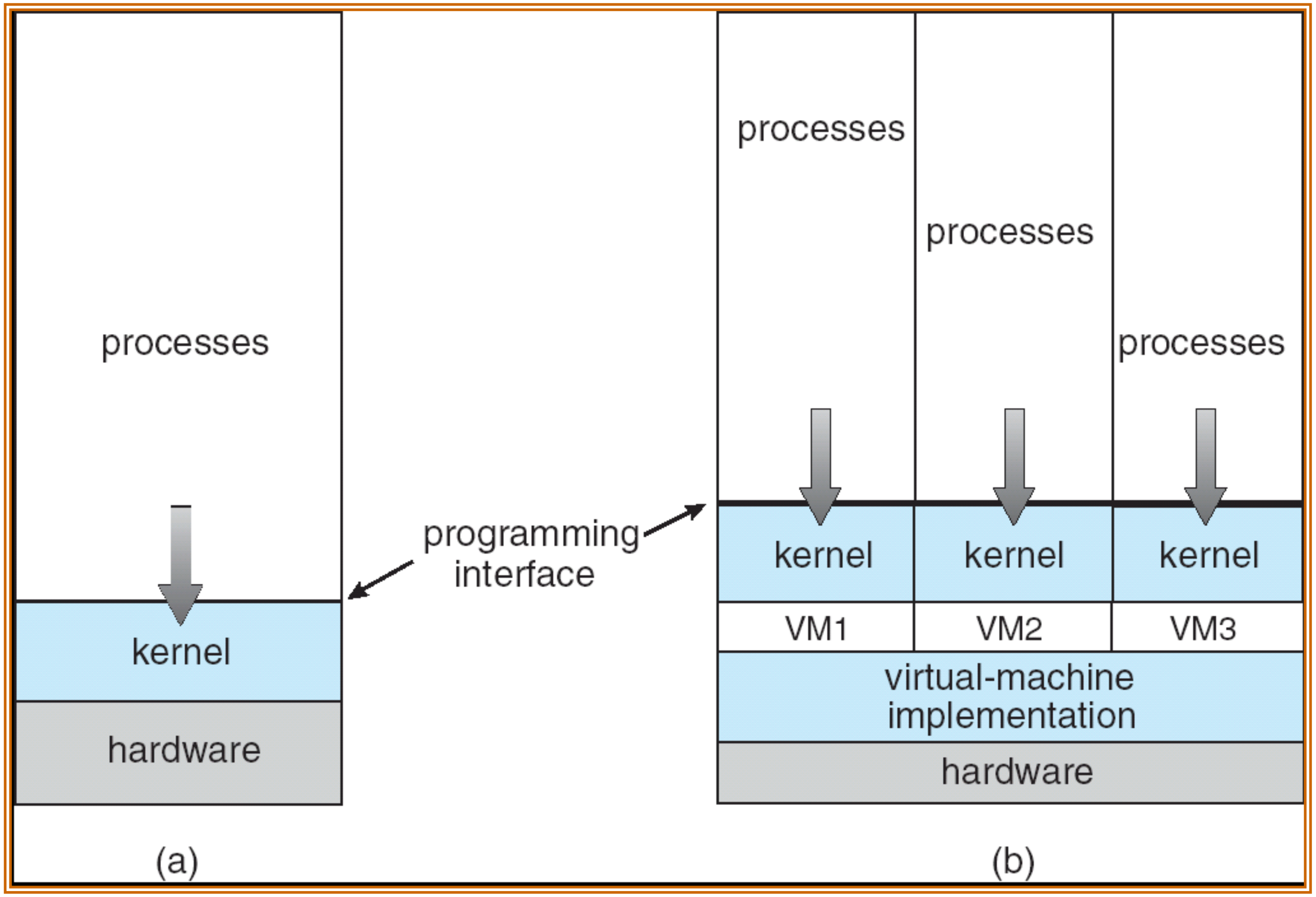
Virtual Machines

- A *virtual machine* takes the layered approach to its logical conclusion. It treats hardware and the operating system kernel as though they were all hardware
- A virtual machine provides an interface *identical* to the underlying bare hardware
- The operating system creates the illusion of multiple processes, each executing on its own processor with its own (virtual) memory

Virtual Machines (Cont.)

- The resources of the physical computer are shared to create the virtual machines
  - CPU scheduling can create the appearance that users have their own processor
  - Spooling and a file system can provide virtual card readers and virtual line printers
  - A normal user time-sharing terminal serves as the virtual machine operator's console

Virtual Machines (Cont.)



(a) Nonvirtual machine (b) virtual machine

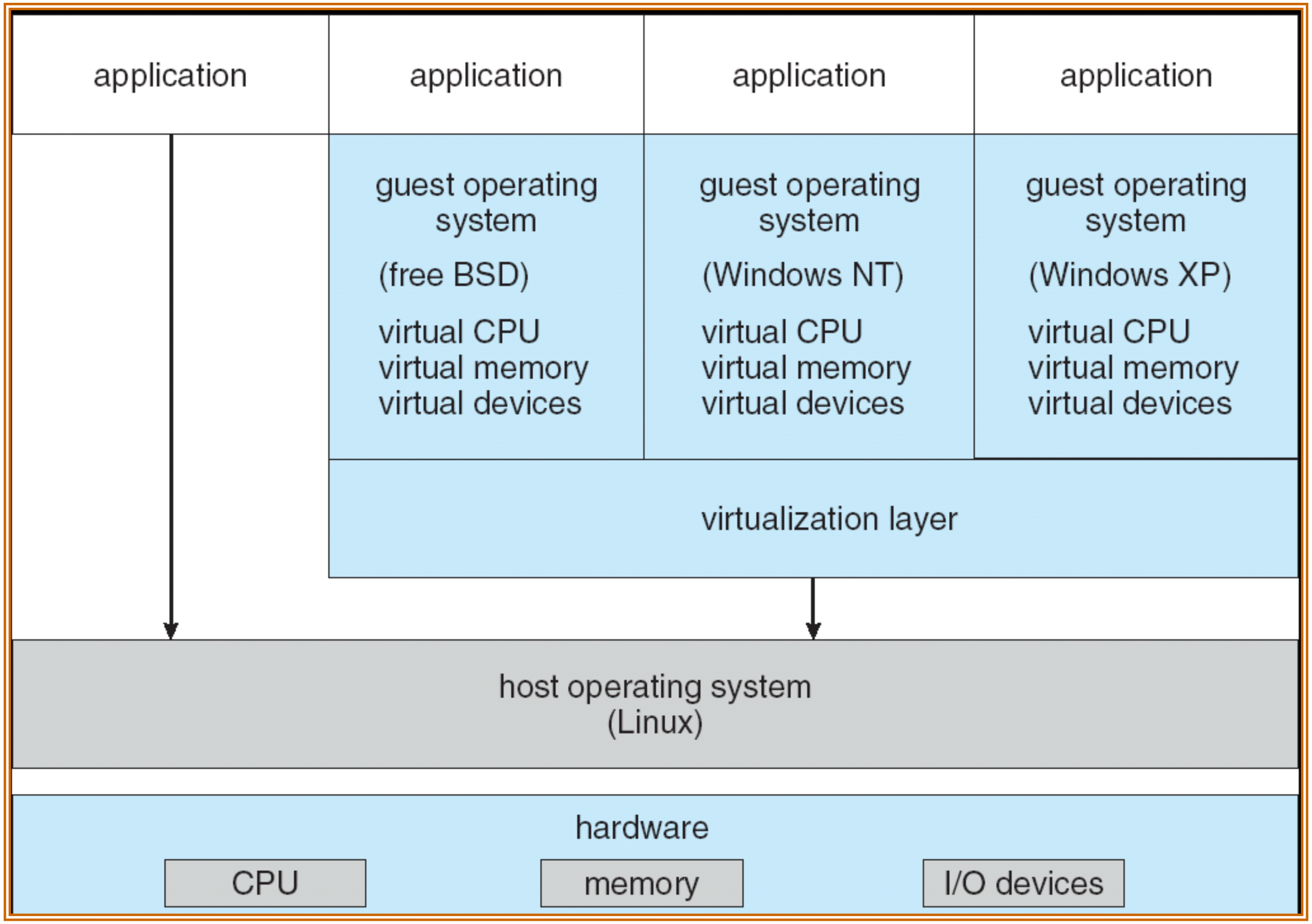
Virtual Machines (Cont.)

- The virtual-machine concept provides complete protection of system resources since each virtual machine is isolated from all other virtual machines
  - This isolation, however, permits no direct sharing of resources

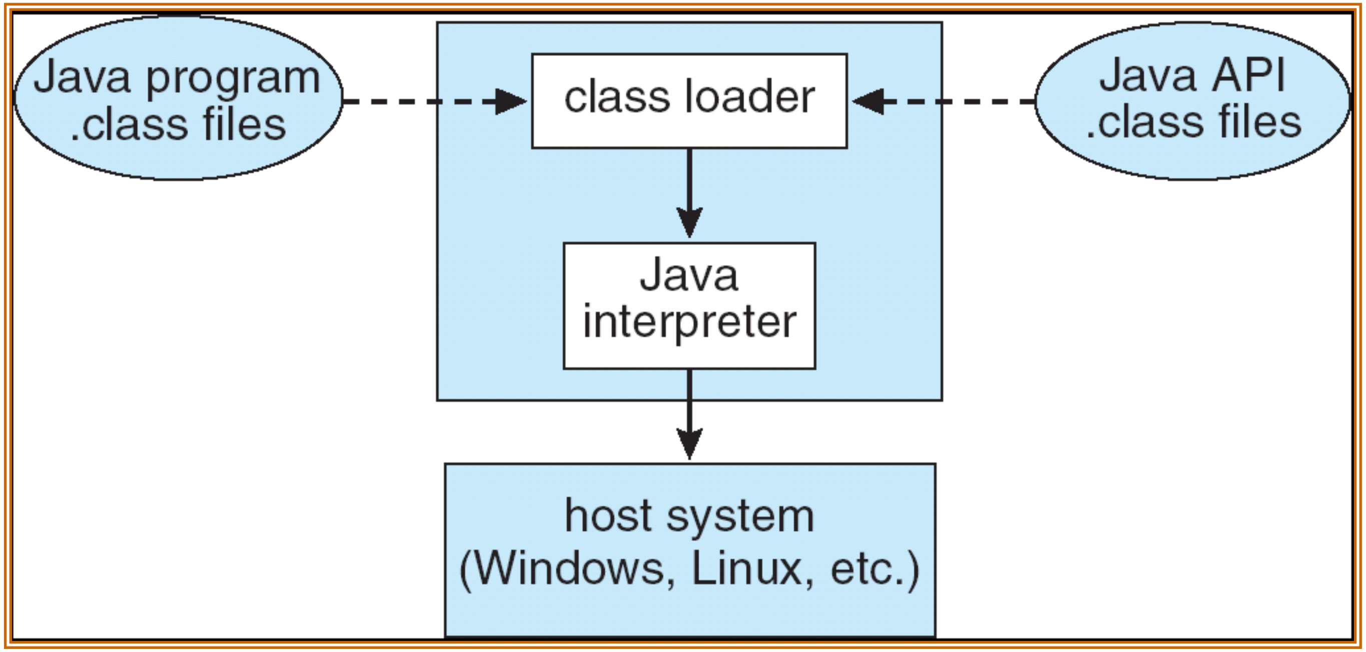
- A virtual-machine system is a perfect vehicle for operating-systems research and development.
  - System development is done on the virtual machine, instead of on a physical machine and so does not disrupt normal system operation

- The virtual machine concept is difficult to implement due to the effort required to provide an *exact* duplicate to the underlying machine

VMware Architecture



The Java Virtual Machine



System Boot

- Operating system must be made available to hardware so hardware can start it
  - Small piece of code – **bootstrap loader**, locates the kernel, loads it into memory, and starts it
  - Sometimes two-step process where **boot block** at fixed location loads bootstrap loader
  - When power initialized on system, execution starts at a fixed memory location
    - **Firmware used to hold initial boot code**

The Boot Process – Big Picture

- Each time a computer is turned on, it must familiarize itself with its internal components and the peripheral world
  - This start-up process is called the "***boot process***"

- The basic steps of "Boot Process"
  - CPU reset and run the bootstrap code in ROM BIOS (Basic Input Output System)
    - **BIOS: firmware containing code for Input/output between OS and hardware**
    - **Stores inside ROM to maintain code without power**
  - Pre-POST (Power-on Self Test)
  - POST
  - Disk boot
    - **MBR**
    - **VBR**

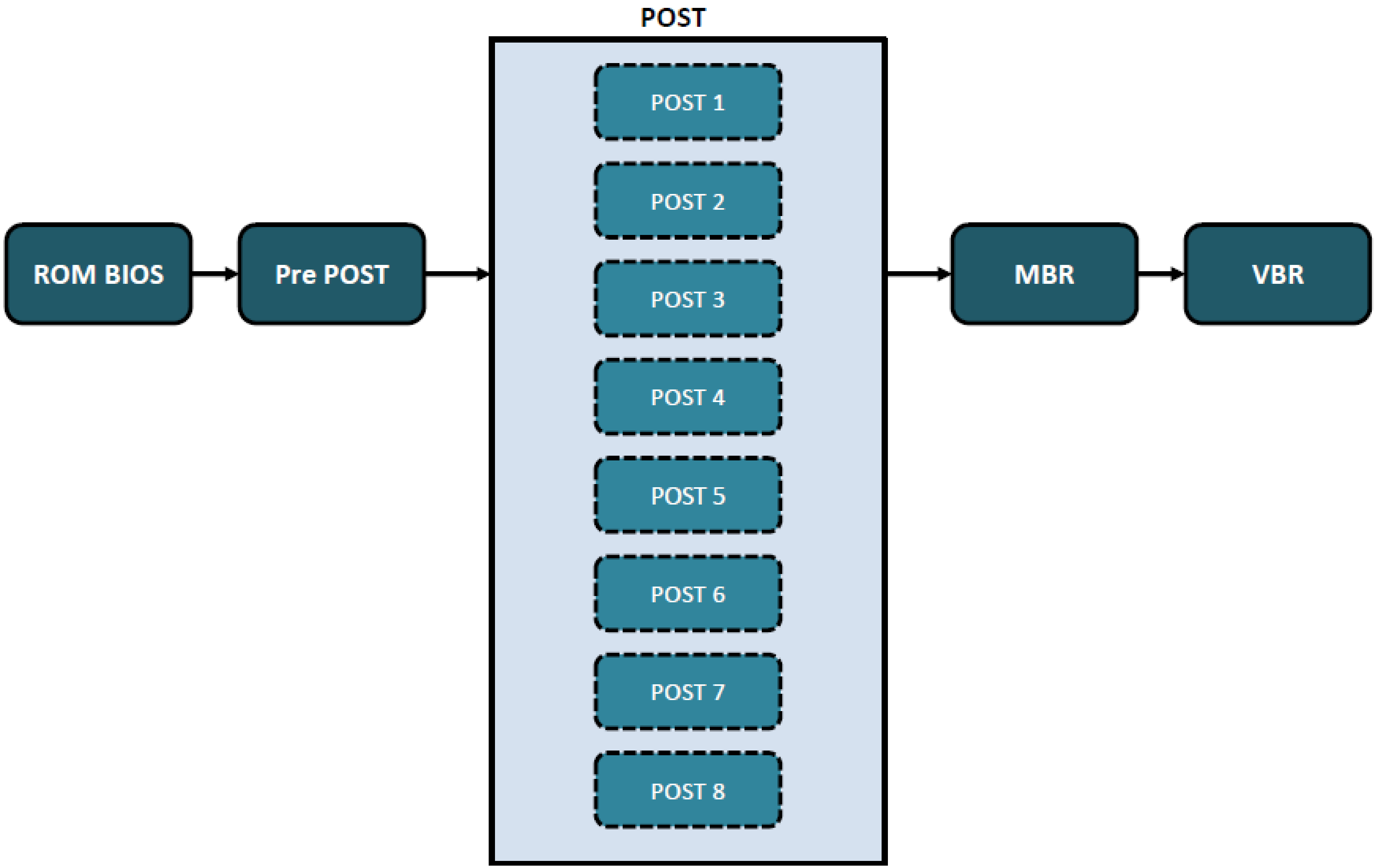
The Boot Process – Big Picture (Continued)

- POST results are compared with CMOS chip
- CMOS chip stores information about the computer drives, keyboard, monitor, current date and time
- Problem may result in beeps (example code on next slide), or error messages or simply fail to boot up
- If BIOS POST completes, BIOS instructs the CPU to look for a disk containing an Operating System

Example POST Beep Codes

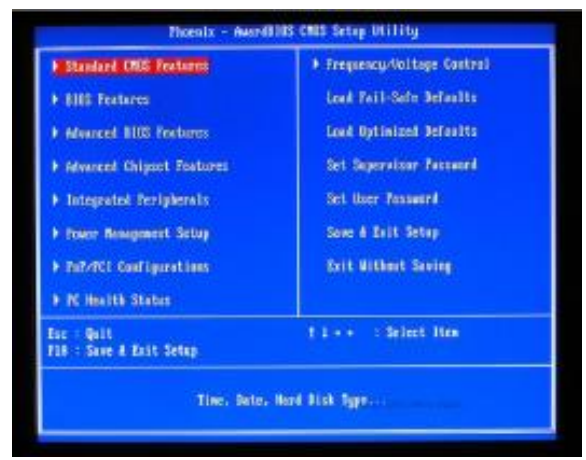
- BIOS vendors used a sequence of beeps from the motherboard-attached loudspeaker to signal error codes
  - Original IBM POST beep codes
    - 1 short beep - Normal POST - system is OK
    - 2 short beeps - POST error - error code shown on screen
    - No beep - Power supply, system board problem, disconnected CPU, or disconnected speaker,
    - Continuous beep - Power supply, system board, or keyboard problem
    - Repeating short beeps - Power supply or system board problem or keyboard
    - 1 long, 1 short beep - System board problem
    - 1 long, 2 short beeps - Display adapter problem (MDA, CGA)
    - 1 long, 3 short beeps - Enhanced Graphics Adapter (EGA)
    - 3 long beeps - 3270 keyboard card
  - Intel-based Macs
    - 1 beep = no RAM installed
    - 2 beeps = incompatible RAM types
    - 3 beeps = no good banks
    - 4 beeps = no good boot images in the boot ROM (and/or bad sys config block)
    - 5 beeps = processor is not usable

Common Boot Process



The Boot Process – ROM BIOS

- ROM BIOS stage: the first stage in “Boot Process” is to get the CPU started (reset) with an electrical pulse
  - By power on switch button or over network
  - Once CPU is reset, PC is initialized with 0xF000
    - **Address of bootstrap program in the ROM BIOS (Basic Input and Output System)**
  - Bootstrap program in ROM BIOS chips that contain computer start-up instructions starts



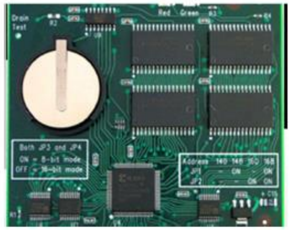
The Boot Process – Pre-POST

- BIOS does a series of tests to test computer hardware to be sure it is connected and operating correctly
  - Pre-POST: basic test for POST
- Pre-POST (Power on Self Test) freeze is indicative of some sort of hardware failure
- If test results matches with stored value in ROM BIOS, continue to POST

The Boot Process – POST

- 1^{st} Step: System bus test
  - Power-On Self Test (POST)
  - Send special signal to the system buses to ensure that the bus is properly functioning
  - If it passes, POST continues to the next step

- 2^{nd} Step: Real-Time Clock (RTC) or System clock test
  - Check system clock
    - **Stores system date and time and also keeps all system electrical signals in synchronization**
  - Inside the CMOS chip as a form of RTC/NVRAM
    - **NVRAM (Non-Volatile RAM): stores basic system information for booting such as size of memory, drive type, etc**



The Boot Process – POST (Continued)

- 3rd Step: System's Video Components test
  - The video memory is tested, as are the signals sent by this device
  - If it passes, POST continues to the next step

- 4th Step: Main Memory (RAM) test
  - The data is written to RAM
  - The data is read and compared to the original data sent
  - If it matches, it passes and go to the next step

- 5th Step: Keyboard test
  - Check whether the keyboard is properly attached and whether any keys are pressed
  - If it passes, go to next step

The Boot Process – POST (Continued)

- 6th Step: Drive test
  - Sends signals over specific bus pathways to determine which drives (floppies, CD & DVDs, hard disk drives) are available to the system
  - If it passes, go to next step

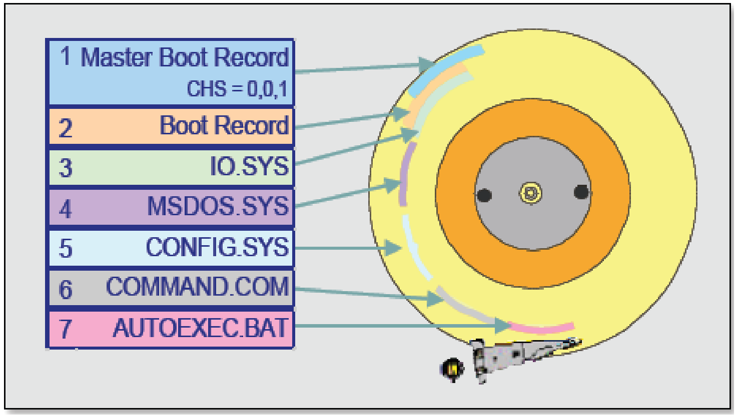
- 7th Step: Check the POST result
  - POST results are compared to the expected system settings store in CMOS
  - If it passes, go to next step

- 8th Step: Additional BIOS loading
  - Load additional BIOS (SCSI BIOS, etc.) to RAM if necessary

The Boot Process -- Disk Boot

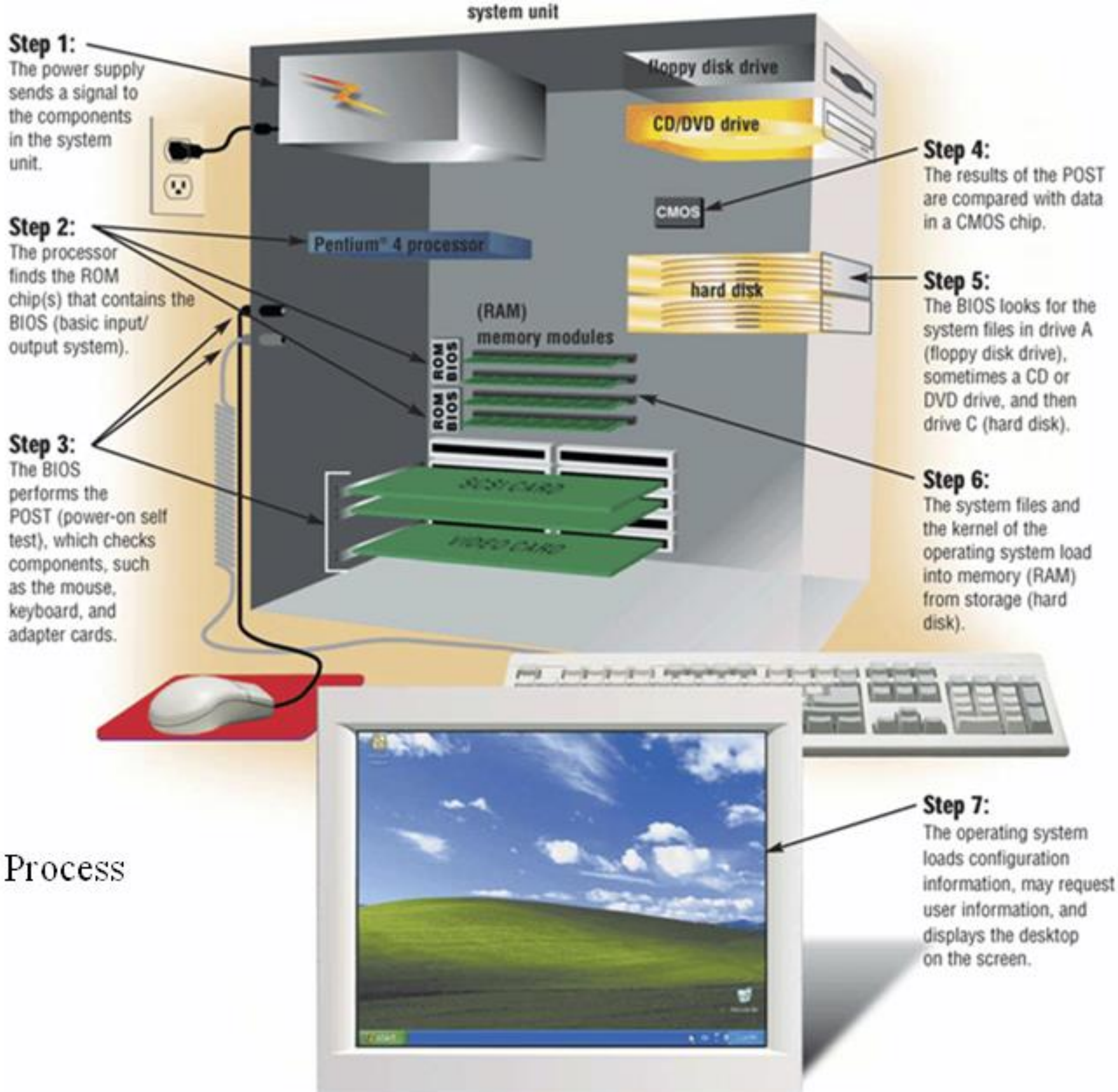
- If BIOS POST completes, the bootstrap code in ROM BIOS instructs the CPU to look for a disk containing an Operating System according to the order set forth in the boot sequence
  - The place where this information is stored is called the "master boot record" (***MBR***)
  - Also referred to as the "master boot sector" or "boot sector"

- The MBR is always located as cylinder 0, head 0, and sector 1



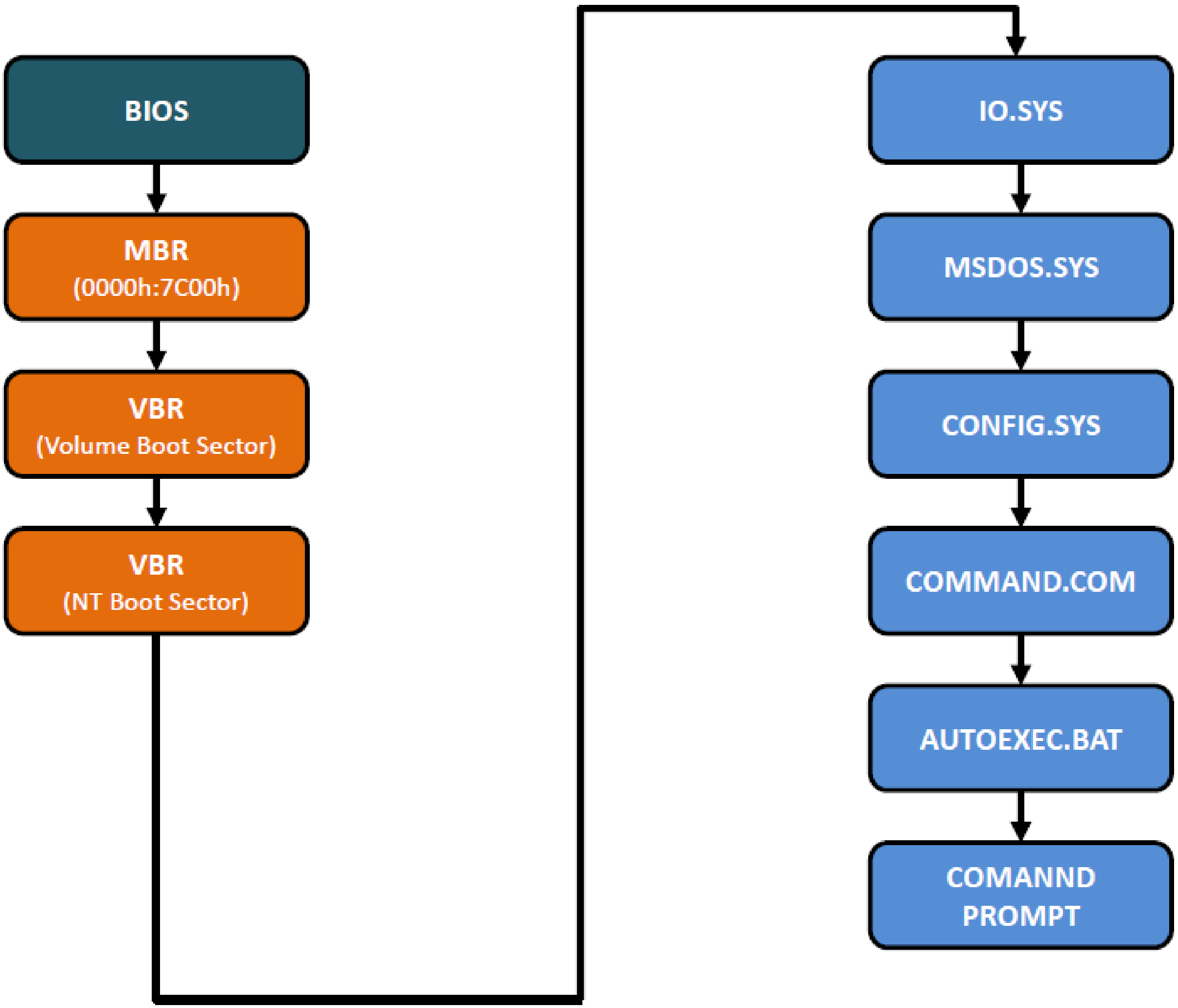
The Boot Process -- Disk Boot (Continued)

- The MBR contains following structure
  - Master Partition Table
    - **This small table contains the description of the partitions that are contained on the hard disk**
      - **There is only room for the information describing 4 (primary) partitions**
  - Master Boot Code
    - **This small initial boot program loaded and executed to start the boot process by BIOS**
      - **Since the master boot code is the first program executed when you turn on your PC, this is a favorite place for virus writers to target**
- Jump to the Volume Boor Record (VBR) of bootable partition
  - VBR code searches for and runs the OS on that volume

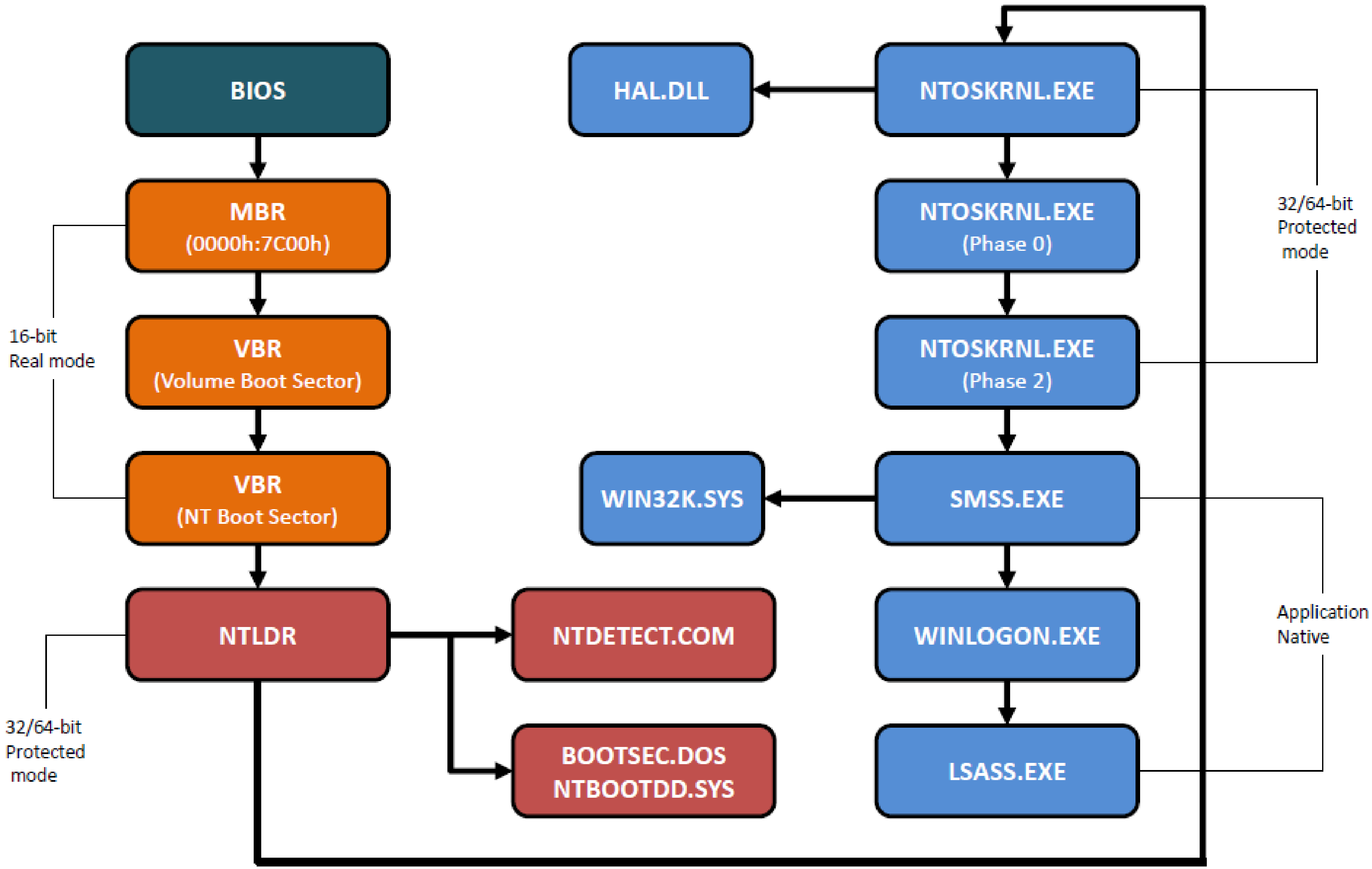


Boot Process

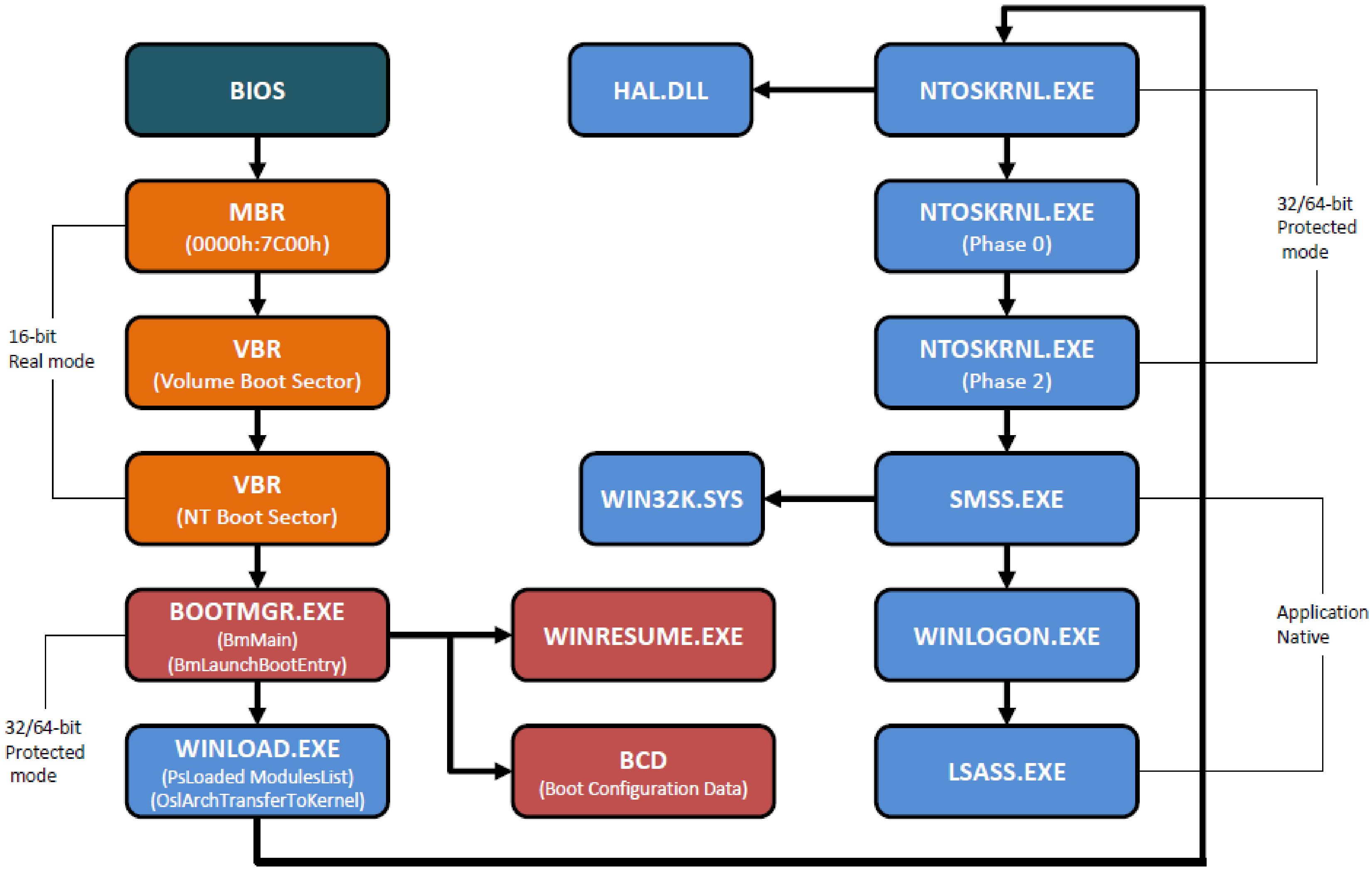
DOS Boot Process



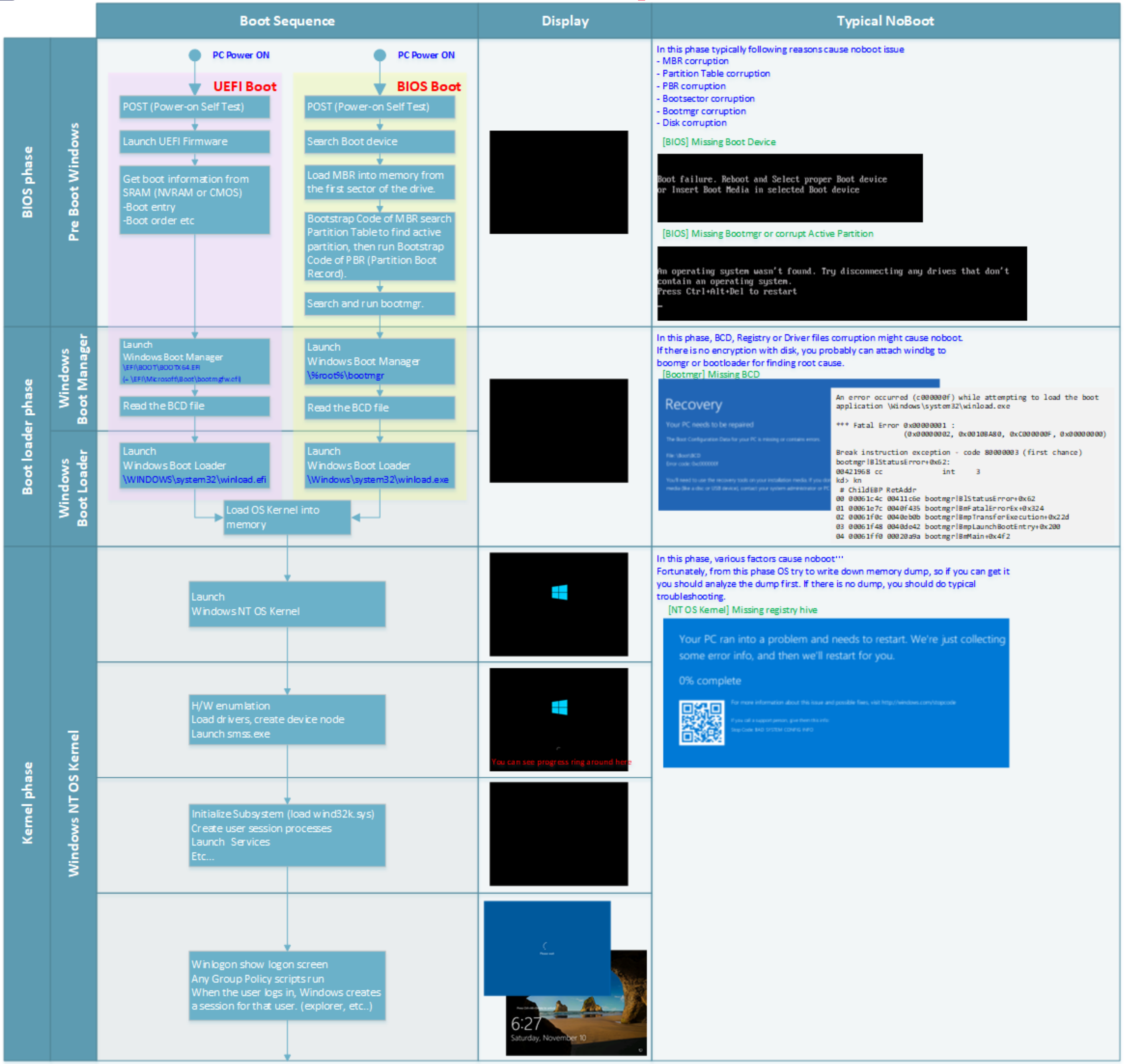
Windows NT/2000/XP Boot Process



Windows Vista/7 Boot Process



Windows 10 Boot sequence flowchart



Controlled Boot Environment

- Boot the computer and load an OS in a forensically sound manner so the evidentiary media is not changed
- When the disk contains evidence, the ability to prevent a computer from using the operating system on the hard disk is crucial
  - Ex) In Intel-based machine, a floppy diskette containing OS can be inserted to prevent the OS on the hard disk from loading
- Why is it important to have a controlled boot environment?