Chapter 2: System Structures

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Chapter 2: System Structures

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

Objectives

- To describe the services an operating system provides to users, processes, and other systems
  - How OSs interacts with user programs (via system calls)

- To discuss the various ways of structuring an operating system
  - How OSs are structured

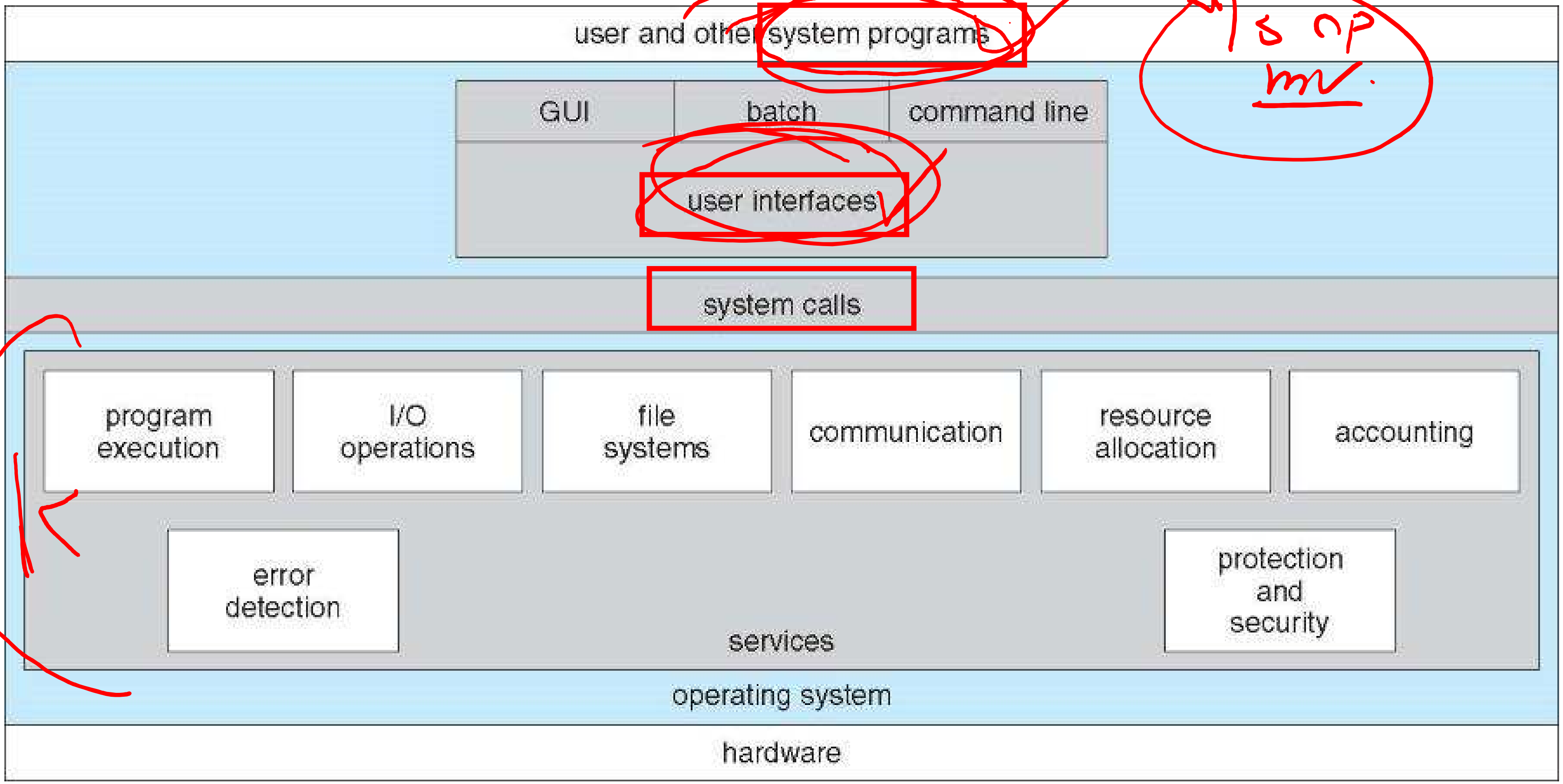
OPERATING SYSTEM SERVICES

A View of Operating System Services

POISX spec

UNIX = kernl + sys progrm → binutil coreutil

ls cp mv



Operating System Services

- 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,mainmemory, 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 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
    - If a system is to be protected and secure, precautions must be instituted throughout it. A chain is only as strong as its weakest link.

OPERATING-SYSTEM USER INTERFACE

Operating-System User Interface - CLI

- Shell refers to the interface program between users and the kernel
  - Text-driven: Command Line Interface (CLI)
  - Graphics-driven: Graphical User Interface (GUI)
- CLI allows direct command entry
  - 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

CLI in Windows/Linux

```
cmd
C:\windows\system32>cd \

C:\>dir/w
 磁碟區 C 中的磁碟是 TI30940600B
 磁碟區序號:  0A90-10B7

 C:\ 的目錄

[BaKoMa TeX]                [EcpaComponent]
[Intel]                     [LJP1100_P1560_P1600_Full_Solution]
[PerfLogs]                  [Program Files]
[Program Files (x86)]       SSUUpdater.log
[TOSHIBA]                   [Users]
[UTDService]                [Windows]
               1 個檔案              282 位元組
              11 個目錄   55,639,674,880 位元組可用

C:\>_
```

```
Loading...

Welcome to JS/Linux (x86)

Use 'vflogin username' to connect to your account.
You can create a new account at https://vfsync.org/signup .
Use 'export_file filename' to export a file to your computer.
Imported files are written to the home directory.

[root@localhost ~]# ls -l
total 8
drwxr-xr-x    3 root     root           163 Aug 21  2011 dos
-rw-r--r--    1 root     root           242 Jul 15  2017 hello.c
[root@localhost ~]# pwd
/root
[root@localhost ~]#
```

User Operating System Interface - GUI

WIMP

- 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 by 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
  - Solaris is CLI with optional GUI interfaces (Java Desktop, KDE)

PARC’s accomplishments:
mouse, GUI, WYSIWYG editors,
postscript language, laser printers, ethernet, small talk

The Mac OS X GUI

Touchscreen Interfaces

(PDA)

Palm Pilot

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

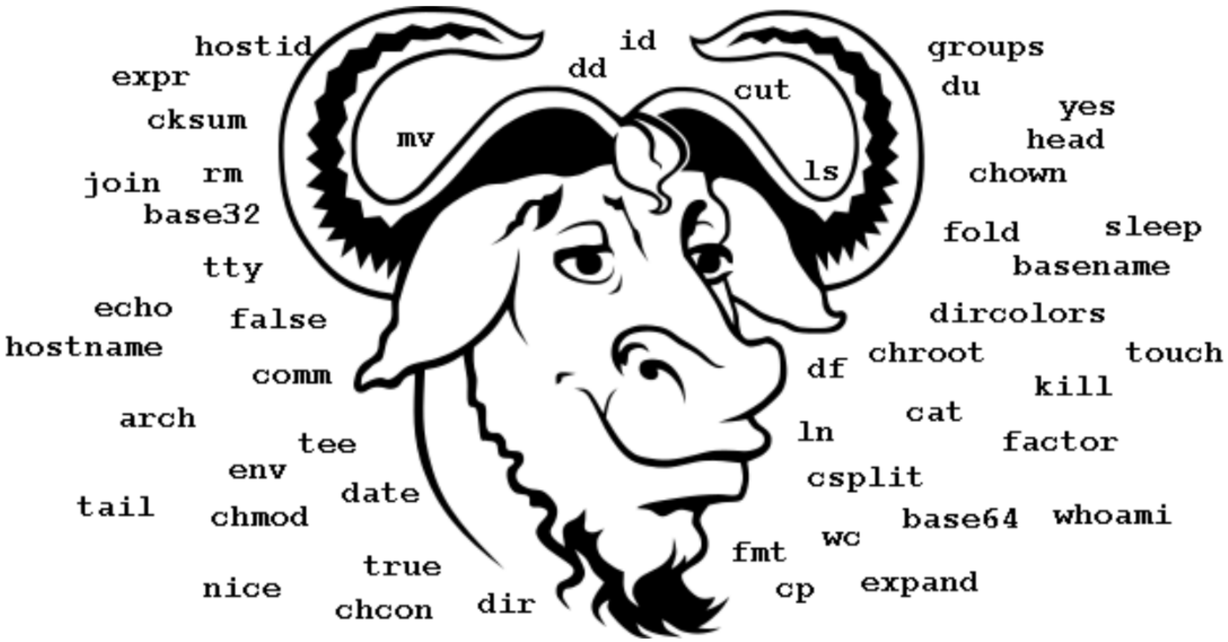
SYSTEM PROGRAMS

System Programs

- System programs provide a convenient environment for program development and execution. The can be divided into:
  - File manipulation (cp, mv…)
  - Status information (ls…)
  - File modification (vi…)
  - Programming language support (cc, as, ld, ar…)
  - Program loading and execution
  - Communications (telnet…)

- Most users’ view of the operation system is defined by system programs, not the actual system calls

GNU coreutils + binutils



System Programs

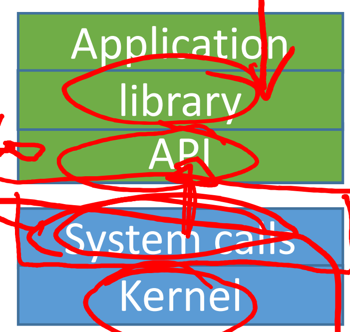
- Provide a convenient environment for program development and execution
  - Some of them are simply user interfaces to system calls; others are considerably more complex
- File management - Create, delete, copy, rename, print, dump, list, and generally manipulate files and directories
- Programming-language 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

SYSTEM CALLS

System Calls

- Programming interface to the services provided by the OS
- Mostly accessed by programs via a high-level Application Program Interface (API) rather than direct system call use
  - ~~Typically written in a high~~-level language (C or C++)
  - Portability and simplicity
- 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)

user U
kernel K



W10 W11
W7 Vista

C standard library API:	fopen("w+"…)	C language
WIN32 API:	CreateFile()	Windows >= win4.0, >=95
Kernel API:	NTCreateFile()	WinNT, 2k,XP, vista
System Call:	int 2e	X86 machine instruction

```
int printf ( const char * format, ... );
```

```
BOOL WINAPI WriteFile(
  _In_          HANDLE hFile,
  _In_          LPCVOID lpBuffer,
  _In_          DWORD nNumberOfBytesToWrite,
  _Out_opt_     LPDWORD lpNumberOfBytesWritten,
  _Inout_opt_   LPOVERLAPPED lpOverlapped
);
```

```
NTSTATUS NtWriteFile
(
 HANDLE               hFile,
 HANDLE               hEvent,
 PIO_APC_ROUTINE      apc,
 void*                apc_user,
 PIO_STATUS_BLOCK     io_status,
 const void*          buffer,
 ULONG                length,
 PLARGE_INTEGER       offset,
 PULONG               key
)
```

```
Err… Not disclosed by Microsoft…

May look like:
        mov eax, <service #>
        lea edx, <addr of 1st arg>
        int 2e
```

Example of Standard API

- Consider the ReadFile() function in the Win32 API—a function for reading from a file
-
```
return value

BOOL    ReadFile c   (HANDLE          file,
                      LPVOID          buffer,
                      DWORD           bytes To Read,      parameters
                      LPDWORD         bytes Read,
                      LPOVERLAPPED    ovl);

             function name
```

async I/O

- 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

System Call Implementation

Trap

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

Dual Mode Operations

- Application calls into the kernel through trap

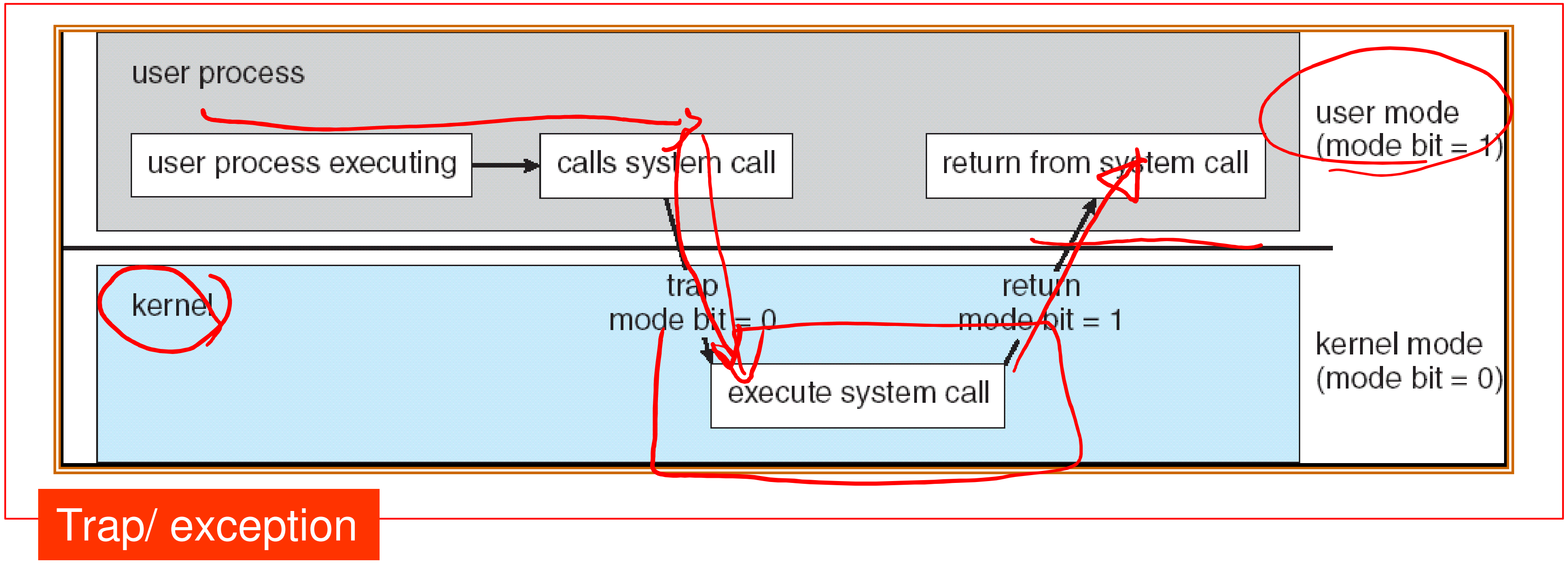
- Interrupt driven by hardware (IRQ)
- Software error or request creates trap or exception
  - Division by zero, memory access violation, etc
  - Request for operating system service (system calls)

Dual Mode Operations

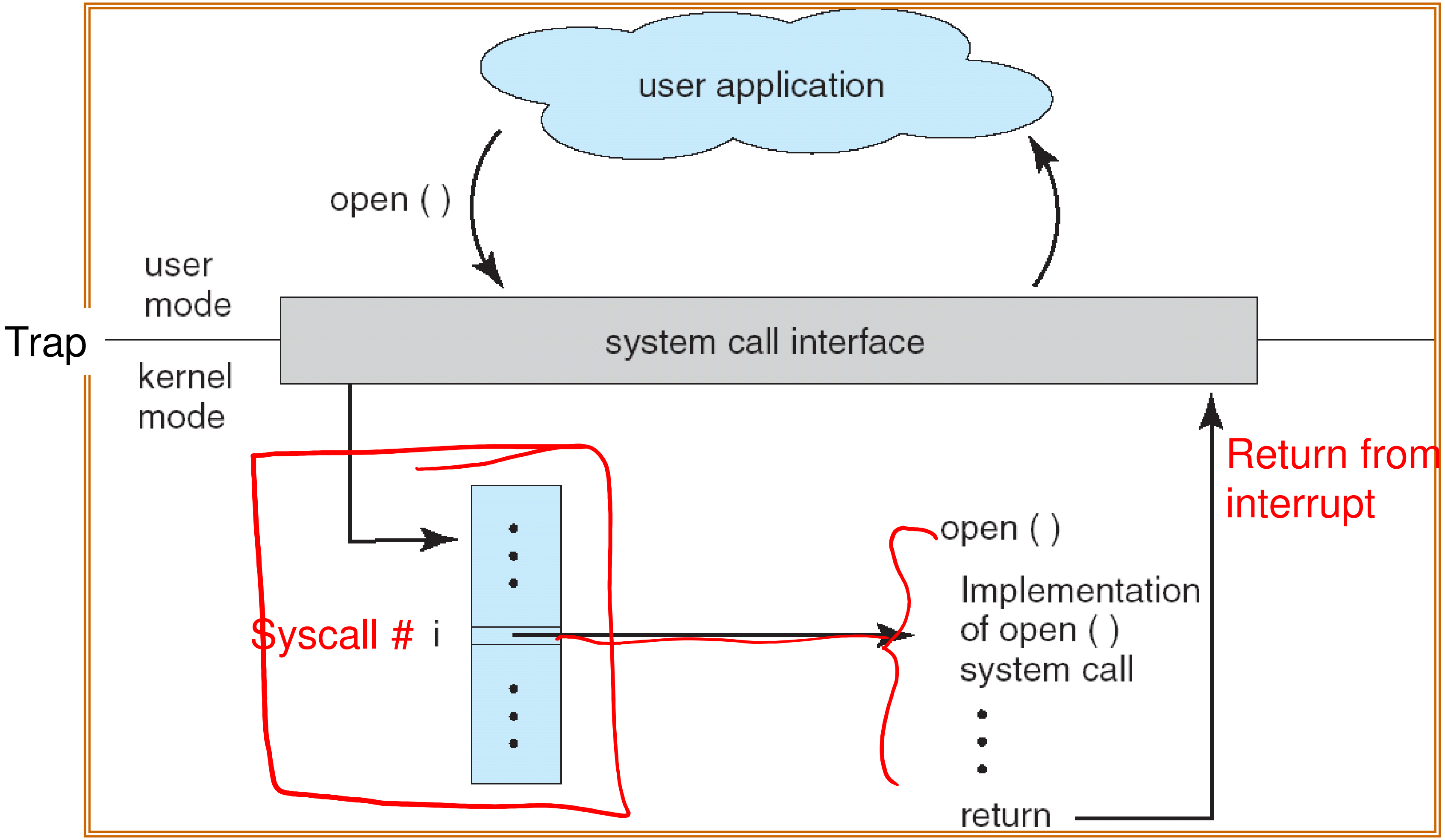
- Dual-mode operation allows OS to protect itself and other system components
  - User mode and kernel mode
  - Mode bit provided by hardware

- The purpose of dual-mode design
  - Provides ability to distinguish when system is running user code or kernel code
  - Some instructions designated as privileged, only executable in kernel mode
  - System call changes mode to kernel, return from call resets it to user

Transition from User to Kernel Mode

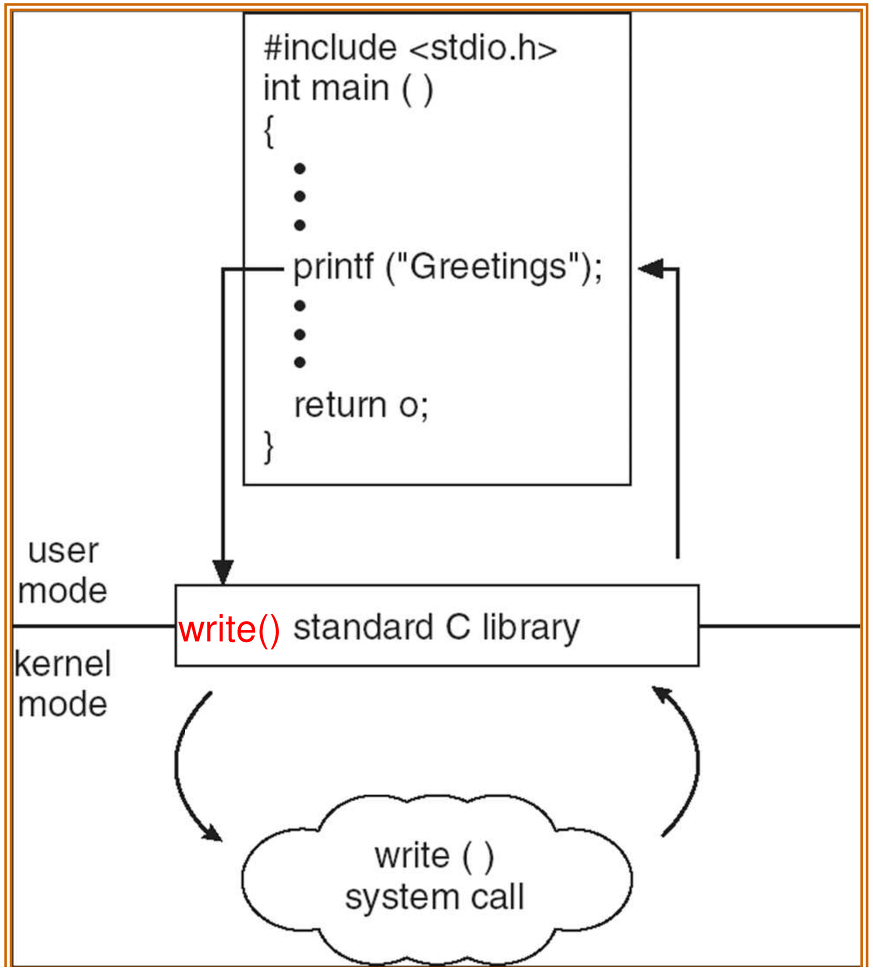


API – System Call – OS Relationship



Standard C Library Example

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



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
  - Pass the parameters in registers
  - Parameters stored in a block, or table, in memory, and address of block passed as a parameter in a register
  - Parameters placed, or pushed, into the stack by the program and popped off the stack by the operating system

sp →

push

0x80 Linux 0x2e Win process

System Call in Linux (NASM Syntax)

16 B

```
section .data                    ;declare section
msg db   "Hello World! :)",0xa   ;our dear string
len equ $ - msg                  ;length of our dear string

section .text                    ; section declaration

    global _start                ; exporting entry point
                                 ; to the ELF linker
_start:
; write Hello World string
    mov edx,len    ;third arg: message length
    mov ecx,msg    ;second arg: pointer to message to write
    mov ebx,1      ;first arg: file handle (stdout)
    mov eax,4      ;system call nr. (sys_write)
    int 0x80       ;call kernel (trigger a trap)
; and exit
    mov ebx,0      ;first syscall args: exit code
    mov eax,1      ;system call no. (sys_exit)
    int 0x80       ;call kernel
```

$ len=16 entry

Stack

data

Hello

Text (code)

eax 32-bit reg

d

More on System Calls

Reg

IVT

- System Call in Windows
  - Use the following fragment of assembly code to call the kernel

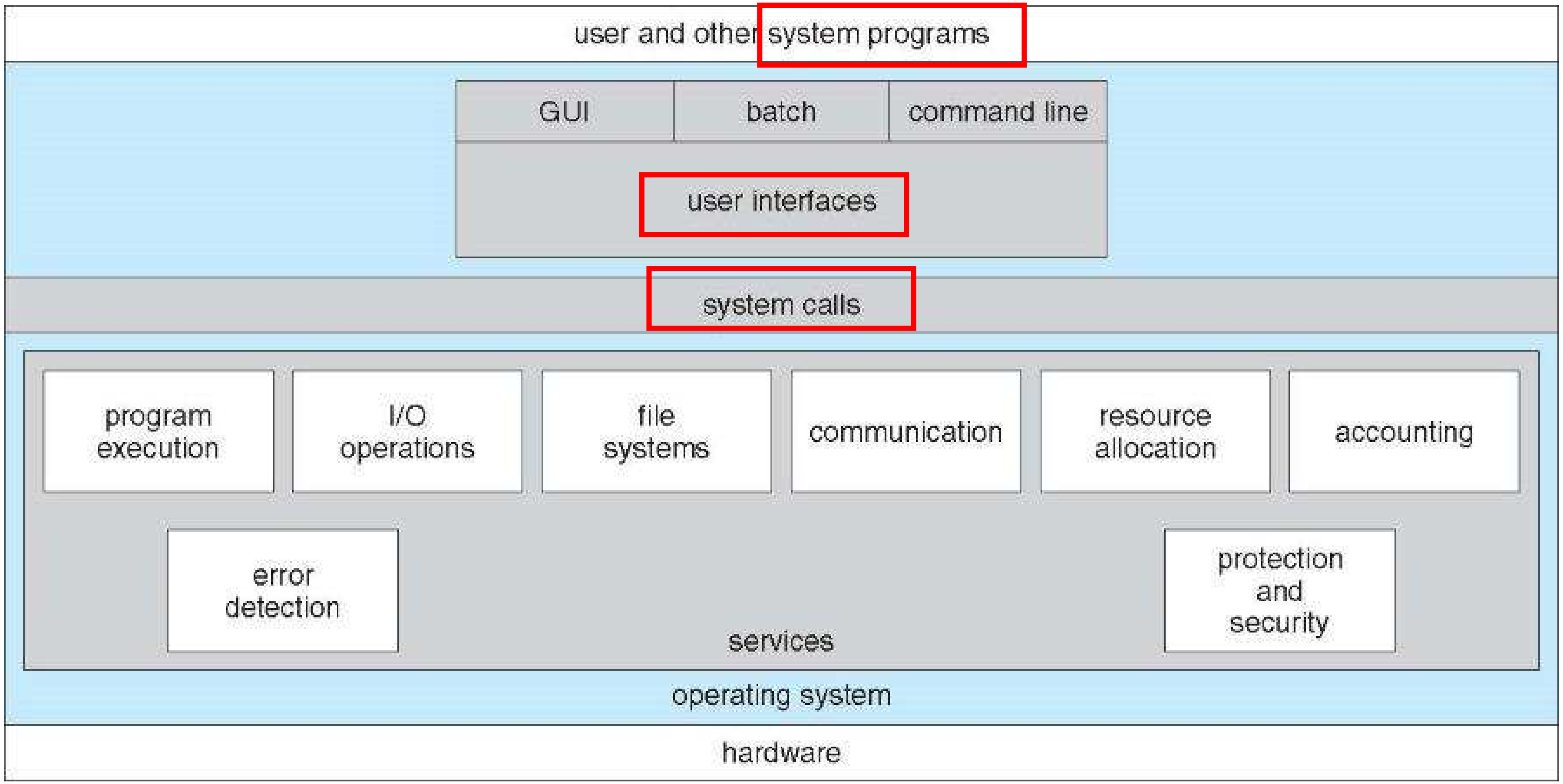
```
MOV EAX, <service #>
LEA EDX, <addr of 1st arg>
INT 2E
```

0 INT

  - Return value is in EAX (if any)

- For modern Intel / AMD CPUs, SYSENTER / SYSCALL are suggested for making system calls, respectively
  - System call entry address is stored in a control register

Recap



user and other system programs
GUI
batch
command line
user interfaces
system calls
program execution
I/O operations
file systems
communication
resource allocation
accounting
error detection
protection and security
services
operating system
hardware

TYPES OF SYSTEM CALLS

Types of System Calls

- Process control
- File management
- Device management
- Information maintenance
- Communications

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()

Stdout "file" device

Linux System Calls

main() {
≡
ϕ → exit(0);

List by system call number

00 sys_setup [sys_ni_syscall]
01 sys_exit
02 sys_fork
03 sys_read
04 sys_write
05 sys_open
06 sys_close
07 sys_waitpid
08 sys_creat
09 sys_link
10 sys_unlink
11 sys_execve
12 sys_chdir
13 sys_time
14 sys_mknod
15 sys_chmod
16 sys_lchown
17 sys_break [sys_ni_syscall]
18 sys_oldstat [sys_stat]
19 sys_lseek
20 sys_getpid
21 sys_mount
…

70 sys_setreuid
71 sys_setregid
72 sys_sigsuspend
73 sys_sigpending
74 sys_sethostname
75 sys_setrlimit
76 sys_getrlimit
77 sys_getrusage
78 sys_gettimeofday
79 sys_settimeofday
80 sys_getgroups
81 sys_setgroups
82 sys_select [old_select]
83 sys_symlink
84 sys_oldlstat [sys_lstat]
85 sys_readlink
86 sys_uselib
87 sys_swapon
88 sys_reboot
89 sys_readdir [old_readdir]
90 sys_mmap [old_mmap]
91 sys_munmap
…

140 sys__llseek [sys_lseek]
141 sys_getdents
142 sys__newselect [sys_select]
143 sys_flock
144 sys_msync
145 sys_readv
146 sys_writev
147 sys_getsid
148 sys_fdatasync ~ fsync
149 sys__sysctl [sys_sysctl]
150 sys_mlock
151 sys_munlock
152 sys_mlockall
153 sys_munlockall
154 sys_sched_setparam
155 sys_sched_getparam
156 sys_sched_setscheduler
157 sys_sched_getscheduler
158 sys_sched_yield
159 sys_sched_get_priority_max
160 sys_sched_get_priority_min
161 sys_sched_rr_get_interval
…

OPERATING SYSTEM DESIGN AND IMPLEMENTATION

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 –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

- Design issues for different types of systems
  - Real-time OS: time predictability, low latency, romability
  - Mainframe OS: throughput, scalability
  - Desktop OS: responsiveness, user friendly

Operating System Design and Implementation (Cont.)

- Important principle to separate
  - Mechanism: How to do it?
  - Policy: What will be done?
- Mechanisms determine how to do something, policies decide what will be done next
- The separation of policy from mechanism is a very important principle, it allows maximum flexibility if policy decisions are to be changed later
- Use disk I/O as an example:
  - Mechanism: How to read and write from disk?
  - Policy: Which disk I/O operation should be performed first?

performance ✓
correctness ✗

e.g., fifo, deadline
⋮

Which one(s) of the following are policies; which are mechanisms?

a) process suspend/resume M

b) P allocating the smallest among the memory blocks which are larger than the requested size

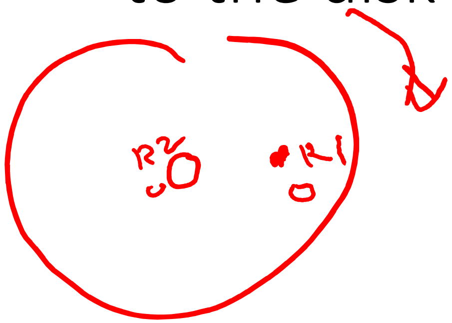
Best Fit

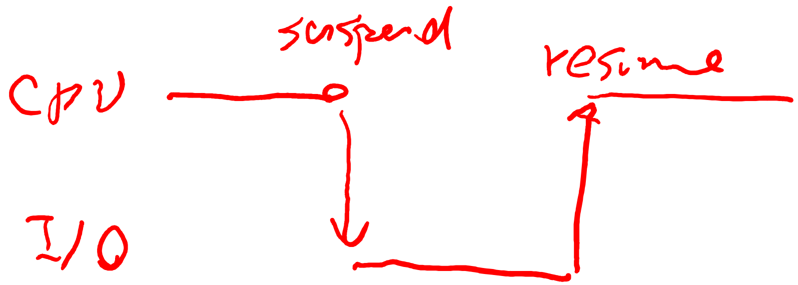
90KB

100KB 50 KB 1MB

c) M marking a disk block as allocated

d) P servicing the disk I/O request which is closest to the disk head





Simple	→ MSDOS
Monolith	→ UNIX
Microkernel	→ Mach
Layered	→ Err….
Virtual machine	→ Cloud

OPERATING-SYSTEM STRUCTURE

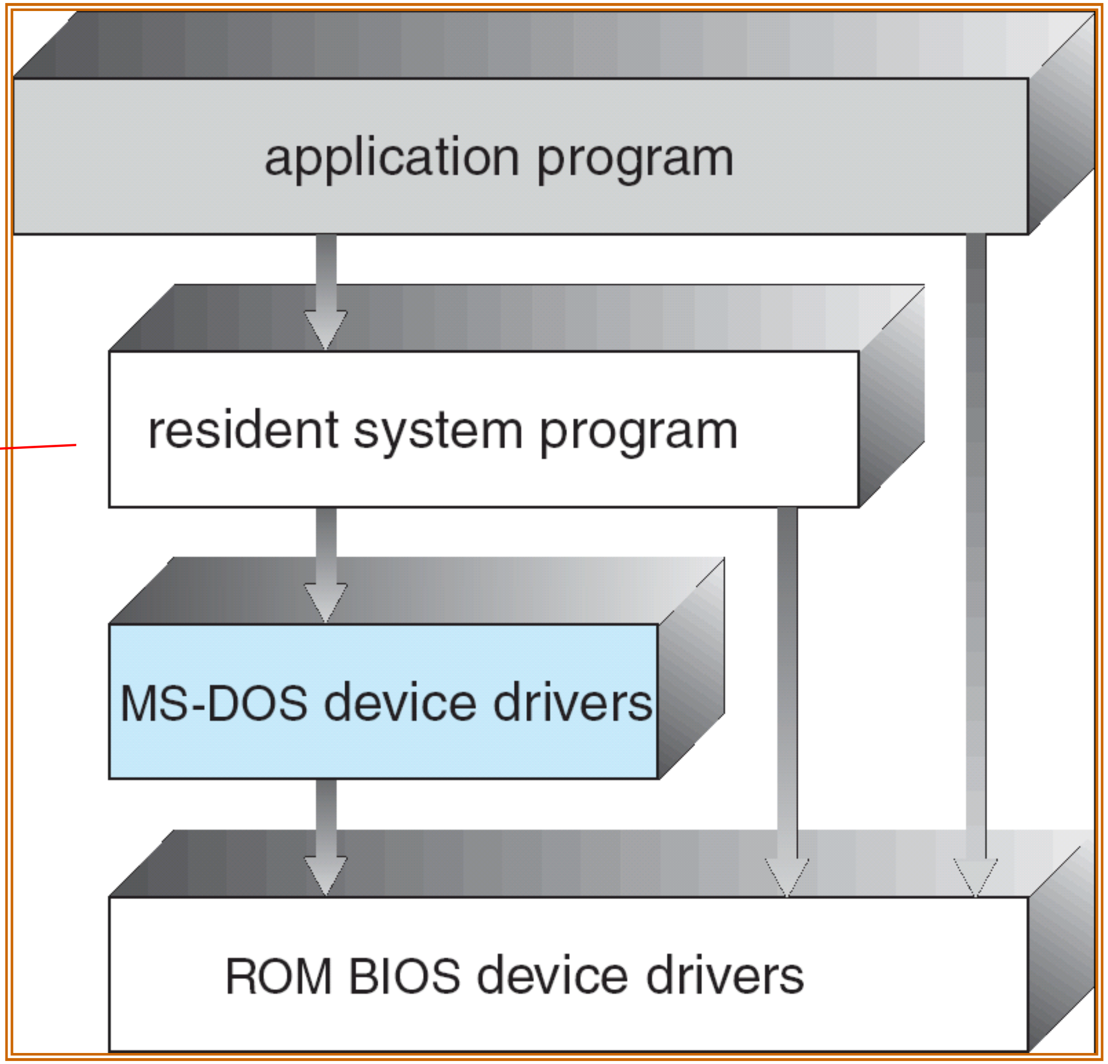
Simple Structure

- 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
- No protection. Applications can directly access any memory addresses and control hardware
- MS-DOS is left no choice because the CPU 8086 offers no hardware protection for user-kernel separation

MS-DOS Layer Structure

TSR programs

Such as
dosshell,
sidekick…



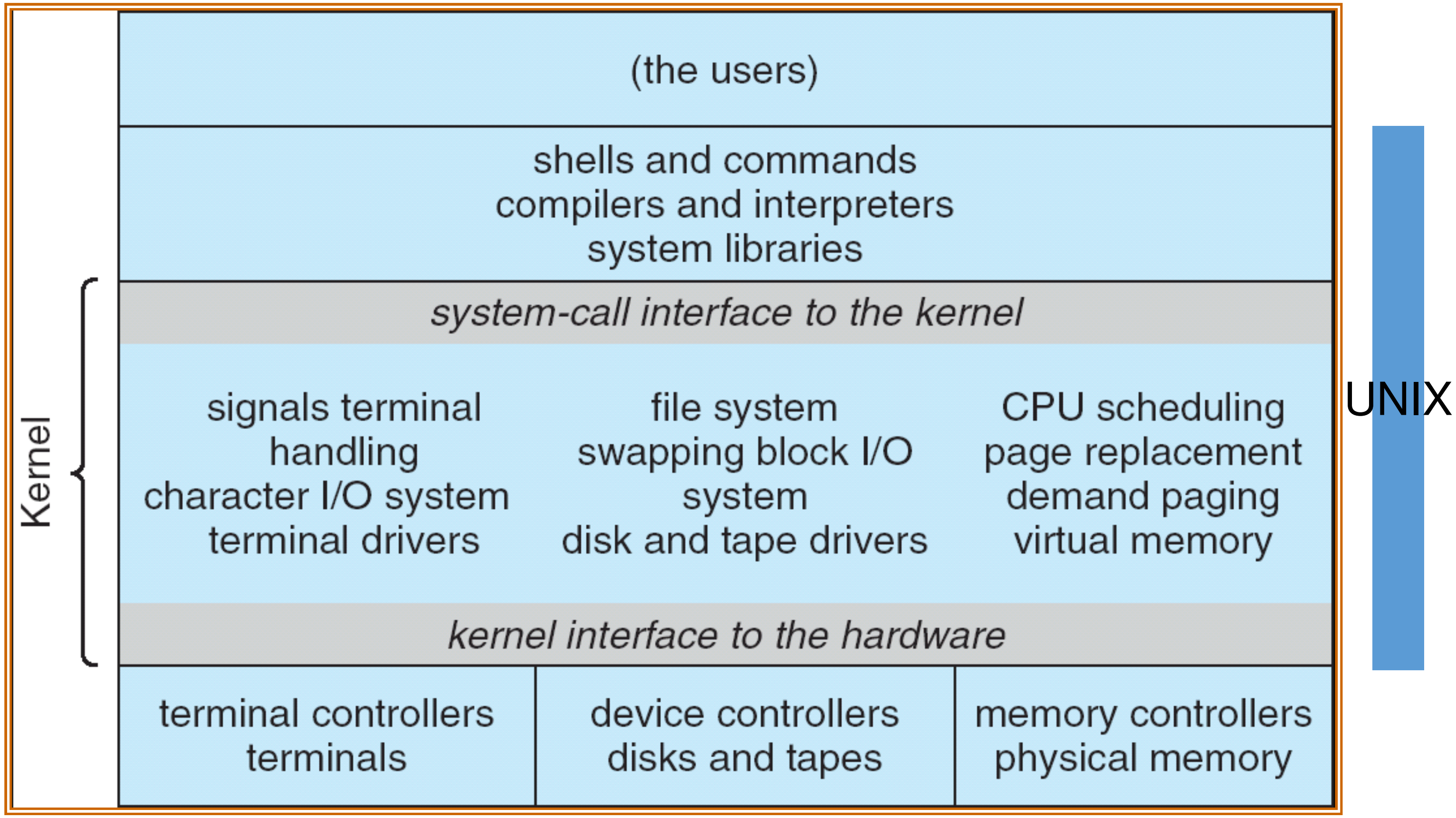
Booting MS-DOS

UNIX--monolithic

- UNIX – limited by hardware functionality, the original UNIX operating system had limited structuring. The UNIX OS consists of two separable parts:

1. Systems programs
   - binutils + coreutils: ls, mv, cp, etc
2. 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

UNIX System Structure



UN*X is, of course, a huge monolith operating system

Modules

- Most modern operating systems implement 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

Common interfaces of a Linux kernel module
Initialize
Clean up
Read (char)
Write (char)
Read (block)
Write (block)

Case Study: Linux Module

```
#include <linux/kernel.h> /* header file for structure pr_info */
#include <linux/init.h>
#include <linux/module.h> /* header file for all modules */
#include <linux/version.h>

MODULE_DESCRIPTION("Hello World !!");
MODULE_AUTHOR("John Doe");
MODULE_LICENSE("GPL");

static int __init hello_init(void)
{
    pr_info("Hello, world\n");
    pr_info("The process is \"%s\" (pid %i)\n", current->comm, current->pid);
    return 0;
}

static void __exit hello_exit(void)
{
    printk(KERN_INFO "Goodbye\n");
}

module_init(hello_init);
module_exit(hello_exit);
```

Source:
http://blog.wu-boy.com/2010/06/linux-kernel-driver-%E6%92%B0%E5%AF%AB%E7%B0%A1%E5%96%AE-hello-world-module-part-1/

Case Study: Linux Module

- Insert & init the module
  - insmod ./hello.ko
- Remove & clean up the module
  - rmmod ./hello.ko

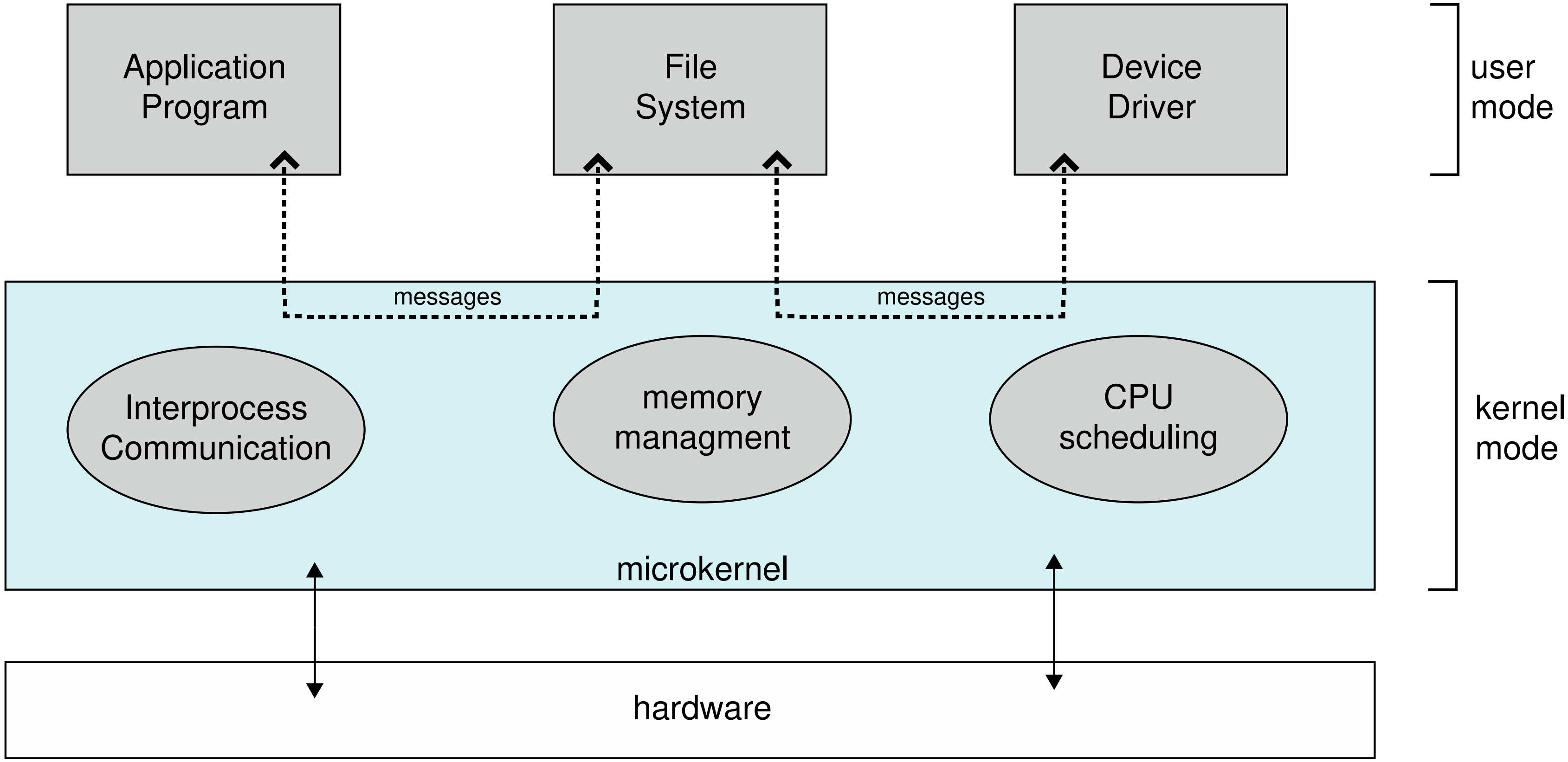
```
Jun 21 11:50:00 cvs5 kernel: [8381603.818051] The process is "insmod" (pid 30560)
Jun 21 11:50:08 cvs5 kernel: [8381612.335386] Goodbye
Jun 21 12:07:13 cvs5 rsyslogd: [origin software="rsyslogd" swVersion="4.2.0" x-pid='
.com"] rsyslogd was HUPed, type 'lightweight'.
Jun 21 12:07:13 cvs5 rsyslogd: [origin software="rsyslogd" swVersion="4.2.0" x-pid='
.com"] rsyslogd was HUPed, type 'lightweight'.
Jun 21 14:55:23 cvs5 kernel: [8392723.612597] Hello, world
Jun 21 14:55:23 cvs5 kernel: [8392723.612601] The process is "insmod" (pid 10072)
Jun 21 14:55:37 cvs5 kernel: [8392737.604360] Goodbye
Jun 21 15:05:18 cvs5 kernel: [8393318.795982] Hello, world
Jun 21 15:05:18 cvs5 kernel: [8393318.795985] The process is "insmod" (pid 13127)
Jun 21 15:05:25 cvs5 kernel: [8393325.537903] Goodbye
```

Source:
http://blog.wu-boy.com/2010/06/linux-kernel-driver-%E6%92%B0%E5%AF%AB%E7%B0%A1%E5%96%AE-hello-world-module-part-1/

Microkernel System Structure

- Moves as much from the kernel into “user” space
- Communication takes place between user modules using message passing
- Benefits:
  - Easier to extend a microkernel (by adding user-mode modules)
  - Easier to port the operating system to new architectures
  - More reliable and secure (less code is running in kernel mode)
- Detriments:
  - Performance overhead of user space to kernel space communication and user-kernel mode switches
  - What happened to Windows NT 3.5?

Microkernel System Structure



The Famous Tanenbaum–Torvalds Debate

- *"I'm doing a (free) operating system (just a hobby, won't be big and professional like gnu) for 386(486) AT clones."*

  -- Linus Torvalds

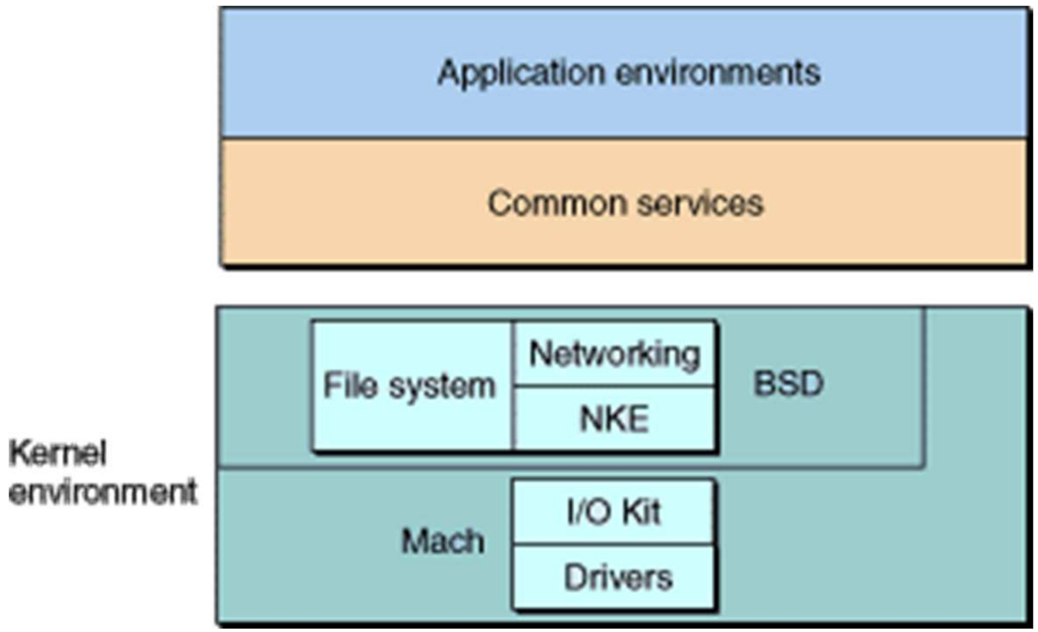
- *“LINUX is a monolithic style system. This is a giant step back into the 1970s”*

  -- Andrew Tanenbaum

- Wiki entry

Mac OS X Structure

- Mach (μ-kernel): memory management, RPC, IPC, message passing, thread scheduling
- BSD: networking, file systems, POSIX APIs
-



Google Fuchsia

- A new operating system developed by Google, based on the Zircon microkernel
- Reportedly designed for IoT devices

Flutter (UI framework) + Dart (language)→ UI
Fuchsia→ system services and IPC
Zircon→ microkernel

Quiz

What are the design objectives of the micro-kernel approach?

1. Scalability
2. Robustness
3. Efficiency
4. Security

Virtual Machines

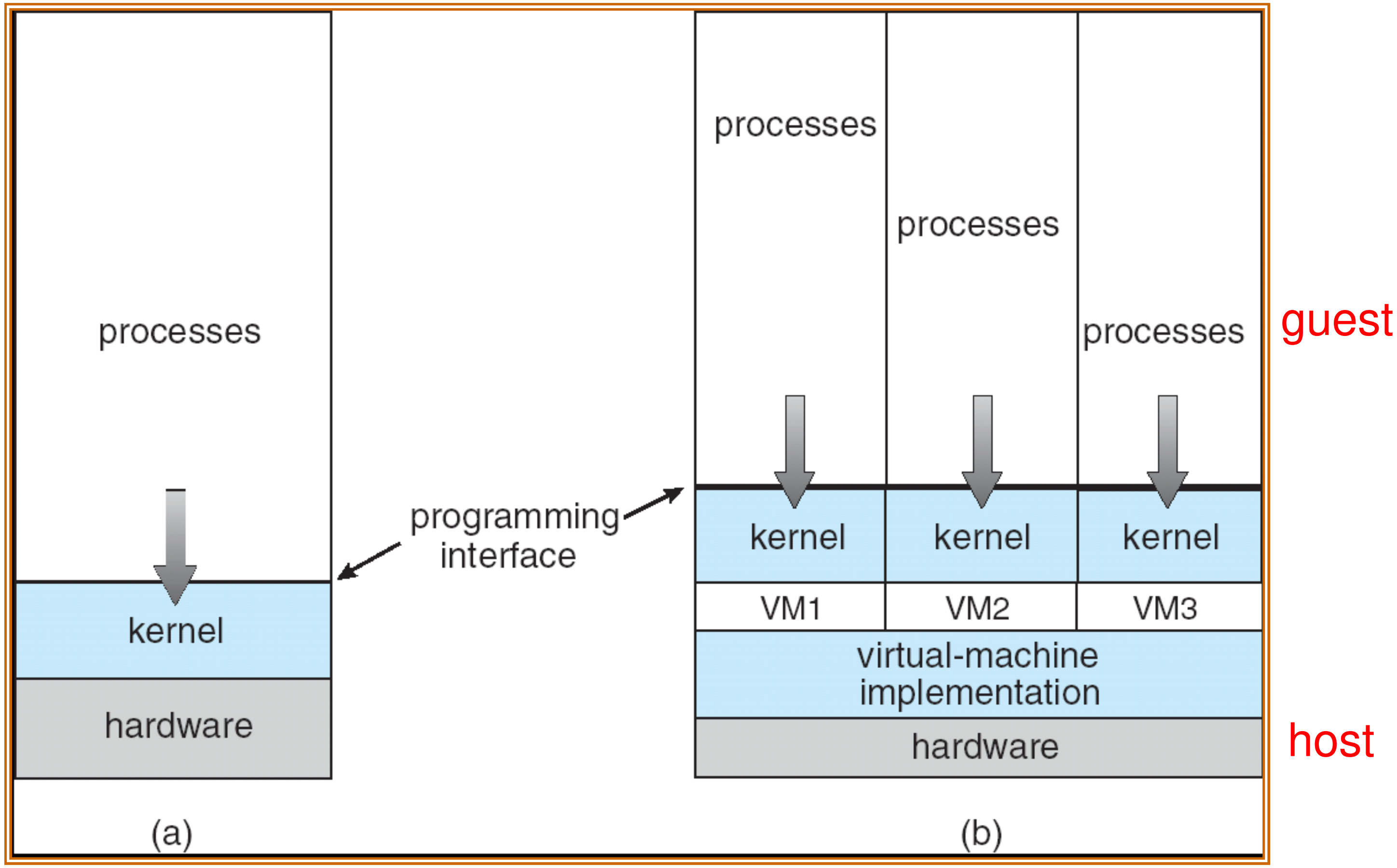
- A virtual machine takes the layered approach to its logical conclusion. It treats hardware and the operating system kernel as though they were all hardware
- A virtual machine provides an interface identical to the underlying bare hardware
- The operating system creates the illusion of multiple processes,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

- Virtual machine is not a new concept. It has been developed in 197x. VM again become popular because
  - It becomes hard to maintain outdated servers
  - Cloud computing (service virtualization)

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.)

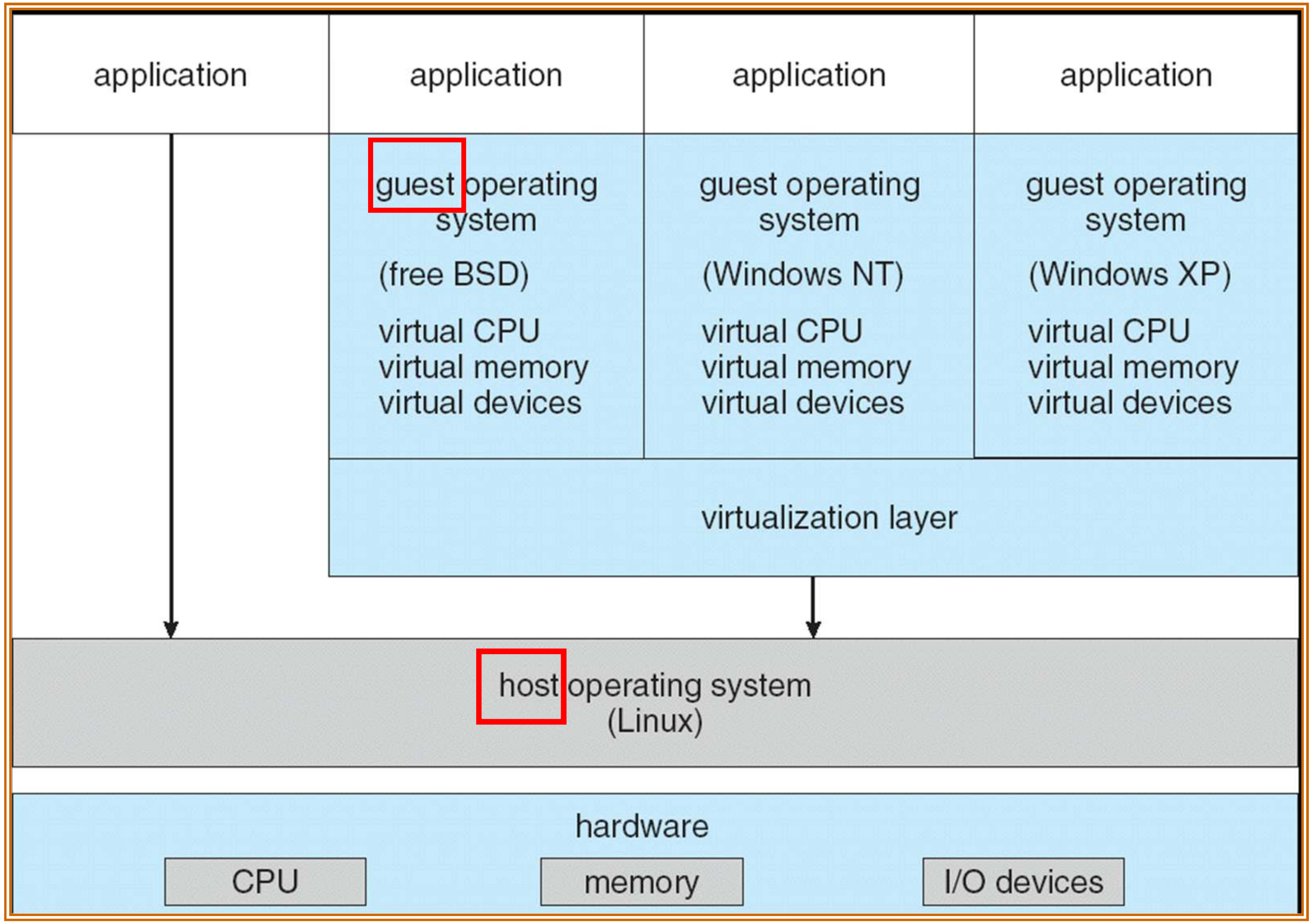


(a) bare-metal (b) virtual machines

Virtual Machines (Cont.)

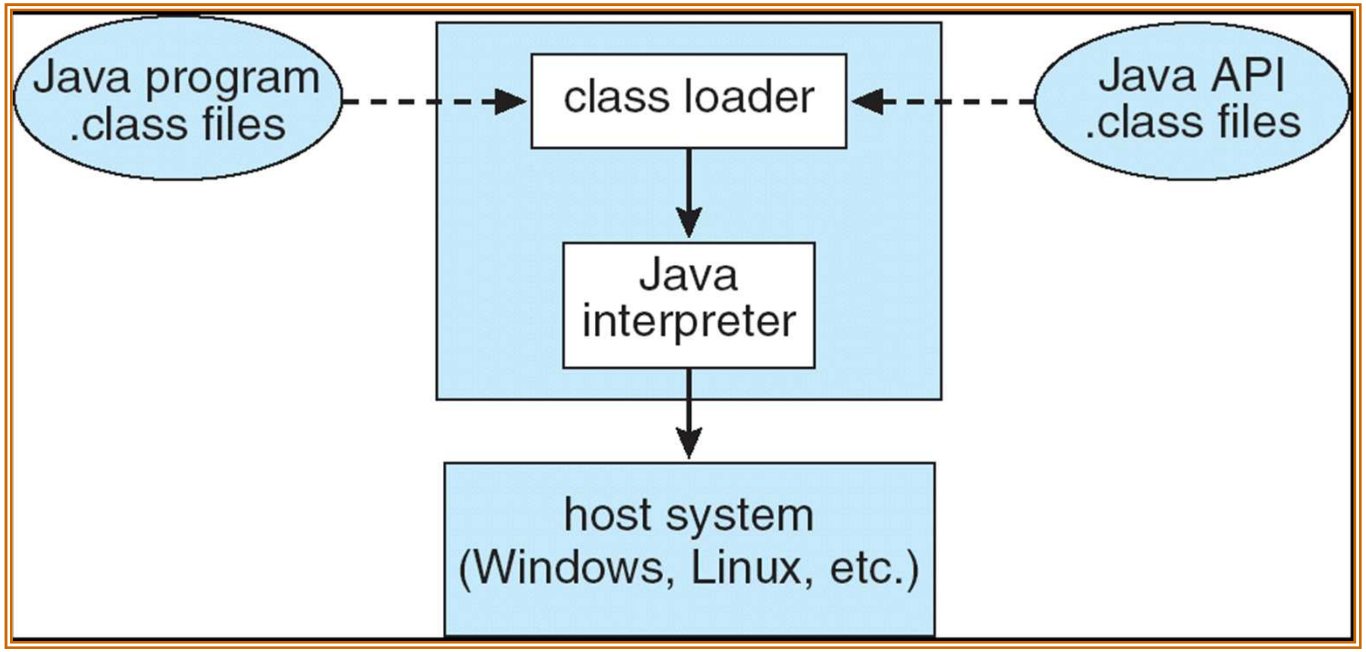
- The virtual-machine concept provides complete protection of system resources since each virtual machine is isolated from all other virtual machines. This isolation, however, permits no direct sharing of resources.
- A virtual-machine system is a perfect vehicle for operating-systems research and development. 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



Native execution

The Java Virtual Machine

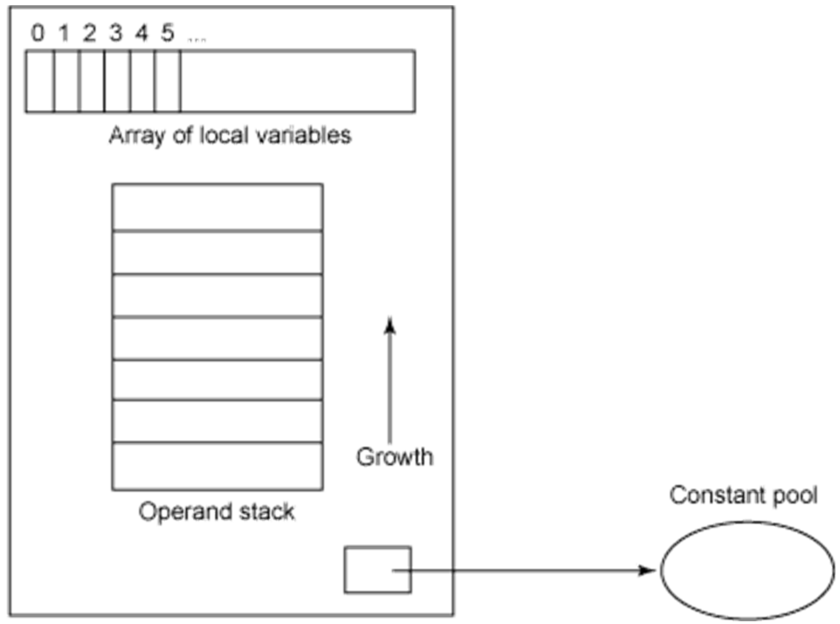


Java programs: the source code
Byte code: the compiled binary for JVM
JVM or java runtime: a hardware-independent virtual machine

*Non-native execution

Java Bytecode

```
iload_1
iload_2
iadd
istore_3
```



Quiz

The virtual machine approach is suitable to which one(s) of the following scenarios?

1. OS development
2. Cloud computing
3. Performance-critical gaming
4. Writing an application for heterogeneous hardware platforms

Summary: Virtual Machines

- Virtualizes hardware
- Pros
  - Guest operating systems run without modifications
  - Perfect resource partition and fault isolation
- Cons
  - Inefficient mapping between emulated hardware and the underlying hardware
  - Hard to implement hardware virtualization

Summary: Microkernel

- Provide “a minimal set of kernel primitives”
- Pros
  - Stable, extendible, secure, portable
- Cons
  - Frequent mode switches
  - High message-passing overhead

Review

- Simple structure
  - Pros: simple, cons: poorly structured
- Monolith
  - Pros: efficient, cons: not scalable
- Layered
  - Pros: more structured, cons: difficult to comply with
- Microkernel
  - Pros: robust and scalable, cons: inefficient
- Virtual machine
  - Pros: perfect resource isolation, cons: possibly inefficient mapping from VM to host hardware

End of Chapter 2