

# **Chapter 2: Operating-System Structures**

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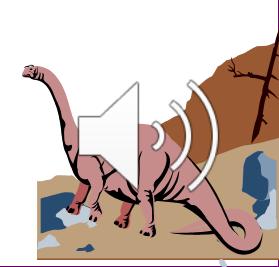
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# Chapter 2: Operating-System Structures

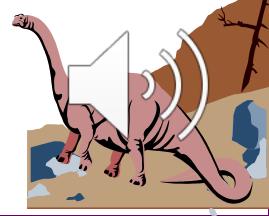
- Operating System Services
- User Operating System Interface
- System Calls
- Types of System Calls
- System Programs
- Operating System Design and Implementation
- Operating System Structure
- Virtual Machines
- Operating System Generation
- System Boot





# Question about OS Services

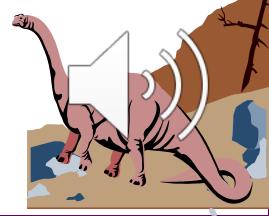
- Name (as many as you can) system services you expect from an operating system





# Question about OS Services

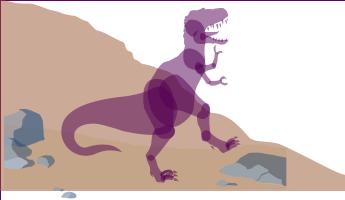
- Name (as many as you can) system services you expect from an operating system
  - ◆ Process scheduling (or job scheduling)
  - ◆ Inter-process communication (IPC)
  - ◆ Memory management
    - ✓ Protection, sharing, demand paging
  - ◆ File system for organizing external storage
  - ◆ Access to I/O devices, e.g., microphones, speaker
  - ◆ Access to the networks





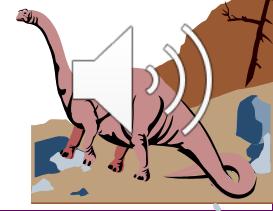
# Common System Components (and Types of System Calls)

- Process Management
- Main Memory Management
- File Management
- I/O System Management
- Secondary-Storage Management
- Networking
- Protection System
- Command-Interpreter System



# Process Management

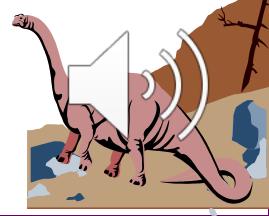
- A *process* is a program in execution.
- The operating system is responsible for the following activities in connection with process management.
  - ◆ Process creation and deletion.
  - ◆ Process suspension and resumption.
  - ◆ Provision of mechanisms for:
    - ✓ Process synchronization
    - ✓ Process communication
    - ✓ Deadlock handling

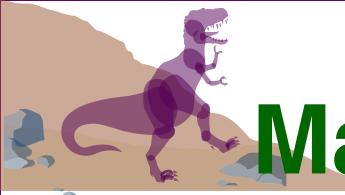




# Main-Memory Management

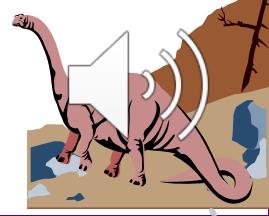
- Memory is a large array of words or bytes, each with its own address. It is a repository of quickly accessible data shared by the CPU and I/O devices.
- Main memory is a volatile storage device. It loses its contents in the case of system failure.





# Main-Memory Management (Cont.)

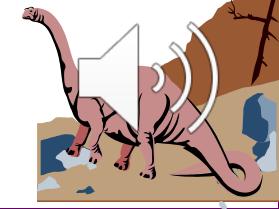
- The operating system is responsible for the following activities in connections with memory management:
  - ◆ Keep track of which parts of memory are currently being used and by whom.
  - ◆ Decide which processes to load when memory space becomes available.
  - ◆ Allocate and reclaim memory space as needed.





# File Management

- There are different types of physical media to persistently store information. Each of them has its own characteristics and physical organization
- Operating System provides a uniform logical view of information storage, i.e., file.
- A file is a collection of related information defined by its creator. Commonly, files represent programs (both source and object forms) and data.

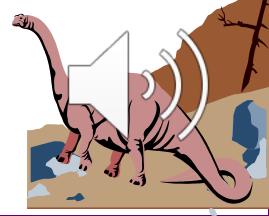




# File Management (Cont.)

■ The operating system is responsible for the following activities in connections with file management:

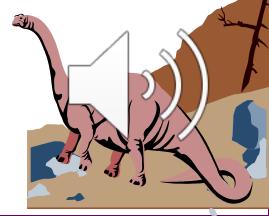
- ◆ File creation and deletion.
- ◆ Directory creation and deletion.
- ◆ Support of primitives for manipulating files and directories, for upper-layer applications.
- ◆ Mapping files onto secondary storage.
- ◆ File backup on stable (nonvolatile) storage media.





# Secondary-Storage Management

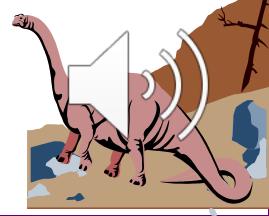
- Since main memory (*primary storage*) is volatile and too small to accommodate all data and programs permanently, the computer system must provide *secondary storage* to back up main memory.
- Most modern computer systems use hard disk drives (HDD) or solid-state drives (SSD) as the principle on-line storage medium, for both programs and data.





# Secondary-Storage Management

- The operating system is responsible for the following activities in connection with disk management:
  - ◆ Free space management
  - ◆ Storage allocation
  - ◆ Disk scheduling

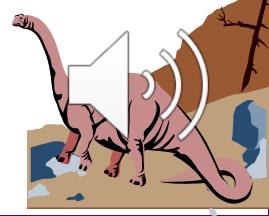




# I/O System Management

■ The I/O subsystem consists of:

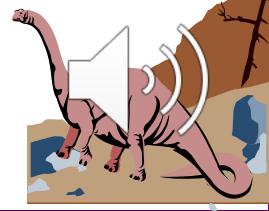
- ◆ A buffer-caching system
- ◆ A general device-driver interface
- ◆ Drivers for specific hardware devices





# Networking (Distributed Systems)

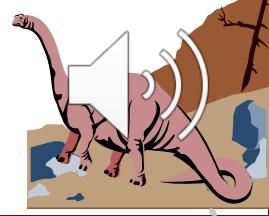
- A *distributed* system is a collection of processors that do not share memory or a clock. Each processor has its own local memory.
- The processors in the system are connected through a communication network.
- Communication takes place using a *protocol*.





# Networking (Distributed Systems)

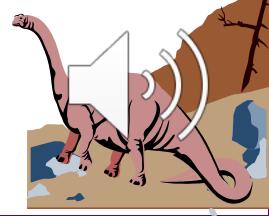
- A distributed system provides user access to various system resources.
- Access to a shared resource allows:
  - ◆ Computation speed-up
  - ◆ Increased data availability
  - ◆ Enhanced reliability





# Protection System

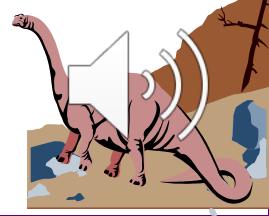
- *Protection* refers to a mechanism for controlling access by programs, processes, or users to both system and user resources.
- The protection mechanism must:
  - ◆ distinguish between authorized and unauthorized usage.
  - ◆ specify the controls to be imposed and means for enforcement.





# Command-Interpreter System

- Many commands are given to the operating system by control statements which deal with:
  - ◆ process creation and management
  - ◆ I/O handling
  - ◆ secondary-storage management
  - ◆ main-memory management
  - ◆ file-system access
  - ◆ protection
  - ◆ networking



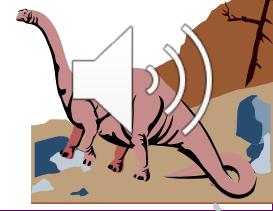


# Command-Interpreter System (Cont.)

■ The program that reads and interprets control statements is called variously:

- ◆ command-line interpreter
- ◆ shell (in UNIX)

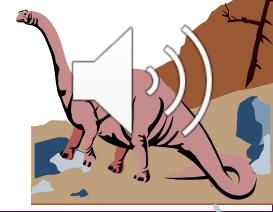
Its function is to get and execute the next command statement.





# Operating System Services

- Program execution – system capability to load a program into memory and to run it.
- I/O operations – since user programs cannot execute I/O operations directly, the operating system must provide some means to perform I/O.
- File-system manipulation – program capability to read, write, create, and delete files.
- Communications – exchange of information between processes
- Error detection – ensure correct computing by detecting errors in the CPU and memory hardware, in I/O devices, or in user programs.

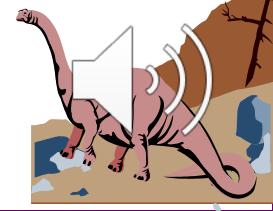




# Additional Operating System Functions

Additional functions exist not for helping the user, but rather for ensuring efficient system operations.

- Resource allocation – allocating resources to multiple users or multiple jobs running at the same time.
- Accounting – keep track of and record which users use how much and what kinds of computer resources for account billing or for accumulating usage statistics.
- Protection – ensuring that all access to system resources is controlled.



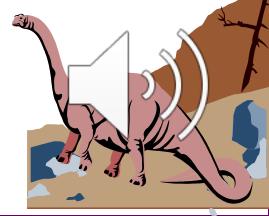


# System Calls

- System calls provide the interface between a running program and the operating system.
  - ◆ Generally available as assembly-language instructions.
  - ◆ Languages defined to replace assembly language for systems programming allow system calls to be made directly (e.g., C, C++)

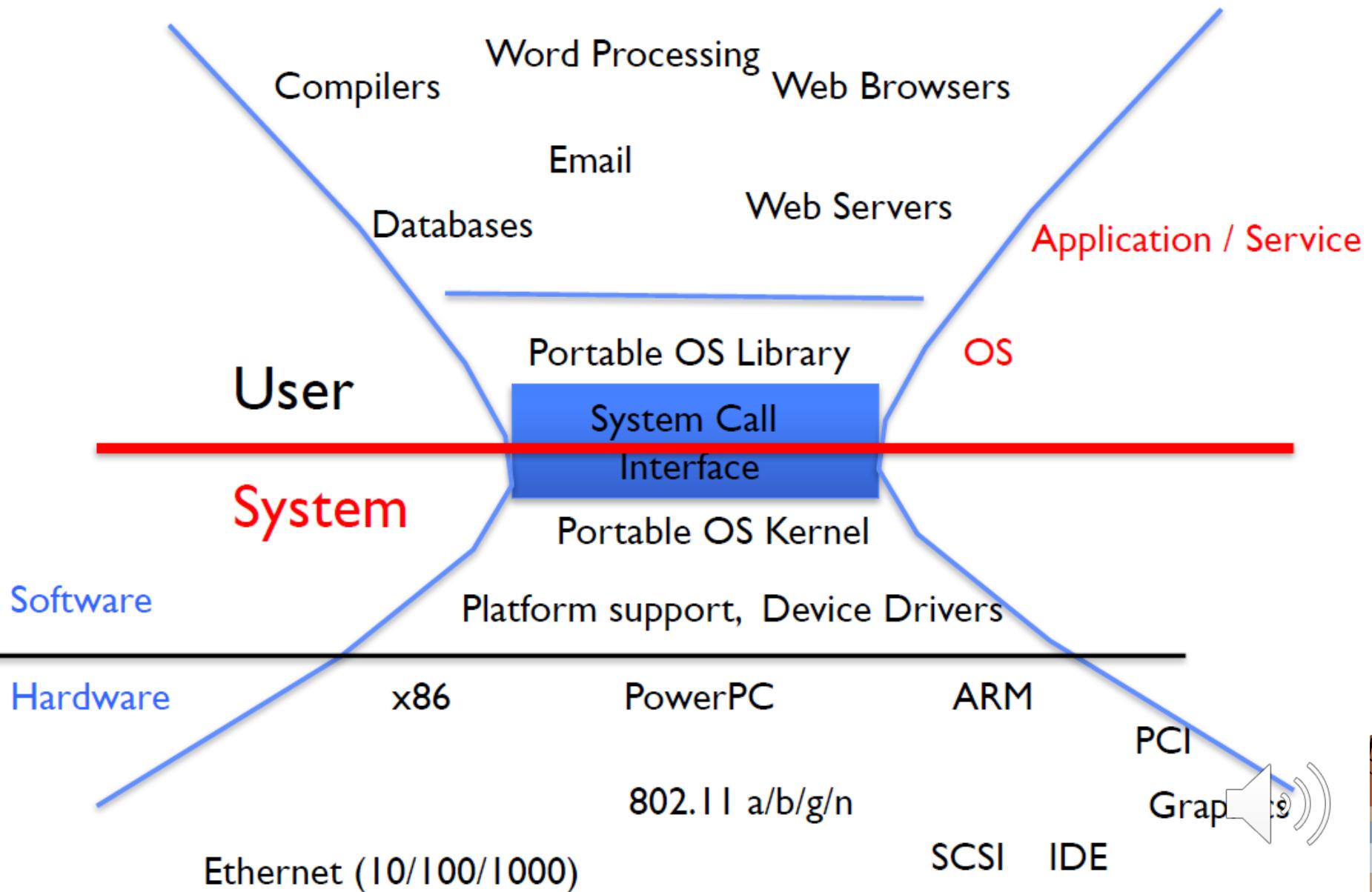
[https://en.wikipedia.org/wiki/System\\_call#Typical\\_implementations](https://en.wikipedia.org/wiki/System_call#Typical_implementations)

[http://docs.cs.up.ac.za/programming/asm/derick\\_tut/syscalls.html](http://docs.cs.up.ac.za/programming/asm/derick_tut/syscalls.html)





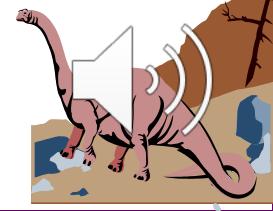
# Operating System as Design

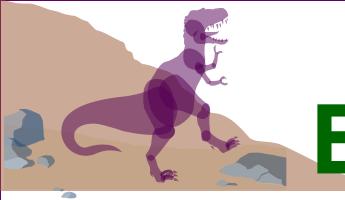




# Example of System Calls (1/2)

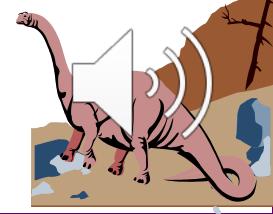
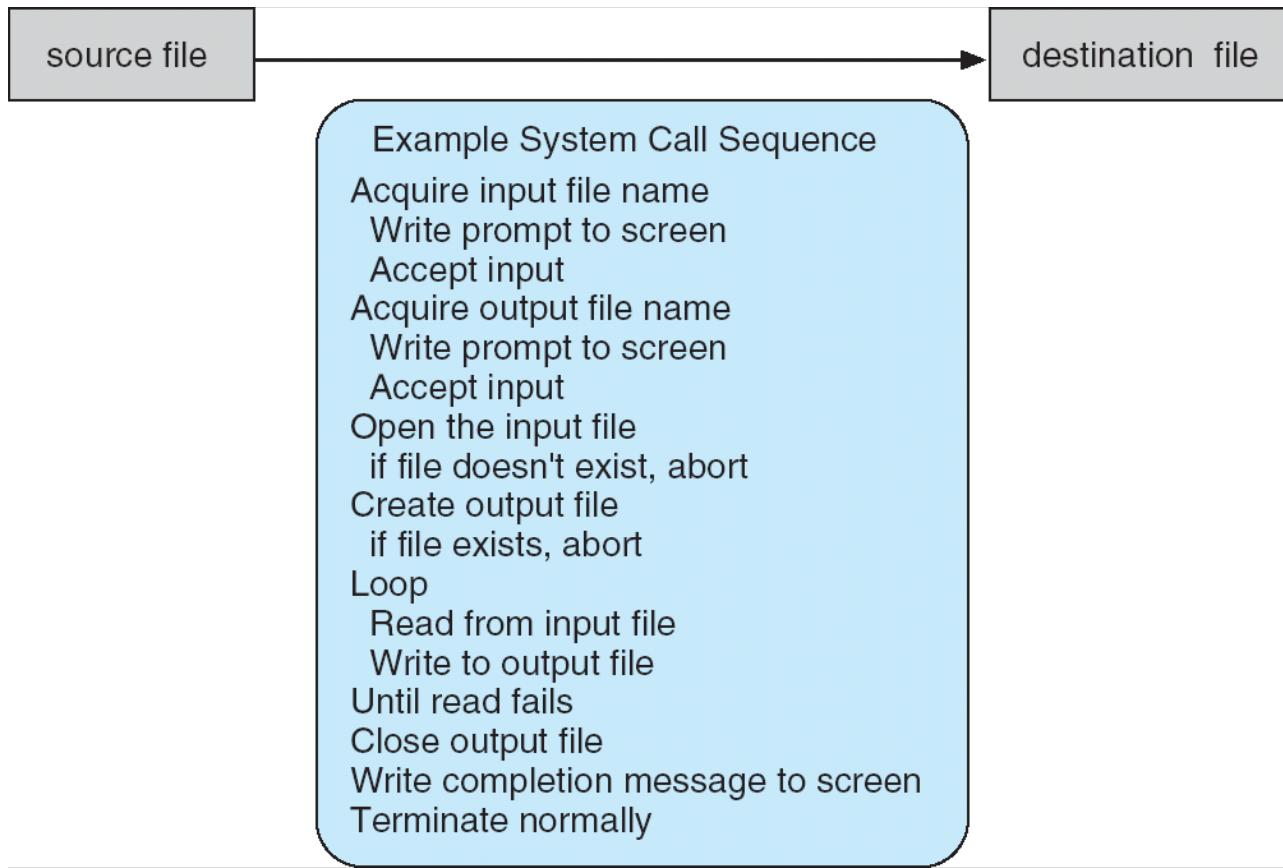
- **cp** is the command line tool in Linux, which makes a copy of your files or directories.
  - ◆ For instance, let's say you have a file named **picture.jpg** in your working directory, and you want to make a copy of it called **picture-02.jpg**. You would run the command:  
  
**cp picture.jpg picture-02.jpg**
- System call sequence to copy the contents of one file to another file





# Example of System Calls (2/2)

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

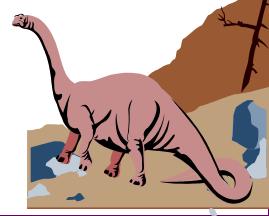




# Question about HW/SW interaction

■ What happen when you click the mouse?

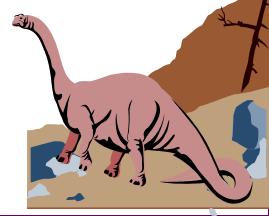
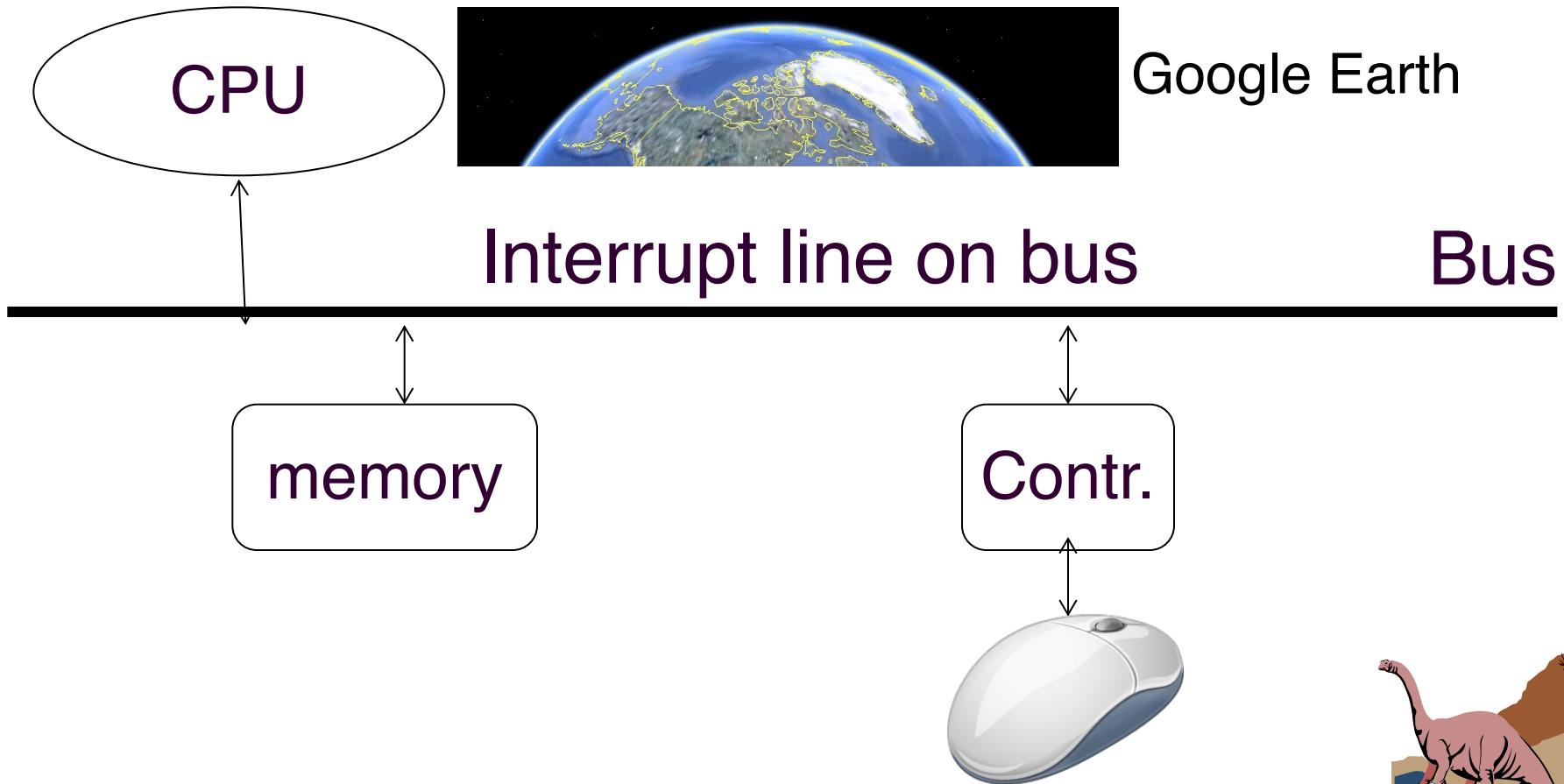
- Mouse clicks correspond to specific CPU instructions
- Mouse click starts up a specific program to read spatial coordinates of mouse
- It results in a CPU interrupt





# An example of HW/SW Interaction

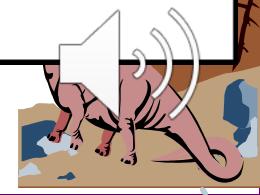
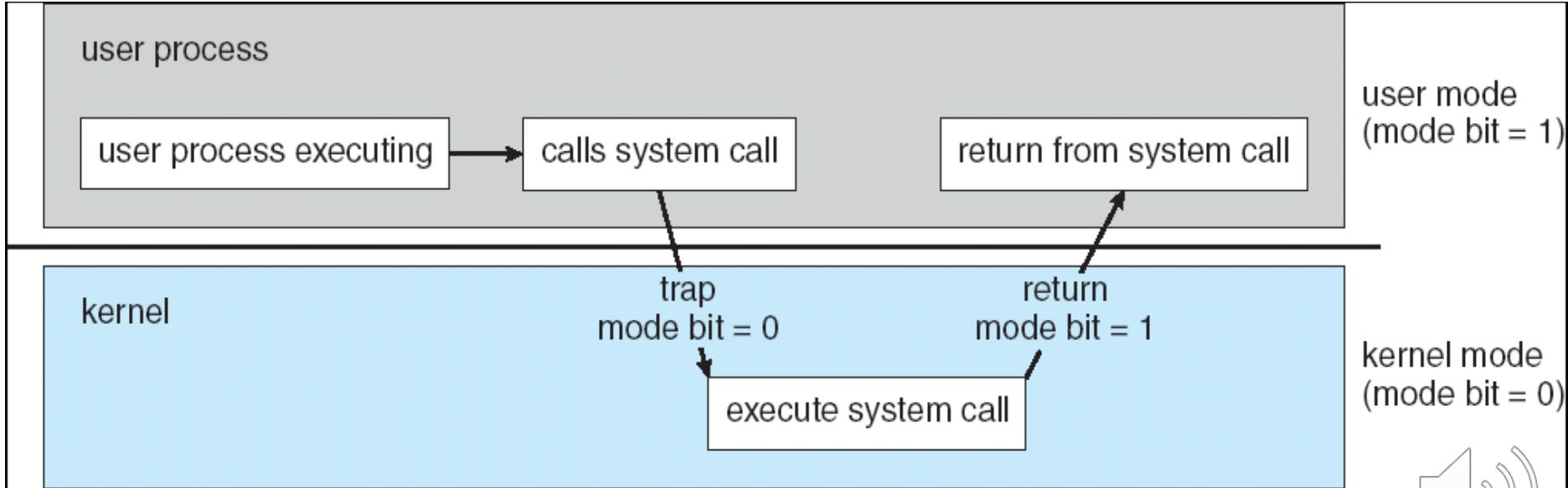
- What happens when you click your mouse?





# Why Execute a System Call from a Trap (or Software Interrupt)?

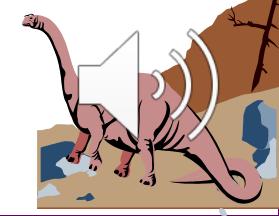
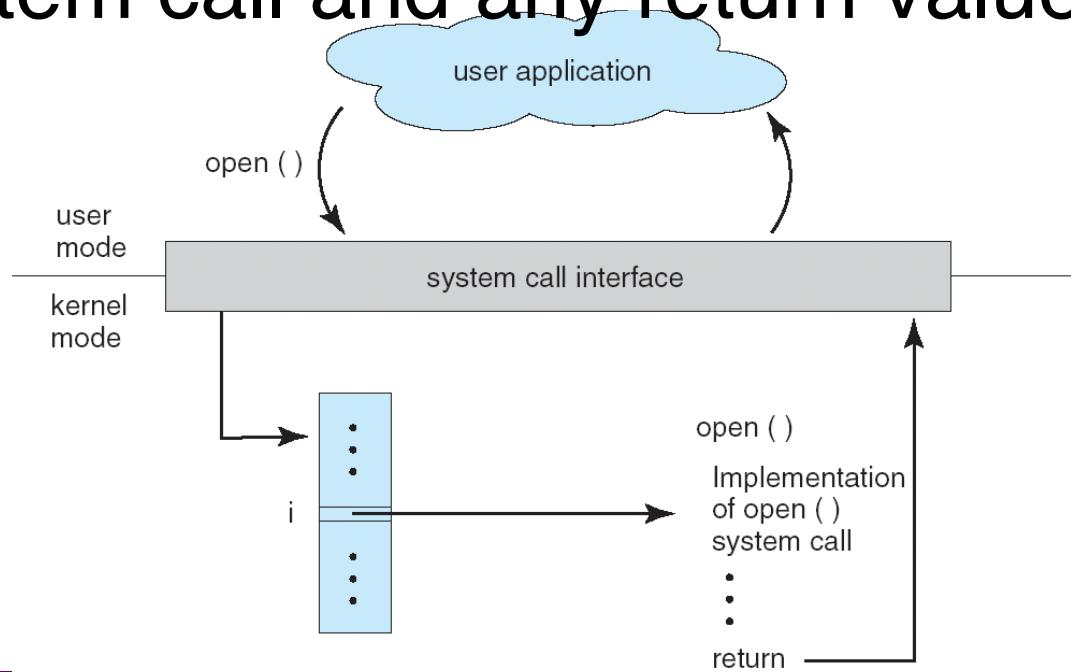
- Protection is achieved via dual mode (user mode vs. kernel mode) and system call.
  - ◆ A system call is executed from a trap, via a trap-handler, and ended by a return-from-trap.





# System Call Implementation

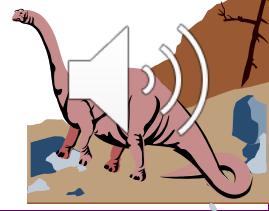
- A number associated with each system call
  - ◆ System-call interface maintains a table indexed according to these numbers
- The system call interface invokes intended system call in OS kernel and returns status of the system call and any return values





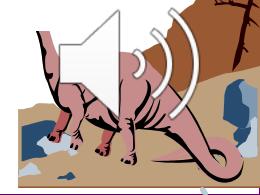
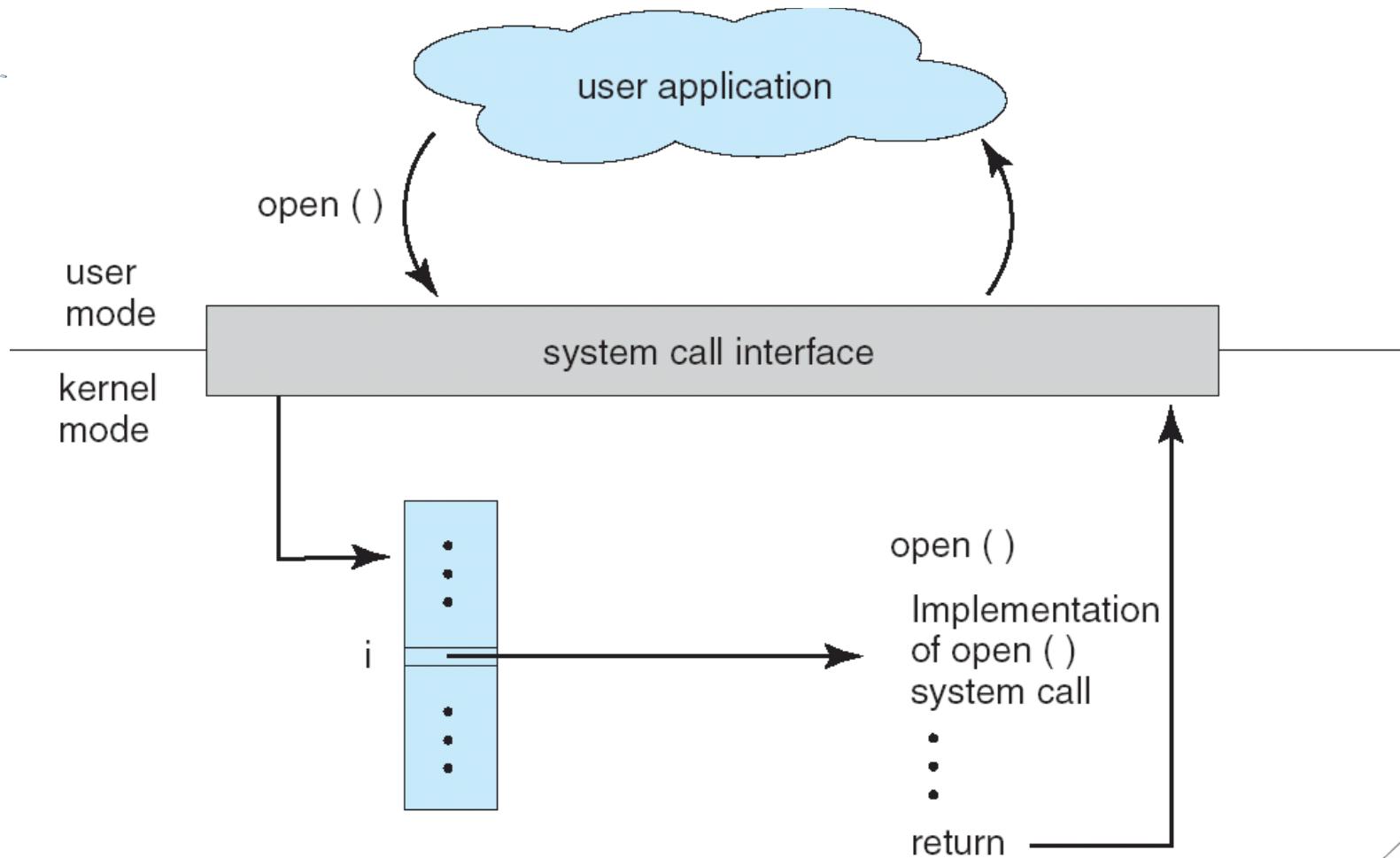
# System Call Implementation (Cont.)

- The caller needs 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 (Please recall the concept of “abstraction”)
    - ✓ Managed by run-time support library (set of functions built into libraries included with compiler)





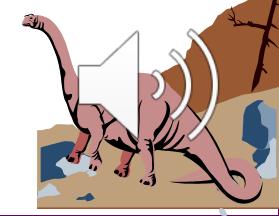
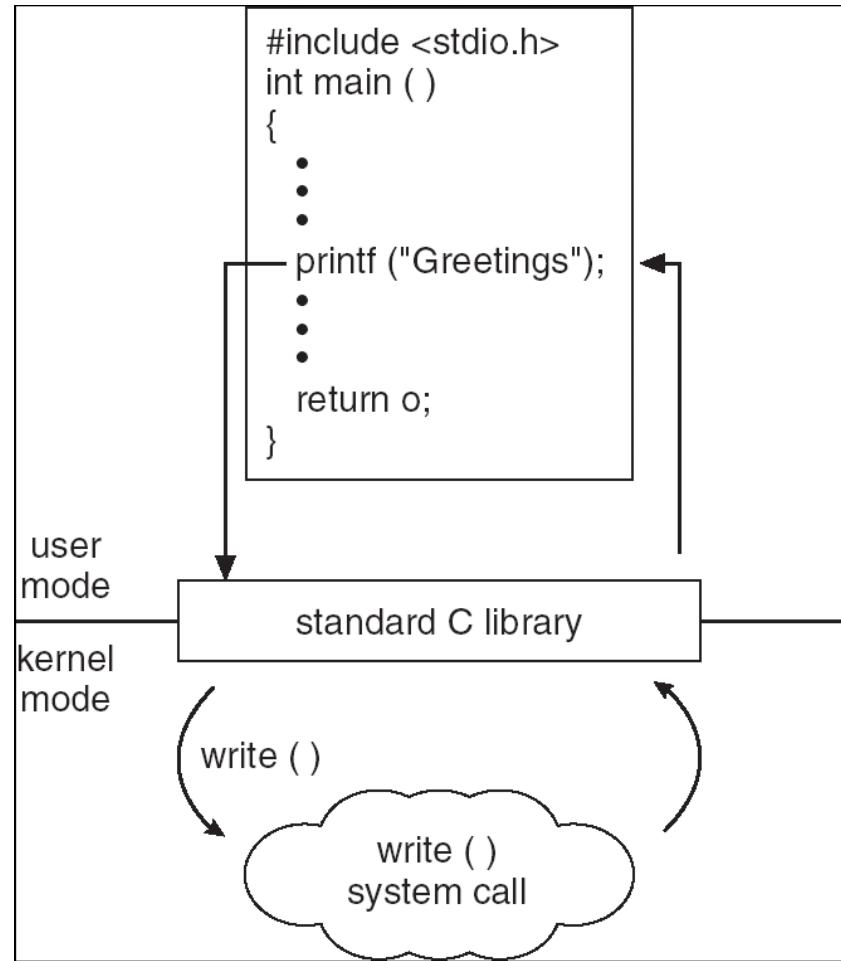
# API – System Call – OS Relationship





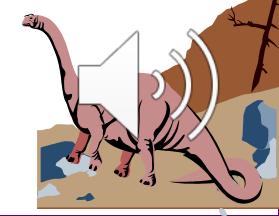
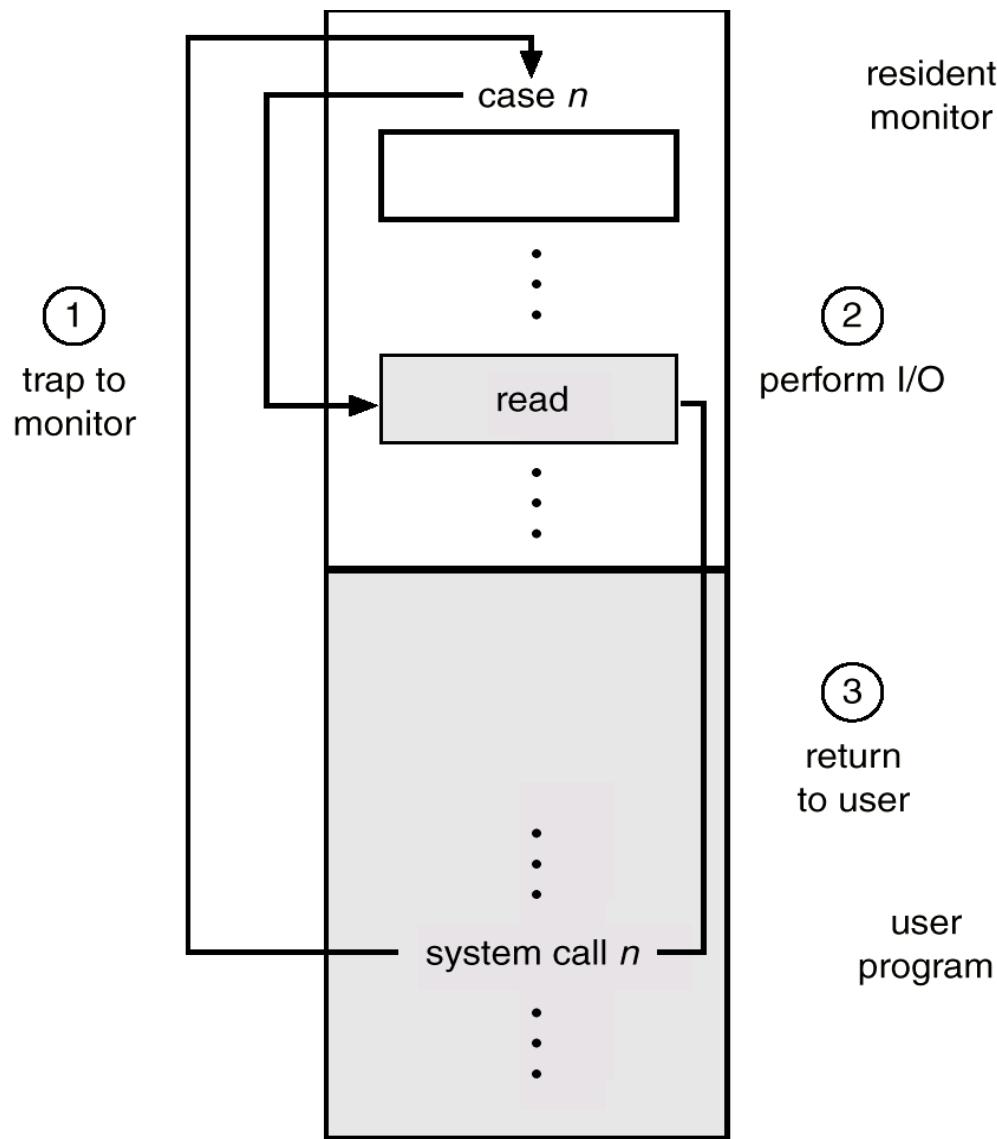
# Standard C Library Example

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





# Use of A System Call to Perform I/O





# System Calls for the Linux 2.2 Kernel

- On the left are the numbers of the system calls. This number will be put in register %eax.
- On the right are the types of values to be put into the remaining registers before calling the trap 'int 0x80'.
- After each syscall, an integer is returned in %eax.

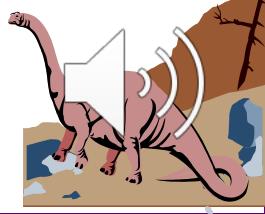
%eax	Name	Source	%ebx	%ecx	%edx	%esx	%edi
1	sys_exit	<a href="#">kernel/exit.c</a>	int	-	-	-	-
2	sys_fork	<a href="#">arch/i386/kern el/process.c</a>	<a href="#">struct pt_regs</a>	-	-	-	-
3	sys_read	<a href="#">fs/read_write.c</a>	unsigned int	char *	<a href="#">size_t</a>	-	-
4	sys_write	<a href="#">fs/read_write.c</a>	unsigned int	const char *	<a href="#">size_t</a>	-	-
5	sys_open	<a href="#">fs/open.c</a>	const char *	int	int	-	-
6	sys_close	<a href="#">fs/open.c</a>	unsigned int	-	-	-	
7	sys_waitpid	<a href="#">kernel/exit.c</a>	pid_t	unsigned int *	int	-	





# 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





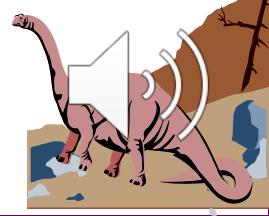
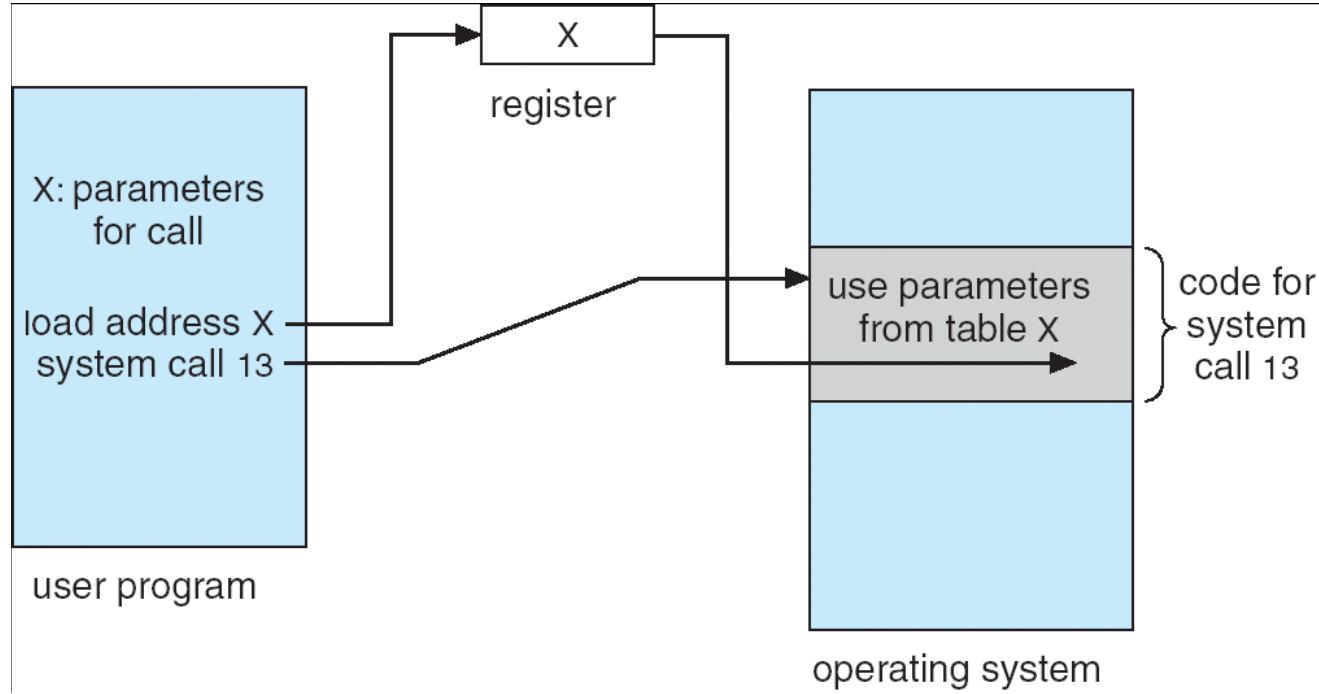
# System Call Parameter Passing (Cont.)

- ◆ 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





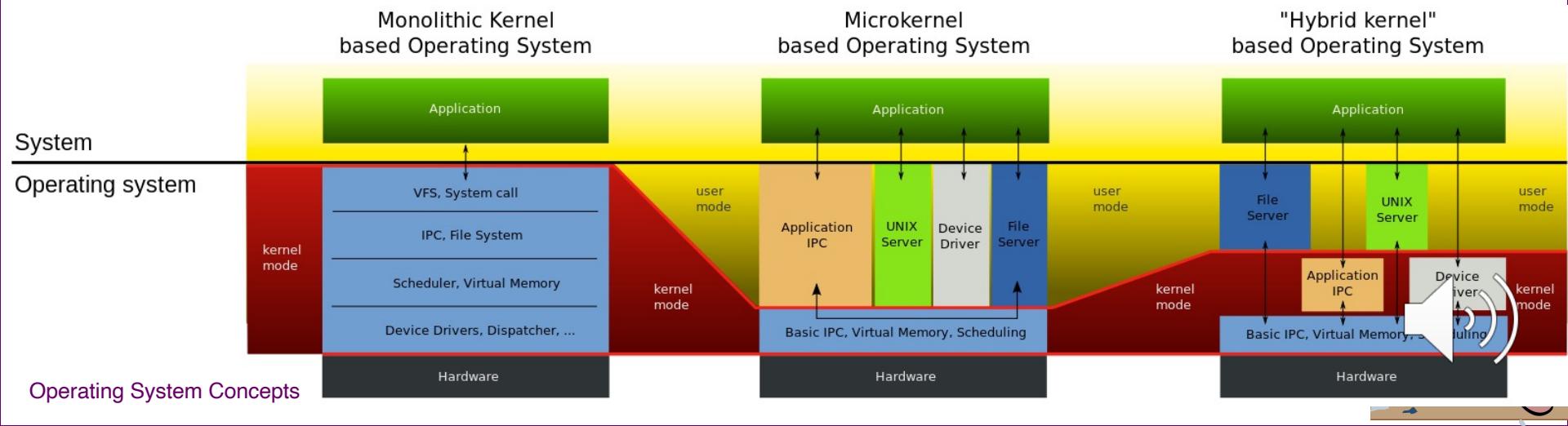
# Parameter Passing via Table





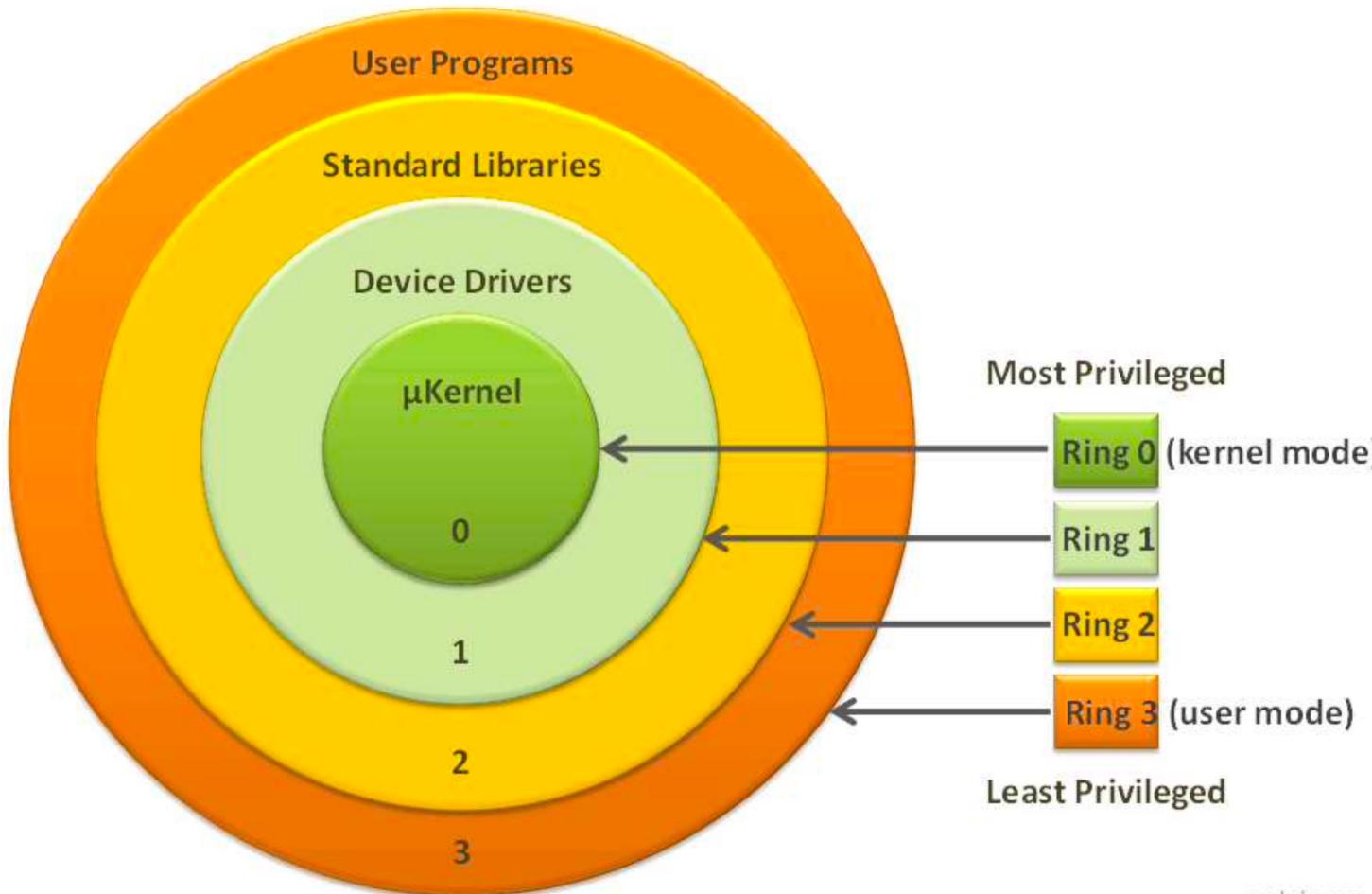
# What is OS Structure?

- The way the OS software is organized with respect to the applications that it serves and the underlying hardware that it manages
  - ◆ Monolithic kernel (单内核、宏内核、巨内核)
  - ◆ Microkernel system structure (微内核)
  - ◆ Hybrid kernel, and Monolithic kernel with modules



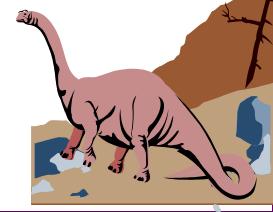


# Protection Rings with Different Privileged Levels



onekobo.com

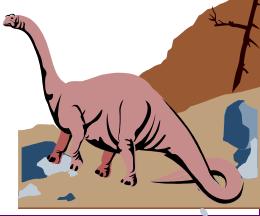
[https://en.wikipedia.org/wiki/Protection\\_ring](https://en.wikipedia.org/wiki/Protection_ring)





# Implementation of a Malware

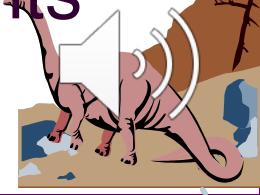
- Ring 3: A program (i.e. on Windows, Mac OS X, Linux, iOS/Android etc.)
- Ring 1: A kernel driver (i.e. on Windows, Mac OS X, Linux etc.)
- A non-persistent patch to existing code (anything)
- Ring 0: Malicious firmware (embedded devices)
  - ◆ **malicious** code in the **firmware** has the potential to subvert the kernel and thus conceptually possess even higher privileges than **Ring 0**.





# Goal of OS Structure Design

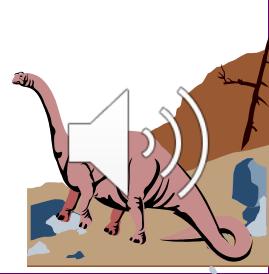
- Protection: within and across **users** + the **OS** itself
- Performance: **time** taken to perform the services
- Flexibility: Extensibility => **Not** one size fits all
- Scalability: performance $\uparrow$  if hardware resources $\uparrow$
- Agility: **adapting** to changes in application needs and/or resource availability
- Responsiveness: **reaching** to the external events





# DOS-like Structure

- MS-DOS – written to provide the most functionality in the least space
  - ◆ Performance: Access to system services is like a procedure call
  - ◆ Although MS-DOS has some structure, its interfaces and levels of functionality are not well separated
  - ◆ Bad Protection: an error of application can corrupt the OS
  - ◆ Not divided into modules



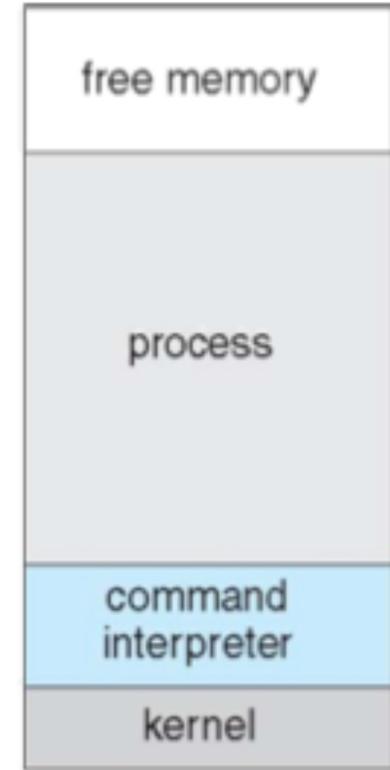


# MS-DOS (Microsoft DOS) Execution (Single Program)

- Single-tasking, single memory space
- Shell (command interpreter) invoked when system booted
- Simple method to run program
  - ◆ Loads program into memory, overwriting all but the kernel and small part of CI
  - ◆ No process created
- Program exit → the remaining CI reloads shell from disk



(a) At system startup



(b) running a program





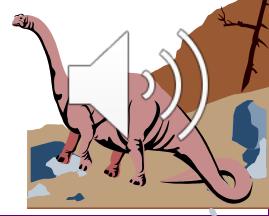
# DOS-like Structure (cont.)



No protection between the applications and the OS, which are in the same address space



Managed by the OS





# Monolithic Structure

App 1

App 2

.....

App n



Each App in its own hardware address space

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OS  
Services and  
Device Drivers

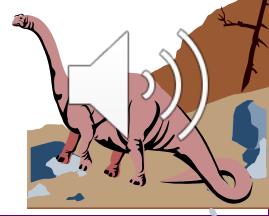


OS in its own hardware address space

Hardware



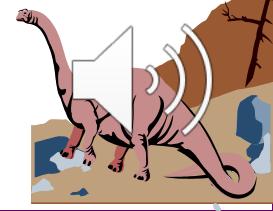
Managed by the OS





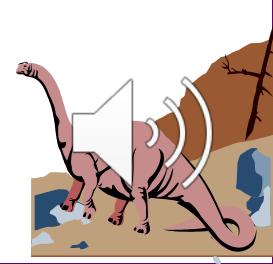
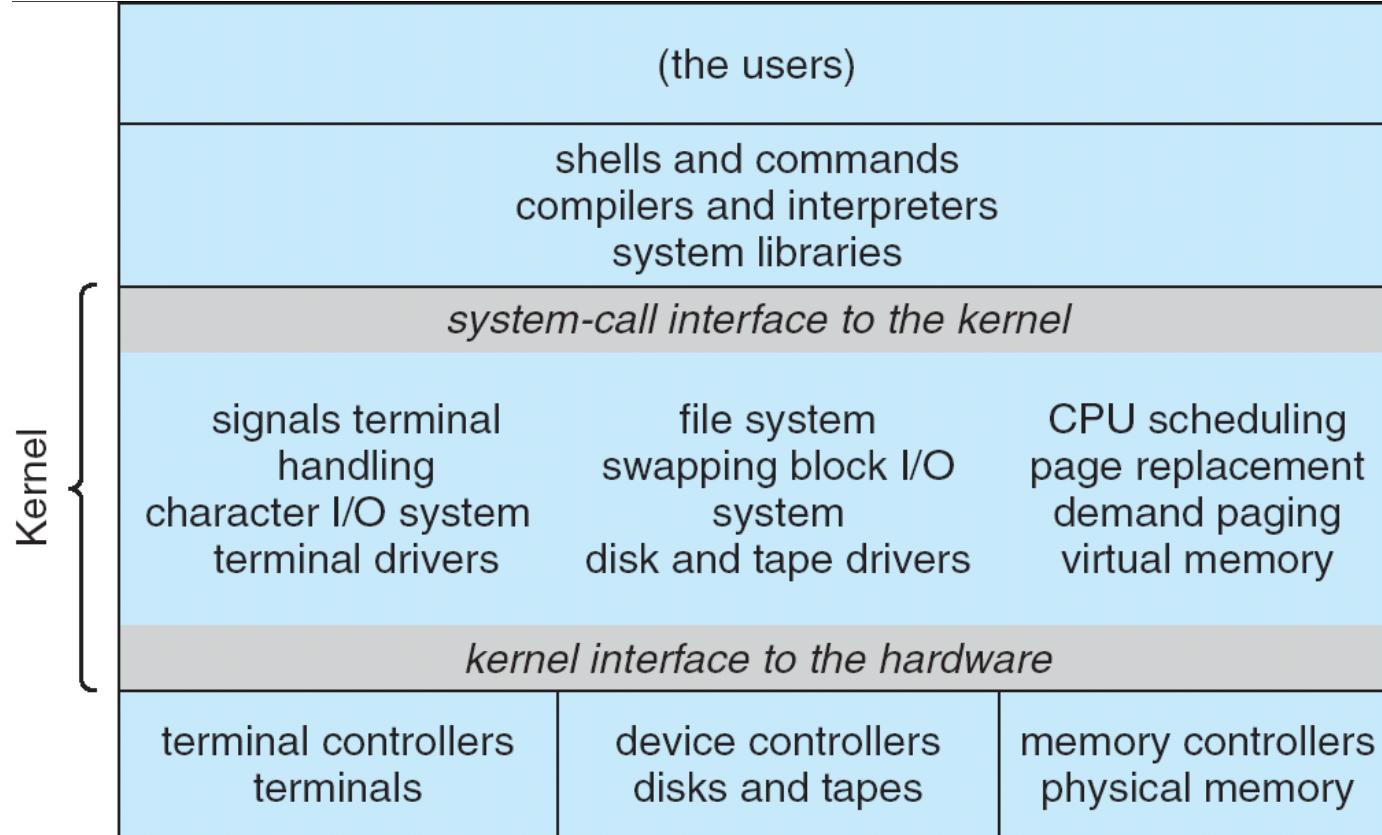
# Monolithic Architecture Example: UNIX

- UNIX – limited by hardware functionality, the original UNIX operating system had limited structuring.
- The UNIX OS consists of two separable parts
  - ◆ Systems programs
  - ◆ The kernel
    - ✓ Consists of everything below the system-call interface and above the physical hardware
    - ✓ Provides the file system, CPU scheduling, memory management, and other operating-system functions; a large number of functions for one level





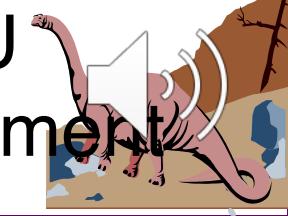
# UNIX System Structure





# Gain and Loss of Monolithic Structure

- Fix the loss of protection in DOS-like structure
  - ◆ Unacceptable for a general-purpose OS
- Monolithic Structure
  - ◆ Reduce performance loss by consolidation
- But ...
  - ◆ Monolithic structure => no customization
- Need for customization
  - ◆ Applications of video game and computing prime numbers may have different needs for CPU scheduling, file access or memory management





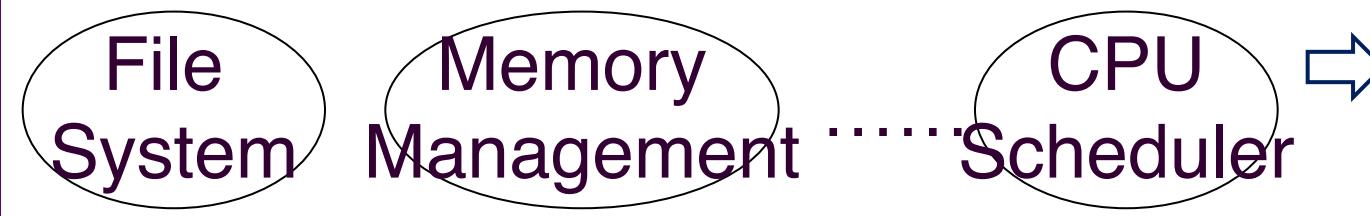
# Microkernel OS Structure

Communication takes place between user modules using IPC-based message passing

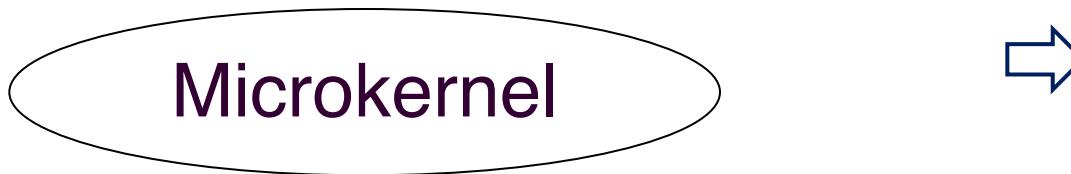


Each App in its own hardware address space

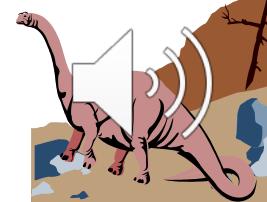
OS Services



Each service in its own address space

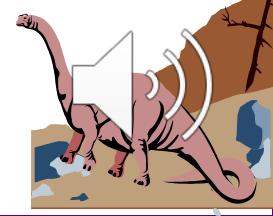
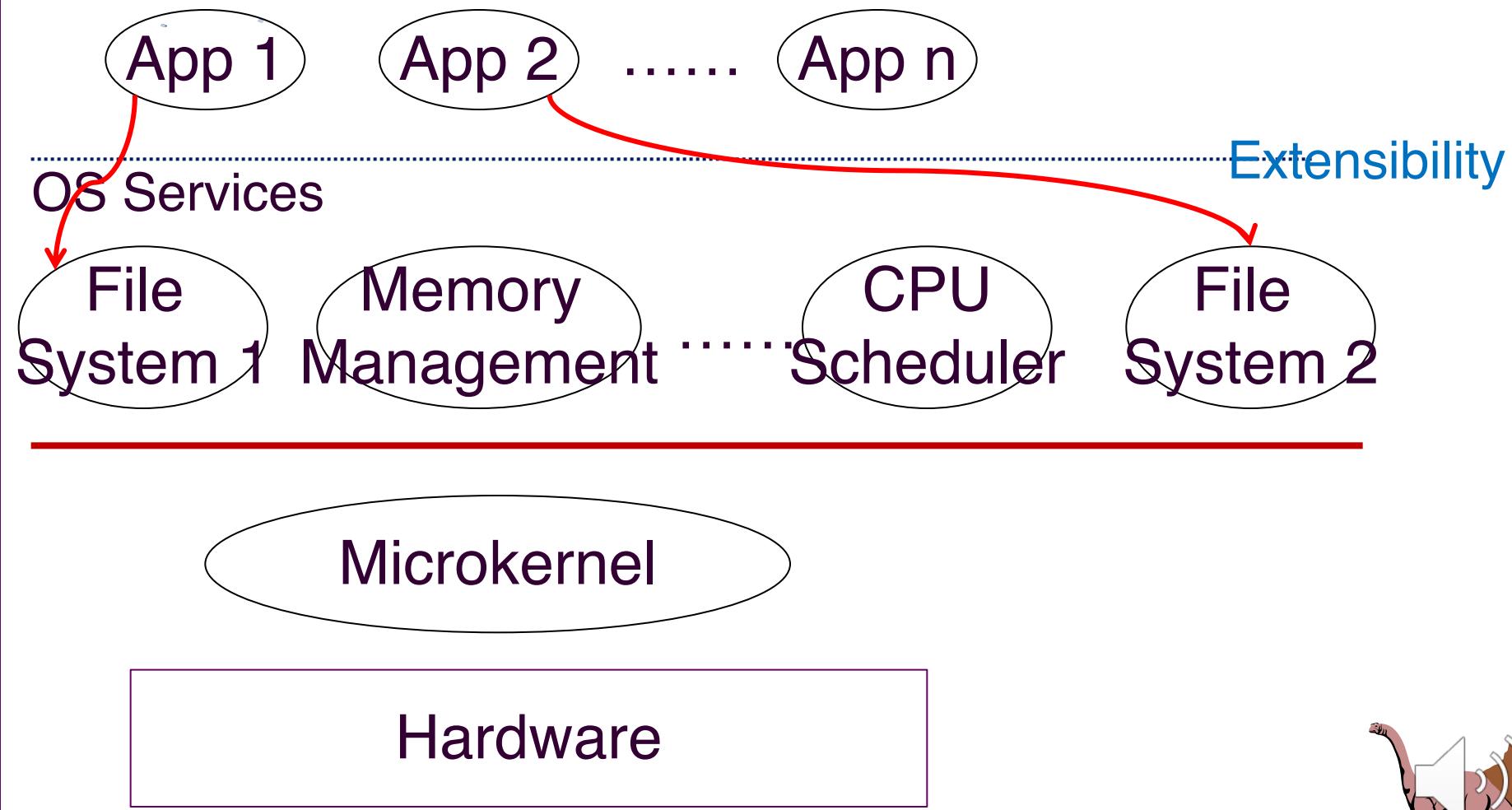


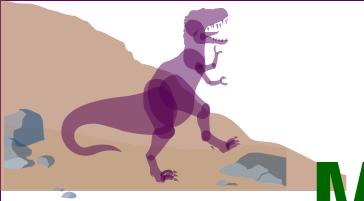
Simple abstraction  
➤ Process management  
➤ Address space  
➤ IPC





# Advantage of Microkernel-based Design





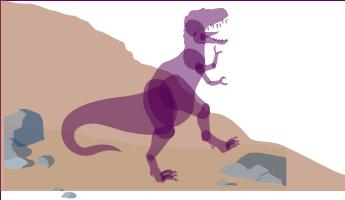
# Pros and Cons of Microkernel System Structure

## ■ 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

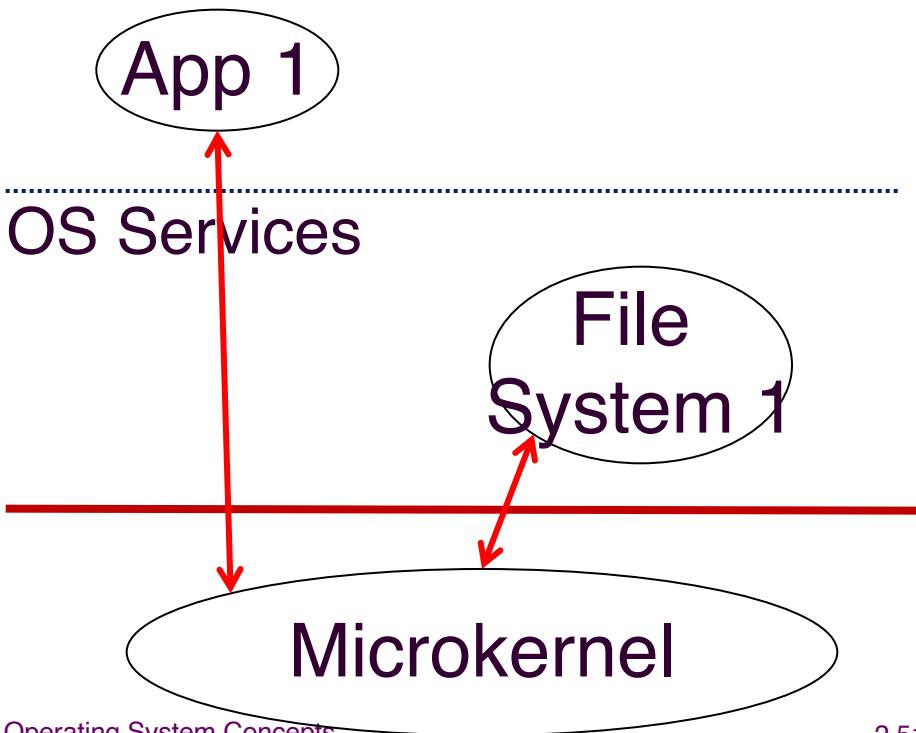


# Why Performance Loss

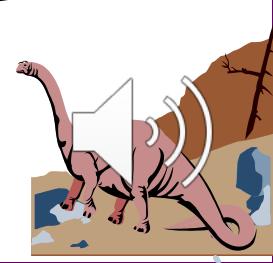
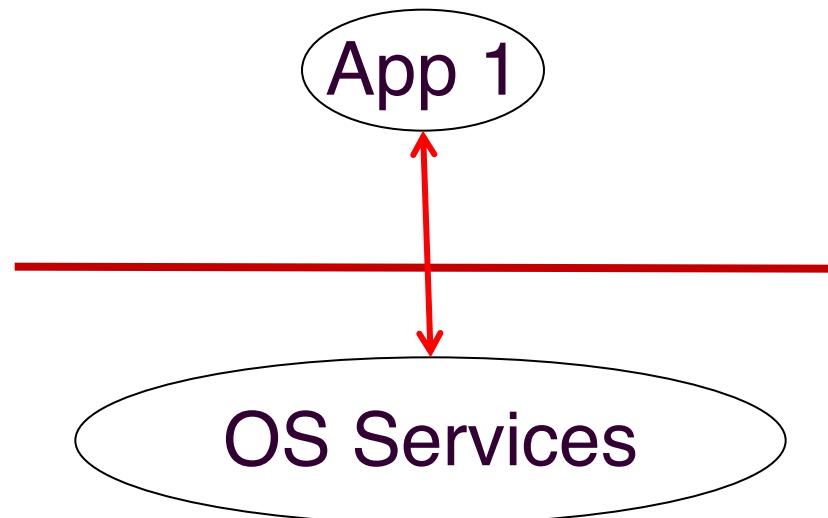
## ■ Border Crossing

- ◆ Change in locality, e.g., memory address space
- ◆ Copy data between user and system spaces

### Microkernel



### Monolithic

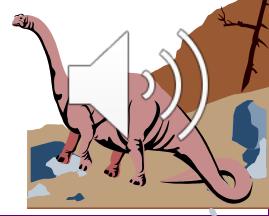




# Question

■ Based on discussion thus far ....

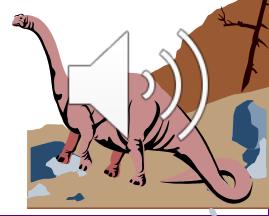
Feature	DOS-like OS	Monolithic OS	Microkernel OS
Extensibility	✓		✓
Protection		✓	✓
Performance	✓	✓	





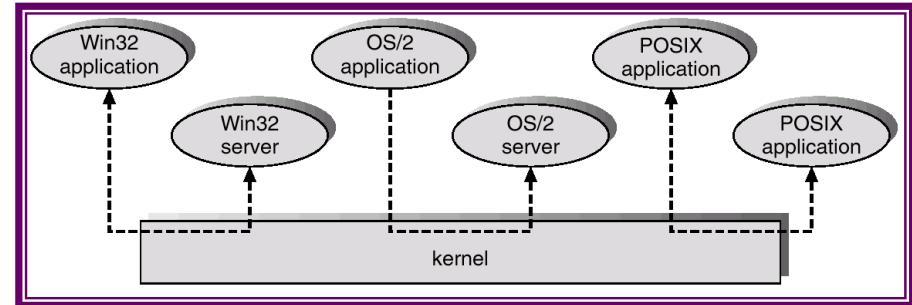
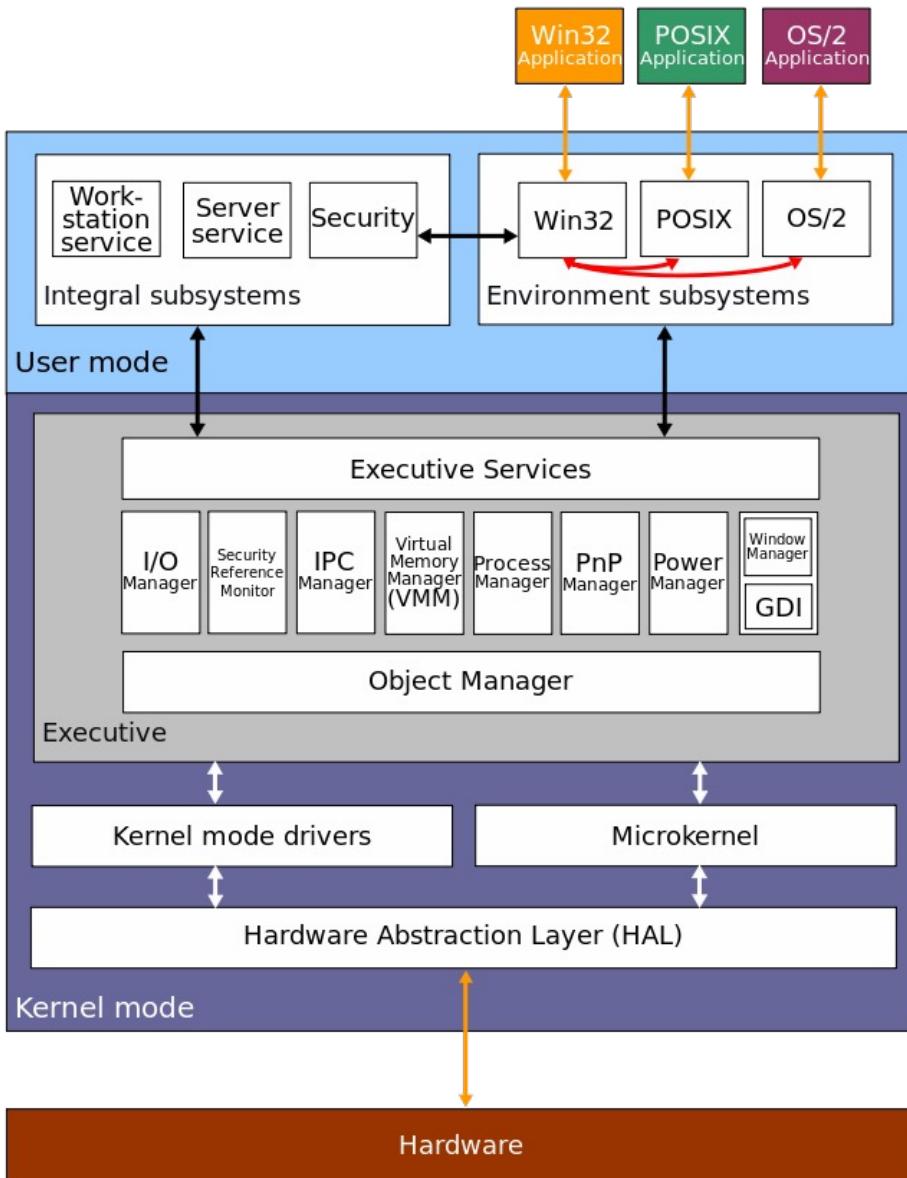
# Hybrid Kernel Approach

- The idea behind a hybrid kernel is to have a kernel structure similar to that of a microkernel, but to implement that structure in the manner of a monolithic kernel.
- In contrast to a microkernel, all (or nearly all) operating system services in a hybrid kernel are still in kernel space.





# Hybrid Kernel Example: Windows NT Client-Server Structure

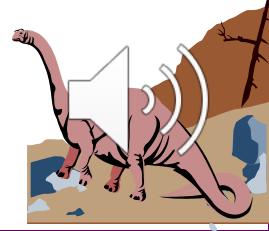
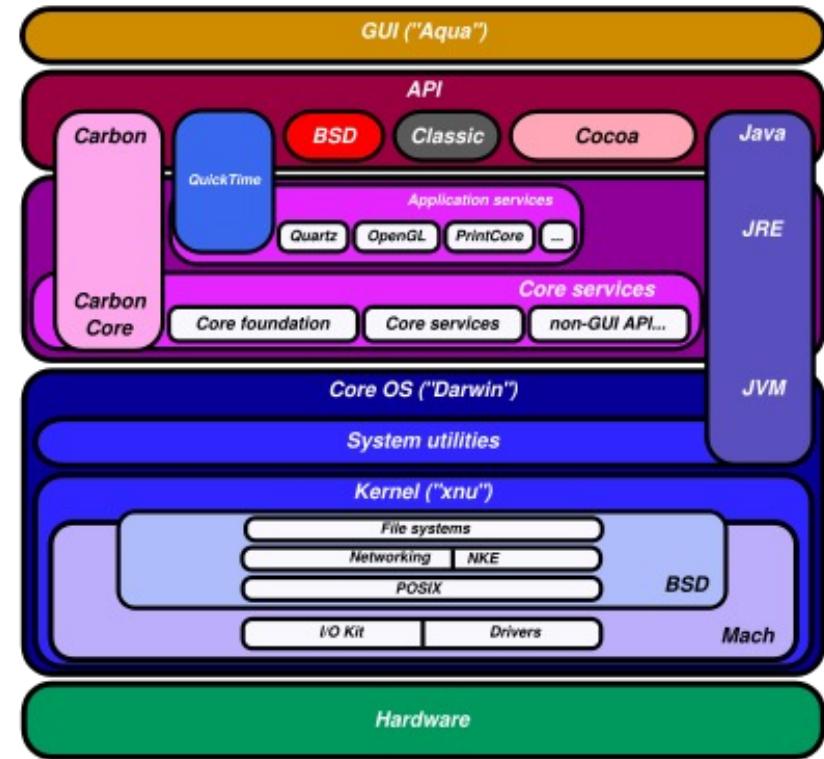
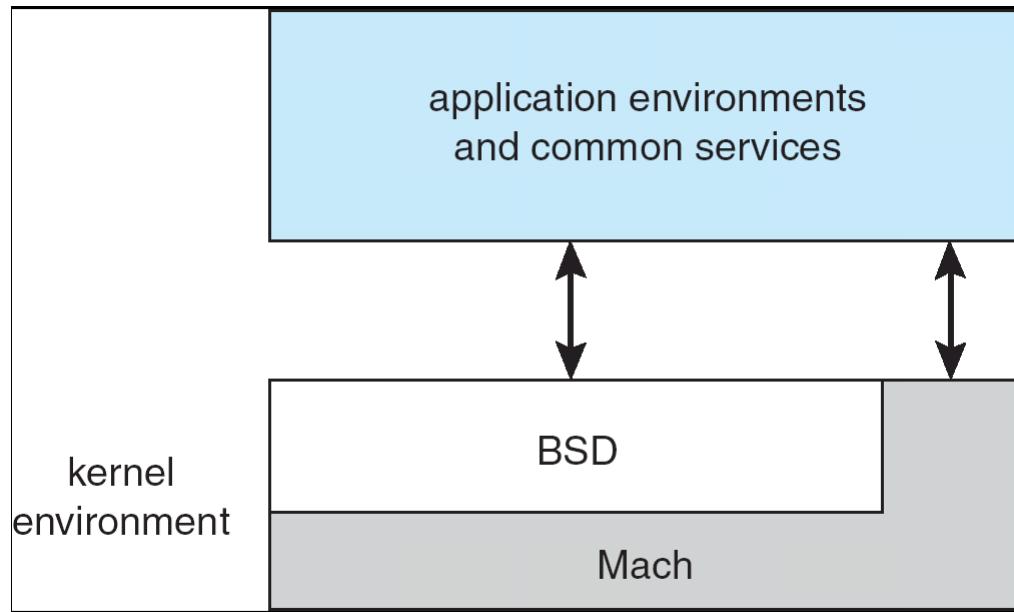


**Windows NT**, 新技术视窗操作系统 (Windows New Technology) 的简称，是[美国微软公司](#)1993年推出的纯[32位](#)操作系统核心。其基于OS/2 NT的基础构造。

Windows 10	个人使用：家庭版（包括S模式的家庭版） <a href="#">[10]</a> 、专业版（包括S模式的专业版） <a href="#">[10]</a> 、专业工作站版 商用：企业版、教育版、专业教育版（包括S模式的专业教育版） <a href="#">[10]</a> 移动设备：移动版、移动企业版 物联网设备：Windows 10 IoT	2015年7月29日
NT 10.0		
Windows Server 2016	Essentials、Standard、Datacenter	2016年9月26日
Windows Server 2019	Essentials、Standard、Datacenter	2018年10月2日
Windows Server 2022	Essentials、Standard、Datacenter	2021年8月18日
Windows 11	个人使用：家庭版、专业版、专业工作站版 商用：企业版、教育版、专业教育版	2021年10月5日

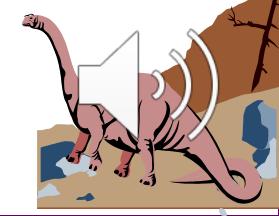
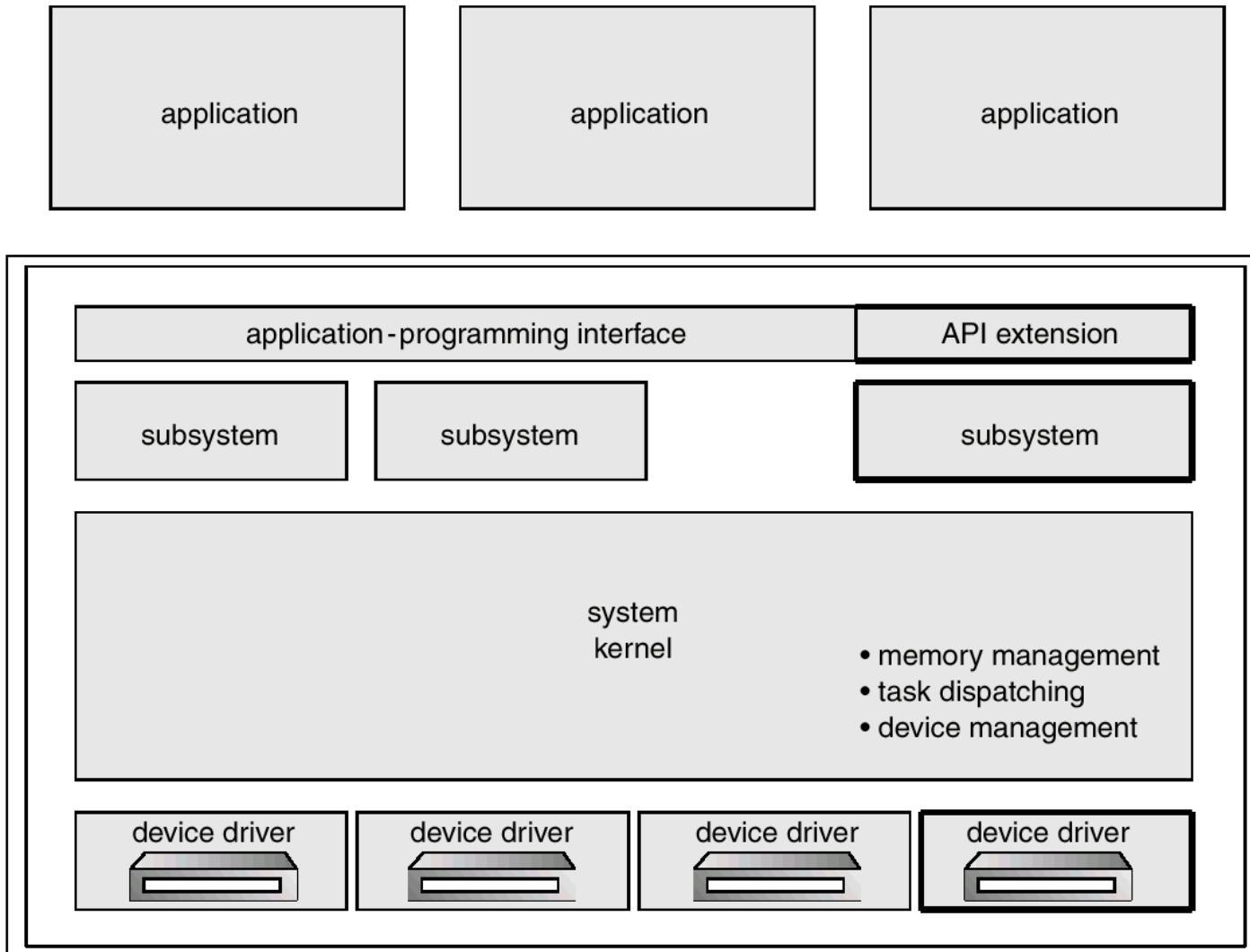


# Hybrid Kernel Example: Mac OS X Structure





# Hybrid Kernel Example: OS/2 Layer Structure

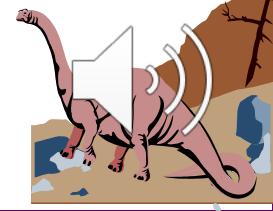




# Monolithic Kernel with Dynamically Loadable Modules

- 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
- Overall, similar to layers but with more flexible

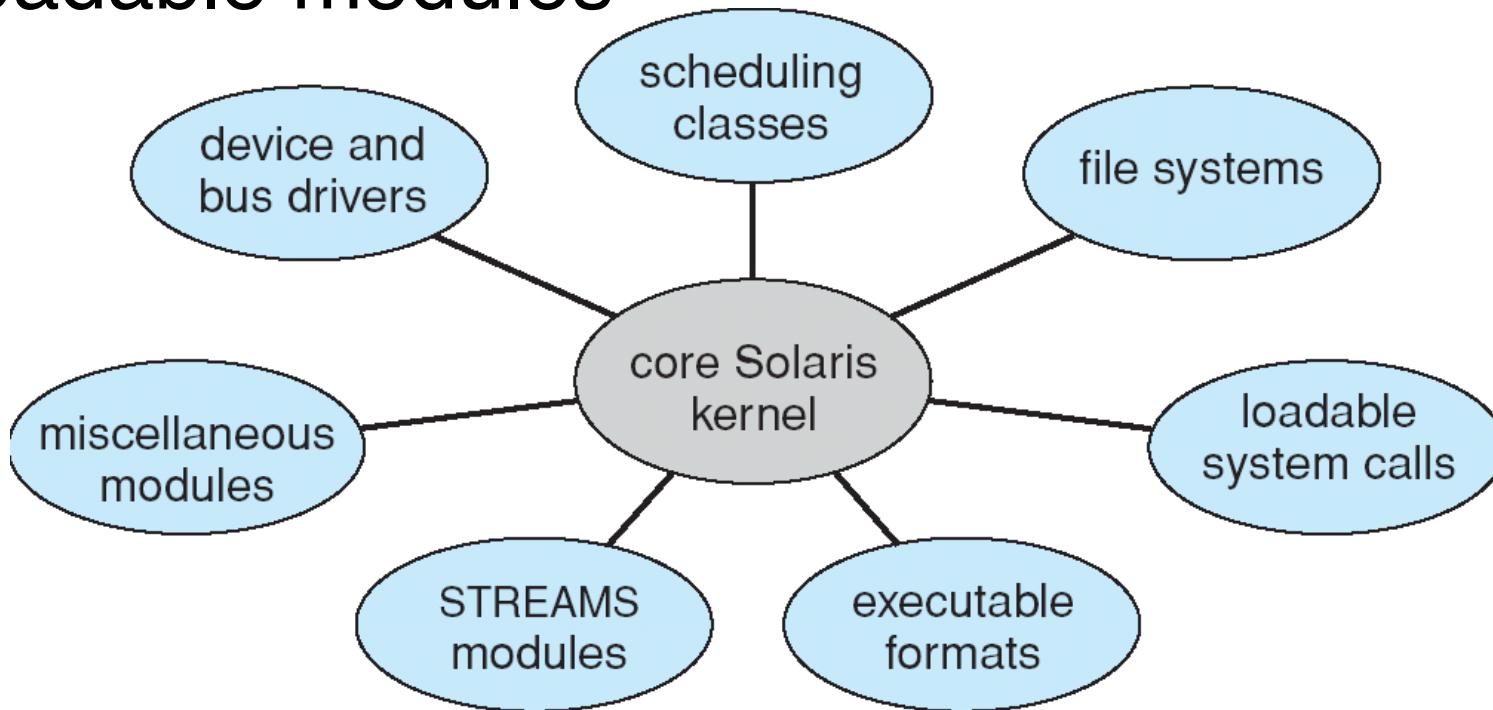
知乎: Linux 为什么还要坚持使用宏内核?  
<https://www.zhihu.com/question/20314255>



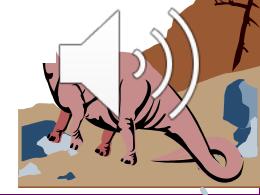


# Solaris Modular Approach

- Solaris is a Unix operating system originally developed by Sun Microsystems.
- Kernel type is Monolithic with dynamically loadable modules



[https://en.wikipedia.org/wiki/Solaris\\_\(operating\\_system\)](https://en.wikipedia.org/wiki/Solaris_(operating_system))

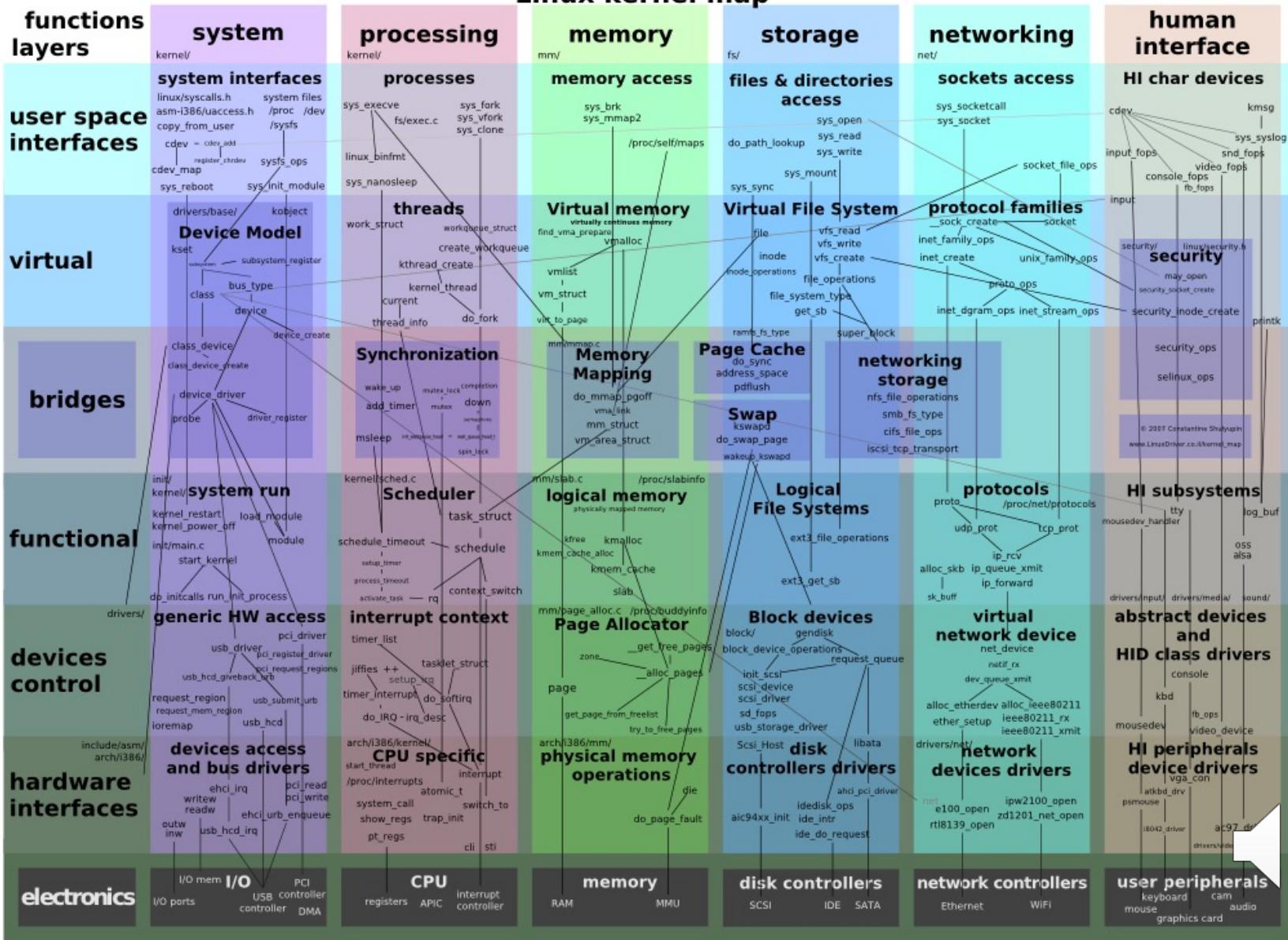




# Linux is also a

# modular monolithic kernel

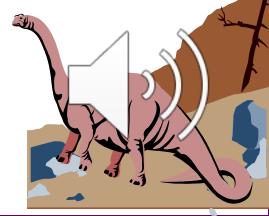
Linux kernel map





# Concept of Virtualization

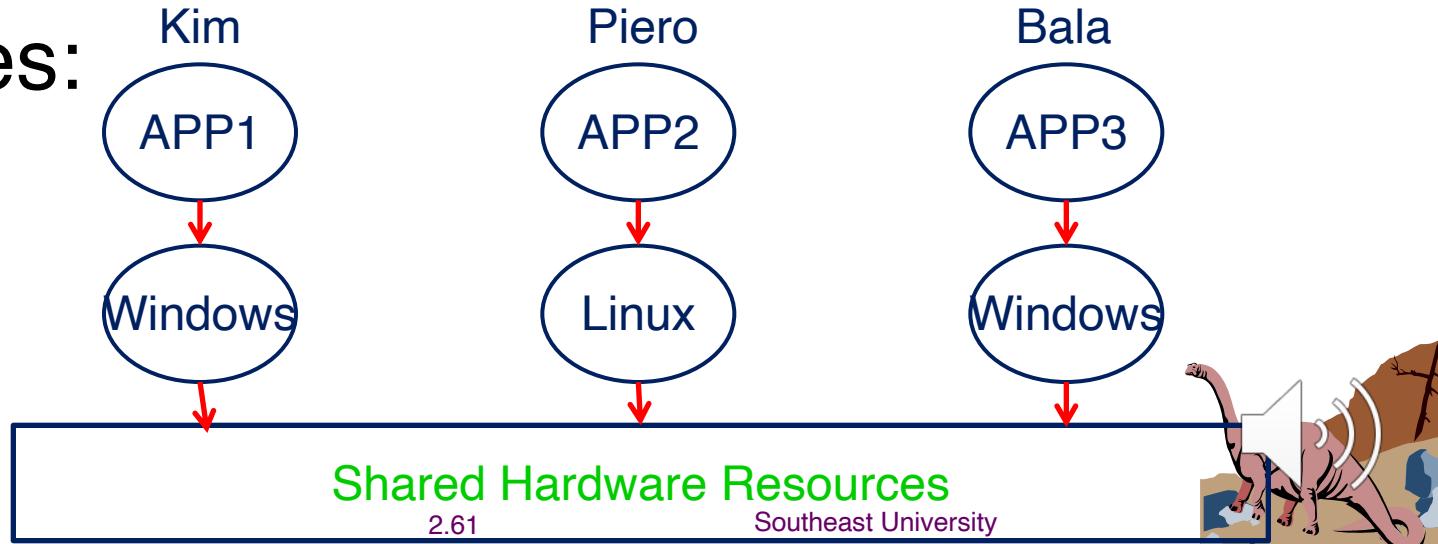
- Virtualization refers to the act of creating a virtual (rather than actual) version of something, including
  - ◆ hardware platform virtualization,
  - ◆ memory virtualization,
  - ◆ CPU virtualization,
  - ◆ storage virtualization,
  - ◆ network virtualization, etc.





# Virtual Machines

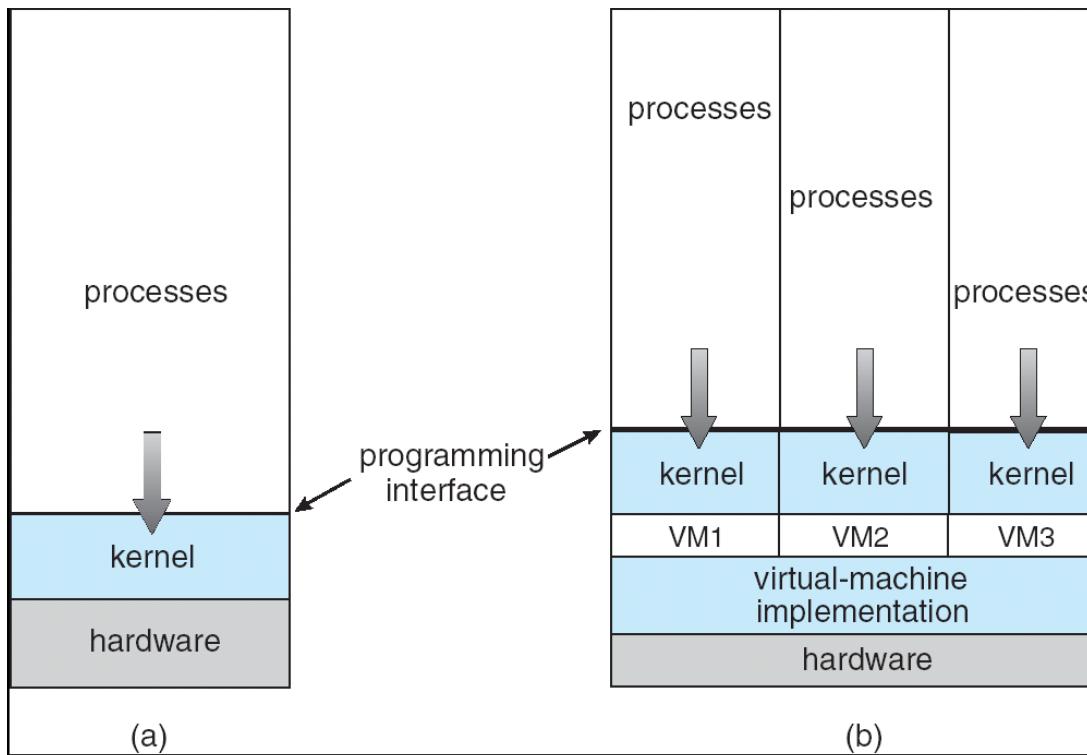
- The operating system creates the **illusion of multiple processes**, each executing on its own processor with its own (virtual) memory
- A *virtual machine system* provides an interface *identical* to the underlying bare hardware, creating an **illusion of multiple (virtual) machines**
- User Drives:





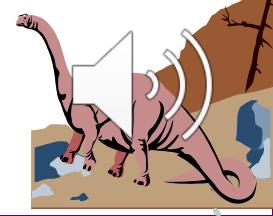
# Virtual Machine Implementation 1: Native Hypervisor

- A **hypervisor** or **virtual machine monitor (VMM)** is a piece of computer software, firmware or hardware that creates and runs virtual machines



Non-virtual Machine

Virtual Machines over Native VMM



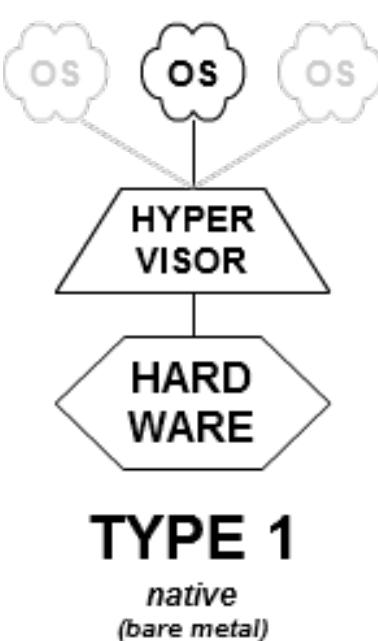


# Virtual Machine Implementation 2: Hosted Hypervisor

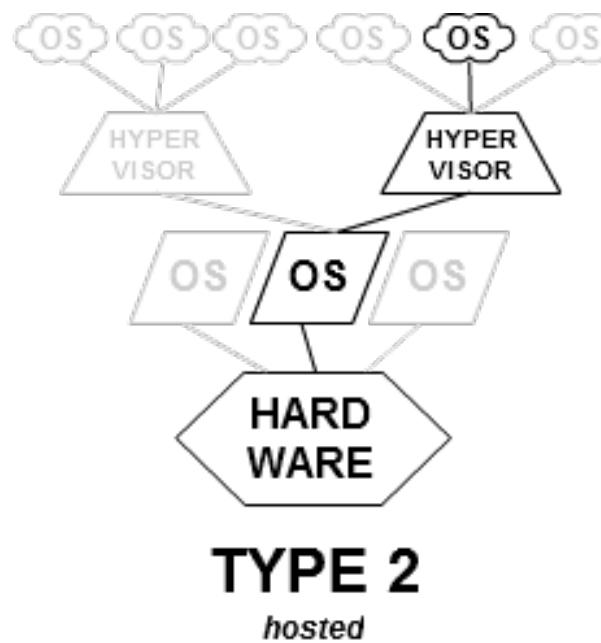
- A hosted hypervisor takes the layered approach to its logical conclusion. It treats underlying hardware and the host operating system kernel as though they were all hardware.



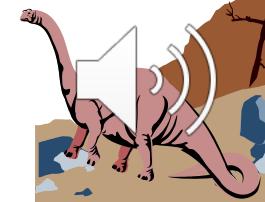
KVM converts Linux into a type-1 (bare-metal) hypervisor. KVM is part of Linux. If you've got Linux 2.6.20 or newer, you've got KVM.



Bare-metal hypervisor



Hosted hypervisor



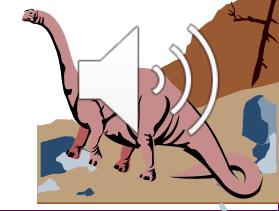


# Virtual Machine Implementation 2: Hosted Hypervisor

## ■ This is how it works:

- ◆ Your main OS runs like usual (Windows in LiLi's case). This OS is called "Host OS".
- ◆ A virtualization software (e.g., VirtualBox or VMWare) will launch a second OS on top of the first one.
- ◆ The virtualization software will trick the second OS and give him some virtual hardware.

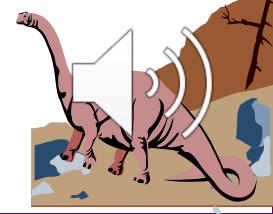
## ■ Each OS, no matter virtual or host, is not aware of the other's existence.





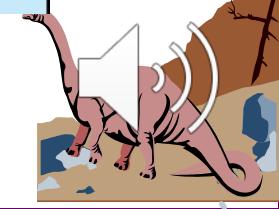
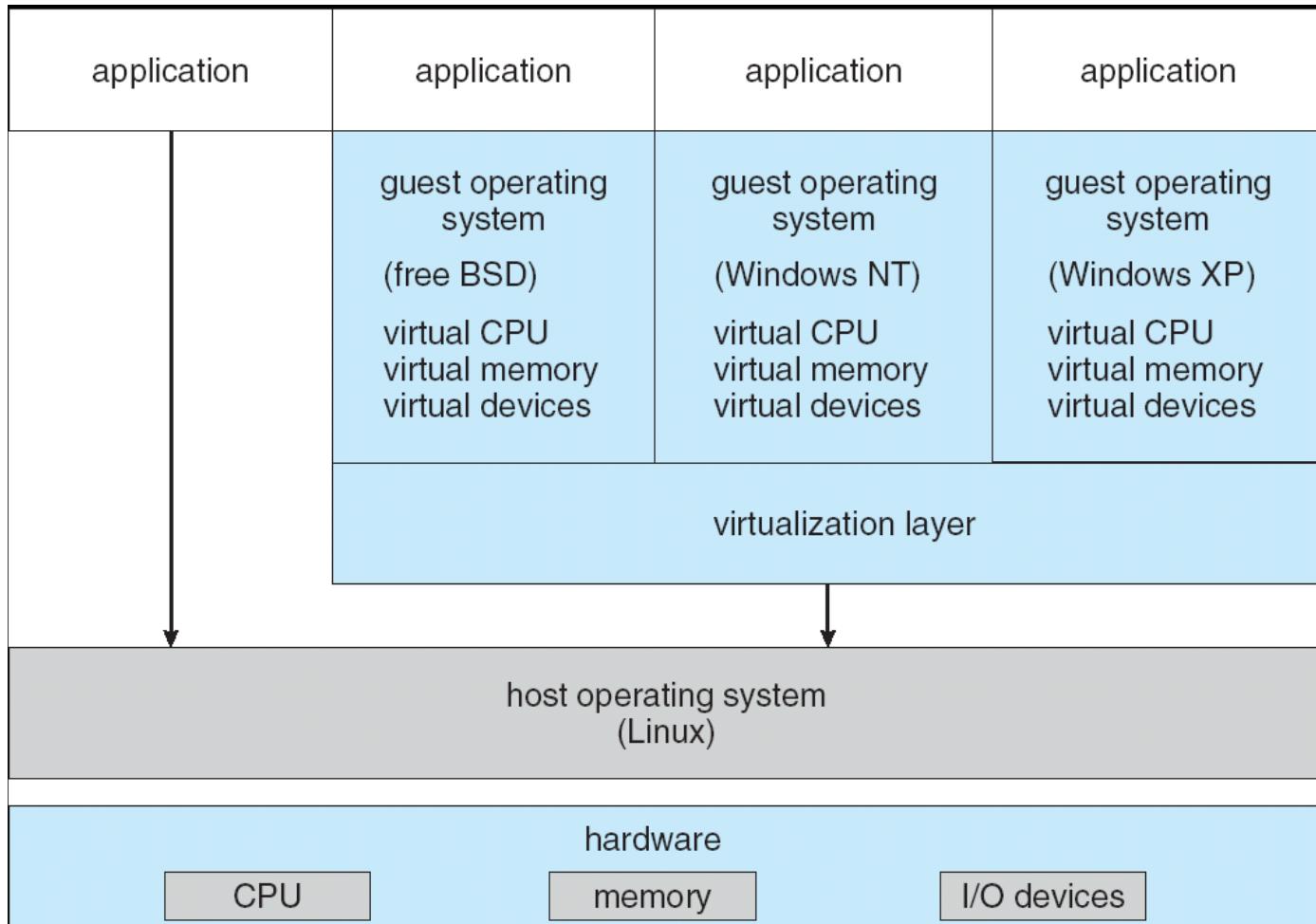
# Virtual Machine Implementation 2: Hosted Hypervisor

- 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 disk, virtual card readers, and virtual line printers
  - ◆ A normal user time-sharing terminal serves as the virtual machine operator's console





# VMware Architecture





# Virtual Machines Advantages

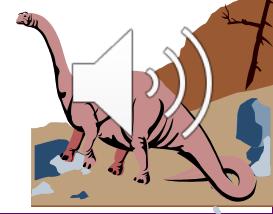
- The virtual-machine concept provides complete protection of system resources since each virtual machine is isolated from all other virtual machines. This isolation, however, permits no direct sharing of resources.
- A virtual-machine system is a perfect vehicle for operating-systems research and development. System development is done on the virtual machine, instead of on a physical machine and so does not disrupt normal system operation.



# Virtual Machines Disadvantage

- The virtual machine concept is difficult to implement due to the effort required to provide an *exact* duplicate to the underlying machine
- Other lightweight virtualization mechanisms are available

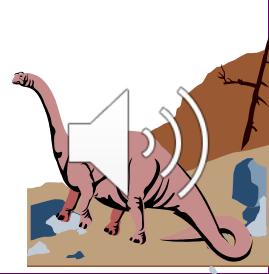
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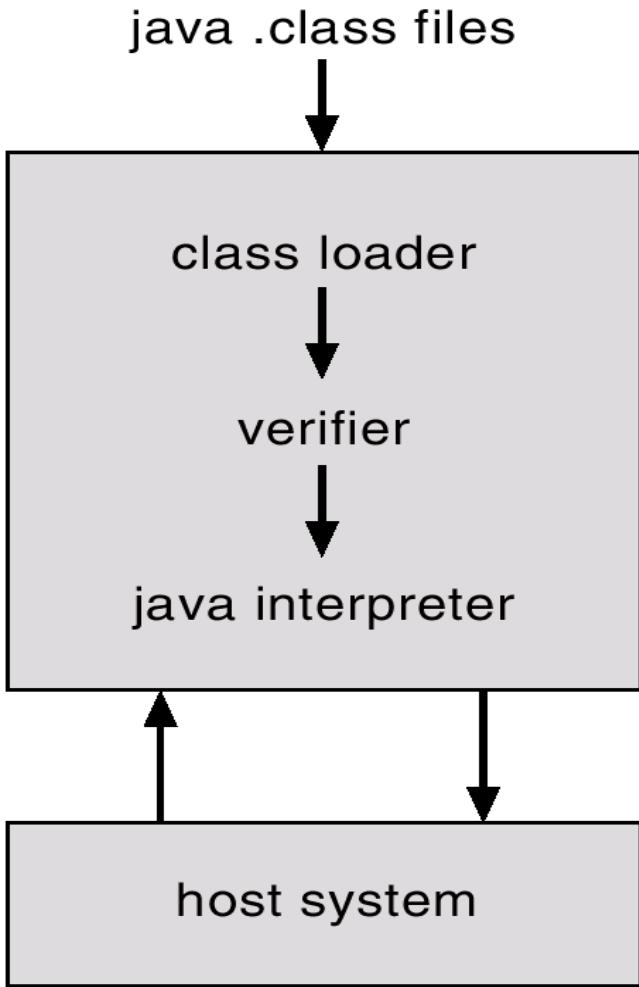


# Java Virtual Machine

- Compiled Java programs are platform-neutral bytecodes executed by a Java Virtual Machine (JVM).
- JVM consists of
  - class loader
  - class verifier
  - runtime interpreter
- Just-In-Time (JIT) compilers increase performance



# Java虚拟机比Docker Engine更轻量级



- A java program running on top of the JVM will be a single Linux process.
- The JVM runs inside the process, and interprets (or compiles) the Java byte code in your classes.
- A docker container is more heavyweight. There's the docker daemon, the docker container, which is actually a virtualized Linux instance, and then your JVM running under that.



# Java Virtual Machine (Cont.)

- 因为有JIT (Just In Time) 编译器，所有java程序有个慢热问题。
- 需要学习找到 bytecode 中的频繁执行的热点代码，并且把 hotspot 编译成本地代码执行。
- 所以Java程序在启动的时候会比平时花费多几倍的CPU时钟

