Chapter 2: Operating-System Structures

肖 卿 俊
办公室：九龙湖校区计算机楼212室
电邮：csqjxiao@seu.edu.cn
主页： https://csqjxiao.github.io/PersonalPage
电话：025-52091022

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.

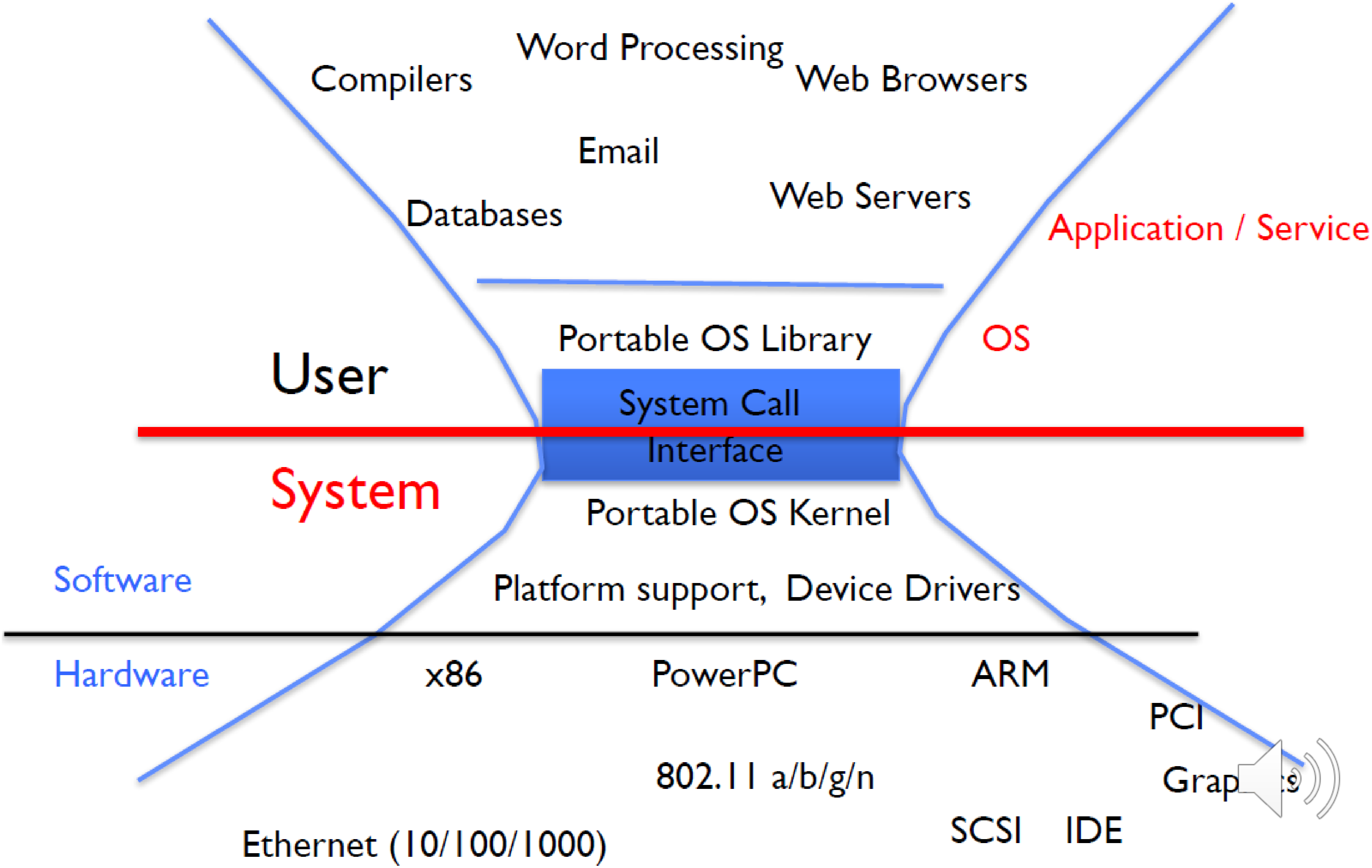
- Resource allocation – allocating resources to multiple users or multiple jobs running at the same time.
- Accounting – keep track of and record which users use how much and what kinds of computer resources for account billing or for accumulating usage statistics.
- Protection – ensuring that all access 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
http://docs.cs.up.ac.za/programming/asm/derick_tut/syscalls.html

Operating System as Design



Example of System Calls (1/2)

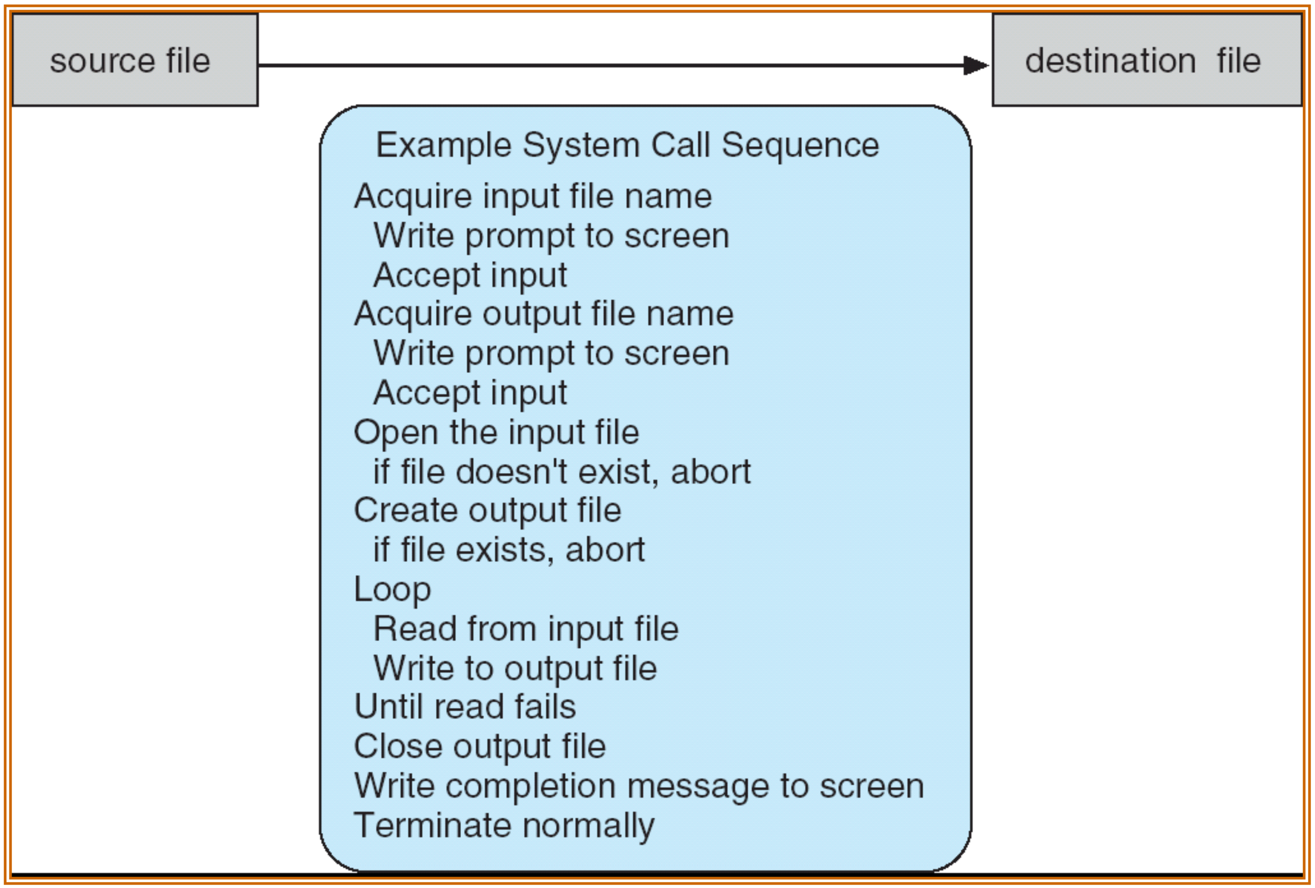
- **cp** is the command line tool in Linux, which makes a copy of your files or directories.
  - For instance, let's say you have a file named **picture.jpg** in your working directory, and you want to make a copy of it called **picture-02.jpg**. You would run the command:

cp picture.jpg picture-02.jpg

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

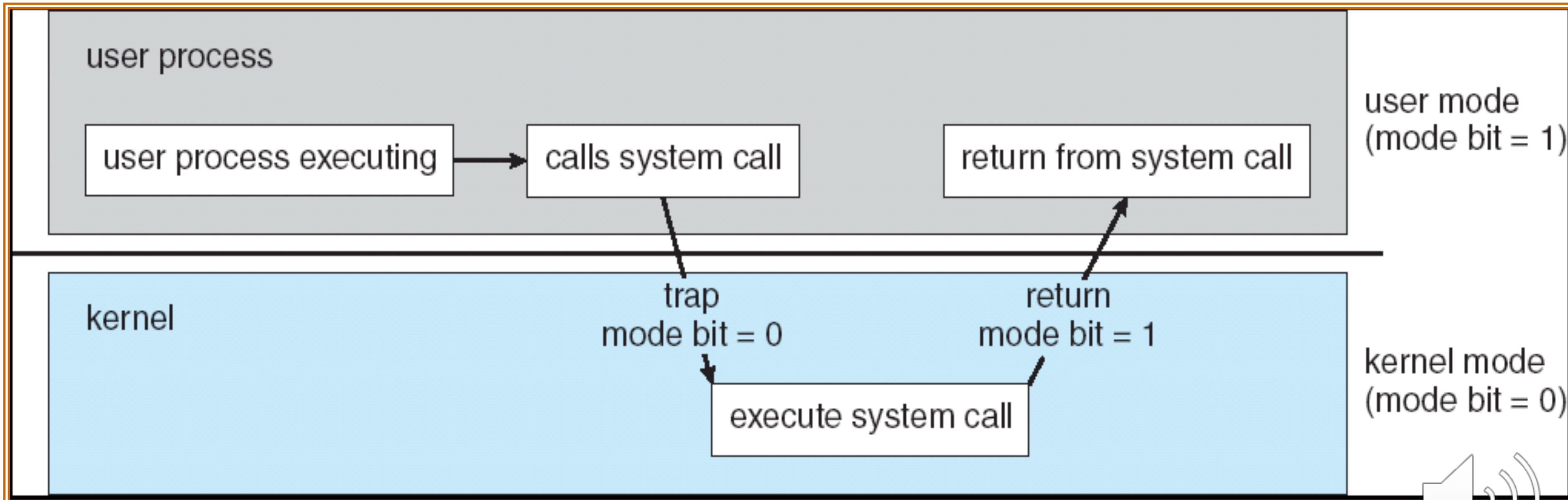
Example of System Calls (2/2)

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



Why Execute a System Call from a Trap (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

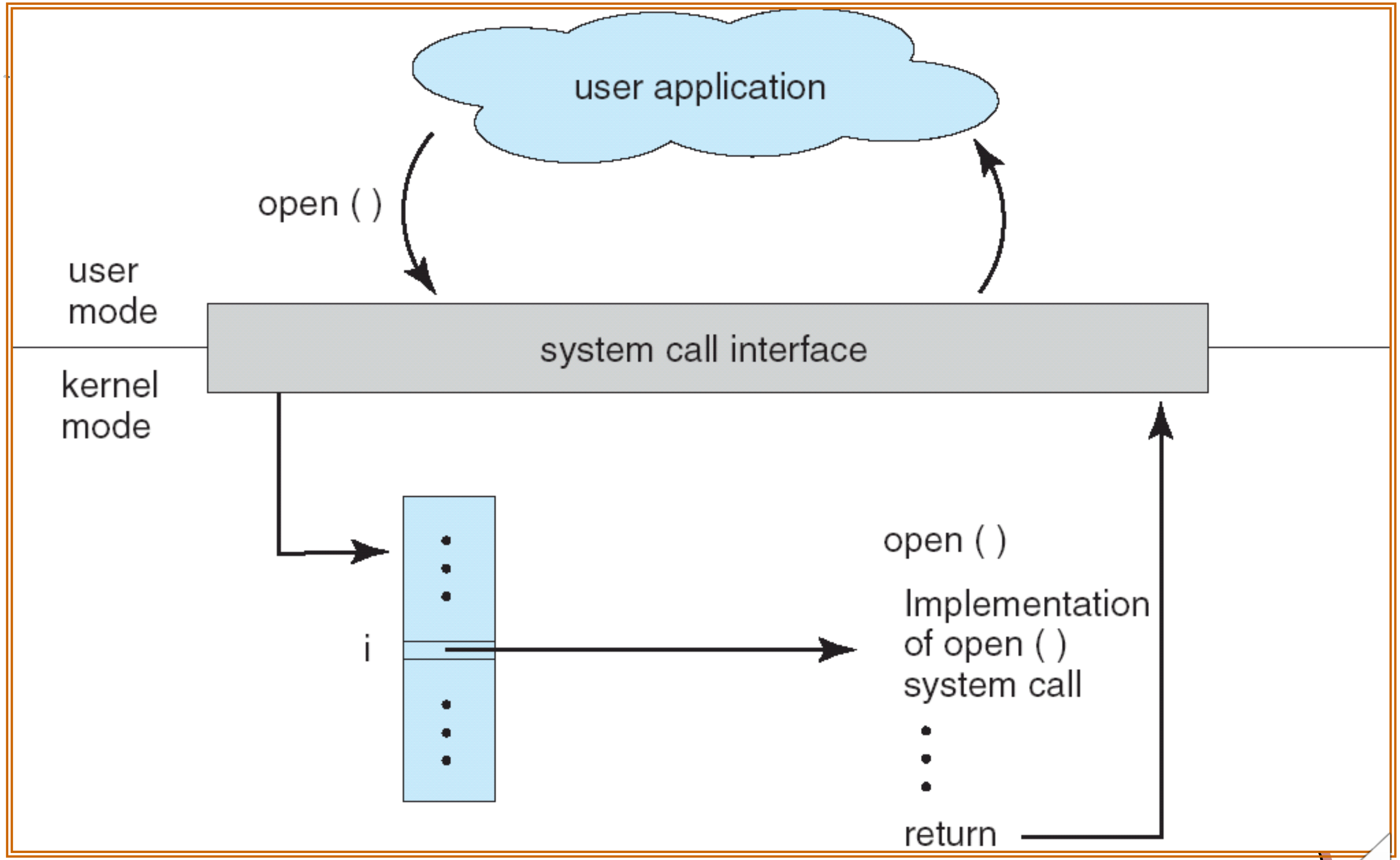
- Typically, a number associated with each system call
  - System-call interface maintains a table indexed according to these numbers
- The system call interface invokes intended system call in OS kernel and returns status of the system call and any return values

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

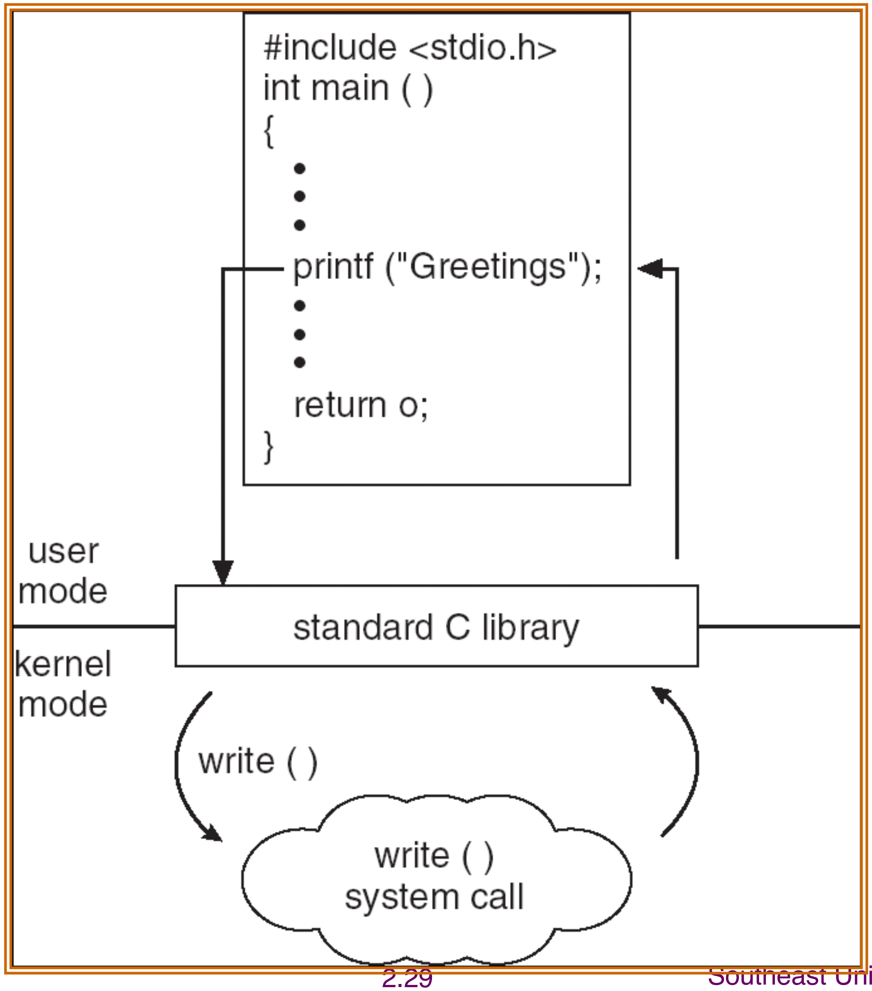
  - Most details of OS interface hidden from programmer by API
    - ✓ Managed by run-time support library (set of functions built into libraries included with compiler)

API – System Call – OS Relationship

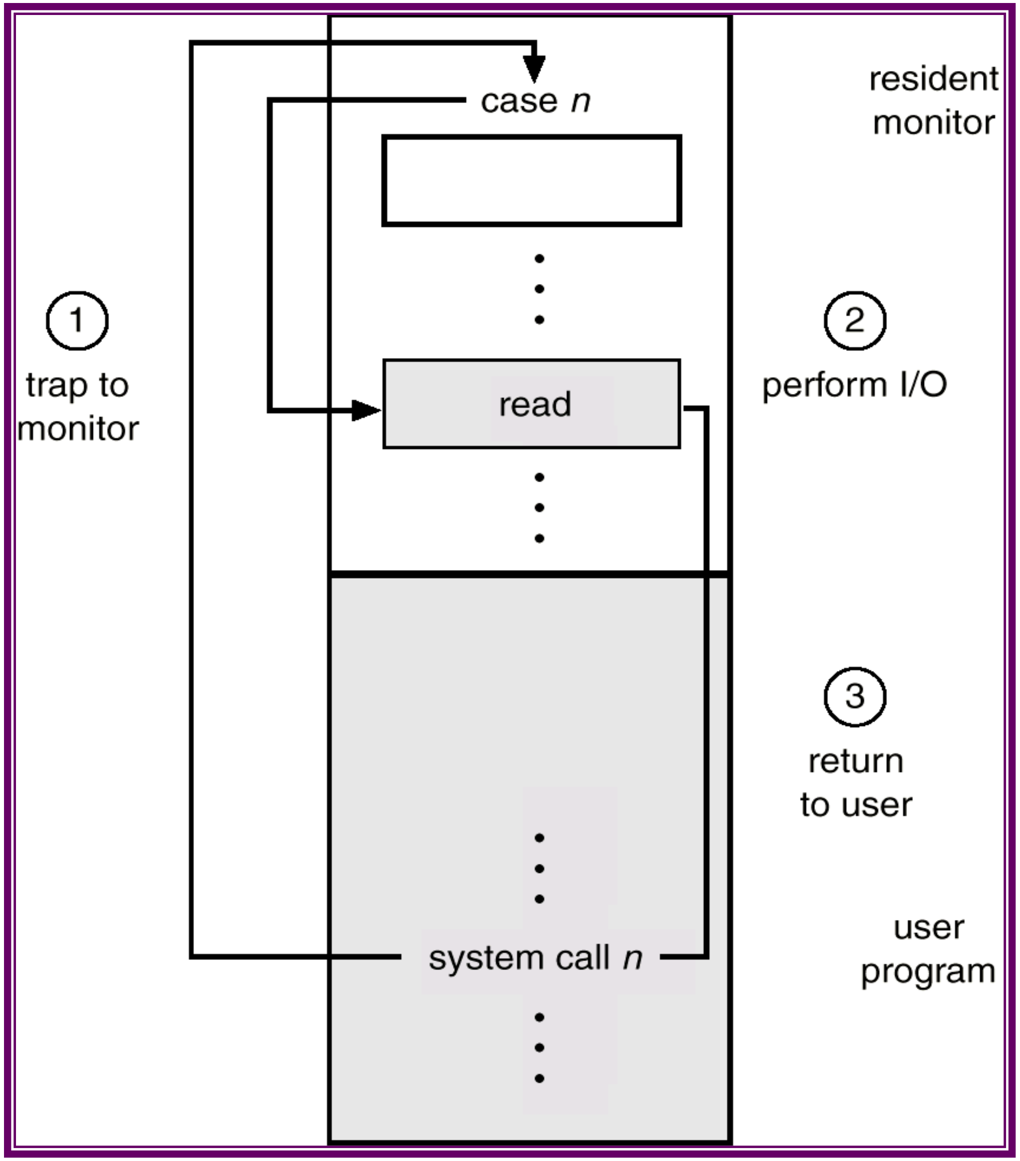


Standard C Library Example

- 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	kernel/exit.c	int	-	-	-	-
2	sys_fork	arch/i386/kernel/process.c	struct pt_regs	-	-	-	-
3	sys_read	fs/read_write.c	unsigned int	char *	size_t	-	-
4	sys_write	fs/read_write.c	unsigned int	const char *	size_t	-	-
5	sys_open	fs/open.c	const char *	int	int	-	-
6	sys_close	fs/open.c	unsigned int	-	-	-	-
7	sys_waitpid	kernel/exit.c	pid_t	unsigned int *	int	-	-

System Call Parameter Passing

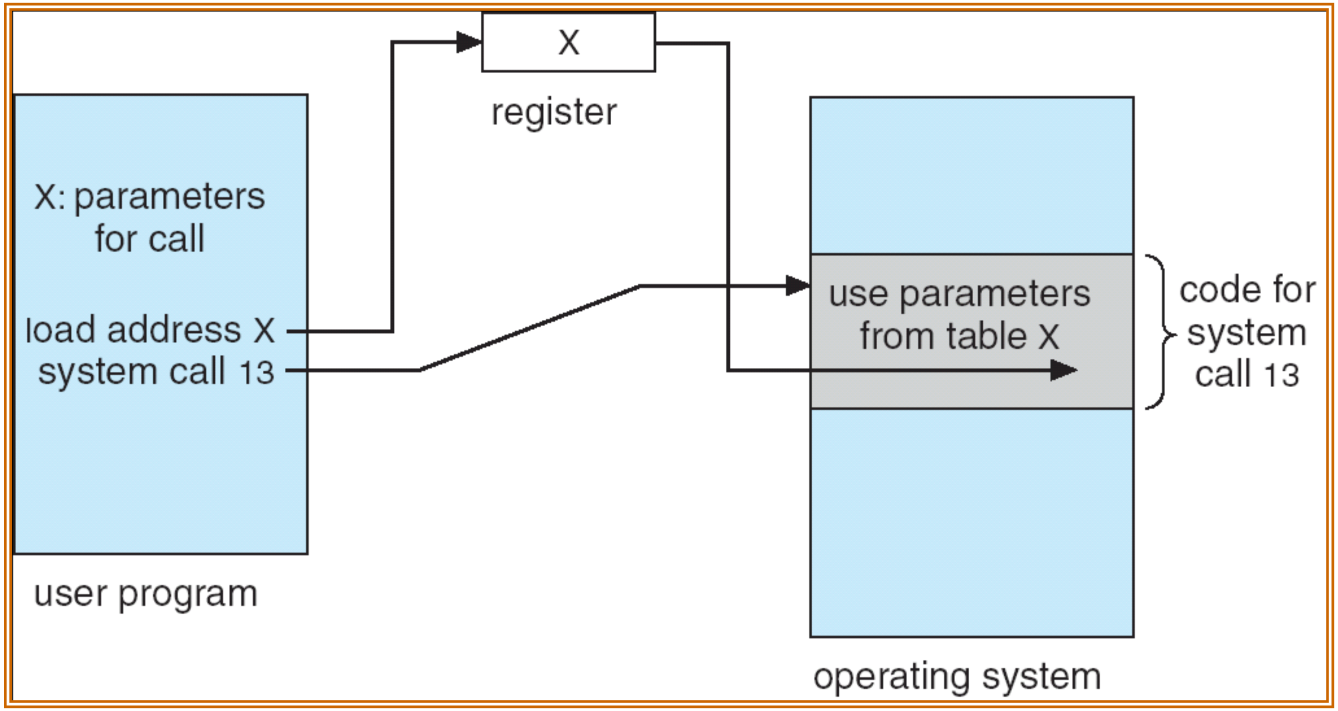
- Often, more information is required than simply identity of desired system call
  - Exact type and amount of information vary according to OS and call
- Three general methods used to pass parameters to the OS

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

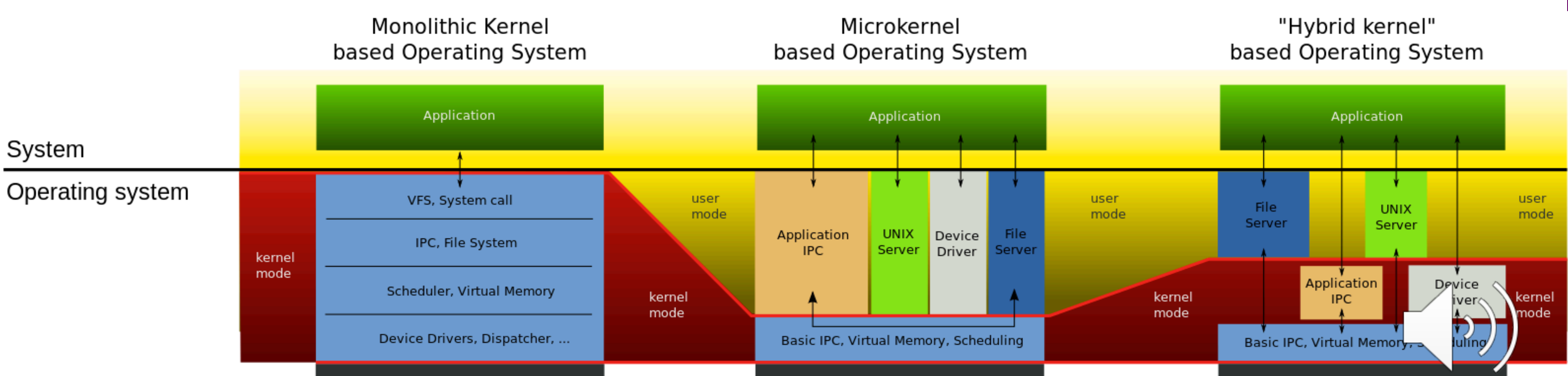
- Block and stack methods do not limit the number or length of parameters being passed

Parameter Passing via Table

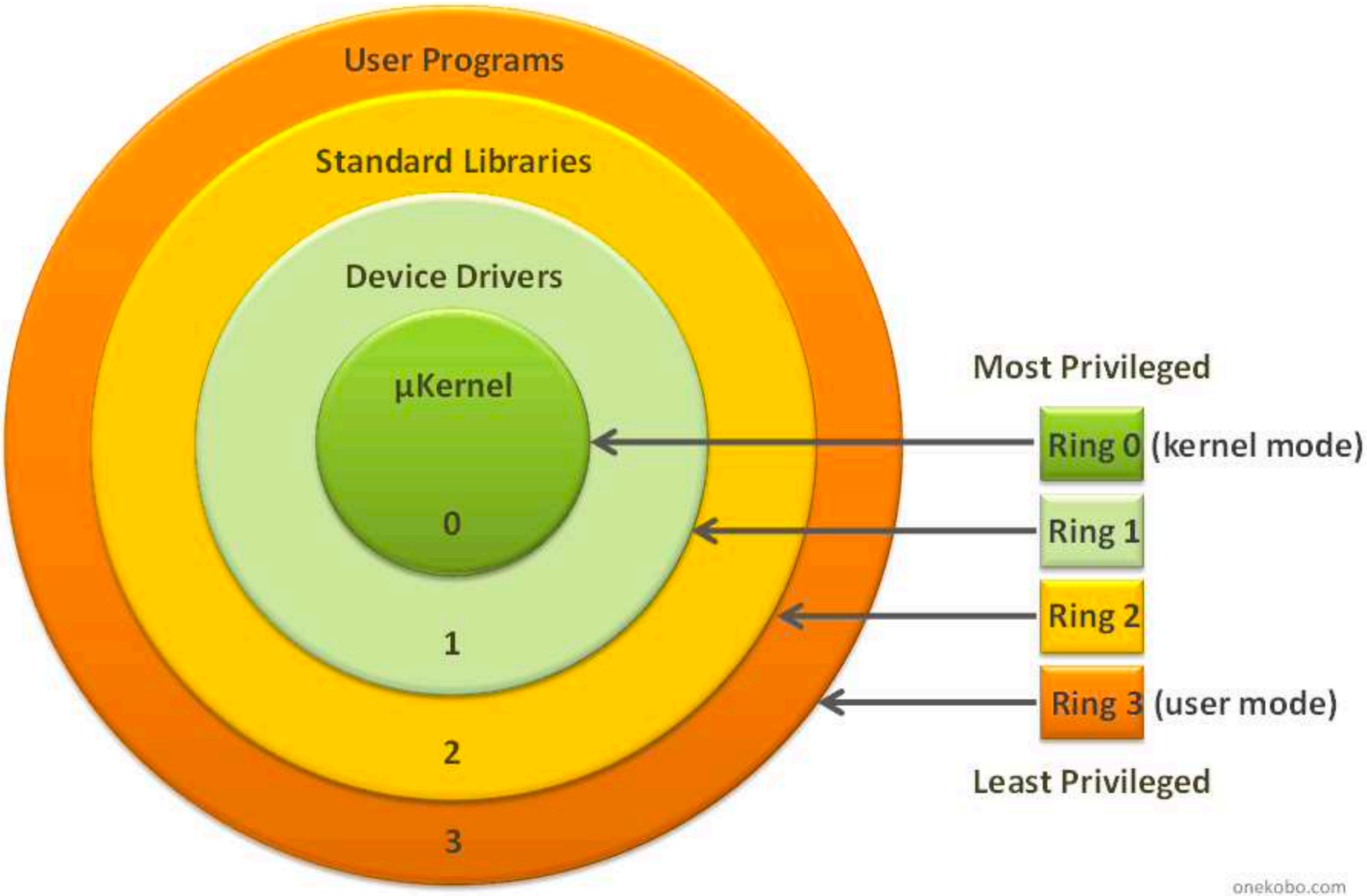


What is OS Structure?

- 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



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**.

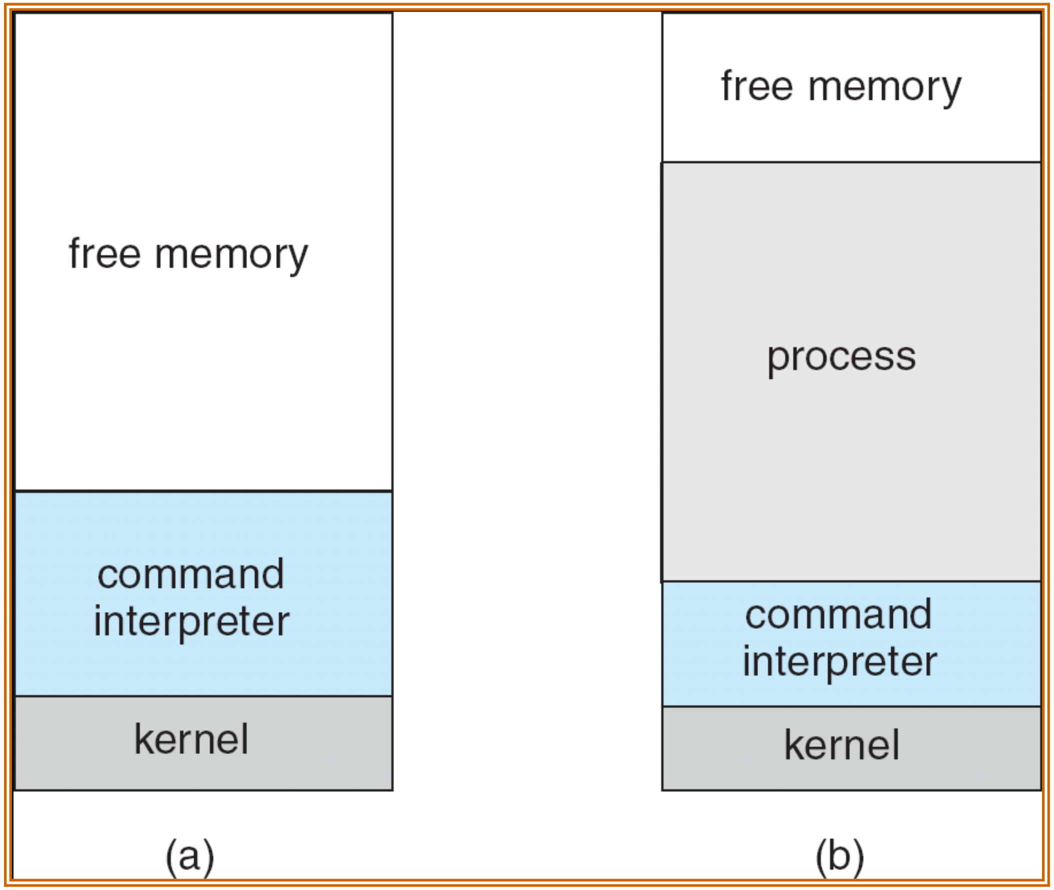
Goal of OS Structure Design

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

DOS-like Structure

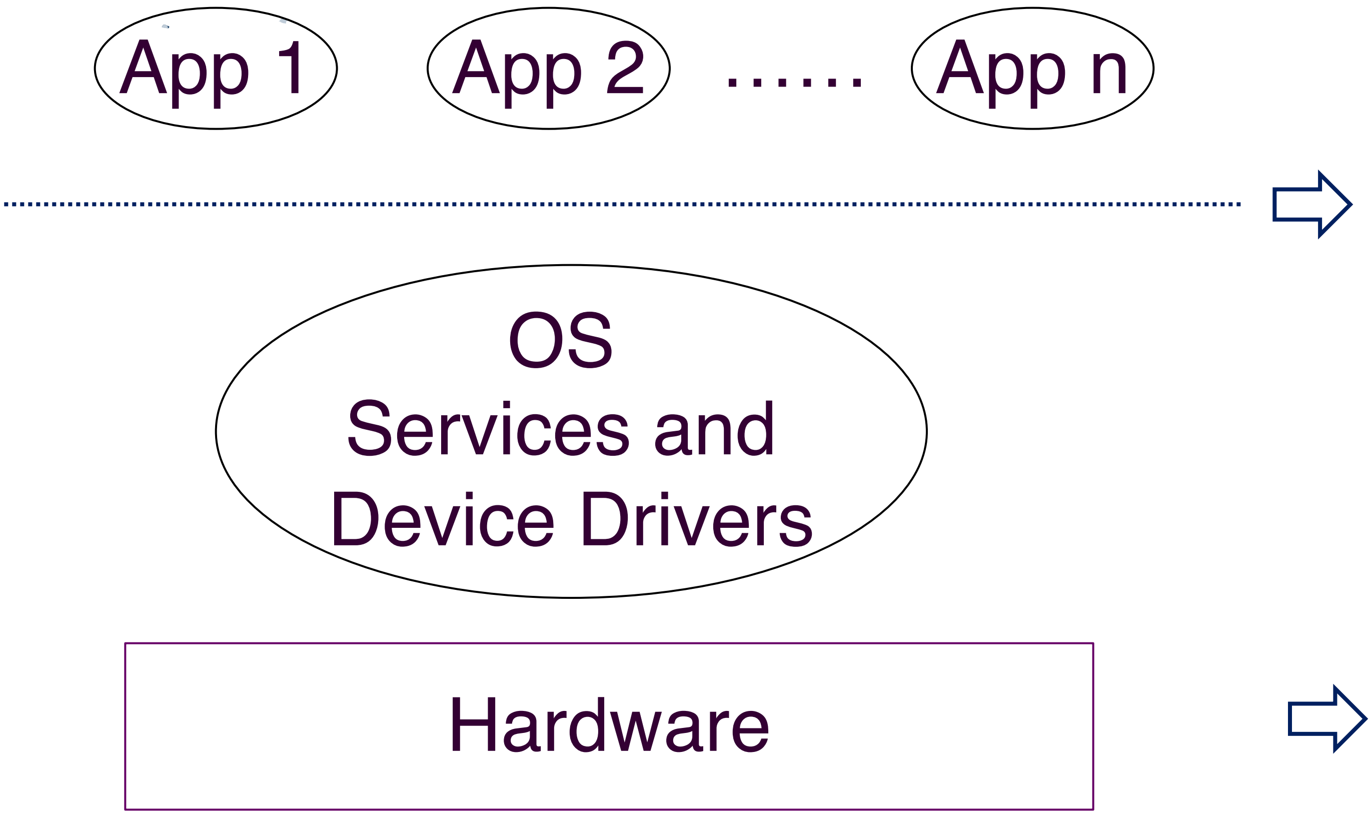
- MS-DOS – written to provide the most functionality in the least space
  - Performance: Access to system services is like a procedure call
  - Although MS-DOS has some structure, its interfaces and levels of functionality are not well separated
  - Bad Protection: an error of application can corrupt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

MS-DOS execution (Single Program)



(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

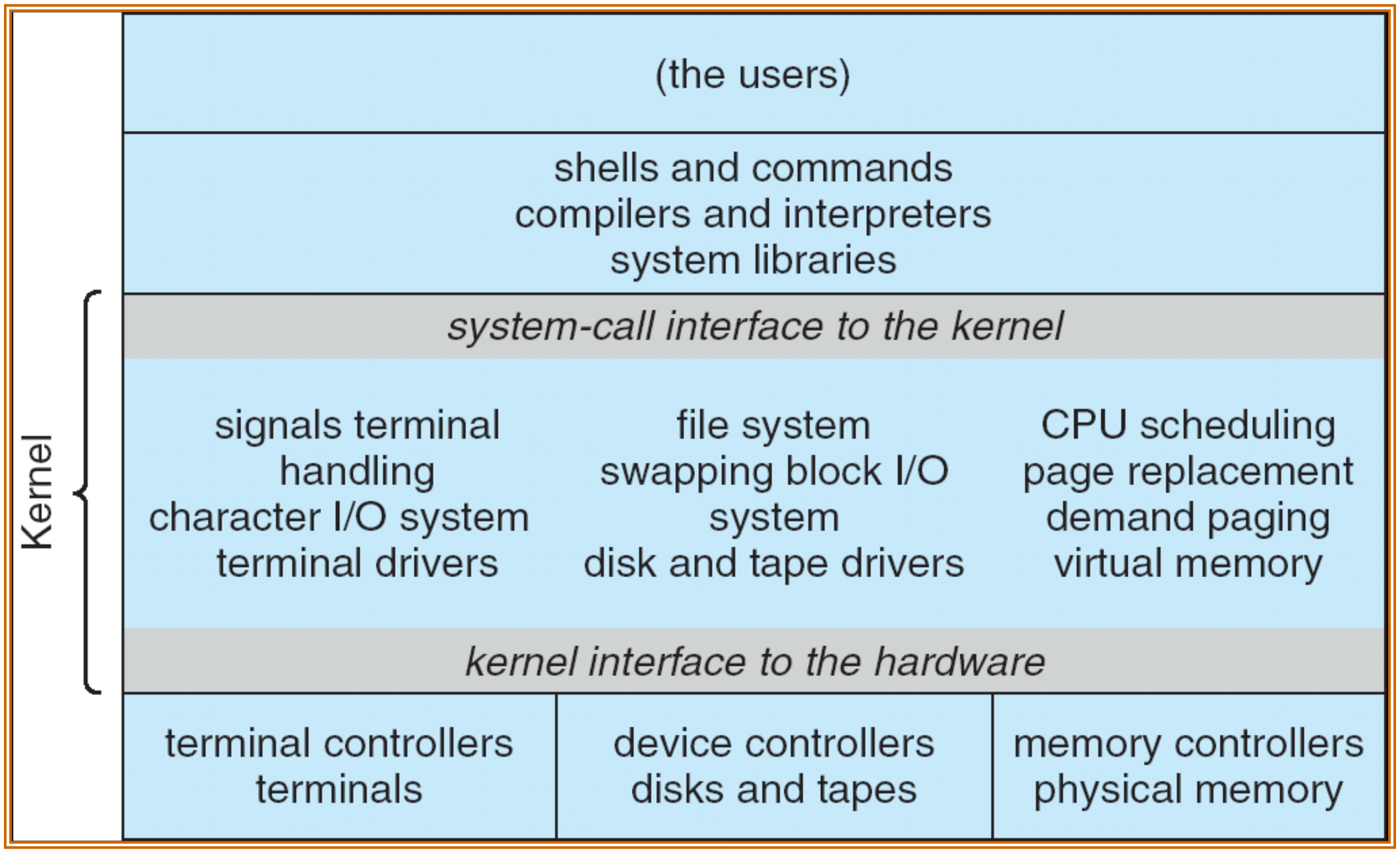
Managed by the OS

Monolithic Structure

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

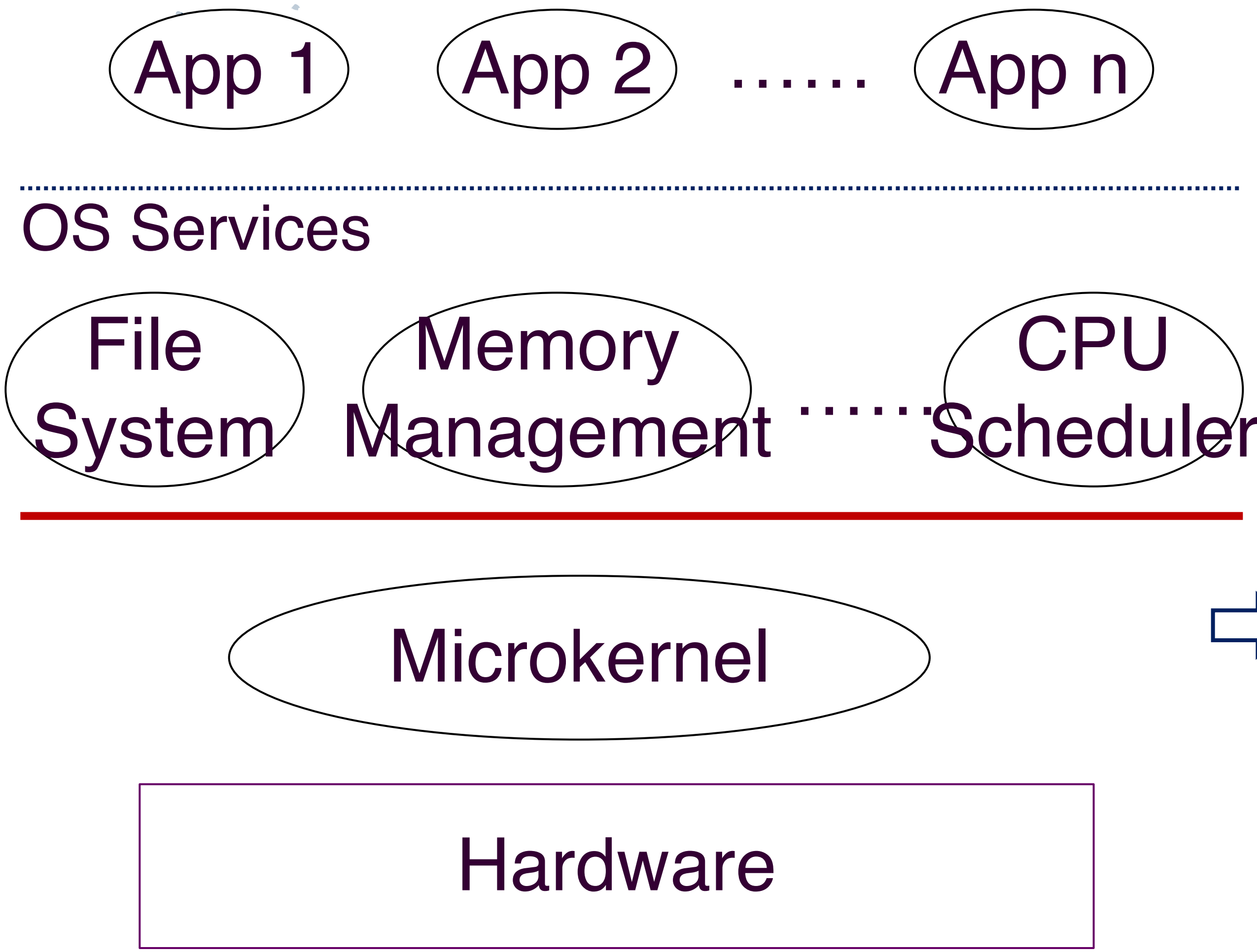


Gain and Loss of Monolithic Structure

- 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



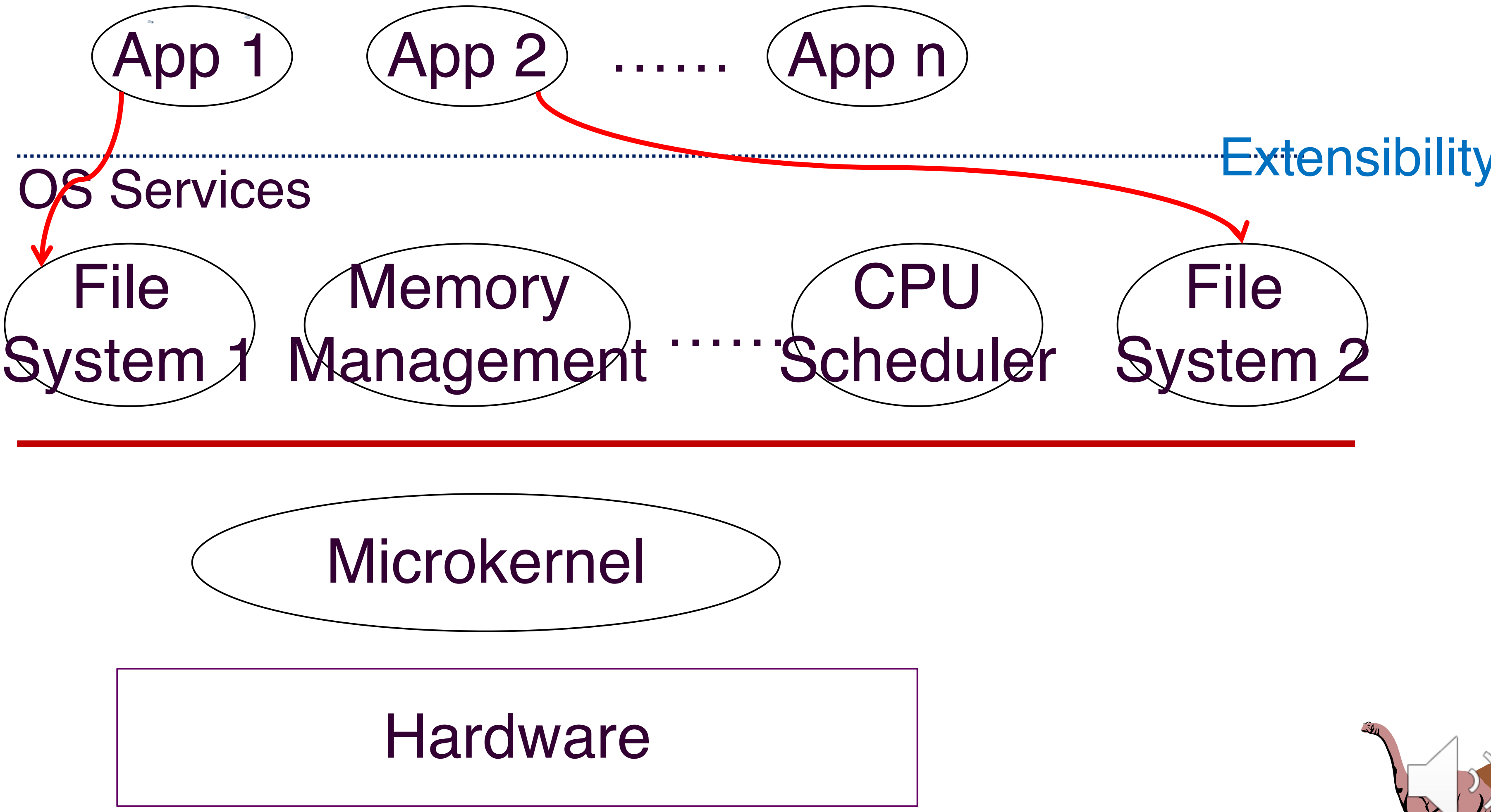
Each App in its own hardware address space

Each service in its own address space

Simple abstraction

- Process management
- Address space
- IPC

Advantage of Microkernel-based Design



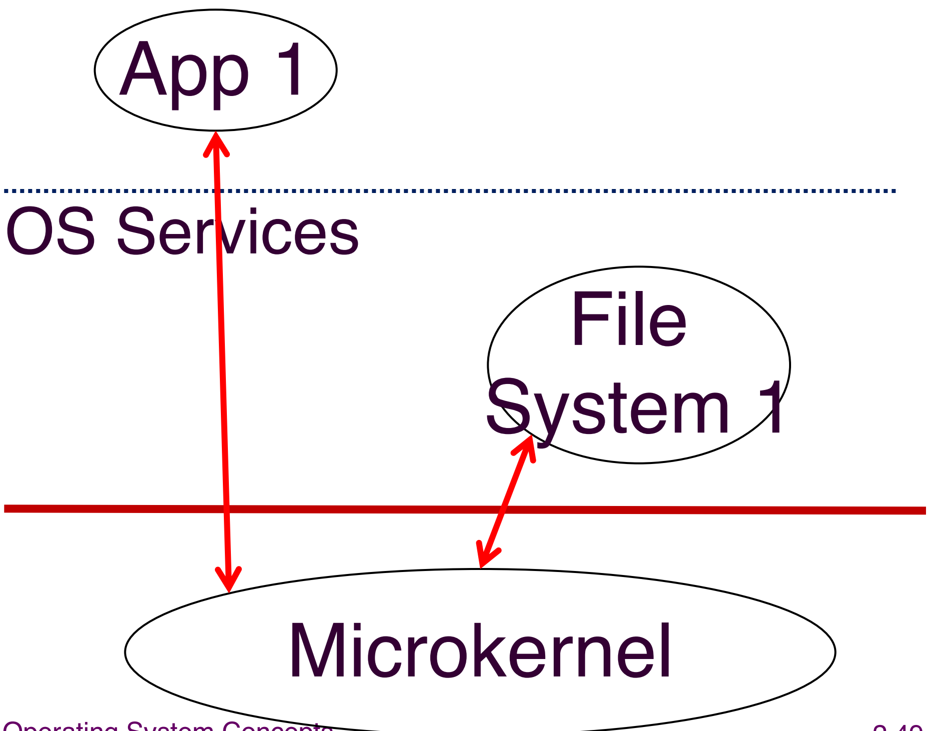
Pros and Cons of Microkernel System Structure

- 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

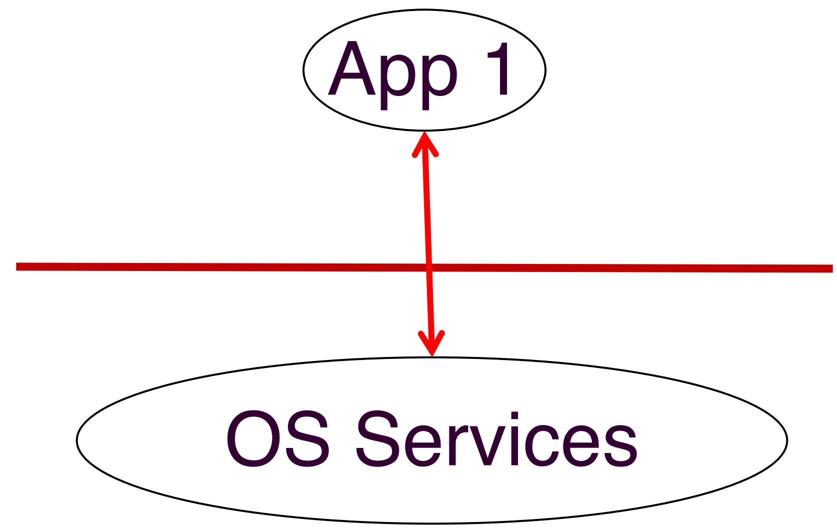
Why Performance Loss

- 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 ….

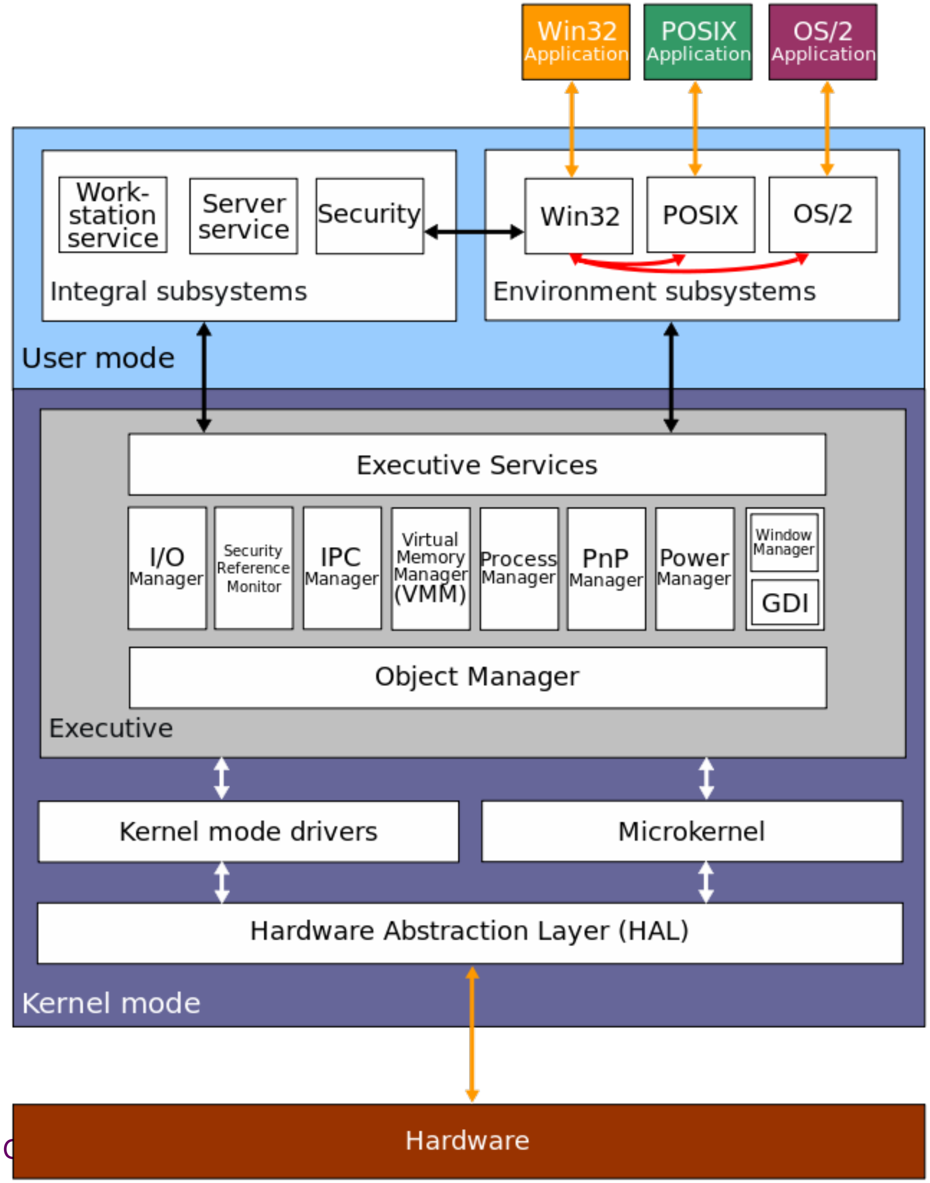
Feature	DOS-like OS	Monolithic OS	Microkernel OS
Extensibility	√		√
Protection		√	√
Performance	√	√	

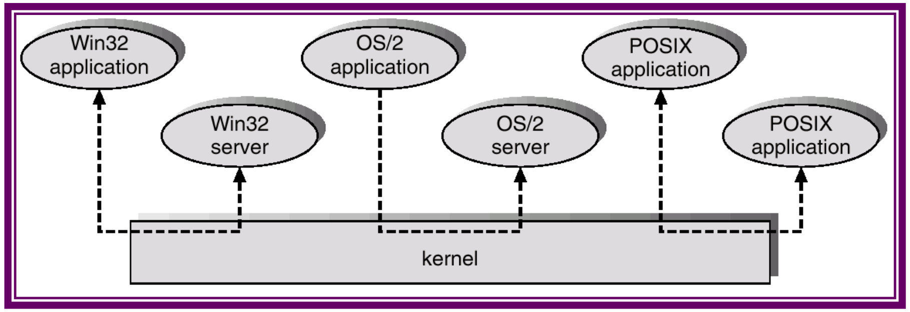
Hybrid Kernel Approach

- 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.

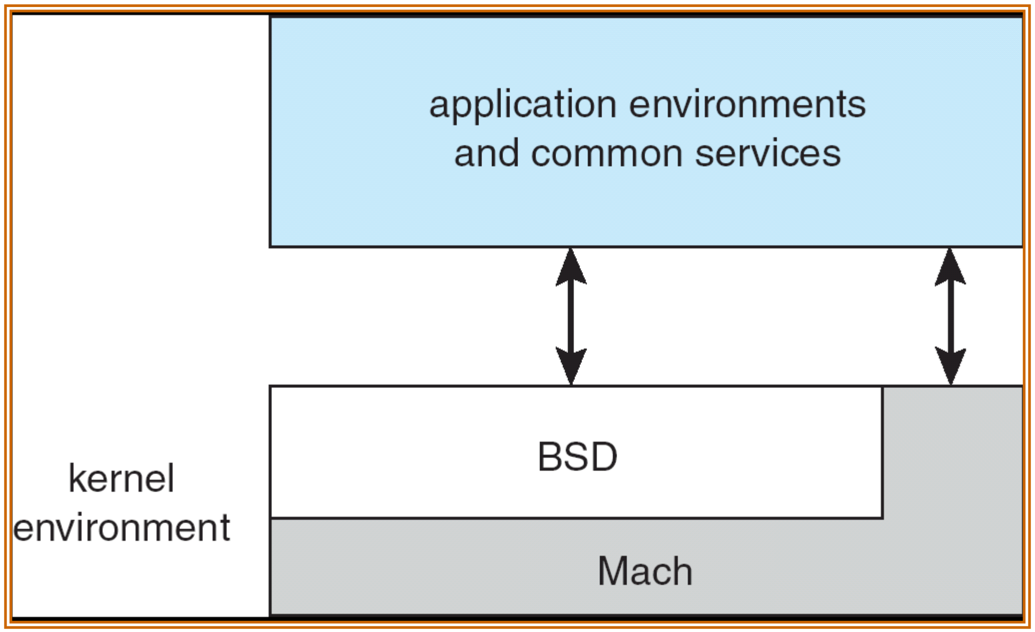
- In contrast to a microkernel, all (or nearly all) operating system services in a hybrid kernel are still in kernel space.

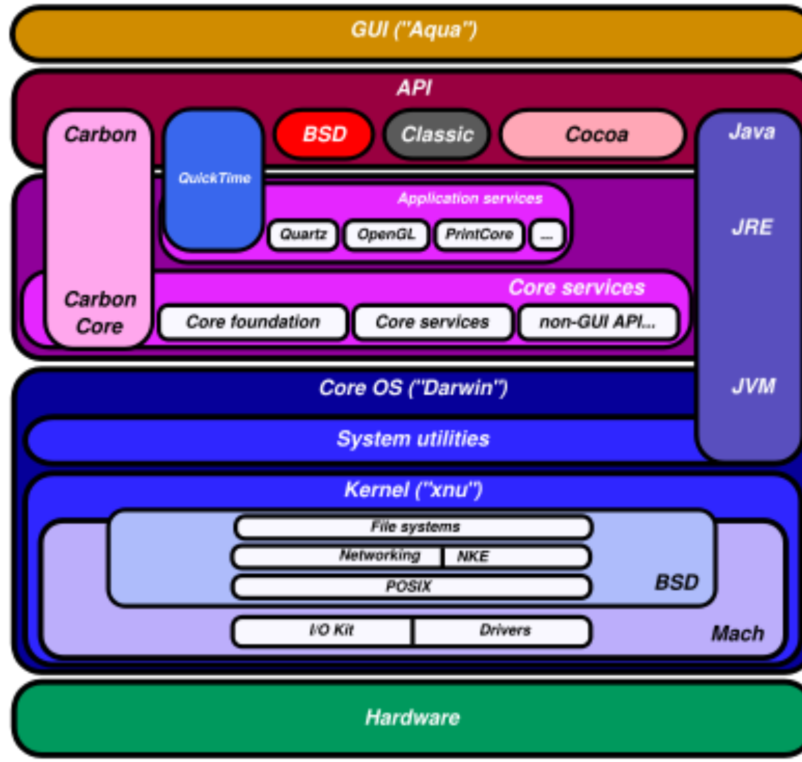
Hybrid Kernel Example: Windows NT Client-Server Structure



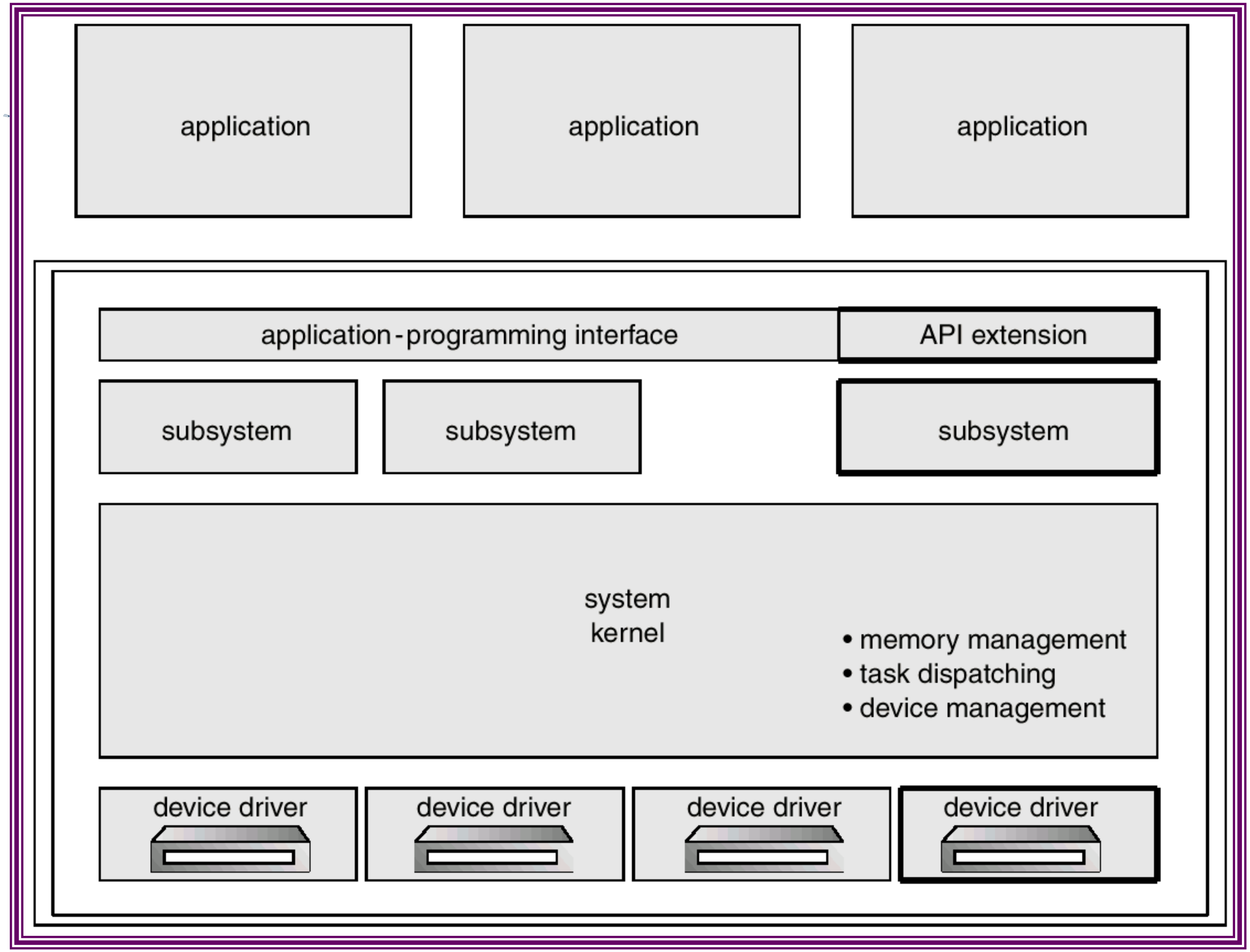


Hybrid Kernel Example: Mac OS X Structure





Hybrid Kernel Example: OS/2 Layer Structure



https://en.wikipedia.org/wiki/OS/2

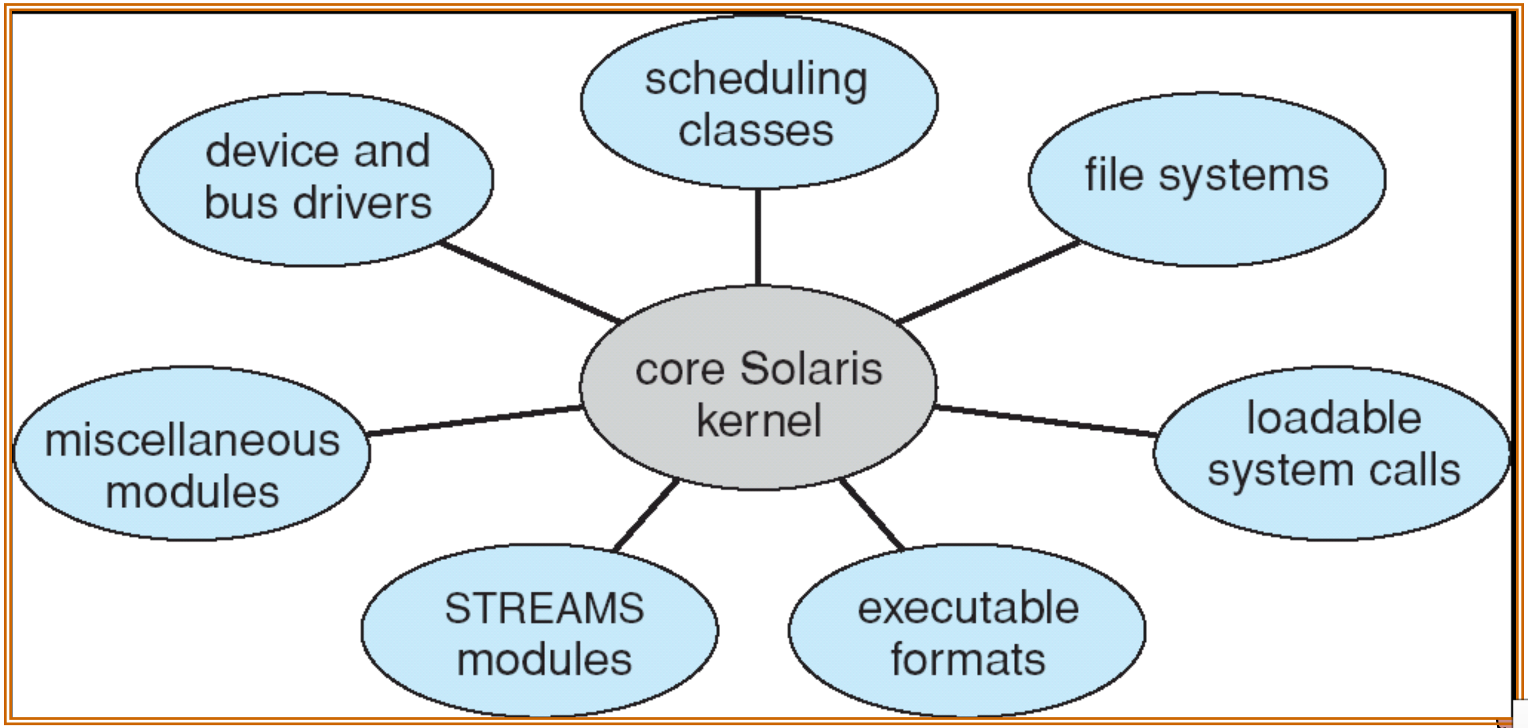
Monolithic Kernel with Dynamically Loadable Modules

- 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

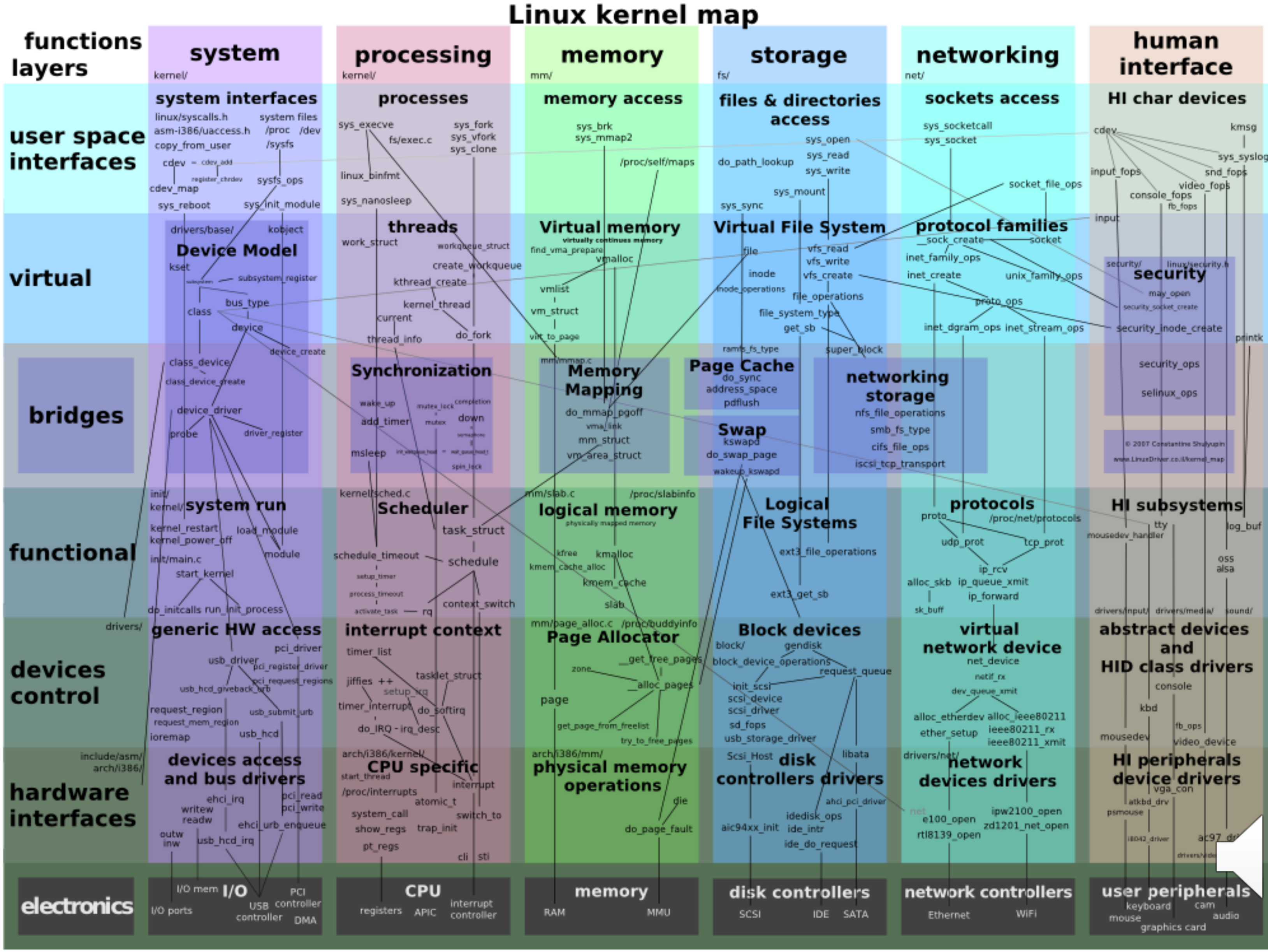
Solaris Modular Approach

- 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)

Linux is also a modular monolithic kernel



Question about Virtualization

- What comes to your mind when you hear about the word “virtualization”
  - Memory Systems
  - Data Centers
  - Java Virtual Machine
  - Virtual Box
  - IBM VM/370
  - Google Glass
  - Cloud Computing
  - Dalvik JVM
  - VMWare Workstation
  - The movie “Inception”

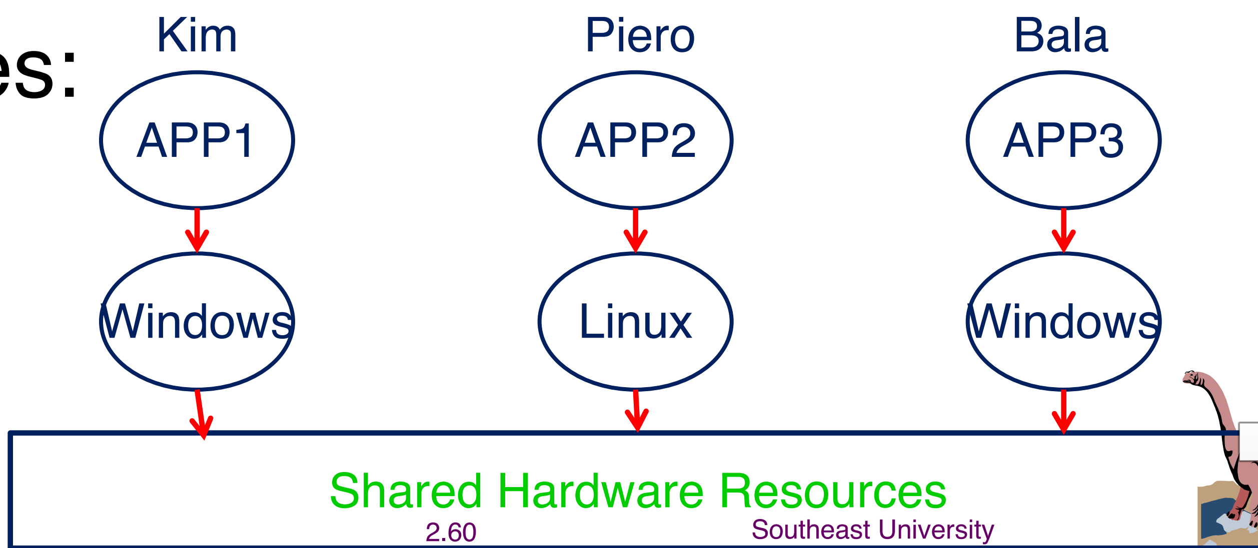
https://en.wikipedia.org/wiki/Virtualization
https://en.wikipedia.org/wiki/VirtualBox

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.

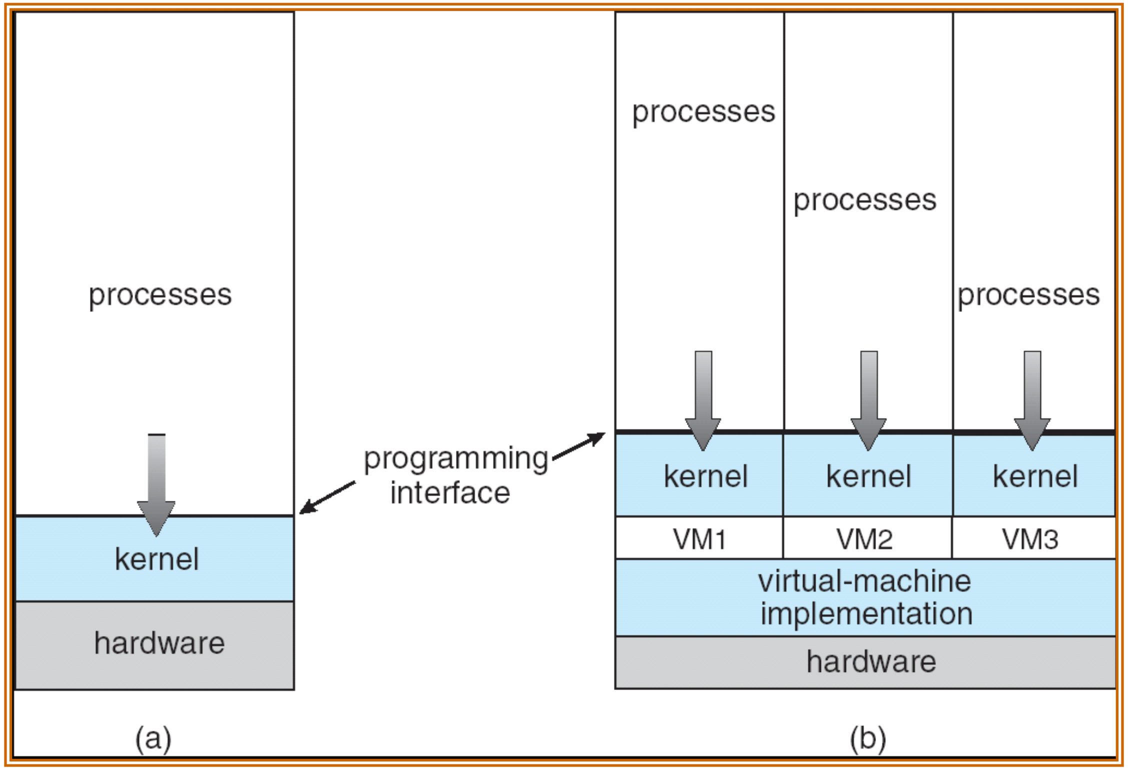
Virtual Machines

- 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

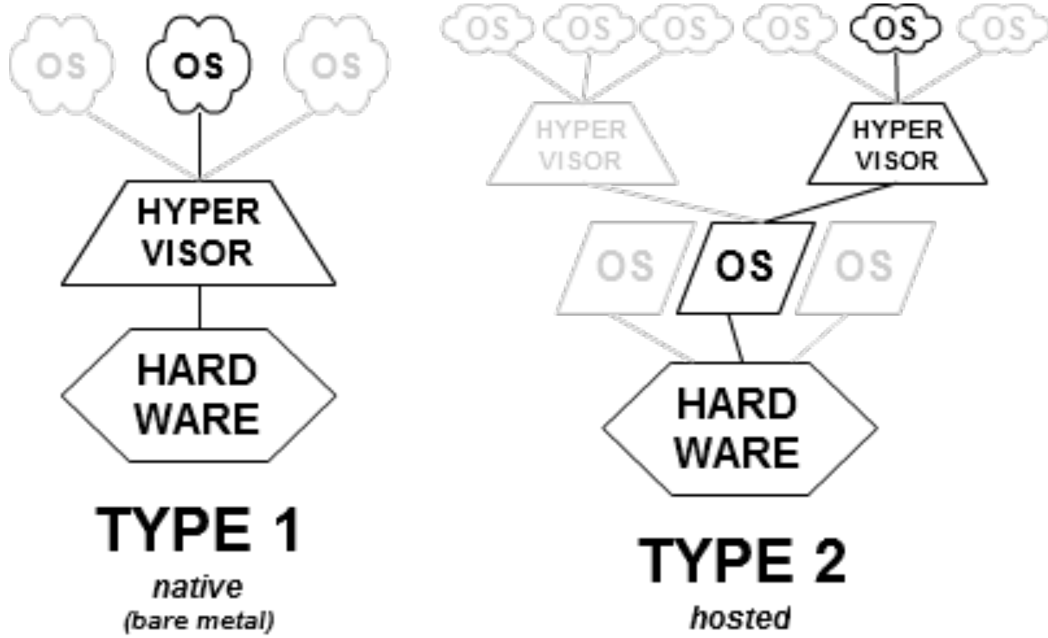
https://en.wikipedia.org/wiki/Hypervisor

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

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

vmware

ORACLE VM VirtualBox

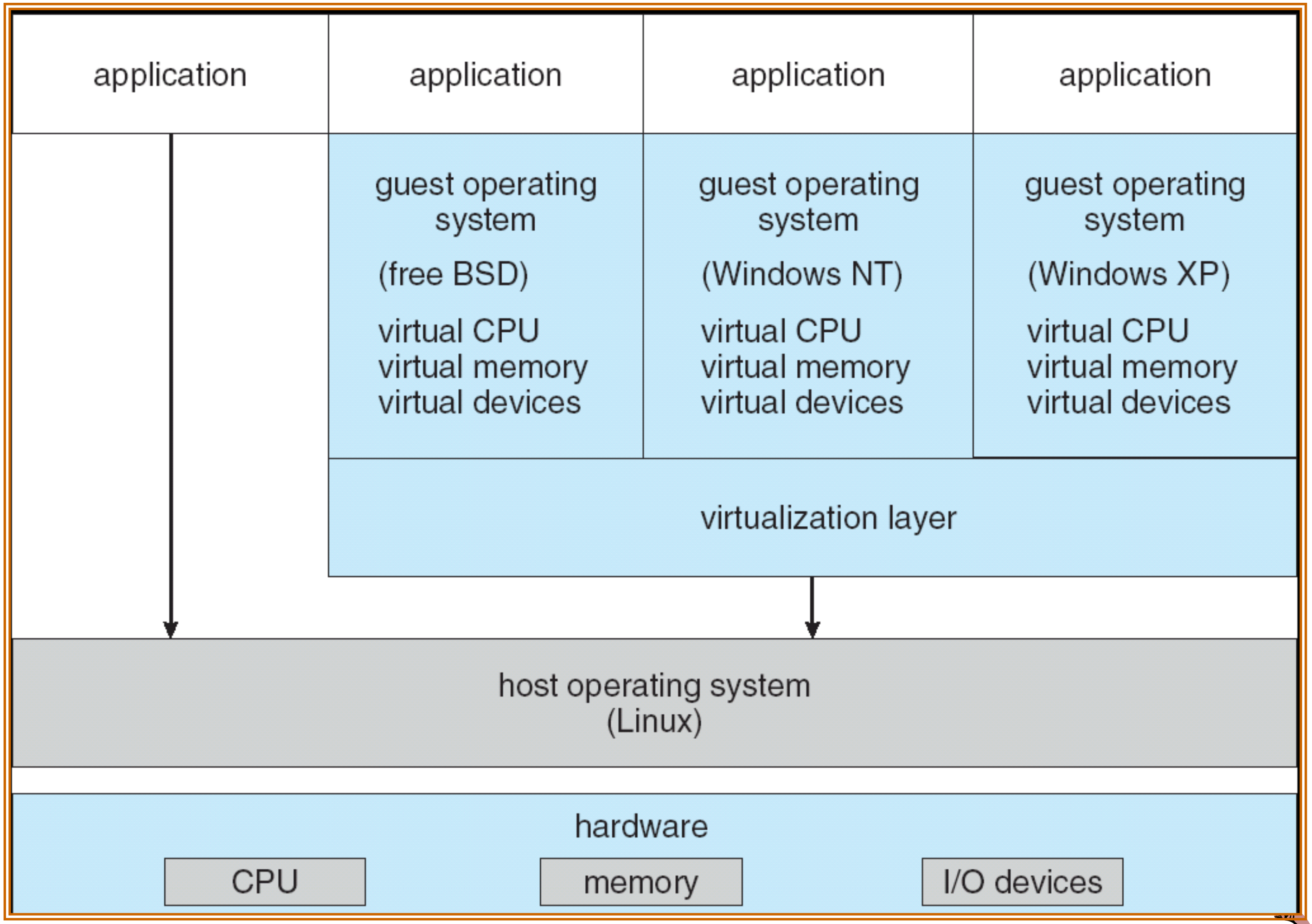
Virtual Machine Implementation 2: Hosted Hypervisor

- 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

https://en.wikipedia.org/wiki/Virtualization

未来趋势：云基础设施容器化

■ 虚拟机的性能短板

vmware

KVM

ORACLE VM VirtualBox

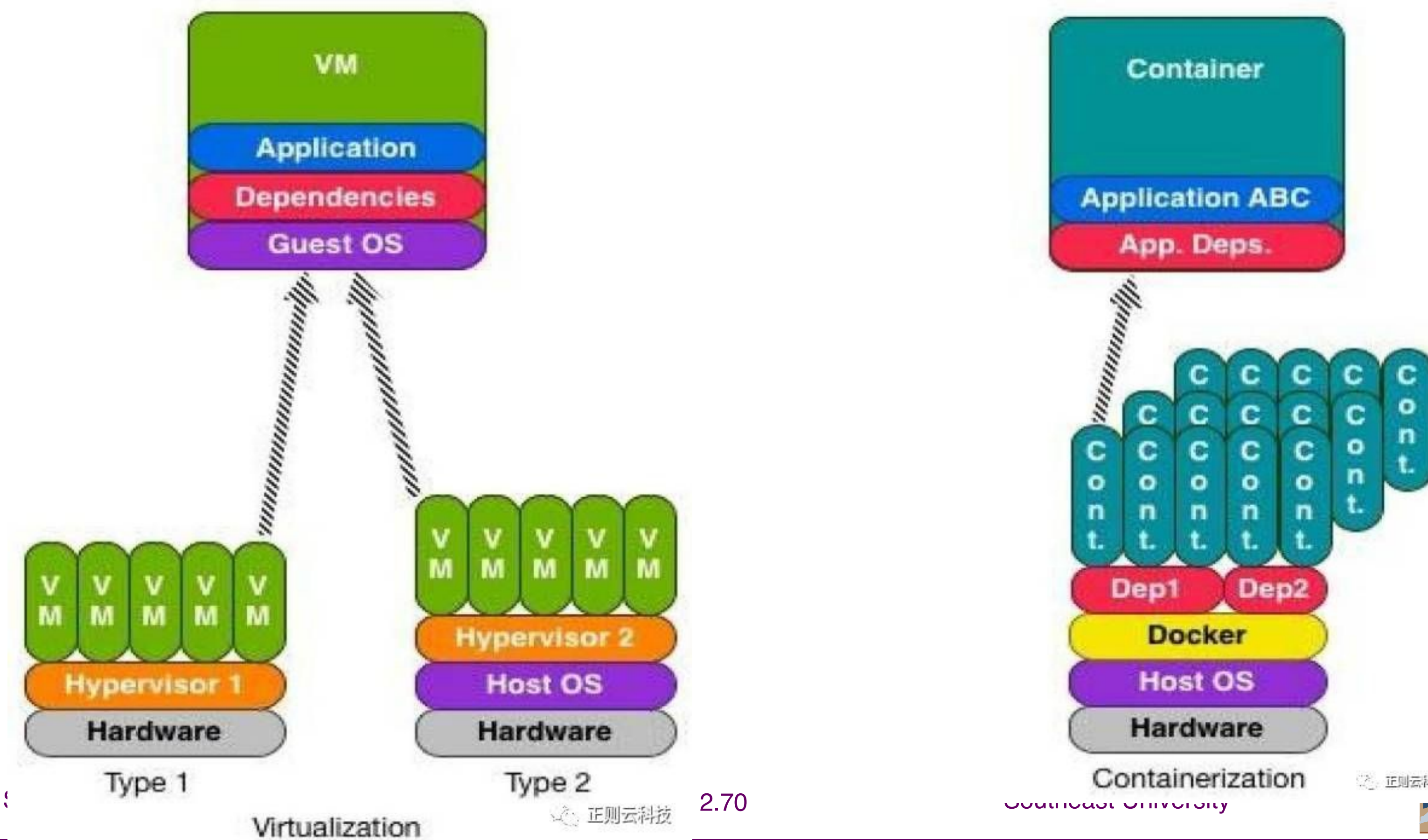
云用户需求：更轻、更快、更灵活

Docker容器工具简介

- Docker的核心：容器。
  - 容器提供了在计算机上的隔离环境中安装和运行应用程序的方法。在容器内运行的应用程序仅可使用于为该容器分配的资源，例如：CPU，内存，磁盘，进程空间，用户，网络，卷等。在使用有限的容器资源的同时，并不与其他容器冲突。您可以将容器视为简易计算机上运行应用程序的隔离沙箱。
  - Docker本身不是容器，是创建容器的工具。

虚拟机 vs. Docker容器

- 在容器化部署的时候，不再需要臃肿的客户机guest operating system了。只是通过docker容器引擎模拟了应用程序的依赖环境



Docker容器工具简介

特性	虚拟机	容器
隔离级别	操作系统级	进程级
隔离策略	Hypervisor	CGroups
系统资源	5~15%	0~5%
启动时间	分钟级	秒级
镜像存储	GB-TB	KB-MB
集群规模	上百	上万
高可用策略	备份、容灾、迁移	弹性、负载、动态

容器和虚拟机的对比

Docker

- 在Docker的世界，使用别人的镜像作为基础镜像来创建自己的镜像是十分普遍的。例如，官方Redis Docker镜像就是基于Debian文件系统快照（rootfs tarball），并安装在其上配置Redis。

redis

https://hub.docker.com/_/redis

debian

https://hub.docker.com/_/debian

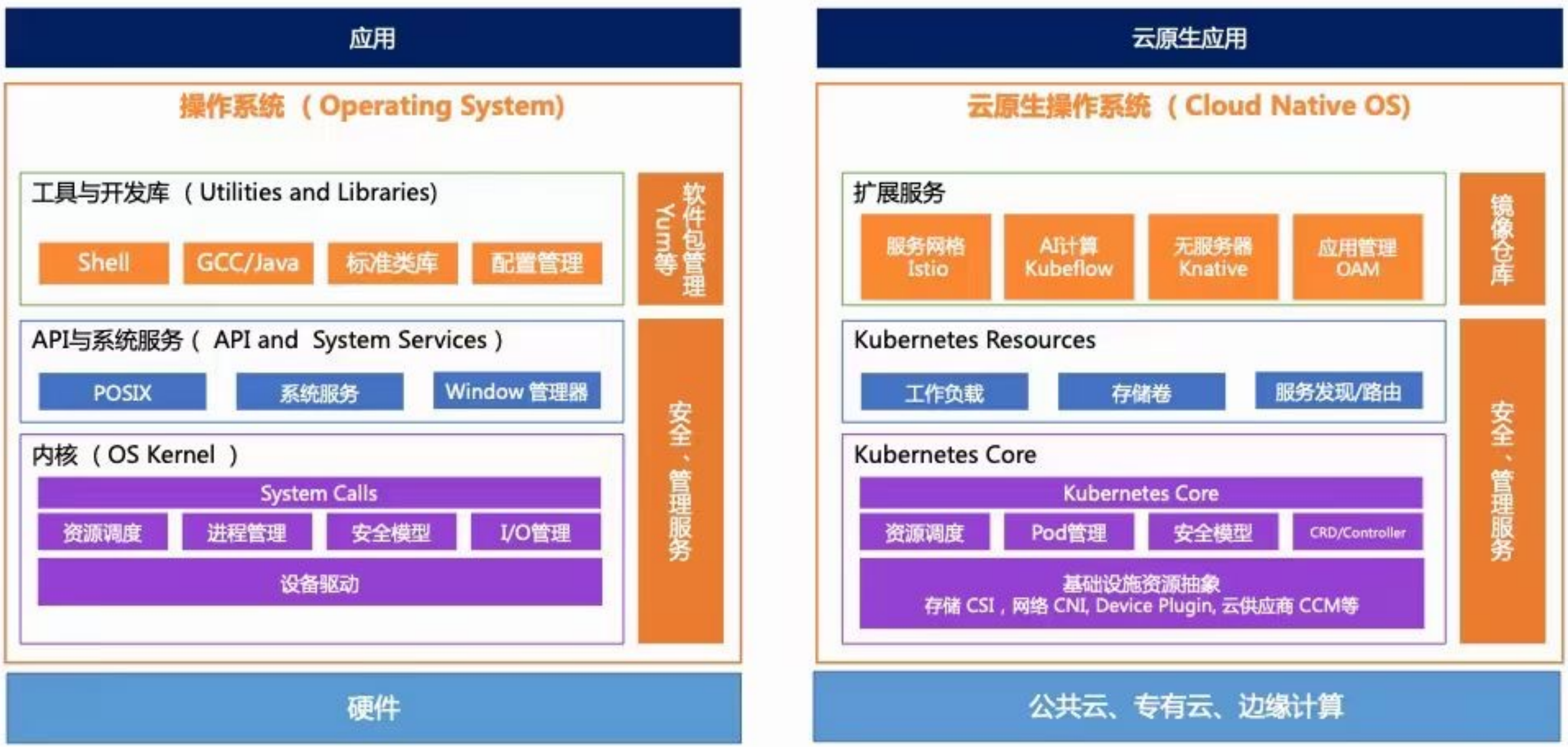
- docker镜像网站docker hub：https://hub.docker.com/

Kubernetes

- 就在Docker容器技术被炒得热火朝天之时，大家发现，如果想要将Docker应用于具体的业务实现，是存在困难的——编排、管理和调度等各个方面，都不容易。
  - ✓
- 于是，人们迫切需要一套管理系统，对Docker及容器进行更高级更灵活的管理。就在这个时候，K8S出现了（8代表中间八个字母）。

应“云”而生：虚拟化的云原生操作系统

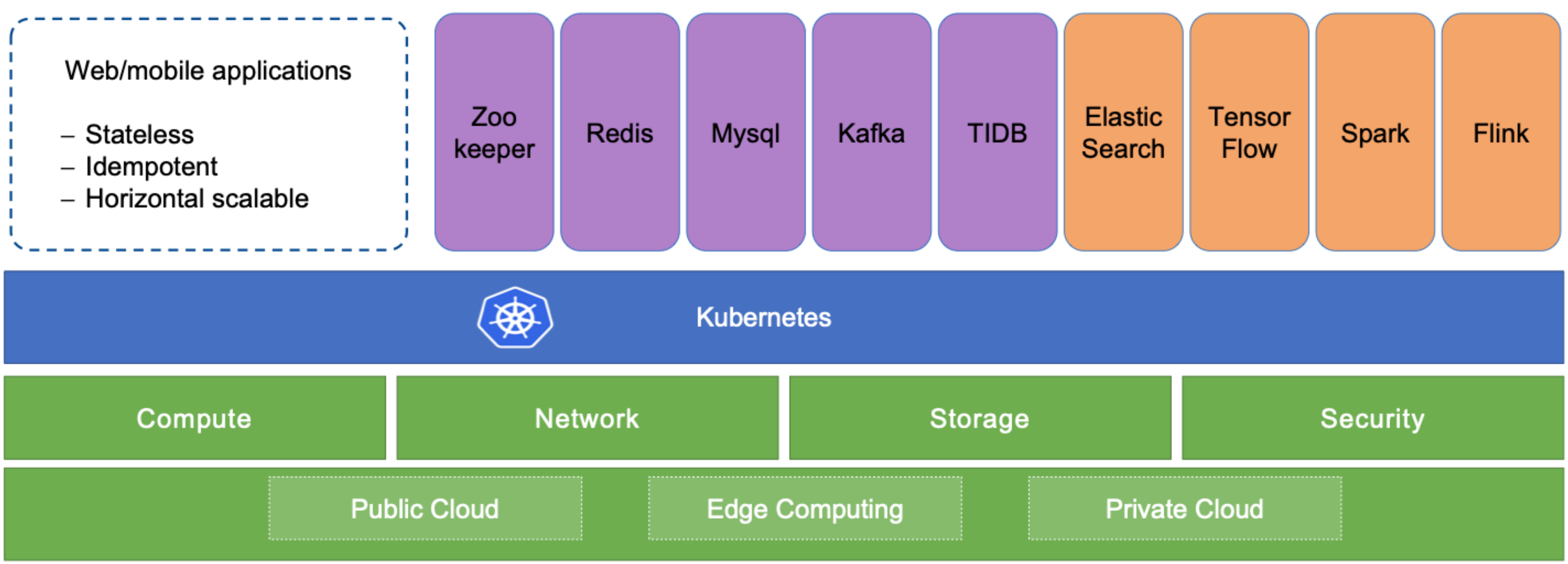
- 2013年Docker**提出应用和依赖整体打包的规范，称为“容器”，远比虚拟机要轻量级化**
- 2016年Google**开放容器编排运维框架**Kubernetes



应“云”而生：虚拟化的云原生操作系统

- Kubernetes**逐渐演变成云原生操作系统**
- **支撑上层应用：内存数据缓存**Redis，**持久化数据库**Mysql、**持久消息**Kafka，**分布式计算**Spark、**流式数据处理**Flink，**人工智能**TF/Pytorch

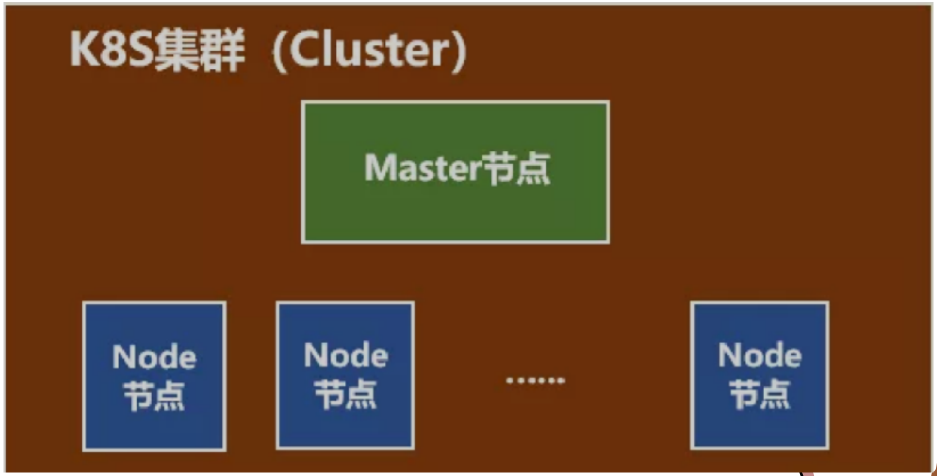
从无状态应用，到企业核心应用，到数据智能应用



Kubernetes

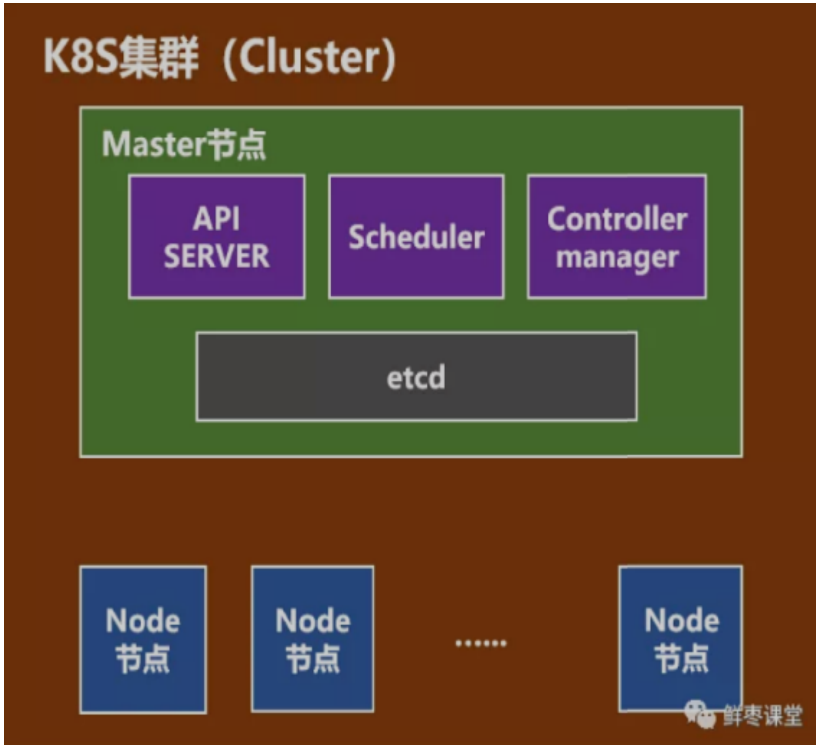
- 一个K8S系统，通常称为一个K8S集群（Cluster）。

- 集群通常有两个部分：
  - 一个Master节点
  - 多个Node节点



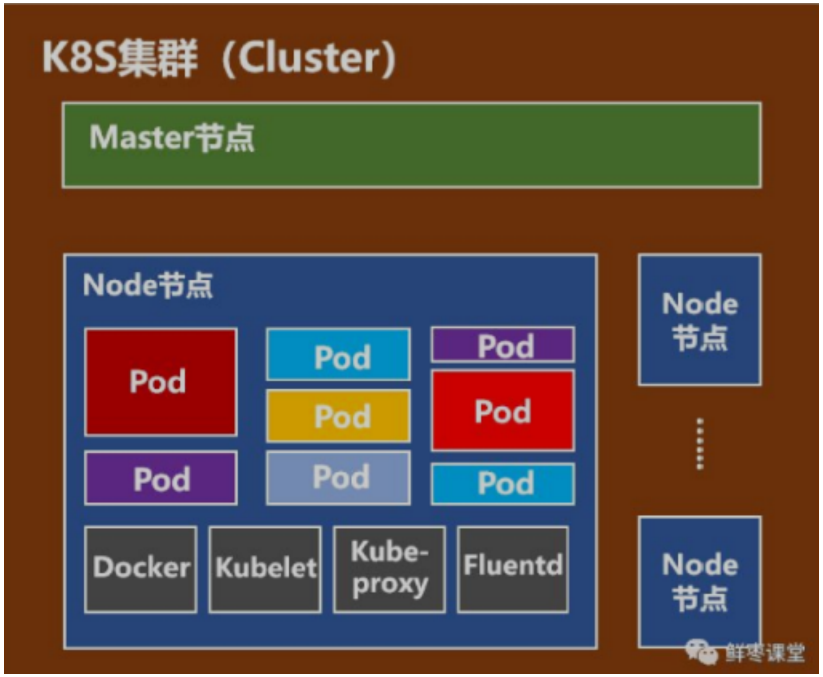
Kubernetes

- Master节点包括
  - API Server 提供对外接口
  - Scheduler 负责集群内部资源调度
  - Controller manager 负责管理控制器



Kubernetes

- Node节点包括
  - Pod：一个Pod代表集群中的一个进程，内部封装了多个容器
  - Docker 创建容器
  - Kubelet：负责监控Pod
  - Kube-proxy：为Pod提供代理
  - Fluentd：日志收集



Java Virtual Machine

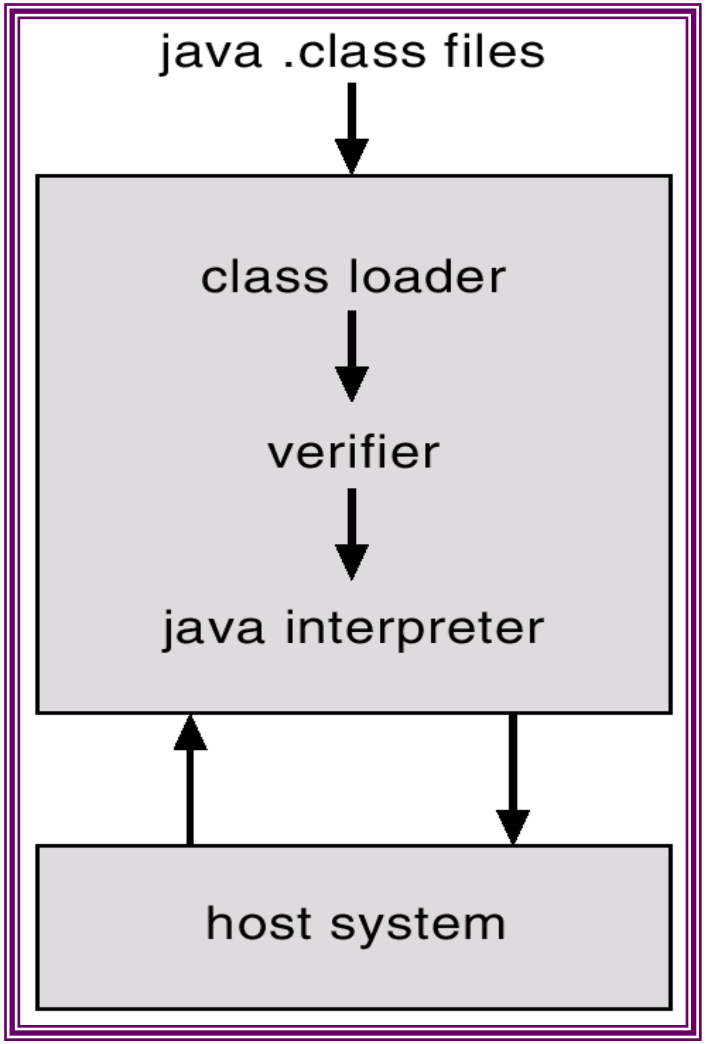
- Compiled Java programs are platform-neutral bytecodes executed by a Java Virtual Machine (JVM).
- JVM consists of

  - class loader

  - class verifier

  - runtime interpreter
- Just-In-Time (JIT) compilers increase performance

Java Virtual Machine



Java Virtual Machine (Cont.)