Lecture 2
OS Basics

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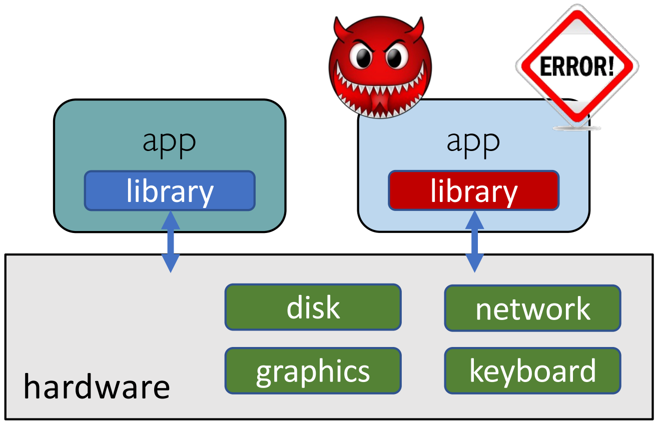
Outline

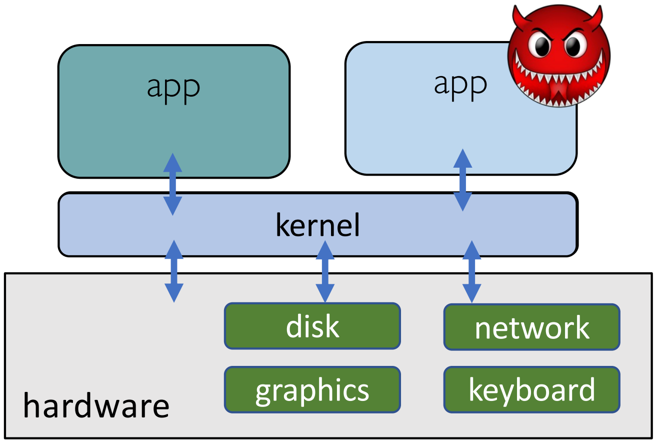
- Dual-mode operations
- Kernel structure
- Operating system services

Dual-mode Operations

Evolution of Operating Systems

- A library to handle low-level I/O
  - Issue: Fault and security isolation
- Kernel: A bigger "library" to handle low-level I/O
  - Kernel needs to be protected from faulty/malicious apps

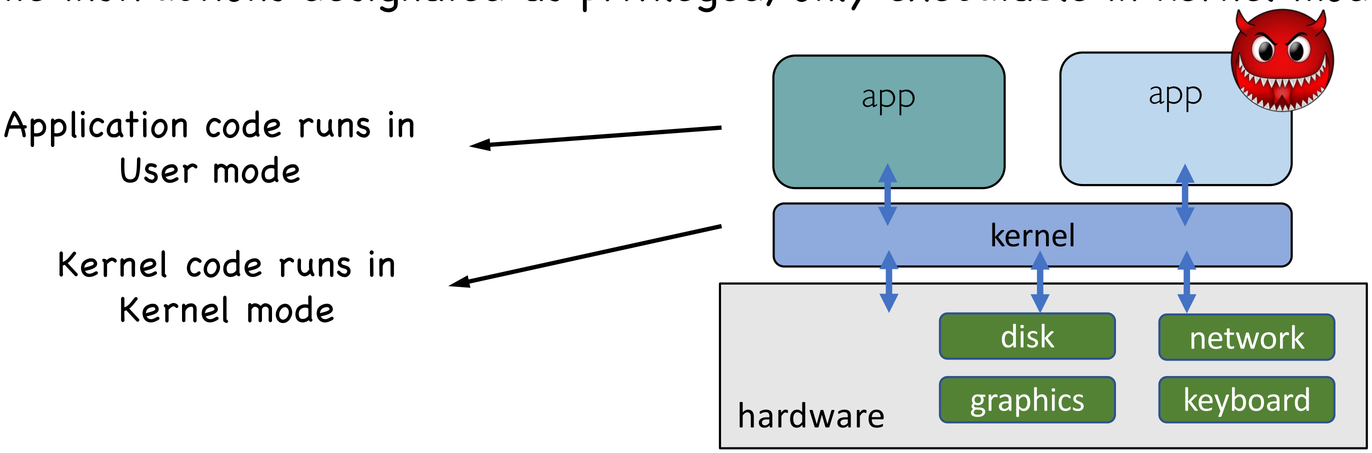




Kernel Mode vs. User Mode

操作系统需要保护自己和硬件资源，防止普通程序随意访问、破坏系统

- Dual-mode operation allows OS to protect itself and other system components
  - Mode bits provided by CPU hardware
    - Provides ability to distinguish when system is running user code or kernel code
    - Some instructions designated as privileged, only executable in kernel mode



Application code runs in User mode

Kernel code runs in Kernel mode

CPU 提供了 双模式 (dual-mode)：

・用户态 (User Mode)：应用程序运行的模式，权限受限。

・内核态 (Kernel Mode)：操作系统内核运行的模式，权限最高，可以直接操作硬件。

普通应用程序（app）运行在 用户态，只能通过调用系统调用 (system call) 请求操作系统服务。

系统调用会触发 从用户态切换到内核态，操作系统帮它执行需要高权限的操作（如访问磁盘、网络、显卡、键盘）。

执行完后再切回用户态，返回应用程序。

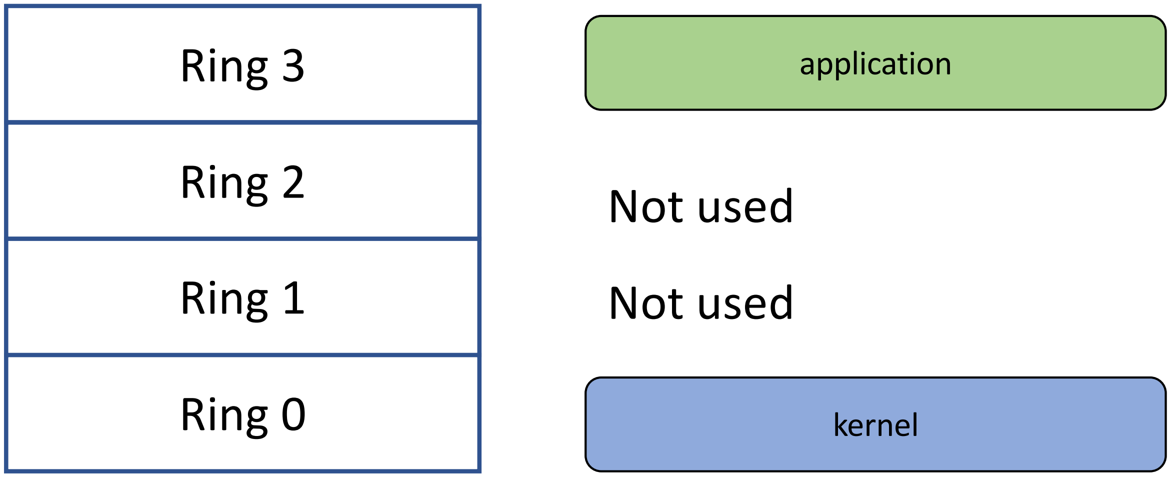
Dual-mode Operation

- Hardware provides at least two modes:
  - “Kernel” mode: Run kernel code
  - “User” mode: Normal programs executed
- What is needed in the hardware to support “dual mode” operation?
  - A bit for representing current mode (user/kernel mode bit)
  - Certain operations / actions only permitted in kernel mode
    - In user mode they fail or trap 某些操作（比如 I/O、修改页表、关/开中断）只能在内核态执行。
  - User → Kernel transition *sets* kernel mode AND saves the user PC
    - Operating system code carefully puts aside user state then performs the necessary operations
  - Kernel → User transition *clears* kernel mode AND restores appropriate user PC 用户态 → 内核态 的切换
    - 当用户程序需要执行特权操作时，会通过 系统调用 (system call) 触发切换。
    - CPU 将模式位切换为内核态，并且 保存用户态的程序计数器 (PC)。
    - 操作系统接管，执行相应的服务（比如访问磁盘）

内核态 → 用户态 的切换

- 内核完成操作后，CPU 清除模式位（回到用户态），恢复保存的用户 PC。
- 程序继续从切换前的位置运行

Mode Bits in CPUs



Ring 3 — application

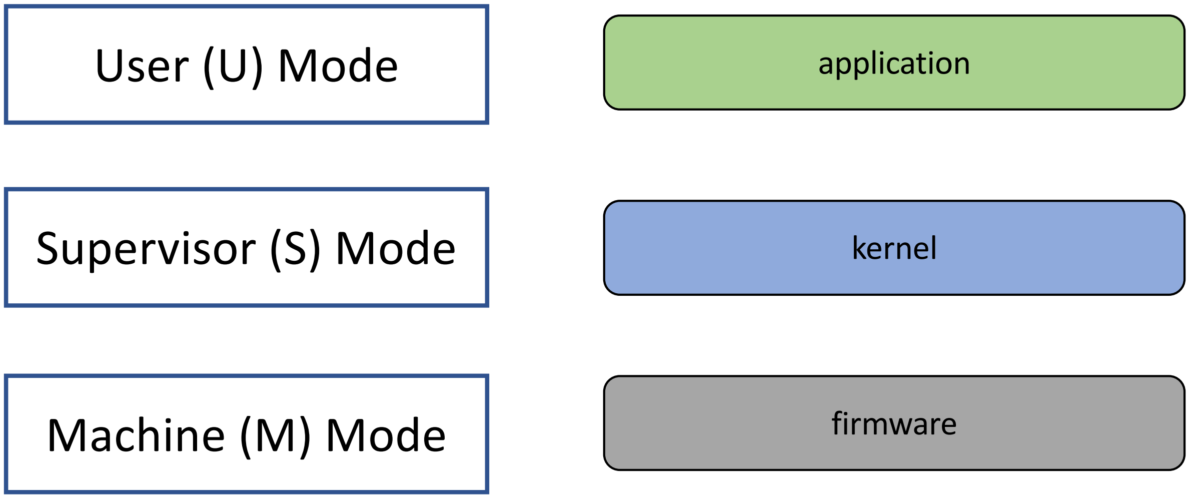
Ring 2 — Not used

Ring 1 — Not used

Ring 0 — kernel

x86
(Intel & AMD)

Mode Bits in CPUs (Cont'd)



User (U) Mode

Supervisor (S) Mode

Machine (M) Mode

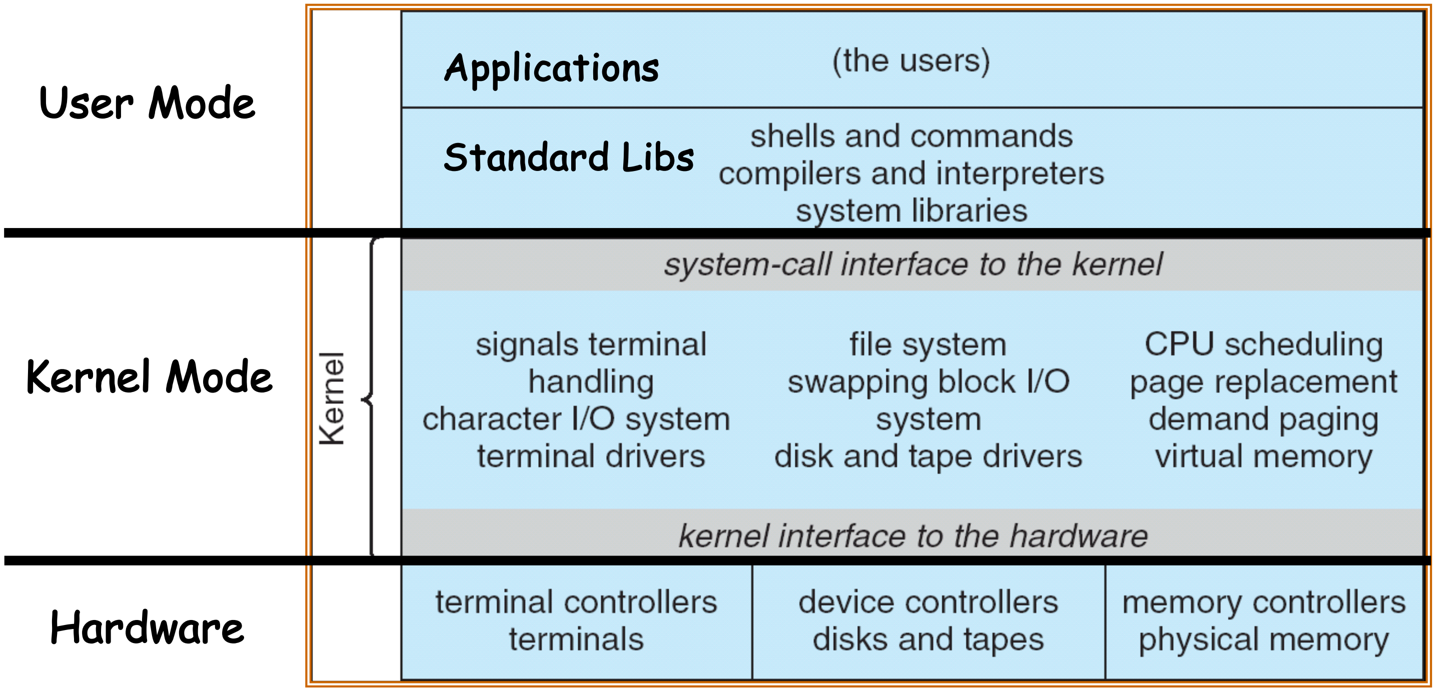
application

kernel

firmware

RISC-V

Unix System Structure



User Mode

Applications (the users)

Standard Libs shells and commands compilers and interpreters system libraries

Kernel Mode

Kernel

system-call interface to the kernel

signals terminal handling character I/O system terminal drivers

file system swapping block I/O system disk and tape drivers

CPU scheduling page replacement demand paging virtual memory

kernel interface to the hardware

Hardware

terminal controllers terminals

device controllers disks and tapes

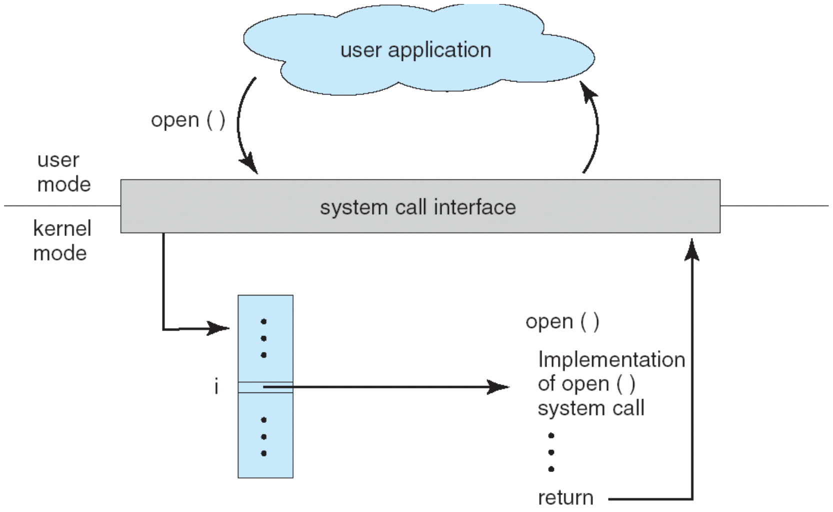
memory controllers physical memory

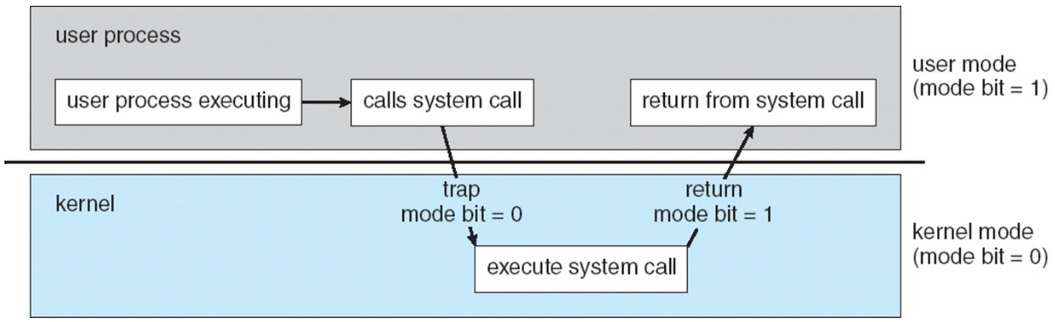
3 types of Mode Transitions

- System call
  - Process requests a system service, e.g., exit
  - Like a function call, but "outside" the process
  - Does not have the address of the system function to call
  - Marshall the syscall id and args in registers and exec syscall
- Interrupt
  - External asynchronous event triggers context switch
  - e. g., Timer, I/O device
  - Independent of user process
- Trap or Exception
  - Internal synchronous event in process triggers context switch
  - e.g., Protection violation (segmentation fault), Divide by zero, …

System Calls

- Programming interface to the services provided by the OS
- Typically written in a high-level language (C or C++)



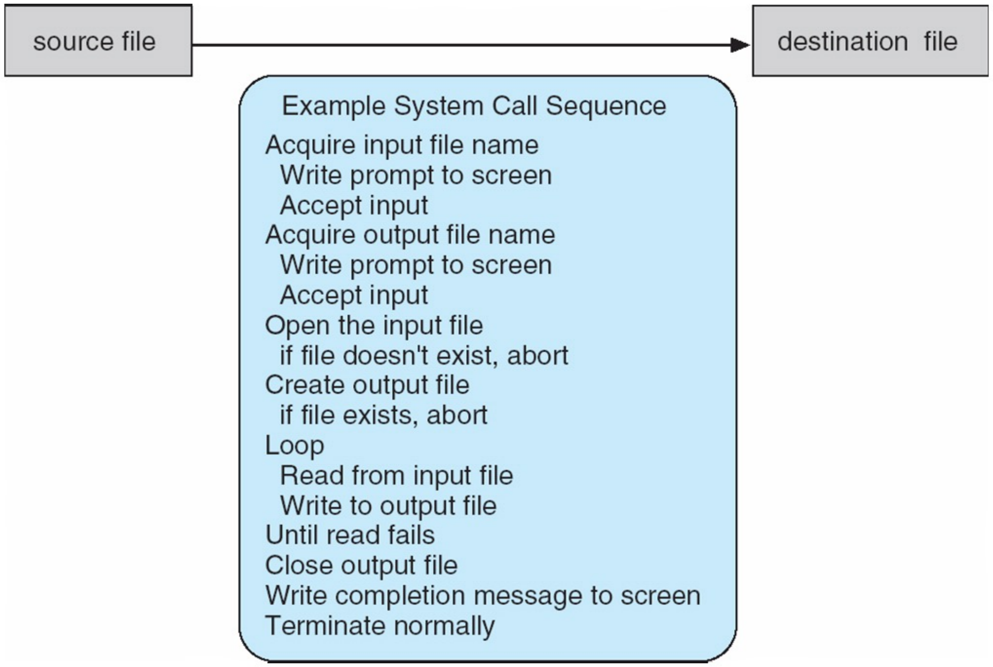


System Call Implementation

- Typically, a number associated with each system call
  - System-call interface maintains a table indexed according to these numbers
- The system call interface invokes intended system call in OS kernel and returns status of the system call and any return values
- The caller needs to know nothing about how the system call is implemented
  - Just needs to obey calling convention and understand what OS will do
  - Most details of OS interface hidden from programmer by library API
    - Managed by run-time support library (set of functions built into libraries included with compiler)

Example of System Calls

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

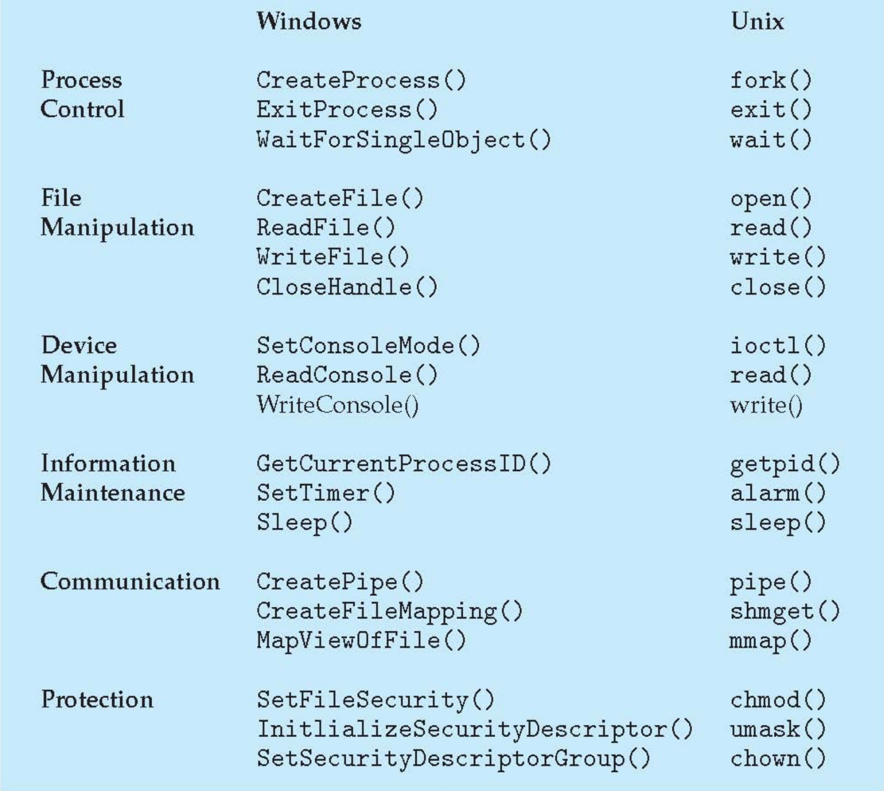


Example System Call Sequence

```
Acquire input file name
  Write prompt to screen
  Accept input
Acquire output file name
  Write prompt to screen
  Accept input
Open the input file
  if file doesn't exist, abort
Create output file
  if file exists, abort
Loop
  Read from input file
  Write to output file
Until read fails
Close output file
Write completion message to screen
Terminate normally
```

Types of System Calls

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



	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()

Exception and Interrupt

和代码有关，每次都会在同样的地方exception

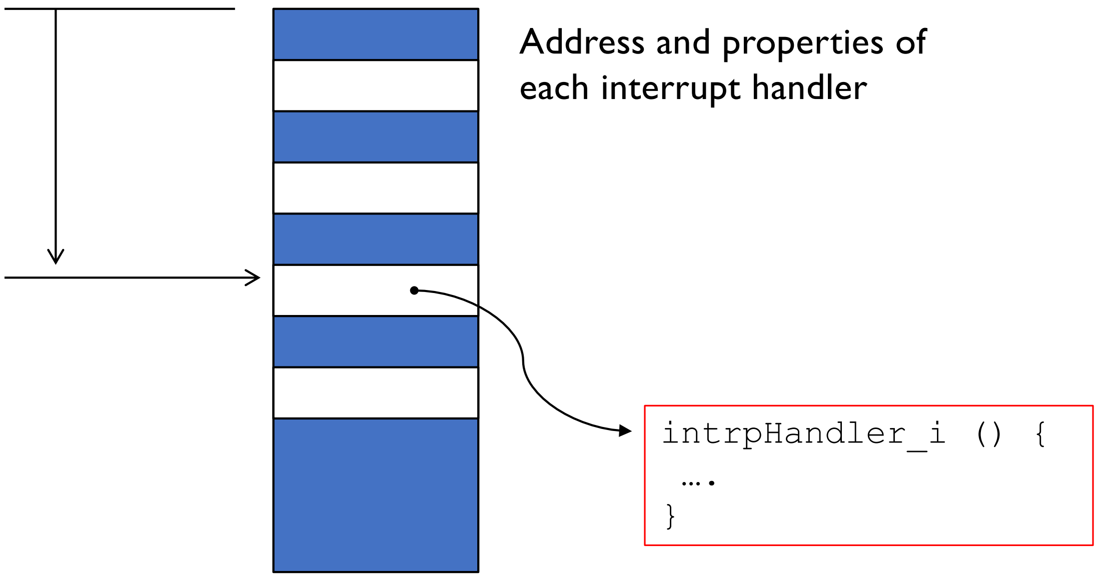
- Exceptions (synchronous) react to an abnormal condition
  - E.g., Map the swapped-out page back to memory
  - Divide by zero
  - Illegal memory accesses

interrupt和代码没关系，而是和什么时候接收到cpu的指令决定的

- Interrupts (asynchronous) preempt normal execution
  - Notification from device (e.g., new packets, disk I/O completed)
  - Preemptive scheduling (e.g., timer ticks)
  - Notification from another CPU (i.e., Inter-processor Interrupts)

Exception and Interrupt (cont'd)

- Same procedure
  - Stop execution of the current program
  - Start execution of a handler
  - Processor accesses the handler through an entry in the Interrupt Descriptor Table (IDT)
  - Each interrupt is defined by a number



Address and properties of each interrupt handler

```
intrpHandler_i () {
 ….
}
```

Kernel Structures

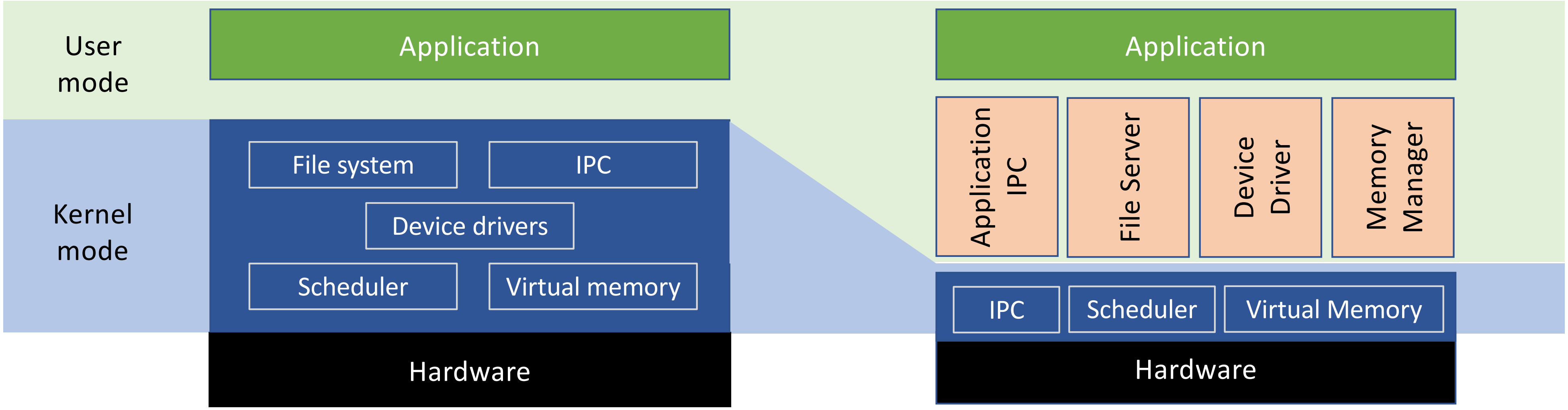
宏内核

Monolithic Kernel

- A monolithic kernel is an operating system software framework that holds all privileges to access I/O devices, memory, hardware interrupts and the CPU stack.
- Monolithic kernels contain many components, such as memory subsystems and I/O subsystems, and are usually very large
  - Including filesystems, device drivers, etc.
- Monolithic kernel is the basis for Linux, Unix, MS-DOS.

Micro Kernel

- Microkernels outsource the traditional operating system functionality to ordinary user processes for better flexibility, security, and fault tolerance.



Micro Kernel (Cont'd)

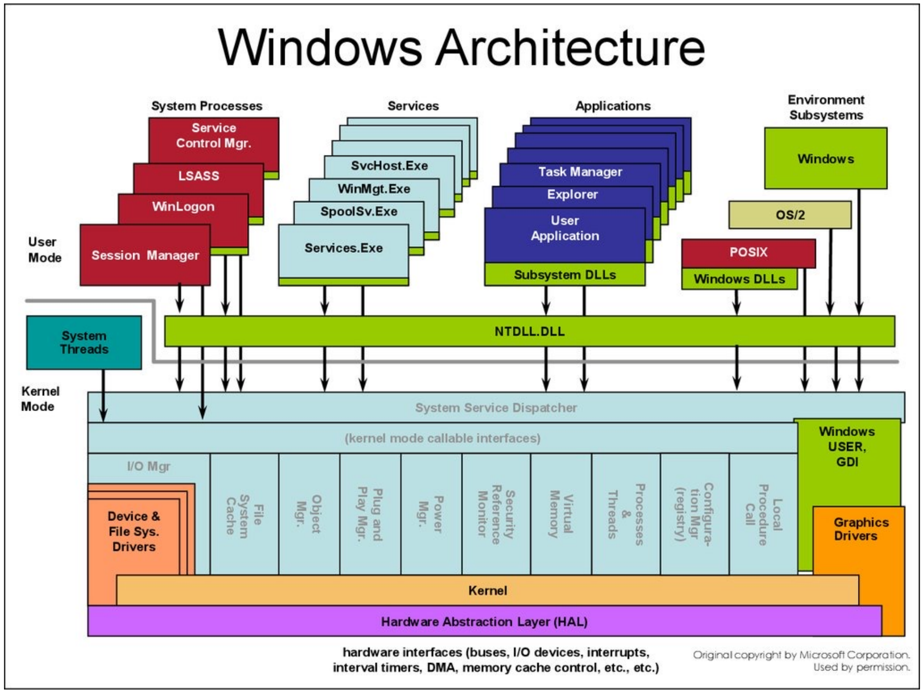
- OS functionalities are pushed to user-level servers (e.g., user-level memory manager)
- User-level servers are trusted by the kernel (often run as root)
- Protection mechanisms stay in kernel while resource management policies go to the user-level servers
- Representative micro-kernel OS
  - Mach, 1980s at CMU
  - seL4, the first formally verified micro-kernel, http://sel4.systems/

Micro Kernel (Cont'd)

- Pros
  - Kernel is more responsive (kernel functions in preemptible user-level processes)
  - Better stability and security (less code in kernel)
  - Better support of concurrency and distributed OS (later…..)
- Cons
  - More IPC needed and thus more context switches (slower)

Hybrid Kernel

- A combination of a monolithic kernel and a micro kernel
  - Example: Windows OS



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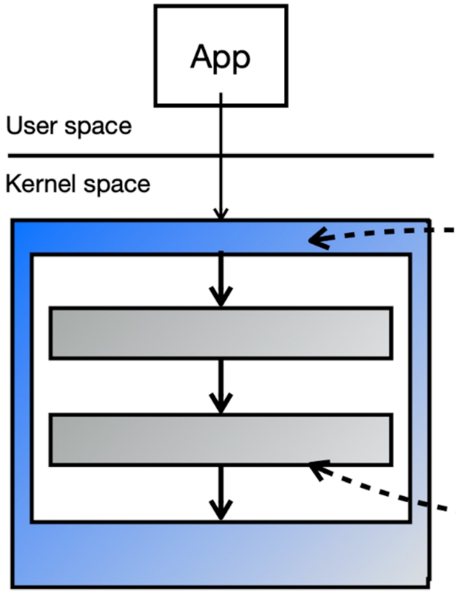
FrameKernel

A framekernel = single address space + safe language + safe/unsafe halves



Framekernel

	Allow unsafe?	Responsibilities	Code Sizes	Memory Safety
Privileged OS Framework	Yes	Encapsulate low-level unsafe code into safe abstractions	Small	Examined by programmers
De-privileged OS Services	No	Implement OS functionalities, including device drivers	Large	Guaranteed by Rust compiler

Asterinas: the First FrameKernel Impl

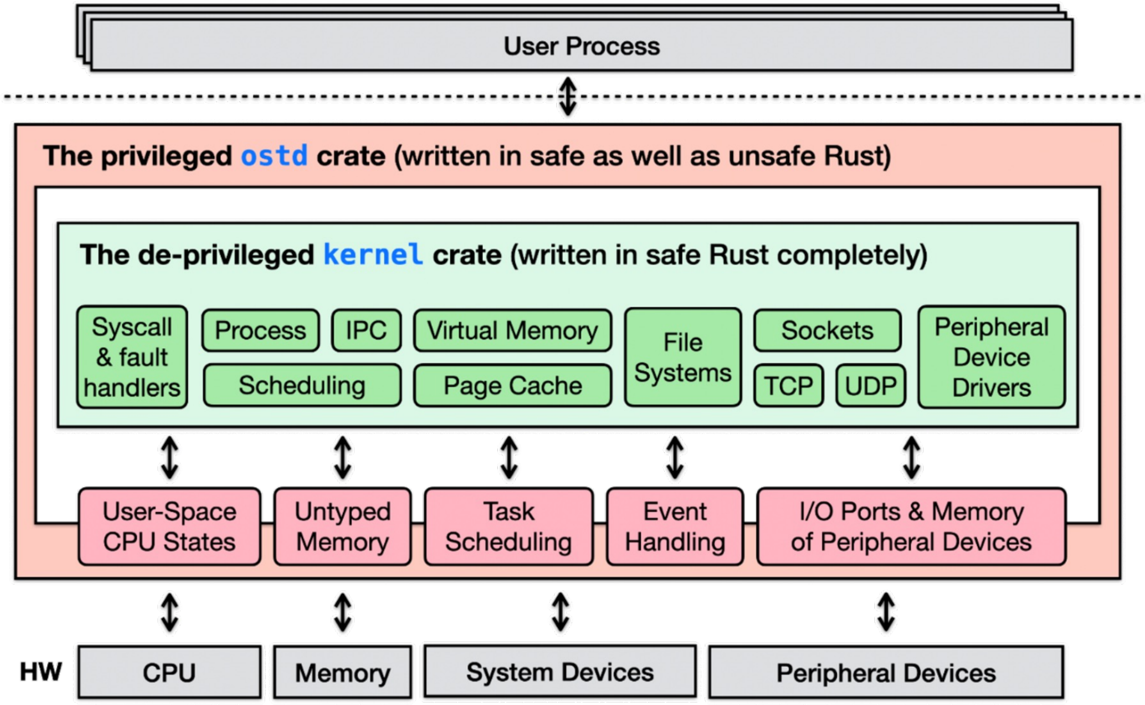
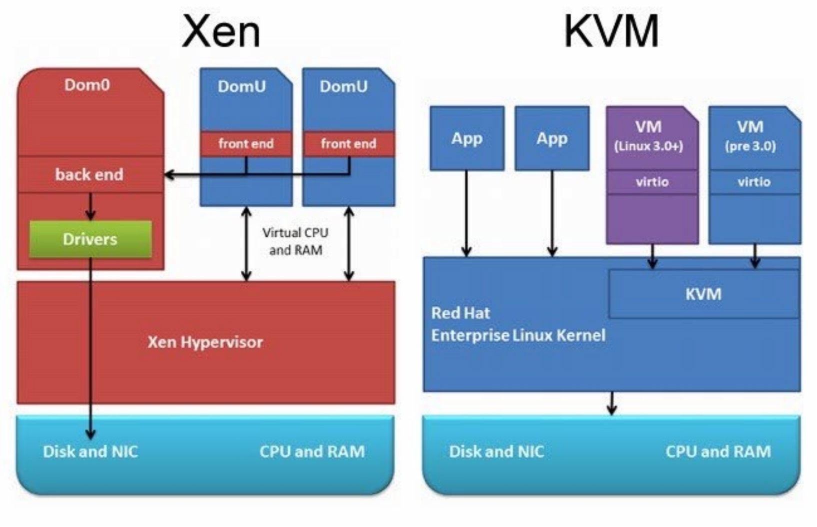


Figure. An overview of Asterinas

- **Feature rich:** >170 Linux system calls implemented with a total of 70K lines of Rust
- **Minimized TCB:** ~20% compared to RedLeaf (~60%) and Theseus (~50%)
- **Open sourced:** https://github.com/asterinas/asterinas

Virtualization and Hypervisors

- Hypervisor (or virtual machine manager/monitor, or VMM) emphasizes on **virtualization** and **isolation**
    - OS can run on hypervisor (almost) without modification
    - Resource partition among VMs
    - Micro kernel can sometimes be used to implement hypervisors



OS Design Principles

- Internal structure of different Operating Systems can vary widely
    - Start by defining goals and specifications
    - Affected by choice of hardware, type of system
- User goals and System goals
    - User goals – operating system should be convenient to use, easy to learn, reliable, safe, and fast
    - System goals – operating system should be easy to design, implement, and maintain, as well as flexible, reliable, error-free, and efficient

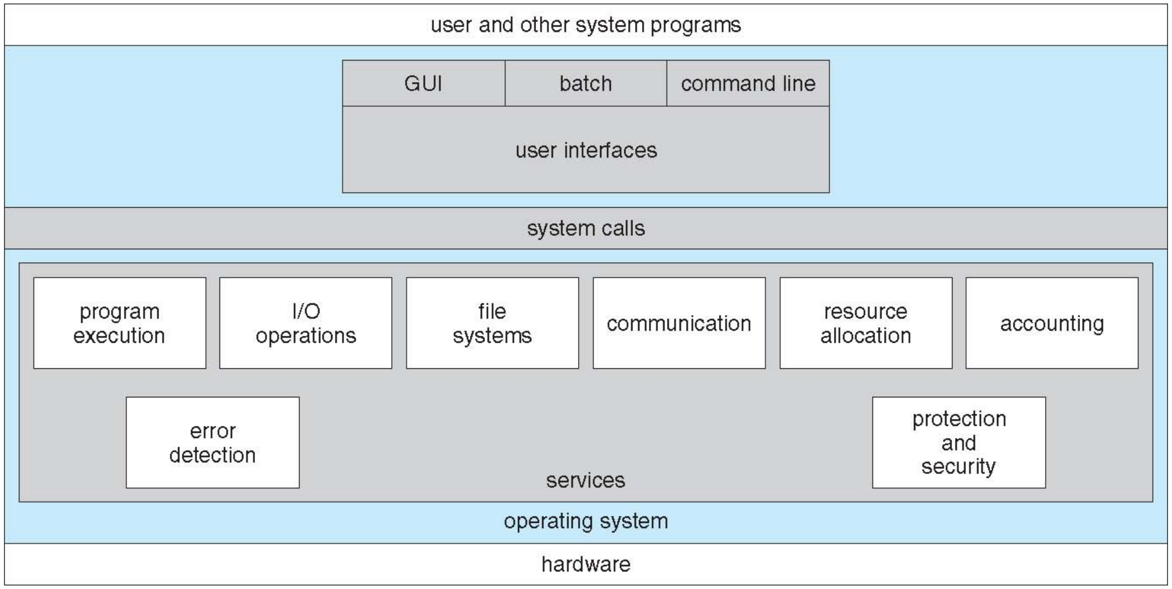
OS Design Principles

- OS separates policies and mechanisms
  - Policy: which software could access which resource at what time
    - E.g., if two processes access the same device at the same time, which one goes first
    - E.g., if a process hopes to read from keyboard
  - Mechanism: How is the policy enforced
    - E.g., request queues for devices, running queues for CPUs
    - E.g., access control list for files, devices, etc.
  - The separation of policy from mechanism is a very important principle, it allows maximum flexibility if policy decisions are to be changed later

Operating System Services

Operating System Services

- Operating system provides a set of services to application programs



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, main memory, and file storage) may have special allocation code, others (such as I/O devices) may have general request and release code
  - **Accounting** - To keep track of which users use how much and what kinds of computer resources
  - **Protection and security** - The owners of information stored in a 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

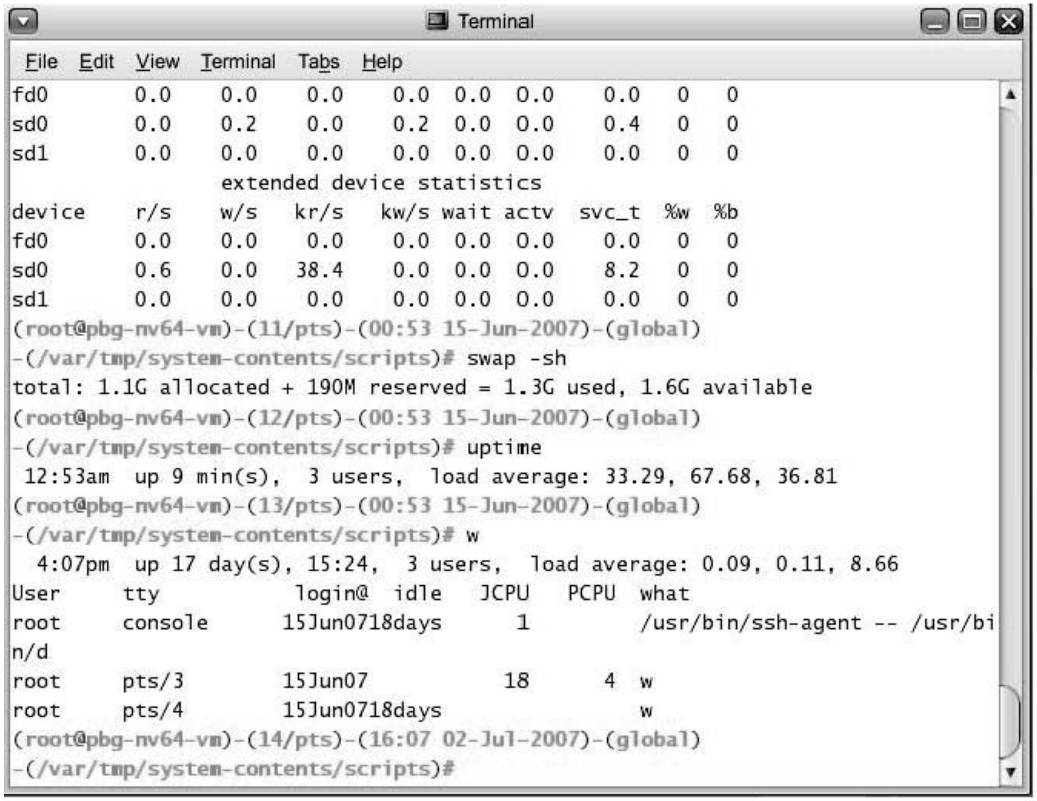
User Operating System Interface - CLI

- Command Line Interface (CLI) or command interpreter allows direct command entry
  - Sometimes implemented in kernel, sometimes by systems program
  - Shells: Bourne shell, C Shell, Bourne-Again Shell, Korn Shell
  - 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

User Operating System Interface - GUI

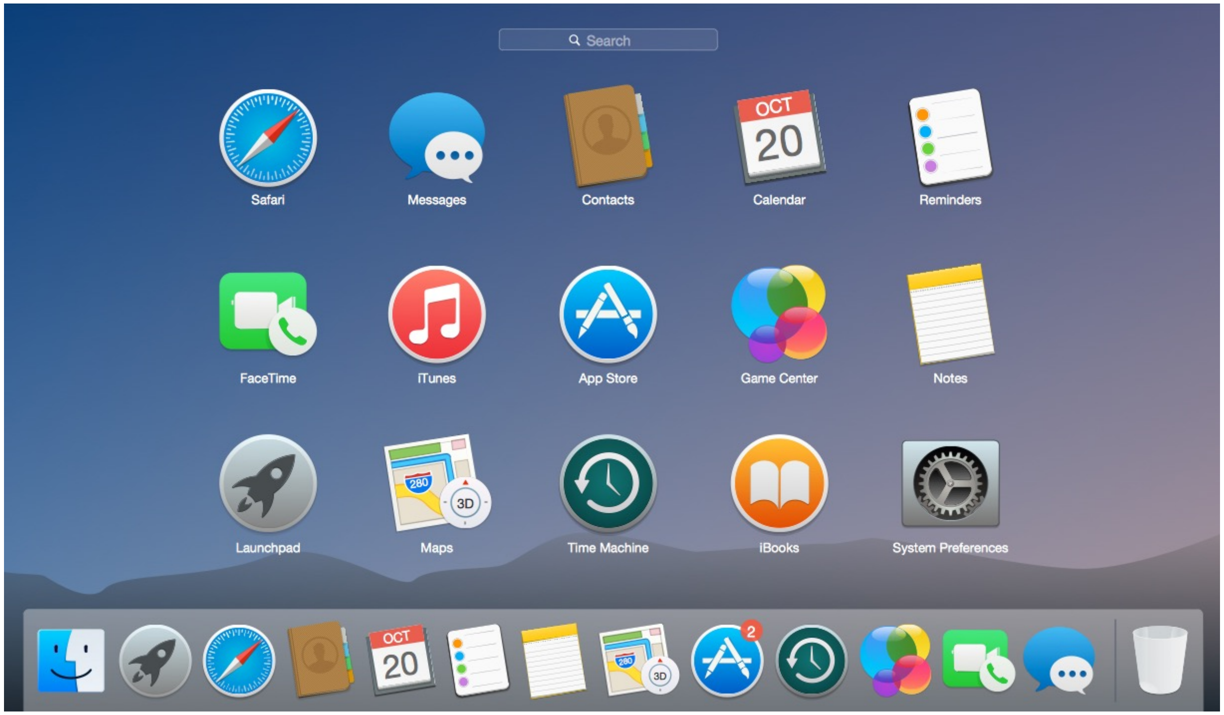
- User-friendly desktop metaphor interface
  - Usually mouse, keyboard, and monitor
  - Icons represent files, programs, actions, etc
  - Various mouse buttons over objects in the interface cause various actions: provide information, options, execute function, open directory (known as a folder)
  - Invented at Xerox PARC
- Many systems now include both CLI and GUI interfaces
  - Microsoft Windows is GUI with CLI “command” shell
  - Apple Mac OS X as “Aqua” GUI interface with UNIX kernel underneath and shells available
  - Solaris is CLI with optional GUI interfaces (Java Desktop, KDE)

Bourne Shell Command Interpreter



```
fd0       0.0    0.0    0.0    0.0  0.0  0.0    0.0   0   0
sd0       0.0    0.2    0.0    0.2  0.0  0.0    0.4   0   0
sd1       0.0    0.0    0.0    0.0  0.0  0.0    0.0   0   0
                 extended device statistics
device    r/s    w/s   kr/s   kw/s wait actv  svc_t  %w  %b
fd0       0.0    0.0    0.0    0.0  0.0  0.0    0.0   0   0
sd0       0.6    0.0   38.4    0.0  0.0  0.0    8.2   0   0
sd1       0.0    0.0    0.0    0.0  0.0  0.0    0.0   0   0
(root@pbg-nv64-vm)-(11/pts)-(00:53 15-Jun-2007)-(global)
-(/var/tmp/system-contents/scripts)# swap -sh
total: 1.1G allocated + 190M reserved = 1.3G used, 1.6G available
(root@pbg-nv64-vm)-(12/pts)-(00:53 15-Jun-2007)-(global)
-(/var/tmp/system-contents/scripts)# uptime
 12:53am  up 9 min(s),  3 users,  load average: 33.29, 67.68, 36.81
(root@pbg-nv64-vm)-(13/pts)-(00:53 15-Jun-2007)-(global)
-(/var/tmp/system-contents/scripts)# w
  4:07pm  up 17 day(s), 15:24,  3 users,  load average: 0.09, 0.11, 8.66
User     tty           login@  idle   JCPU   PCPU  what
root     console      15Jun0718days      1         /usr/bin/ssh-agent -- /usr/bi
n/d
root     pts/3        15Jun07           18      4  w
root     pts/4        15Jun0718days                w
(root@pbg-nv64-vm)-(14/pts)-(16:07 02-Jul-2007)-(global)
-(/var/tmp/system-contents/scripts)#
```

The Mac OS X GUI



System Programs

- System programs provide a convenient environment for program development and execution. They can be divided into:
  - File manipulation
  - Status information
  - File modification
  - Programming language support
  - Program loading and execution
  - Communications
  - Application programs
- Most users' view of the operation system is defined by system programs

System Programs (cont'd)

- Provide a convenient environment for program development and execution
  - Some of them are simply user interfaces to system calls; others are considerably more complex
- File management - Create, delete, copy, rename, print, dump, list, and generally manipulate files and directories
- Status information
  - Some ask the system for info - date, time, amount of available memory, disk space, number of users
  - Others provide detailed performance, logging, and debugging information
  - Typically, these programs format and print the output to the terminal or other output devices
  - Some systems implement a registry - used to store and retrieve configuration information

System Programs (cont'd)

- File modification
  - Text editors to create and modify files
  - Special commands to search contents of files or perform transformations of the text
- Programming-language support - Compilers, assemblers, debuggers and interpreters sometimes provided
- Program loading and execution
- Communications - Provide the mechanism for creating virtual connections among processes, users, and computer systems
  - Allow users to send messages to one another's screens, browse web pages, send electronic-mail messages, log in remotely, transfer files from one machine to another

Thank you!