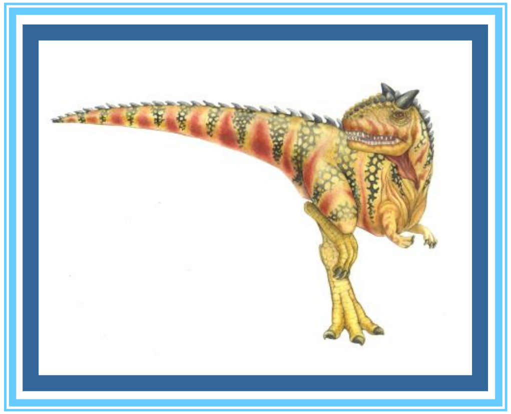
Chapter 2: Operating-System Services



Objectives

- Identify services provided by an operating system
- Illustrate how system calls are used to provide operating system services
- Compare and contrast monolithic, layered, microkernel, modular, and hybrid strategies for designing operating systems
- Apply tools for monitoring operating system performance
- Design and implement kernel modules for interacting with a Linux kernel

Operating System Services

- Operating systems provide an environment for execution of programs and services to programs and users
- One set of operating-system services provides functions that are helpful to the user:
  - **User interface** - Almost all operating systems have a user interface (**UI**).
    - Varies between **Command-Line** (**CLI**), **Graphics User Interface** (**GUI**), **touch-screen**, **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. Programs need to read and write files and directories, create and delete them, search them, list file Information, permission management.

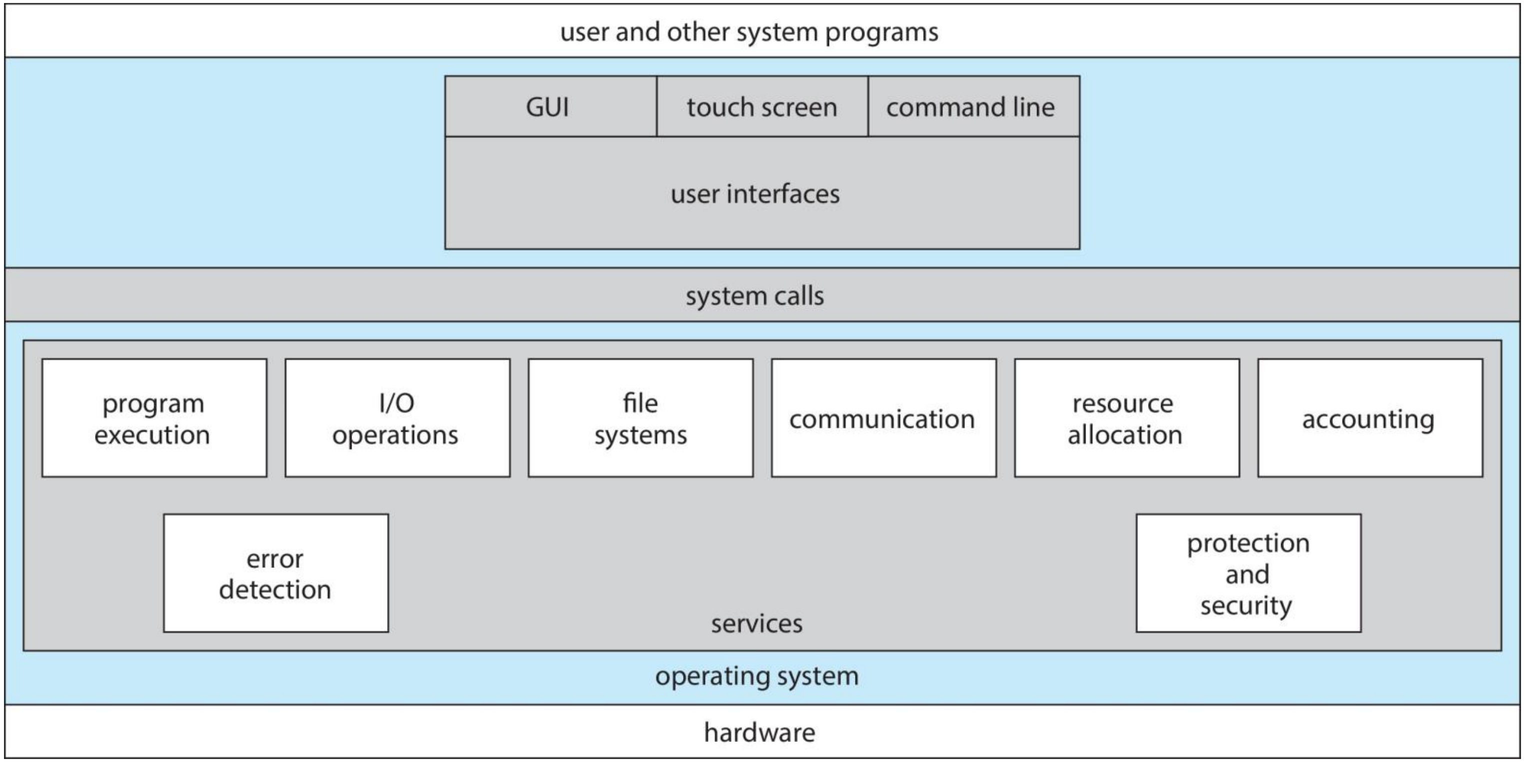
Operating System Services (Cont.)

- 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.)

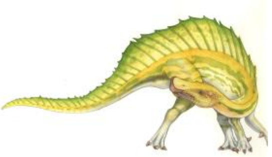
- Another set of OS functions exists for ensuring the efficient operation of the system itself via resource sharing
  - **Resource allocation -** When multiple users or multiple jobs running concurrently, resources must be allocated to each of them
    - Many types of resources -   CPU cycles, main memory, file storage, I/O devices.
  - **Logging -** 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

A View of Operating System Services



Command Line interpreter

- Command interpreter as a special program that is running when a process is initiated or when a user first logs on
  - ***C shell***, ***Bourne-Again (bash) shell***, ***Korn shell***
- CLI allows direct command entry
- Sometimes implemented in kernel, sometimes by systems program
- Sometimes multiple flavors implemented – **shells**
- Primarily fetches a command from user and executes it
- Sometimes commands built-in, sometimes just names of programs
  - If the latter, adding new features doesn't require shell modification

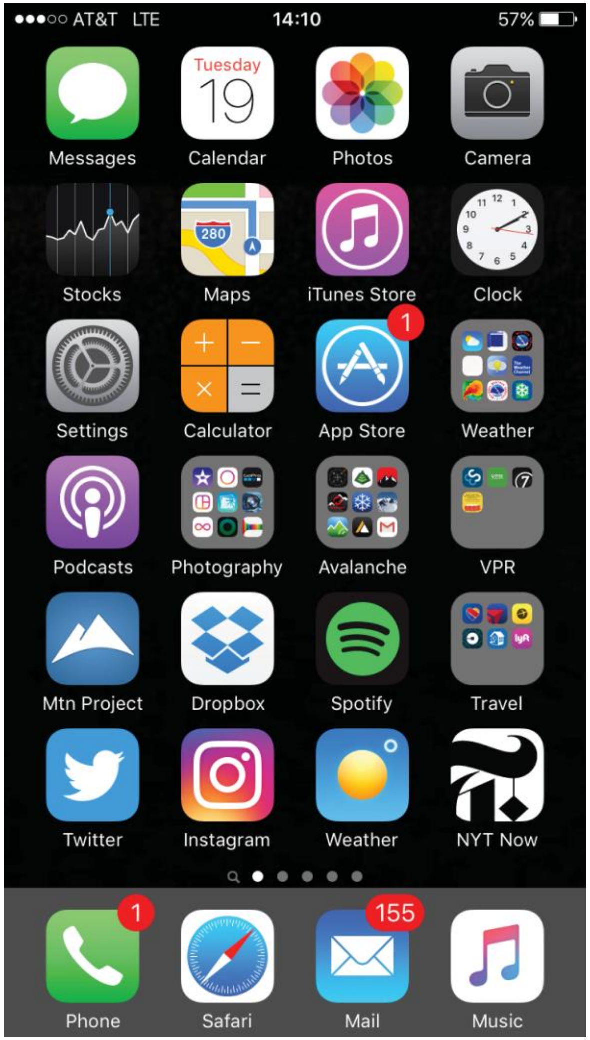


User Operating System Interface - GUI

- 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 i.e., **folder**)
  - Invented at Xerox PARC
- Many systems now include both CLI and GUI interfaces (Why??)
  - Microsoft Windows is GUI with CLI “command” shell
  - Apple Mac OS X is “Aqua” GUI interface with UNIX kernel underneath and shells available
  - Unix and Linux have CLI with optional GUI interfaces (CDE, KDE, GNOME)

Touchscreen Interfaces

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

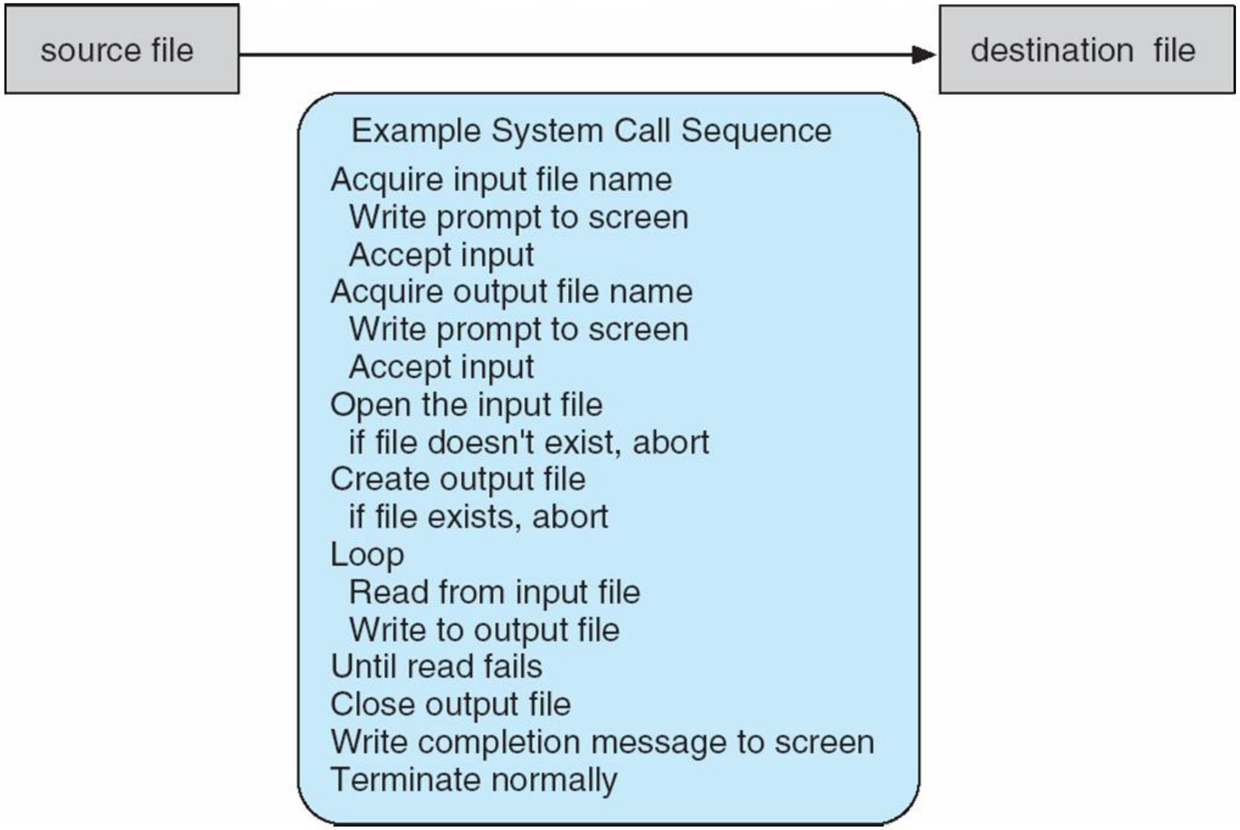


System Calls

- Programming interface to the services provided by the OS
- Typically written in a high-level language (C or C++)
  - certain low-level tasks may be written using assembly-language instructions
- Mostly accessed by programs via a high-level **Application Programming Interface** (**API**) rather than direct system call use
- Three most common APIs are Win32 API for Windows, POSIX API for POSIX-based systems (including virtually all versions of UNIX, Linux, and Mac OS X), and Java API for the Java virtual machine (JVM)

Example of System Calls

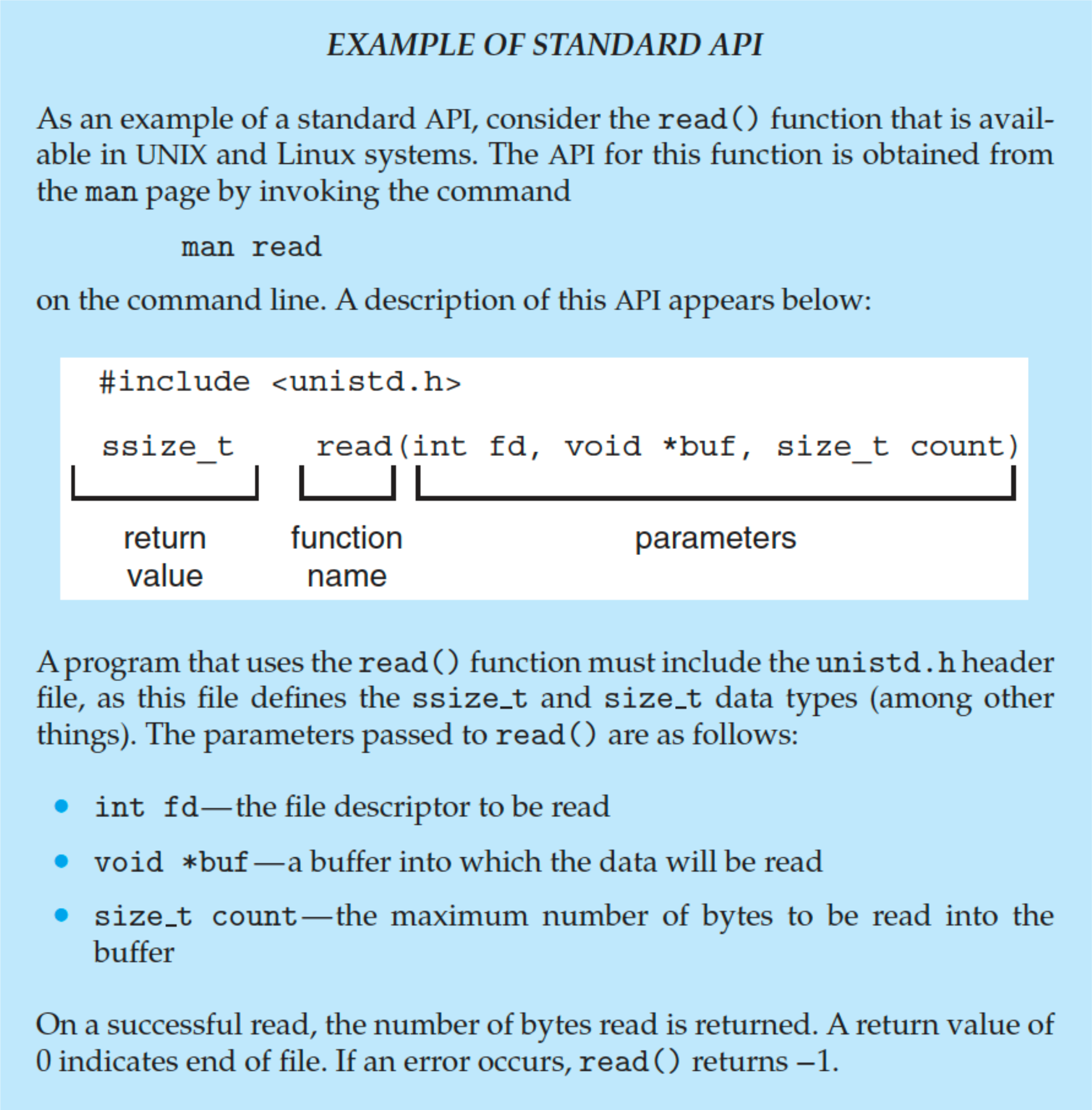
- System call sequence to copy the contents of one file to another file
- cp in.txt out.txt



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
```

Example of Standard API



EXAMPLE OF STANDARD API

As an example of a standard API, consider the `read()` function that is available in UNIX and Linux systems. The API for this function is obtained from the `man` page by invoking the command

```
man read
```

on the command line. A description of this API appears below:

```
#include <unistd.h>

ssize_t     read(int fd, void *buf, size_t count)
```

return value

function name

parameters

A program that uses the `read()` function must include the `unistd.h` header file, as this file defines the `ssize_t` and `size_t` data types (among other things). The parameters passed to `read()` are as follows:

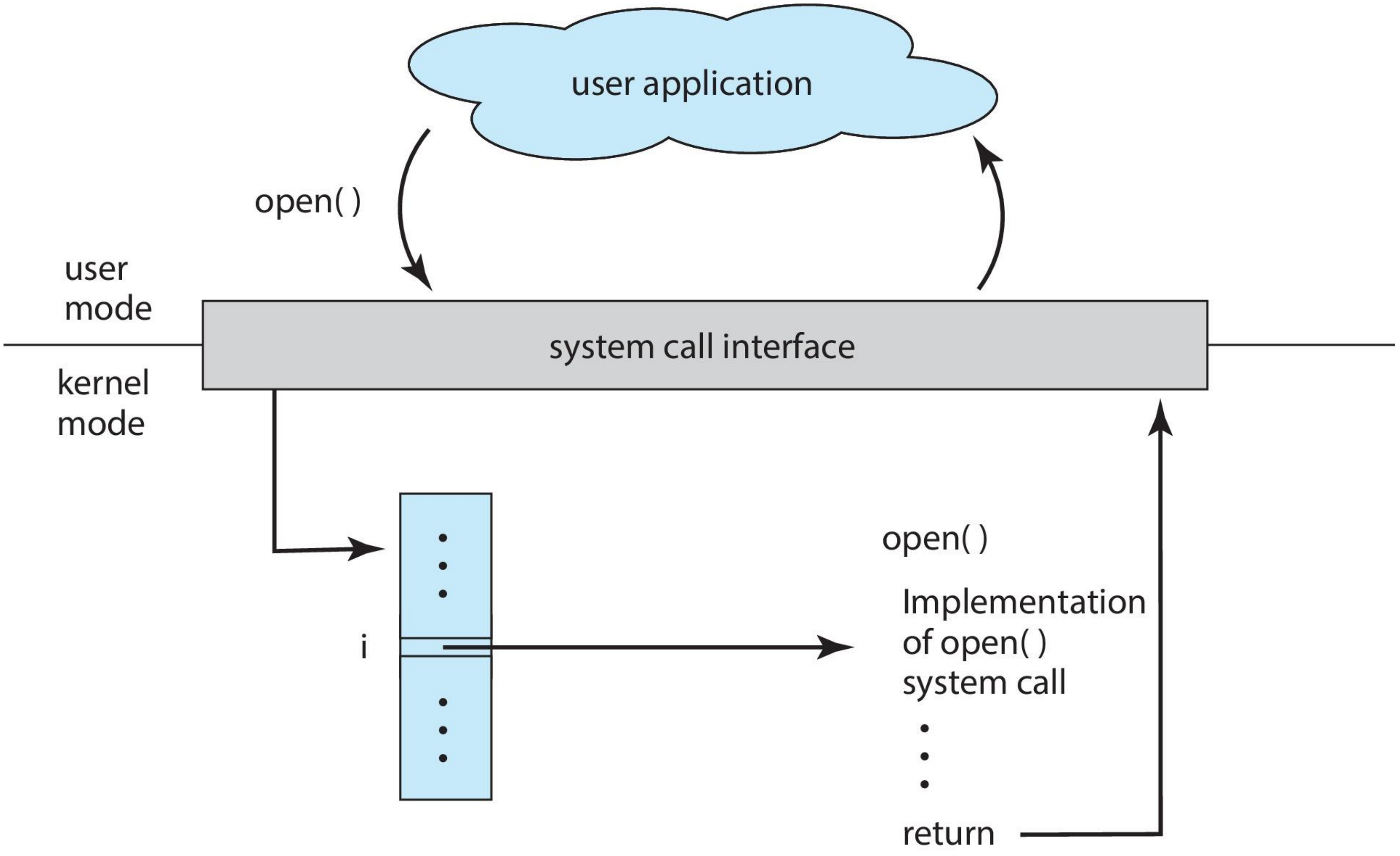
- `int fd`—the file descriptor to be read
- `void *buf`—a buffer into which the data will be read
- `size_t count`—the maximum number of bytes to be read into the buffer

On a successful read, the number of bytes read is returned. A return value of 0 indicates end of file. If an error occurs, `read()` returns −1.

System Call Implementation

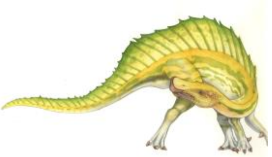
- Typically, a number is associated with each system call
  - **System-call interface** maintains a table indexed according to these numbers
- The system call interface invokes the intended system call in OS kernel and returns status of the system call and any return values
- The caller need know nothing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

API – System Call – OS Relationship

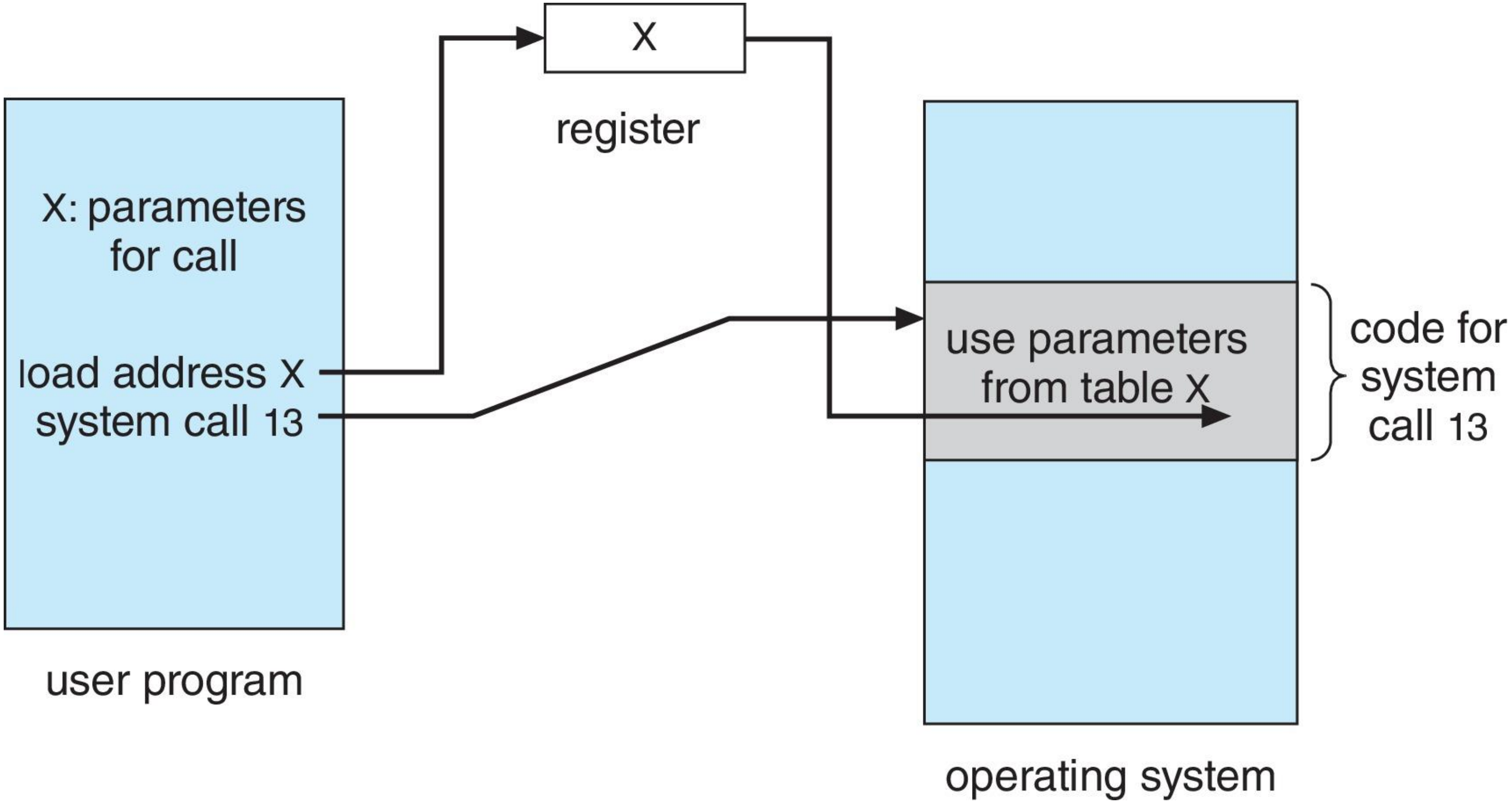


System Call Parameter Passing

- Often, more information is required than simply identity of desired system call
  - Exact type and amount of information vary according to OS and call
- Why parameter passing?
- Three general methods used to pass parameters to the OS
  - Simplest: pass the parameters in registers
    - In some cases, may be more parameters than registers
  - Parameters stored in a block, or table, in memory, and address of block passed as a parameter in a register
    - This approach taken by Linux and Solaris
  - Parameters placed, or **pushed**, onto the **stack** by the program and **popped** off the stack by the operating system
  - Block and stack methods do not limit the number or length of parameters being passed



Parameter Passing via Table



Types of System Calls

- Process control
  - create process *create_process()*, terminate process *terminate process()*
  - end, abort
  - load, execute
  - get process attributes, set process attributes
  - wait for time
  - wait event, signal event
  - allocate and free memory

Types of System Calls (Cont.)

- File management
  - create file, delete file
  - open, close file
  - read, write, reposition
  - get and set file attributes
- Device management
  - request device, release device
  - read, write, reposition
  - get device attributes, set device attributes
  - logically attach or detach devices

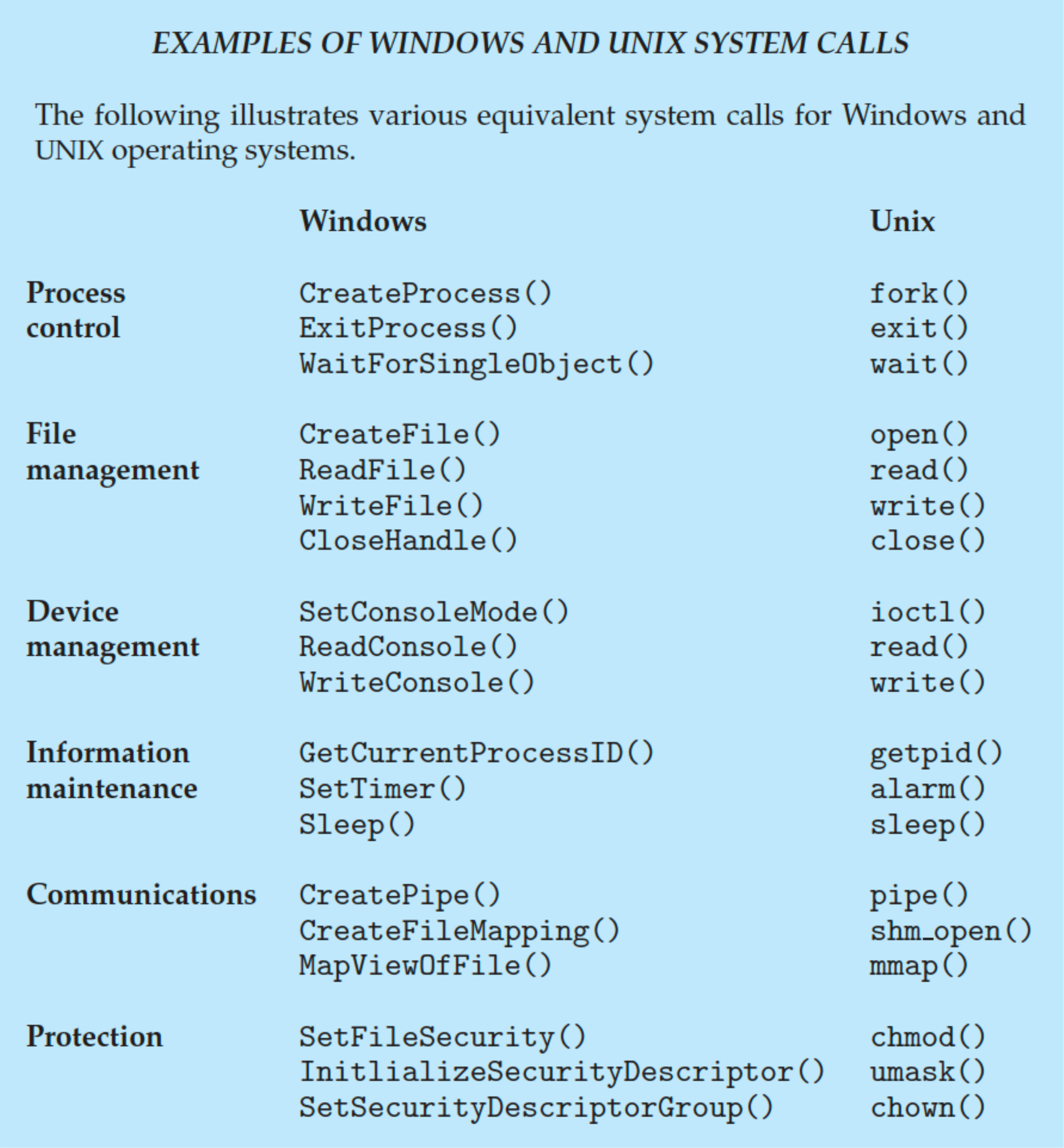
Types of System Calls (Cont.)

- Information maintenance
  - get time or date, set time or date
  - get system data, set system data
  - get and set process, file, or device attributes
- Communications
  - create, delete communication connection
  - send, receive messages if **message passing model**
    - From **client** to **server**
  - **Shared-memory model** create and gain access to memory regions
  - transfer status information
  - attach and detach remote devices

Types of System Calls (Cont.)

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

Examples of Windows and Unix System Calls



EXAMPLES OF WINDOWS AND UNIX SYSTEM CALLS

The following illustrates various equivalent system calls for Windows and UNIX operating systems.

	Windows	**Unix**

Process control	`CreateProcess()`
	`ExitProcess()`
	`WaitForSingleObject()`
		`fork()`
		`exit()`
		`wait()`

File management	`CreateFile()`
	`ReadFile()`
	`WriteFile()`
	`CloseHandle()`
		`open()`
		`read()`
		`write()`
		`close()`

Device management	`SetConsoleMode()`
	`ReadConsole()`
	`WriteConsole()`
		`ioctl()`
		`read()`
		`write()`

Information maintenance	`GetCurrentProcessID()`
	`SetTimer()`
	`Sleep()`
		`getpid()`
		`alarm()`
		`sleep()`

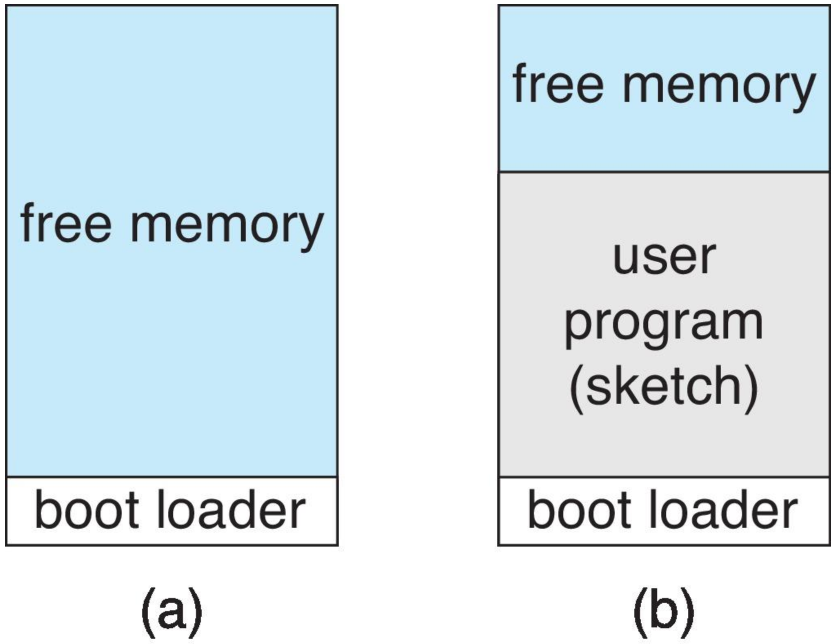
Communications	`CreatePipe()`
	`CreateFileMapping()`
	`MapViewOfFile()`
		`pipe()`
		`shm_open()`
		`mmap()`

Protection	`SetFileSecurity()`
	`InitlializeSecurityDescriptor()`
	`SetSecurityDescriptorGroup()`
		`chmod()`
		`umask()`
		`chown()`

Example: Arduino

- Arduino is a simple hardware platform consisting of a microcontroller along with input sensors that respond to a variety of events.
- the Arduino provides no user interface beyond hardware input sensors.

- Single-tasking
- No operating system
- Boot loader loads program
- Programs (sketch) loaded via USB into flash memory
- Single memory space
- Program exit -> shell reloaded

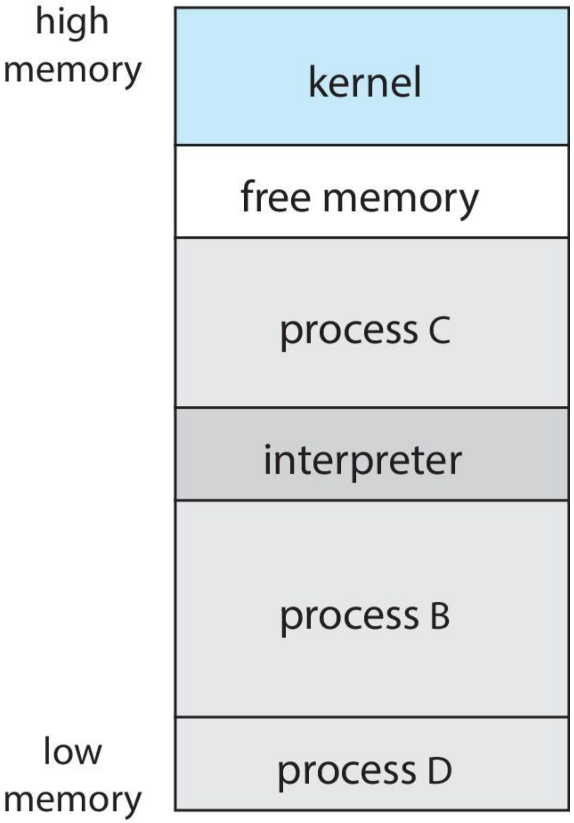


At system startup

running a program

Example: FreeBSD

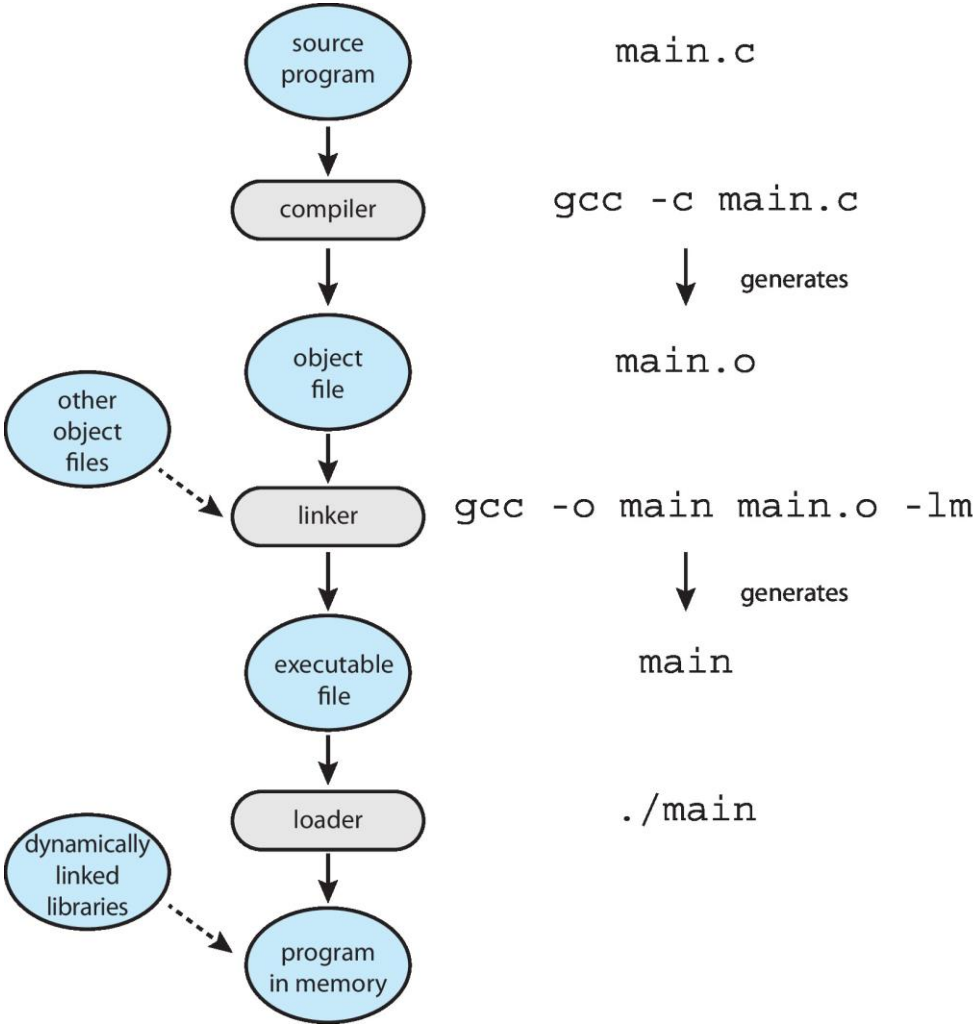
- Unix variant
- Multitasking
- User login -> invoke user's choice of shell
- Shell executes fork() system call to create process
  - Executes exec() to load program into memory
  - Depending on how the command was issued,
    - the shell either waits for the process to finish
    - or runs the process "in the background."
  - Process exits with:
    - code = 0 – no error
    - code > 0 – error code



Linkers and Loaders

- Source code compiled into object files designed to be loaded into any physical memory location – **relocatable object file**
- **Linker** combines these into single binary **executable** file
  - Also brings in libraries
- Program resides on secondary storage as binary executable
- Must be brought into memory by **loader** to be executed
  - **Relocation** assigns final addresses to program parts and adjusts code and data in program to match those addresses
- Modern general purpose systems don’t link libraries into executables
  - Rather, **dynamically linked libraries** (in Windows, **DLLs**) are loaded as needed, shared by all that use the same version of that same library (loaded once)

The Role of the Linker and Loader



```
main.c

gcc -c main.c

main.o

gcc -o main main.o -lm

main

./main
```

Why Applications are Operating System Specific

- Apps compiled on one system usually not executable on other operating systems
- Each operating system provides its own unique system calls
  - Own file formats, etc.
- Apps can be multi-operating system
  - Written in interpreted language like Python, Ruby, and interpreter available on multiple operating systems
  - App written in language that includes a VM containing the running app (like Java)
  - Use standard language (like C), compile separately on each operating system to run on each
- The general lack of application mobility has several causes, all of which still make developing cross-platform applications a challenging task.

Design and Implementation

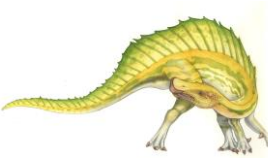
- Design and Implementation of OS is not “solvable”, but some approaches have proven successful
- Internal structure of different Operating Systems can vary widely
- Start the design by defining goals and specifications
- Affected by choice of hardware, type of system
- **User** goals and **System** 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
- Specifying and designing an OS is highly creative task of **software engineering**

Policy and Mechanism

- Important design principle: **Separation of policy from mechanism**
- **Policy**: **What** needs to be done?
  - Example: Interrupt after every 100 seconds
- **Mechanism**: **How** to do something?
  - Example: timer
- The separation of policy from mechanism is a very important principle, it allows maximum flexibility if policy decisions are to be changed later.
  - Example: change 100 to 200

Implementation

- Operating systems are collections of many programs, written by many people over a long period of time
- Much variation
  - Early OSes in assembly language; Now C, C++
- Actually usually a mix of languages; Example Android
  - Kernel is written mostly in C with some assembly language
  - system libraries are written in C or C++
  - application frameworks, which provide the developer interface to the system, are written mostly in Java
- More high-level language (because of interpreter) easier to **port** to other hardware
  - But slower



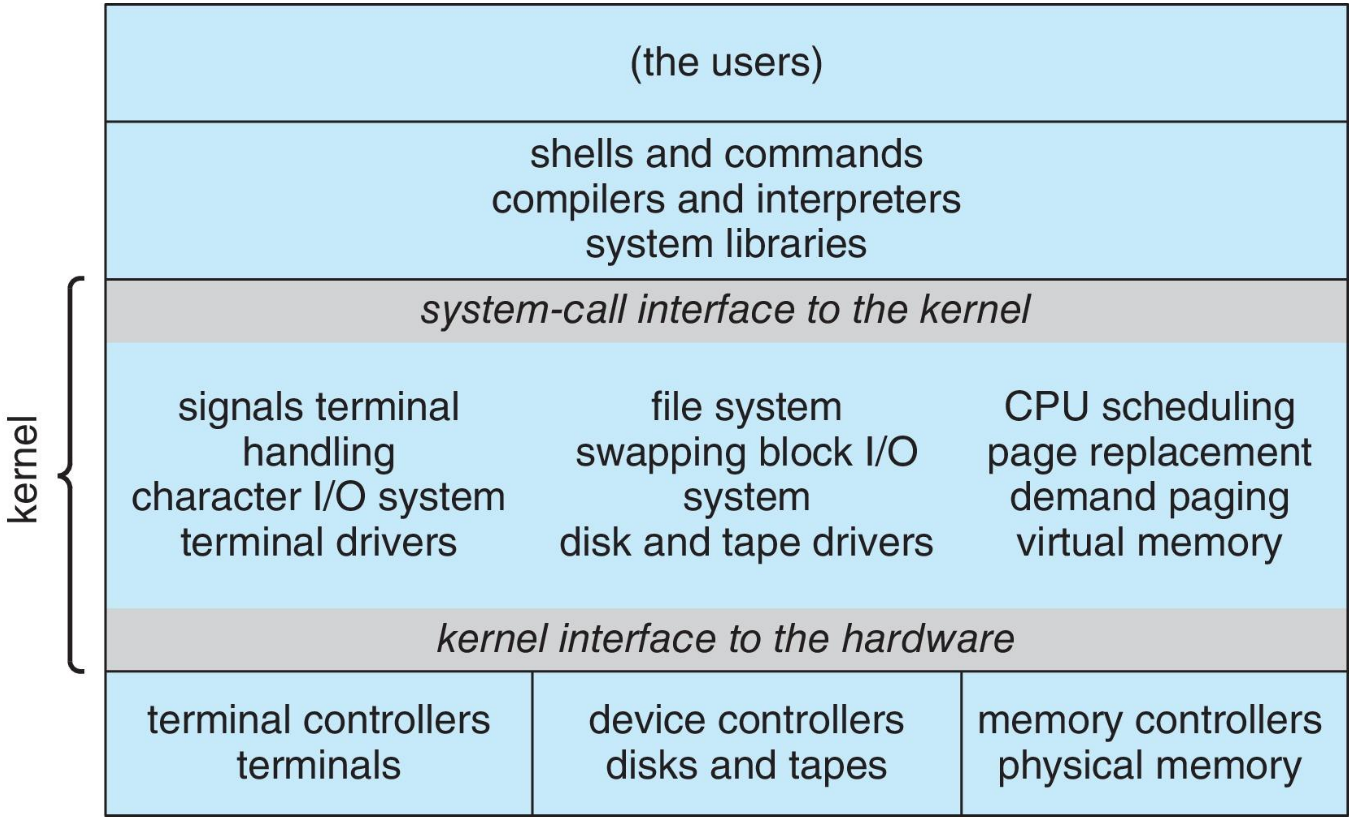
Operating System Structure

Monolithic Structure – Original UNIX

- The simplest structure for organizing an operating system is no structure at all.
  - place all of the functionality of the kernel into a single, static binary file that runs in a single address space. (Any Advantage ??)
- 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

Traditional UNIX System Structure

Beyond simple but not fully layered



(the users)

shells and commands
compilers and interpreters
system libraries

system-call interface to the kernel

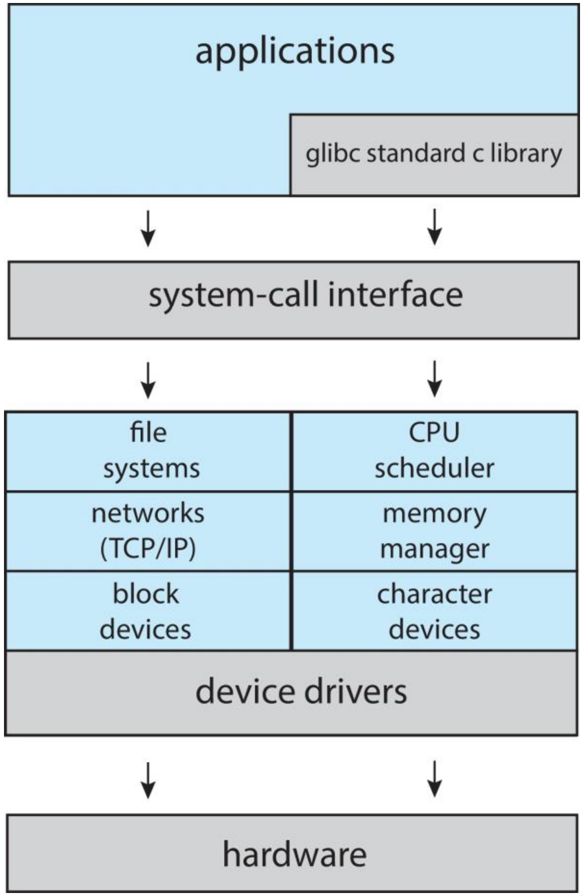
signals terminal handling character I/O system terminal drivers	file system swapping block I/O system disk and tape drivers	CPU scheduling page replacement demand paging virtual memory

kernel interface to the hardware

terminal controllers terminals	device controllers disks and tapes	memory controllers physical memory

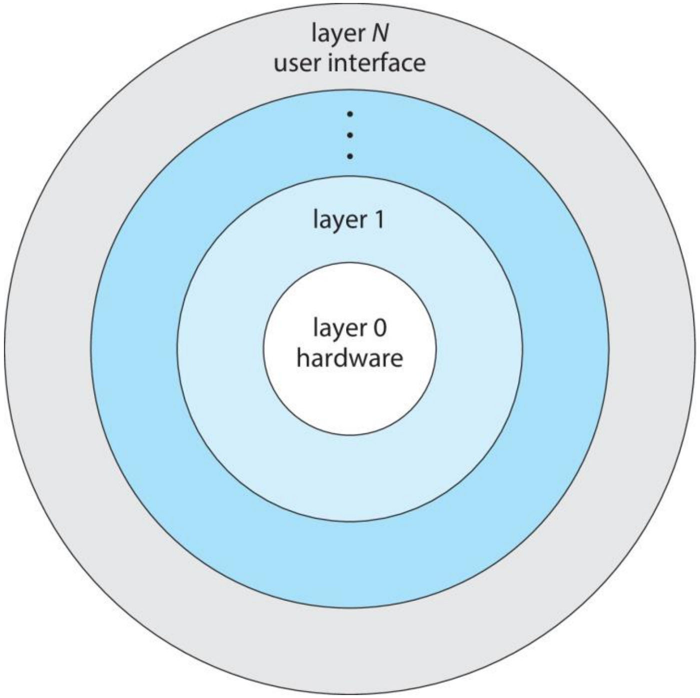
Linux System Structure

- Monolithic plus modular design
- The Linux kernel runs entirely in kernel mode in a single address space



Layered Approach

- monolithic approach->**tightly coupled**
  - changes to one part of the system can have wide-ranging effects on other parts.
- The operating system is divided into a number of layers (levels), each built on top of lower layers. The bottom layer (layer 0), is the hardware; the highest (layer N) is the user interface.
- With modularity, layers are selected such that each uses functions (operations) and services of only lower-level layers
- layer *M*—consists of data structures and a set of functions that can be invoked by higher-level layers. Layer *M,* in turn, can invoke operations on lower-level layers.
- Simplicity of construction and debugging



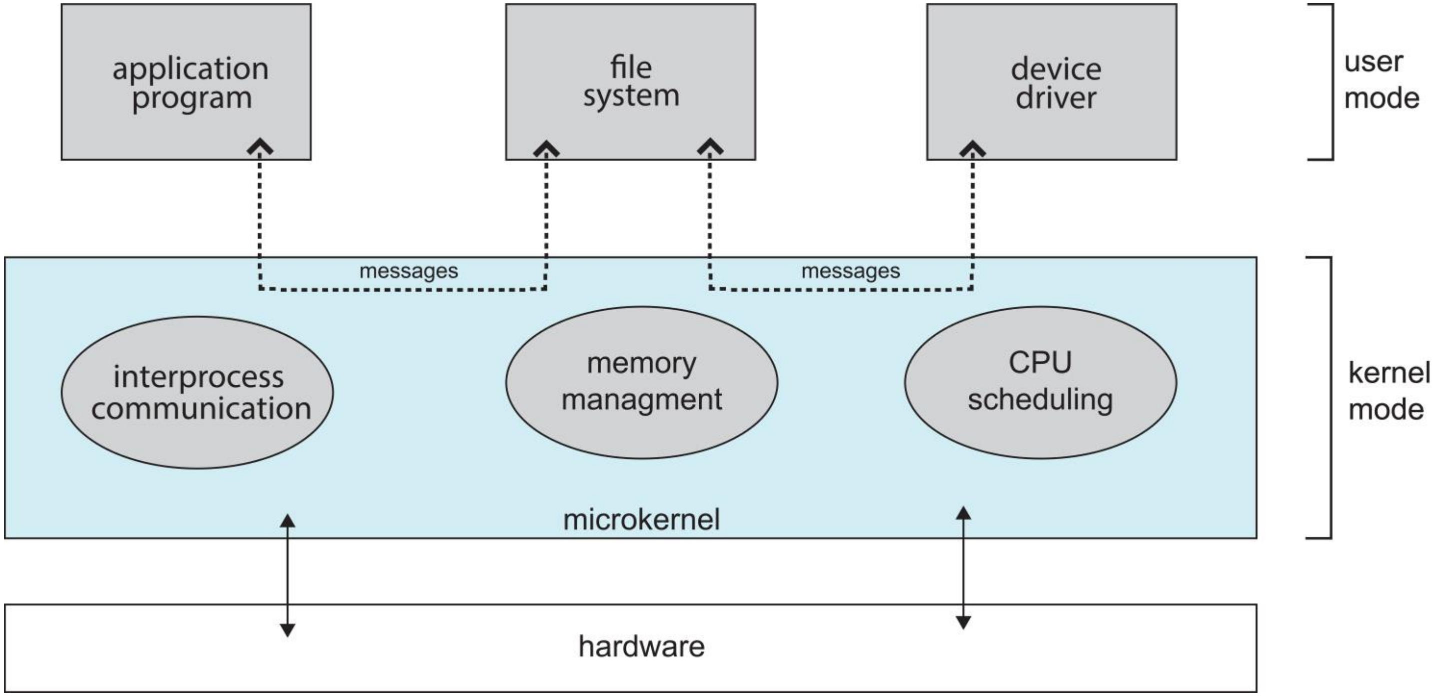
- Not used for full design; used within several important **OS subsystems** e.g., networking

Microkernels

- **Theme**: Moves as much from the kernel into user space
- **Mach** is an example of **microkernel**
  - Mac OS X kernel (**Darwin**) partly based on Mach
- Communication takes place between user modules using **message passing**
- Benefits:
  - Easier to extend a microkernel (All new services are added to user space)
  - Easier to port the operating system to new architectures
  - More reliable (less code is running in kernel mode)
  - More secure (most services are running as user)
- Detriments:
  - Performance overhead of user space to kernel space communication

Microkernel System Structure

- Microkernel is to provide communication between the client program and the various services that are also running in user space.



Modules

- Many modern operating systems implement **loadable kernel** mo**dules** (**LKMs**)
  - 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
- This type of design is common in modern implementations of UNIX, such as Linux, macOS, and Solaris, as well as Windows.
- Overall, similar to layers but with more flexible

Hybrid Systems

- Most modern operating systems are not one pure model
  - Hybrid combines multiple approaches to address performance, security, usability needs
  - Linux and Solaris kernels in kernel address space, so monolithic, plus modular for dynamic loading of functionality
  - Windows mostly monolithic, plus microkernel for different subsystem ***personalities***
- Apple Mac OS X hybrid
  - Below is kernel consisting of Mach microkernel and BSD Unix parts, plus I/O kit and dynamically loadable modules (called **kernel extensions**)

macOS and iOS Structure

- Read by yourself

Darwin

- Read by yourself

Android

- Read by yourself

Building and Booting an Operating System

- Operating systems generally designed to run on a class of systems with variety of peripherals
- Commonly, operating system already installed on purchased computer
  - But can build and install some other operating systems
  - If generating an operating system from scratch
    - Write the operating system source code
    - Configure the operating system for the system on which it will run
    - Compile the operating system
    - Install the operating system
    - Boot the computer and its new operating system

Building and Booting Linux

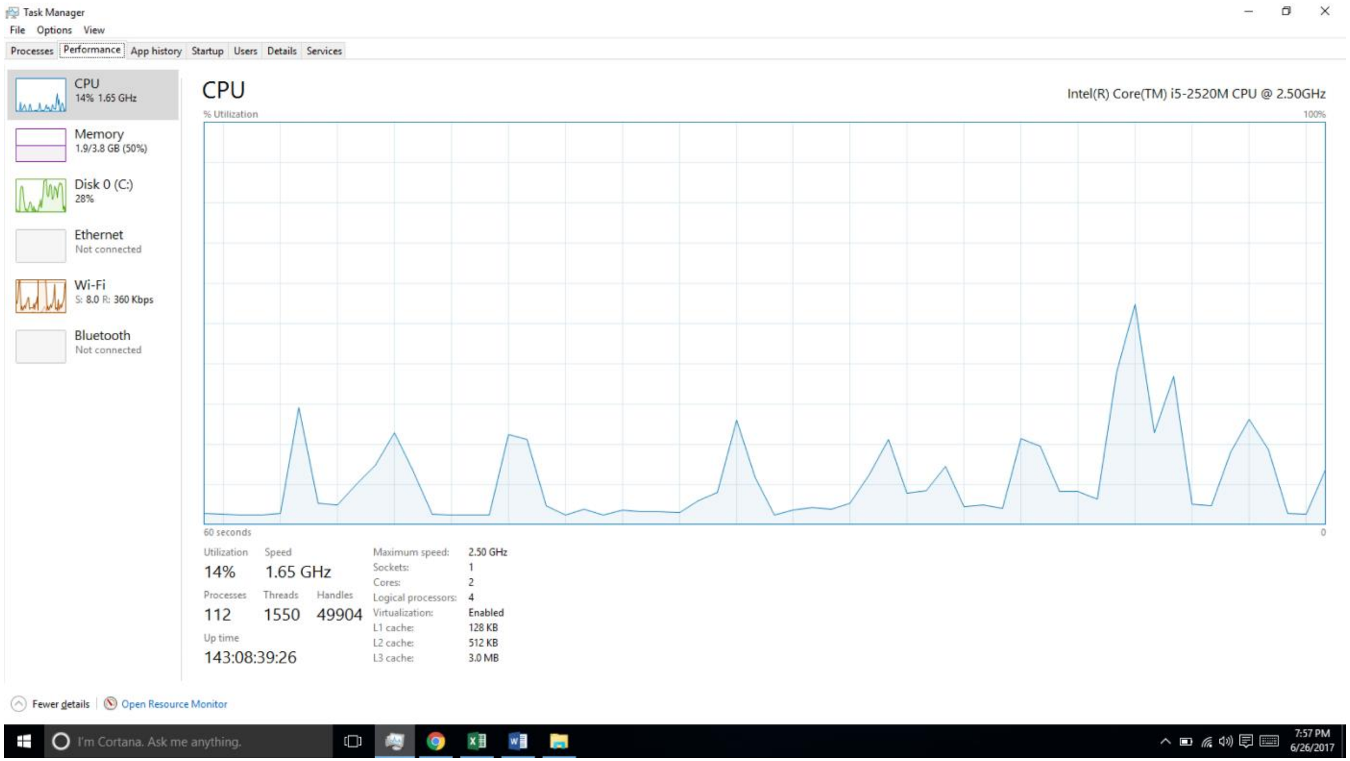
- Download Linux source code (http://www.kernel.org)
- Configure kernel via “`make menuconfig`”
- Compile the kernel using “`make`”
  - Produces `vmlinuz`, the kernel image
  - Compile kernel modules via “`make modules`”
  - Install kernel modules into `vmlinuz` via “`make modules_install`”
  - Install new kernel on the system via “`make install`”

Operating-System Debugging

- **Debugging** is finding and fixing errors, or **bugs**
- Also **performance tuning**
- OS generate **log files** containing error information
- Failure of an application can generate **core dump** file capturing memory of the process
- Operating system failure can generate **crash dump** file containing kernel memory
- Beyond crashes, performance tuning can optimize system performance
  - Sometimes using ***trace listings*** of activities, recorded for analysis
  - **Profiling** is periodic sampling of instruction pointer to look for statistical trends

Performance Tuning

- Improve performance by removing bottlenecks
- OS must provide means of computing and displaying measures of system behavior
- For example, Windows Task Manager



CPU
14% 1.65 GHz

Memory
1.9/3.8 GB (50%)

Disk 0 (C:)
28%

Ethernet
Not connected

Wi-Fi
S: 8.0 R: 360 Kbps

Bluetooth
Not connected

CPU Intel(R) Core(TM) i5-2520M CPU @ 2.50GHz

Utilization 14%
Speed 1.65 GHz
Processes 112
Threads 1550
Handles 49904
Up time 143:08:39:26

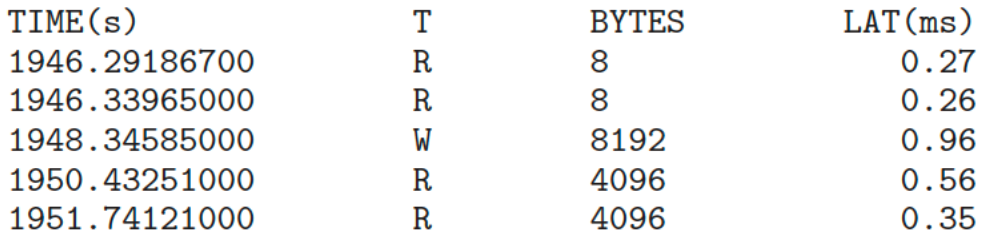
Maximum speed: 2.50 GHz
Sockets: 1
Cores: 2
Logical processors: 4
Virtualization: Enabled
L1 cache: 128 KB
L2 cache: 512 KB
L3 cache: 3.0 MB

Tracing

- Collects data for a specific event, such as steps involved in a system call invocation
- Tools include
  - strace – trace system calls invoked by a process
  - gdb – source-level debugger
  - perf – collection of Linux performance tools
  - tcpdump – collects network packets

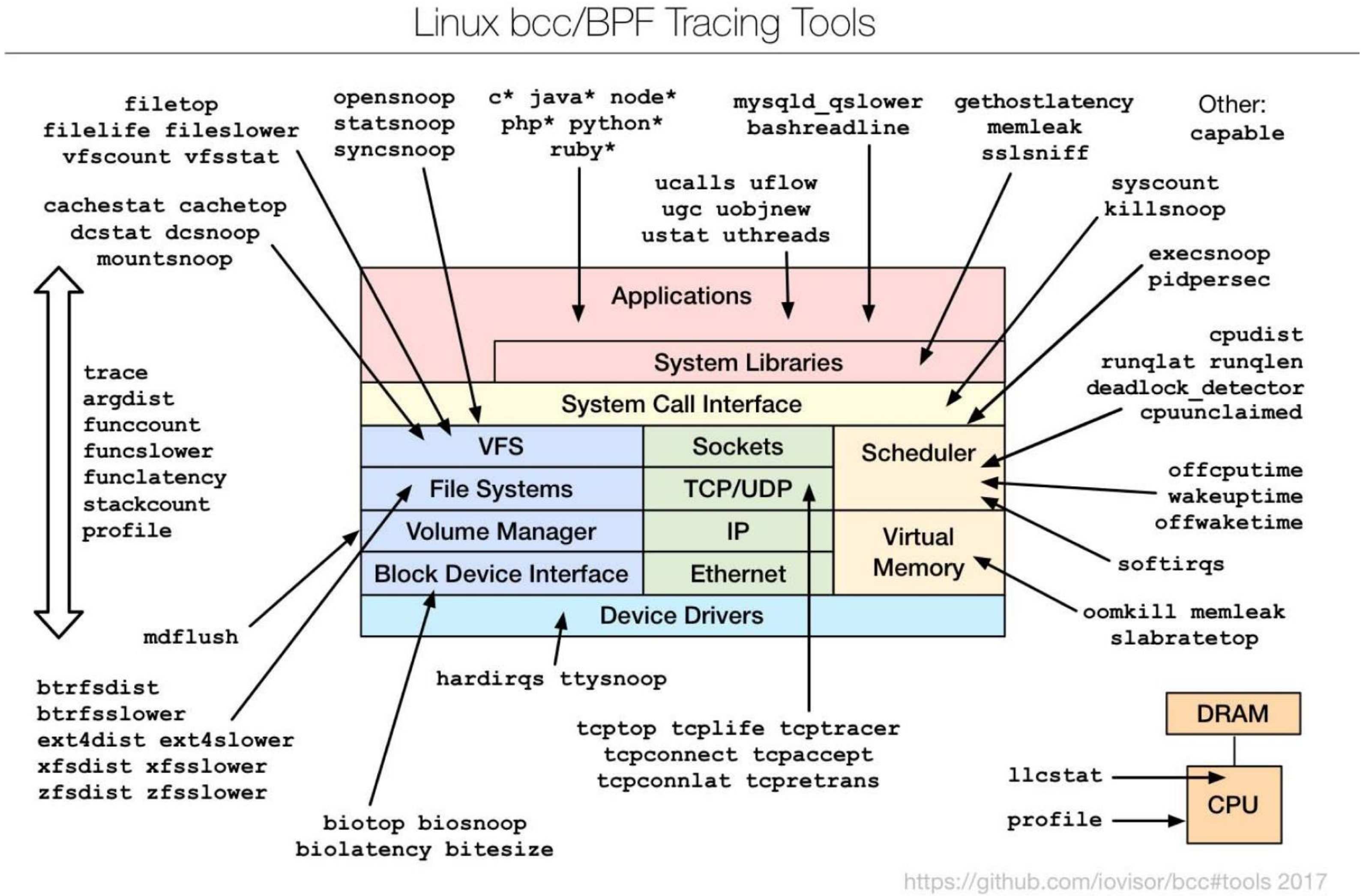
BCC

- Debugging interactions between user-level and kernel code nearly impossible without toolset that understands both an instrument their actions
- BCC (BPF Compiler Collection) is a rich toolkit providing tracing features for Linux
- For example, disksnoop.py traces disk I/O activity



```
TIME(s)             T        BYTES       LAT(ms)
1946.29186700       R        8              0.27
1946.33965000       R        8              0.26
1948.34585000       W        8192           0.96
1950.43251000       R        4096           0.56
1951.74121000       R        4096           0.35
```

Linux bcc/BPF Tracing Tools



Linux bcc/BPF Tracing Tools

filetop
filelife fileslower
vfscount vfsstat

opensnoop
statsnoop
syncsnoop

c* java* node*
php* python*
ruby*

mysqld_qslower
bashreadline

gethostlatency
memleak
sslsniff

Other:
capable

ucalls uflow
ugc uobjnew
ustat uthreads

syscount
killsnoop

execsnoop
pidpersec

cachestat cachetop
dcstat dcsnoop
mountsnoop

trace
argdist
funccount
funcslower
funclatency
stackcount
profile

Applications

System Libraries

System Call Interface

VFS

Sockets

Scheduler

File Systems

TCP/UDP

Volume Manager

IP

Virtual Memory

Block Device Interface

Ethernet

Device Drivers

cpudist
runqlat runqlen
deadlock_detector
cpuunclaimed

offcputime
wakeuptime
offwaketime

softirqs

oomkill memleak
slabratetop

mdflush

btrfsdist
btrfsslower
ext4dist ext4slower
xfsdist xfsslower
zfsdist zfsslower

hardirqs ttysnoop

tcptop tcplife tcptracer
tcpconnect tcpaccept
tcpconnlat tcpretrans

biotop biosnoop
biolatency bitesize

DRAM

llcstat

CPU

profile

https://github.com/iovisor/bcc#tools 2017

End of Chapter 2