CS370 Operating Systems

Colorado State University

Yashwant K Malaiya

Spring 2021 Lecture 3

Slides based on

- Text by Silberschatz, Galvin, Gagne
- Various sources

Today

- **Multiprocessors**
- **OS Operations/Modes**
- **Storage hierarchy**
- **OS Services**
- **Shells/User interfaces**

Course Notes

- Follow updates and notes on Teams
- Slides, TA Office hour info on website
  - Start early to identify question
  - Help Session Wed. 5:30 PM, CSB 130
- IClicker cloud
  - Exit poll: Identify[1 or 2] concepts you found most challenging or significant
  - IClicker App must be registered and configured properly, otherwise the scores will not be uploaded in Canvas[check].
  - Purpose of iClicker is to automate data collection, and get feedback

Perspective

Differences among Subroutines/traps/Interrupt service routines

- Subroutines: program specifies transfer of control
- Traps: transfer of control to a system routine
- Interrupt: hardware request transfers control to the interrupt service routine

Interrupts: Why? How?

- *Interrupt request line* is hardware
- Interrupt causes transfer of control to *Interrupt Service Routine*
- Hence need to save *context*. Context restored when returning.

Interrupts/Exceptions

- Interrupt mechanism also used for **exceptions,** which include
  - Terminate process, crash system due to hardware error
  - Page fault executes when memory access error
  - OS causes switch to another process
  - System call executes via **trap** to trigger kernel to execute request

Direct Memory Access (DMA)

- for movement of a block of data
  - To/from disk, network etc.
- Requires **DMA** controller unit.
- Bypasses CPU to transfer data directly between I/O device and memory
- OS initiates a DMA transfer.
  - When done, interrupt is sent to the CPU to signal completion

FAQ: DMA, Driver vs Controller

When is Direct Memory Access (DMA) needed:

- When a block of data needs to be transferred memory <-> ext device (disk or network controller)

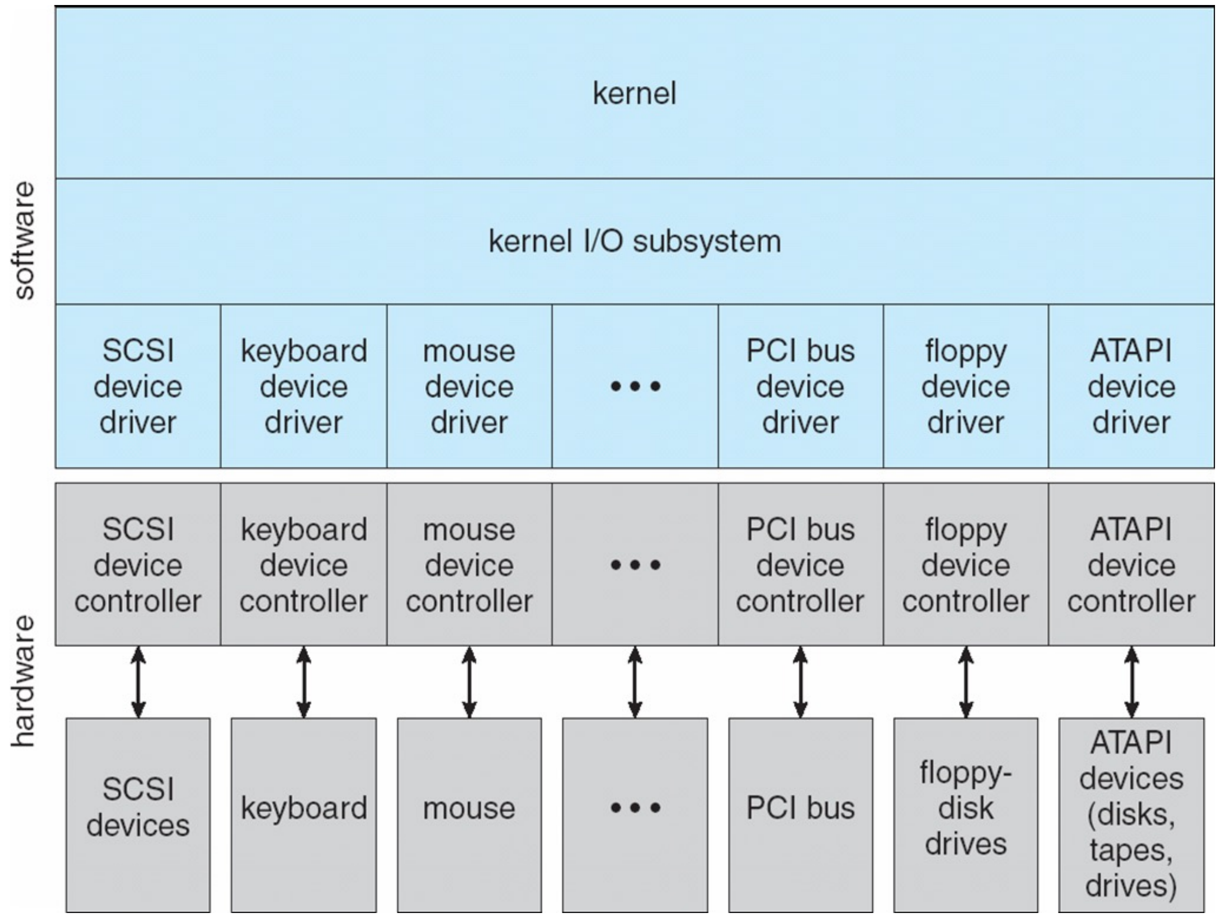
Block transfer using DMA Controller vs CPU

- CPU needs to fetch instructions for each word transfer: too much overhead
- DMA Controller, once initialized, doesn't need to fetch instructions
- DMA: direct connection between memory and IO device

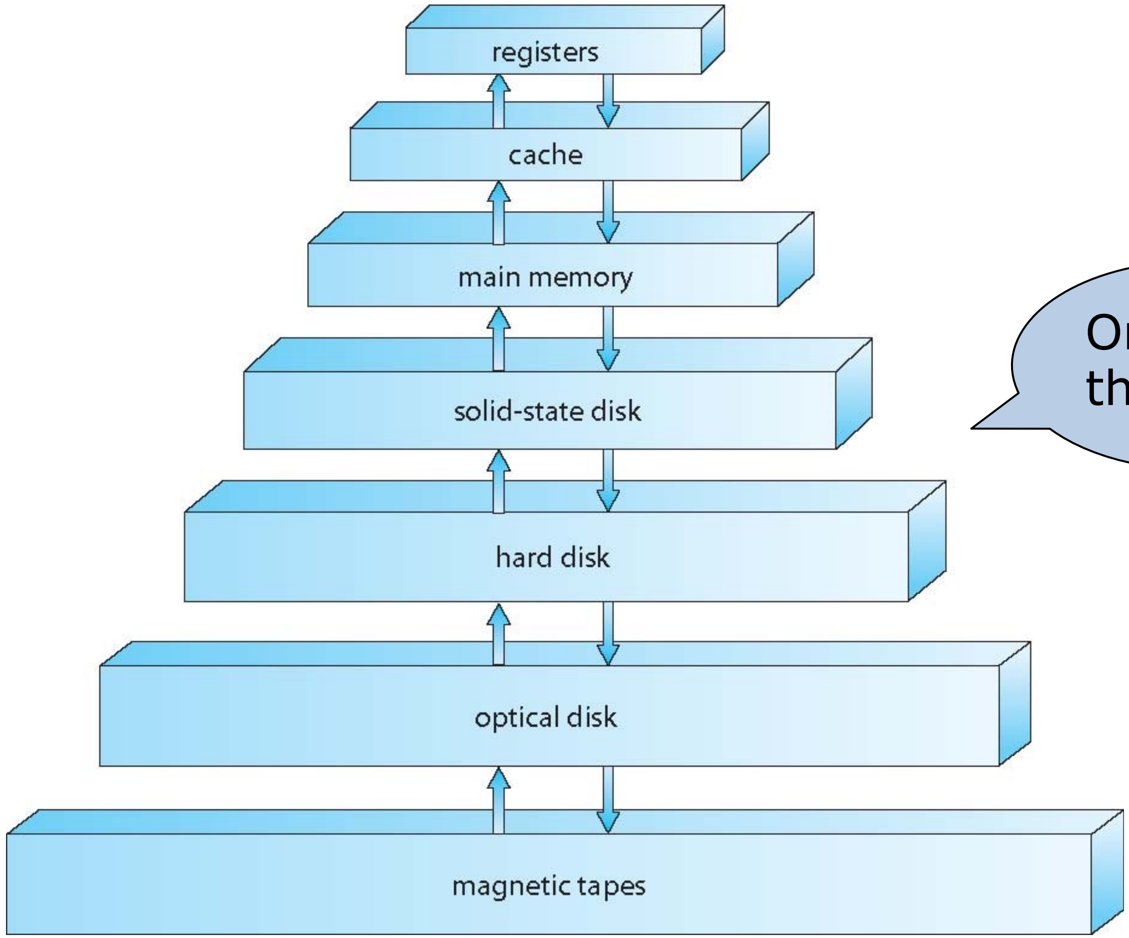
Device Driver (software) vs Device controller (hardware):

- Device controller understands software commands to handle hardware actions
- Device driver: hides device details from kernel

A Kernel I/O Structure



Storage-Device Hierarchy



One or
the other

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General Concept: Caching

- Important principle, performed at many levels in a computer (in hardware, operating system, software)
- Information in use copied from slower to faster storage temporarily
- Faster storage (cache) checked first to determine if information is there
  - If it is, information used directly from the cache (fast)
  - If not, data copied to cache and used there
- Cache smaller than storage being cached
  - Cache management important design problem
  - Cache size and replacement policy
- Examples: “cache”, browser cache ..

Cache la Poudre?

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Multilevel Caches

- **Cache**: between registers and main memory
  - Cache is faster and smaller than main memory
  - Makes main memory appear to be much faster, if the stuff is found in the cache much of the time
  - Hardware managed because of speed requirements
- Multilevel caches
  - L1: smallest and fastest of the three (about 4 cycles, 32 KB)
  - L2: bigger and slower than L1 (about 10 cycles, 256KB)
  - L3: bigger and slower than L2 (about 50 cycles, 8MB)
  - Main memory: bigger and slower than L3 (about 150 cycles, 8GB)
- You can mathematically show that multi-level caches improve performance with usual high hit rates.

Multiprocessors

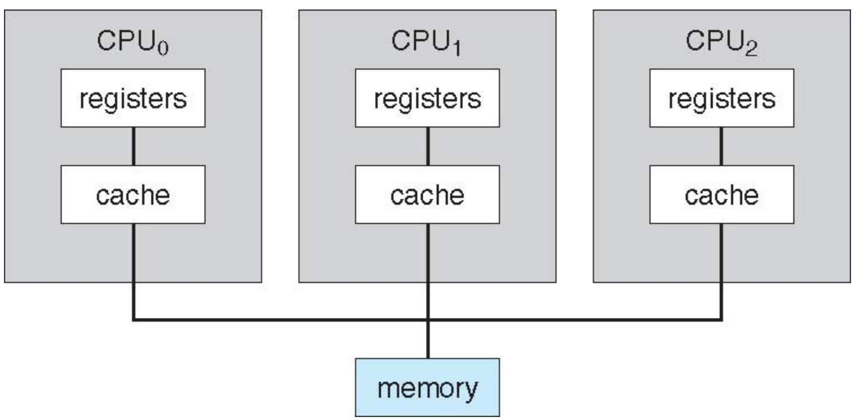
Multiprocessors

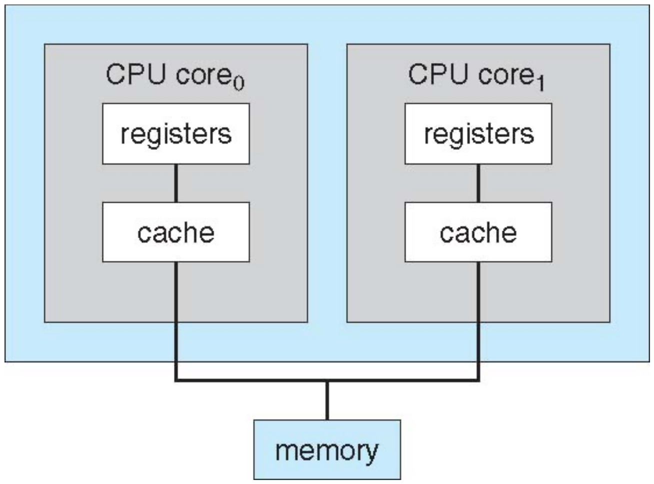
- Past systems used a single general-purpose processor
  - Most systems have special-purpose processors as well
- **Multiprocessor** systems were once special, now are common
  - Advantages include:
    1. **Increased throughput**
    2. **Economy of scale**
  - Two types:
    1. **Asymmetric Multiprocessing** – each processor is assigned a specific task. (older systems)
    2. **Symmetric Multiprocessing** – each processor performs all tasks

Multiprocessing Architecture

Multi-chip and multicore

- Multi-chip: Systems containing all chips
  - Chassis containing multiple separate systems
- Multi-core





FAQ: How does system decide what information should be in cache?

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Multiprogramming and multitasking

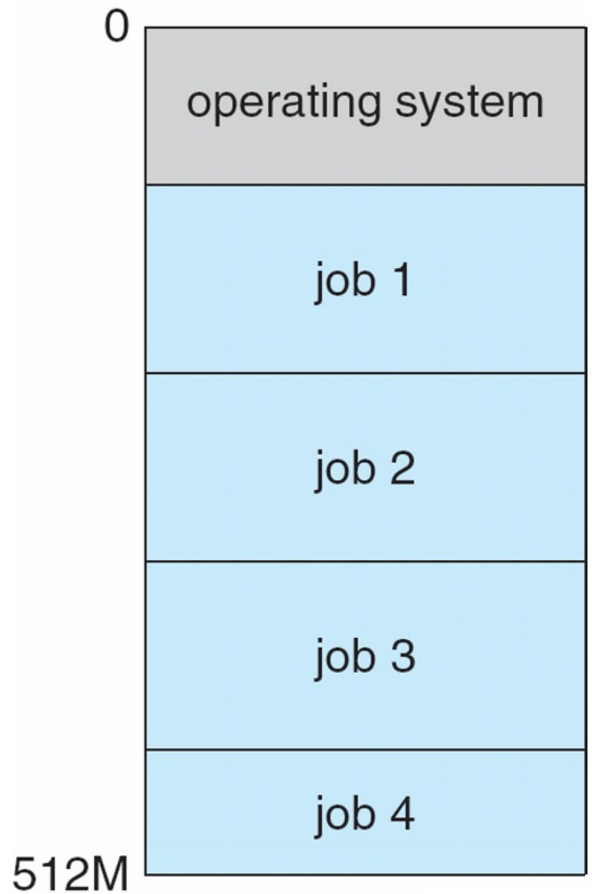
- **Multiprogramming** needed for efficiency
  - Single user cannot keep CPU and I/O devices busy at all times
  - Multiprogramming organizes jobs (code and data) so CPU always has one to execute
  - A subset of total jobs in system is kept in memory
  - One job selected and run via **job scheduling**
  - When it has to wait (for I/O for example), OS switches to another job

- **Timesharing** (**multitasking**) is logical extension in which CPU switches jobs so frequently that users can interact with each job while it is running, creating **interactive** computing
  - **Response time** should be < 1 second
  - Each user has at least one program executing in memory ⇨ **process**
  - If several jobs ready to run at the same time ⇨ **CPU scheduling**
  - If processes don't fit in memory, **swapping** moves them in and out to run
  - **Virtual memory** allows execution of processes not completely in memory

Multiprogramming, Multitasking, Multiprocessing

- **Multiprogramming:** multiple program under execution at the same time, switching programs when needed (older term)
- **Timesharing** (***multitasking***): sharing a CPU among multiple users using time slicing (older term). *Multitasking among people …*
- **Multiprocessing**: multiple processors in the system running in parallel.

Memory Layout for Multiprogrammed System



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Switching between modes

- **User and Kernel modes**
  - **Handling system class**
  - **Switching processes**
- **“Interrupts”** (hardware and software)

Operating-System Operations

- **"Interrupts"** (hardware and software)
  - Hardware interrupt by one of the devices
  - Software interrupt (**exception** or **trap):**
    - Software error (e.g., division by zero)
    - Request for operating system service
    - Other process problems like processes modifying each other or the operating system

Operating-System Operations (cont.)

- **Dual-mode** operation allows OS to protect itself and other system components
  - **User mode** and **kernel mode**
  - **Mode bit** provided by hardware
    - Provides ability to distinguish when system is running user code or kernel code
    - Some instructions designated as **privileged**, only executable in kernel mode
    - System call changes mode to kernel, return from call resets it to user
- Increasingly CPUs support multi-mode operations
  - i.e. **virtual machine manager** (**VMM**) mode for guest **VMs**

called Supervisor mode in LC3 processor in P&P book

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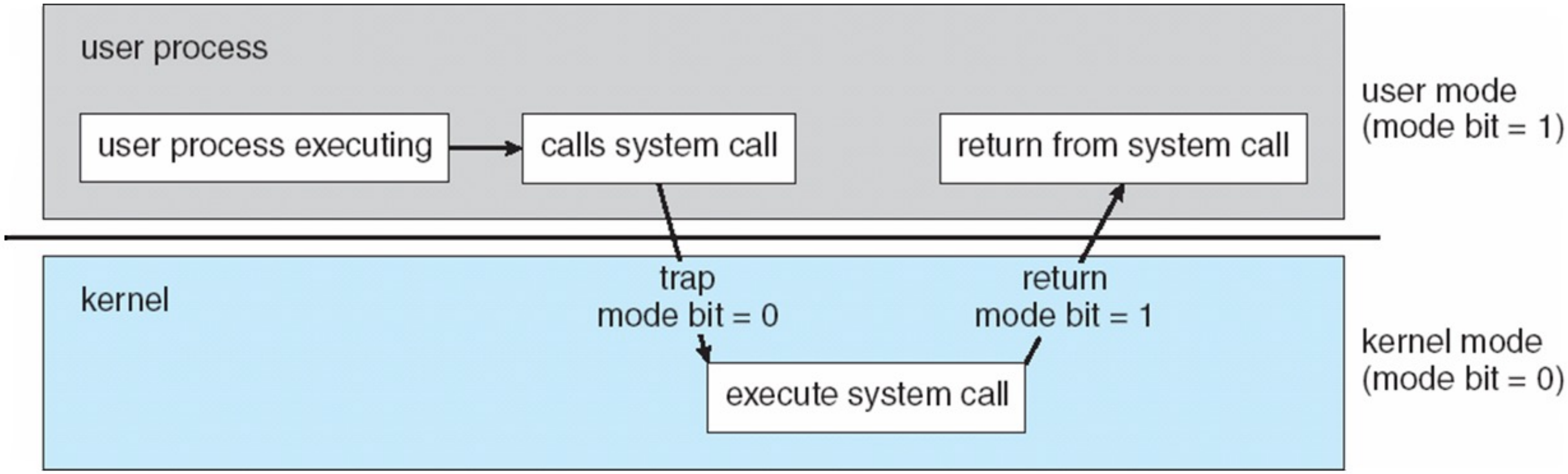
Transition from User to Kernel Mode

- Ex: to prevent a process from hogging resources
  - Timer is set to interrupt the computer after some time period
  - Keep a counter that is decremented by the physical clock.
  - Operating system set the counter (privileged instruction)
  - When counter zero generate an interrupt
  - Set up before scheduling process to regain control or terminate program that exceeds allotted time
- Ex: System calls are executed in the kernel mode



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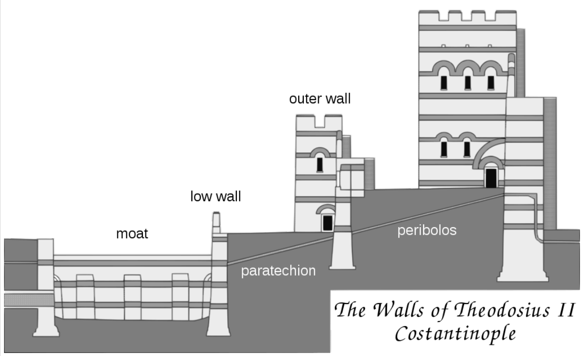
Multiple protection rings

Newer processors may offer multiple modes ("protection rings")

- Ring -1 hypervisor VT-x, SVM
- **Ring 0 Kernel**
- Rings 1,2 Device drivers
- **Ring 3 Applications**

To simplify discussions, we will consider **only two**. Linux uses only these two.

Note that labels/terminology may vary.



The Walls of Theodosius II
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Process Management

- A process is a program in execution. It is a unit of work within the system. Program is a ***passive entity;*** process is an ***active entity***.
- Process needs resources to accomplish its task
  - CPU, memory, I/O, files
  - Initialization data
- Process termination requires reclaim of any reusable resources
- **Single-threaded process** has one **program counter** specifying location of next instruction to execute
  - Process executes instructions sequentially, one at a time, until completion
- **Multi-threaded process** has one program counter per thread
- Typically, system has many processes (some user, some operating system), running concurrently on one or more CPUs
  - Concurrency by multiplexing the CPUs among the processes / threads

A program may involve multiple processes.

Our text uses terms job and process interchangeably.

Process Management Activities

The operating system is responsible for the following activities in connection with process management:

- Creating and deleting both user and system processes
- Suspending and resuming processes
- Providing mechanisms for
  - process synchronization
  - process communication
  - deadlock handling

More about these later

Memory & Storage Management

K-scale: Amount of information/storage

Byte (B) = 8 bits (b)

Amount of info:

Kibibyte?

- A **kilobyte**, or **KB**, is 1,024 (or 2^{10}) bytes
- a **megabyte**, or **MB**, is $1,024^2$ (or 2^{20}) bytes
- a **gigabyte**, or **GB**, is $1,024^3$ bytes
- a **terabyte**, or **TB**, is $1,024^4$ bytes
- a **petabyte**, or **PB**, is $1,024^5$ bytes

Measures of time

- **Milli**seconds, **micro**seconds, **nano**seconds, **pico**seconds: 10^{-3}, 10^{-6}, 10^{-9}, 10^{-12}

Performance of Various Levels of Storage

Level	1	2	3	4	5
Name	registers	cache	main memory	solid state disk	magnetic disk
Typical size	< 1 KB	< 16MB	< 64GB	< 1 TB	< 10 TB
Implementation technology	custom memory with multiple ports CMOS	on-chip or off-chip CMOS SRAM	CMOS SRAM	flash memory	magnetic disk
Access time (ns)	0.25 - 0.5	0.5 - 25	80 - 250	25,000 - 50,000	5,000,000
Bandwidth (MB/sec)	20,000 - 100,000	5,000 - 10,000	1,000 - 5,000	500	20 - 150
Managed by	compiler	hardware	operating system	operating system	operating system
Backed by	cache	main memory	disk	disk	disk or tape

Movement between levels of storage hierarchy can be explicit or implicit

- Cache managed by hardware. Makes main memory appear much faster.
- Disks are several orders of magnitude slower than Main Memory.

Memory Management

means Main Memory here

- To execute a program all (or part) of the instructions must be in memory
- All (or part) of the data that is needed by the program must be in memory.
- Memory management determines what is in memory and when
  - Optimizing CPU utilization and computer response to users

CPU scheduling

- Memory management activities
  - Keeping track of which parts of memory are currently being used and by whom
  - Deciding which processes (or parts thereof) and data to move into and out of memory
  - Allocating and deallocating memory space as needed

Storage Management

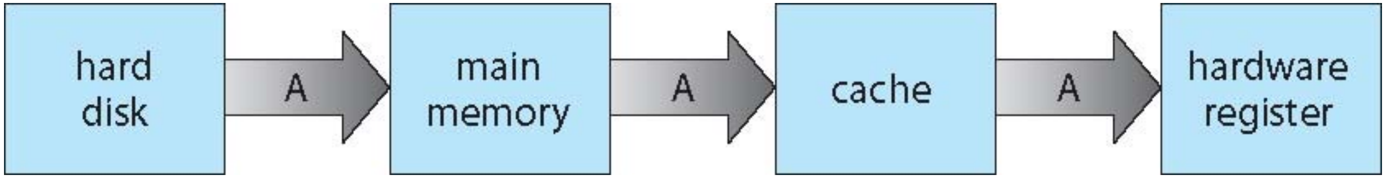
- OS provides uniform, logical view of information storage
  - Abstracts physical properties to logical storage unit - **file**
  - Each medium is controlled by device (i.e., disk drive, tape drive)
    - Varying properties include access speed, capacity, data-transfer rate, access method (sequential or random)
- File-System management
  - Files usually organized into directories
  - Access control on most systems to determine who can access what
  - OS activities include
    - Creating and deleting files and directories
    - Primitives to manipulate files and directories
    - Mapping files onto secondary storage
    - Backup files onto stable (non-volatile) storage media

Mass-Storage Management

- Usually, disks used to store data that does not fit in main memory or data that must be kept for a “long” period of time
- Entire speed of computer operation hinges on disk subsystem and its algorithms
- OS activities
  - Free-space management
  - Storage allocation
  - Disk scheduling (for magnetic disks)
- Some storage need not be fast
  - Tertiary storage includes optical storage, magnetic tape
  - Still must be managed – by OS or applications
  - Varies between WORM (write-once, read-many-times) and RW (read-write)

Migration of data “A” from Disk to Register

- Multitasking environments must be careful to use most recent value, no matter where it is stored in the storage hierarchy



- Multiprocessor environment must provide **cache coherency** in hardware such that all CPUs have the most recent value in their cache
- Distributed environment situation even more complex
  - Several copies of a datum can exist
  - Various solutions covered in Chapter 19 *(will not get to it)*

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OS Structures

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Chap2: Operating-System Structures

Objectives:

- Services OS provides to users, processes, and other systems
- Structuring an operating system
- How operating systems are designed and customized and how they boot

OS Services for the User 1/3

- Operating systems provide an environment for execution of programs and services to programs and users
  - **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

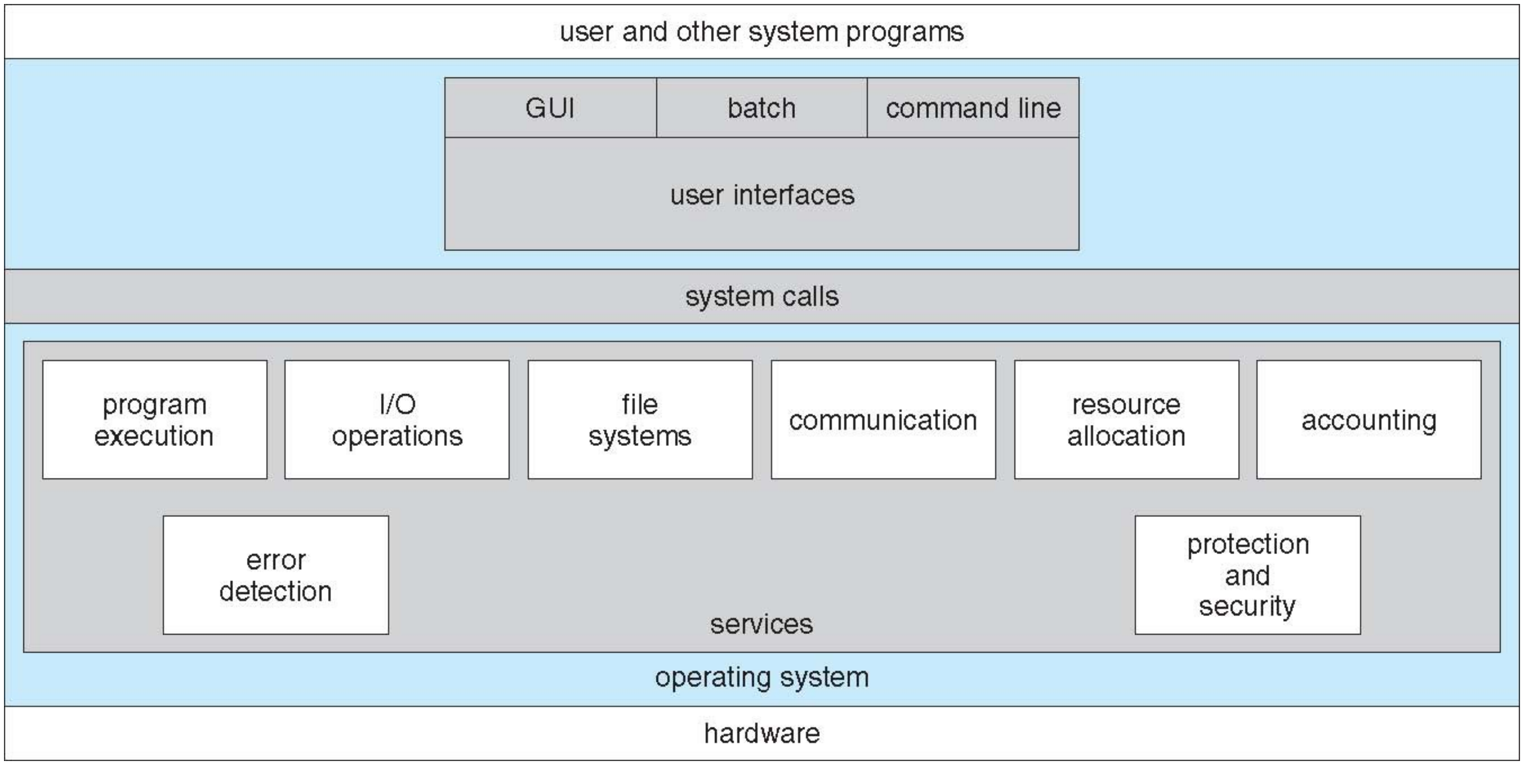
OS services for the User 2/3 (Cont.)

- **File-system operations** - read and write files and directories, create and delete them, search them, list file Information, permission management.
- **Communications** – Processes may exchange information, on the same computer or between computers over a network
  - 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

OS services for system 3/3 (Cont.)

- OS functions for ensuring the efficient 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.
  - **Accounting** - To keep track of which users use how much and what kinds of computer resources
  - **Protection and security** - 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

A View of Operating System Services



User interfaces

Let us see

- CLI: command line interface
- GUI: graphical user interface

User Operating System Interface - CLI

CLI or **command interpreter** allows direct command entry

- Fetches a command from user and executes it
- Sometimes implemented in kernel, sometimes by systems programs
- Sometimes commands built-in, sometimes just names of programs
  - If the latter, adding new features doesn't require shell modification
- Multiple flavors implemented – **shells**

Ex:
Windows: command prompt
Linux: bash

Shell Command Interpreter

A bash session

ymalaiya — -bash — 81×35

```
Last login: Sat Aug 27 22:09:08 on ttys000
Ys-MacBook-Air:~ ymalaiya$ echo $0
-bash
Ys-MacBook-Air:~ ymalaiya$ pwd
/Users/ymalaiya
Ys-MacBook-Air:~ ymalaiya$ ls
270             Desktop         Downloads       Music           android-sdks
Applications    Dialcom         Library         Pictures
DLID Books      Documents       Movies          Public
Ys-MacBook-Air:~ ymalaiya$ w
22:14  up  1:12, 2 users, load averages: 1.15 1.25 1.27
USER     TTY      FROM              LOGIN@  IDLE WHAT
ymalaiya console  -                21:02    1:11 -
ymalaiya s000     -                22:14       - w
Ys-MacBook-Air:~ ymalaiya$ ps
  PID TTY           TIME CMD
  594 ttys000    0:00.02 -bash
Ys-MacBook-Air:~ ymalaiya$ iostat 5
          disk0       cpu     load average
    KB/t tps  MB/s  us sy id   1m   5m   15m
   36.76  17  0.60   5  3 92  1.42 1.31 1.28
^C
Ys-MacBook-Air:~ ymalaiya$ ping colostate.edu
PING colostate.edu (129.82.103.93): 56 data bytes
64 bytes from 129.82.103.93: icmp_seq=0 ttl=116 time=46.069 ms
64 bytes from 129.82.103.93: icmp_seq=1 ttl=116 time=41.327 ms
64 bytes from 129.82.103.93: icmp_seq=2 ttl=116 time=58.673 ms
64 bytes from 129.82.103.93: icmp_seq=3 ttl=116 time=44.750 ms
64 bytes from 129.82.103.93: icmp_seq=4 ttl=116 time=48.336 ms
^C
--- colostate.edu ping statistics ---
5 packets transmitted, 5 packets received, 0.0% packet loss
round-trip min/avg/max/stddev = 41.327/47.831/58.673/5.877 ms
Ys-MacBook-Air:~ ymalaiya$
```

Common bash commands 1/2

pwd	print Working directory	
ls -l	Files in the working dir –long format	
cd dirpath	Change to dirpath dir	
. .. ~username /	This dir , upper, usename’s home, root	
cp f1 d1	Copy f1 to dir d1	
mv f1 d1	Move f1 to d1	
rm f1 f2	Remove f1, f2	
mkdir d1	Create directory d1	
which x1	Path for executable file x1	
man cm help cm	Manual entry or help with command cm	
ls > f.txt	Redirect command std output to f.txt, >> to append	
sort < list.txt	Std input from file	
ls –l | less	Pipe first command into second	

Common bash commands 2/2

echo $((expression))	Evaluate expression	
echo $PATH	Show PATH	
echo $SHELL	Show default shell	
chmod 755 dir	Change dir permissions to 755	
jobs ps	List jobs for current shell, processes in the system	
kill id	Kill job or process with given id	
cmd &	Start job in background	
fg id	Bring job id to foreground	
ctrl-z followed by bg or fg	Suspend job and put it in background	
w who	Who is logged on	
ping ipadd	Get a ping from ipadd	
ssh user@host	Connect to host as user	
grep pattern files	Search for pattern in files	
Ctrl-c	Halt current command	

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 in 1973
- Most systems now include both CLI and GUI interfaces
  - 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.

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The Mac OS X GUI

System Calls

- What are they?
- How are they implemented?

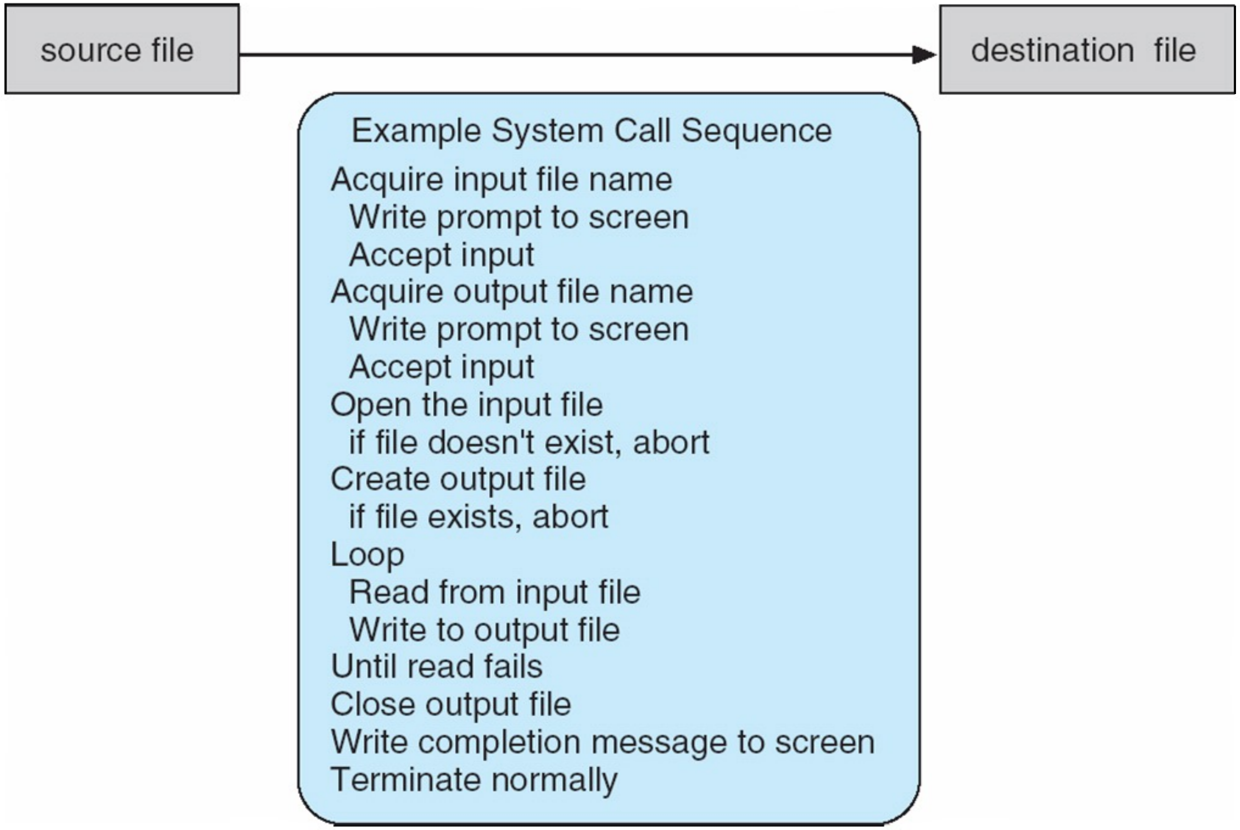
System Calls

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

Note that the system-call names used throughout our text are generic.

Example of System Calls

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



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 where the data will be read into
- `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.

unistd.h header file provides access to the POSIX API