Introduction to the course on

Operating Systems

Sem VI 2021-22

3 Jan 2022

Remembering
one of the True
teachers on the
Teachers’ day
today

3rd Jan 2022

Before we go any further,

What do you want?

How do you want it to be different than CN?

Why is this course important?

In an era of “Data Science” why study “Operating systems” ?

Fashion is temporary, class is permanent.

Toppings keep changing, base does not!

Remember: DO NOT neglect the core courses in Computer Engineering!

Why is this course important?

What will this course teach you

To see “through” the black box called “system”

To see, describe, analyze

EVERYTHING that happens on your computer

Why is this course important?

What will this course teach you

Remove many MISCONCEPTIONS about the "system"

Unfortunately you kept assuming many things about what happens "inside"

Why is this course important?

What will this course teach you

Clearly bring out what happens in hardware and what happens in software

Fill in the gap between what you learnt in Microprocessors+CO and any other programming course

Why is this course important?

This course will

Challenge you to the best of your programming abilities!

Give you many (more) sleepless nights.

Why is this course important?

This course will

Help you solve most of the problems that occur on your computer! Also teach you to raise the most critical unsolved problems in Operating systems.

Be a mechanic and a scientist at the same time!

Why is this course important?

Do we have jobs in Operating Systems domain?

Yes!

Veritas, IBM, Microsoft, NetApp, Amazon (AWS), Oracle, Seagate, Vmware, RedHat, Apple, Google, Intel, Honeywell, HP, ...

Operating Systems: Introduction

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Credits: Slides of “OS Book” ed10.

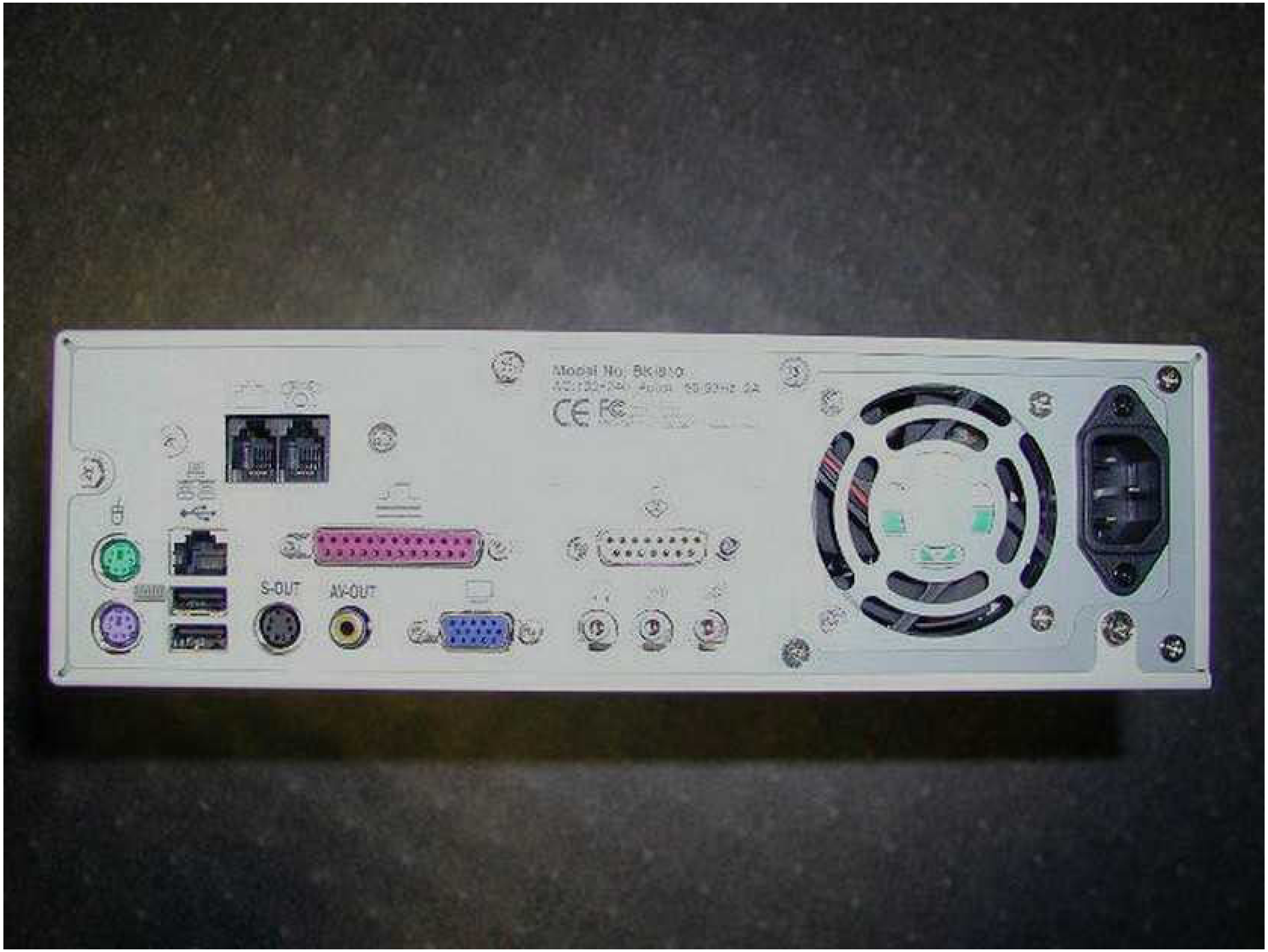
Initial lectures

We will solve a jigsaw puzzle

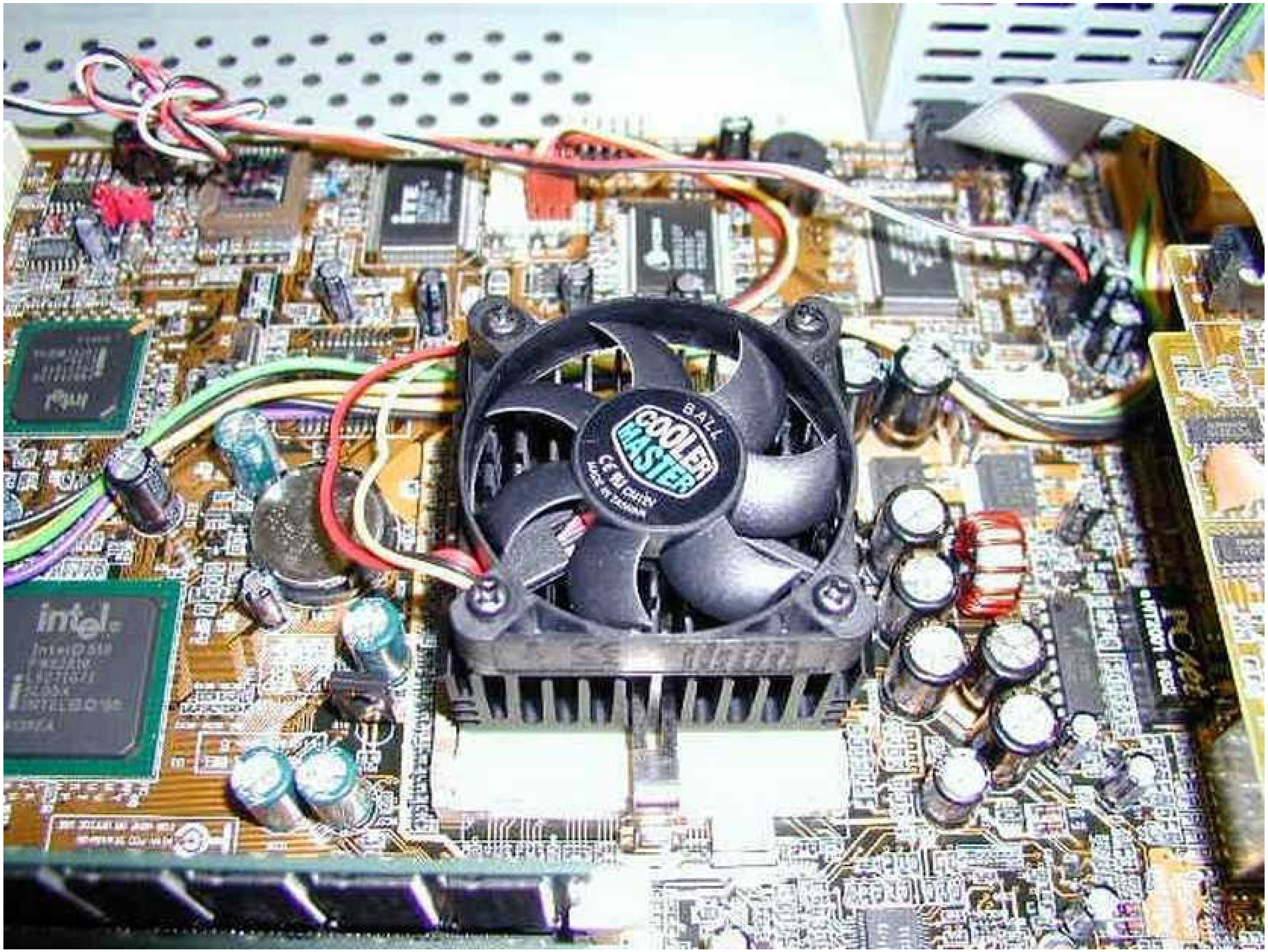
of how the computer system is built

with hardware, operating system and system programs

The “Ports”, what users see



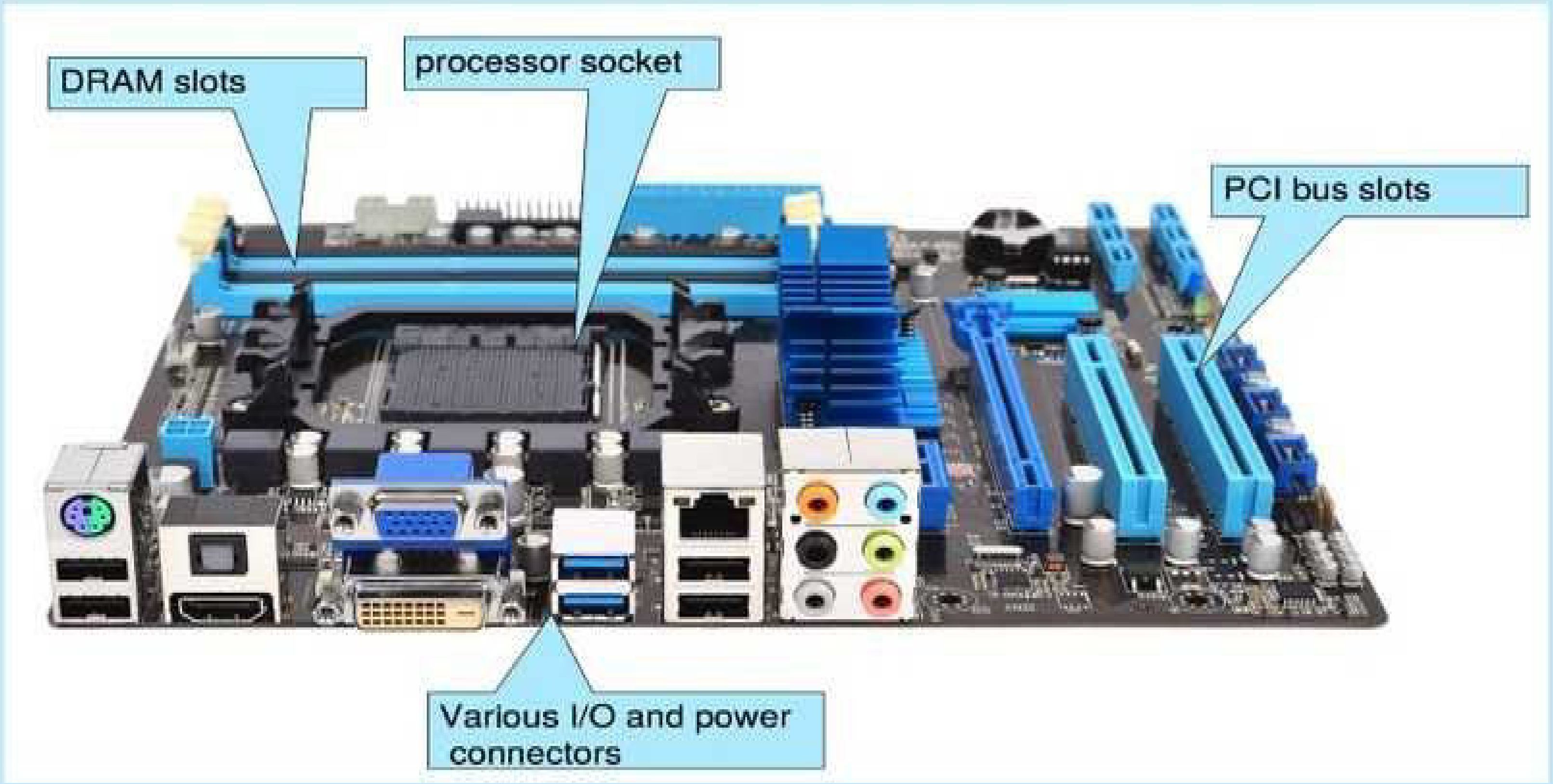
Revision: Hardware : The Motherboard



CPU/Processor

- I3,i5, etc.
- Speeds: Ghz
- “Brain”
- Runs “machine instructions”
- The actual “computer”
- Questions:
  - Where are the instructions that the processor runs?

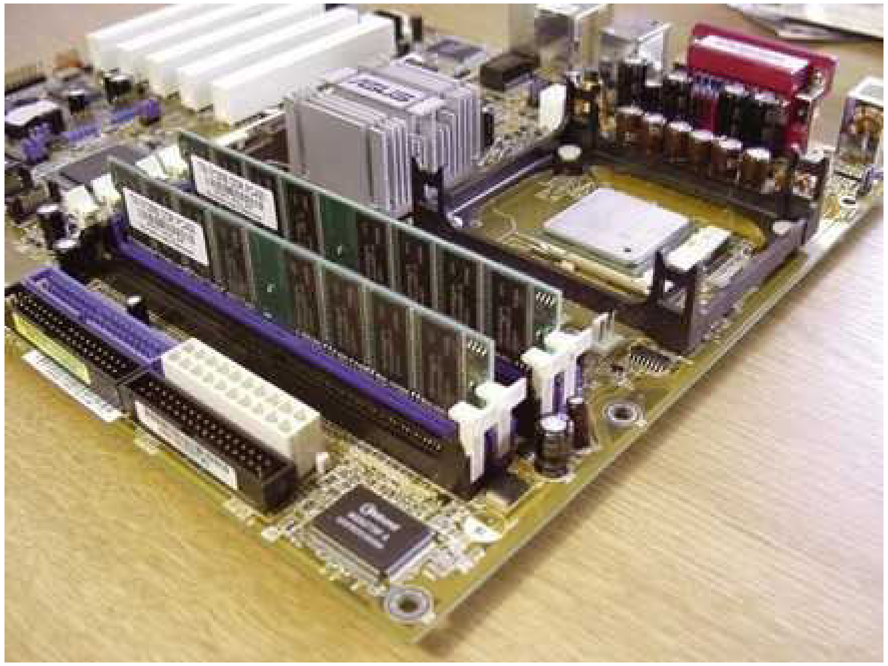
What’s on the motherboard?

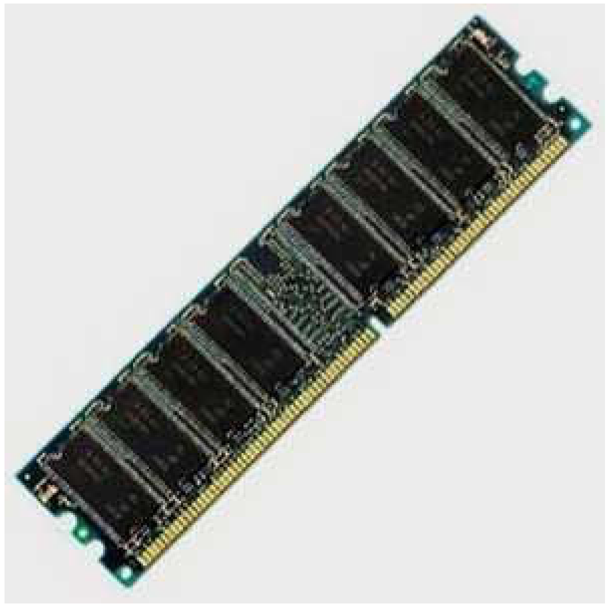


This board is a fully-functioning computer, once its slots are populated.

Memory

- Random Access Memory (RAM)
  - Same time of access to any location – randomly accessible
  - Semiconductor device

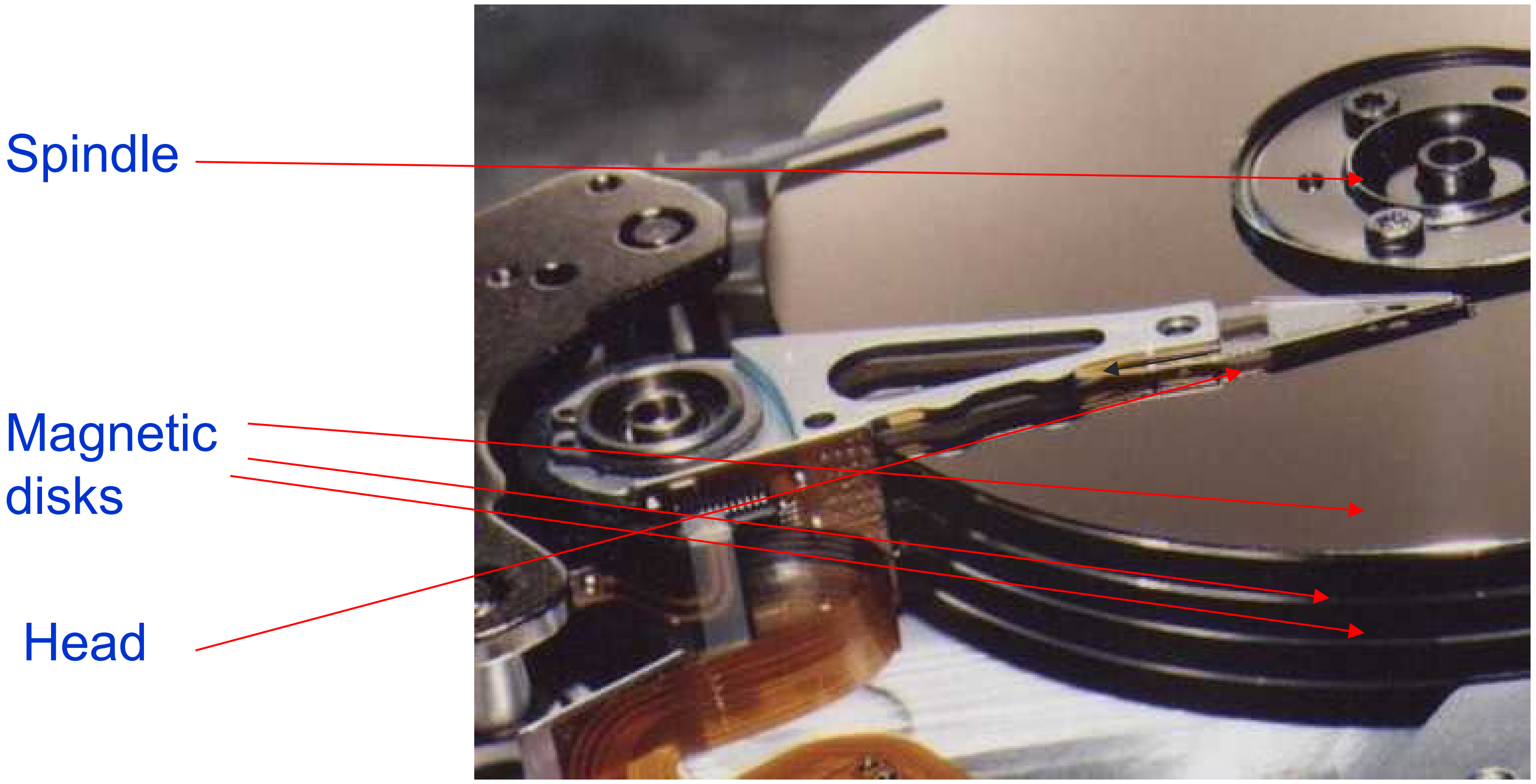




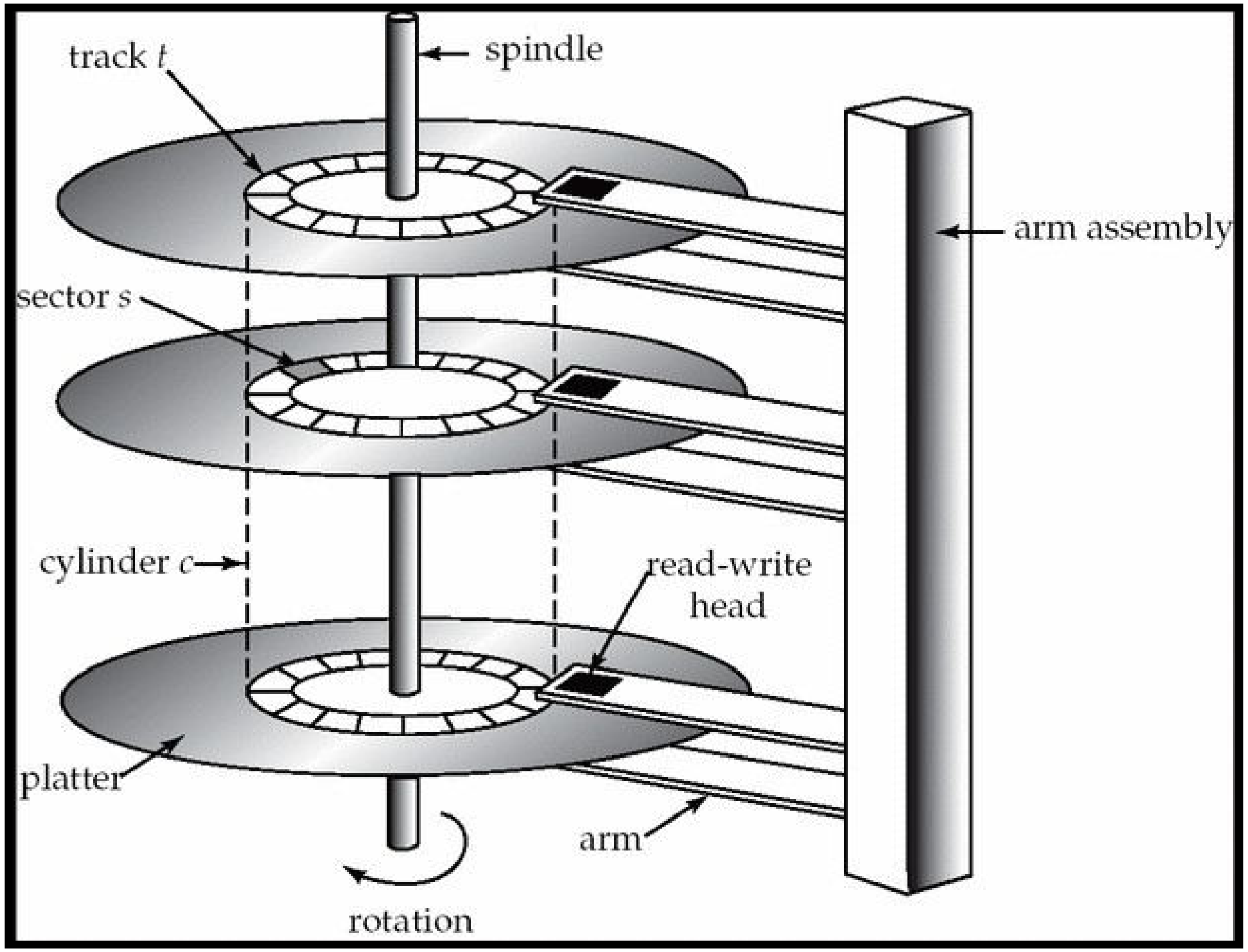
Question:
Can we add more RAM to a computer?

The Hard Drive

The Hard Drive



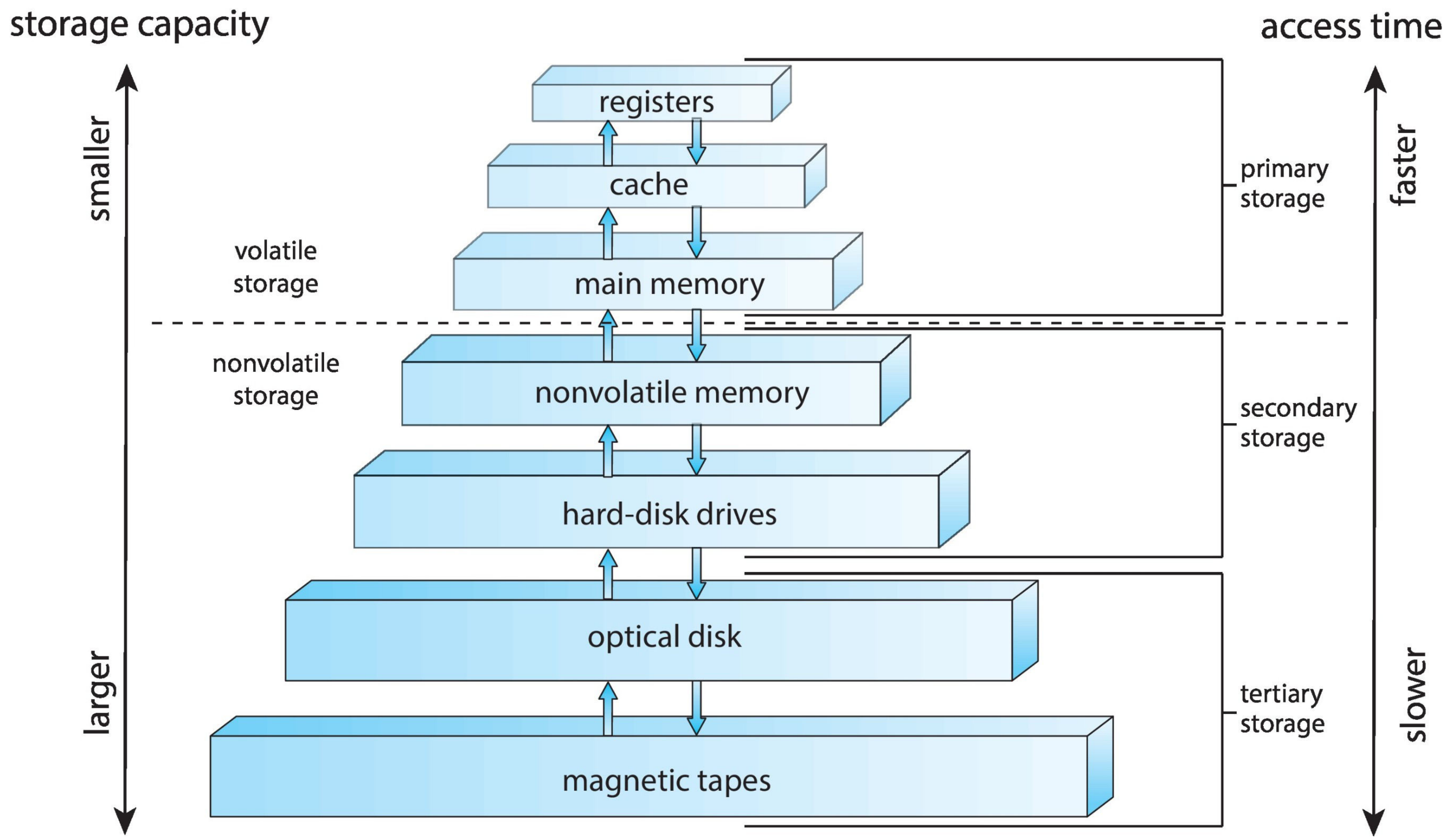
The hard Drive



The Hard Drive

- Is a Magnetic device
- Each disk divided into tiny magnetic spots, each representing 1 or 0
  - What's the physics ?
  - Two orientations of a magnet
- Is “persistent”
  - Data stays on powering-off
- Is slow
- IDE, SATA, SCSI, PATA, SAS, …

Storage-Device Hierarchy



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

Figure 1.11 Performance of various levels of storage.

Computer Organization

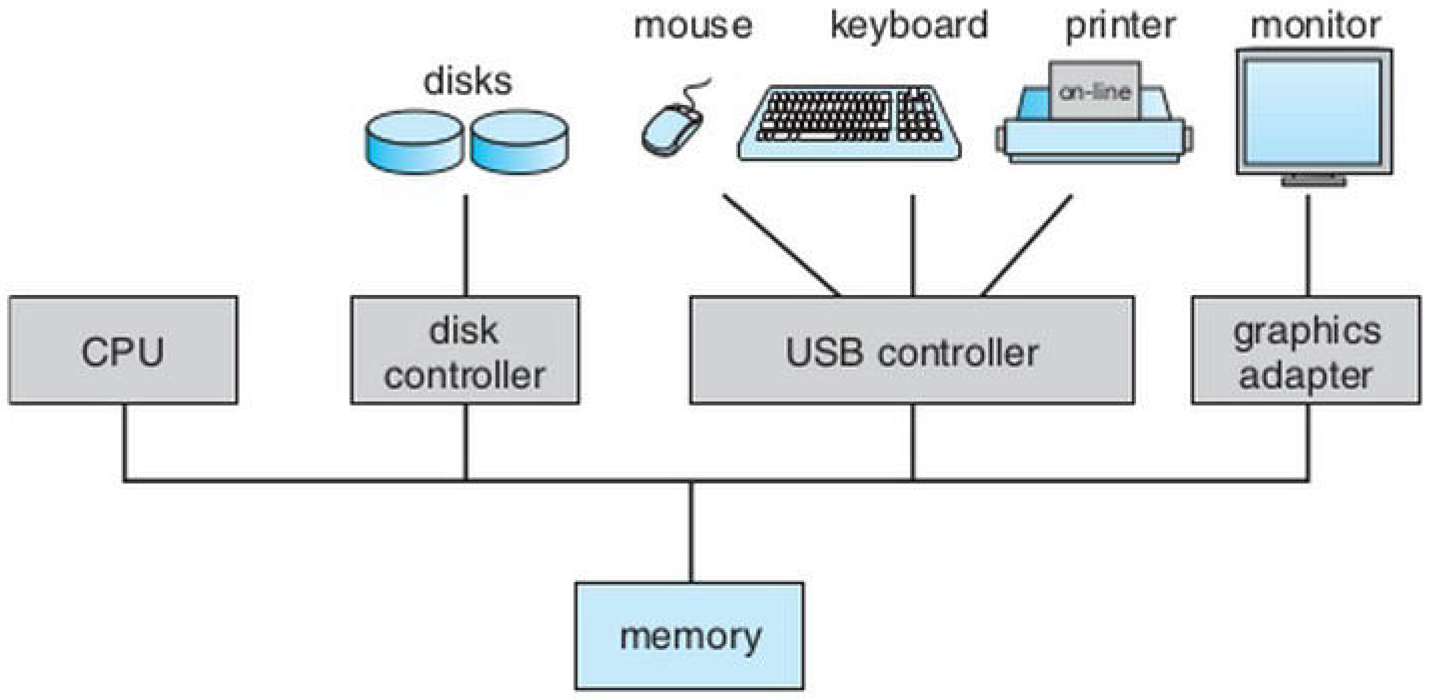


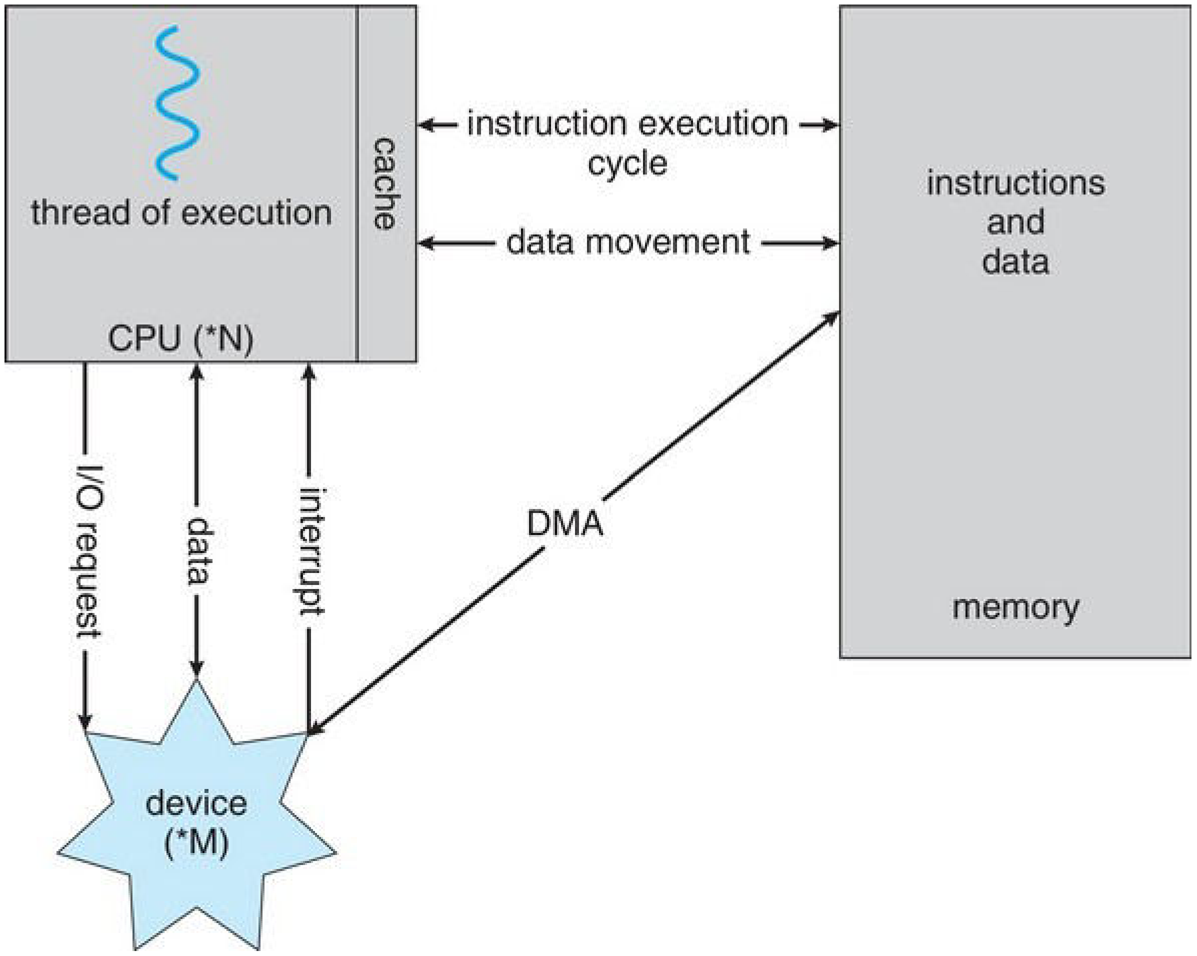
Figure 1.2 A modern computer system.

https://aycaakcay.medium.com/computer-system-organization-6f04c5a314fd

Important Facts

- Processor (CPU) transfers data between itself and main memory(RAM) only!
- No data transfer between CPU and Hard Disk, CPU and Keyboard, CPU and Mouse, etc.
- I/O devices transfer (how?) data to memory(RAM) and CPU instructions access data from the RAM

How a Modern Computer Works



A von Neumann architecture

What does the processor do?

- From the moment it’s turned on until it’s turned off, the processor simply does this
  1) Fetch the instruction from RAM (Memory).
     - Location is given by Program Counter (PC) register
  2) Decode the instruction and execute it
     - While doing this may fetch some data from the RAM
  3) While executing the instruction change/update the Program Counter
  4) Go to 1

Immediate questions

- What’s the initial value of PC when computer starts ?
- Who puts “this” value in PC ?
- What is there at the initial location given by PC ?

A critical question you need to keep thinking about ...

- Throughtout this course, With every concept that you study, Keep asking this question
- Which code is running on the processor?
  - Who wrote it?
  - Which code ran before it
  - Which code can run after it
- Basically try to understand the flow of instructions that execute on the processor

Few terms

- **BIOS**
  - **The code “in-built” into your hardware by manufactuerer**
  - **Runs “automatically” when you start computer**
  - **Keeps looking for a “boot loader” to be loaded in RAM and to be executed**
- **Boot Loader**
  - **A program that exists on (typically sector-0 of) a secondary storage**
  - **Loaded by BIOS in RAM and passed over control to**
  - **E.g. “Grub”**
  - **It’s job is to locate the code of an OS kernel, load it in RAM and pass control over to it**

Kernel, System Programs, Applications

- **Kernel**
  - The code that is loaded and given control by BIOS initially when computer boots
  - Takes control of hardware (how?)
  - Creates an environment for “applications” to execute
  - Controls access to hardware by applications,
  - Etc.
- **Everything else is “applications”**
  - System programs: applications that depend heavily on the kernel and processor
  - E.g. Compiler, linker, loader, etc.
  - Other applicatiosn: GUI, Terminal, Libreoffice, Firefox, VLC, ... Your own programs from data structures, etc.

How is a modern day
Desktop system
built
on top of
this type of hardware?

Components of a computer system

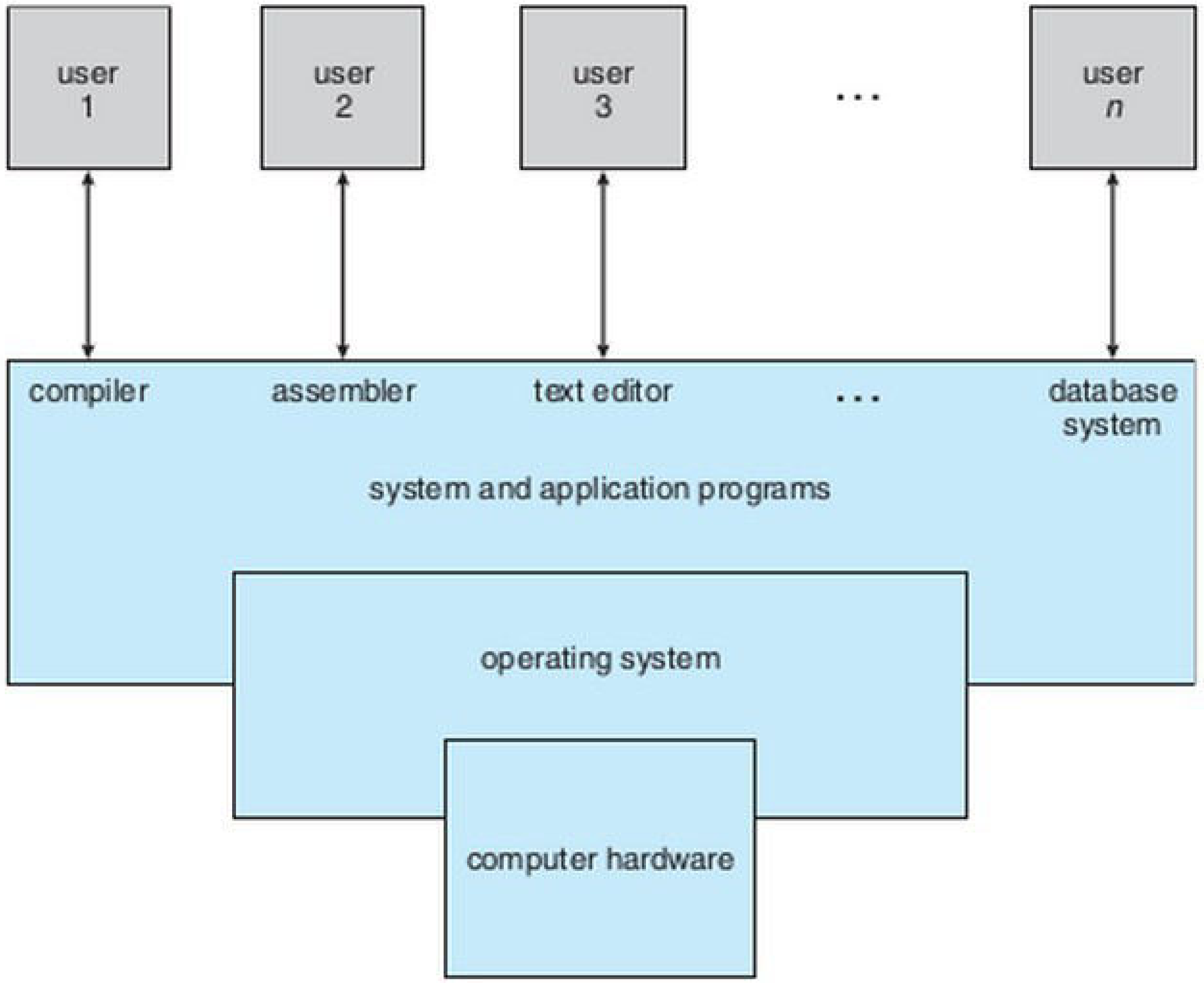


Figure 1.1 Abstract view of the components of a computer system.

Multiprocessor system: SMP

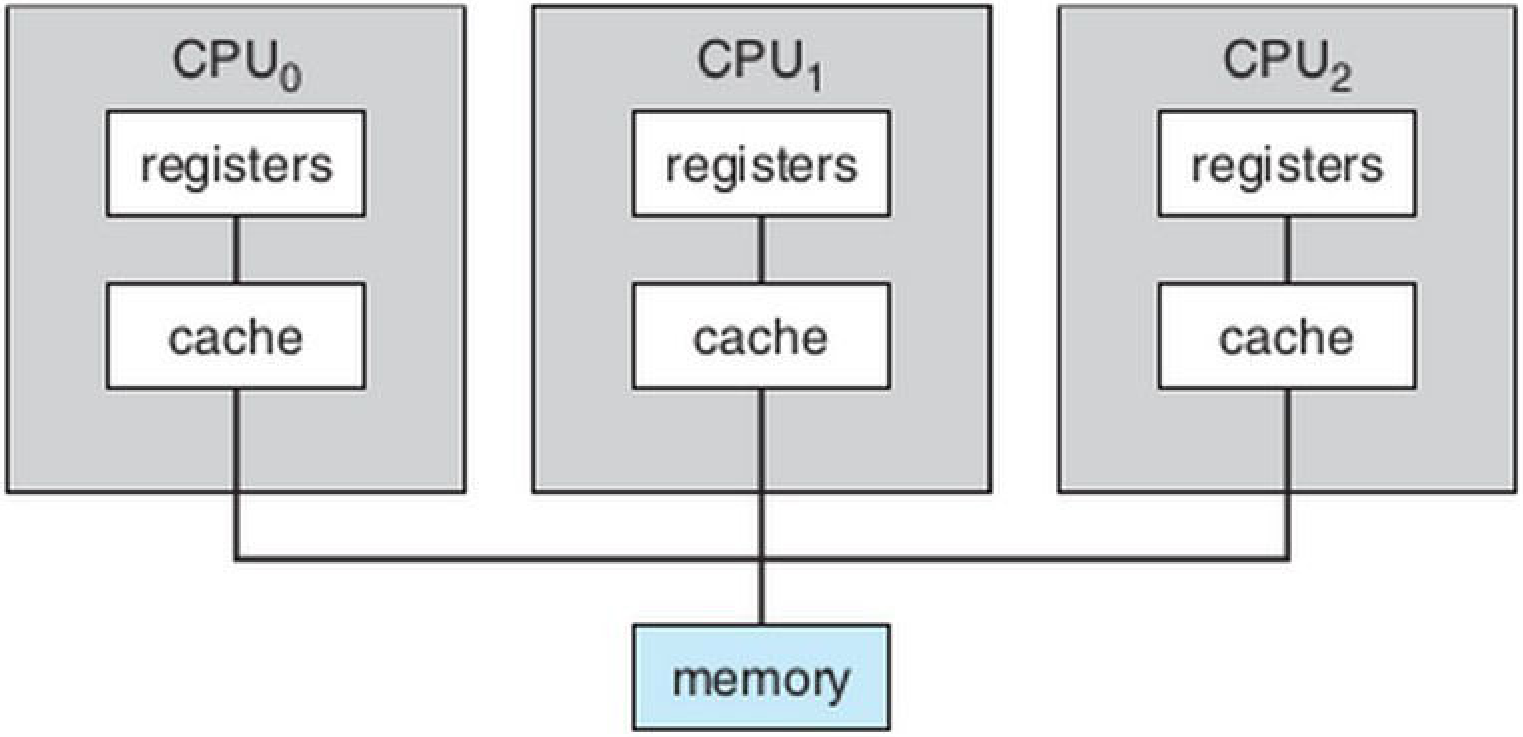


Figure 1.6 Symmetric multiprocessing architecture.

Dual Core: what’s that?

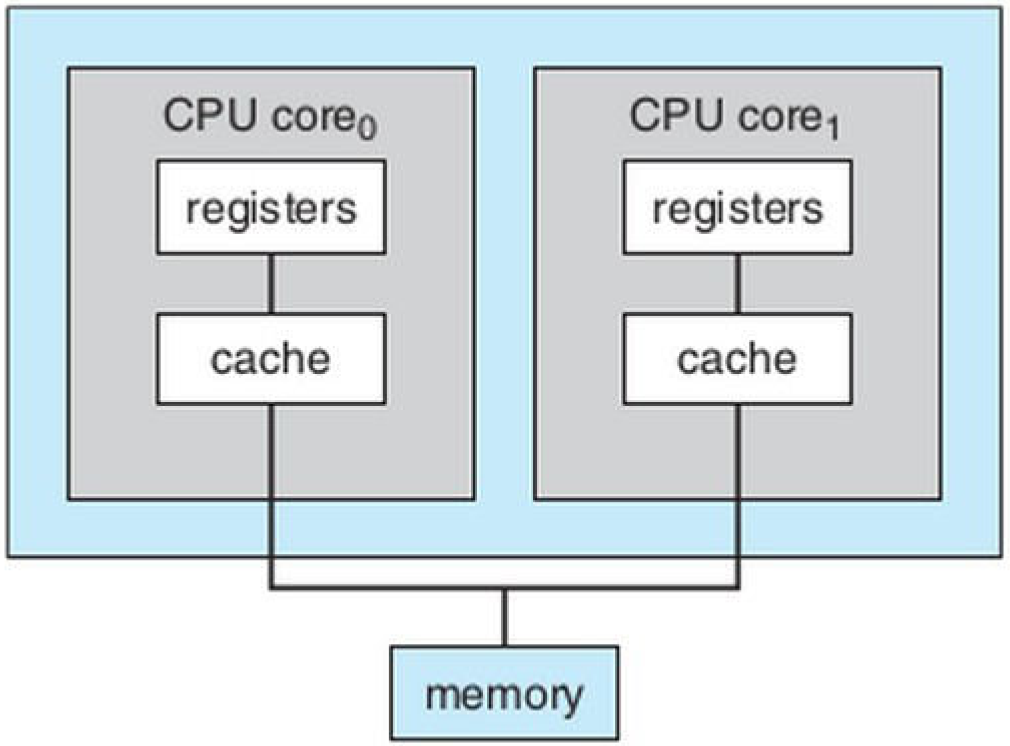


Figure 1.7 A dual-core design with two cores placed on the same chip.

The very important question:

Who does what?

What is done in hardware, by OS, by compiler, by linker, by loader, by human end-user?

There is no magic!

A very intelligent division of work/labour between different components of the computer system makes a system

Event Driven kernel
Multi-tasking, Multi-programming

Earlier...

- **Boot process**
  - **BIOS -> Boot Loader -> OS -> “init” process**
- **CPU doing**

```
for(;;) {
    fetch from @PC;
    deode+execute;
    PC++/change PC
}
```

Understanding hardware interrupts

- **Hardware devices (keyboard, mouse, hard disk, etc) can raise “hardware interrupts”**
- **Basically create an electrical signal on some connection to CPU (/bus)**
- **This is notified to CPU (in hardware)**
- **Now CPU’s normal execution is interrupted!**
  - **What’s the normal execution?**
  - **CPU will not continue doing the fetch, decode, execute, change PC cycle !**
  - **What happens then?**

Understanding hardware interrupts

- On Hardware interrupt
  - The PC changes to a location pre-determined by CPU manufacturers!
  - Now CPU resumes normal execution
    - What’s normal?
    - Same thing: Fetch, Decode, Execute, Change PC, repeat!
    - But...
  - But what’s there at this pre-determined address?
  - OS! How’s that ?

Boot Process

- BIOS runs “automatically” because at the initial value of PC (on power ON), the manufacturers have put in the BIOS code in ROM
  - CPU is running BIOS code . BIOS code also occupies all the addresses corresponding to hardware interrupts.
- BIOS looks up boot loader (on default boot device) and loads it in RAM, and passes control over to it
  - Pass control? - Like a JMP instruction
  - CPU is running boot loader code
- Boot loader gets boot option from human user, and loads the selected OS in memory and passes control over to OS
  - Now OS is running on the processor !

Hardware interrupts and OS

- **When OS starts running initially**
  - **It copies relevant parts of it's own code at all possible memory addresses that a hardware interrrupt can lead to!**
  - **Intelligent, isnt' it?**
- **Now what?**
  - **Whenever there is a hardware interrupt – what will happen?**
  - **The PC will change to predetermined location, and control will jump into OS code**
- **So remember: whenever there is a hardware interrupt, OS code will run!**
- **This is "taking control of hardware"**

Key points

- Understand the interplay of hardware features + OS code + clever combination of the two to achieve OS control over hardware
- Most features of computer systems / operating systems are derived from hardware features
  - We will keep learning this throught the course
  - Hardware support is needed for many OS features

Time Shared CPU

- Normal use: after the OS has been loaded and Desktop environment is running
- The OS and different application programs keep executing on the CPU alternatively (more about this later)
  - The CPU is time-shared between different applications and OS itself
- Questions to be answered later
  - How is this done?
  - How does OS control the time allocation to each?
  - How does OS choose which application program to run next?
  - Where do the application programs come from? How do they start running ?
  - Etc.

Multiprogramming

- Program
  - Just a binary (machine code) file lying on the hard drive. E.g. /bin/ls
  - Does not do anything!
- Process
  - A program that is executing
  - Must exist in RAM before it executes. Why?
  - One program can run as multiple processes. What does that mean?

Multiprogramming

- Multiprogramming
  - A system where multiple processes(!) exist at the same time in the RAM
  - But only one runs at a time!
    - Because there is only one CPU
- Multi tasking
  - Time sharing between multiple processes in a multi-programming system
  - The OS enables this. How? To be seen later.

Question

- Select the correct one

    1) A multiprogramming system is not necessarily multitasking

    2) A multitasking system is not necessarily multiprogramming

Events , that interrupt CPU's functioning

- Three types of "traps" : Events that make the CPU run code at a pre-defined address
  - 1) Hardware interrupts
  - 2) Software interrupt instructions (trap)
    - E.g. instruction "int"
  - 3) Exceptions
    - e.g. a machine instruction that does division by zero
    - Illegal instruction, etc.
    - Some are called "faults", e.g. "page fault", recoverable
    - some are called "aborts", e.g. division by zero, non-recoverable
- The OS code occupies all memory locations corresponding to the PC values related to all the above events!

Multi tasking requirements

- Two processes should not be
  - Able to steal time of each other
  - See data/code of each other
  - Modify data/code of each other
  - Etc.
- The OS ensures all these things. How?
  - To be seen later.

But the OS is “always” “running”
“in the background”
Isn’t it?

Absolutely No!

Let’s understand What kind of Hardware, OS interplay makes Multitasking possible

Two types of CPU instructions and two modes of CPU operation

- CPU instructions can be divided into two types
- Normal instructions
  - mov, jmp, add, etc.
- Privileged instructions
  - Normally related to hardware devices
  - E.g.
    - IN, OUT # write to I/O memory locations
    - INTR # software interrupt, etc.

Two types of CPU instructions and two modes of CPU operation

- CPUs have a mode bit (can be 0 or 1)
- The two values of the mode bit are called: User mode and Kernel mode
- If the bit is in user mode
  - Only the normal instructions can be executed by CPU
- If the bit is in kernel mode
  - Both the normal and privileges instructions can be executed by CPU
- If the CPU is “made” to execute privileged instruction when the mode bit is in “User mode”
  - It results in a illegal instruction execution
  - Again running OS code!

Two types of CPU instructions and two modes of CPU operation

- The opearting system code runs in kernel mode.
  - How? Wait for that!
- The application code runs in user mode
  - How? Wait !
  - So application code can not run privileged hardware instructions
- Transition from user mode to kernel mode and vice-versa
  - Special instruction called “software interrupt” instructions
  - E.g. INT instruction on x86

Software interrupt instruction

- E.g. INT on x86 processors
- Does two things at the same time!
  - Changes mode from user mode to kernel mode in CPU

    + Jumps to a pre-defined location! Basically changes PC to a pre-defined value.
    - Close to the way a hardware interrupt works. Isn’t it?
  - Why two things together?
  - What’s there are the pre-defined location?
    - Obviously, OS code. OS occupied these locations in Memory, at Boot time.

Software interrupt instruction

- What’s the use of these type of instructions?
  - An application code running INT 0x80 on x86 will now cause
    - Change of mode
    - Jump into OS code
  - Effectively a request by application code to OS to do a particular task!
  - E.g. read from keyboard or write to screen !
  - OS providing hardware services to applications !
  - A proper argument to INT 0x80 specified in a proper register indicates different possible request

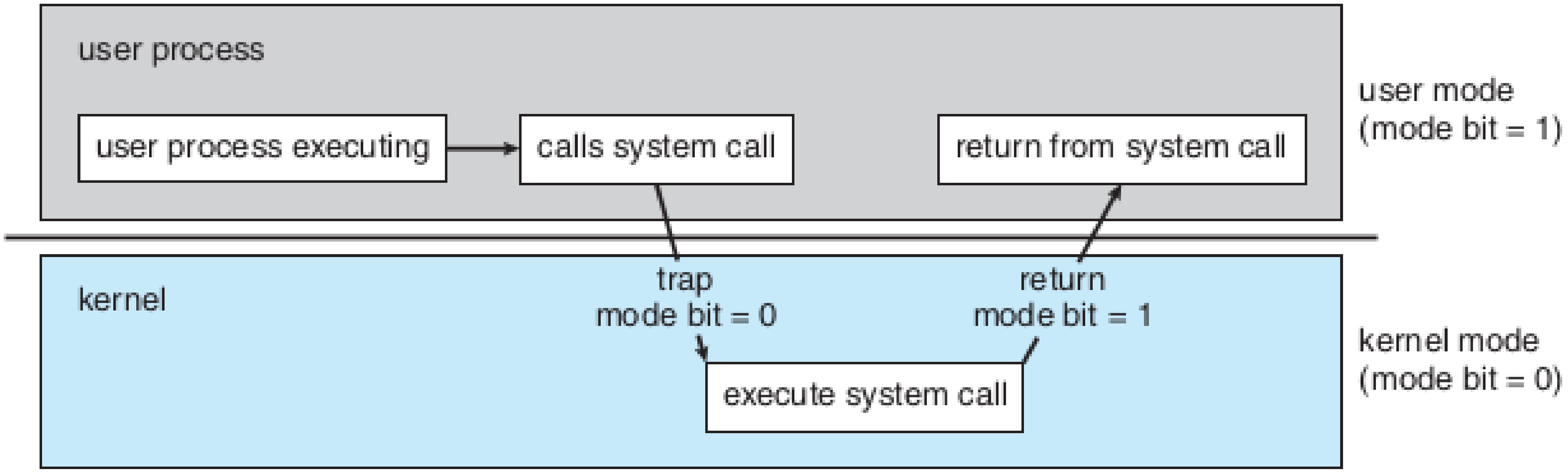


Figure 1.10 Transition from user to kernel mode.

Software interrupt instruction

- How does application code run INT instruction?
  - C library functions like printf(), scanf() which do I/O requests contain the INT instruction!
  - Control flow
    - Application code -> printf -> INT -> OS code -> back to printf code -> back to application code

Example: C program

```
int main() {
    int i, j, k;
    k = 20;
    scanf("%d", &i);  // This jumps into OS and returns back
    j = k + i;
    printf("%d\n", j); // This jumps into OS and returns back
    return 0;
}
```

Interrupt driven OS code

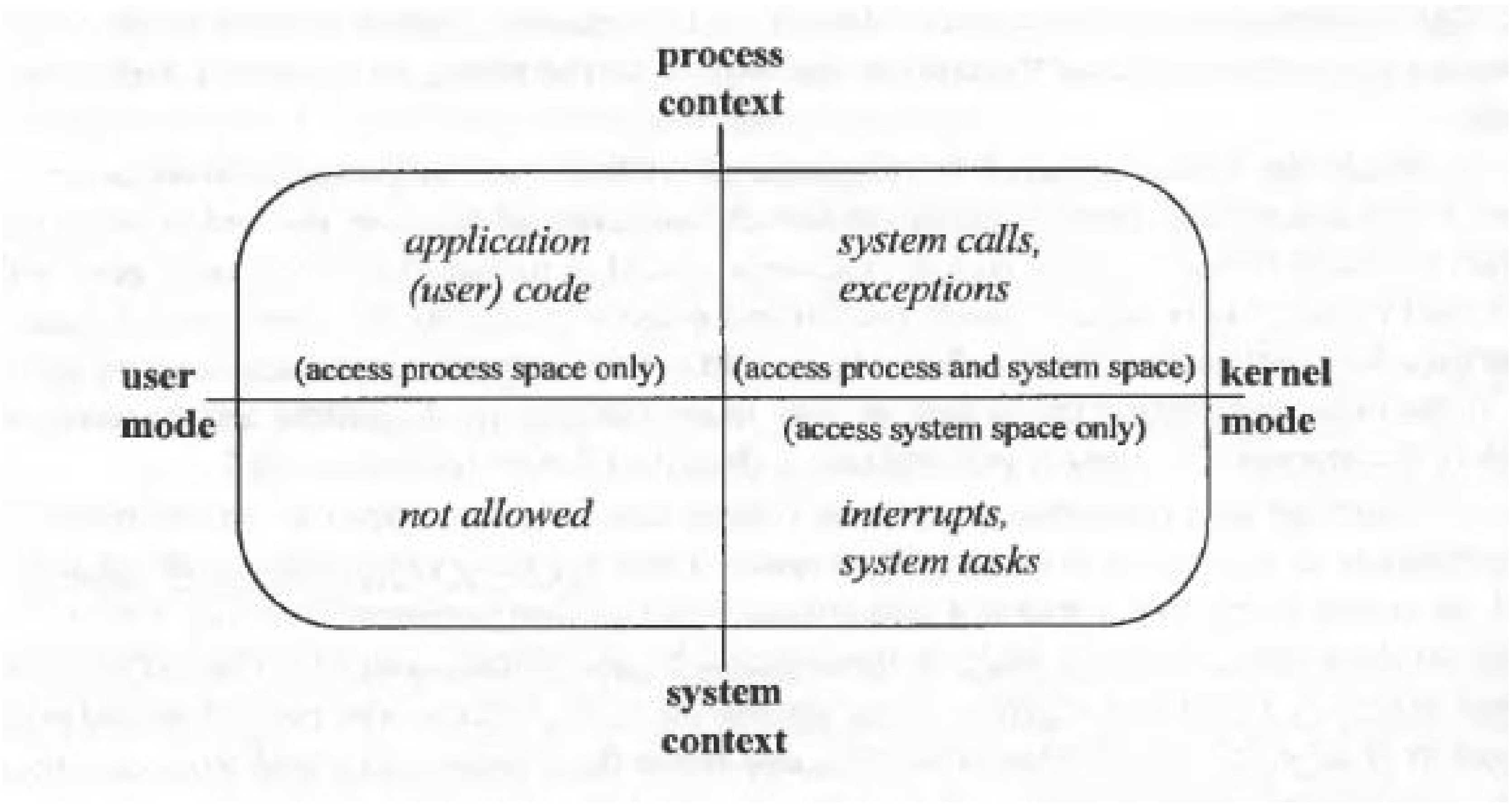
- OS code is sitting in memory , and runs intermittantly . When?
  - On a software or hardware interrupt or exception!
  - Event/Interrupt driven OS!
  - Hardware interrupts and exceptions occur asynchronously (un-predictedly) while software interrupts are caused by application code

Interrupt driven OS code

- Timer interrupt and multitasking OS
  - Setting timer register is a privileged instruction.
  - After setting a value in it, the timer keeps ticking down and on becoing zero the timer interrupt is raised again (in hardware automatically)
  - OS sets timer interrupt and “passes control” over to some application code. Now only application code running on CPU !
  - When time allocated to process is over, the timer interrupt occurs and control jumps back to OS (hardware interrupt mechanism)
  - The OS code that runs here (the ISR) is called “scheduler”
  - OS can now schedule another program

What runs on the processor ?

- 4 possibilities.



System Calls, fork(), exec()

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Credits: Slides of “OS Book” ed10.

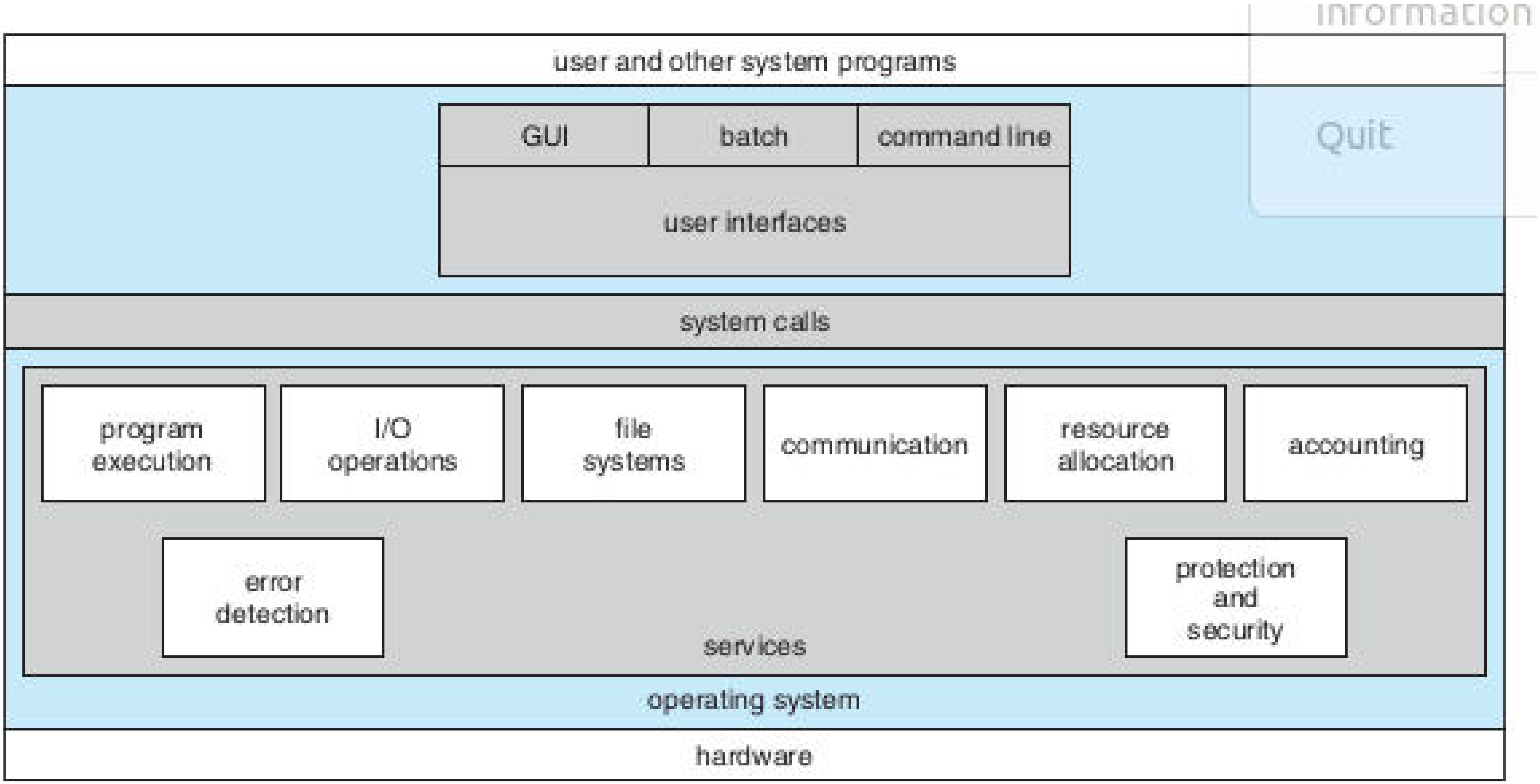


Figure 2.1 A view of operating system services.

System Calls

- Services provided by operating system to applications
  - Essentially available to applications by calling the particular software interrupt application
    - All system calls essentially involve the “INT 0x80” on x86 processors + Linux
    - Different arguments specified in EAX register inform the kernel about different system calls
- The C library has wrapper functions for each of the system calls
  - E.g. open(), read(), write(), fork(), mmap(), etc.

Types of System Calls

- **File System Related**
  - **Open(), read(), write(), close(), etc.**
- **Processes Related**
  - **Fork(), exec(), ...**
- **Memory management related**
  - **Mmap(), shm_open(), ...**
- **Device Management**
- **Information maintainance – time,date**
- **Communication between processes (IPC)**
- **Read man syscalls**

https://linuxhint.com/list_of_linux_syscalls/

EXAMPLES OF WINDOWS AND UNIX SYSTEM CALLS

	Windows	**Unix**
Process Control	`CreateProcess()`	`fork()`
	`ExitProcess()`	`exit()`
	`WaitForSingleObject()`	`wait()`
File Manipulation	`CreateFile()`	`open()`
	`ReadFile()`	`read()`
	`WriteFile()`	`write()`
	`CloseHandle()`	`close()`
Device Manipulation	`SetConsoleMode()`	`ioctl()`
	`ReadConsole()`	`read()`
	`WriteConsole()`	write()
Information Maintenance	`GetCurrentProcessID()`	`getpid()`
	`SetTimer()`	`alarm()`
	`Sleep()`	`sleep()`
Communication	`CreatePipe()`	`pipe()`
	`CreateFileMapping()`	`shm_open()`
	`MapViewOfFile()`	`mmap()`
Protection	`SetFileSecurity()`	`chmod()`
	`InitlializeSecurityDescriptor()`	`umask()`
	`SetSecurityDescriptorGroup()`	`chown()`

Code schematic

```
int main() {
    int a = 2;
    printf("hi\n");
}
-----
C Library
-----
int printf("void *a, ...) {
    ...
    write(1, a, ...);
}
int write(int fd, char *, int len) {
    int ret;
    ...
    mov $5, %eax,
    mov ... %ebx,
    mov ..., %ecx
    int $0x80
    __asm__("movl  %eax, -4(%ebp)");
# -4ebp is ret
    return ret;
}
```

```
-------user-kernel-mode-boundary----
//OS code
int sys_write(int fd, char *, int len) {
    figure out location on disk
    where to do the write and
    carry out the operation,
    etc.
}
```

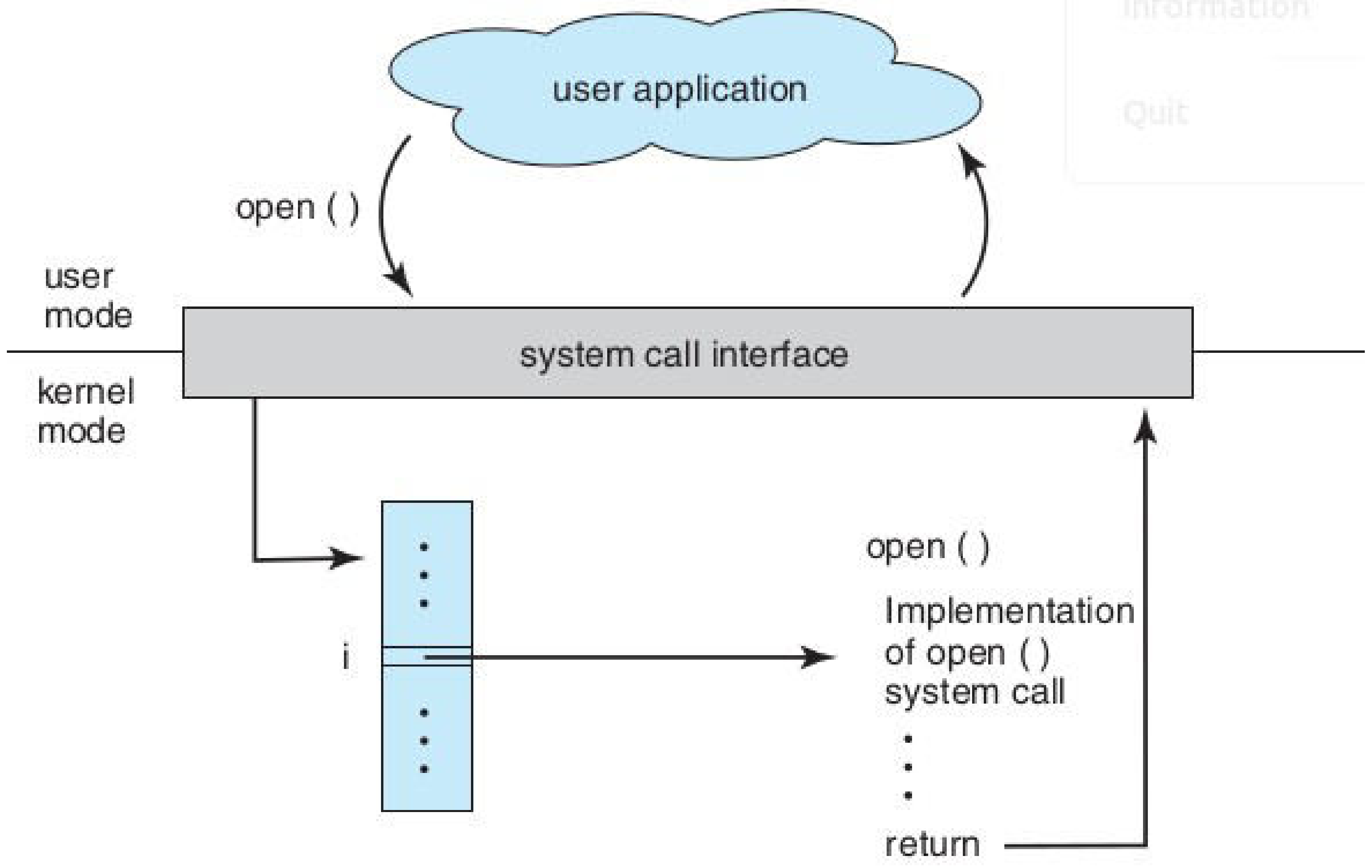


Figure 2.6 The handling of a user application invoking the `open()` system call.

Two important system calls
Related to processes

fork() and exec()

Process

- A program in execution
- Exists in RAM
- Scheduled by OS
  - In a timesharing system, intermittantly scheduled by allocating a time quantum, e.g. 20 microseconds
- The “ps” command on Linux

Process in RAM

- **Memory is required to store the following components of a process**
  - **Code**
  - **Global variables (data)**
  - **Stack (stores local variables of functions)**
  - **Heap (stores malloced memory)**
  - **Shared libraries (e.g. code of printf, etc)**
  - **Few other things, may be**

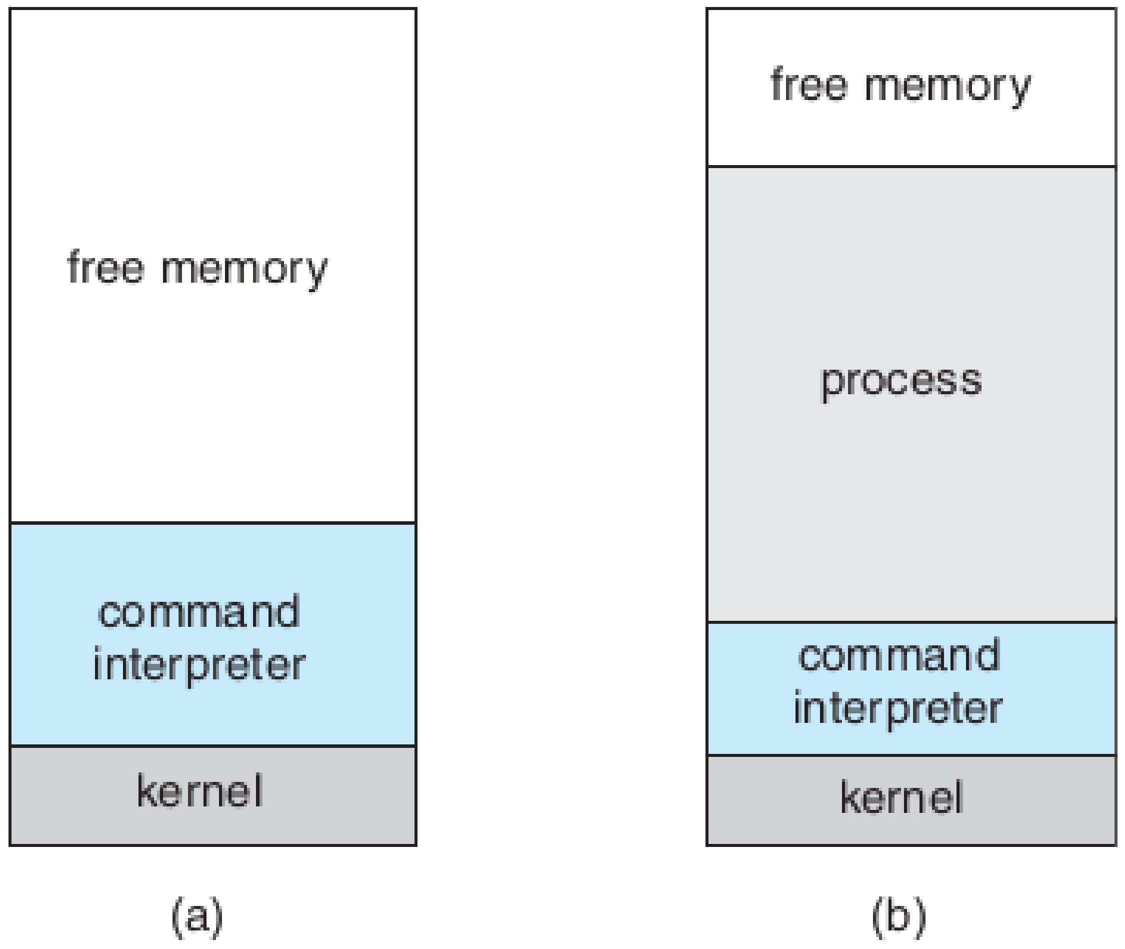
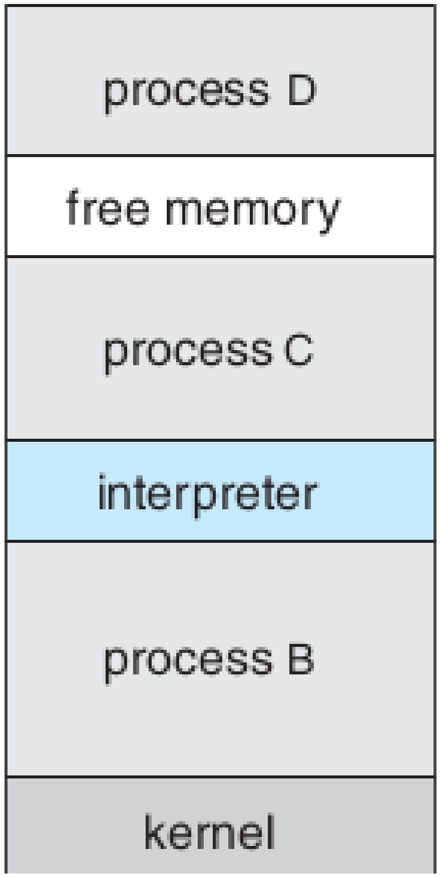


Figure 2.9 MS-DOS execution. (a) At system startup. (b) Running a program.

MS-DOS: a single tasking operating system
Only one program in RAM at a time, and only one program can run at a time



A multi tasking system
With multiple programs loaded in memory
Along with kernel
(A very simplified conceptual diagram. Things are more complex in reality)

fork()

- A running process creates it’s duplicate!
- After call to fork() is over
  - Two processes are running
  - Identical
  - The calling function returns in two places!
  - Caller is called parent, and the new process is called child
  - PID is returned to parent and 0 to child

exec()

- Variants: execvp(), execl(), etc.
- Takes the path name of an executable as an argument
- Overwrites the existing process using the code provided in the executable
- The original process is OVER ! Vanished!
- The new program starts running overwritting the existing process!

Shell using fork and exec

- Demo
- The only way a process can be created on Unix/Linux is using fork() + exec()
- All processes that you see were started by some other process using fork() + exec() , except the initial *“init” process*
- *When you click on “firefox” icon, the user-interface program does a fork() + exec() to start firefox; same with a command line shell program*
- The “bash” shell you have been using is nothing but an advanced version of the shell code shown during the demo
- See the process tree starting from “init”
- Your next assignment

The boot process, once again

- BIOS
- Boot loader
- OS – kernel
- Init created by kernel by Hand(kernel mode)
- Kernel schedules init (the only process)
- Init fork-execs some programs (user mode)
  - Now these programs will be scheduled by OS
- Init -> GUI -> terminal -> shell
  - One of the typical parent-child relationships