Operating System Concepts

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* **Introduction:**
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  - What is an OS?
  - Booting process in brief
  - Functions of an OS

Operating System Concepts

* **UNIX System Architecture Design**
  - Major subsystem of an UNIX system: File subsystem & Process Control subsystem.
  - System Calls & its catagories
  - Dual Mode Operation

* **Process Management**
  - What is Process & PCB?
  - States of the process
  - CPU scheduling & CPU scheduling algorithms
  - Inter Process Communication: Shared Memory Model & Message Passing Model

Operating System Concepts

* **Process Management**
  - Process Synchronization/Co-ordination
  - Deadlocks & deadlock handling methods

* **Memory Management**
  - Swapping
  - Memory Allocation Methods
  - Internal Fragmentation & External Fragmentation
  - Segmentation
  - Paging
  - Virtual Memory Management

* **File Management**
  - What is file?
  - What is filesystem & filesystem structure?
  - Disk space allocation methods
  - Disk scheduling algorithms

Q. Why there is a need of an OS?

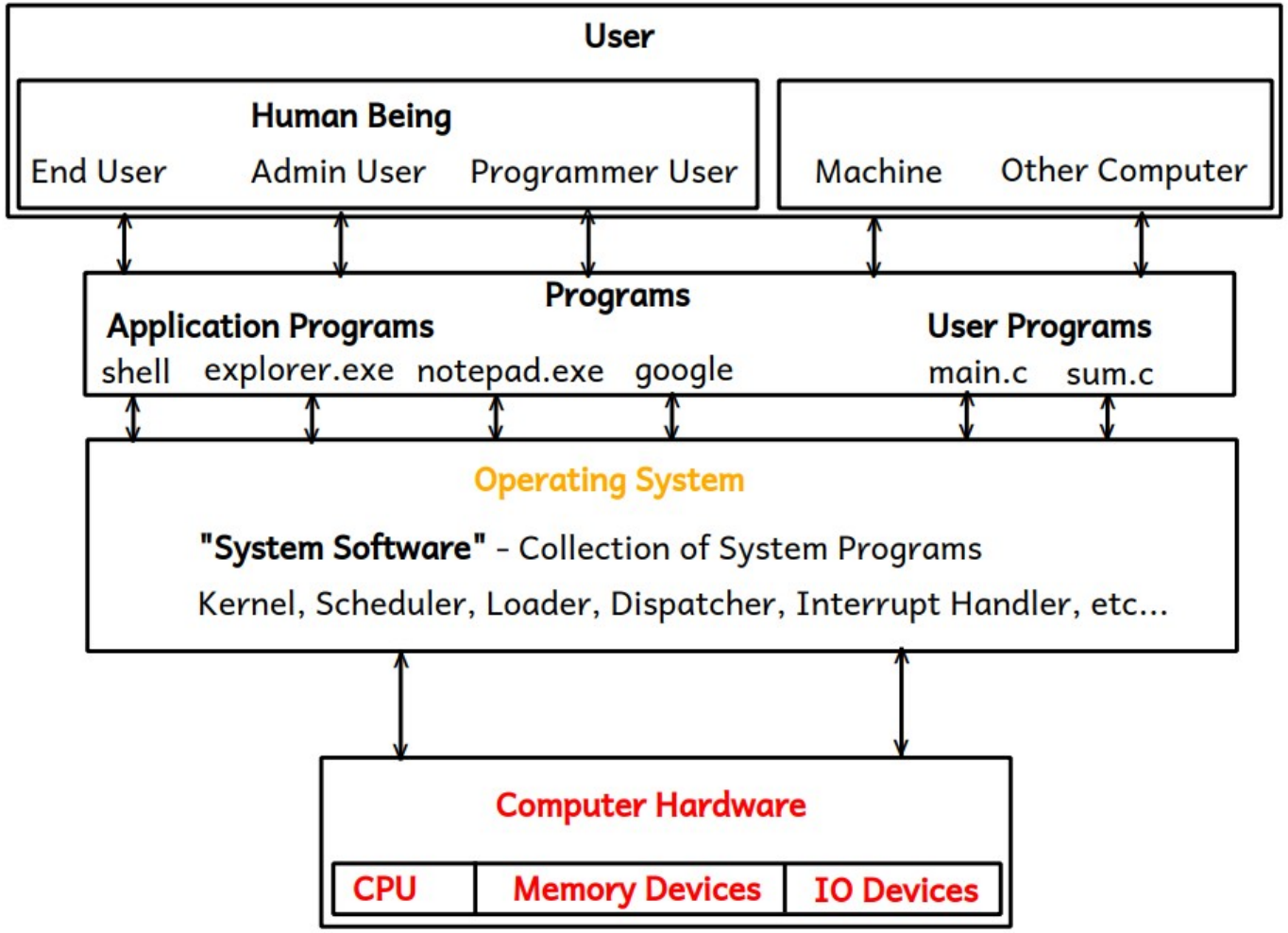
- Computer is a machine/hardware does different tasks efficiently & accurately.

- Basic functions of computer:

    1. Data Storage
    2. Data Processing
    3. Data Movement
    4. Control

- As any user cannot communicates/interacts directly with computer hardware to do different tasks, and hence there is need of some interface between user and hardware.

Operating System Concepts



Operating System Concepts

Q. What is a Software?

- Software is a collection of programs.

Q. What is a Program?

- Program is a finite set of instructions written in any programming language (either low level or high level programming language) given to the machine to do specific task.

- Three types of programs are there:

1. **"user programs":** programs defined by the programmer user/developers
   e.g. main.c, hello.java, addition.cpp etc....
2. **"application programs":** programs which comes with an OS/can be installed later
   e.g. MS Office, Notepad, Compiler, IDE's, Google Chrome, Mozilla Firefox, Calculator, Games etc....
3. **"System Programs":** programs which are inbuilt in an OS/part of an OS.
   e.g. Kernel, Loader, Scheduler, Memory Manager etc...

Q. What is an IDE (Integrated Software Developement) ?

- It is an application software i.e. collection of tools/programs like **source code editor, preprocessor, compiler, linker, debugger** etc... required for **faster software developement.**

e.g. VS code editor, MS Visual Studio, Netbeans, Android Studio, Turbo C etc....

1. "Editor": it is an application program used for to write a source code.

e.g. notepad, vi editor, gedit etc...

2. "Preprocessor": it is an application program gets executes before compilation and does two jobs - it executes all preprocessor directives and removes all comments from the source code.

e.g. cpp

3. "Compiler": it is an application program which convert high level programming language code into low level programming language code i.e. human understandable language code into the machine understandable language code.

e.g. gcc, tc, visual c etc...

4. "Assembler": it is an application program which converts assembly language code into machine language code/object code.

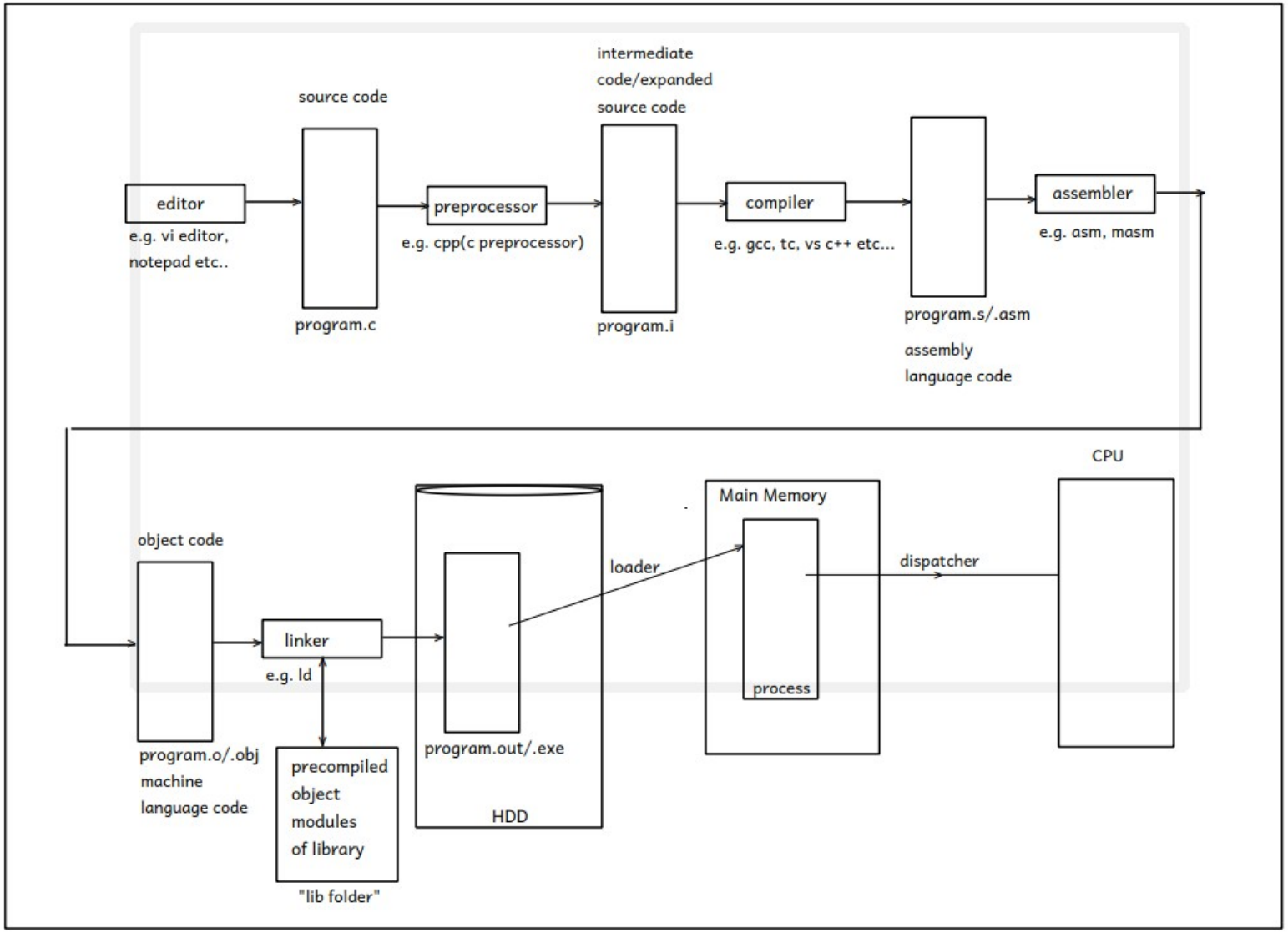
e.g. masm, tasm etc...

- Program written in any programming language is called as a **"source code".**

5. "Linker": it is an application program which links object file/s in a program with precompiled object modules of library functions exists in a lib folder and creates final single executable file.

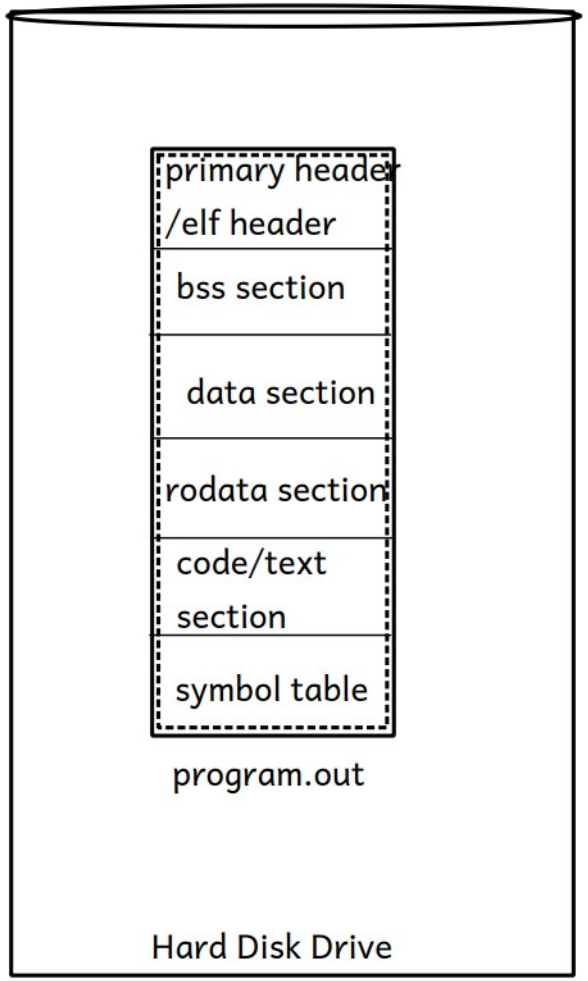
e.g. ld: link editor in Linux.

Operating System Concepts



Structure of an executable file

ELF file format in Linux



1. **primary header/exe header:** it contains information which is required to starts an execution of the program.

e.g. - addr of an entry point function --> main() function

- **magic number:** it is constant number generated by the compiler which is file format specific.

- magic number in Linux starts with ELF in its eq **hexadecimal format**.

- info about remaining sections.

2. **bss(block started by symbol) section:** it contains uninitialized global & static vars
3. **data section:** it contains initialized global & static vars
4. **rodata (readonly data) section:** it contains string literals and constants.
5. **code/text section:** it contains an executable instructions
6. **symbol table:** it contains info about functions and its vars in a tabular format.

Q. What is an Operating System?

- An OS is a **system software** (i.e. collection of system programs) which acts as an interface between user and hardware.

- An OS also acts as an interface between programs and hardware.

- An OS allocates resources like main memory, CPU time, i/o devices access etc... to all running programs, hence it is also called as a **resource allocator.**

- An OS controls an execution of all programs and it also controls hardware devices which are connected to the computer system and hence it is also called as a **control program.**

Q. What is an Operating System?

- An OS manages limited available resources among all running programs, hence it is also called as a **resource manager.**

- From End User: An OS is a software (i.e. collection of programs) comes either in CD/DVD, has following main components:

1. Kernel: It is a core program/part of an OS which runs continuosly into the main memory does basic minimal functionalities of it.

e.g. Linux: vmlinuz, Windows: ntoskrnl.exe

2. Utility Softwares: e.g. disk manager, windows firewall, anti-virus software etc...

3. Application Softwares: e.g. google chrome, shell, notepad, msoffice etc...

 # Functions of an OS:

Basic minimal functionalities/Kernel functionalities:

1. Process Management
2. Memory Management
3. Hardware Abstraction
4. CPU Scheduling
5. File & IO Management

Extra utility functionalities/optional:

6. Protection & Security
7. User Interfacing
8. Networking

 # Booting:

- There are two steps of booting:

1. Machine Boot:

Step-1: when we switched on the power supply current gets passed to the motherboard on which from ROM memory one micro-program gets executes first called as **BIOS(Basic Input Output System).**

Step-2: first step of BIOS is **POST(Power On Self Test),** under POST it checks wheather all peripheral devices are connected properly or not and their working status.

Step-3: After POST it invokes **Bootstrap Loader** programs, which searches for available **bootable devices** presents in the system, and it selects only one bootable device at a time as per the priority decided in BIOS settings.

2. System Boot:

Step-4: After selection of a bootable device (budefault HDD), **Bootloader Program** in it gets invokes which displays list of names operating systems installed on the disk, from which user need to select any one OS.

Step-5: Upon selection of an OS, **Bootstrap Program** of that OS gets invokes, which locates the kernel and load into the main memory

UNIX Operating System:

- UNIX: UNICS – **Uniplexed Information & Computing Services/System.**

- UNIX was developed at **AT&T Bell Labs** in US, in the decade of 1970's by Ken Thompson, Denies Ritchie and team.

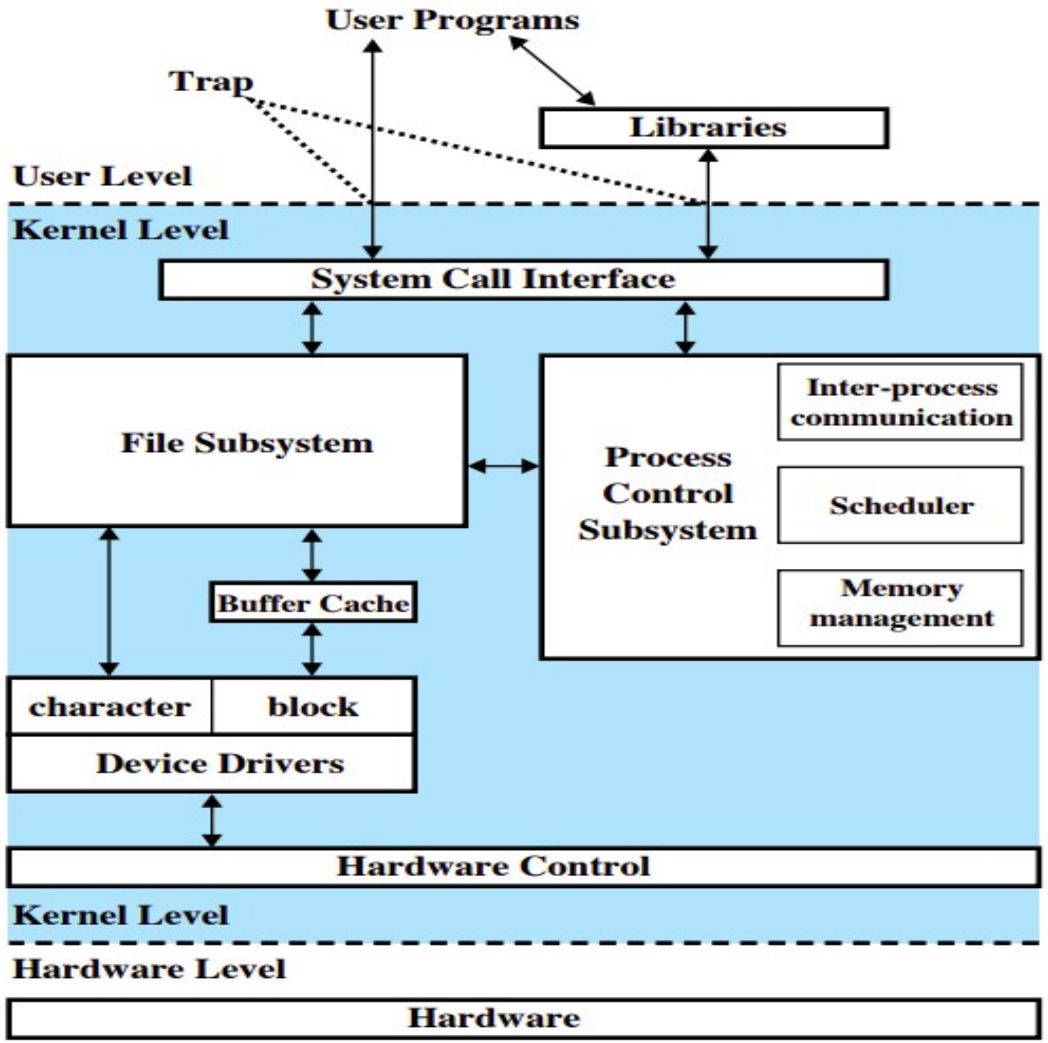
- It was first run on a machine **DEC-PDP-7** (Digital Equipment Corporation – Programmable Data Processing-7).

- UNIX is the first **multi-user, multi-programming** & **multi-tasking** operating system.

- UNIX was specially designed for developers by developers

- System architecture design of UNIX is followed by all modern OS's like Windows, Linux, MAC OS X, Android etc..., and hence UNIX is referred as mother of all modern operating systems.

Operating System Concepts



Operating System Concepts

- Kernel acts as an interface between programs and hardware.

- Operating System has subsystems like **System Call Interface, File subsystem, Process Control Subsystem(IPC, Memory Management & CPU Scheduling), Device Driver, Hardware Control/Hardware Abstraction Layer.**

- There are two major subsystems:

1. Process Control Subsystem

2. File Subsystem

- In UNIX, whatever is that can be stored is considered as a file and whatever is active is reffered as a process.

- File has space & Process has life.

- From UNIX point of view all devices are considered as a file
- In UNIX, devices are catagorises into two catagories:

1. Character Devices: Devices from which data gets transfered character by character --> character special device file

e.g. keyboard, mouse, printer, monitor etc...

2. Block Devices: Devices from which data gets transfered block by block --> block special device file

e.g. all storage devices.

- **Device Driver:**It is a program/set of programs enable one or more hardware devices to communicate with the computer’s operating system.

Operating System Concepts

- Hardware Control Layer/Block does communication with control logic block i.e. controller of a hardware.

 # System Calls: are the functions defined in a C, C++ & Assembly languages, which provides interface of services made available by the kernel for the user (programmer user).

- If programmers want to use kernel services in their programs, it can be called directly through system calls or indirectly through set of libary functions provided by that programming language.

- There are 6 catagories of system calls:

1. **Process Control System Calls:** e.g. fork(), _exit(), wait() etc...
2. **File Operations System Calls:** e.g. open(), read(), write(), close() etc...
3. **Device Control System Calls:** e.g. open(), read(), write(), ioctl() etc...

4. Accounting Information System Calls: e.g. getpid(), getppid(), stat() etc...

5. Protection & Security System Calls: e.g. chmod(), chown() etc...

6. Inter Process Communication System Calls: e.g. pipe(), signal(), msgget() etc...

- In UNIX 64 system calls are there.

- In Linux more than 300 system calls are there

- In Windows more than 3000 system calls are there

- When system call gets called the CPU switched from user defined code to system defined code, and hence system calls are also called as **software interrupts/trap.**

 # Dual Mode Operation:

- System runs in two modes:

1. System Mode

2. User Mode

1. System Mode:

- When the CPU executes system defined code instructions, system runs in a system mode.

- System mode is also reffered as kernel mode/monitor mode/supervisor mode/priviledged mode.

2. User Mode:

- When the CPU executes user defined code instructions, system runs in a user mode.

- User mode is also reffered as non-priviledged mode.

- Throughout execution, the CPU keeps switch between kernel mode and user mode

 # Dual Mode Operation:

- Throughout an execution of any program, the CPU keeps switcesh in between kernel mode and user mode and hence system runs in two modes, it is reffered as **dual mode operation.**

- To differentiate between user mode and kernel mode one bit is there onto the CPU which is maintained by an OS, called as **mode bit**, by which the CPU identifies wheather currently executing instruction is of either system defined code instruction/s or user defined code instruction/s.

- In Kernel mode value of **mode bit = 0**, whereas

- In User mode **mode bit = 1.**

Process Management

- When we say an OS does process management it means an OS is responsible for process creation, to provide environment for an execution of a process, resource allocation, scheduling, resources management, inter process comminication, process coordination, and terminate the process.

Q. What is a Program?

- **User view:** Program is a set of instructions given to the machine to do specific task.

- **System view:** Program is an executable file divided into sections like exe header, bss section, data section, rodata section, code section, symbol table.

Q. What is a Process?

User view:

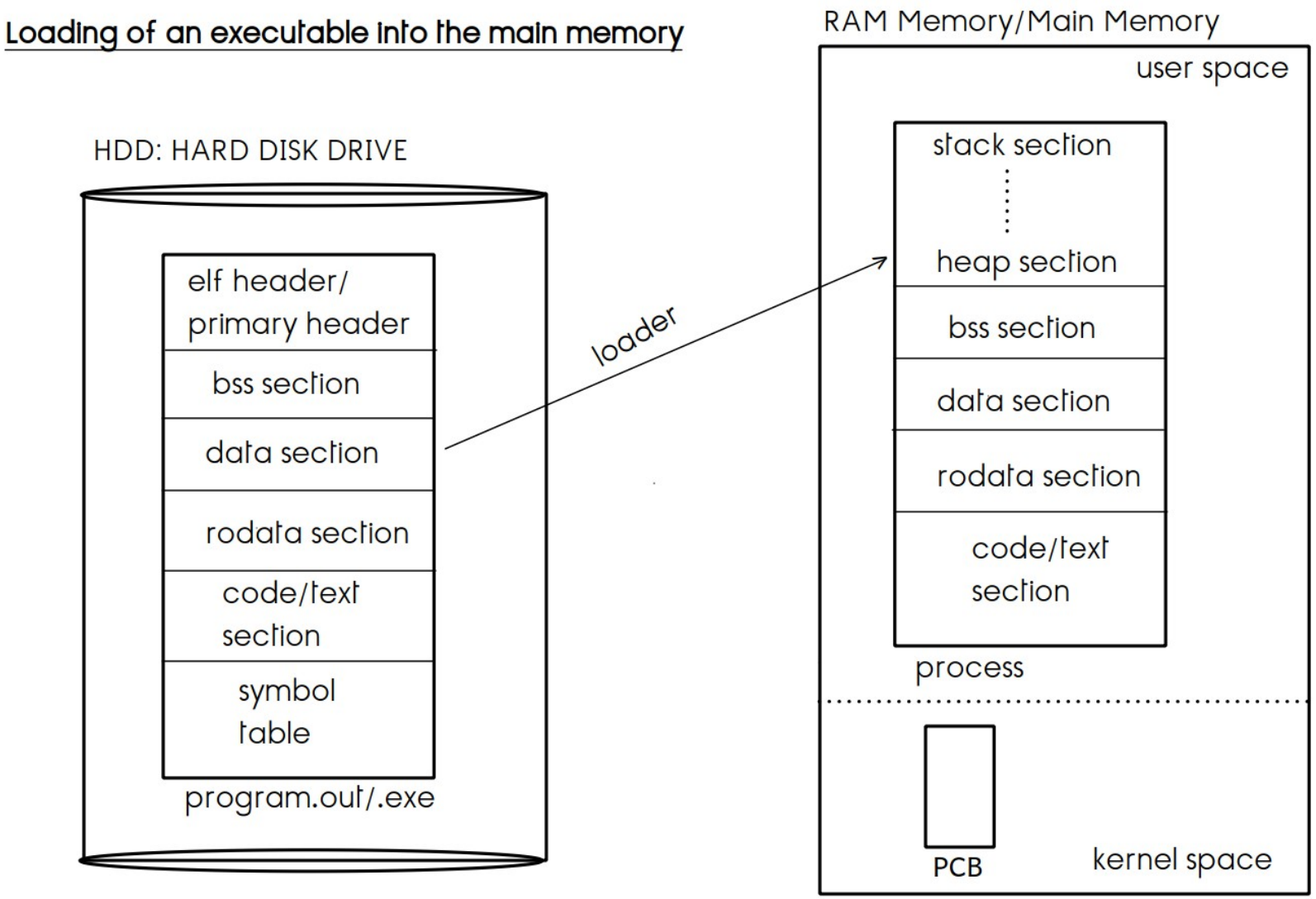
- Program in execution is called as a process.
- Running program is called as a process.
- When a program gets loaded into the main memory it is reffered as a process.
- Running instance of a program is reffered as a process.

System view:

- Process is a file loaded into the main memory which has got bss section, rodata section, code section, and two new sections gets added for the process:

stack section: contains function activation records of called functions.

heap section: dynamically allocated memory


Loading of an executable into the main memory
HDD: HARD DISK DRIVE
elf header/
primary header
bss section
data section
rodata section
code/text
section
symbol
table
program.out/.exe
loader
RAM Memory/Main Memory
user space
stack section
heap section
bss section
data section
rodata section
code/text
section
process
PCB
kernel space

Operating System Concepts

- As a kernel, core program of an a OS runs continuosly into the main memory, **part of the main memory which is occupied by the kernel reffered as kernel space and whichever part is left is reffered as an user space**, so main memory is divided logically into two parts: **kernel space & user space.**

- User programs gets loaded into the user space only.

- When we execute a program or upon submission of a process very first one structure gets created into the main memory inside kernel space by an OS in which all the information which is required to control an execution of that process can be kept, this structure is reffered as a **PCB: Process Control Block**, is also called as a **Process Descriptor.**

- Per process one PCB gets created and PCB remains inside the main memory throughout an execution of a program, upon exit PCB gets destroyed from the main memory.

- PCB mainly contains: PID, PPID, PC, CPU sched information, memory management information, information about resources allocated for that process, execution context etc...

 # Process States:

- Throughout execution, process goes through different states out of which at a time it can be only in a one state.

- States of the process:

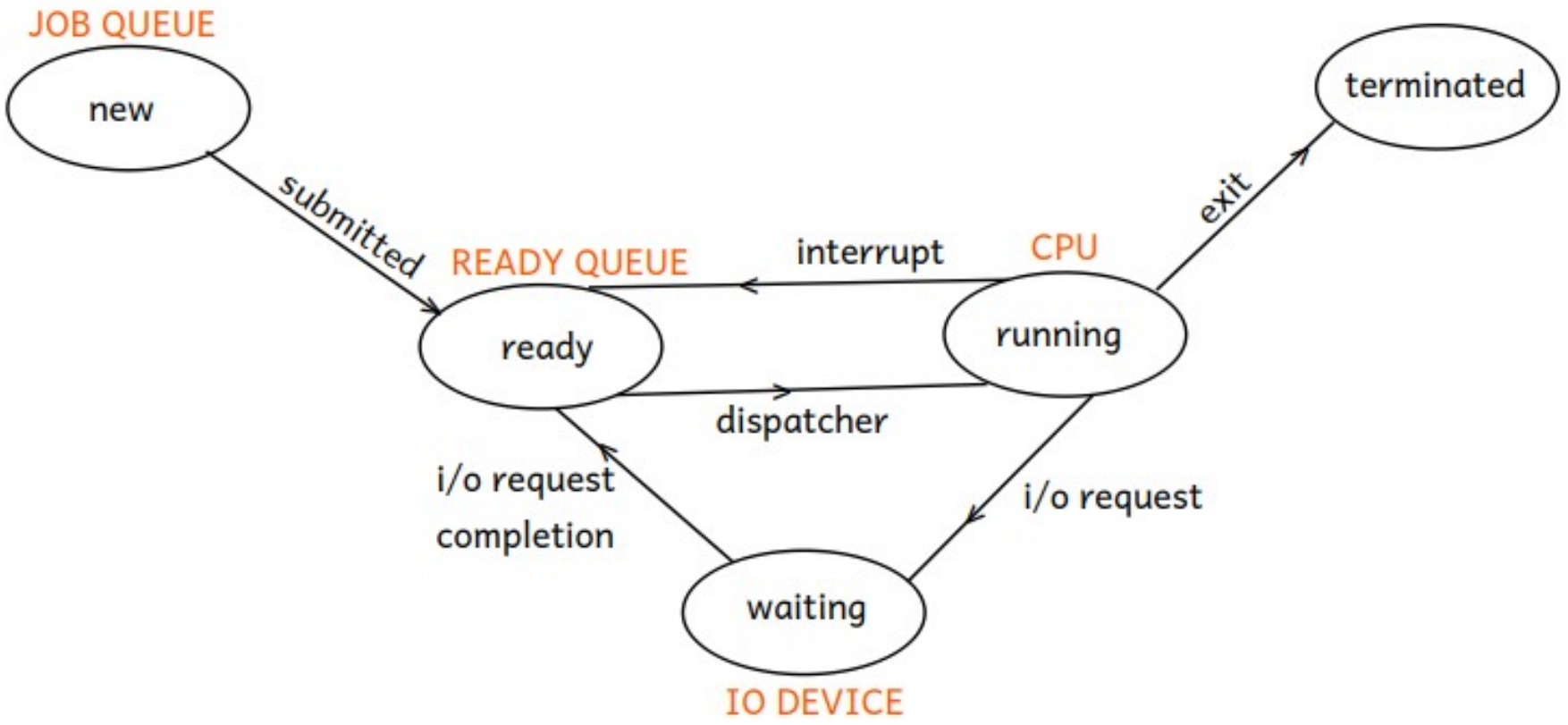
1. New state: upon submission or when a PCB for a process gets created into the main memory process is in a new state.

2. Ready state: after submission, if process is in the main memory and waiting for the CPU time, it is in a ready state.

3. Running state: if currently the CPU is executing any process then state of that process is considered as a running state.

4. Waiting state: if a process is requesting for any i/o device then state of that process is considered as a waiting state.

5. Terminated state: upon exit, process goes into terminated state and its PCB gets destroyed from the main memory.



PROCESS STATE DIAGRAM

Operating System Concepts

1. multi-programming: system in which more than one processes can be submitted/ an execution of more than one programs can be started at a time.

- **degree of multi-programming:** no. of programs that can be submitted into the system at a time.

2. multi-tasking: system in which, the CPU can execute more than one programs simultaneously/concurrently, the speed at which it executes multiple programs simultaneosuly it seems that it executes multiple programs at a time.

At a time the CPU can execute only one program

- **time-sharing:** system in which CPU time gets shared among all running programs.

3. multi-threading: system in which it seems that the CPU can execute more than one threads which are of either same process or are of different processes simultaneously/concurrently.

4. multi-processor: system can run on a machine in which more than one CPU's are connected in a closed circuit.

5. multi-user: system in which multiple users can loggedin at a time.

Operating System Concepts

 # Process States:

- To keep track on all running programs, an OS maintains few **data structures** reffered as **kernel data structures:**

1. Job queue: it contains list of PCB's of all submitted processes.

2. Ready queue: it contains list of PCB's of processes which are in the main memory and waiting for the CPU time.

3. Waiting queue: it contains list of PCB's of processes which are requesting for that particular device.

1. Job Scheduler/Long Term Scheduler: it is a system program which selects/schedules jobs/processes from job queue to load them onto the ready queue.

2. CPU Scheduler/Short Term Scheduler: it is a system program which selects/schedules job/process from ready queue to load it onto the CPU.

- Dispatcher: it is a system program which loads a process onto the CPU which is scheduled by the CPU scheduler, and the time required for the dispatcher to stops an execution of one process and to starts an execution of another process is reffered as **dispatcher latency.**

 # Context Switch:

- As during context-switch, the CPU gets switched from an execution context of one process onto an execution context of another process, and hence it is reffered as "context-switch".

- context-switch = state-save + state-restore

- **state-save** of suspended process can be done i.e. an execution context of suspended process gets saved into its PCB.

- state-restore of a process which is scheduled by the CPU scheduler can be done by the dispacther, dispather copies an execution context of process scheduled by the cpu scheduler from its PCB and restore it onto the CPU registers.

- When a high priority process arrived into the ready queue, low priority process gets suspended by means of sending an interrupt, and control of the CPU gets allocated to the high priority process, and its execution gets completed first, then low priority process can be resumed back, i.e. the CPU starts executing suspended process from the point at which it was suspended and onwards.

- CPU Scheduler gets called in the following four cases:

Case 1: Running -> Terminated

Case 2: Running -> Waiting

Case 3: Running -> Ready

Case 4: Waiting -> Ready

- There are two types of CPU scheduling:

1. Non-preemptive: under non-preemptive cpu scheduling, process releases the control of the CPU by its own i.e. voluntarily.

e.g. in above case 1 & case 2

2. Preemptive: under preemptive cpu scheduling, control of the CPU taken away forcefully from the process.

e.g. in above case 3 & 4.

- Following algorithms used for CPU Scheduling:

1. FCFS (First Come First Served) CPU Scheduling

2. SJF (Shortest Job First) CPU Scheduling

3. Round Robin CPU Scheduling

4. Priority CPU Scheduling

- Multiple algorithms are there for CPU scheduling, so there is need to decide which algorithm is best suited at specific situation and which algorithm is an efficient one, to decide this there are certain criterias called as **scheduling criterias**: **cpu utilization, throughput, waiting time, response time and turn-around-time.**

 # CPU Scheduling Criterias:

1. CPU Utilization: one need to select such an algorithm in which utilization of the CPU must be as **maximum** as a possible.

2. Throughput: total work done per unit time. One need to select such an algorithm in which throughput must be as **maximum** possible.

3. Waiting Time: it is the toal amount of time spent by the process into the ready queue for waiting to get control of the CPU from its time of submission. One need to select such an algorithm in which waiting time must be as **minimum** as possible.

4. Response Time: it is a time required for the process to get first response from the CPU from its time of submission. One need to select such an algorithm in which response time must be as **minimum** as possible.

5. Turn-Around-Time: it is the total amount of time required for the process to complete its execution from its time of submission.

One need to select such an algorithm in which turn-around-time must be as **minimum** as possible.

- Turn-around-time is the sum of periods spent by the process into ready queue for waiting and onto the CPU for execution from its time of submission.

Execution Time: it is the total amount of time spent by the process onto the CPU to complete its execution.

CPU Burst Time: total no. of CPU cycles required for the process to complete its execution.

- **Turn-Around-Time = Waiting Time + Execution Time.**

1. FCFS (First Come First Served) CPU Scheduling

- In this algorithm, process which is arrived first into the ready queue gets the control of the CPU first i.e. control of the CPU gets allocated for processes as per their order of an arrival into the ready queue.

- This algorithm is simple to impelement and can be implemented by using fifo queue.

- It is a non-preemptive scheduling algorithm.

 # Convoy effect: due to an arrival of longer processes before shorter processes, shorter processes has to wait for longer time and their average waiting time gets increases, which results into an increase in an average turn-around-time and hence overall system performance gets down.

2. SJF(Shortest Job First) CPU Scheduling:

- In this algorithm, process which is having minimum CPU burst time gets the control of the CPU first.
- SJF algorithm ensures minimum waiting time.
- Under non-preemptive SJF, algorithm fails if the submission time of processes are not same, and hence it can be implemented as preemptive as well.
- Non-preemptive SJF is also called as **SNTF(Shortest-Next-Time-First).**
- Preemptive SJF is also called as **SRTF(Shortest-Remaining-Time-First).**

Starvation: in this algorithm, as shorter processes has got higher priority, process which is having larger CPU burst time may gets blocked i.e. control of the CPU will never gets allocated for it, such situation is called as starvation/indefinite blocking.

3. Round Robin Scheduling Algorithm

- In this algorithm, fixed **time slice** or **time quantum** gets decided in advanced, and at a time control of the CPU may remains allocated with any process maximum for decided time-slice, once the given time slice is finished process gets suspended and control of the CPU gets allocated to the next process for maximum the decided time slice and so on each process gets control of the CPU in a round robin manner.

- If any process completes its execution before allocated time slice then control of the CPU gets allocated for the next process as soon as it is completed for maximum utilization of the CPU.

- This algorithm is purely preemptive.

- This algorithm ensures minimum response time.

- If time slice is minimum then there will be extra overhead onto the CPU due to frequent context-switch.

4. Priority Scheduling

- In this algorithm, process which is having highest priority gets control of the CPU first, each process is having priority in its PCB.

- Minimum priority value indicates highest priority.

- This algorithm is purely preemptive.

- Due to the very low priority process may gets blocked into the ready queue and control of the CPU will never gets allocated for such a process, this situation is reffered as a **starvation** or **indifinite blocking.**

- **Ageing:** it is a technique in which, an OS gradually increments the priority of blocked process, i.e. priority of blocked process gets incremented after some fixed time interval by an OS, so that priority of blocked process becomes sufficient enough to get control of the CPU, and starvation can be avoided.

Inter Process Communication

- Processes running into the system can be divided into two catagories:

1. Independent Processes:

- Process which do not shares data with any other process reffered as an independent process. **OR** Process which do not affects or not gets affected by any other process reffered as an independent process.

2. Co-operative Processes:

- Process which shares data with any other process reffered as co-operative process. **OR** Process which affects or gets affected by any other process reffered as co-operative process.

Q. Why there is need of an IPC?

As concurrently executing co-operative processes shares common resources, so there are quite chances to occur conflictions between them and to avoid this conflictions there is a need of communication takes place between them.

Inter Process Communication

An IPC is one of the important service made available by the kernel, by using which co-operative processes can communicates with each other.

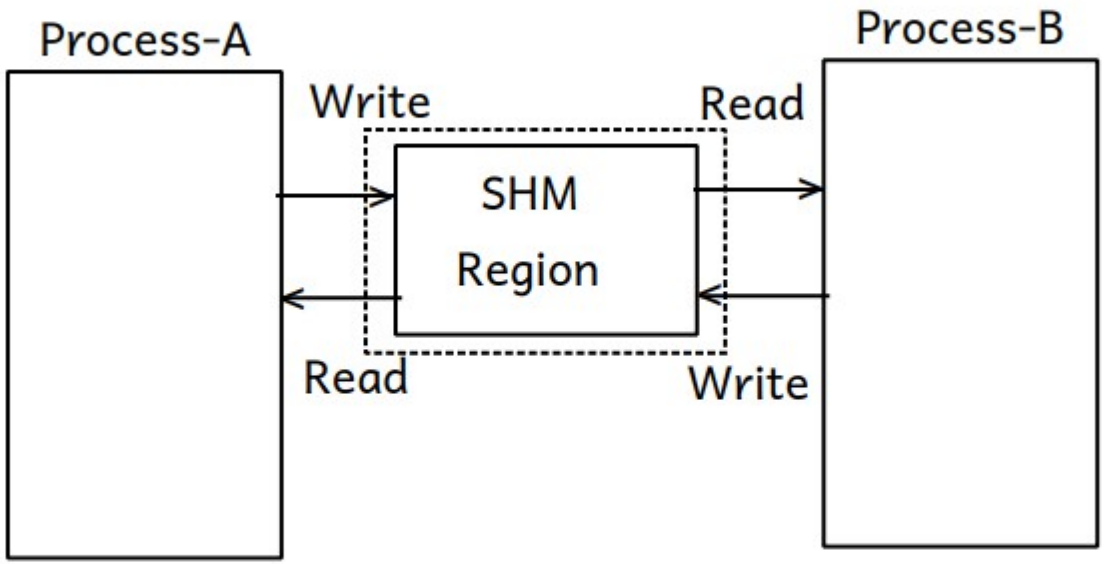
- Inter process communication takes place only between cooperative processes.

- There are two techniques by which IPC can be done/there are two IPC Models:

1. Shared Memory Model: under this technique processes can communicates with each other by means of reading and writing data into the **shared memory region** which is provided by an OS on request by processes want to communicates.

2. Message Passing Model: under this technique, processes can communicates with each other by means of sending messages.

- Shared Memory Model is faster than Message Passing Model.



SHARED MEMORY MODEL

Inter Process Communication

2. Message Passing Model: there are further different IPC techniques under message passing model.

i. Pipe:

- By using Pipe mechanism one process can send message to another process, vice-versa is not possible and hence it is a **unidirectional communication technique.**

- In this IPC mechanism, from one end i.e. from write end one process can writes data into the pipe, wheras from another end i.e. from read end, another process can read data from it, and communication takes place.

- There are two types of pipes:

1. unnamed pipe: in this type of pipe mechanism, only related processes can communicates by using **pipe (|) command.**

2. named pipe: in this type of pipe mechanism, related as well as non-related processes can communicates by using **pipe() system call.**

- By using Pipe only processes which are running on the same system can communicates,

Inter Process Communication

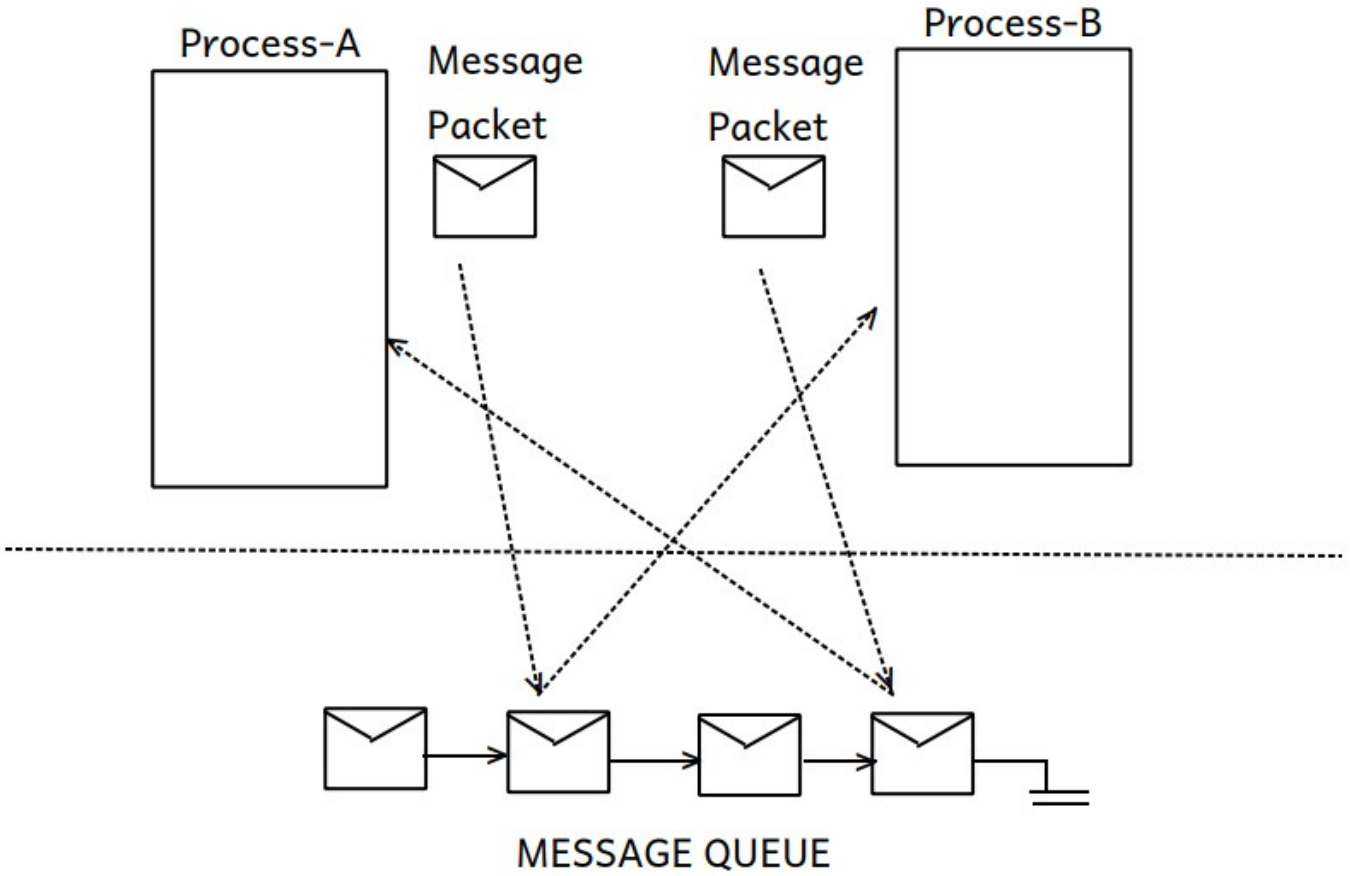
ii. Message Queue:

- By using message queue technique, processes can communicates by means of sending as well as recieving **message packets** to each other via **message queue** provided by the kernel, and hence it is a **bidirectional communication.**

- **Message Packet: Message Header(Information about the message) + Actual Message.**

- Internally an OS maintains message queue in which message packets sent by one process are submitted and can be sent to reciever process and vice-versa.

Inter Process Communication



Inter Process Communication

iii. Signals:

- Processes communicates by means of sending signals as well.

- One process can send signal to another process through an OS.

- An OS sends signal to any process but any other process cannot sends signal to an OS.

Example: When we shutdown the machine an OS sends **SIGTERM** signal to all processes due to which processes gets **terminated normally**, few processes can handle SIGTERM and hence even after recieving this signal from an OS continues execution, to such processes an OS sends **SIGKILL** signal due to which processes gets **terminated forcefully.**

e.g. SIGSTOP, SIGCONT, SIGSEGV etc...

Inter Process Communication

iv. Socket

- Limitation of above all IPC techniques is, only processes running on the same system can communicates, to overcome this limtation **Socket IPC mechanism** has been designed.

- By using socket IPC mechanism, process which is running on one machine can communicates with process running on another machine whereas machines are at remote distance from each other provided they connected in a network (either LAN/WAN/Internet).

- Socket = IP Address + Port Number.

e.g. chat application.

 # Process Coordination/Process Synchronization

Why Process Co-ordination/Synchronization?

- If concurrently executing cooperative processes are accessing common resouces, then there conflictions takes place which may results into the problem of data incosistency, to avoid this problem co-ordination/synchronization between them is required.

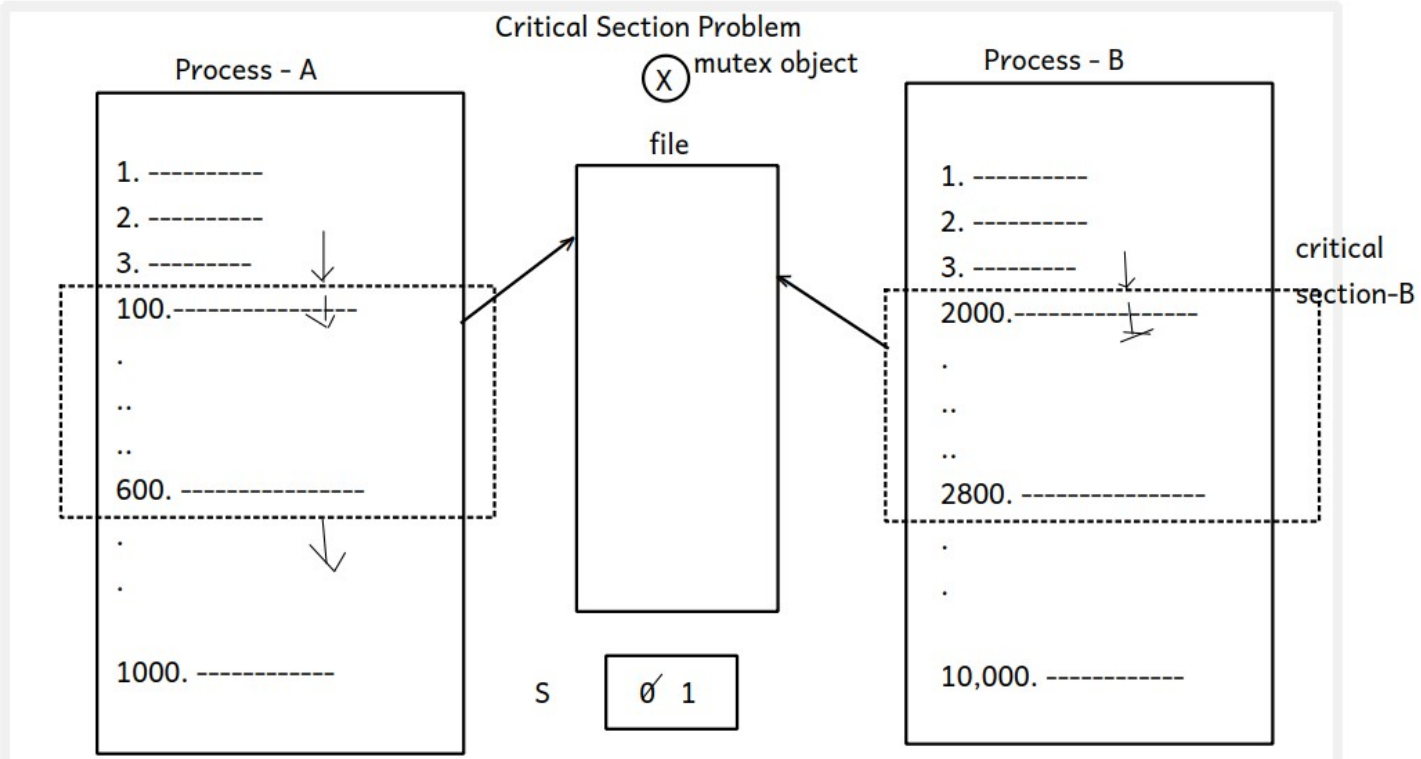
Race Condition: if two or more processes are trying to access same resource at a time, race condition occures, and **data inconsistency** problem may takes place.

- Race condition can be avoided by an OS by

1. deciding order of allocation of resource for processes, and

2. whichever changes did by the last accessed process onto the resource remains final changes.

Critical Section Problem:



"data incosistency" problem occure in above case only when both the sections of process A & B are runniing at a same time, and hence these sections are reffered as critical section, and hence data inconsistency problem may occure when two or more processes are running in their critical sections at a same time, and this problem is also reffered as "critical section problem".

Synchronization Tools:

1. Semaphore: there are two types of semaphore

i. Binary semaphore: can be used when at a time resource can be acquired by only one process.

- It is an integer variable having either value is 0 or 1.

ii. Classic semaphore: can be used when at a time resource can be acquired by more than one processes.

2. Mutex Object: can be used when at a time resource can be acquired by only one process.

- Mutex object has two states: **locked** & **unlocked**, and at a time it can be only in a one state either locked or unlocked.