
Operating System Concepts

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* **Introduction:**

- Why there is need of an OS?
- What is an OS?
- Booting process in brief
- Functions of an OS



* **UNIX System Architecture Design**

- Major subsystem of an UNIX system: File subsystem & Process Control subsystem.
- System Calls & its categories
- 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



* **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

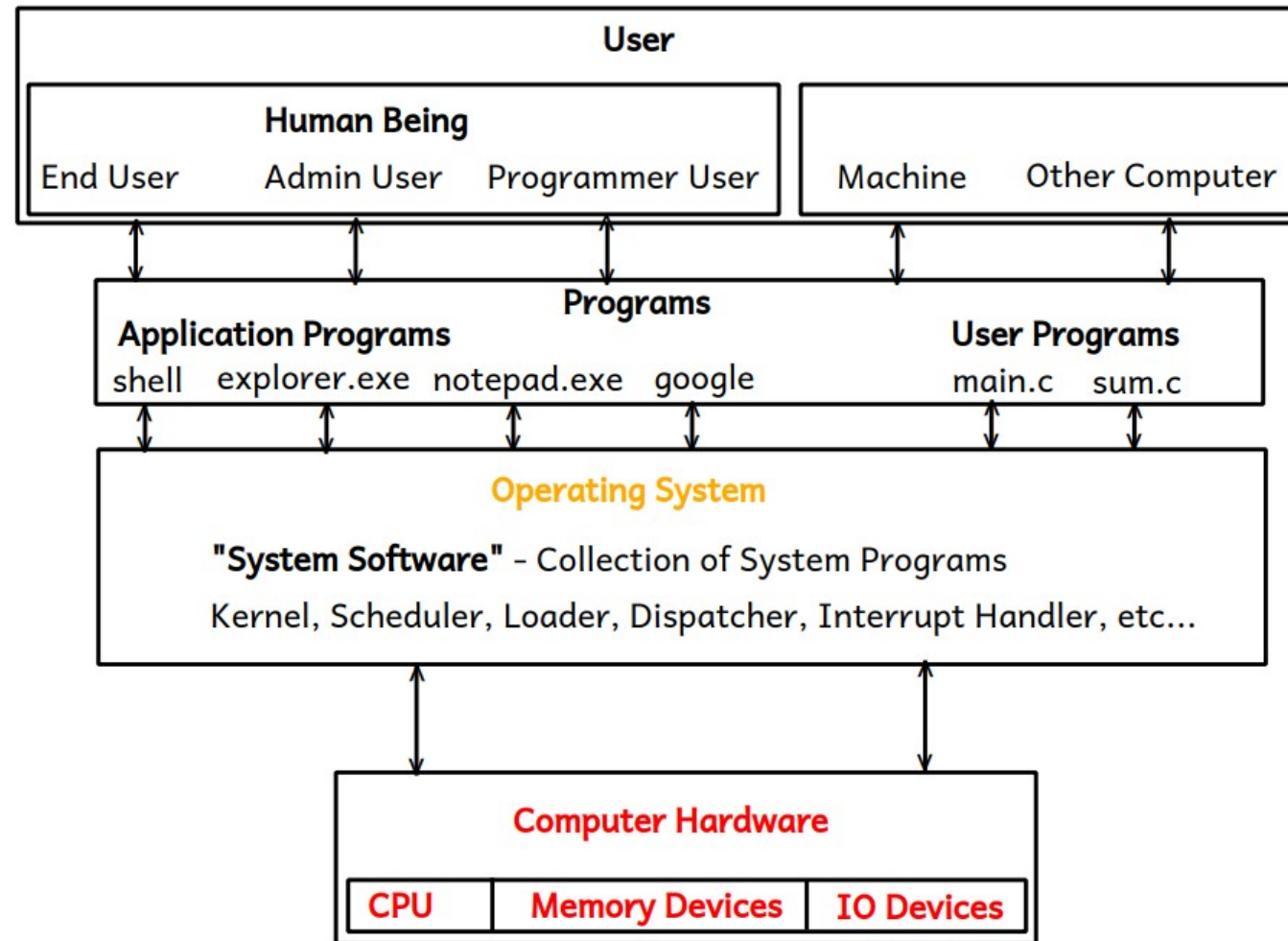


Q. Why there is a need of an OS?

- 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.



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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...



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

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

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...

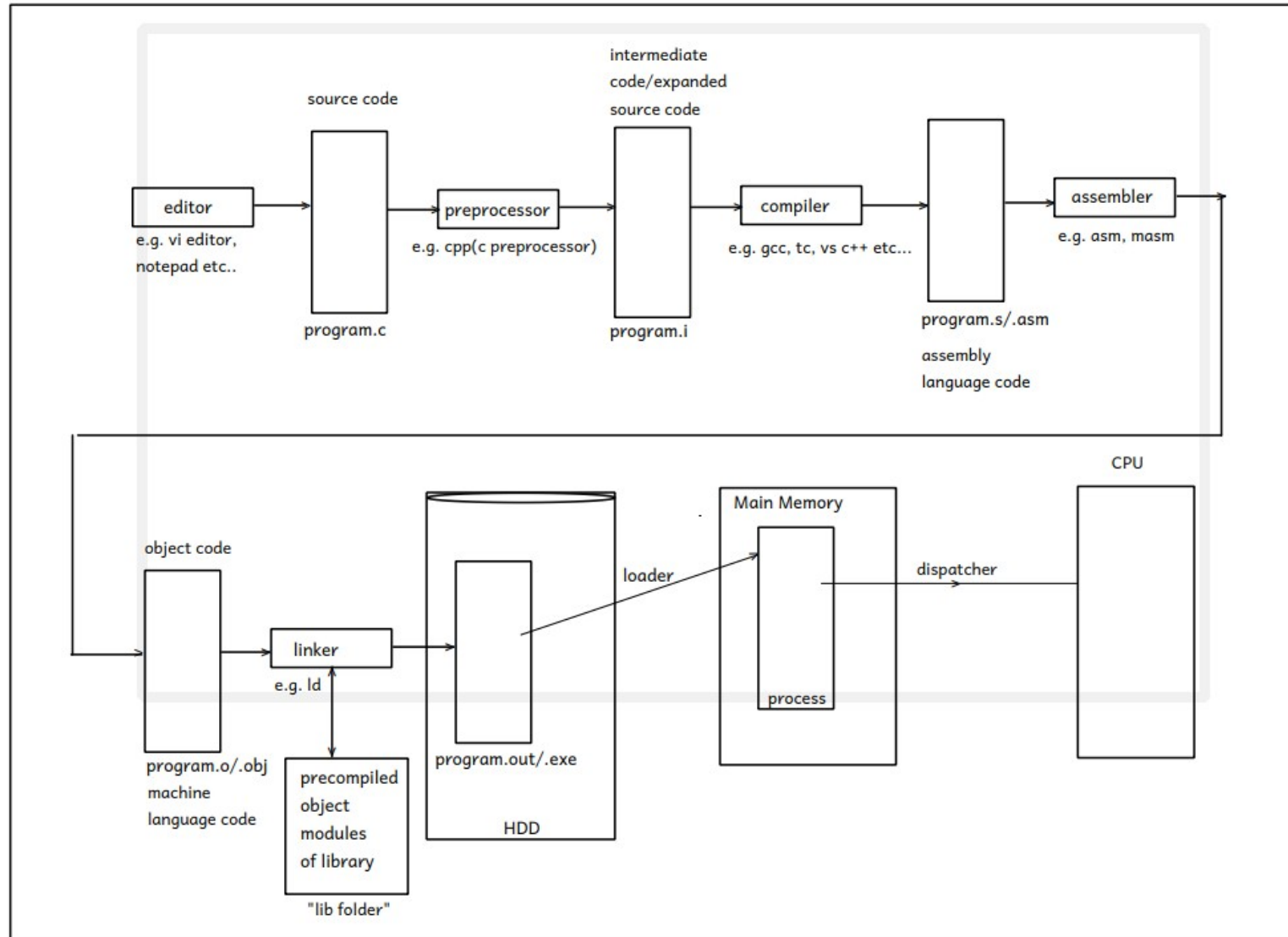
- Program written in any programming language is called as a "**source code**".

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.

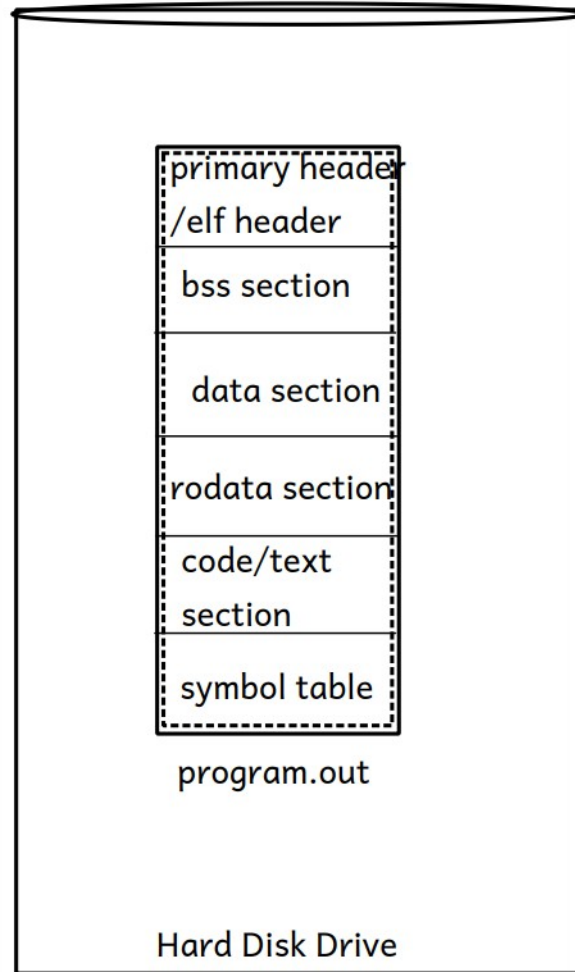


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Structure of an executable file
ELF file format in Linux



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

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

- **magic number:** it is a 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 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 continuously 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



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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



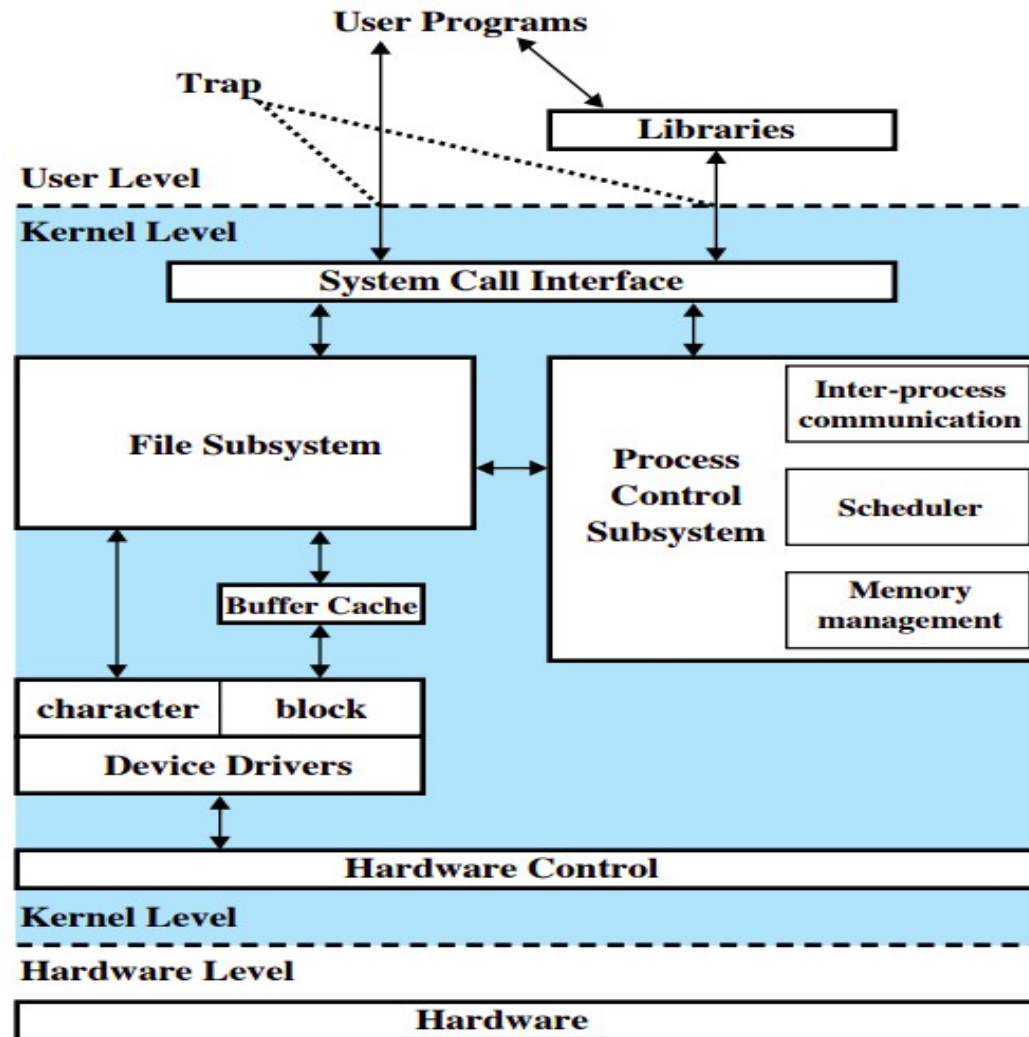
UNIX Operating System:

- 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.



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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 referred as a process.
- **File has space & Process has life.**



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

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

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

2. Block Devices: Devices from which data gets transferred 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.



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- 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 library functions provided by that programming language.

- There are 6 categories 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**.



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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 referred as kernel mode/monitor mode/supervisor mode/privileged mode.

2. User Mode:

- When the CPU executes user defined code instructions, system runs in a user mode.
- User mode is also referred as non-privileged 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 switch in between kernel mode and user mode and hence system runs in two modes, it is referred 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 whether 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 communication, 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 referred as a process.
- Running instance of a program is referred 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:

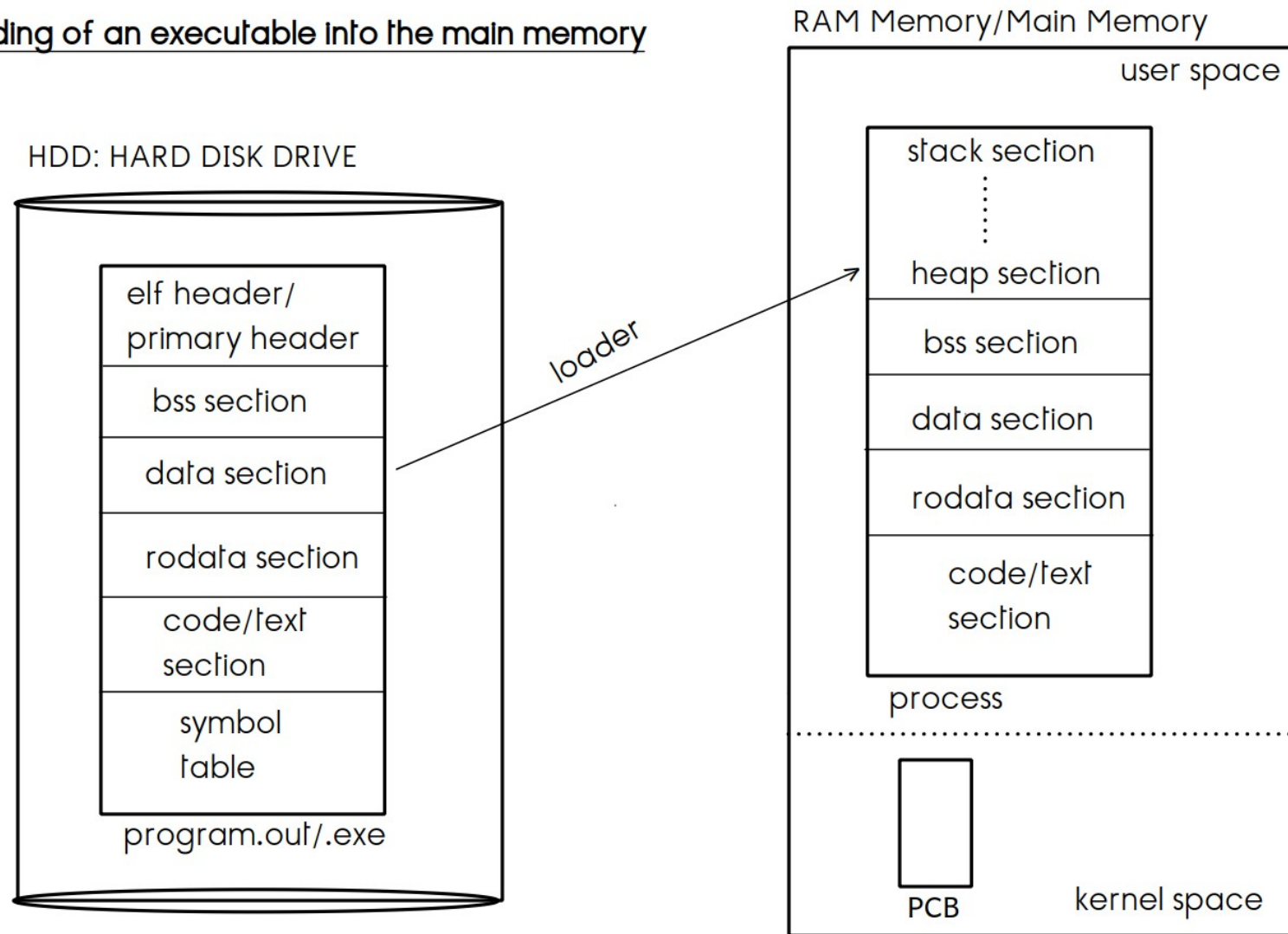
stack section: contains function activation records of called functions.

heap section: dynamically allocated memory



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Loading of an executable into the main memory



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



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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.

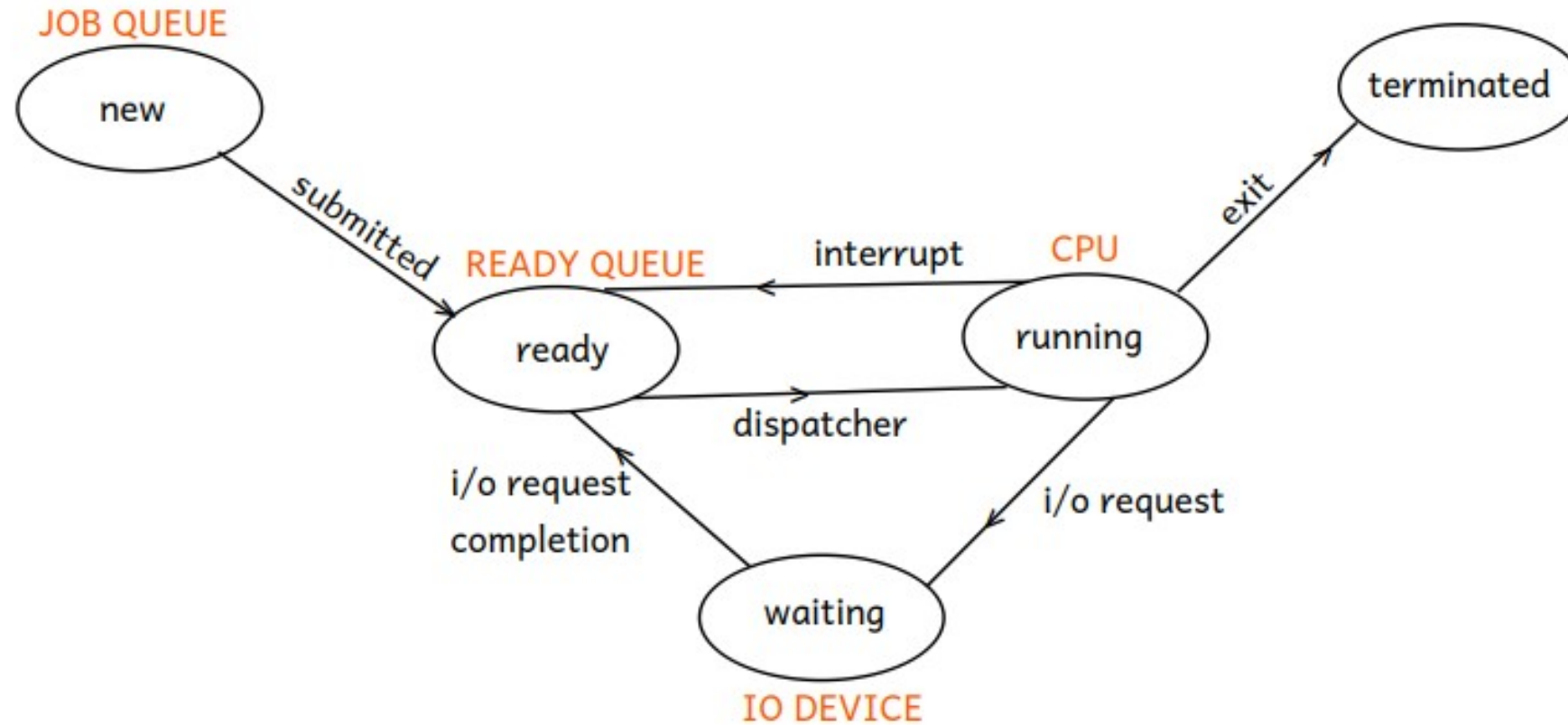
- 3. Running state:** if currently the CPU is executing any process then state of that process is considered as a running state.

- 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.



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PROCESS STATE DIAGRAM



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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 simultaneously 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.



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Process States:

- To keep track on all running programs, an OS maintains few **data structures** referred 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 referred as **dispatcher latency**.



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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 referred 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 dispatcher, dispatcher 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.



Operating System Concepts

- 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 implement 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 categories:

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 communicate 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:

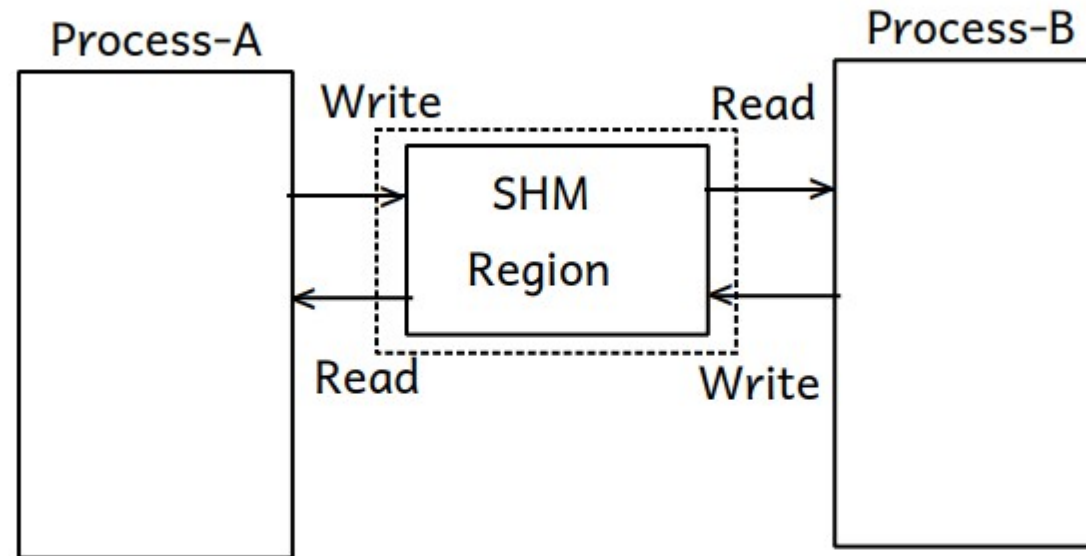
1. Shared Memory Model: under this technique processes can communicate with each other by means of reading and writing data into the **shared memory region** which is provided by an OS on request by processes want to communicate.

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

- Shared Memory Model is faster than Message Passing Model.



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SHARED MEMORY MODEL

Operating System Concepts

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 write data into the pipe, whereas 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 communicate by using **pipe (|) command**.
 - 2. named pipe:** in this type of pipe mechanism, related as well as non-related processes can communicate by using **pipe() system call**.
- By using Pipe only processes which are running on the same system can communicate,



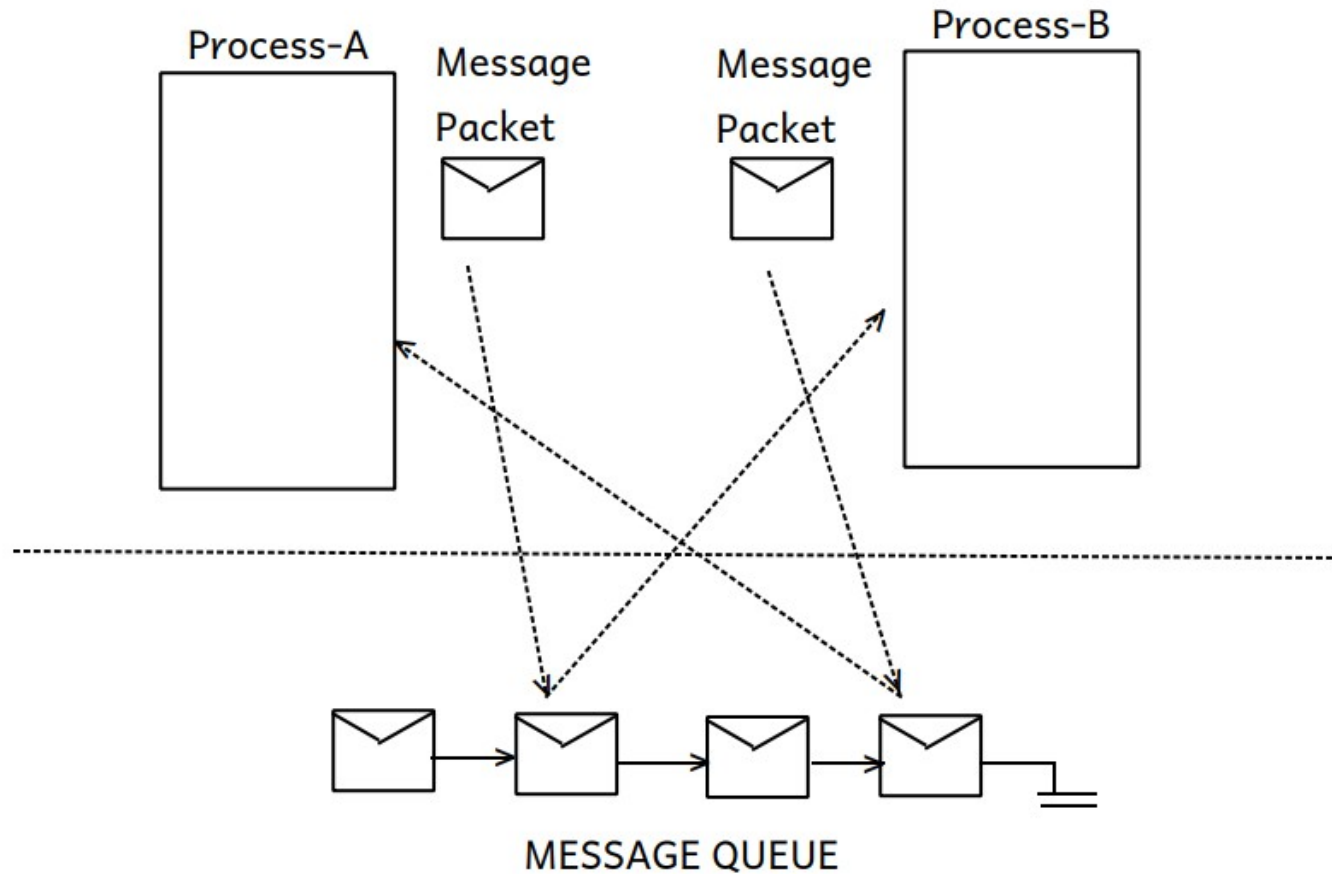
Inter Process Communication

ii. Message Queue:

- By using message queue technique, processes can communicate by means of sending as well as receiving **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 receiver process and vice-versa.



Inter Process Communication



Inter Process Communication

iii. Signals:

- Processes communicate 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 send signal to an OS.

Example: When we shutdown the machine an OS sends **SIGTERM** signal to all processes due to which processes get **terminated normally**, few processes can handle SIGTERM and hence even after receiving this signal from an OS continues execution, to such processes an OS sends **SIGKILL** signal due to which processes get **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 communicate, to overcome this limitation **Socket IPC mechanism** has been designed.
- By using socket IPC mechanism, process which is running on one machine can communicate with process running on another machine whereas machines are at remote distance from each other provided they are 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 resources, then there are conflicts which may result into the problem of data inconsistency, to avoid this problem co-ordination/synchronization between them is required.

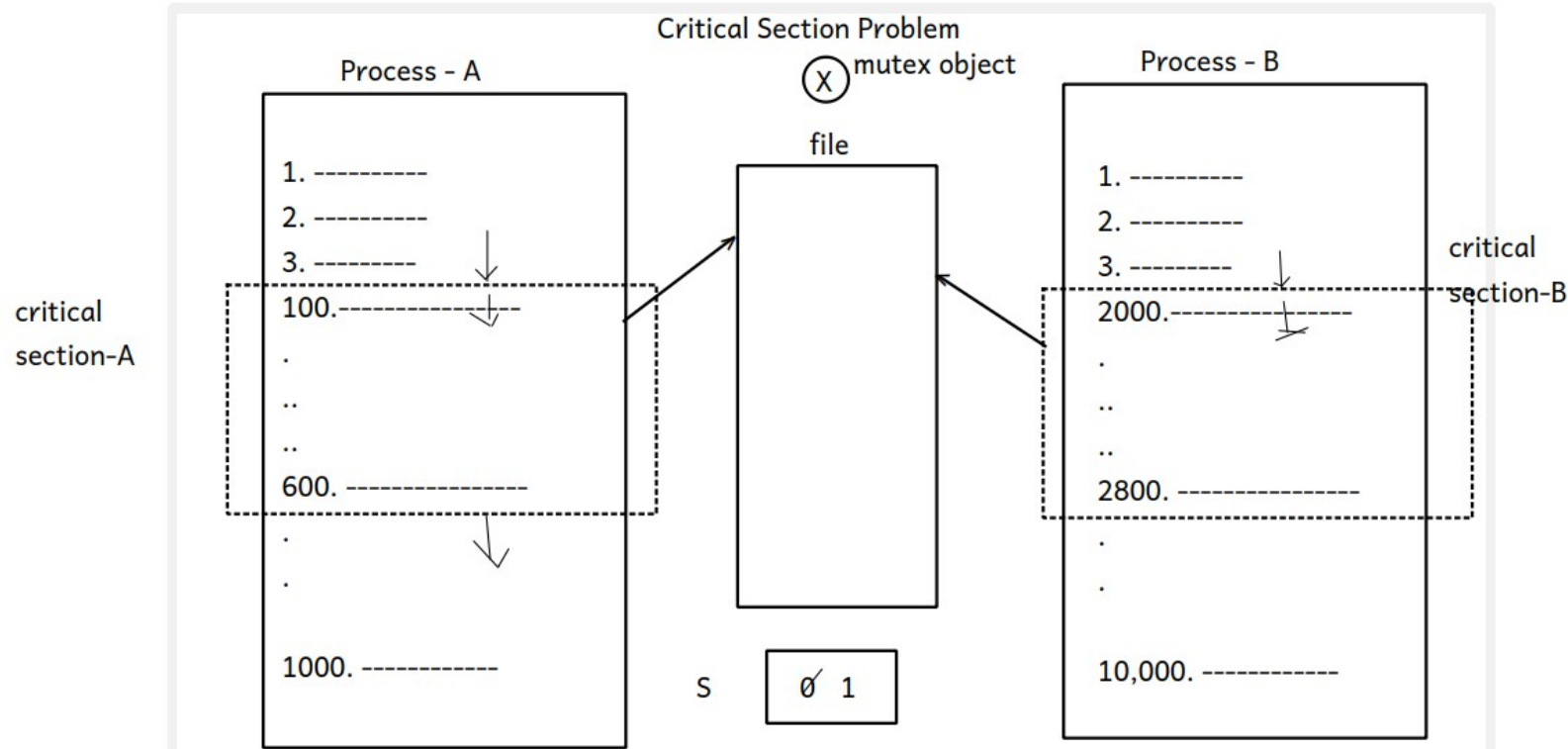
Race Condition: if two or more processes are trying to access same resource at a time, race condition occurs, and **data inconsistency** problem may take place.

- 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.



Operating System Concepts

Critical Section Problem:



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



Deadlock:

- There are four necessary and sufficient conditions to occur deadlock.

1. Mutual Exclusion: at a time resource can be acquired by only one process.

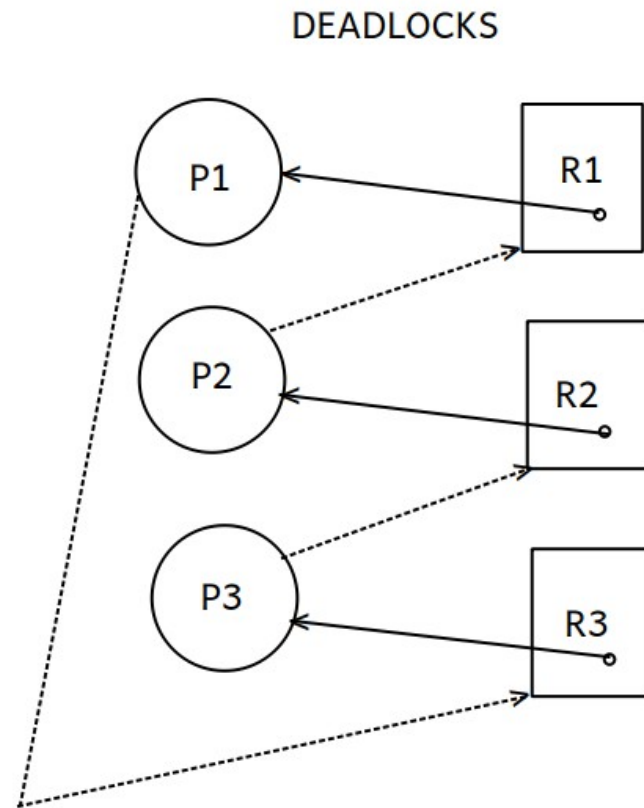
2. No Preemption: control of the resource cannot be taken away forcefully from any process.

3. Hold & Wait: every process is holding one resource and waiting for the resource which is held by another process.

4. Circular Wait: process P1 is holding resource and waiting for the resource held by another process P2, and process P2 is also holding resource and waiting for the resource held by process P1.



Deadlock: Resource Allocation Graph



- Three deadlock handling methods are there:

- 1. Deadlock Prevention:** deadlock can be prevented by discarding any one condition out of four necessary and sufficient conditions.

- 2. Deadlock Detection & Avoidance:** before allocating resources for processes all the input given to deadlock detection algorithm in advanced and if there are chances to occur deadlock then it can be avoided by doing necessary changes.

- There are two deadlock detection algorithms:

1. Resource Allocation Graph Algorithm

2. Banker's Algorithm



3. Deadlock Recovery:

- System can be recovered from the deadlock by two ways:

1. Process termination: in this method any one process gets selected and terminated to recover system from deadlock, process which gets terminated is referred as a **victim process**.

2. Resource preemption: in this method control of the resource taken away forcefully from a process to recover system from deadlock.



Memory Management

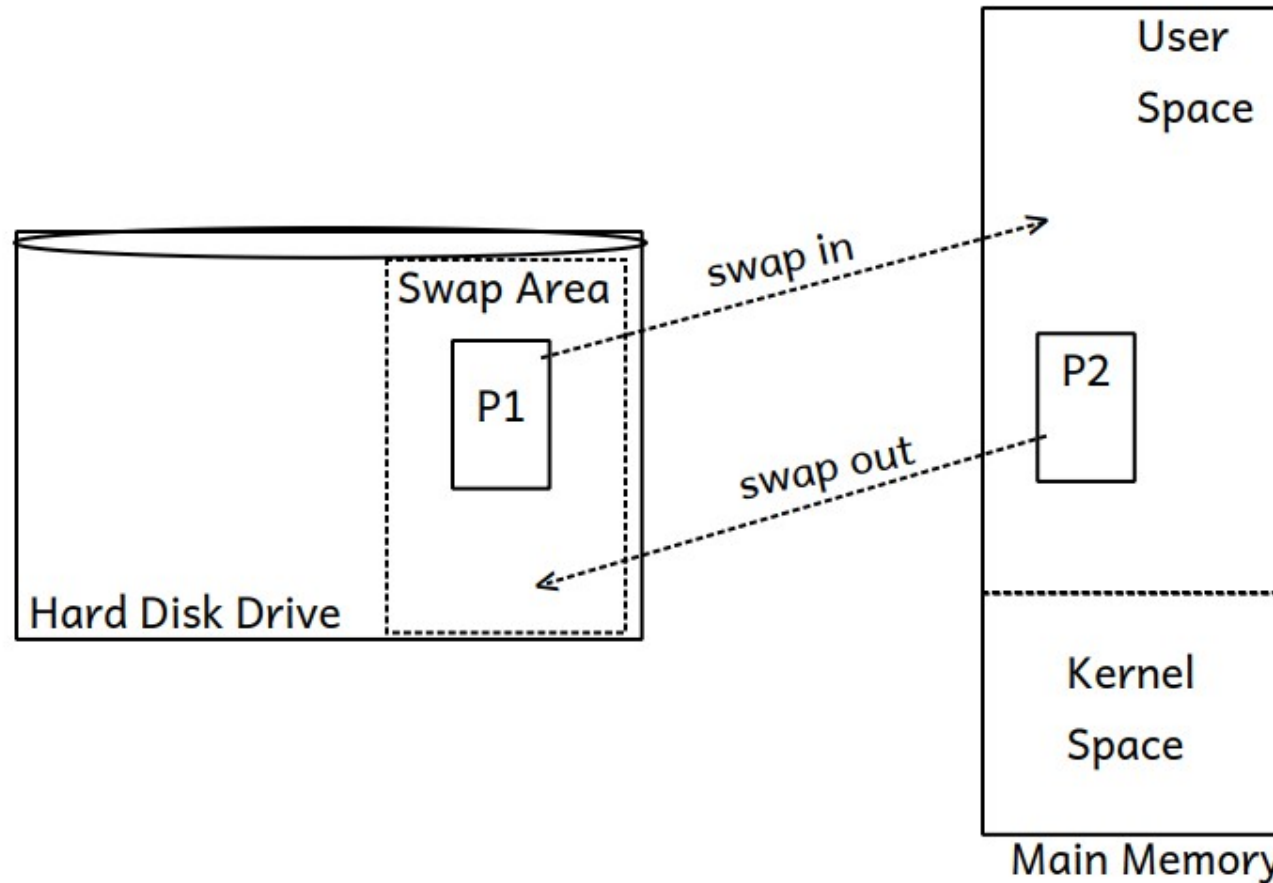
Q. Why there is a need of memory (main memory)management?

- As main memory is must for an execution of any program and it is a limited memory, hence an OS manages main memory.
- To achieve maximum CPU utilization, an OS must support multi-tasking, and to support multi-tasking multiple porcesses must be submitted into the system at a time i.e. it must support multi-programming, but as main memory is limited to support multi-programming an OS has to do memory management to complete an execution of all submitted processes.
- Memory space of one process should gets protected from another process.



Operating System Concepts

SWAPPING: MEMORY MANAGER



Swapping:

- **Swap area:** it is a portion of the hard disk drive (keep reserved while installation of an OS) can be used by an OS as an extension of the main memory in which inactive running programs can be kept temporarily and as per request processes can be swapped in and swapped out between swap area and the main memory.
- In Linux swap area can be maintained in the form of swap partition, whereas in Windows swap area can be maintained in the form of swap files.
- **Conventionally size of the swap area should be doubles the size of the main memory**, i.e. if the size of main memory is 2 GB then size of swap area should be 4 GB, if the size of main memory is 4 GB then size of swap area should be 8 GB and so on.



Swapping:

- Swapping done by the program of an OS named as **Memory Manager**, it swapin active programs into the main memory from swap area and swapout inactive running programs from the main memory and keep them temporarily into the swap area.
- there are two variants of swapping: swapin & swapout.



Swapping:

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Operating System Concepts

- Addresses generated by compiler (i.e. compiler + linker) are referred as **logical addresses**.
- Addresses which can see process when it is in the main memory referred as **physical addresses**.
- **MMU (Memory Management Unit)**: which is a hardware unit converts logical address into physical address.
- MMU is a hardware contains adder circuit, comparator circuit, base register and limit register, values of base register and limit registers gets change during context-switch, and memory space of one process can be protected from another process.
- CPU always executes program in its logical memory space.



Memory Allocation:

- When a process is requesting for the main memory, there are two methods by which memory gets allocated for any process

1. Contiguous Memory Allocation
2. Non-contiguous Memory Allocation

1. Contiguous Memory Allocation:

Under this method, process can complete its execution only if memory gets allocated for it in a contiguous manner.

- There are two methods by which memory gets allocated for process under contiguous memory allocation method.

1. Fixed Size Partitioning
2. Variable Size Partitioning



1. Fixed Size Partitioning:

- In this method, physical memory i.e. main memory (user space) is divided into fixed number of partitions and size of each partition remains fixed.
- When a process is requesting for the memory it can be loaded into any free partition in which it can fit.

Advantages:

- This method is simple to implement



Disadvantages:

- **Internal fragmentation:** memory remains unused which is internal to the partition.
- Degree of multi-programming is limited to the number of partitions in the main memory.
- Maximum size of a process is limited to max size partition in the main memory.
- To overcome limitations/disadvantages of fixed size partitioning method variable/dynamic size partitioning method has been designed.



2. Variable/Dynamic Size Partitioning:

- In this method, initially whole user space i.e. physical memory is considered as a single free partition, and processes get loaded into the main memory as they request for it.
- Size of partition and number of partitions are not fixed in advance, it gets decided dynamically.

Advantages:

- Degree of multi-programming is not limited/fixed
- Size of the process is not also limited, any size process may get loaded into the main memory.

Disadvantages:

- **External fragmentation:** due to loading and removing of processes into and from the main memory, main memory is fragmented i.e. gets divided into used partitions and free partitions.



2. Variable/Dynamic Size Partitioning:

- **External fragmentation:** due to loading and removing of processes into and from the main memory, main memory is fragmented i.e. it gets divided into used partitions and free partitions.

In such case, if any new process is requesting for the memory and even if the requested size of memory is available but due to unavailability of memory in a contiguous manner process cannot be loaded into the main memory, this problem is referred as an external fragmentation.

- External fragmentation is the biggest problem under contiguous memory allocation, and hence there are two solutions on this problem:

1. Compaction

2. Non-contiguous Memory Allocation



Operating System Concepts

1. Compaction: shuffling of main memory can be done in such a way that all used partitions can be shifted to one side and all free partitions can be shifted to other side and contiguous large free partition will be made available for the new processes.

- Compaction is practically not feasible as there is need to do recalculations of addresses every time.

2. Non-contiguous Memory Allocation:

- Under this method, process can complete its execution even if memory gets allocated for it in a non-contiguous manner, and it can be achieved by two memory management techniques:

1. Segmentation

2. Paging

- So by using segmentation & paging techniques, process can complete its execution even after memory gets allocated for it in a non-contiguous manner.



1. Segmentation

- In this technique, process in its logical memory is divided into small size segments like **stack segment, heap segment, data segment, bss segment, rodata segment, code segment etc...**, and when process is requesting for memory it is not requesting memory contiguously for whole process, memory gets allocated contiguously only for small size segments, and segments of one process may get load into the memory randomly at any locations, i.e. for a process memory gets allocated in a non-contiguous manner, and then only an execution of a process can be completed.
- As segments of a one process gets loaded randomly, and in a system thousands processes are running at a time, hence to keep track on all the segments of each process, an OS maintains one table per process referred as a **segment table** in which information about all the segments of that process can be kept.
- Using segmentation an external fragmentation can be reduced but cannot be completely avoided.



Operating System Concepts

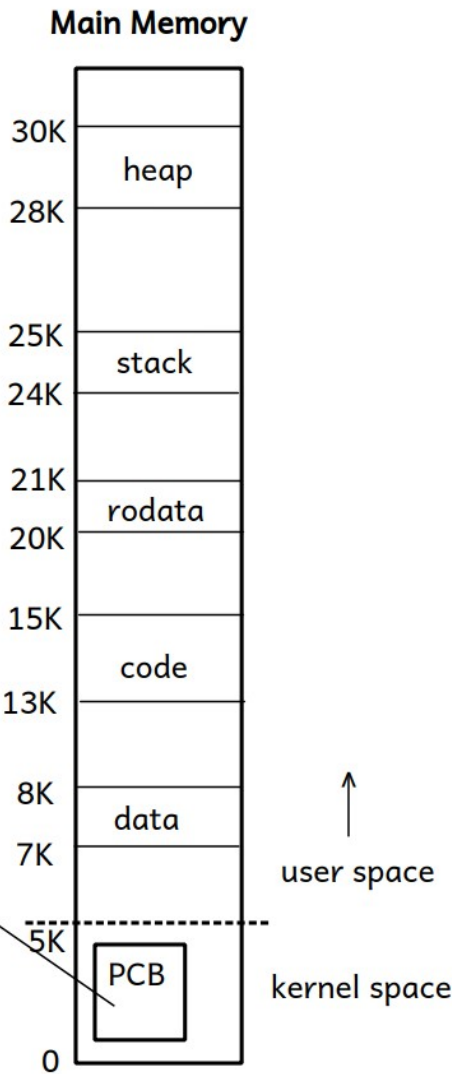
Segmentation

Big size process gets divided
logically into small size segments

Process: Size 7 K

0	stack	1K
1	heap	1K
2	rodata	1K
3	data	2K
4	code	2K

kernel space		
segment table		
seg addr	limit	base
0	1K	24000
1	1K	28000
2	1K	20000
3	2K	7000
4	2K	13000
5	null	null



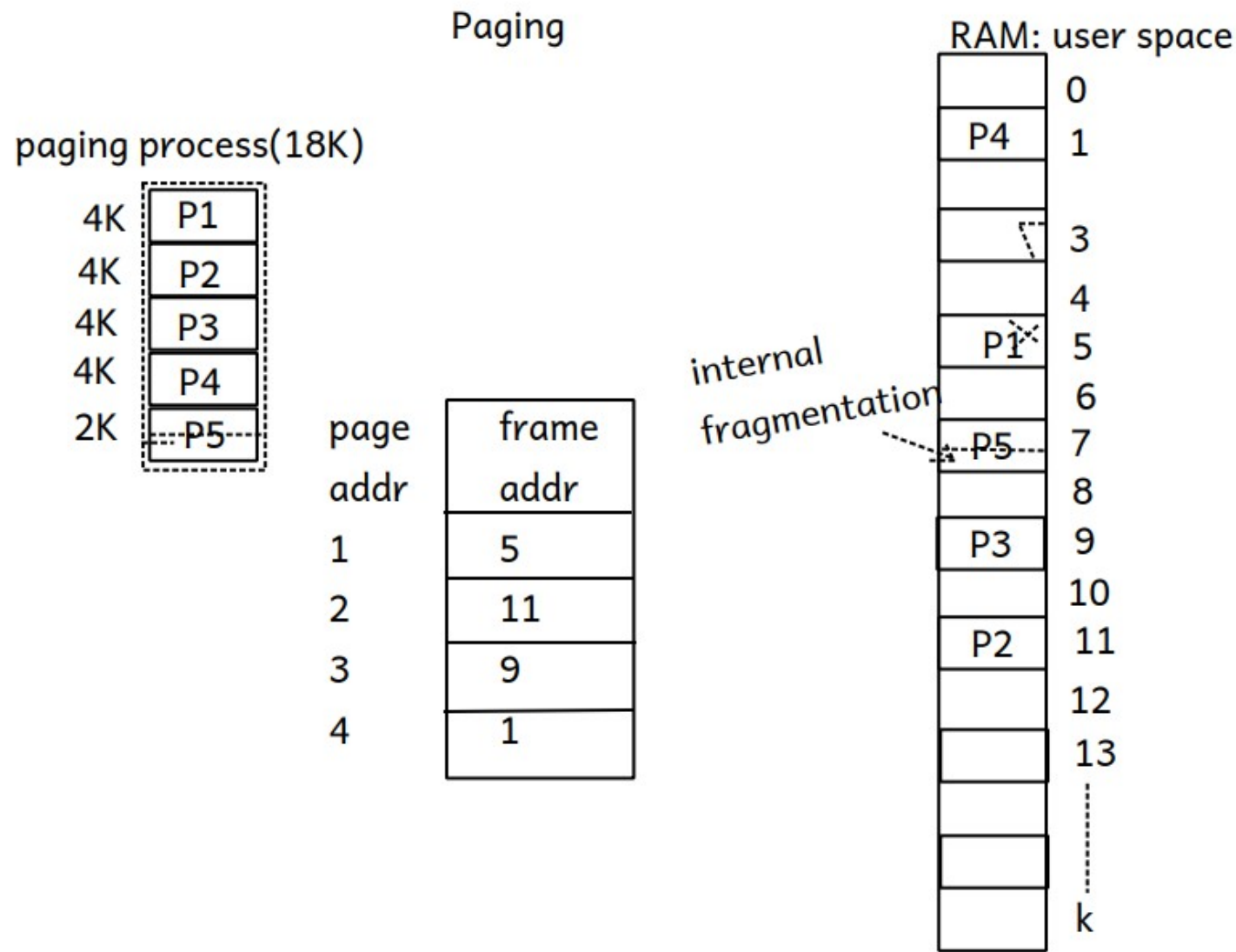
Operating System Concepts

2. Paging

- In this technique, **physical memory** (i.e. user space of a main memory) is divided into fixed size of blocks referred as **frames**, and process's **logical memory** space is divided into same size of blocks referred as **pages**, whereas maximum size of page must be equal to size of frame, i.e. if e.g. size of frame = 4K, then maximum size of each page must be 4K, size of page may be less than 4K.
- As process is divided into pages, so when it is requesting for memory, pages of one process may get loaded into the main memory at any free frames, and for a process memory gets allocated in a non-contiguous manner.
- As pages of a one process get loaded randomly into the main memory, and in a system thousands of processes are running at a time, to keep track of all the pages of each process, an OS maintains one table per process referred as a **page table** in which information about all the pages of that process can be kept.
- There is no external fragmentation in paging.
- Internal fragmentation may exist in paging when the size of page is less than size of frame.



Operating System Concepts



Operating System Concepts

Virtual Memory Management:

- As we seen an OS does memory management for completing an execution of multiple submitted processes at once.
- An OS also able to complete an execution of such a process having size bigger than size of main memory itself, and to achieve this an OS manages swap area memory as well with main memory and hence it is reffered as **virtual memory management**.
- As an OS manages such a memory which is physically not a main memory and hence it is reffered as virtual memory management.
- Virtual memory management can be implemented by using **Paging + Swapping**.
- In this technique for a process to complete its execution it is not mandatory it must exists wholely in a main memory, even its part is their into the main memory then execution of such process can be completed part by part.
- Big size process is divided into pages and when a process is requesting for memory few pages gets loaded into the main memory and few pages can be kept into the swap area, and as per the request pages of that process can swappedin and swapped out between main memory and swap area.



Virtual Memory Management:

- **Demand Paging:** any page of a process gets loaded into the main memory only after requesting by that process i.e. on demand and hence referred as **demand paging**, page which is never requested never gets loaded into the main memory and hence it also called as **pure demand paging**.
- If a process is requesting for any page and if that page is not exists in the main memory, then it is referred as **page fault**.
- As the size of process may be bigger than size of main memory itself, and in a system multiple processes are running at a time, hence no. of pages are more than no. of frames, so there are quite good chances that all frames becomes full, and in this case if any process is requesting for a page which does not exists in the main memory at that time there is need to remove any one page from the main memory so that into that free frame requested page will get loaded.
- So there is need to decide which page should get removed and requested page gets replaced in that frame, to do this there are certain algorithms referred as **page replacement algorithms**.



Operating System Concepts

Page Replacement Algorithms:

1. FIFO Page Replacement: page which was inserted first gets replaced by the requested page.

2. Optimal Page Replacement: page which will not get used in a near future gets replaced by the requested page

3. LRU(Least Recently Used) Page Replacement: least recently used page gets replaced by the requested page.

4. LFU(Least Frequently Used) Page Replacement: least frequently used page gets replaced by the requested page.

5. MFU(Most Frequently Used) Page Replacement: most frequently used page gets replaced by the requested page.

- Algorithms 1, 2 & 3 uses **stack based** approach, whereas algorithms 4 & 5 uses counting based approach.

- Conceptually Optimal Page Replacement is the most efficient page replacement algorithm, as no. of page faults in this algorithm are very less, but as its practical implementation is not feasible hence LRU is the most efficient algorithm (implementationwise).



- **Thrashing:** If any process spends more time on paging rather than execution, then this high paging activity is referred as thrashing.



File Management

Q. What is file?

User view:

- File is a named collection of logically related information/data.
- File is a container which contains logically related information/data.
- File is a collection of characters/records/lines.
- File is a basic storage unit

System view:

- File is a stream of bits/bytes.
- **File = data + metadata**
 - data = actual file contents
 - metadata = information about the file.



Operating System Concepts

- Data of the file exists inside the file whereas information about the file gets stored inside one structure referred as **FCB (File Control Block)**.
- In UNIX environment FCB is also called as an iNode.
- FCB/iNode contains information about the file like:
 1. iNode number: unique identifier of a file
 2. Name of the file
 3. Type of the file
 4. Size of the file
 5. Parent folder location
 6. Access permissions
 7. Time stampsetc...



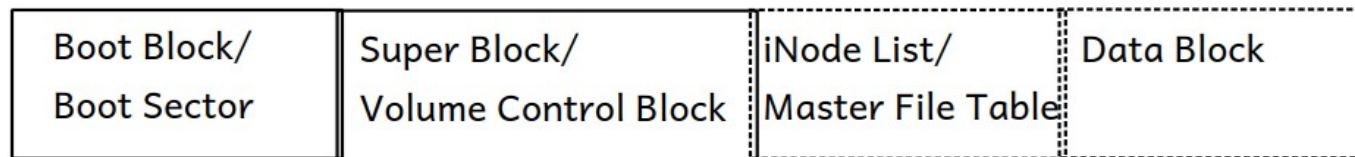
Operating System Concepts

- Per file one iNode/FCB gets created by the system and hence no. of iNodes = no. of files onto the disk.
- data + metadata of all the files are kept onto the disk, as disk may contents thousands of files, so thousands of iNodes and millions of bytes of data gets stored onto the disk, and hence all this data + metadata of all files need be keep onto the disk in an organized manner so that it can be accessed efficiently.
- **Filesystem:** filesystem is a way to store data onto the disk in an organized manner so that it can be accessed efficiently and conveniently.
e.g. Each OS has its own filesystem like, UNIX: UFS(UNIX Filesystem), Linux: Extended filesystem ext2, ext3, ext4, Windows: FAT, NTFS etc..., MAC OSX: HFS(Hierarchical Filesystem) etc...



Filesystem Structure: Filesystem divides disk/partition logically into sectors/blocks, like **boot sector/boot block, volume control block/super block, master file table/iNode list block**

FILESYSTEM STRUCTURE



1. Boot Block: It contains information about booting the system like bootstrap program, bootloader etc...
2. Super Block: It contains information about remaining sections, like total no. of data blocks, no. of free data blocks, no. of allocated data blocks etc....
3. iNode List: It contains linked list of iNode's of all files exists on a disk.
4. Data Block: It contains actual data.



Disk space allocation methods:

- When a file is requesting for free data blocks, then in which manner free data blocks gets allocated for that file and how its information can be kept inside inode of that file is referred as **disk space allocation method**.

- Three disk space allocation methods are there:

- 1. Contiguos Allocation:** free data blocks gets allocated for a file in a contiguos manner.

- 2. Linked Allocation:** any free data blocks gets allocated for a file in a linked list manner.

- 3. Indexed Allocation:** any free data blocks gets allocated for a file, as by maintaining an index data block information about allocated data blocks can be kept inside it.



Operating System Concepts

Disk Scheduling Algorithms:

- When system want to access data from a disk, request can sent to disk controller and disk controller accepts one request at a time and complete it.
- There are chances that at a time more than one requests for accessing data from the disk can be made by the processes running in a system, in that case all the requests can be kept in a waiting queue of the disk maintained by an OS, and there is need to schedule/select only one request at a time and sent it to the disk controller, to do this there are certain algorithms referred as disk scheduling algorithms.

- 1. FCFS (First Come First Served):** request which is arrived first gets accepted and completed.
- 2. SSTF (Shortest Seek Time First):** request which is closed to the current position of the head gets accepted and completed.
- 3. SCAN:** head keeps scanning the disk from starting cylinder to end cylinder and whichever request came across gets accepted and completed.
- 4. C-SCAN (Circular SCAN):** head scans the disk only in a one direction
- 5. LOOK:** this policy can be used either with SCAN/C-SCAN, in this, if there is no request in a waiting queue then movement of the head gets stopped.

