

## -----Linux kernel and Booting process-----

**Operating System:** An operating system is a "resource allocator" and a "controlling of operations" program.

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**Real mode:** This is the only mode which was supported by the 8086 (the very first processor of the x86 series). The 8086 had 20 address lines, so it was capable of addressing "2 raised to the power 20" i.e. 1 MB of memory. No multi-tasking – no protection is there to keep one program from overwriting another program.

**Protected mode:** Multitasking and There is no 1 MB limit in protected mode. Support for virtual memory, which allows the system to use the hard disk to emulate additional system memory when needed.

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### **Multicore system:**

A processor that has more than one core is called Multicore Processor while one with single core is called Unicore Processor or Uniprocessor. Nowadays, most of systems have four cores (Quad-core) or eight cores (Octa-core). These cores can individually read and execute program instructions, giving feel like computer system has several processors but, they are cores and not processors. cores are integrated into single chip and will require less time.-----

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### **Multiprocessor system:**

Systems which have more than one processor are called multiprocessor system. These systems are also known as parallel systems or tightly coupled systems.

**Multiprocessor systems have the following advantages.**

- **Increased Throughput:** Multiprocessor systems have better performance than single processor systems. It has shorter response time and higher throughput. User gets more work in less time.
- **Reduced Cost:** Multiprocessor systems can cost less than equivalent multiple single processor systems. They can share resources such as memory, peripherals etc.
- **Increased reliability:** Multiprocessor systems have more than one processor, so if one processor fails, complete system will not stop. In these systems, functions are divided among the different processors.

### **Differences b/w multiprocessor and multicore system:**

Only common thing between Multicores and Multiprocessor is to increase processing speed.

Cost of Multicore system is lesser compared to cost of multiprocessor system because of use of more physical processors in multiprocessor system.

If you want to run single program, then multicore system will be faster. But if you are running multiple programs then multiprocessor system will be faster.

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### **Advantages of distributed system (loosely coupled) are:**

- Resources get shared
  - Load gets shared
  - Reliability is improved
  - Provide a support for inter-process communication
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### **SMP:**

- It is called as symmetric multiprocessing which is multiprocessor system.
  - In it each processor runs an identical copy of the operating system.
  - These copies communicate with one another as needed.
  - These processor systems lead to increased throughput.
  - These systems are also called parallel systems or tightly coupled systems.
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**Kernel has two components:** core component (physical memory manager, virtual memory manager, file manager, Interrupt handler, process manager etc.), non-core component (compiler, libs etc.)

**Monolithic:** All the parts of a kernel components like the Scheduler, File System, Memory Management, Networking Stacks, Device Drivers, etc., are maintained in one unit within the kernel in Monolithic Kernel. Faster processing.

**Microkernel:** Only the very important parts like IPC (Inter process Communication), basic scheduler, basic memory handling, basic I/O primitives etc., are put into the kernel. Communication happen via message passing. Others are maintained as server processes in User Space. Slower Processing due to additional Message Passing.

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**An Introduction to Linux:** When installing Linux, the source code is usually stored in /usr/src/linux.

**Kernel: kernel performs below main tasks:**

- Process management
- Device management
- Memory management
- Interrupt handling
- I/O communication
- File system management

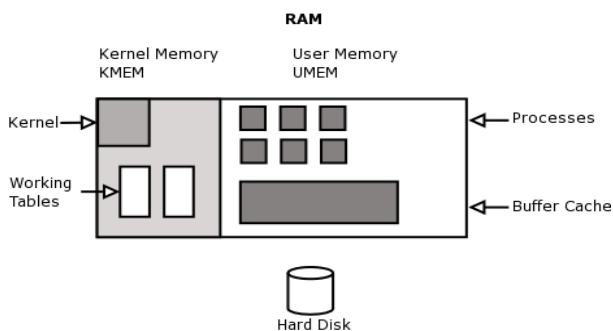
The kernel exists as a physical file on the file system in Linux it is /boot directory and is usually called vmlinuz.  
**/boot/vmlinuz-2.4.18-22**

- At system boot time RAM only contains the boot loader, consuming a few kilobytes at the beginning of memory.
- The boot loader loads the kernel binary into memory from the hard disk, and places it at the beginning of memory.
- Once the kernel has been read in the boot loader tells the CPU to execute it by issuing a JMP (Jump) instruction.

**Memory is divided into two areas, kernel memory and user memory.**

Kernel memory is also known as kmem, kernel space and kernel land. This contains the kernel binary itself, working tables to keep track of status on the system and buffers.

Examples of working tables that the kernel keeps in kernel memory for the operation of the system are the Global Open File Table, the Process Table and the Mount Table.



**Linux Booting:**



**steps:**

### **1. BIOS.**

- BIOS performs a POST (Power On Self Test) to check and scan if all the hardware devices are properly connected.
- Then it scans the first sector of Hard-drive partition to find the boot loader (GRUB LILO for Linux).
- BIOS loads the MBR into memory.
- Gives the control to MBR

### **2. MBR.**

- MBR or Master Boot Record holds information of your current Boot-loader of your Operating System.
- MBR is less than 512 bytes in size and holds various information like boot loader information, validation check and the partition table present in your hard-drive.
- It is always stored in the first sector of your hard-drive.
- MBR loads the first stage loader (stage1).
- The first stage boot loader (stage 1), loads the rest of boot loader prompting you an option to select multiple OS (if you have installed multiple OS) or loads the Operating System on hard-drive.
- MBR loads the GRUB (boot loader for mostly all Linux OS) and gives the control over to GRUB.

### **3. GRUB.**

- GRUB, also known as Grand Unified Bootloader is the most common boot loader for various Linux distributions.
- GRUB gives you an option to select multiple OS, if you have them in your hard-drive partitions.
- The second stage loader (stage2) is loaded, giving you the GRUB screen where you can select multiple OS or change the default settings or edit start-up parameters.
- GRUB has the kernel and initrd images, which it loads and executes.

### **4. Kernel.**

- Kernel is loaded in two steps:
  1. Kernel is loaded in Memory and decompressed and sets up the crucial functions.
  2. Kernel then runs the init process (in /sbin/init). It also sets up user space and essential processes needed for environment and for user login.
- To initialize the scheduler which has Process ID (PID 0) of 0, run the init process (PID 1) and then mount the system in rw mode are the responsibilities of kernel.
- The init process in the second step loads the critical daemons, checks the fstab file and loads the partitions accordingly.

### **5. Init Process.**

- This process checks the '/etc/inittab' file to choose the run level.
- It reads the file to check default init level and executes it.
- Various init levels are:
  - 0 = Halt, 1 = Single user mode, 2 = Multiuser mode w/o NFS, 3 = Full multiuser mode.
  - 4 = Reserved (for future use), 5 = X11, 6 = Reboot.

### **6. Run level programs.**

- If you press any key when you see the GUI and system is loading up, you go into the text mode, where you can see the kernel starting and testing all the daemons. Eg: Starting DHCP server.... Ok.

## **-----The Kernel versus Process Management-----**

### **Process:**

A process is a program that is running and under execution. On batch systems, it is called as a "job" while on time sharing systems, it is called as a "task".

### **Important functions of process management are:**

- Creation and deletion of system processes.
- Creation and deletion of users.
- CPU scheduling.
- Process communication and synchronization.

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### Context switching:

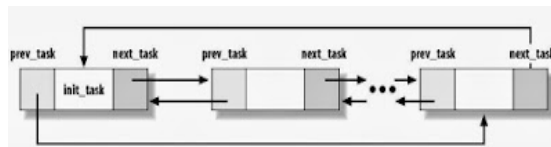
- It is the process of switching the CPU from one process to another.
  - This requires to save the state of the old process and loading the saved state for the new process.
  - The context of the process is represented in the process control block.
  - During switching the system does no useful work.
  - How the address space is preserved and what amount of work is needed depends on the memory management.
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### PCB contains:

- **Program counter:** It indicates the address of the next instruction to be executed for this process.
  - **CPU Registers:** They include index registers, stack pointer and general-purpose registers. It is used to save process state when an interrupt occurs, so that it can resume from that state.
  - **CPU-scheduling information:** it includes process priority, pointer to scheduling queue.
  - **Memory management information:** value of the base and limit registers, page tables depending on the memory system.
  - **Accounting information:** it contains an amount of CPU and real time used, time limits process number and so on.
  - **I/O status information:** It includes a list of I/O devices allocated to the process, a list of open files and so on.
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### Process Descriptor and the Task Structure:

The kernel stores the list of processes in a circular doubly linked list called the task list. Process descriptor is nothing but each element of this task list of the type **struct task\_struct**, which is defined in `<linux/sched.h>`. The process descriptor contains all the information about a specific process. The task\_struct is a relatively large data structure, at around 1.7 kilobytes on a 32-bit machine.



Each thread has its own thread\_info. There are two basic reasons why **there are two such structures**.

**Process state:** It represents status of the process. It may be new, ready, running or waiting.

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### Process State:

**Running or Runnable State (R):** When a new process is started, it'll be placed into the running or runnable state. In the running state, the process takes up a CPU core to execute its code and logic.

#### **Sleeping State: Interruptible (S) and Uninterruptible (D):**

The uninterruptible sleeping state will only wait for the resources to be available before it transits into a runnable state, and it doesn't react to any signals. **On the other hand**, the interruptible sleeping state (s) will react to signals and the availability of resources.

**Stopped State (T):** From a running or runnable state, we could put a process into the stopped state (T) using the **SIGSTOP** or **SIGTSTP** signals.

**Zombie State (Z):** When a process has completed its execution or is terminated, it'll send the **SIGCHLD** signal to the parent process and go into the zombie state. The zombie process, also known as a defunct process, will remain in this state until the parent process clears it off from the process table

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### Process Context vs Interrupt Context:

The process and interrupt context is with reference to the kernel execution, when kernel is working on behalf of a process or it is running some kernel threads it is said to be executing in process context whereas when the kernel is handling some interrupt handler then it is said to be working in interrupt context.

**When program stops execution, it saves the current contents of several processor registers in the process descriptor:**

The program counter (PC) and stack pointer (SP) registers

The general-purpose registers

The floating point registers

The processor control registers (Processor Status Word) containing information about the CPU state

The memory management registers used to keep track of the RAM accessed by the process

When the kernel decides to resume executing a process, it uses the proper process descriptor fields to load the CPU registers. Since the stored value of the program counter points to the instruction following the last instruction executed, the process resumes execution from where it was stopped.

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**Daemon process:** Disk and execution monitor, is a process that runs in the background without user's interaction. They usually start at the booting time and terminate when the system is shut down. The name of daemons usually end with 'd' at the end in Unix. **Ex: httpd, named, lpd.**

**Orphan process:** is a computer process whose parent process has finished or terminated, though it (child process) remains running itself.

**Zombie process:** is a process that has completed execution but still has an entry in the process table as its parent process didn't invoke an wait () system call.

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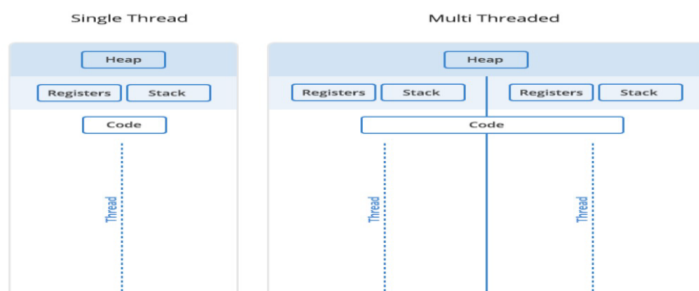
**Threads:** the units of execution within a program.

Each thread within a process has a

1. **unique program counter**
2. **process stack,**
3. **set of processor registers.**

Threads are light weight. They don't have their own memory spaces and other resources unlike processes. All processes start with a single thread. So they behave like lightweight processes but are always tied to a parent "thick" process. So, creating a new process is a slightly heavy task and involves allocating all these resources while creating a thread does not. Killing a process also involves releasing all these resources while a thread does not. However, killing a thread's parent process releases all resources of the thread.

A process is suspended by itself and resumed by itself. Same with a thread but if a thread's parent process is suspended then the threads are all suspended.



**Multi-threading:**

Threads are popular way to improve application through parallelism. For example, in a browser, multiple tabs can be different threads. MS word uses multiple threads, one thread to format the text, other thread to process inputs, etc.

**Threads operate faster than processes due to following reasons:**

- 1) **Thread creation is much faster.**
- 2) **Context switching between threads is much faster.**

### 3) Threads can be terminated easily

### 4) Communication between threads is faster.

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**Fork:** The fork system call is used to create a new process. The newly created process is the child process. The process which calls fork and creates a new process is the parent process. The child and parent processes are executed concurrently. Fork returns 0 for child process and positive value for parent process and -1 for error. //child process does not inherit parent's memory locks and timers. child process inherits mutex, condition variables, open file descriptor, message queue descriptor. page tables are copied, and page frames are shared.

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#### **Exec:**

The exec call is a way to basically replace the entire current process with a new program. It loads the program into the current process space and runs it from the entry point. As a new process is not created, the process identifier (PID) does not change, but the machine code, data, heap, and stack of the process are replaced by those of the new program. Exec() replaces the current process with a the executable pointed by the function.

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**Vfork:** The basic difference between vfork and fork is that when a new process is created with vfork(), the parent process is temporarily suspended, and the child process might borrow the parent's address space. This strange state of affairs continues until the child process either exits, or calls execve(), at which point the parent process continues.

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**Clone :** Clone, as fork, creates a new process. Unlike fork, these calls allow the child process to share parts of its execution context with the calling process, such as the memory space, the table of file descriptors, and the table of signal handlers.

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#### **Scheduler:**

The scheduler is invoked: when there is change in process state, new process is created, software interrupt, hardware interrupt etc.

#### **Why we use scheduler:**

Max CPU utilization  
Max throughput  
Min waiting time

#### **Scheduling Algorithms:**

Preemptive algorithms  
Round Robin Scheduling  
Shortest Job First Scheduling (can be both)  
Priority Scheduling (can be both)  
Non-preemptive algorithms  
First Come First Served Scheduling

**First Come First Serve (FCFS):** Simplest scheduling algorithm that schedules according to arrival times of processes. First come first serve scheduling algorithm states that the process that requests the CPU first is allocated the CPU first. It is implemented by using the FIFO queue.

**Round robin:** Each process is assigned a fixed time(Time Quantum/Time Slice) in cyclic way. It is designed especially for the time-sharing system. The ready queue is treated as a circular queue. The CPU scheduler goes around the ready queue, allocating the CPU to each process for a time interval of up to 1-time quantum.

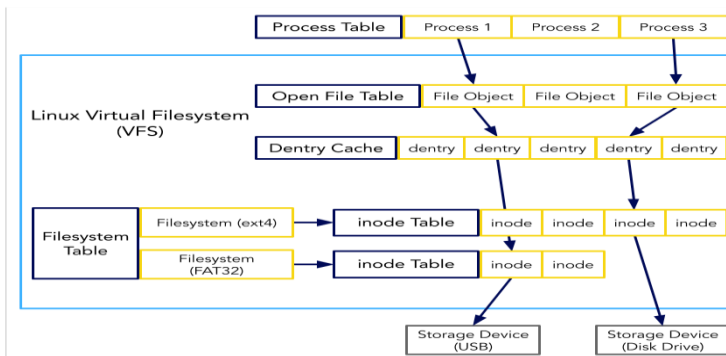
**Thread:** we use clone () to create thread, thread is different from process. Thread uses process address space and threads communicate through shared memory. In linux, we call pthread\_create for creating the thread.

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#### **VFS:**

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The VFS is sandwiched between two layers: the upper and the lower. The upper layer is the system call layer where a user space process traps into the kernel to request a service (which is usually accomplished via libc wrapper functions) -- thus catalyzing the VFS's processes. The lower layer is a set of function pointers, one set per filesystem implementation, which the VFS calls when it needs an action performed that requires information specific to a particular filesystem.



There are four important VFS objects:

- 1) **Superblock object**: represents a specific mounted filesystem.
- 2) **Inode object**: represents a specific file.
- 3) **Dentry object**: represents a directory entry, a single component of a path.
- 4) **File object**: represents an open file as associated with a process.

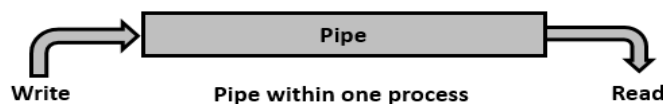
## -----IPCS-----

**Signals**: One process can raise the signal and can deliver to others. When signal is sent to process: Every process has process descriptor and process descriptor has three fields:

- 1) Signal pending field
- 2) Signal masking/unmasking field
- 3) Signal handler table.

Let's assume process is trying to access invalid logical virtual address and memory exception will be generated. Exception handler will generate SIGSEGV to current process, when system scans for pending signal, this pending signal will be addressed, and appropriate action will be taken.

**Unnamed pipe**: It is used for related process (within process) unidirectional byte stream which connects o/p of one process into i/p of other process. Pipes are implemented using file descriptor.



This system call would create a pipe for one-way communication i.e., it creates two descriptors, first one is connected to read from the pipe and other one is connected to write into the pipe.

**Named/fifo pipes**: we can use single named pipe that can be used for two-way communication (communication between the server and the client, plus the client and the server at the same time) as Named Pipe supports bi-directional communication.

**shared memory**: Two or more process can access the common memory and communication is done via this shared memory where changes made by one process can be viewed by another process. The problem with pipes, fifo and message queue – is that for two processes to exchange information. The information goes through the kernel. To reiterate, each process has its own address space, if any process wants to communicate with some information from its own address space to other processes, then it is only possible with IPC (inter process communication) techniques.

```
//Create the shared memory segment or use an already created shared memory segment (shmget())
//Attach the process to the already created shared memory segment (shmat())
//Detach the process from the already attached shared memory segment (shmdt())
//Control operations on the shared memory segment (shmctl())
```

**Message Queue**: A message queue is a linked list of messages stored within the kernel and identified by a message queue identifier. A new queue is created or an existing queue opened by msgget(). New messages are added to the end of a queue by msgsnd().



```
//Create a message queue or connect to an already existing message queue (msgget())
//Write into message queue (msgsnd())
//Read from the message queue (msgrcv())
//Perform control operations on the message queue (msgctl())
```

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**//Shared\_memory vs message queues:** As understood, once the message is received by a process it would be no longer available for any other process. Whereas in shared memory, the data is available for multiple processes to access. Shared memory data need to be protected with synchronization when multiple processes communicating at the same time.

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**//Socket programming:** Socket is used in a client-server application framework.

**//Socket types:** Stream Sockets (TCP/IP): It's reliable protocol and also data integrity is maintained. It's connection oriented. (Transmission control protocol)

**//dataGram socket:** UDP:It's not reliable.It's connection less.

**//How to make a Server**

**//Create a socket with the socket() system call.**

**//Bind the socket to an address using the bind() system call.** For a server socket on the Internet, an address consists of a port number on the host machine.

**//Listen for connections with the listen() system call.**

**//Accept a connection with the accept() system call.** This call typically blocks the connection until a client connects with the server.

**//Send and receive data using the read () and write() system calls.**

**//Make client:**

**//Create a socket with the socket () system call.**

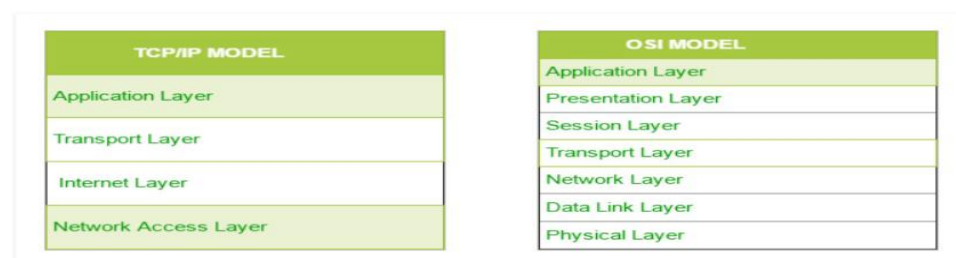
**//Connect the socket to the address of the server using the connect () system call.**

**//Send and receive data.** There are a number of ways to do this, but the simplest way is to use the read() and write() system calls.

**//Blocking and Non-Blocking Socket I/O:**TCP sockets are placed in a blocking mode. This means that the control is not returned to your program until some specific operation is complete. For example, if you call the connect () method, the connection blocks your program until the operation is complete.

**//we should make non-blocking calls and can be done by calling socket. setblocking(0)**

**//TCP/IP nad OSI model:**



BASIS FOR COMPARISON	SEMAPHORE	MUTEX
Basic	Semaphore is a signalling mechanism.	Mutex is a locking mechanism.
Existence	Semaphore is an integer variable.	Mutex is an object.
Function	Semaphore allow multiple program threads to access a finite instance of resources.	Mutex allow multiple program thread to access a single resource but not simultaneously.
Ownership	Semaphore value can be changed by any process acquiring or releasing the resource.	Mutex object lock is released only by the process that has acquired the lock on it.
Categorize	Semaphore can be categorized into counting semaphore and binary semaphore.	Mutex is not categorized further.

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**Semaphore:** A semaphore is a hardware or a software tag variable whose value indicates the status of a common

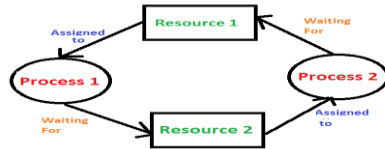


resource.

- Its purpose is to lock the common resource being used. A process which needs the resource will check the semaphore to determine the status of the resource followed by the decision for proceeding.
- In multitasking operating systems, the activities are synchronized by using the semaphore techniques is a better option in case there are multiple instances of resources available. In the case of single shared resource mutex is a better choice.

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**Deadlock:** A deadlock happens in operating system when two or more processes need some resource to complete their execution that is held by the other process.



**Is it possible to have a deadlock involving only one process: No**

A deadlock situation can arise if the following four conditions hold simultaneously in a system.

- **Mutual Exclusion:** The resources available are not sharable. This implies that the resources used must be mutually exclusive.
- **Hold and Wait:** Any process requires some resources in order to be executed. In case of insufficient availability of resources, a process can take the available resources, hold them and wait for more resources to be available.
- **No Preemption:** The resources that a process has on hold can only be released by the process itself voluntarily. This resource cannot be preempted by the system.
- **Circular Waiting:** A special type of waiting in which one process is waiting for the resources held by a second process. The second process is in turn waiting for the resources held by the first process.

**Methods for handling deadlock:**

There are three ways to handle deadlock

1) **Deadlock prevention or avoidance:** The idea is to not let the system into a deadlock state.

One can zoom into each category individually; Prevention is done by negating one of above-mentioned necessary conditions for deadlock.

Avoidance is kind of futuristic in nature. By using strategy of "Avoidance", we must assume. We need to ensure that all information about resources which process will need are known to us prior to execution of the process. We use Banker's algorithm (Which is in-turn a gift from Dijkstra) to avoid deadlock.

2) **Deadlock detection and recovery:** Let deadlock occur, then do preemption to handle it once occurred. (**Killing the process and Preemption of resource**)

3) **Ignore the problem altogether:** If deadlock is very rare, then let it happen and reboot the system. This is the approach that both Windows and UNIX take.

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**Critical section:** is a code segment where the shared variables can be accessed. An atomic action is required in a critical section i.e., only one process can execute in its critical section at a time. All the other processes must wait to execute in their critical sections.

**ldd:** load dynamic dependency--> ldd executable name will list out dynamic library dependencies for that executable.

The main advantage of a preemptive kernel is that sys-calls do not block the entire system. If a syscall takes a long time to finish then it doesn't mean the kernel can't do anything else in this time.

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**Interrupt, exception, and system calls**

**Interrupts and Exceptions:**

**Interrupt:** Interrupt can be understood as a signal from a device causing context switch. To handle the interrupts, interrupt handlers or service routines are required. The address of each Interrupt service routine is provided in a list which is maintained in interrupt vector. Interrupts are often divided into synchronous and asynchronous interrupts:

**Synchronous interrupts:** are produced by the CPU control unit while executing instructions and are called synchronous because the control unit issues them only after terminating the execution of an instruction.

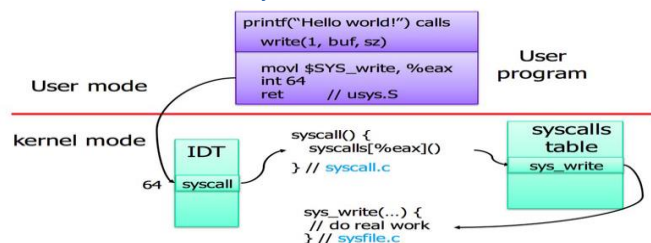
**Asynchronous interrupts:** are generated by other hardware devices at arbitrary times with respect to the CPU clock signals.

## System call: Types of System Call

System calls can be grouped roughly into five major categories:

Sr No.		Example
1	Process control	Create process, terminate process, end, allocate and free memory etc
2	File manipulation	Create file, delete file, open file, close file, read, write.
3	Device manipulation	request device, release device, read, write, reposition, get device attributes, set device attributes etc.
4	Information maintenance	get or set process, file, or device attributes
5	Communications	Send, receive messages, transfer status information

open/read/write/fork. read(c program in user space)--> printf calls write and write assign interrupt no. To sys\_write. Now interrupt no. Is mached in IDT to call sysem call table and then from there correct system call is called.



## Maskable and non-maskable interrupt:

Non-maskable interrupt cannot be ignored by CPU (chipset errors, memory corruption problems, parity errors and high-level errors needing immediate attention)

Maskable interrupt can be ignored by CPU

## Hardware Interrupt handling:

- Device raises an interrupt on the corresponding IRQ pin.
- PIC (Programmable Interrupt Controller) converts the IRQ into a vector number and writes it to a port for CPU to read PIC raises an interrupt on CPU INTR pin
- PIC waits for CPU to acknowledge an interrupt CPU handles the interrupt

arch/x86/include/asm/irq\_vectors.h

0	0..31, system traps and exceptions
1	
32	32..127, device interrupts
128	int80 syscall interface 129..255, other interrupts
129	
255	



### Top Halves and Bottom Halves

#### Limitations On interrupt handler: -

- 1) It runs asynchronously by interrupting the other code.
- 2) All interrupt on the current processor disabled.
- 3) Interrupts are often time critical as they deal with hardware.
- 4) We cannot block interrupt handler as they run in interrupt context.

#### Interrupt handling is divided into two parts:

- 1) Top Halves: - It is executed as immediate response to interrupt.
- 2) Bottom Halves: - It is executed sometime later when CPU get free time.

**Top Halves:** - Top halves executes as soon as CPU receives the interrupt. Following work are generally performed in top halves

- 1) Acknowledgment of receiving the interrupt
- 2) copy if some data is received
- 3) if the work is sensitive needs to perform in top halves.
- 4) If the work is related to hardware needs to perform in top halves.
- 5) If the work needs to be ensure that another interrupt does not interrupt it , should be perform in interrupt handler.

#### Softirqs vs Tasklet:

Softirqs are re-entrant , that is the different CPU can take the same softirq and execute it while the Tasklets are serialized that is the same CPU which is running the tasklet has the right to complete it.

### Difference between Hard link and soft link:

#### Hard Link:

A hard link acts as a copy (mirrored) of the selected file. It accesses the data available in the original file. If the earlier selected file is deleted, the hard link to the file will still contain the data of that file.

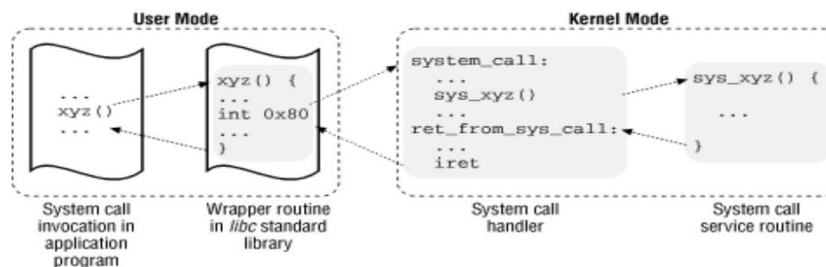
#### Soft Link:

A soft link (also known as Symbolic link) acts as a pointer or a reference to the file name. It does not access the data available in the original file. If the earlier file is deleted, the soft link will be pointing to a file that does not exist anymore.

#### CPU switches from User mode to Kernel mode in following cases:

- 1) User process triggers system calls (software interrupts)
- 2) Device sends interrupt (hardware interrupt)
- 3) CPU raises exception. (Exception)

**Figure 8-1. Invoking a system call**



When user space process calls system calls, corresponding wrapper function will be available in libc library. This wrapper function will set vector no. 0x80. CPU will save the current process context in system stack and also will change processor state. In Kernel space, this will be checked in Interrupt vector table and system call table will be called and corresponding system call routine will be called.

**Ldconfig:** Ldconfig is used to create, update and remove symbolic

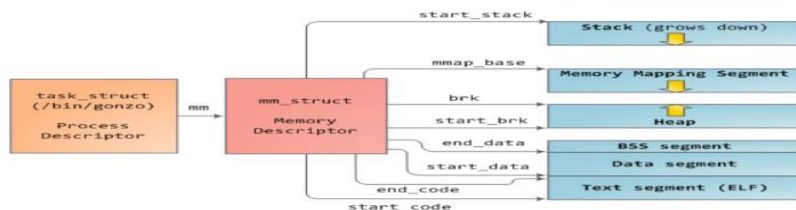
links for the current shared libraries based on the lib directories present in the /etc/ld.so.conf

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## Memory Management

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**Memory Management:** Memory management is the functionality of an operating system which handles or manages primary memory and moves processes back and forth between main memory and disk during execution. Memory management keeps track of each memory location, regardless of whether it is allocated to some process, or it is free. It checks how much memory is to be allocated to processes. It decides which process will get memory at what time. It tracks whenever some memory gets freed or unallocated and correspondingly it updates the status.



### Why Memory Management is required:

- Allocate and de-allocate memory before and after process execution.
- To keep track of used memory space by processes.
- To minimize fragmentation issues.
- To proper utilization of main memory.
- To maintain data integrity while executing of process.

### Levels of memory:

#### Level 1 or Register –

It is a type of memory in which data is stored and accepted that are immediately stored in CPU. Most commonly used register is accumulator, Program counter, address register etc.

#### Level 2 or Cache memory –

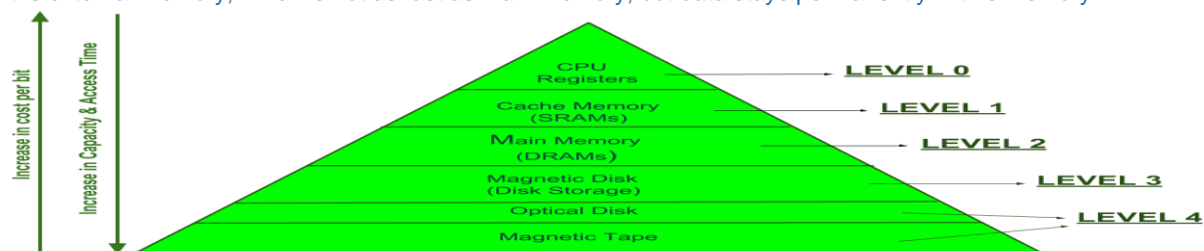
It is the fastest memory which has faster access time where data is temporarily stored for faster access.

#### Level 3 or Main Memory –

It is memory on which computer works currently. It is small and once power is off data no longer stays in this memory.

#### Level 4 or Secondary Memory –

It is external memory, which is not as fast as main memory, but data stays permanently in this memory.



### MEMORY HIERARCHY DESIGN

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**Cache Memory:** is a special very high-speed memory. It is used to speed up and synchronizing with high-speed CPU. Cache memory is costlier than main memory or disk memory but economical than CPU registers. Cache memory is an extremely fast memory type that acts as a buffer between RAM and the CPU. It holds frequently requested data and instructions so that they are immediately available to the CPU when needed.

Cache memory is used to reduce the average time to access data from the Main memory. The cache is a smaller and faster memory which stores copies of the data from frequently used main memory locations. There are various independent caches in a CPU, which store instructions and data.

#### Cache Performance:

When the processor needs to read or write a location in main memory, it first checks for a corresponding entry in the cache. If the processor finds that the memory location is in the cache, a cache hit has occurred, and data is read from cache. If the processor does not find the memory location in the cache, a cache miss has occurred. For a cache miss, the cache allocates a new entry and copies in data from main memory, then the request is fulfilled from the contents of the cache.

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**Translation Lookaside Buffer (i.e. TLB):** is required only if Virtual Memory is used by a processor. In short, TLB speeds up the translation of virtual addresses to a physical address by storing page-table in faster memory. In fact, TLB also sits between CPU and Main memory.

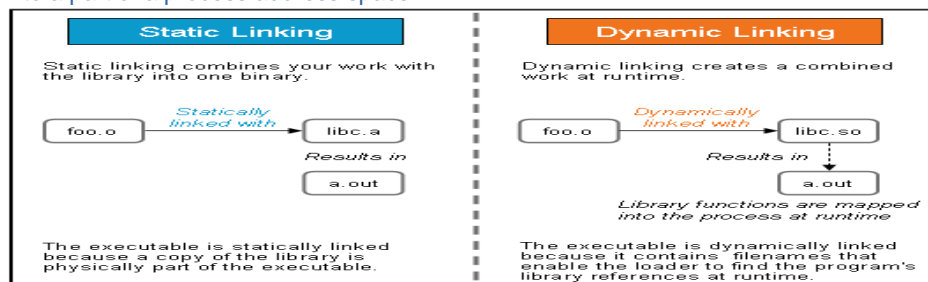
#### Reentrant Kernels:

All Unix kernels are reentrant: this means that several processes may be executing in Kernel Mode at the same time.

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**Process Address Space:** Each process runs in its private address space. A process running in User Mode refers to private stack, data, and code areas.

Linux supports the `mmap()` system call, which allows part of a file or the memory residing on a device to be mapped into a part of a process address space.



Whenever there is change in static lib, code must be recompiled as well but it is secured no other app can corrupt it. While dynamic lib is not part of executable but only one copy can be shared by multiple apps.

To create a dynamic library, write the following command:

```
gcc -g -fPIC -Wall -Werror -Wextra -pedantic *.c -shared -o liball.so
```

The **-fPIC** flag allows the following code to be referenced at any virtual address at runtime. It stands for Position Independent Code.

```
export LD_LIBRARY_PATH=.:$LD_LIBRARY_PATH
```

#### Static library creation:

```
ar rc liball.a dog.o cat.o bird.o
```

ar is for archiving and -rc is for replace and create....

#### Logical and Physical Address Space:

**Logical Address space:** An address generated by the CPU is known as "Logical Address". It is also known as a Virtual address. Logical address space can be defined as the size of the process. A logical address can be changed.

**Physical Address space:** An address seen by the memory unit (i.e the one loaded into the memory address register of the memory) is commonly known as a "Physical Address". A Physical address is also known as a Real address. The set of all physical addresses corresponding to these logical addresses is known as Physical address space. A physical address is computed by MMU. The run-time mapping from virtual to physical addresses is done by a hardware device Memory Management Unit(MMU). The physical address always remains constant.

**Static and Dynamic Loading:** To load a process into the main memory is done by a loader. There are two different types of loading:

**Static loading:** - loading the entire program into a fixed address. It requires more memory space.

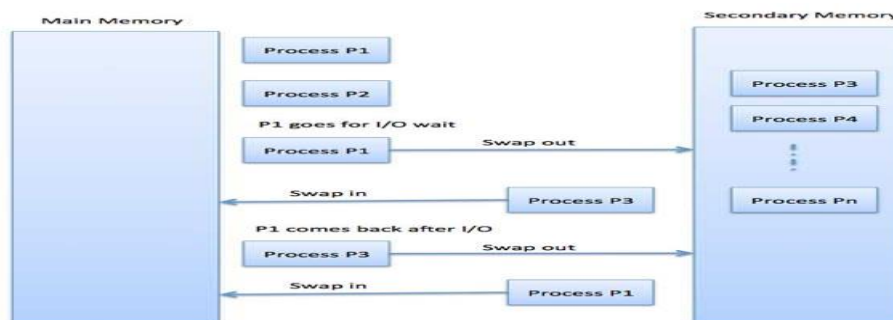
- **Dynamic loading:** - The entire program and all data of a process must be in physical memory for the process to execute. So, the size of a process is limited to the size of physical memory. To gain proper memory utilization, dynamic loading is used. In dynamic loading, a routine is not loaded until it is called. All routines are residing on disk in a relocatable load format. One of the advantages of dynamic loading is that unused routine is never loaded. This loading is useful when a large amount of code is needed to handle it efficiently.

**Static and Dynamic linking:** To perform a linking task a linker is used. A linker is a program that takes one or more object files generated by a compiler and combines them into a single executable file.

**Static linking:** In static linking, the linker combines all necessary program modules into a single executable program. So there is no runtime dependency. Some operating systems support only static linking, in which system language libraries are treated like any other object module.

- **Dynamic linking:** The basic concept of dynamic linking is like dynamic loading. In dynamic linking, "Stub" is included for each appropriate library routine reference. A stub is a small piece of code. When the stub is executed, it checks whether the needed routine is already in memory or not. If not available, then the program loads the routine into memory.

**Swapping:** Swapping is a memory management scheme in which any process can be temporarily swapped from main memory to secondary memory so that the main memory can be made available for other processes. It is used to improve main memory utilization. Swapping is also known as roll-out, roll in, because if a higher priority process arrives and wants service, the memory manager can swap out the lower priority process and then load and execute the higher priority process. After finishing higher priority work, the lower priority process swapped back in memory and continued to the execution process.



### Memory Allocation:

Main memory usually has two partitions –

- Low Memory – Operating system resides in this memory.
- High Memory – User processes are held in high memory.

Operating system uses the following memory allocation mechanism.

S.N.	Memory Allocation & Description
1	<p><b>Single-partition allocation</b></p> <p>In this type of allocation, relocation-register scheme is used to protect user processes from each other, and from changing operating-system code and data. Relocation register contains value of smallest</p>

	physical address whereas limit register contains range of logical addresses. Each logical address must be less than the limit register.
2	<p><b>Multiple-partition allocation</b></p> <p>In this type of allocation, main memory is divided into several fixed-sized partitions where each partition should contain only one process. When a partition is free, a process is selected from the input queue and is loaded into the free partition. When the process terminates, the partition becomes available for another process.</p>

**Fragmentation** As processes are loaded and removed from memory, the free memory space is broken into little pieces. It happens after sometimes that processes cannot be allocated to memory blocks considering their small size and memory blocks remains unused. This problem is known as Fragmentation.

#### Internal fragmentation:

Internal fragmentation occurs when memory blocks are allocated to the process more than their requested size. Due to this some unused space is leftover and creates an internal fragmentation problem.

**Example:** Suppose there is a fixed partitioning is used for memory allocation and the different size of block 3MB, 6MB, and 7MB space in memory. Now a new process p4 of size 2MB comes and demand for the block of memory. It gets a memory block of 3MB but 1MB block memory is a waste, and it cannot be allocated to other processes too. This is called internal fragmentation.

#### External fragmentation:

In external fragmentation, we have a free memory block, but we cannot assign it to process because blocks are not contiguous.

**Example:** Suppose (consider above example) three process p1, p2, p3 comes with size 2MB, 4MB, and 7MB respectively. Now they get memory blocks of size 3MB, 6MB, and 7MB allocated respectively. After allocating process p1 process and p2 process left 1MB and 2MB. Suppose a new process p4 comes and demands a 3MB block of memory, which is available, but we cannot assign it because free memory space is not contiguous. This is called external fragmentation.

Both the first fit and best-fit systems for memory allocation affected by external fragmentation. To overcome the external fragmentation problem Compaction is used. In the compaction technique, all free memory space combines and makes one large block. So, this space can be used by other processes effectively.

Another possible solution to the external fragmentation is to allow the logical address space of the processes to be noncontiguous, thus permit a process to be allocated physical memory wherever the latter is available.

**Paging:** Paging is a memory management scheme that eliminates the need for contiguous allocation of physical memory. This scheme permits the physical address space of a process to be non-contiguous.

- Logical Address or Virtual Address (represented in bits): An address generated by the CPU
- Logical Address Space or Virtual Address Space (represented in words or bytes): The set of all logical addresses generated by a program
- Physical Address (represented in bits): An address available on a memory unit
- Physical Address Space (represented in words or bytes): The set of all physical addresses corresponding to the logical addresses

#### Example:

The mapping from virtual to physical address is done by the memory management unit (MMU) which is a hardware device, and this mapping is known as the paging technique.

- The Physical Address Space is conceptually divided into several fixed-size blocks, called frames.
- The Logical Address Space is also split into fixed-size blocks, called pages.
- Page Size = Frame Size

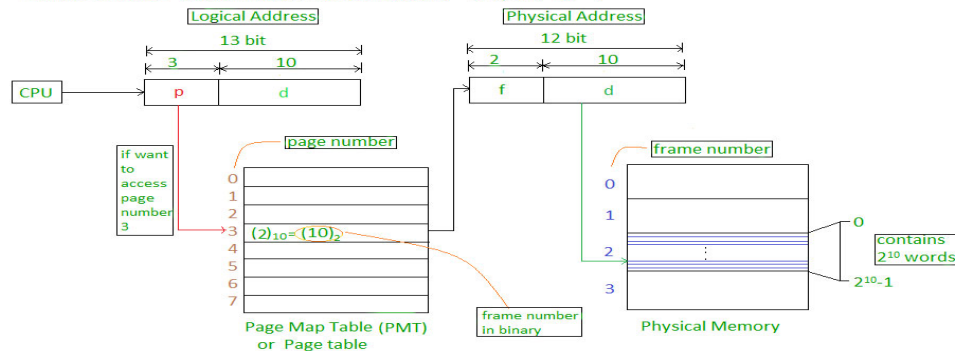
#### Let us consider an example:

- Physical Address = 12 bits, then Physical Address Space = 4 K words



- Logical Address = 13 bits, then Logical Address Space = 8 K words
- Page size = frame size = 1 K words (assumption)

Number of frames = Physical Address Space / Frame size =  $4 \text{ K} / 1 \text{ K} = 4 = 2^2$   
 Number of pages = Logical Address Space / Page size =  $8 \text{ K} / 1 \text{ K} = 8 = 2^3$

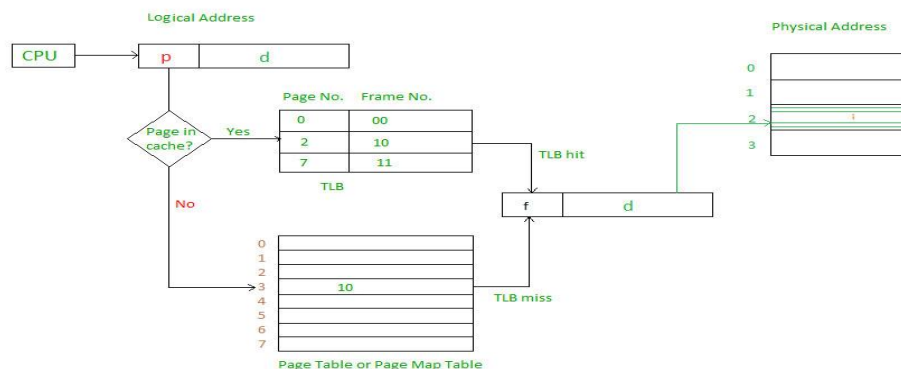


The address generated by the CPU is divided into:

- **Page number(p):** Number of bits required to represent the pages in Logical Address Space or Page number
- **Page offset(d):** Number of bits required to represent a particular word in a page or page size of Logical Address Space or word number of a page or page offset.

Physical Address is divided into:

- **Frame number(f):** Number of bits required to represent the frame of Physical Address Space or Frame number frame
  - **Frame offset(d):** Number of bits required to represent a particular word in a frame or frame size of Physical Address Space or word number of a frame or frame offset.
- The hardware implementation of the page table can be done by using dedicated registers. But the usage of register for the page table is satisfactory only if the page table is small. If the page table contains many entries, then we can use TLB (translation Look-aside buffer), a special, small, fast look-up hardware cache.
- The TLB is an associative, high-speed memory.
  - Each entry in TLB consists of two parts: a tag and a value.
  - When this memory is used, then an item is compared with all tags simultaneously. If the item is found, then the corresponding value is returned.



**Thrashing:** - In virtual memory system, thrashing is a high page fault scenario. It occurs due to under-allocation of pages required by a process. The system becomes extremely slow due to thrashing leading to poor performance.

### Belady's anomaly occur?

The Belady's anomaly is a situation in which the number of page faults increases when additional physical memory is added to a system.

---

### Advantages and Disadvantages of Paging:

- Paging reduces external fragmentation, but still suffer from internal fragmentation.
  - Paging is simple to implement and assumed as an efficient memory management technique.
  - Due to equal size of the pages and frames, swapping becomes very easy.
  - Page table requires extra memory space, so may not be good for a system having small RAM.
- 

**Segmentation:** is a memory management technique in which each job is divided into several segments of different sizes, one for each module that contains pieces that perform related functions. Each segment is actually a different logical address space of the program.

When a process is to be executed, its corresponding segmentation are loaded into non-contiguous memory though every segment is loaded into a contiguous block of available memory.

---

### Virtual memory:

A computer can address more memory than the amount physically installed on the system. This extra memory is called **virtual memory** and it is a section of a hard disk that's set up to emulate the computer's RAM.

#### Virtual memory advantages:

The main visible advantage of this scheme is that programs can be larger than physical memory. Virtual memory serves two purposes. First, it allows us to extend the use of physical memory by using disk. Second, it allows us to have memory protection, because each virtual address is translated to a physical address.

Virtual memory is commonly implemented by demand paging. It can also be implemented in a segmentation system. Demand segmentation can also be used to provide virtual memory.

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### Demand Paging:

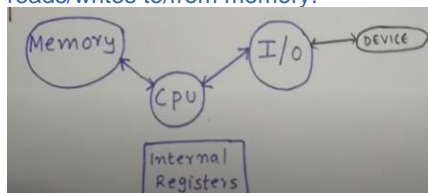
A demand paging system is like a paging system with swapping where processes reside in secondary memory and pages are loaded only on demand, not in advance. When a context switch occurs, the operating system does not copy any of the old program's pages out to the disk or any of the new program's pages into the main memory. Instead, it just begins executing the new program after loading the first page and fetches that program's pages as they are referenced.

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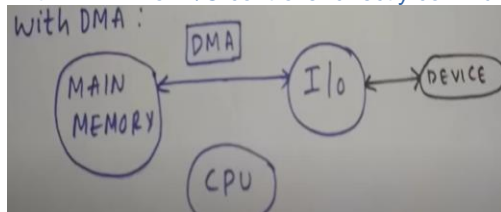
### Direct Memory Access (DMA):

Slow devices like keyboards will generate an interrupt to the main CPU after each byte is transferred. If a fast device such as a disk generated an interrupt for each byte, the operating system would spend most of its time handling these interrupts. So, a typical computer uses direct memory access (DMA) hardware to reduce this overhead. Direct Memory Access (DMA) means CPU grants I/O module authority to read from or write to memory without involvement. DMA module itself controls exchange of data between main memory and the I/O device. CPU is only involved at the beginning and end of the transfer and interrupted only after entire block has been transferred.

**Without DMA:** Device will send data to I/O controller and I/O controller will communicate with CPU then CPU reads/writes to/from memory.



**With DMA:** Now I/O controller directly communicate with memory.



### Preemptive kernel:

A preemptive kernel is one that can be interrupted in the middle of executing code - for instance in response for a system call - to do other things and run other threads, possibly those that are not in the kernel.

**Priority inversion** is a operating system scenario in which a higher **priority** process is preempted by a lower **priority** process.

**Scenario:** Three process p1(High), p2(medium), p3(low). P1 & p3 have to execute in critical section. P3 has locked mutex and executing in cs, in between, p2 preempts p3 and p1 preempts p2.. so p1 cannot execute cs since it has been locked by p3. This becomes priority inversion.

**Priority inheritance:** The basic idea of the **priority inheritance** protocol is that when a job blocks one or more high-**priority** jobs, it ignores its original **priority** assignment and executes its critical section at an elevated **priority** level.

### -----Device Drivers-----

The kernel interacts with I/O devices by means of device drivers. Device drivers are included in the kernel and consist of data structures and functions that control one or more devices

#### --Installing kernel:

- 1) Download and extract kernel code.
- 2) copy current kernel's configuration.
- 3) Make menuconfig
- 4) make --> compiles and links the kernel image. This is a single file named vmlinuz.
- 5) make modules\_install --> **installs your kernel modules to /lib/modules or /lib/modules/<version>**
- 6) make install--> installs your built kernel to /vmlinuz

#### Writing my kernel module and loading dynamically:

##### Modprobe Vs insmod:

modprobe is the intelligent version of insmod. insmod simply adds a module where modprobe looks for any dependency (if that particular module is dependent on any other module) and loads them.

**Module will be loaded into *proc/modules/***

**Rmmod:** remove modules from module list

##### Type of Devices:

**character devices**(serial ports, parallel ports, sounds cards)

**Block devices**(hard disk, floppy disk)

**Network devices**(switches, bridge,router)

##### Majors and minors:

Char devices are accessed through names in the filesystem.

Major no is of 12bits and Minor no. Is of 20bits. Major no. Is for driver and minor no. is for device.

Device file can be created using mknod: **mknod /dev/mycdev c 42 0**

##### Steps performed for device driver:

**load driver->open device->read device/write to device->close device->unload driver**

**Reading from device-> uses copy\_to\_user**

**Write to device-> copy\_from\_user**

**ioctl:** The system call ioctl() is provided for device-specific custom commands (such as format, reset and shutdown) that are not provided by standard system calls such as read(), write and mmap(). To invoke ioctl commands of a device, the user-space program would open the device first, then send the appropriate ioctl() and any necessary arguments

### -----GDB-----

compile with -g to load debug symbols.  
Gdb executable name( **gdb b main/ gdb b file.c:233**)  
b/break fun\_name/line no.  
Run(r)  
s(step into)  
n(next line)  
c(continue)

\*\*\*\*\*

### **mknod /dev/rama c 12 5**

To deploy a module inside kernel, what are the possible methods.? Mention actual difference among them.

**insmod** requires you to pass it the full pathname and to insert the modules in the right order, while **modprobe** just takes the name, without any extension, and figures out all it needs to know by parsing /lib/modules/version/modules.dep.

Explain about about ksets, kobjects and ktypes. How are they related?

Kobjects have a name and a reference count.

- A ktype is the type of object that embeds a kobject. Every structure that embeds a kobject needs a corresponding ktype. The ktype controls what happens to the kobject when it is created and destroyed.

- A kset is a group of kobjects. These kobjects can be of the same ktype or belong to different ktypes. The kset is the basic container type for collections of kobjects. Ksets contain their own kobjects, but you can safely ignore that implementation detail as the kset core code handles this kobject automatically.

### **1. As kernel can access user space memory, why should copy\_from\_user is needed?**

Disables SMAP (Supervisor Mode Access Prevention) while copying from user space

### **2. how many ways we can assign a major minor number to any device?**

There are two ways of a driver assigning major and minor number.

#### **1. Static Assignment:**

register\_chrdev\_region is the function to allocate device number statically.

2. **Dynamic Assignment:** alloc\_chrdev\_region is the kernel function to allocate device numbers dynamically

### **3. How is container\_of( ) macro implemented?**

### **4. Main Advantages and disadvantages of having separate user space and kernel space?**

**system** calls might be **faster** (i.e. **lower latencies**), as the CPU doesn't have to switch from application mode into kernel. you might get **direct access to the system's hardware** via memory and I/O ports.

### **5. What is re entrant function: It can be reentered by another thread.**

### **6. How will you insert a module statically in to linux kernel:**

you just need to do a bit of hacking to move the external module into the kernel source tree, tweak the Makefiles/Kconfig a bit so that the code is built-in, and then build your kernel image.

### **7. how the device files are created in Linux:**

They're called **device** nodes, and are **created** either manually with mknod or automatically by udev

8. How can a static driver runs? Without doing any insmod?

### **9. What is the path of your driver inside kernel? /lib/modules/\$(uname -r)**

### **10. Diff b/w SLAB and Vmalloc**

**Kmalloc** is similar to malloc function, we use in our C program to allocate memory in user space. kmalloc allocates memory in kernel space. kmalloc allocates contiguous memory in physical memory as well as virtual memory. vmalloc is the other call to allocate memory in kernel space as like kmalloc.

**vmalloc** allocates contiguous memory in virtual memory but it doesn't guarantee that memory allocated in physical memory will be contiguous.

11. How do you pass a value to a module as a parameter? ->**module\_param()**

### **12. What is the functionality of PROBE function**

**The purpose of the probe routine is to detect devices residing on the bus and to create device nodes corresponding to these device**

13. How do you get the list of currently available drivers ?

14. What is the use of file->private\_data in a device driver structure ?

Private data to driver.

15. What is a device number ?

16. What are the two types of devices drivers from VFS point of view ?

17. How to find a child process in linux/unix.?

using the -P option of pgrep (pgrep -P pid)

18. What is the difference between fork( ) and vfork( )?

The primary **difference between** the **fork()** and **vfork()** system call is that the child process created using **fork** has separate address space as that of the parent process. On the other hand, child process created using **vfork** must share the address space of its parent process.

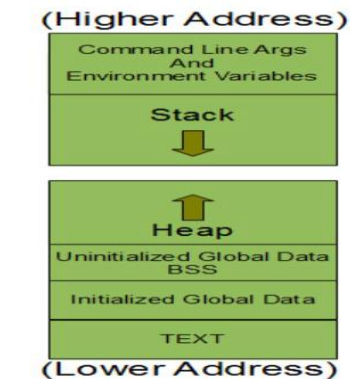
19. **What are the processes with PID 0 is Sched and PID 1 is init**(process primarily responsible for starting and shutting down the system)

20. What is the difference between interruptible and uninterruptible task states?

21. How processes and threads are created? (From user level till kernel level)

**22. How to determine if some high priority task is hogging CPU: top**

23. Priority inversion, priority inheritance, priority ceiling



25. how much memory is occupied by process address space.

4 GB

26. When a same executable is executed in two terminals like terminal 1 execute ./a.out and terminal

2 executed ./a.out what will the program address space look like on RAM

27. **what is diff b/w process and threads?**

A **process** is a program under execution i.e an active program. A **thread** is a lightweight **process** that can be managed independently by a scheduler. **Processes** require more time for context switching as they are more heavy. **Threads** require less time for context switching as they are lighter than **processes**

28. Will threads have their own stack space?

Yes

29. **Can one thread access the address space of another thread?**

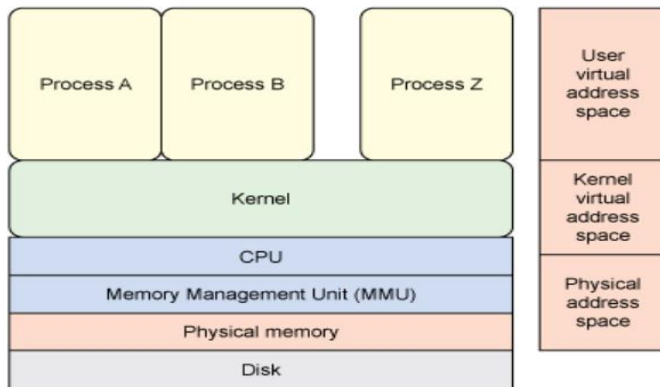
In general, each *thread* has its own registers (including its own program counter), its own stack pointer, and its own stack. Everything else is shared between the threads sharing a process.

A *process* is generally considered to consist of a set of threads sharing an address space, heap, static data, and code segments, and file descriptors\*.

**30. What is task\_struct and how are task states maintained?**

Task\_struct is structure used to instantiate for each process.

Task\_states are: Running, uninterruptible sleep(D), interruptible sleep(S), Zombies



Virtual address space to Physical address space.

**Mutex:** When want to provide atomic access to critical section. A mutex provides mutual exclusion, either producer or consumer can have the key (mutex) and proceed with their work. As long as the buffer is filled by producer, the consumer needs to wait, and vice versa.

**Semaphore:** we can split the 4 KB buffer into four 1 KB buffers (identical resources). A semaphore can be associated with these four buffers. The consumer and producer can work on different buffers at the same time.

**Spinlock:** Use a spinlock when you really want to use a mutex, but your thread is not allowed to sleep. e.g.: An interrupt handler within OS kernel must never sleep.

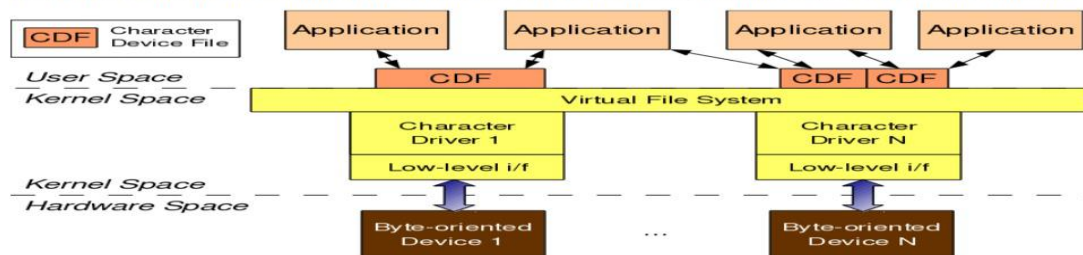
**Deadlock:** If a thread which had already locked a mutex, tries to lock the mutex again, it will enter the waiting list of that mutex, which results in deadlock.

**Scheduling methods** such as First Come First Serve, Round Robin, Priority-based scheduling

**Steps to invoke device driver:**

- 1) User space process tries to write to character device.
- 2) **Device file:** All data will be communicated through device file will be in *dev*.
- 3) **Device driver:** This is the software interface for the device and resides in the kernel space.
- 4) **Device:** This can be the actual device present at the hardware level, or a pseudo device.

In fact, all device drivers that are neither storage nor network device drivers are some type of a character driver. Let's look into the commonalities of these character drivers, and how Shweta wrote one of them.



**Inode:**

The inode (index node) keeps information about a file in the general sense (abstraction): regular file, directory, special file (pipe, fifo), block device, character device, link, or anything that can be abstracted as a file.

**Interview questions:**

**As kernel can access user space memory, why should `copy_from_user` is needed?**

If kernel directly accesses the user data structure, system will panic if it's not a valid address (eg NULL pointer). To avoid this situation, `copy_from_user(..)` is used. This function will fail, if proper user address is not provided and does not bring down the system.

**To deploy a module inside kernel, what are the possible methods.? Mention actual difference among them?**

1. dynamic insertion as a kernel module (modprobe and insmod)
2. linking statically to the kernel code But everyone will prefer modprobe because insmod have no capability to resolve dependency issue. But modprobe can do that.

**What is cache ? How it is used and mapped the physical address cache and virtual address cache ?**

Cache is a component that improves performance by transparently storing data such that future requests for that data can be served faster.

The data that is stored within a cache might be values that have been computed earlier or duplicates of original values that are stored elsewhere. If requested data is contained in the cache (cache hit), this request can be served by simply reading the cache, which is comparably faster.

**How one can measure time spent in context switch?**

record the timestamps of the first and last instructions of the swapping processes. The context switch time is the difference between the two processes.

**How to debug kernel?**

printks ! Simple and very convenient. KDB and kernel probes can also be used.

**What is the difference between kill-6 and kill -9**

Kill-9: SIGKILL

Kill-6: SIGABRT

**How would you handle sleeping or blocking instructions in an Interrupt Service Routine (if unavoidable) or basically if the length of ISR is long?**

Sleep or blocking cannot be allowed in ISR(Interrupt context), Task lets(soft interrupt context)  
But allowed in Work Queues(kernel context).

**Explain device tree concepts in linux.** : is a data structure describing the hardware components of a particular computer so that the operating system's kernel can use and manage those components, including the CPU or CPUs, the memory, the buses and the integrated peripherals.

**Given a pid, how will you distinguish if it is a process or a thread ?**

ps -AL | grep pid

1st column is parent id and the second column is thread (LWP) id. if both are same then its a process id otherwise thread.