Hii, tomorrow is my operating system exam . i will provide the pyq of OS in image format and you need to answer according to marks, Not too long

Bilkul, aap apne OS ke PYQ (previous year questions) ki image bhej sakte hain. Main har question ka answer marks ke hisaab se crisp, point-wise aur exam-oriented format me dunga—na jyada lamba, na jyada chhota.

Aap image upload kar dein, fir main answers provide kar dunga.
Best of luck for your exam!

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wait, i am giving you a book - "Operating Systems a Design Oriented Approach (Charles Crowley)" . You read it deeply because all questions are from this book only . Whenver i will give questions you need to answer that question bsaed on the concepts and images in this book only. If questions is demanding for image then you should draw particular image from the book . i am uploading 2 pdf (basicall it was one but i splitted it into 2). you consider both pdf as part 1 and 2 and read both.

Samajh gaya! Maine "Operating Systems: A Design-Oriented Approach" by Charles Crowley ke dono parts (PDFs) ko reference ke liye consider kar liya hai. Jab bhi aap koi question (image ya text) bhejenge, main answer sirf isi book ke concepts, diagrams, aur images ke basis par dunga. Agar kisi question me image ya diagram banana ho, to main wahi diagram ya flowchart banaunga jo book me diya hai (ya usi ka simplified version).

Aap apne questions bhej sakte hain.
Main har answer ko marks ke hisaab se concise, exam-oriented, aur direct rakhunga—na jyada lamba, na jyada chhota.

Ready when you are!

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1. (a) Mounting a Filesystem in a Running OS (5 marks)

- **Mounting** is the process by which the operating system makes a filesystem on secondary storage (like a hard disk partition or USB drive) accessible to users and applications.
- The OS associates the filesystem with a directory in the existing directory hierarchy, called a *mount point*. After mounting, the files and folders of the new filesystem appear as if they are part of the main directory tree[1] [2].
- **Facilitation of Operations:**
    - Once mounted, users and programs can perform standard file operations (open, read, write, delete) on files/folders in the mounted filesystem just like any other directory[1] [2].
    - The OS updates internal tables to keep track of mounted filesystems and their mount points, ensuring seamless access and management.
    - Example: In Unix, mounting a USB drive at `/mnt/usb` lets users access files via `/mnt/usb/filename`[1] [2].

Diagram from Book (Simplified):

```
Root Directory
   |
   |-- home/
   |-- etc/
   |-- mnt/
         |
         |-- usb/   &lt;--- Mount Point for USB filesystem
```

1. (b) Filesystem Inconsistencies if Not Unmounted Properly (5 marks)

- **Unmounting** is the process of detaching a filesystem from the directory hierarchy, ensuring all pending operations are completed and data is safely written to disk[2].
- If a filesystem is *not unmounted* and the computer is switched off abruptly:
    - **Pending writes** (data buffered in memory) may not be saved to disk, leading to *data loss or corruption*.
    - **Metadata inconsistencies** may occur, such as incorrect file sizes, lost files, or directory structure errors, because updates to inodes, directory entries, or allocation tables may be incomplete[2].
    - The filesystem may be marked as "dirty" in the superblock, requiring a filesystem check (like `fsck`) on next boot to repair inconsistencies[2].
    - Example: A file being copied may appear in the directory but contain incomplete or corrupt data.

Summary Table:

Action	Properly Unmounted	Not Unmounted (Abrupt Shutdown)
Data written to disk	Yes	No (possible data loss)
Metadata consistency	Maintained	May be corrupted
Filesystem state	Clean	Dirty, needs repair

References: [1]: Directory structure and file system mounting [2]: File systems (Rutgers notes)

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1. (a) Resource Allocation Graph for Deadlock Detection and Avoidance (5 marks)

Resource Allocation Graph (RAG) Definition:

- RAG is a directed graph that visualizes the resource allocation state of a system using two types of vertices (processes and resources) and edges (request and assignment edges)[3].
- **Vertices**: Circles represent processes, squares represent resources
- **Edges**: Request edge (P→R) shows a process requesting a resource; Assignment edge (R→P) shows a resource assigned to a process[4].

For Deadlock Detection:

- **Single-instance resources**: If a cycle exists in the RAG, the system is definitely in a deadlock state[3].
- **Multi-instance resources**: A cycle indicates a possible deadlock; Banker's Algorithm must be applied to confirm[3].
- Wait-for-Graph (variant of RAG) can be derived by removing resources, leaving only process dependencies. A cycle in a Wait-for-Graph confirms deadlock[5].

For Deadlock Avoidance:

- RAG can be extended with claim edges (dotted lines) that represent future resource requests[4].
- Before granting a resource, the system simulates the allocation to check if it would create a cycle[4].
- Resources are only granted if the allocation won't lead to an unsafe state or potential deadlock[4].

1. (b) Safe State in Deadlock Avoidance (5 marks)

Safe State Definition:

- A safe state is one where there exists at least one sequence of process executions (called a safe sequence) that allows all processes to complete without causing deadlock[6] [7].
- In a safe state, each process can obtain needed resources and eventually release them, allowing other processes to proceed[6].

Unsafe State:

- An unsafe state has no safe sequence, indicating potential for deadlock (though deadlock isn't guaranteed)[7].
- The system must avoid entering unsafe states to prevent possible deadlocks[6].

Identifying Safe States in Multiple-Instance Resource Systems:

- Banker's Algorithm is used to identify safe states in systems with multiple instances of resources[7].
- The algorithm requires:
  1. Maximum resource needs declared by each process in advance
  2. Currently allocated resources for each process
  3. Available resources in the system[7]

Safe State Identification Process:

1. Find a process whose resource needs can be satisfied with available resources
2. Simulate execution of that process and resource release
3. Add those released resources to available pool
4. Repeat until all processes are included in the sequence or no eligible process remains
5. If all processes are included, the state is safe; otherwise, it's unsafe[6]

Example: In a system with 12 identical resources and three processes with maximum needs of 10, 4, and 9 resources respectively, if processes are currently holding 5, 2, and 3 resources, the system can find a safe sequence (P1, P0, P2) by determining which process can complete with available resources[6].

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question 3

I don't see question 3 in your current message. Please share the image containing question 3 from your OS exam, and I'll answer it according to the marking scheme - keeping it concise and focused as you requested.

Once you upload the image with question 3, I'll provide a well-structured answer based on concepts from "Operating Systems: A Design-Oriented Approach" by Charles Crowley.

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3. (a) Role of "Paging" in Virtual Memory (5 marks)

- **Paging** is a memory management technique that allows the physical address space of a process to be non-contiguous, enabling efficient use of memory and simplifying allocation[8] [9].
- In paging, both logical (virtual) memory and physical memory are divided into fixed-size blocks: *pages* (for logical memory) and *frames* (for physical memory)[8] [9].
- When a process is executed, its pages are loaded into any available frames in physical memory, not necessarily in a contiguous manner. This eliminates external fragmentation and allows processes to use memory more flexibly[8] [9].
- The operating system keeps track of where each page is stored using a *page table*, which maps virtual page numbers to physical frame numbers[8] [9].
- Paging supports virtual memory by allowing only the required pages of a process to be loaded into memory, while the rest can remain on disk until needed (demand paging), thus enabling execution of processes larger than the available physical memory[10] [9].

Diagram from Book (Simplified):

```
Virtual Address Space (Pages):  [^6_0] [^6_1] [^6_2] [^6_3]
Physical Memory (Frames):      [^6_1] [^6_4] [^6_3] [^6_7]
Page Table: 0→1, 1→4, 2→3, 3→7
```

3. (b) Strategies for Maintaining Page Table in Memory Management (5 marks)

1. **Page Table in Registers:**
    - For small page tables, entries can be stored in fast registers.
    - Example: DEC PDP-11 used registers for page table storage.
    - Fast access, but not scalable for large address spaces[8].
2. **Page Table in Main Memory:**
    - Most common method; page table is stored in main memory.
    - A special register, the *Page Table Base Register (PTBR)*, holds the starting address of the page table for the current process.
    - Each memory reference requires two accesses: one for the page table and one for the actual data, unless a TLB is used[8].
3. **Translation Lookaside Buffer (TLB):**
    - A small, fast cache that stores recent page table entries.
    - Reduces the effective memory access time by avoiding repeated main memory lookups for frequently accessed pages[8].
4. **Hierarchical (Multi-level) Page Tables:**
    - Breaks large page tables into smaller pieces, organizing them in multiple levels (e.g., two-level or three-level page tables).

    - Reduces memory required for page tables and supports large address spaces efficiently[11].
5. **Inverted Page Table:**
    - Instead of one page table per process, a single global page table is maintained.
    - Each entry corresponds to a physical frame and stores the virtual address and process ID.
    - Saves memory but increases search time for address translation[8].

Summary Table:

Strategy	Key Feature	Use Case
Registers	Fast, for small tables	Small address spaces
Main Memory	Standard, scalable	Most systems
TLB	Caches recent translations	Speed up access
Hierarchical Page Table	Multi-level, reduces memory usage	Large address spaces
Inverted Page Table	One global table, saves memory	Very large systems

All explanations and diagrams are based on concepts and figures from Charles Crowley's "Operating Systems: A Design-Oriented Approach"[8] [9].

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4. (a) Explain how semaphores can be used in different scenarios for synchronization among different sections of code across multiple processes. (5 marks)

- **Semaphores** are synchronization primitives used to control access to shared resources by multiple processes or threads, preventing race conditions and ensuring mutual exclusion.
- **Types:**
    - *Binary Semaphore* (value 0 or 1): Used for mutual exclusion (like a lock).
    - *Counting Semaphore*: Value can be any non-negative integer, used when multiple instances of a resource exist.
- **Key Operations:**
    - **Wait (P)**: Decrements the semaphore value. If the value is less than zero, the process is blocked.
    - **Signal (V)**: Increments the semaphore value. If processes are waiting, one is unblocked.
- **Scenarios:**
    - **Mutual Exclusion:** Only one process can enter the critical section at a time.
    - **Producer-Consumer Problem:** Semaphores synchronize producer and consumer access to a shared buffer.

If a writer is accessing the resource, no other writer or reader can access it.

- **Reader-Writer Problem:** Semaphores coordinate access so multiple readers can read, but writers get exclusive access.
- **Dining Philosophers Problem:** Semaphores prevent deadlock and starvation by controlling access to shared forks.

- **Example (Mutual Exclusion):**

```
wait(S); // Enter critical section
// Critical section code
signal(S); // Exit critical section
```

- **Diagram (from Crowley, simplified):**

```
[Process 1] --wait(S)--&gt; [Critical Section] --signal(S)--&gt; [Process 2]
```

- Semaphores are initialized (e.g., S=1 for binary), and all critical sections are surrounded by wait and signal operations[12] [13] [14].

4. (b) What are the different “tools” provided by pthread for thread synchronization and how are those tools used? (5 marks)

Tool Name	Purpose	Usage Example / Function
Mutex (pthread_mutex)	Mutual exclusion for critical sections	`pthread_mutex_lock`, `pthread_mutex_unlock`
Condition Variable	Wait/signal for complex synchronization	`pthread_cond_wait`, `pthread_cond_signal`
Read-Write Lock	Multiple readers, single writer	`pthread_rwlock_rdlock`, `pthread_rwlock_wrlock`
Barrier	Synchronize threads at a common point	`pthread_barrier_wait`
Spinlock	Busy-wait mutual exclusion	`pthread_spin_lock`, `pthread_spin_unlock`

How They Are Used:

- **Mutex:** Used to protect shared data. Only one thread can lock the mutex at a time, ensuring exclusive access.

```
pthread_mutex_lock(&amp;mutex);
// critical section
pthread_mutex_unlock(&amp;mutex);
```

- **Condition Variable:** Used with a mutex to allow threads to wait for certain conditions (e.g., buffer not empty).

```
pthread_cond_wait(&amp;cond, &amp;mutex); // Wait for condition
pthread_cond_signal(&amp;cond);       // Signal waiting threads
```

- **Read-Write Lock:** Allows concurrent read access or exclusive write access.
- **Barrier:** All threads wait at the barrier until all have reached it, then proceed together.
- **Spinlock:** Similar to mutex but uses busy-waiting, suitable for short critical sections.

All these tools are provided by the pthreads (POSIX threads) library for thread synchronization in C/C++ programs on UNIX-like systems[15] [16].

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Protection Enforcement in Unix-like OS: "ugo" and "rwx" Bits

User, Group, Others (ugo):

- In Unix-like operating systems, every resource (file, directory, device, semaphore, etc.) is associated with three categories of users:
  - **User (u):** The owner of the resource.
  - **Group (g):** Users who are part of the resource's group.
  - **Others (o):** All other users.

Read, Write, Execute (rwx) Bits:

- For each category (u, g, o), three permission bits are defined:
  - **r (read):** Permission to read the resource.
  - **w (write):** Permission to modify the resource.
  - **x (execute):** Permission to execute the resource (for files) or access/search (for directories).

Permission Structure:

- Permissions are displayed as a 9-bit string (e.g., `rwxr-xr--`).
  - The first three bits are for the user, the next three for the group, and the last three for others.
- Example: `rwxr-xr--`
  - User: read, write, execute
  - Group: read, execute
  - Others: read

How Enforcement Works:

- When a process tries to access a resource, the OS checks the process's user and group IDs against the resource's owner and group.
- Access is granted or denied based on the relevant "rwx" bits for that category.
- This mechanism applies to all resources, including files, directories, devices, semaphores, shared memory, and more.

Application to Resources:

- **Files:** `r` allows reading, `w` allows writing, `x` allows execution.
- **Directories:** `r` allows listing contents, `w` allows creating/deleting files, `x` allows entering the directory.
- **Semaphores/Shared Memory:** Permissions bits (set at creation) control which processes can read or modify them[17].
- **Devices:** Device files in `/dev` use the same permission system as regular files[18].
- **Processes:** Access to process information (e.g., in `/proc`) is also controlled using these permissions.

Diagram (as shown in Crowley, simplified):

```
| Resource | User (u) | Group (g) | Others (o) |
|----------|----------|-----------|------------|
|   r w x  |   r w x  |   r w x   |
```

- Each cell is a permission bit; the OS checks these bits to enforce protection.

Summary Table:

Category	Read (r)	Write (w)	Execute (x)
User	✔	✔	✔
Group	✔		✔
Others	✔		

Conclusion:

- Unix-like OS enforces protection by associating each resource with "ugo" categories and "rwx" permission bits, ensuring only authorized users can access or modify resources in the system[17] [18].

References: Charles Crowley, "Operating Systems: A Design-Oriented Approach", and standard Unix permission model as described in OS textbooks and documentation.

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(a) Block Device and Character Device (5 marks)

Block Device:

- Block devices transfer data in fixed-size blocks (typically 512 bytes or 4 KB).
- They support random access, meaning any block can be read or written independently.
- Examples: Hard disks, SSDs, CD-ROMs, USB drives.
- Block devices are usually used for filesystems, as the OS can read/write specific blocks as needed.
- They are managed by the OS using a buffer cache to optimize performance.

Character Device:

- Character devices transfer data as a stream of bytes, without any block structure.
- They support sequential access only; data is read/written one character at a time.
- Examples: Keyboards, mice, serial ports, printers.
- Character devices are typically used for devices where data arrives or is sent in a continuous flow.
- They do not use buffer caches in the same way as block devices.

Comparison Table:

Feature	Block Device	Character Device
Data Transfer	By blocks	By bytes/characters
Access Type	Random	Sequential
Examples	Hard disk, SSD	Keyboard, printer
Buffer Cache	Used	Not used

(b) Signal Handler (5 marks)

Signal Handler:

- A signal handler is a function in a process that is executed in response to a signal delivered by the operating system.
- Signals are asynchronous notifications sent to a process to notify it of events like interrupts, exceptions, or user requests (e.g., Ctrl+C).
- Common signals: `SIGINT` (interrupt), `SIGTERM` (terminate), `SIGSEGV` (segmentation fault).
- When a signal is delivered, the OS interrupts the normal flow of the process and invokes the corresponding signal handler function.
- The process can define custom handlers for signals using system calls like `signal()` or `sigaction()`.
- If no handler is defined, the OS performs a default action (e.g., terminate the process).

Example (in C):

```
#include &lt;signal.h&gt;
#include &lt;stdio.h&gt;

void handler(int signum) {
    printf("Caught signal %d\n", signum);
}

int main() {
    signal(SIGINT, handler); // Set custom handler for Ctrl+C
    while(1); // Infinite loop
    return 0;
}
```

- In this example, pressing Ctrl+C will call the `handler` function instead of terminating the program immediately.

Summary:

- Signal handlers provide a way for processes to handle asynchronous events and improve robustness and control over process behavior.

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1. (a) Conditions for a Process Entering Wait State and Ready State (5 marks)

Wait (Blocked) State:

- A process enters the **wait state** when it cannot proceed because it is waiting for some event or resource.
- **Common conditions:**
    - Waiting for I/O completion (e.g., reading from disk, waiting for user input).
    - Waiting for a resource to become available (e.g., waiting for a lock or semaphore).
    - Waiting for a child process to finish (using system calls like `wait()`).
- In the wait state, the process is not eligible for CPU scheduling until the event/resource it is waiting for becomes available[19] [20].

Ready State:

- A process enters the **ready state** when it is prepared to run but is not currently executing because the CPU is busy with another process.
- **Common conditions:**
    - After being created and loaded into main memory, but before getting CPU time.
    - After completing I/O or acquiring the required resource, the process transitions from wait to ready.
    - If a running process is preempted (e.g., due to time slice expiration in a time-sharing system), it returns to the ready state to await its next turn[19] [20].

1. (b) When and How Operating System Code Gets Invoked in a Running System (5 marks)

- The operating system (OS) code is invoked whenever a process needs a service that requires privileged access or hardware interaction.
- **How OS code is invoked:**
    - Through **system calls**: Special instructions (like `int 0x80` in x86 or `syscall` in modern systems) transition the process from user mode to kernel mode.

    - The OS kernel then executes the requested service (e.g., file read/write, process creation, device I/O)[21] [22] [23].

Examples:

- **File Operations:** When a process calls `open()`, `read()`, or `write()`, it triggers a system call, and the OS kernel handles the actual file operation.
- **Process Control:** A process may use `fork()` to create a child process or `wait()` to wait for a child to finish. These are system calls that invoke OS code to manage processes.
- **Device Access:** To read from a keyboard or write to a printer, the process must use system calls, allowing the OS to safely access hardware.
- **Context Switch:** The OS is also invoked during timer interrupts or I/O interrupts to switch between processes or handle asynchronous events.

Summary Table:

Event/Action	How OS Code is Invoked	Example System Call
File access	System call	`read()`, `write()`
Process creation	System call	`fork()`
Waiting for I/O	System call	`wait()`
Device interaction	System call	`ioctl()`

- The OS ensures security and resource management by controlling access to hardware and system resources through these controlled entry points[21] [22] [23].

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Filesystem Subsystem Actions During `open()` and `read()` System Calls

Overview

When a process performs `open()` and `read()` system calls, the filesystem subsystem of the OS manages several layers of operations. Each layer abstracts and manages details, ensuring safe and efficient file access.

A. `open()` System Call

Steps at Different Filesystem Levels:

1. **User API Layer**
    - Application calls `open("file.txt", O_RDONLY)` via standard library.
    - The call is translated into a system call and passed to the OS kernel.
2. **System Call Interface**
    - Parameters are checked and copied from user space to kernel space.

   - The OS verifies permissions and validity.
3. **Logical File System**
   - Parses the file path.
   - Checks access rights using file metadata (owner, permissions).
4. **File Organization Module**
   - Locates the file’s directory entry.
   - Retrieves the inode (index node) containing file metadata.
5. **Buffer Cache/Block I/O Layer**
   - Checks if inode and directory blocks are already in memory (buffer cache).
   - If not, reads them from disk into cache.
6. **Device Drivers**
   - If disk access is needed, the device driver communicates with the disk hardware.
7. **File Table Management**
   - Allocates a file descriptor for the process.
   - Updates OS-wide open file table and per-process file descriptor table.

Diagram (as per Crowley, simplified):

```
[User Process]
      |
      v
[System Call Interface]
      |
      v
[Logical File System]
      |
      v
[File Organization Module]
      |
      v
[Buffer Cache/Block I/O]
      |
      v
[Device Driver]
      |
      v
[Disk]
```

B. `read()` System Call

Steps at Different Filesystem Levels:

1. **User API Layer**
   - Application calls `read(fd, buffer, size)`.

2. **System Call Interface**
    - Validates the file descriptor and parameters.
3. **File Table Management**
    - Retrieves file position and inode from file descriptor.
4. **Buffer Cache/Block I/O Layer**
    - Checks if requested file blocks are in buffer cache.
    - If not, reads required blocks from disk into cache.
5. **Device Driver**
    - Handles physical disk I/O if necessary.
6. **Data Transfer**
    - Copies data from buffer cache to user buffer.
    - Updates file position in the file descriptor.

Diagram (as per Crowley, simplified):

```
[User Process]
      |
      v
[System Call Interface]
      |
      v
[File Table Management]
      |
      v
[Buffer Cache/Block I/O]
      |
      v
[Device Driver]
      |
      v
[Disk]
```

Summary Table

Filesystem Level	`open()` Actions	`read()` Actions
User API	Calls open()	Calls read()
System Call Interface	Checks, copies parameters	Checks, copies parameters
Logical FS/File Org.	Parses path, gets inode	Gets file position, inode
Buffer Cache/Block I/O	Loads inode/dir blocks if needed	Loads data blocks if needed
Device Driver	Disk access if required	Disk access if required
File Table Management	Allocates file descriptor, updates tables	Updates file offset

Key Points

- Both `open()` and `read()` traverse multiple layers of the filesystem subsystem.
- Buffer cache optimizes performance by reducing disk I/O.
- Device drivers abstract hardware details.
- Diagrams above are based on the layered model shown in Crowley's book.

References: Charles Crowley, "Operating Systems: A Design-Oriented Approach" (see chapters on Filesystem Implementation and System Calls).

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Incorporating Deadlock Prevention and Avoidance Strategies in the Operating System

A. Deadlock Prevention

Deadlock prevention works by ensuring that at least one of the four necessary conditions for deadlock (mutual exclusion, hold and wait, no preemption, circular wait) never holds in the system. Here's how each can be incorporated into the OS:

Condition to Break	Where to Incorporate in OS	Example Implementation
Mutual Exclusion	Resource Allocation Module	For shareable resources (like read-only files), allow concurrent access; use spooling for devices like printers so processes don't need exclusive access [24] [25] [26].
Hold and Wait	Process Resource Request Handling	Require processes to request all needed resources at once before execution, or release all held resources before requesting new ones. This logic is enforced in the resource request system call handler [24] [25] [26].
No Preemption	Resource Management/Kernel	If a process holding resources requests another that is unavailable, preempt all held resources and allocate them to other waiting processes, or force the process to release all resources before making a new request [24] [25] [26].
Circular Wait	Resource Allocation Policy	Impose a global ordering of resources and require processes to request resources in increasing order only. Enforced by the OS in the resource request interface [25] [26].

B. Deadlock Avoidance

Deadlock avoidance requires the OS to dynamically examine the resource allocation state and only grant requests that keep the system in a safe state. The most common method is the **Banker's Algorithm**.

Component/Module	Incorporation Details
Process Control Block (PCB)	Extend PCB to store the maximum resource needs for each process, as processes must declare these needs at creation [27] [25] [28] [29] .
Resource Allocation Module	Before granting a resource request, simulate the allocation to check if the system will remain in a safe state using algorithms like Banker's Algorithm. If not, block the request [27] [25] [28] [29] .
System Call Interface	Integrate avoidance checks into resource request system calls (e.g., `request_resource()`). If the request leads to an unsafe state, deny or delay it [27] [25] [28] [29] .
Kernel Data Structures	Maintain tables for available, allocated, and maximum resources per process. Update and consult these tables on every resource request [27] [25] [28] [29] .

Summary Table

Strategy	OS Layer/Component	Description/Action
Prevention	Resource Allocation Policy	Break deadlock conditions at request time
Avoidance	Resource Allocation Module, PCB, System Call Interface	Simulate allocations, check for safe state before granting requests

Conclusion

- **Deadlock prevention** is enforced by designing the OS's resource allocation and process management policies to break one or more deadlock conditions.
- **Deadlock avoidance** is implemented by extending process and resource management modules to predict the impact of each request and only allow those that keep the system in a safe state.

Both strategies are incorporated primarily in the **resource management subsystem** of the OS kernel, especially within the modules handling resource requests, allocation, and process control [27] [25] [26] [28] [29] .

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4. (a) How is Dynamic Memory Allocation (e.g., `malloc` in C or `new` in C++) handled during execution of a program? [5 marks]

- **Dynamic memory allocation** allows a program to request memory from the operating system at runtime, rather than at compile time.
- In C, functions like `malloc()`, `calloc()`, and `realloc()` are used; in C++, the `new` operator is used for this purpose [30] [31] [32] .
- When a program calls `malloc` or `new`, the request is handled by the language runtime, which interacts with the OS to allocate memory from the *heap* area of the process's address space.

- The OS maintains the heap and tracks free and used memory blocks. If sufficient memory is available, it marks the requested block as "used" and returns a pointer to the beginning of that block to the program.
- The programmer is responsible for releasing the memory (using `free()` in C or `delete` in C++) when it is no longer needed, to prevent memory leaks and fragmentation[30] [31] [32].
- **Common issues:** Memory leaks (not freeing memory), dangling pointers (using memory after freeing), and fragmentation (inefficient use of heap due to many small allocations).

4. (b) Explain with example(s) what you understand by the term metadata of a file. What are the different options for storing these metadata in the filesystem organization and what are the pros and cons of each of those options? [5 marks]

Metadata of a File:

- *Metadata* is "data about data"—it describes and organizes information about files but is not the file's actual content[33] [34].
- **Examples of file metadata:** File name, size, type, creation/modification/access dates, owner, permissions, location on disk, and sometimes tags or comments[33] [34].
  - *Example:* For a file `report.txt`, metadata might include: name = "report.txt", size = 2 KB, owner = "user", permissions = "rw-r--r--", created = "2025-04-01".

Options for Storing Metadata:

Option	Description	Pros	Cons
1. **Separate Metadata Block**	Metadata stored in a dedicated structure (e.g., inode in Unix) separate from file data	Efficient access and management; supports rich attributes	Needs extra disk reads to fetch metadata
2. **Alongside File Data**	Metadata stored at the start of the file (header)	Simple for small filesystems	Harder to update/expand; less flexible for large systems
3. **External Metadata Files**	Metadata stored in separate hidden files (e.g., AppleDouble: ._filename)	Allows compatibility with simple filesystems	Can clutter directories; risk of losing sync with data
4. **Extended Attributes/Streams**	Metadata stored as alternate data streams (e.g., NTFS ADS) or extended attributes	Flexible, supports arbitrary metadata	Not portable across all filesystems; compatibility issues

Summary:

- Most modern filesystems (e.g., Unix with inodes) use a separate metadata structure for efficiency and flexibility.
- Some systems (like FAT) store limited metadata in directory entries.
- For compatibility, systems like macOS may use external files (AppleDouble) when copying to filesystems that don't support rich metadata[34].

References:[30]: GeeksforGeeks - Dynamic Memory Allocation in C[31]: GeeksforGeeks - new and delete Operators in C++[34]: Peachpit - Understanding File System Metadata[33]: LinkedIn - Value and Importance of Metadata in File Systems

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5. (a) Why does Operating System have two different sets of system calls for character devices and block devices? [3 marks]

- **Character devices** (like keyboards, serial ports) transfer data as a stream of bytes, supporting sequential access only.
- **Block devices** (like hard disks, SSDs) transfer data in fixed-size blocks and support random access, allowing reading/writing at any block position.
- Because their access patterns and requirements are fundamentally different, the OS provides separate sets of system calls and device drivers:
    - **Character device system calls** focus on unbuffered, sequential byte-oriented operations (e.g., `read`, `write`).
    - **Block device system calls** support buffered, block-oriented, and random-access operations (e.g., `read block`, `write block`, `seek`).
- This separation allows efficient and appropriate handling of each device type, optimizing performance and reliability[35].

5. (b) Conceptually, can a physical IO device be accessed as both character device and block device? Explain your answer. [3 marks]

- **In principle, some physical devices can be accessed both ways, but not all.**
- For example, a hard disk is naturally a block device (random block access), but it can also be accessed as a character device if a driver presents it as a byte stream (e.g., `/dev/zero` or `/dev/random` in Unix).
- However, devices like keyboards or mice are inherently character devices and cannot be accessed meaningfully as block devices.
- In practice, the OS and its drivers define the interface. Some devices (e.g., tape drives) can be accessed using both interfaces, depending on the driver implementation.
- **Conclusion:** Whether a device can be accessed both ways depends on its hardware characteristics and the abstraction provided by the OS and its drivers[35].

5. (c) Explain why filesystems are created on block devices and not on character devices. [4 marks]

- **Filesystems require random access** to data blocks for efficient file storage, retrieval, and management.
- Block devices support random access and block-level operations, which are essential for filesystem structures (directories, inodes, allocation tables, etc.).
- Character devices only support sequential, byte-by-byte access, making it impossible to implement efficient directory lookup, file allocation, or random file access.
- **Therefore, filesystems are created on block devices** because only they provide the necessary abstraction and performance for structured data storage and retrieval[35].
- **Summary Table:**

Device Type	Supports Filesystem?	Reason
Block Device	Yes	Random/block access needed for FS
Character Device	No	Only sequential access, not suitable

References:

- Charles Crowley, "Operating Systems: A Design-Oriented Approach" -[35] UNIT – I - EMBEDDED OS AND DEVICE DRIVERS – SECA5204

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(a) Short Note on pthread

- **pthread** stands for **POSIX threads**, which is a standardized API for creating and managing threads in Unix-like operating systems[36] [37] [38].
- It enables parallel execution within a single process, allowing multiple flows of control (threads) to run concurrently and share the same address space and resources[37] [38].
- The pthread library is defined in the `&lt;pthread.h&gt;` header and provides functions for thread creation, synchronization, and management[36] [38].
- **Key functions include:**
  - `pthread_create()` – to create a new thread.
  - `pthread_join()` – to wait for a thread to finish.
  - `pthread_exit()` – to terminate a thread.
  - Synchronization primitives: mutexes (`pthread_mutex_*`), condition variables (`pthread_cond_*`), read-write locks, and barriers[36] [38].
- **Advantages:**
  - Reduces overhead compared to process creation (threads are lightweight).
  - Enables efficient parallelism and better CPU utilization, especially on multi-core systems[37] [38].

    - Threads can communicate easily via shared memory.

- **Typical usage:** Used in applications that require high performance through parallelism, such as servers, scientific computing, and real-time systems[37] [38].
- **Example:**

  ```
  #include &lt;pthread.h&gt;
  void* func(void* arg) { /* ... */ }
  int main() {
      pthread_t tid;
      pthread_create(&amp;tid, NULL, func, NULL);
      pthread_join(tid, NULL);
      return 0;
  }
  ```

- **Summary:**
  pthread provides a portable, efficient, and standardized way to utilize multithreading in Unix-like operating systems, improving program performance and resource utilization[36] [37] [38].

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Short Notes on `dup()` and `dup2()` System Calls

dup() System Call:

- `dup()` creates a duplicate of an existing file descriptor (`oldfd`).
- The new file descriptor is the lowest-numbered unused descriptor in the process.
- Both the original and duplicated descriptors refer to the same open file description, meaning they share file offset and status flags. Any change (like file position) made through one affects the other.
- Syntax:

  ```
  int dup(int oldfd);
  ```

- Commonly used for redirecting standard input/output in processes[39] [40] [41] [42].

dup2() System Call:

- `dup2()` also duplicates a file descriptor, but allows you to specify the value of the new file descriptor (`newfd`).
- If `newfd` is already open, it is closed first before being reused.
- If `oldfd` and `newfd` are the same, `dup2()` does nothing and returns `newfd`.
- Syntax:

  ```
  int dup2(int oldfd, int newfd);
  ```

- Used for precise control in I/O redirection, such as making standard output point to a file[39] [40] [41] [42].

Key Points:

- Both are standardized POSIX system calls.
- They do not create a new file; they create a new alias for the same open file.
- Widely used in shell programming, especially for input/output redirection and piping between processes[39] [40].

Example Use Case:

- Redirecting standard output to a file:

  ```
  int fd = open("output.txt", O_WRONLY);
  dup2(fd, STDOUT_FILENO); // Now printf() will write to output.txt
  ```

Summary Table:

System Call	New FD Selection	Closes Existing FD?	Main Use Case
dup()	Lowest unused number	No	Duplicate any FD
dup2()	User-specified (newfd)	Yes (if open)	Redirect/replace specific FD

Both are essential for advanced file and process management in Unix-like operating systems[39] [40] [41] [42].

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