**Study Material**

**Topic: *Memory Management Hardware***

**1. Introduction**

* Memory is a key component of a computer system.
* Multiple programs and processes run simultaneously, so the **Operating System (OS)** needs to manage memory efficiently.
* **Memory Management Hardware** is used to support the OS in:
  + Allocating memory to processes.
  + Protecting processes from illegal memory access.
  + Translating addresses from program (logical/virtual) to RAM (physical).

**2. Need for Memory Management Hardware**

1. **Protection:** Prevents a program from accessing memory assigned to another program.
2. **Relocation:** Allows a program to be loaded into any part of physical memory.
3. **Sharing:** Enables multiple processes to share the same code/data safely.
4. **Efficient Utilization:** Avoids memory wastage by managing free/used memory blocks.
5. **Multiprogramming Support:** Helps several programs run concurrently without conflicts.

**3. Key Components of Memory Management Hardware**

**a) Base and Limit Registers**

* **Base Register:** Holds the starting physical address of a process.
* **Limit Register:** Defines the size of the process (maximum address range).
* Any address outside this range causes a **trap (error)** → prevents illegal access.

✅ Example:

* Base = 1000, Limit = 500 → Legal addresses = 1000 to 1499.
* If a process tries to access 1500, hardware raises an exception.

**b) Memory Management Unit (MMU)**

* Special hardware device between CPU and RAM.
* Converts **logical (CPU-generated)** addresses into **physical (RAM)** addresses.
* Ensures safety and efficient allocation.

**c) Address Translation**

* **Logical Address:** Generated by CPU (used by programmer).
* **Physical Address:** Actual address in RAM (used by memory hardware).
* MMU translates logical → physical addresses at runtime.

**d) Paging Hardware**

* Memory is divided into fixed-size blocks:
  + **Page (logical memory unit).**
  + **Frame (physical memory unit).**
* Paging hardware maintains a **page table** that maps pages to frames.
* Eliminates **external fragmentation**.

✅ Example:

* Logical address = Page 2, Offset 50 → Mapped to Frame 5 → Physical address = (Frame 5, Offset 50).

**e) Segmentation Hardware**

* Memory is divided into **logical segments** (code, data, stack, etc.).
* Each segment has:
  + **Base address** (starting location).
  + **Limit** (length of segment).
* Provides **logical view** to programmer (closer to real-world data organization).

✅ Example:

* Code segment = 4000–4999, Data segment = 5000–5999.

**4. Comparison: Paging vs Segmentation**

| **Aspect** | **Paging (Fixed size)** | **Segmentation (Variable size)** |
| --- | --- | --- |
| Division | Pages & Frames | Logical Segments |
| Unit size | Fixed | Variable |
| Fragmentation | Internal fragmentation possible | External fragmentation possible |
| Programmer view | Invisible to programmer | Visible (code, data, stack) |
| Hardware support | Page table | Segment table |

**5. Real-World Examples**

* **x86 Architecture:** Uses segmentation + paging for address translation.
* **Modern CPUs (Intel, AMD):** Largely rely on **paging** with virtual memory.
* **Mobile devices:** Use MMU hardware to protect apps from interfering with each other.

**6. Advantages of Memory Management Hardware**

* Provides **security** and prevents crashes due to illegal access.
* Allows **multiprogramming** and efficient CPU utilization.
* Supports **virtual memory**, making programs think they have more memory than physically available.
* Enables **process isolation and protection** in modern OS.

**7. Summary**

* Memory management hardware is essential for safe and efficient memory use.
* Key components: **Base & Limit Registers, MMU, Paging, Segmentation**.
* Provides protection, relocation, sharing, and efficient utilization.
* Modern systems use **paging + virtual memory** for robust memory management.

**8. Sample Questions for Practice**

**Short Answer (2 Marks):**

1. Define memory management hardware.
2. What is the role of the base register?
3. Differentiate between logical and physical address.

**Medium Answer (5 Marks):**

1. Explain the role of MMU with a neat diagram.
2. Compare paging and segmentation.
3. Why is memory protection important in multiprogramming?

**Long Answer (10 Marks):**

1. Discuss memory management hardware in detail with neat diagrams.
2. Explain paging with an example of address translation.
3. Describe segmentation hardware and its advantages.