Learning Aims

- Describe the uses of and differences between RAM and ROM
- Describe what is meant by virtual memory

Do now

RAM and ROM

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A-level Inputs, outputs and storage

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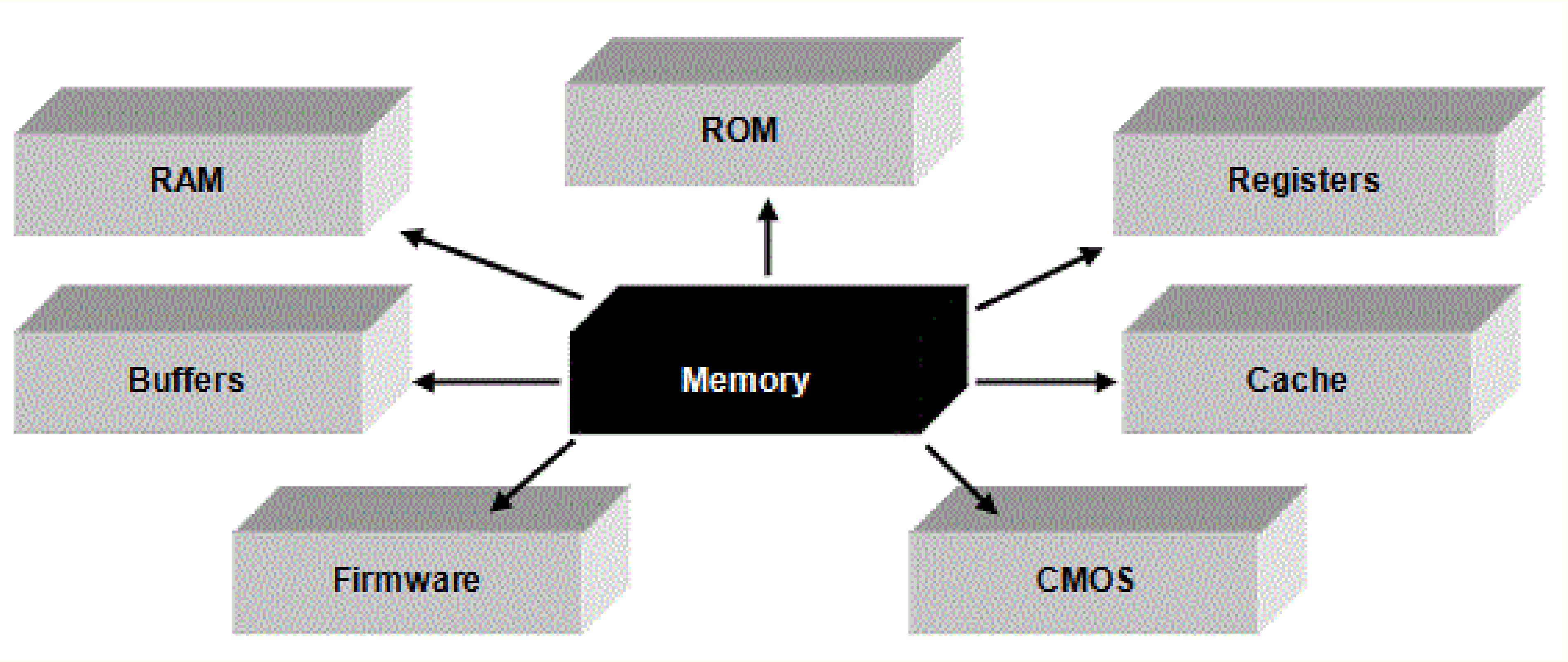
Key Terms

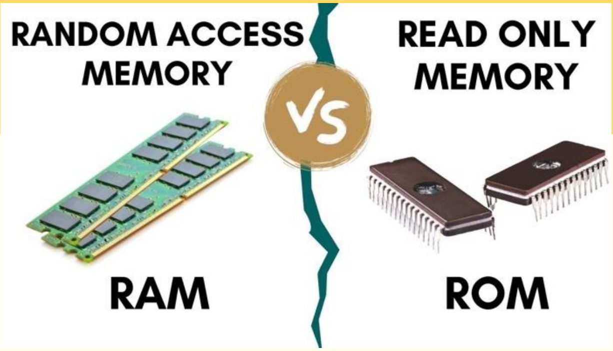
- **RAM**: **Volatile** memory used to store data and programs **currently in use**. Allows read/write access.
- **ROM**: **Non-volatile** memory containing permanent instructions like the bootstrap loader.
- **Virtual Memory**: Uses secondary storage as temporary RAM when physical memory is full; slower access.
- **Cache**: Small, fast memory near CPU storing frequently used instructions/data to improve performance.
- **Register**: A small, fast storage location within the CPU used to temporarily hold data or instructions.

Types of memory

Here is a diagram that summarises the different types of memory you might come across.



RAM and ROM



- Computers have two main types of internal memory: **RAM** and **ROM.**

RAM stores the programs and data that are **currently** being used. It is volatile, **temporary**, so everything in RAM is lost when the power is turned off.	ROM stores data that must stay there **permanently**. It is **non-volatile**, so it keeps its contents even without power. For example, the **bootstrap loader**—the small program that starts the computer and loads the operating system—is stored in ROM. In many embedded systems (like washing machines, cars, or cameras), the software rarely changes, so it is stored in ROM.

Random Access Memory (RAM)

- When people say a computer has 8 GB of RAM, they are talking about this type of memory.
- That number shows how much data and how many programs the computer can hold in memory at one time—about 8 billion memory locations.
- Each small memory location has its own address, and each one can store a piece of data or an instruction for the CPU.
- Having **more RAM** means you can **run more applications at the same time and open larger files.**
- You can never really have too much RAM, but it costs money, and your motherboard has a limit on how much you can install.
- RAM is volatile, which means it loses all its contents when the power is switched off.

Further reading: Static RAM (SRAM) and Dynamic RAM (DRAM)

There are two common types of RAM: **DRAM** and **SRAM**. Each works differently and has its own pros and cons.

DRAM vs. SRAM

- **DRAM** must constantly refresh its data to keep it stored.
- **SRAM** does **not** need refreshing; as long as it has power, it keeps its data.

- Because DRAM needs extra circuits for refreshing, it uses more power and is slower. SRAM is simpler and faster because it doesn't need this process.

Complexity and Cost

- SRAM's design is simple to use in hardware.
- But SRAM needs **six times more components** (transistors and capacitors) than DRAM to store each bit.
- This makes SRAM **much more expensive**.
- Because DRAM is cheaper, it is used as the **main memory** in computers for the operating system, programs, and files.

Where SRAM is used

- SRAM is used when **speed is most important**, especially in **cache memory**. The CPU often needs to reuse certain instructions. If these are stored in fast SRAM instead of slower DRAM, the computer runs much quicker.

Cache matters

- Cache is small but very fast. Since SRAM is costly, computers only include a limited amount. When buying a computer, it's helpful to ask: **"How much cache does it have?"**
- More cache generally means better performance—but at a higher price.

ROM and the start up process

This type of memory holds a special program that starts running when the computer is powered up. It holds a part of a program called the BIOS.

This program does the following:

- ROM contains the computer start up instructions
- **Loads settings/configuration** (CMOS/NVRAM)
- Initialises and checks hardware/peripheral devices are available (carry out a **POST check)** and **reports** errors
- It then loads the bootstrap program, which is responsible for locating the operating system on the hard disk and loading it into RAM.
- Determines the drive on which the OS is stored

ROM (Read-Only Memory)	BIOS (Basic Input/Output System)	Bootstrap Program (Bootloader)
What it is: A type of non-volatile memory chip that **stores data permanently** (data remains even without power). **Main purpose:** Stores **firmware—**very low-level software that the system needs to start up. **Key points:** Hardware component (a memory chip) Non-volatile (keeps data without power) Cannot be easily rewritten (some types can be updated, like EEPROM/Flash ROM) **Stores BIOS** and other permanent instructions	**What it is:** **Firmware** stored inside ROM on the motherboard. **Main purpose:** Acts as the computer's **startup firmware** that initialises hardware and prepares the system to load the operating system. **Key functions:** Performs POST (Power-On Self Test) Detects hardware (CPU, RAM, drives) Provides system settings by **loading system configuration from CMOS/NVRAM** — things like boot device order. Loads the **bootstrap program** **Where it lives:** Inside ROM or flash memory on the motherboard. **Relationship to ROM:** BIOS *is stored in* ROM.	**What it is:** A small program that BIOS loads and executes to start loading the operating system. **Main purpose:** Find and load the OS into memory. **Examples:** Windows Boot Manager GRUB (Linux) UEFI bootloader **Steps:** BIOS runs the bootstrap program The bootstrap program loads the operating system kernel **Relationship to BIOS:** BIOS → loads the bootstrap program → loads the OS.

Why is the operating system not stored in ROM on a personal computer?

You may have wondered why there appears to be such a roundabout system of loading up your operating system, why you have to run some instructions in ROM that looks for a program called the 'bootstrap' on the hard disk that then loads up the operating system!

Why not just put the operating system in ROM and let it load up straight away when you boot up the computer?

The answer is **flexibility**.

You should understand that you, the user, can't normally change the contents of ROM. If you wanted to change operating systems, for example, from Windows 98 to Windows XP, and the operating system was in ROM, you would be stuck!

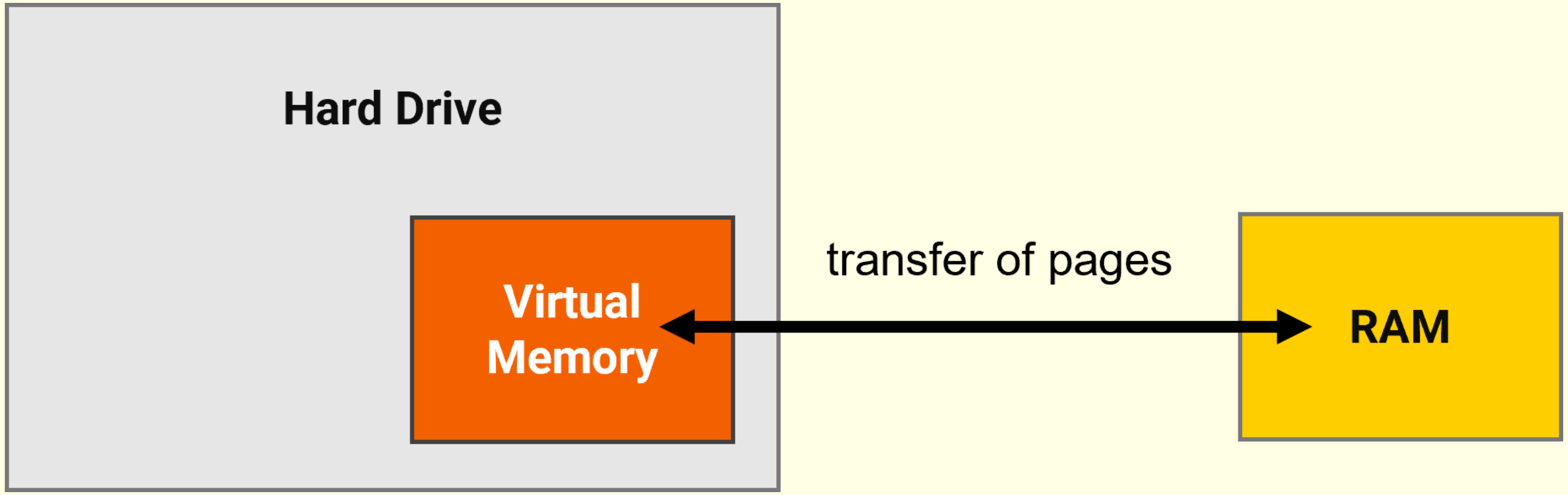
However, by putting the OS on the hard disk, you can upgrade it anytime you want and you don't need to change the program in ROM.

Virtual memory

- In some cases, the computer's RAM may not be not large enough to store all these programs simultaneously, so the hard disk is used as an extension of memory – called virtual memory.

- MS Word may be open on your desktop but if you are not actually using it at a particular time, the operating system may copy the Word software and data to hard disk to free up RAM for the browser software.

- When you switch back to Word, the operating system will reload it into memory.



Disk thrashing

There is a potential problem with using virtual memory.

Secondary storage devices are much slower than RAM.

If you spend a lot of time **swapping parts of applications** in and out of RAM to and from the hard disk, you may end up slowing the computer right down.

Virtual memory works really well as long as you only need to use it to increase the total possible memory space in RAM by five percent or so.

Any more, and you might have to sit there watching your computer, as it takes seconds or even minutes to swap applications out of the hard disk and into RAM.

Why increase RAM?

- Allows more active/running/temporary data in RAM
- It reduces the need to use virtual memory
- RAM is faster to access than VM/secondary storage…
- …because data in VM/SS has to be swapped with data in RAM first
- Use of RAM rather than VM reduces the risk of disk thrashing
- Faster bootup/ shutdown time // reduces load/access time

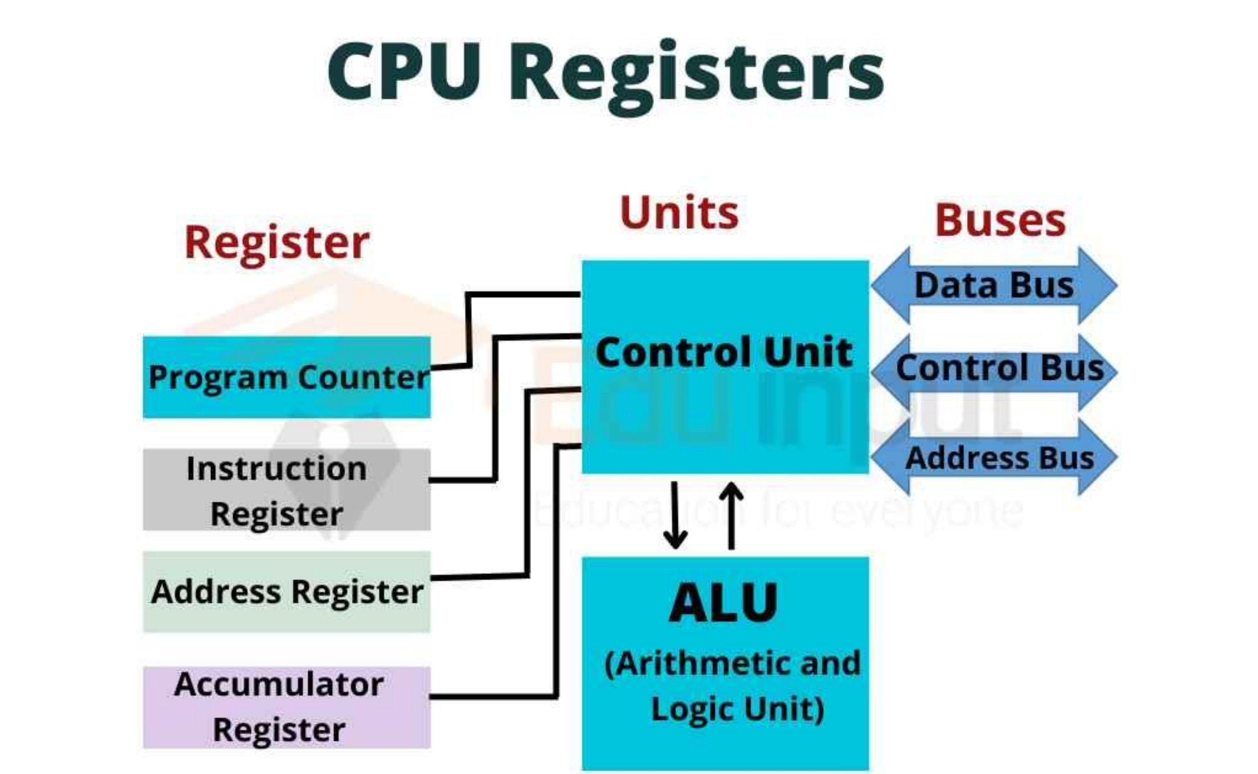
Registers

We have come across these before!

Registers are part of the design of the CPU.

They are memory circuits and are very very fast because they are constantly being accessed by the CPU.

Examples of registers include the Accumulator and the Program Counter.



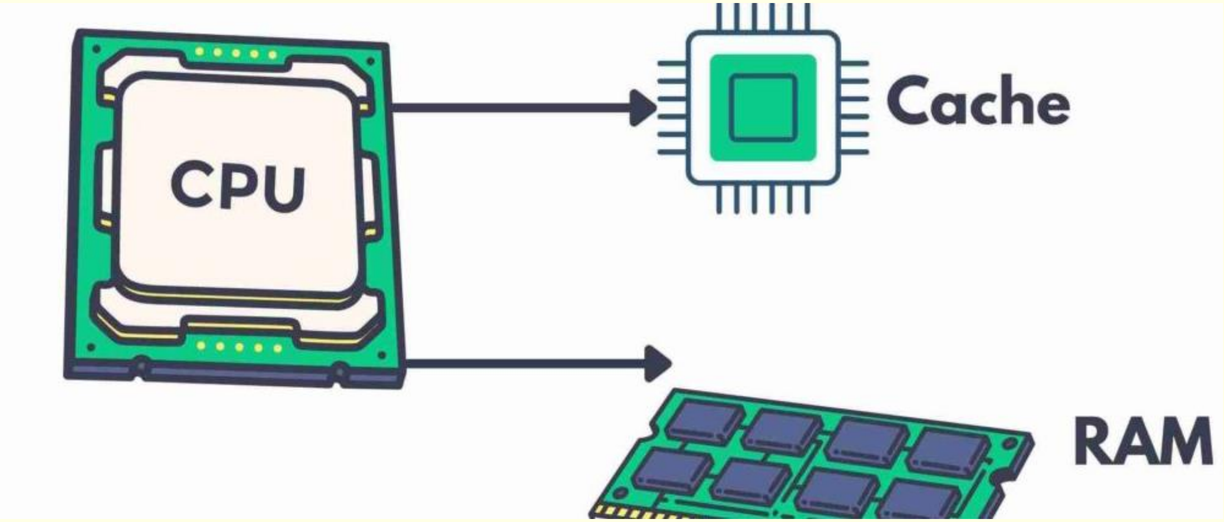
Cache

- Another important type of memory is **cache**, which is used to speed up processing. Like other memory, it is measured in bytes (KB, MB, etc.).

- Programs contain instructions that the CPU must fetch from memory during the **fetch–decode–execute cycle**. The CPU also fetches data from memory, and some pieces of data are needed again and again.

- Fetching data repeatedly from RAM is slow and wastes time. To speed things up, frequently used data and instructions are stored in **cache**, a very fast type of memory—faster than RAM, but not as fast as the CPU's registers.

- Cache is expensive to produce, so computers only include a small amount of it.
- When buying a computer, it's worth asking: **"How much cache does it have?"**
- More cache usually means faster performance, but it also raises the cost.



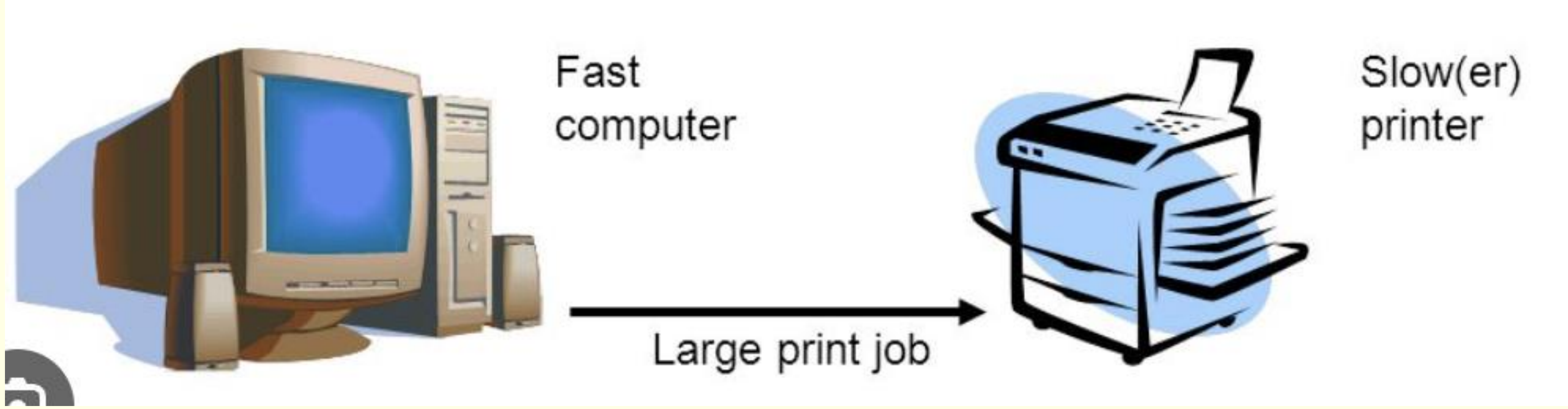
Buffers

- A **buffer** is a special area of RAM set aside to help transfer data between parts of a computer that work at different speeds.

- Buffers are used anywhere two devices don’t match in speed.

Examples include:

- Moving data from the keyboard to the CPU
- Sending data from the CPU to a printer



How to compare different types of memory (including storage devices)

Primary vs. Secondary Memory

- Primary memory is part of the CPU's circuitry. It stores programs and data that the CPU is currently using, as well as results of calculations. This includes **RAM** (also called Immediate Access Storage or IAS).
- Secondary storage includes devices like hard drives and floppy disks. These store data and programs that are not needed immediately.

Read-Only vs. Read/Write Devices

- **Read/Write devices**: Registers, cache, RAM, hard drives, floppy disks, and CD-R/W. You can both read and write data on these.
- **Read-only devices**: ROM, DVDs, and some CD-ROMs. Data can only be read, not changed. These are sometimes called **WORM** devices (Write Once, Read Many).

Volatile vs. Non-Volatile Memory

- **Volatile memory** loses its contents when power is turned off. RAM is volatile.
- Motherboards also have a small battery-backed RAM (CMOS) that stores things like BIOS settings; it keeps data as long as the battery lasts.
- **Non-volatile memory** keeps its contents without power. ROM and hard drives are non-volatile.

Cost, Speed, and Capacity

- Hard drives are cheap per byte. RAM is more expensive. Cache is even more expensive, which is why computers have only a small amount of cache.
- Memory speed depends on how close it is to the CPU:
- **Registers** are closest and fastest.
- **Cache** is very fast but slightly farther away.
- **RAM** is slower because it sits on the motherboard and must be reached through wires.
- Sometimes the CPU must wait for RAM, which is why a **WAIT interrupt** is used.

- **Typical Sizes**
- Registers: a few bytes
- Cache: kilobytes
- RAM: gigabytes
- Hard drives: gigabytes or terabytes