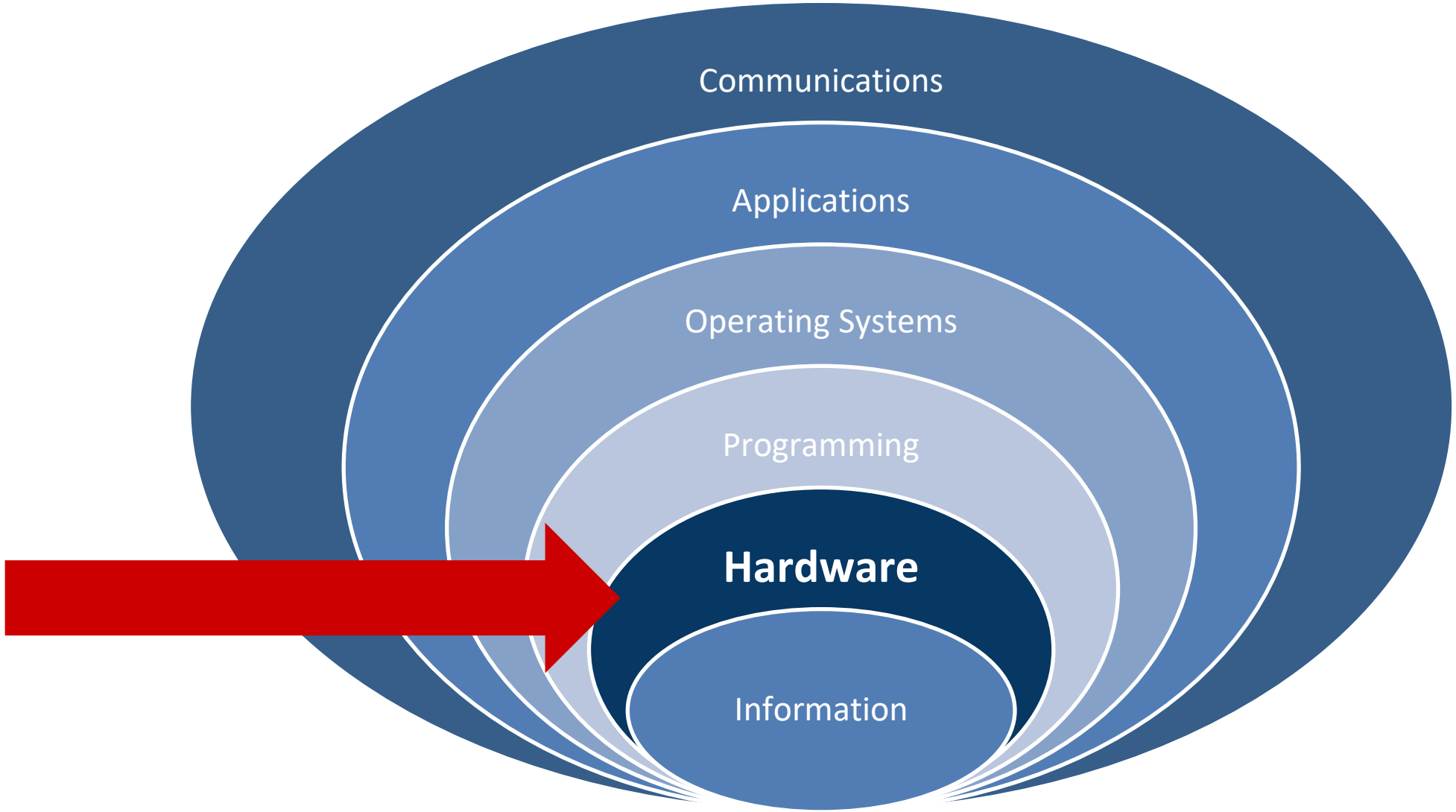
Computer Science Fundamentals

Lecture 5: Computer systems architecture

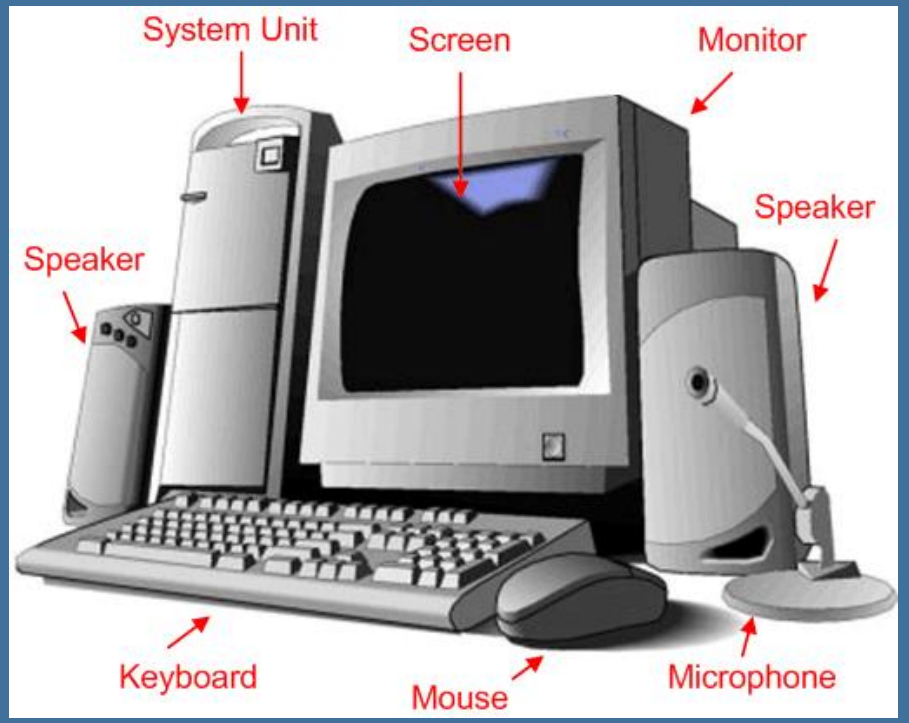
Lecturer: Olga Yugay

Today's focus



Something familiar...

Hardware



Agenda

- Logical structure of Computer System
- Computer Architecture
  - Levels within computer architecture
  - Physical organization of the computer
  - Main components of digital logic layer
  - Processor
  - Control unit
  - ALU

Computer Architecture: Basic Levels

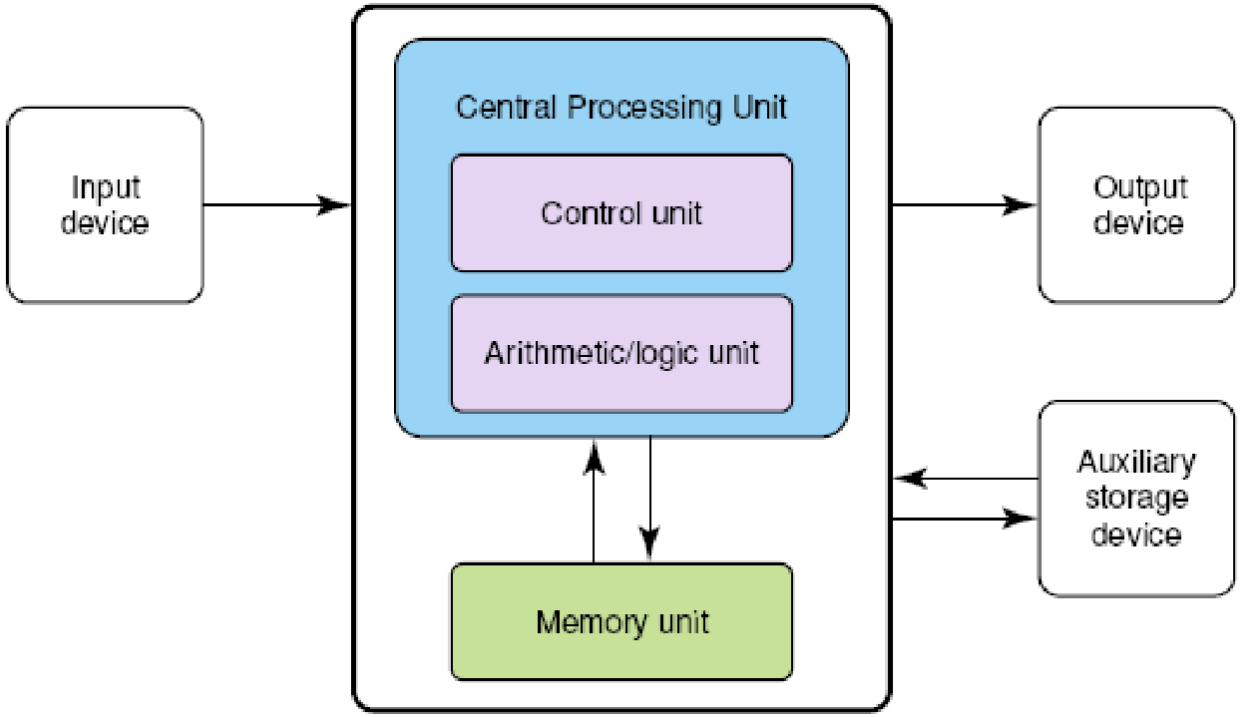
7	SOFTWARE LEVEL
6	
5	
4	HARDWARE LEVEL
3	
2	
1	

Computer Architecture: Levels in detail

7	SOFTWARE LEVEL	Application Layer
6		Higher-Order Software Layer
5		Operating System Layer
4	HARDWARE LEVEL	Machine Layer • Machine language instructions
3		Microprogrammed Layer • Interprets the machine language instructions and directly causes the digital logic elements to perform operations
2		Digital Logic Layer • Gates that are combined onto a single chip
1		Physical Device Layer • Transistors • Capacitors • Resistors

The von Neumann architecture

- Is the computer design principle
- The basis for computers even today
- Main characteristic:
  - Units that **process** information are **separate** from the units that **store** information.



Data flow through a von Neumann machine

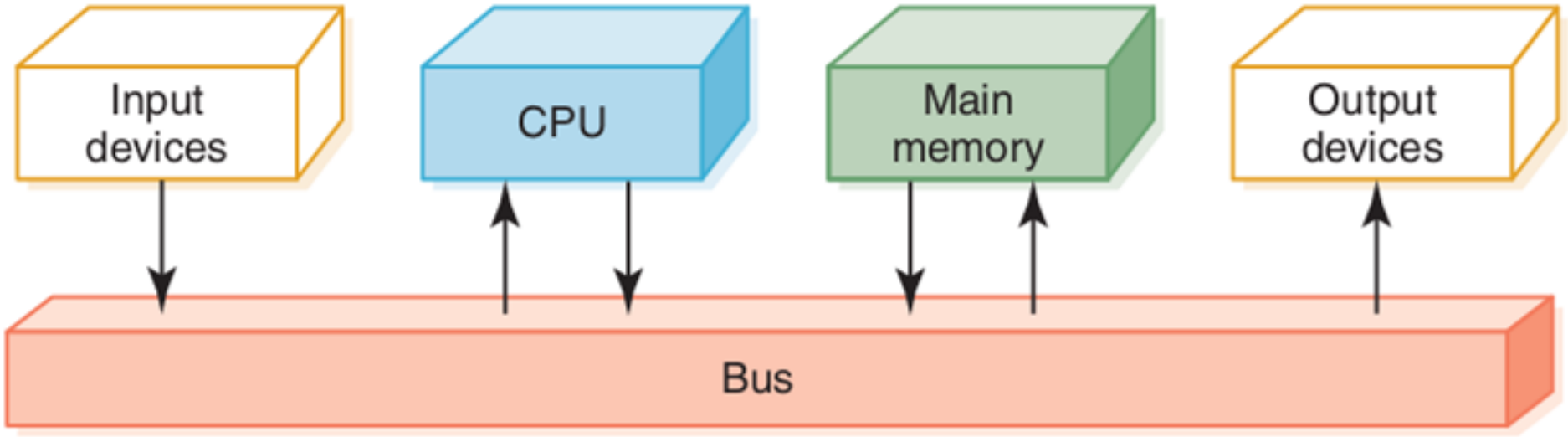


FIGURE 5.2 Data flow through a von Neumann machine

The von Neumann architecture [1]

- **memory unit** holds both data and instructions
- **arithmetic/logic unit** is capable of performing arithmetic and logic operations on data
- **input unit** moves data from the outside world into the computer
- **output unit** moves results from inside the computer to the outside world
- **control unit** acts as the stage manager to ensure that all the other components act in concert

[1] Dale, N., & Lewis, J. (2020). Computer Science Illuminated (7th ed.). Jones & Bartlett Learning, Ch 5

Video

Khan Academy and Code.org | CPU, Memory, Input & Output [2]

[2] Youtube.com. 2018. Khan Academy and Code.org | CPU, Memory, Input & Output. [online] Available at: <http://youtube.com/watch?v=MMzdKTtUIFM> [Accessed 7 June 2022].

Computer configuration

CoreTM i5 is a type of processor, which runs at a speed of 2.5 GHz

FSB - bus between the processor and the outside world is called the front-side bus. FSB is pulsing 1066 million (or just over a billion) times per second.

Cache is small, fast memory that is usually built into the processor chip.
Processor have direct access to 6 MB of memory without using the FSB

Synchronous, dynamic **RAM DD3** - Double Data Rate 3, type of memory

Graphics processor unit
Games and other graphics software interact with GPU =>faster image manipulation

Computer configuration [3]

In general, a faster clock, faster FSB, and more cache would seem to make for a more powerful computer.

But as in all areas of engineering, there are tradeoffs.

- Faster processor => it consumes more power => the circuitry may overheat and shut down.
- Faster FSB => requires faster devices in the outside world => their circuitry is more expensive.
- Cache gets bigger => access to its data becomes slower => slows down the processors.

[3] Dale, N., & Lewis, J. (2020). Computer Science Illuminated (7th ed.). Jones & Bartlett Learning, Ch 5

Hardware and Software

Khan Academy and Code.org | Hardware and Software [4]

[4]Youtube.com. 2022. Khan Academy and Code.org | Hardware and Software. [online] Available at: <https://www.youtube.com/watch?v=VzVSt6jxiqw> [Accessed 7 June 2022].

Motherboard [5]

In a PC the components in a von Neumann machine are physically located in a printed circuit board called the **motherboard**.

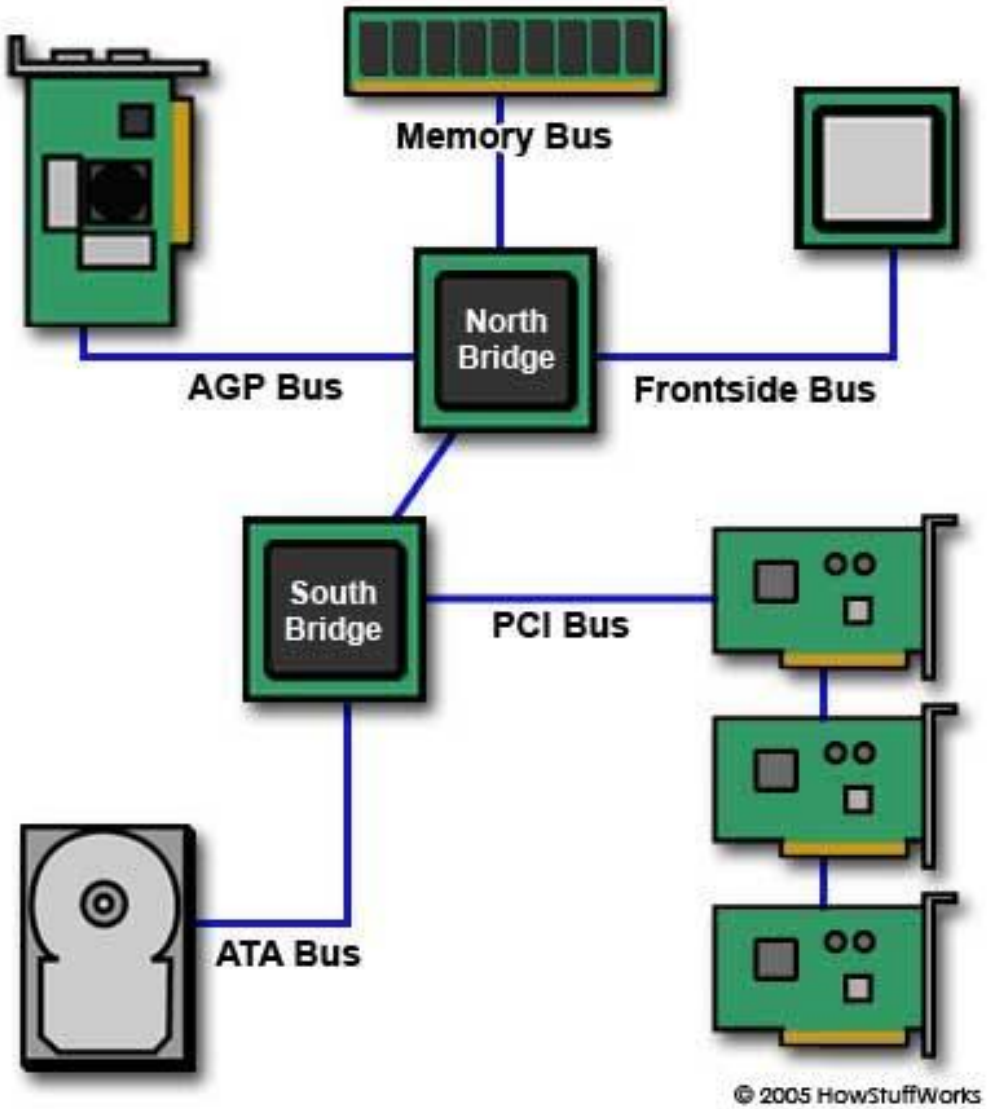
Motherboard is the main circuit board of PC

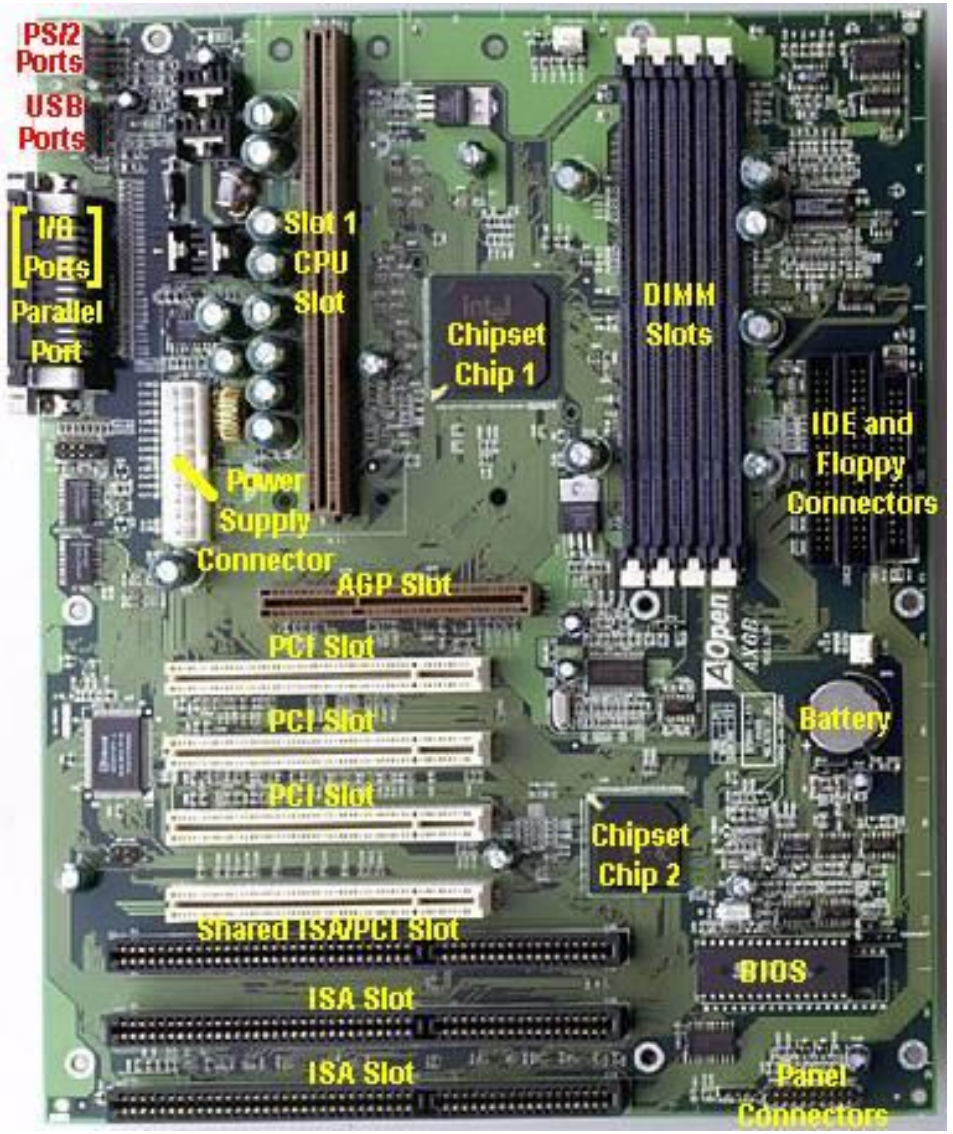
The motherboard also has connections for attaching other devices to the bus:

- a mouse
- a keyboard
- or additional storage devices

[5] Dale, N., & Lewis, J. (2020). Computer Science Illuminated (7th ed.). Jones & Bartlett Learning, Ch 5

Physical organisation of the computer





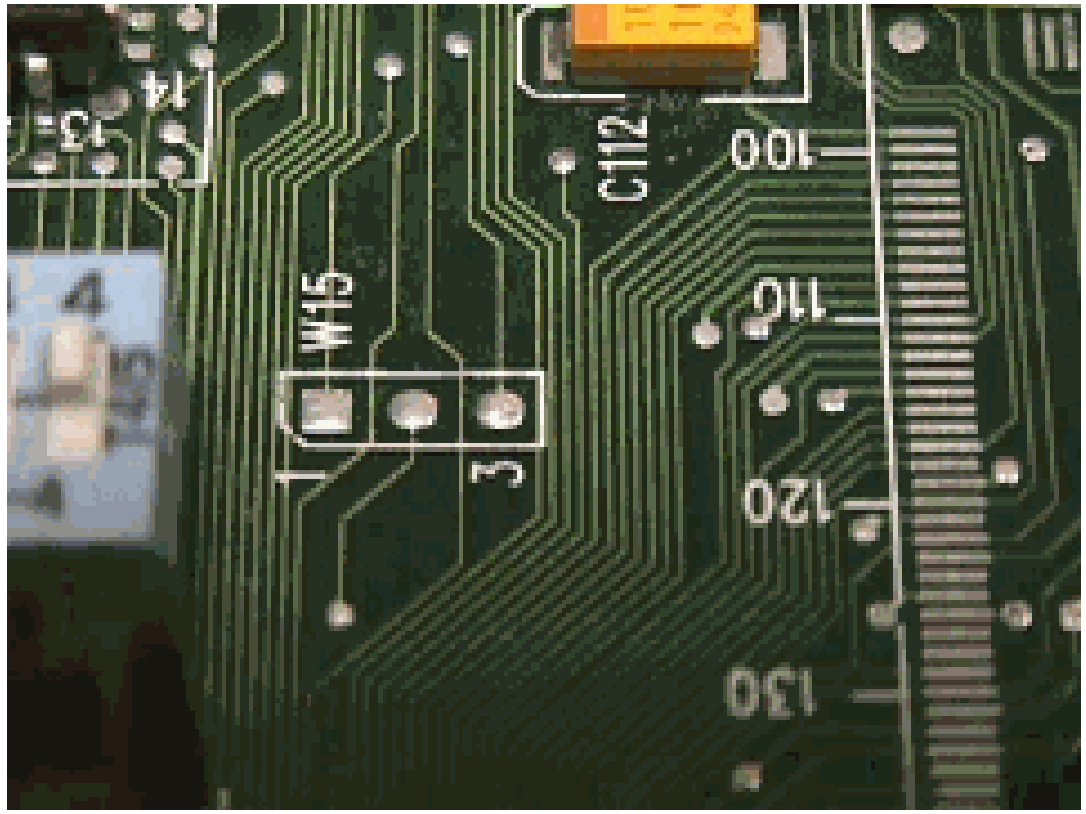
Physical organisation of the computer [6]

- Modular construction
  - Many different microcomputers contain the same microprocessors
- Bus – collection of parallel electrical conductors called “lines” onto which a number of components may be connected
  - Internal buses
  - External buses

[6] Dale, N., & Lewis, J. (2020). Computer Science Illuminated (7th ed.). Jones & Bartlett Learning, Ch 5

Physical organisation of the computer [7]

- Buses convey:
  - Data signals
  - Data address signals
  - Control signals
  - Power
- Bus lines
  - Data lines (Data bus)
  - Address lines (Address bus)
  - Control lines (Control bus)



[7] Dale, N., & Lewis, J. (2020). Computer Science Illuminated (7th ed.). Jones & Bartlett Learning, Ch 5

Example of Bus connections

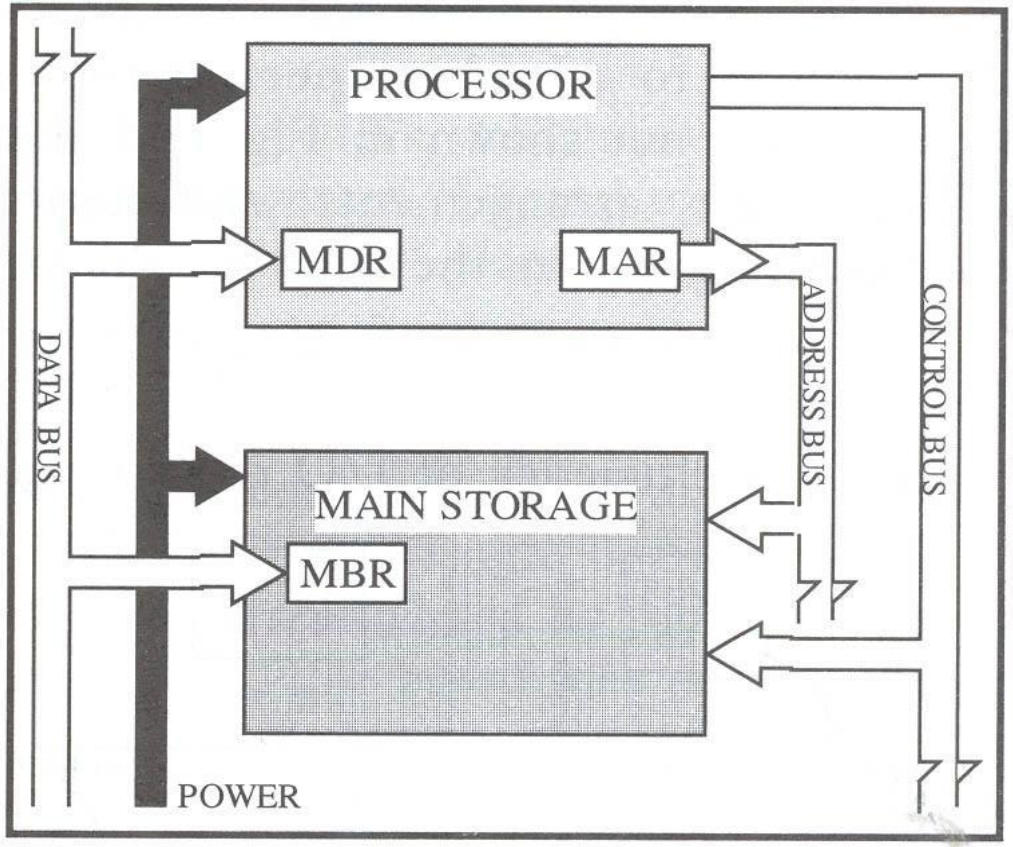


Fig 13.6 An example of Bus connections.

MDR – Memory Data Register

MAR – Memory Address Register

MBR - Memory Buffer Register

Example of Bus connections

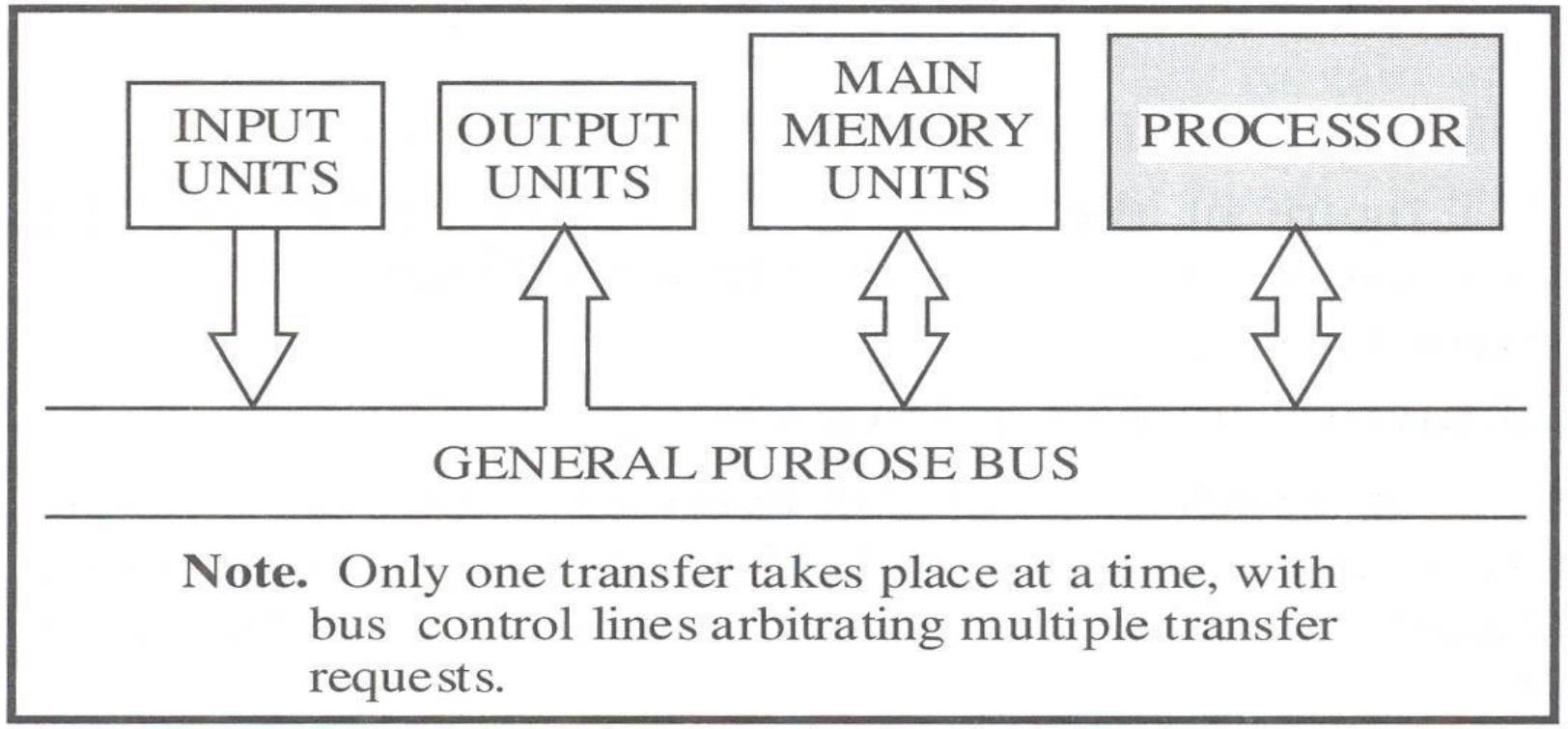


Fig 13.3 A system based on a general-purpose bus.

Example of Bus connections

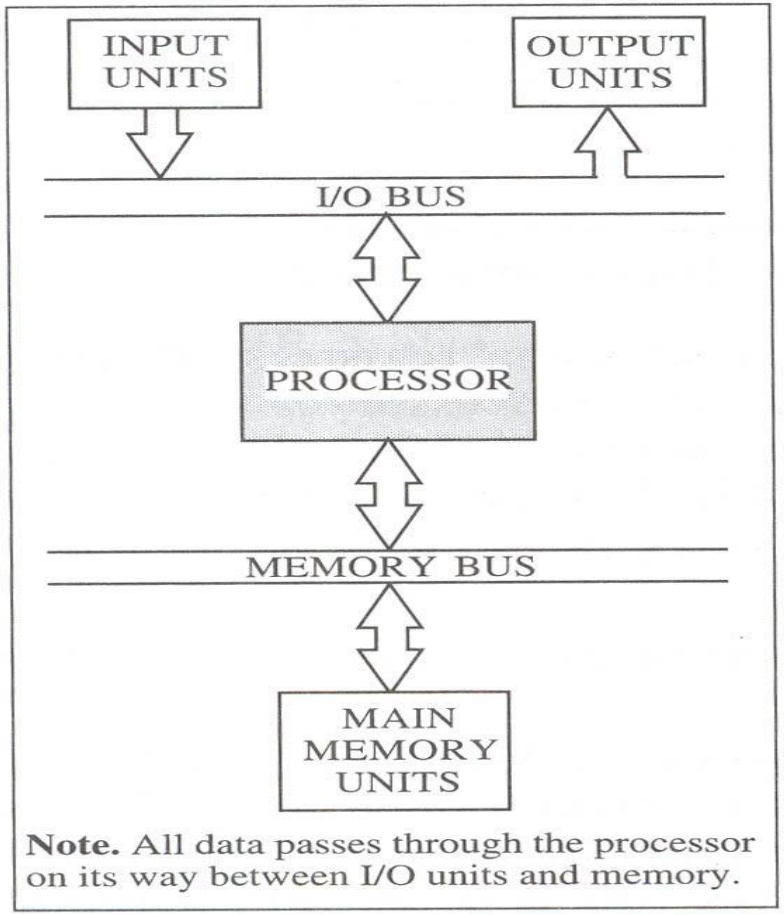


Fig 13.4 A system based on two buses.

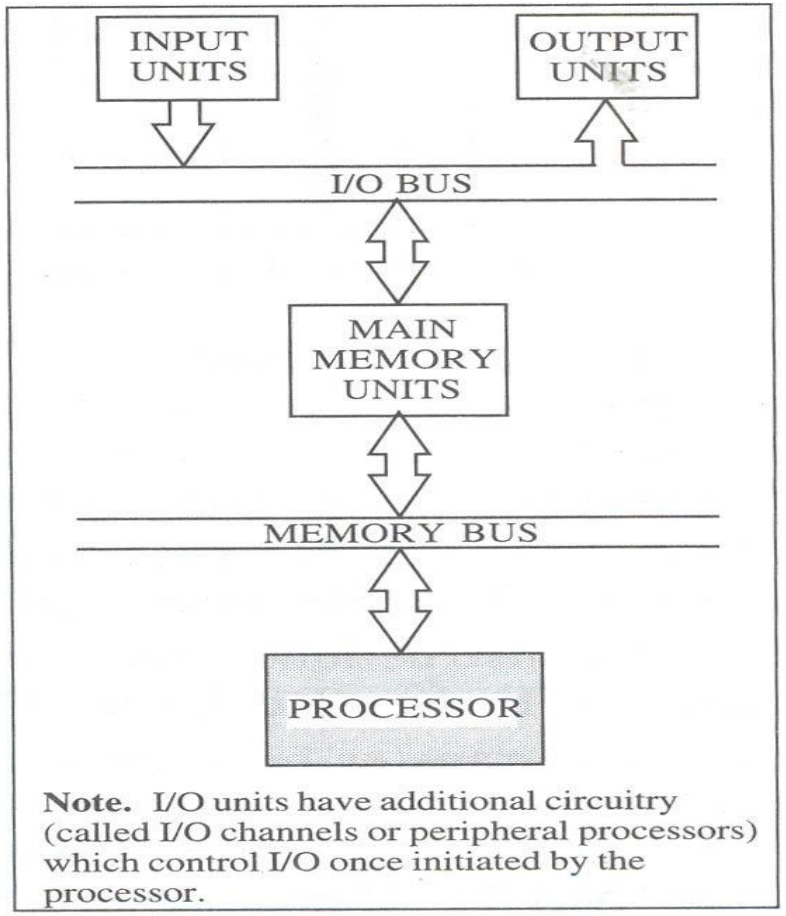


Fig 13.5 Another system based on two buses.

Memory

How your computer memory works [8]

[8] Senanan, K., 2016. How computer memory works. [online] Youtube.com. Available at: <https://www.youtube.com/watch?v=p3q5zWCw8J4> [Accessed 7 June 2022].

Processor [9]

- Functions
  - To control the use of main storage to store data and instructions
  - To control the sequence of operations
  - To give commands to all parts of the computer system
  - To carry out processing
- Consists of two primary elements
  - Control Unit (CU)
  - Arithmetic and Logic Unit (ALU)

[9] Dale, N., & Lewis, J. (2020). Computer Science Illuminated (7th ed.). Jones & Bartlett Learning, Ch 5

Processor [10]

- Registers – special-purpose temporary-storage locations within the processor or other devices

Types of registers

- Memory Data Register (MDR)
  - Handles all data and instructions passing in and out of the **processor**
- Memory Buffer Register (MBR)
  - Handles all data and instructions passing in and out of **main storage**
- Memory Address Register (MAR)
  - Handles location addresses (source/destination) during transfer **between the MDR and MBR**
- Data Buffer Registers
  - Exists in I/O units connected to the processor and have similar purpose to the MBR

[10] Dale, N., & Lewis, J. (2020). Computer Science Illuminated (7th ed.). Jones & Bartlett Learning, Ch 5

Example of bus connections related to processor

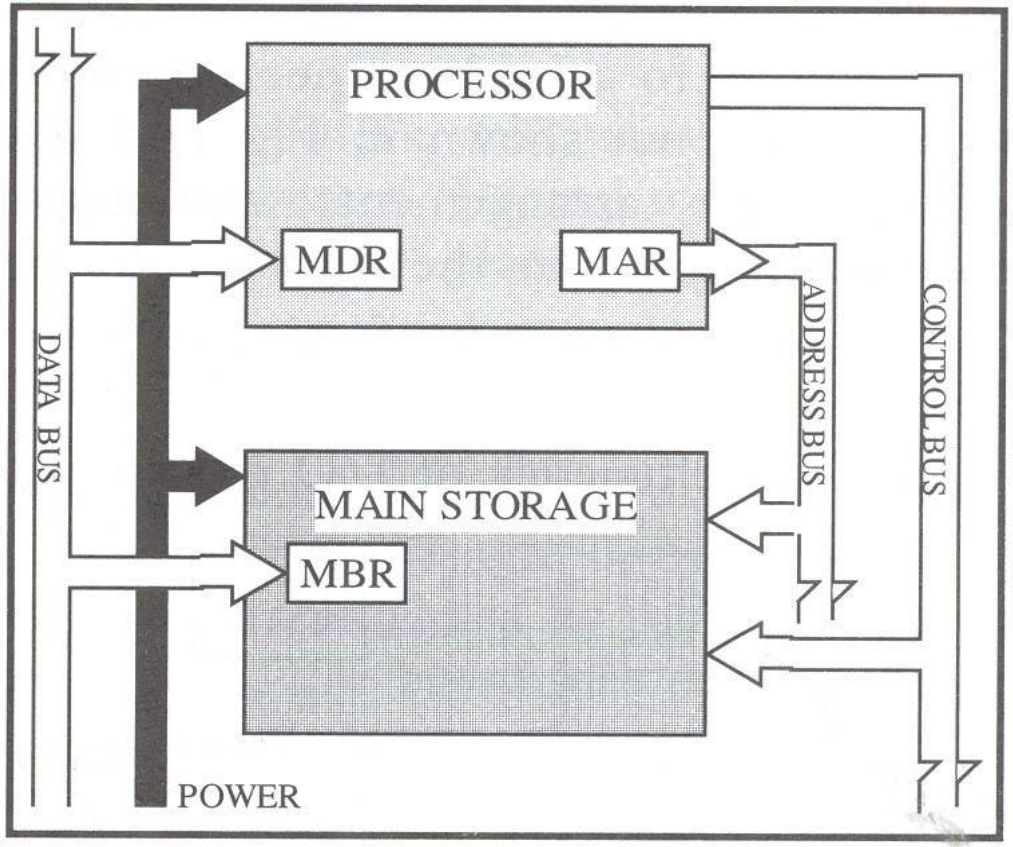


Fig 13.6 An example of Bus connections.

MDR – Memory Data Register

MAR – Memory Address Register

MBR - Memory Buffer Register

Processor registers 11

- Registers in the processor are constructed so that their contents can be accessed and altered **much faster** than the contents of locations of main storage

[11] Dale, N., & Lewis, J. (2020). Computer Science Illuminated (7th ed.). Jones & Bartlett Learning, Ch 5

Details of a processor

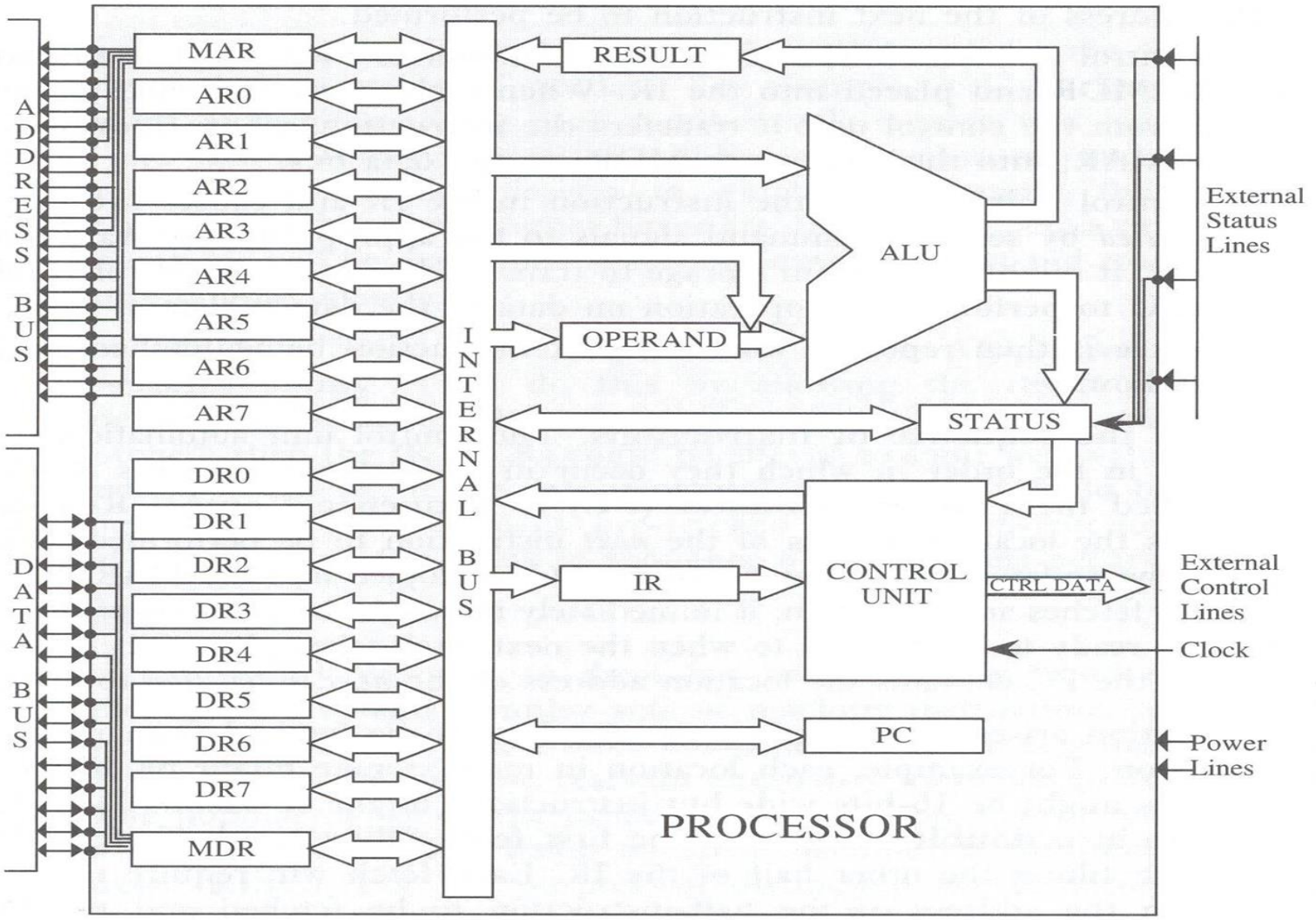


Fig 13.7 Details of a processor.

Processor registers [12]

- **IR (Instruction Register)**
  - Holds an instruction to be executed which was first taken from main storage via the MDR and placed in). There it is rapidly decoded and performed
- **DR (Data Registers) within ALU**
  - Hold data to be processed that was taken from main memory via MDR. The required arithmetic or logic operation is rapidly performed. ALU provides result in one DR from which it is taken and stored in main storage
- **AR (address registers)**
  - hold addresses from Memory Address Register (MAR), either stores the memory address from which data will be fetched to the CPU, or the address to which data will be sent and stored.
- **STATUS register**
  - is used by the control unit as a means of detecting conditions which have occurred such as the ALU detecting the arithmetic error of division by zero.

[12] Dale, N., & Lewis, J. (2020). Computer Science Illuminated (7th ed.). Jones & Bartlett Learning, Ch 5

Details of a processor

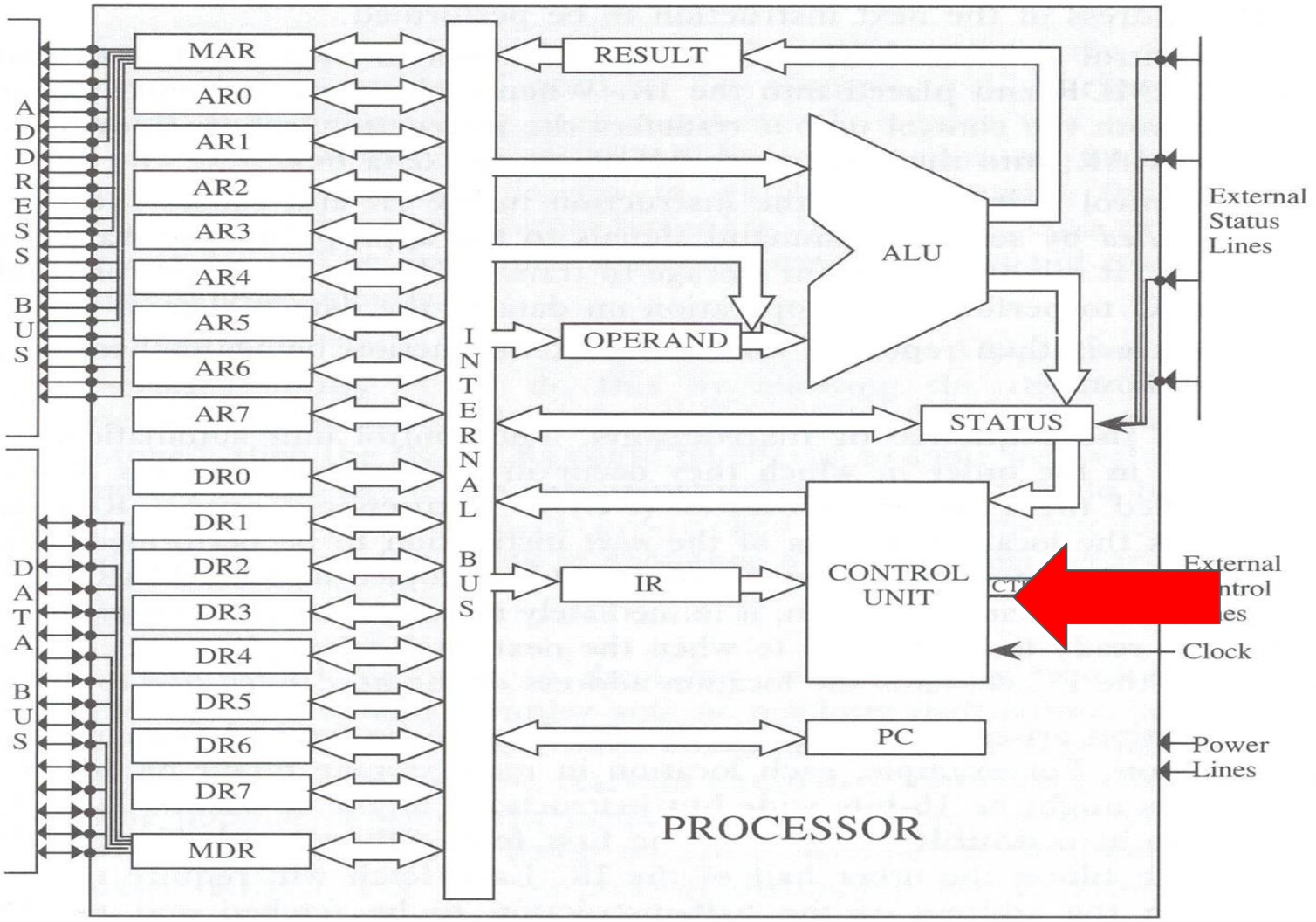


Fig 13.7 Details of a processor.

Processor: Control Unit [13]

- component of a computer's central processing unit (CPU) that directs the operation of the processor.
- Is a nerve centre of the computer
  - Coordinates and controls all-hardware operations (ie, those of peripheral units, main memory and the processor itself)

[13] Dale, N., & Lewis, J. (2020). Computer Science Illuminated (7th ed.). Jones & Bartlett Learning, Ch 5

Control Unit operation [14]

- **Fetch-execute cycle**
  - Control unit causes the requisite instruction to be **fetched** from main storage via the MDR and placed in IR. When main storage receives an appropriate signal from the control unit it transfers the instruction, whose address is specified in the MAR, into the processor's MDR via the data bus
  - The control unit interprets the instruction in the IR and causes the instruction to be **executed** by sending command signals to the appropriate hardware devices.

[14] Dale, N., & Lewis, J. (2020). Computer Science Illuminated (7th ed.). Jones & Bartlett Learning, Ch 5

Fetch-execute cycle

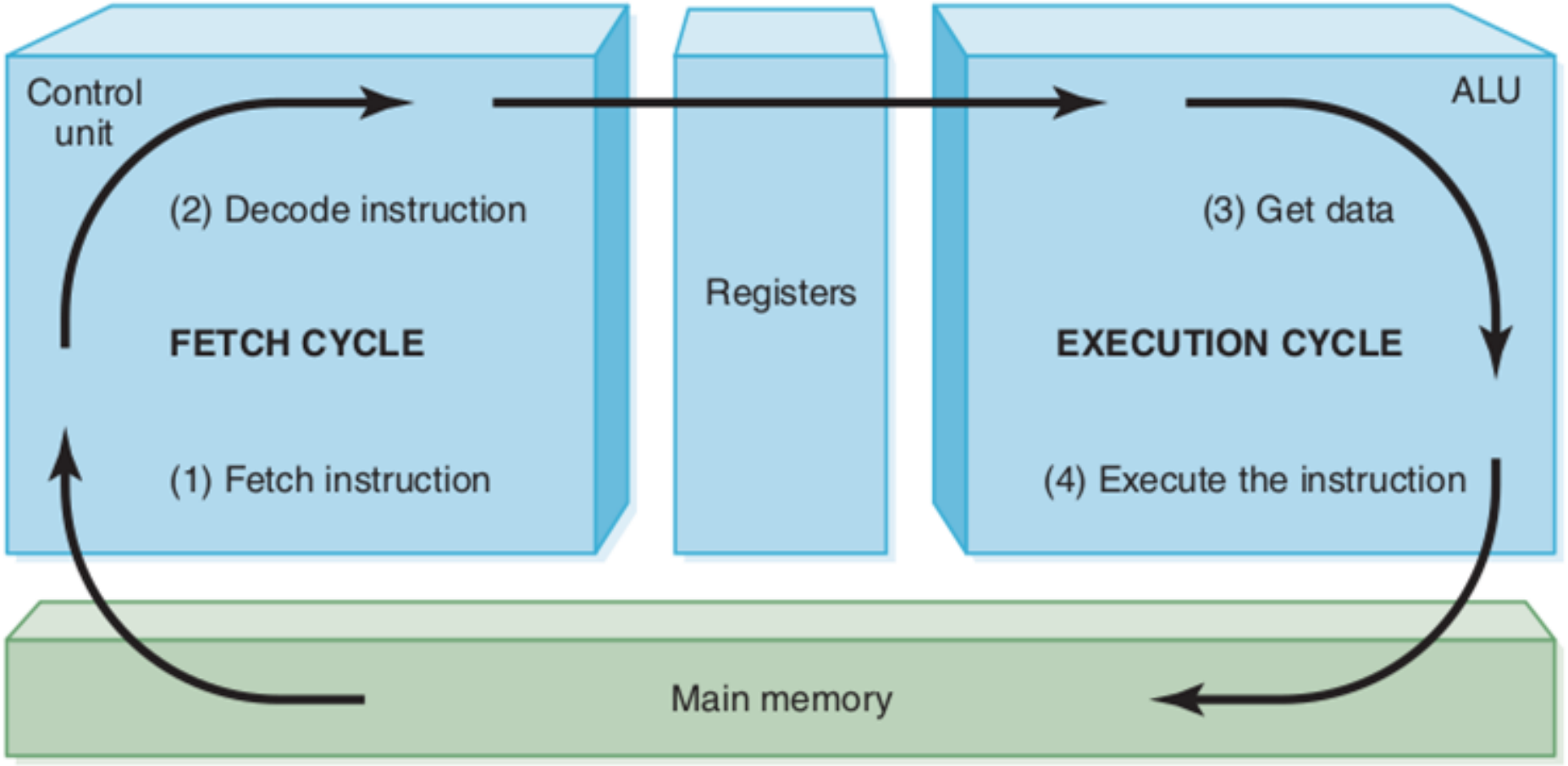


FIGURE 5.3 The fetch–execute cycle

Control Unit – Control of sequence of instructions [15]

- PC (Program Counter) or SCR (Sequence Control Register) registers
  - Hold the location address of the next instruction to be performed

[15] Dale, N., & Lewis, J. (2020). Computer Science Illuminated (7th ed.). Jones & Bartlett Learning, Ch 5

Details of a processor

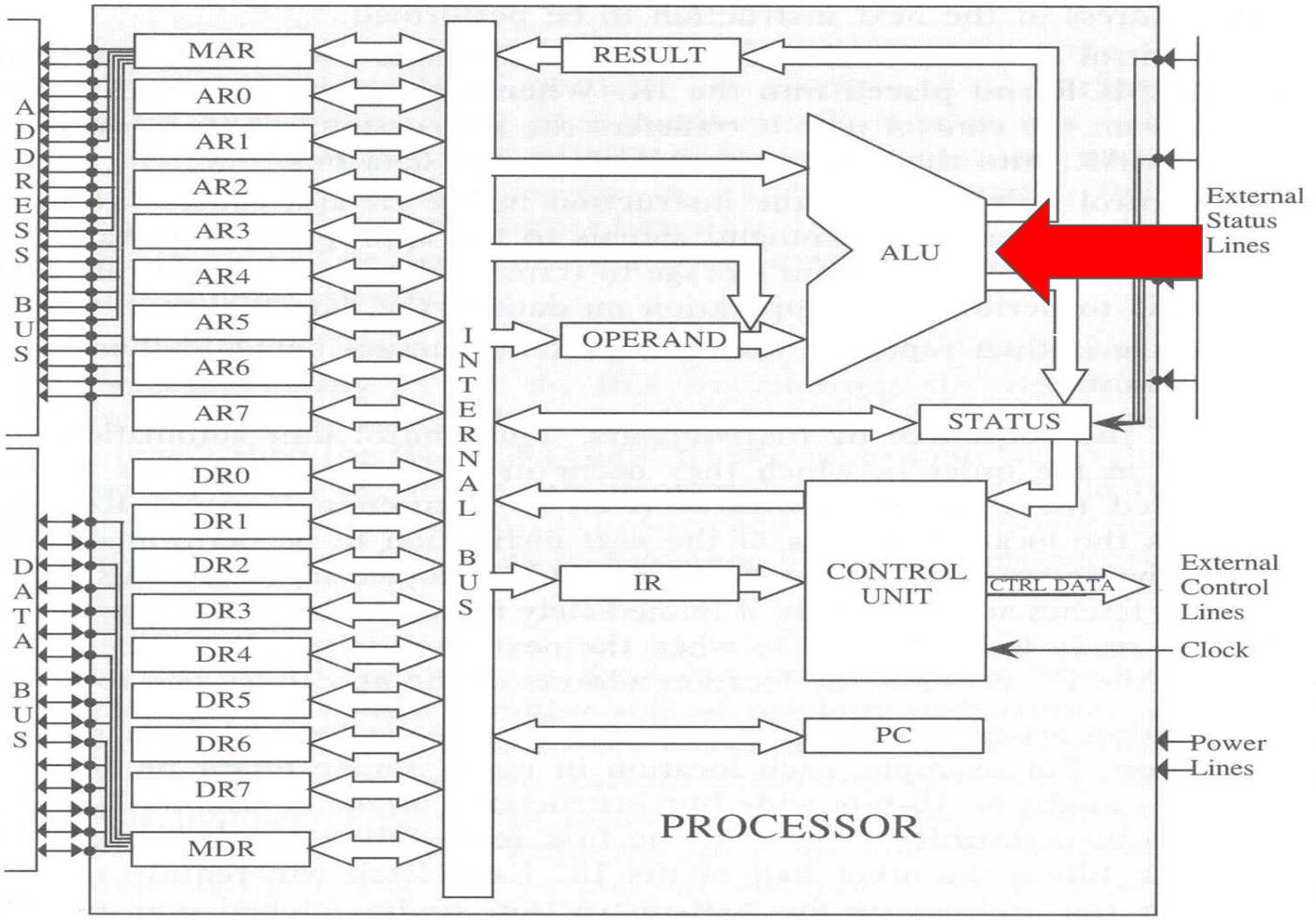


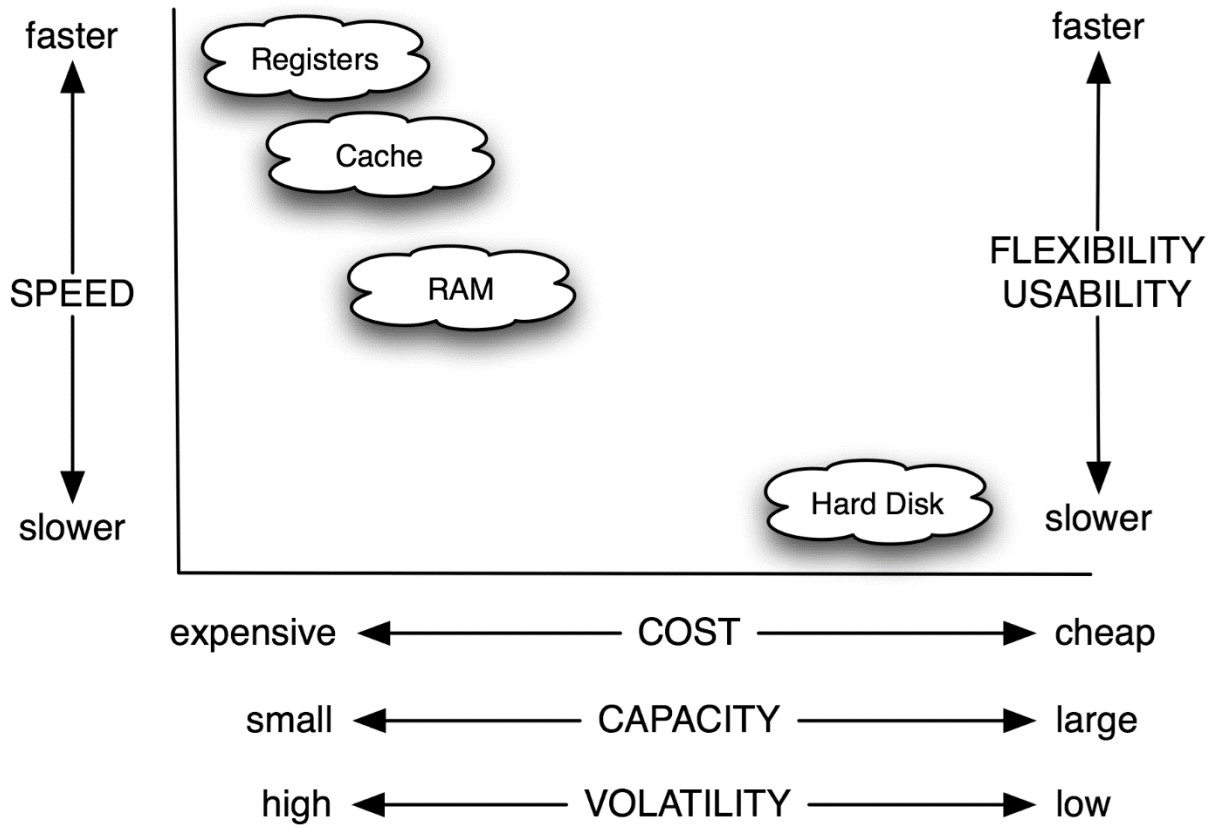
Fig 13.7 Details of a processor.

Processor: Arithmetic and logic unit (ALU) [16]

- Functions
  - Carries out the arithmetic (add, substract, multiply and divide)
  - Performs certain “logical operations” (testing whether two data items match)

[16] Dale, N., & Lewis, J. (2020). Computer Science Illuminated (7th ed.). Jones & Bartlett Learning, Ch 5

Performance and cost



Cache [17]

- is random access memory (RAM) that a computer microprocessor can access more quickly than it can access regular RAM.
- Cache management algorithms
  - LFU (Least Frequently Used) and LRU (Least Recently Used)
  - The difference is that determining which data items to overwrite.

[17] Dale, N., & Lewis, J. (2020). Computer Science Illuminated (7th ed.). Jones & Bartlett Learning, Ch 5

Recommended sources:

Essential material

- Dale, “Computer Science Illuminated”, Chapter 5
- R. White, “How computers work”, Chapters 2, 3, 4

Advanced material related to the topic:

a. What Every Programmer Should Know About Memory
b. Computer Architecture Essentials | James Reinders, former Intel Director
c. How Computers Calculate - the ALU: Crash Course Computer Science #5
d. Registers and RAM: Crash Course Computer Science #6
e. The Central Processing Unit (CPU): Crash Course Computer Science #7
f. Instructions & Programs: Crash Course Computer Science
g. How A CPU Works

References

1. Dale, N., & Lewis, J. (2020). Computer Science Illuminated (7th ed.). Jones & Bartlett Learning, Chapter 5, end of the chapter exercises
2. Drepper, U., 2007. [online] People.freebsd.org. Available at: <https://people.freebsd.org/~lstewart/articles/cpumemory.pdf> [Accessed 7 June 2022].
3. Reinders, J., 2016. *Computer Architecture Essentials*. [online] Youtube.com. Available at: <https://www.youtube.com/watch?v=yOa0WpMwzWk> [Accessed 7 June 2022].
4. Youtube.com. 2017. Registers and RAM: Crash Course Computer Science #6 [online] Available at: <https://www.youtube.com/watch?v=fpnE6UAfbtU&t=539s> [Accessed 29 May 2022].
5. Youtube.com. 2017. The Central Processing Unit (CPU): Crash Course Computer Science #7 [online] Available at: <https://www.youtube.com/watch?v=FZGugFqdr60&t=52s> [Accessed 29 May 2022].
6. Youtube.com. 2017. Instructions & Programs: Crash Course Computer Science [online] Available at: <https://www.youtube.com/watch?v=zltgXvg6r3k&t=205s> [Accessed 29 May 2022].
7. Youtube.com. 2013. *In One Lesson*. [online] Available at: <https://www.youtube.com/watch?v=cNN_tTXABUA> [Accessed 7 June 2022].

References

8. Youtube.com. 2017. How Computers Calculate - the ALU: Crash Course Computer Science #5 [online] Available at: <https://www.youtube.com/watch?v=1I5ZMmrOfnA&list=PL8dPuuaLjXtNlUrzyH5r6jN9ulIgZBpdo&index=7 > [Accessed 29 May 2022].
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10. Youtube.com. 2022. Khan Academy and Code.org | Hardware and Software. [online] Available at: <https://www.youtube.com/watch?v=VzVSt6jxiqw> [Accessed 7 June 2022].
11. Senanan, K., 2016. How computer memory works. [online] Youtube.com. Available at: <https://www.youtube.com/watch?v=p3q5zWCw8J4> [Accessed 7 June 2022].