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Lesson 2
Computer Architecture: Software and Hardware

Programming

Grade in Industrial Technology Engineering

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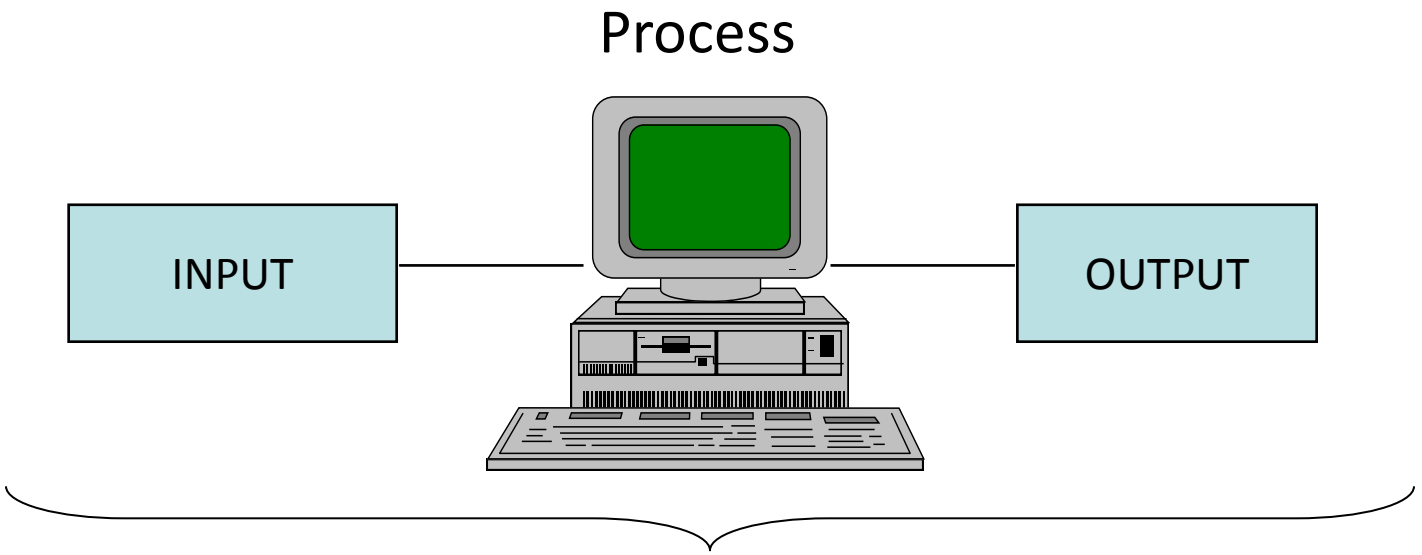
Outline

1. **Logic support: Software**
   - Programming languages
   - *Compilation and translation* programs
   - Operating systems
2. Physical support: Hardware
   - Computer architecture
   - Components
   - Data storage
   - Peripherals
   - Computer networks and the Internet

1. Logic support: Software

Computer: Machine composed of electronical elements, able to accept data from an input device, to process them automatically with a previously stored program, and to provide the resulting information through an output device



- **Software**: Logical elements that make the physical components work to accomplish a task
  - Basic software
    - Programs for the elemental functioning of the computer and the peripherals (BIOS)
    - Operating System for basic tasks of the system: control, resource management, input and output, etc.
    - Resident programs: basic software permanently loaded in the memory
  - Application software
    - Programs for specific purposes, solving a specific problem or family of problems: office (word processors, spread sheets…), games, etc.

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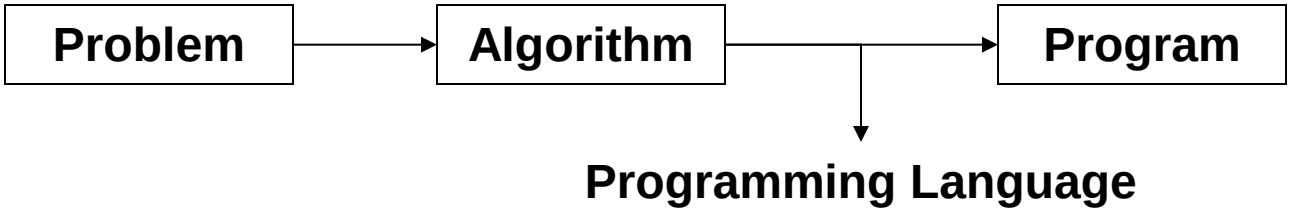
1.1. Programming languages

Program: Set of orders (named instructions or sentences) written in a programming language that are provided to the computer to develop a task.



A program encompasses:

- Program data
  - Information processed by the program
- Expressions
  - Operations on data performed with operators
- Instructions
  - Actions of the program (usually involve data)

Programs are created with the symbols and the rules of the programming language

Types of programming languages

According to the proximity to the natural language

- High-level programming languages
  - *C, C++, Java, Python …*
- Low-level programming languages
  - Machine code
  - Assembly

Binary language (or Machine Code)

It is the ONLY language that the computer directly understands

Data and instructions are encoded by using strips of 0 and 1 that encode operations and memory locations

↑ The fastest: talking to the computer on its own idiom

↓ Very difficult to create programs with it: error prone, debugging is very complicated

↓ Targeted to one machine: it cannot be used in different processor brands, because the instructions use specific hardware components

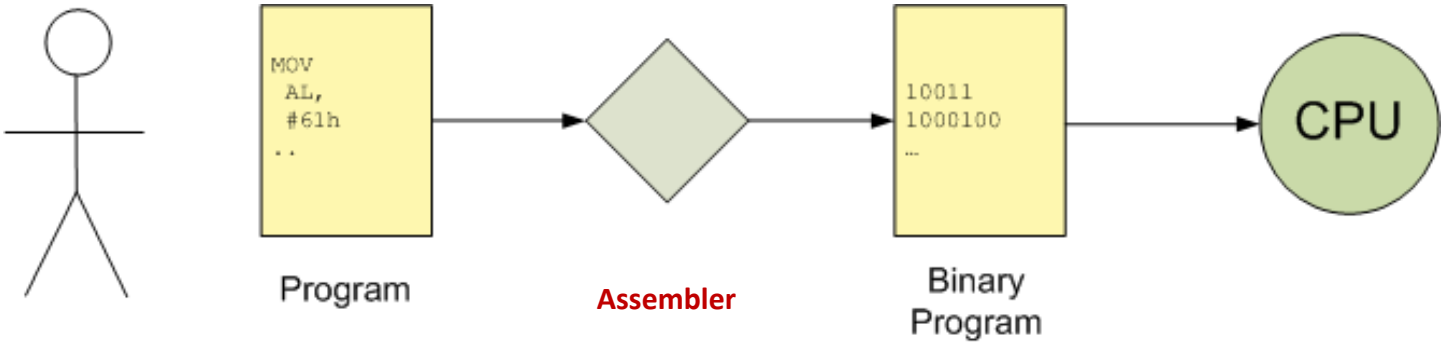
E.g.: Instruction to add the registers 1 and 2 and place the result in register 6 (MIPS architecture)

00000000001000100011000000100000

Meaning					
type	***Op 1***	***Op 2***	***Res***	***Shift***	***Function***
000000	00001	00010	00110	00000	100000

Assembly language

- ↑ Changes binary instructions by mnemonics (labels)
  - Require the use of an *assembler* program to translate the textual language into machine code
- ↓ Low level instructions:
  - Still complicated, it offers low-level primitives that make it difficult to solve comple problems
  - Processor-dependent



High-level languages

↑ They are intended to **bring programming languages closer to human language**

Programs expressed in high-level languages do not depend on the internal architecture of a specific processor

The same program can be run on different machine brands

Programs program must be translated into binary language

↓ This translation is more complex than the assembly process

↑ The same source program can be executed in different operating systems (but specific compilers are required for each platform)

There are more than 300 high-level programming languages (with more than 2400 with dialects): Fortran, Pascal, Cobol, Basic, C, C++, Java, Ada, Python, etc.

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   - Peripherals
     - Storage
     - Output
     - Input
   - Networking: Computer networks and the Internet

1.2. Compilation and translation programs

Translation programs convert instructions in assembly language or high-level language into binary code

- Input: instructions in text format (source code)
- Output: executable program in binary code

The compiler also detects syntactic errors of the program (bad-formed instructions) and informs the programmer to correct them

- These are called **compilation-time** errors

Types of translation programs

- Assembler
- Compiler
- Interpreter

1.2. Compilation and translation programs

Assembler

Transforms the program in assembly language to executable machine code (see previous slides)

Compiler

Transforms the program in a high-level language (source code) to programs in a low-level language (**object code**)

Interpreter

Transforms the program in a high level language (source code) instruction-by-instruction to **executable instructions** and executes them

Compiler

It transforms the program in a high-level language (source code) to programs in a low-level language (object code)

Object code **is not directly executable**; it must be **linked** (with the link program) to join it with other object code (e.g., external libraries) to generate the executable file

The compiler detects syntax errors; if any, it warns the programmer and the object code is not generated

The generated program can be run on any other compatible computer (with the same operating system), even if the compiler is not installed

Interpreter

It analyses and transforms a program instruction expressed in a high-level language (source code) into instruction(s) in machine language (executable)

Translation is performed while there are more instructions available or an error occurs

The interpreter *supervises* the execution of the program

The interpreter must be installed in the computer executing the program

1.2. Compilation and translation programs

Compiler wins over Interpreter

The code is compiled once and used several times (more efficient)

Syntax errors are detected in compilation time (when the program is being developed)

The compiler can optimize large blocks of code

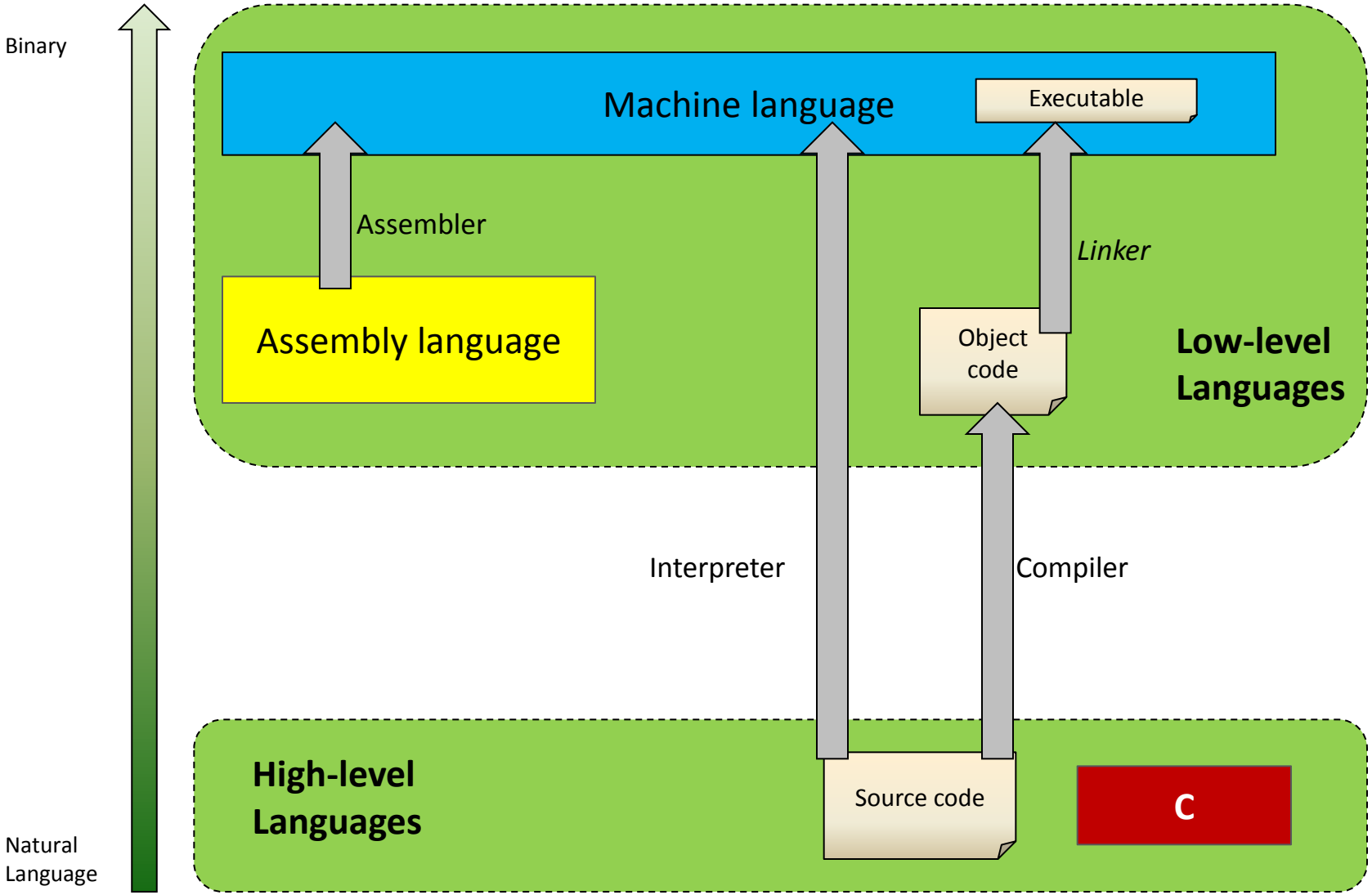
The target computer (where the program is executed) does not need to have the interpreter installed

Interpreter wins over Compiler

The same code can be executed in different operating systems –as long as an interpreter is available

Code modification and variable watching is easier

1.2. Compilation and translation programs



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Operating System

Software that manages the physical elements of the computer to coordinate the execution of a program

Layer between the physical components of the computer and the programs in a programming language

Functions

- Efficient coordination and management of the resources (monitor, printer, keyboard, memory, etc.)
- Facilitate the user-machine interaction
- Process user requests
  - Commands
  - Program calls

Examples:

Windows 8, Mac OS X, Linux

Android, iOS

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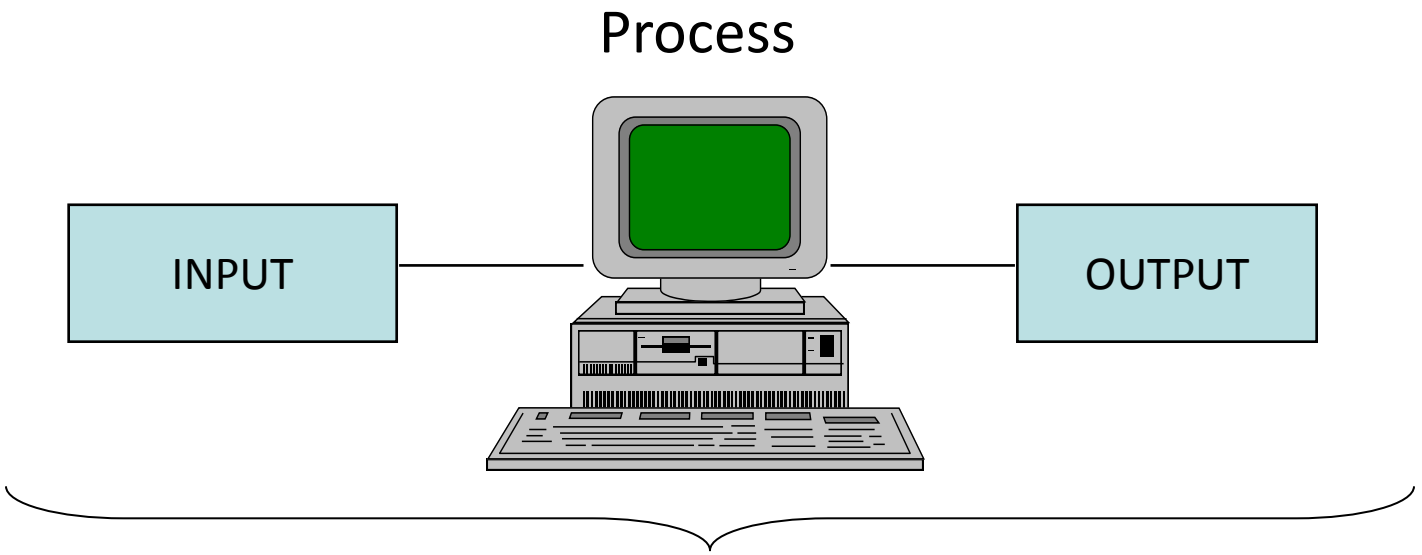

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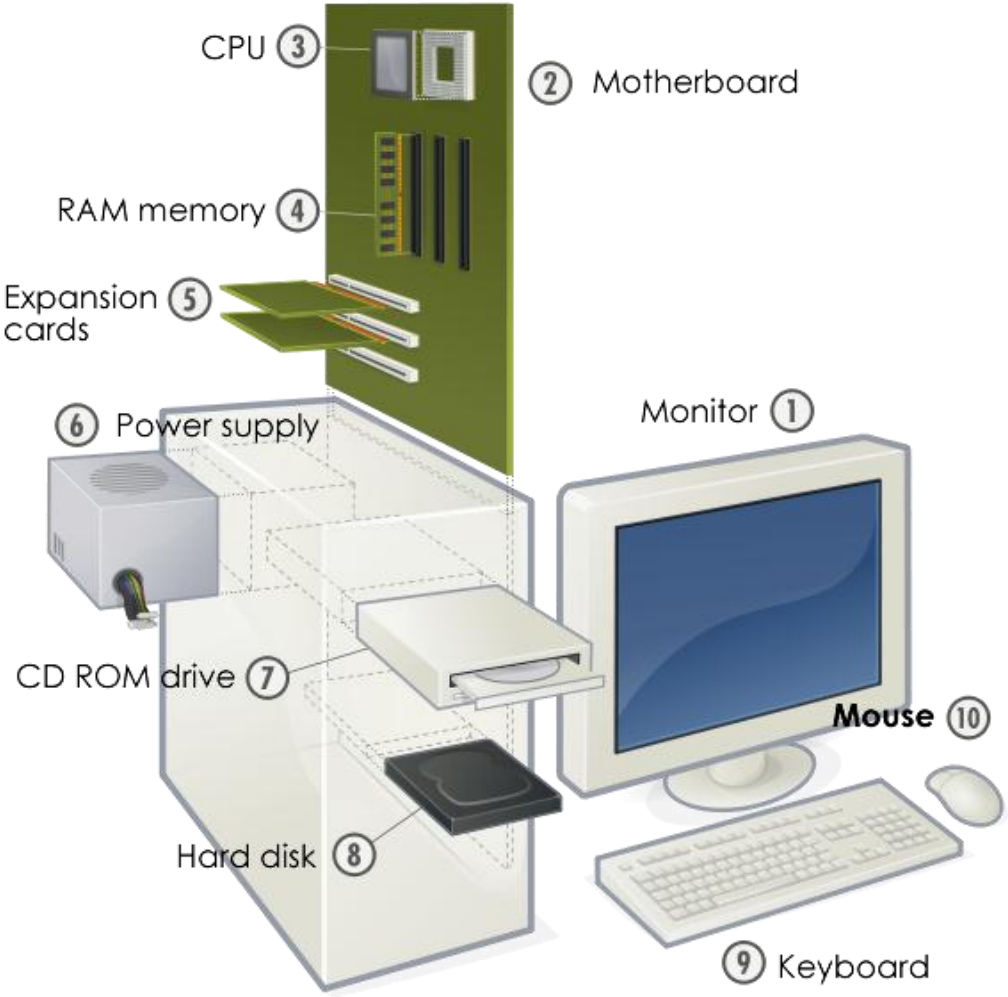
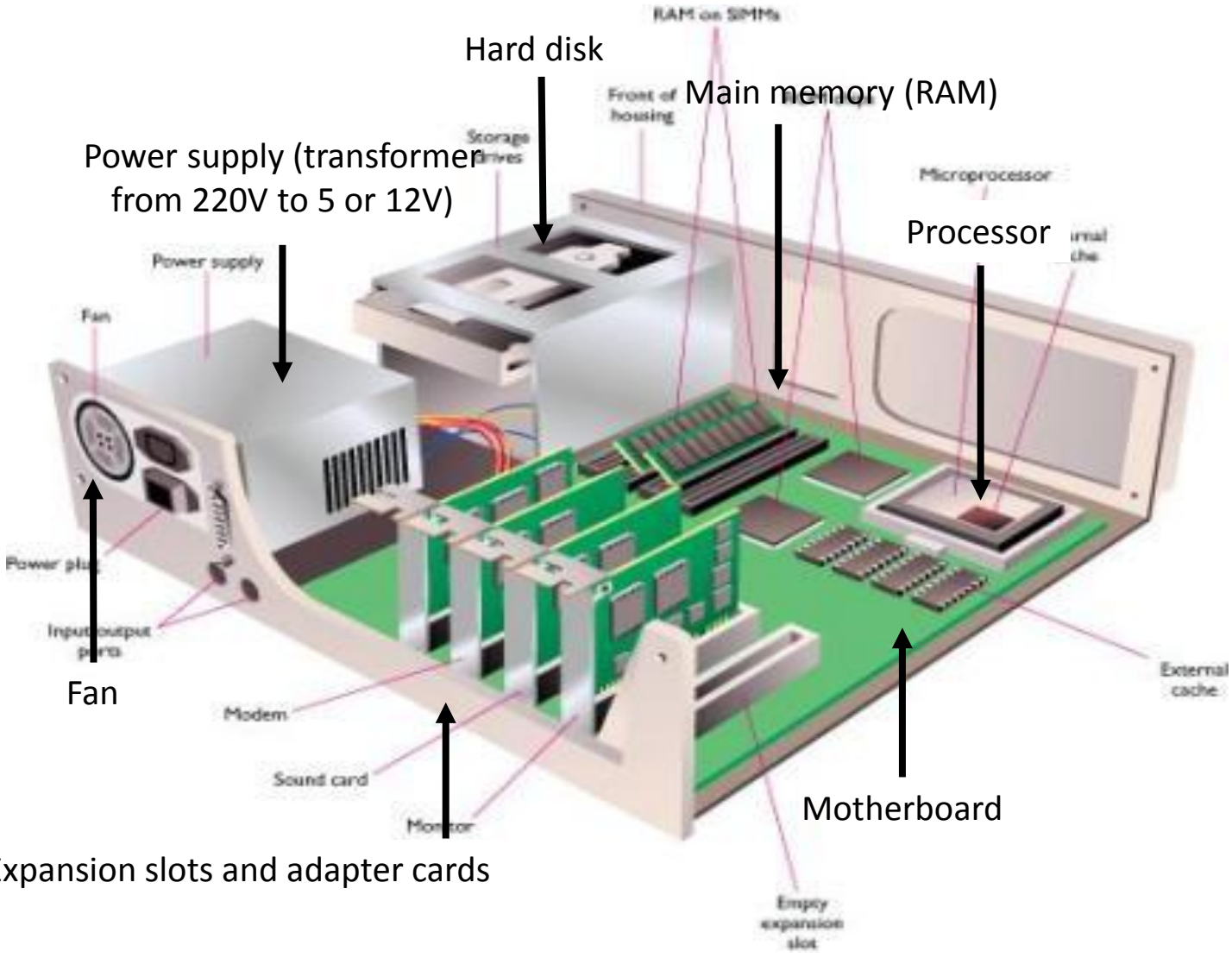
2.1. Computer architecture



Fuente: Wikimedia Commons [link]

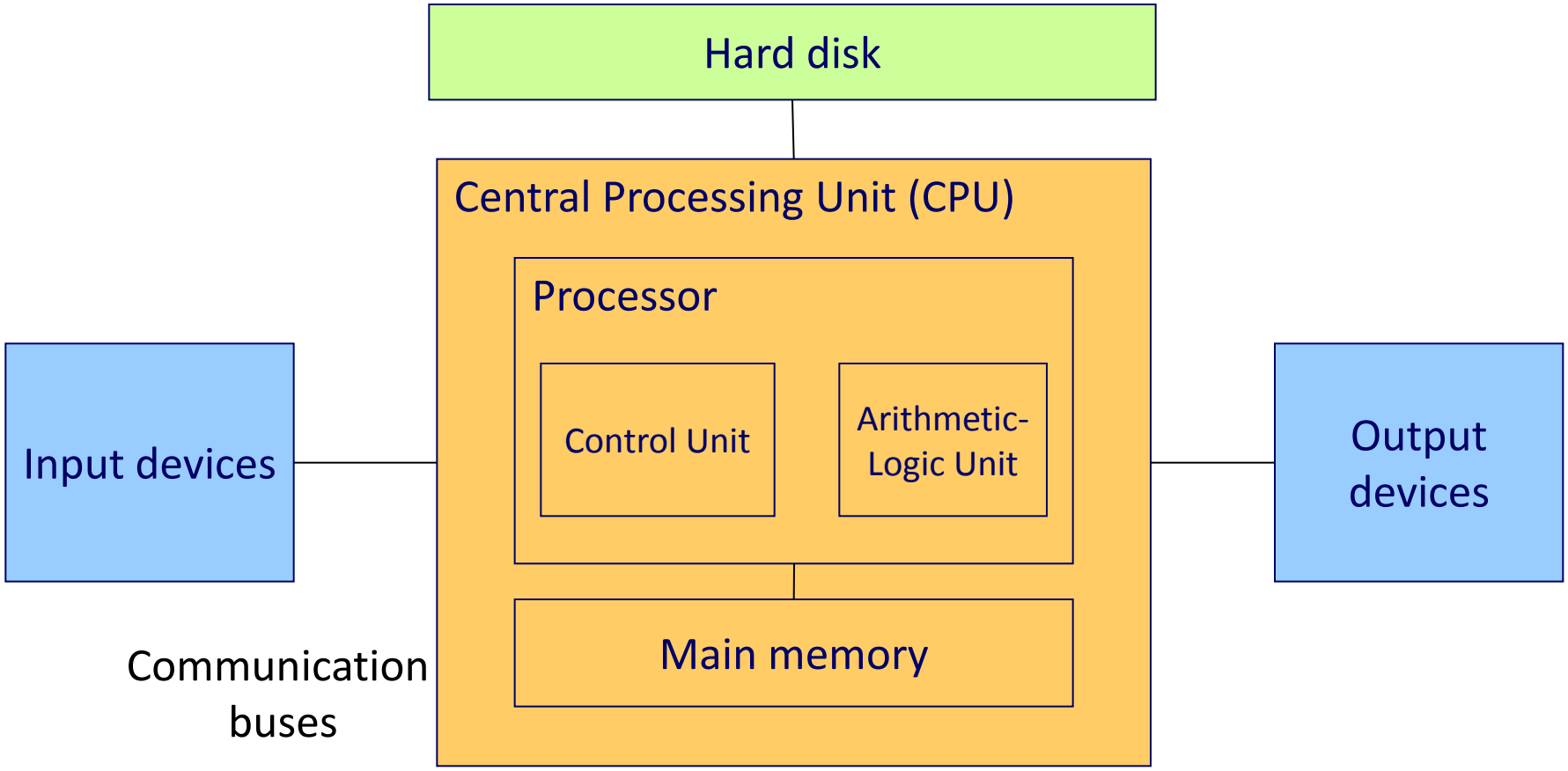
2.1. Computer architecture



http://www.videojug.com/film/what-components-are-inside-my-computer

Basic hardware structure of a computer

Von Neumann architecture (1945)



2.1. Components of the computer

Central Processing Unit (CPU)

Processor: Controls the functioning of the computer

Main memory: Stores data and instructions used by programs

Hard disk

Permanent storage of massive data

Output devices

Show results to users

Input devices

Allow for the introduction of data and programs to the main memory, adapting and encoding them to make them interpretable by the machine

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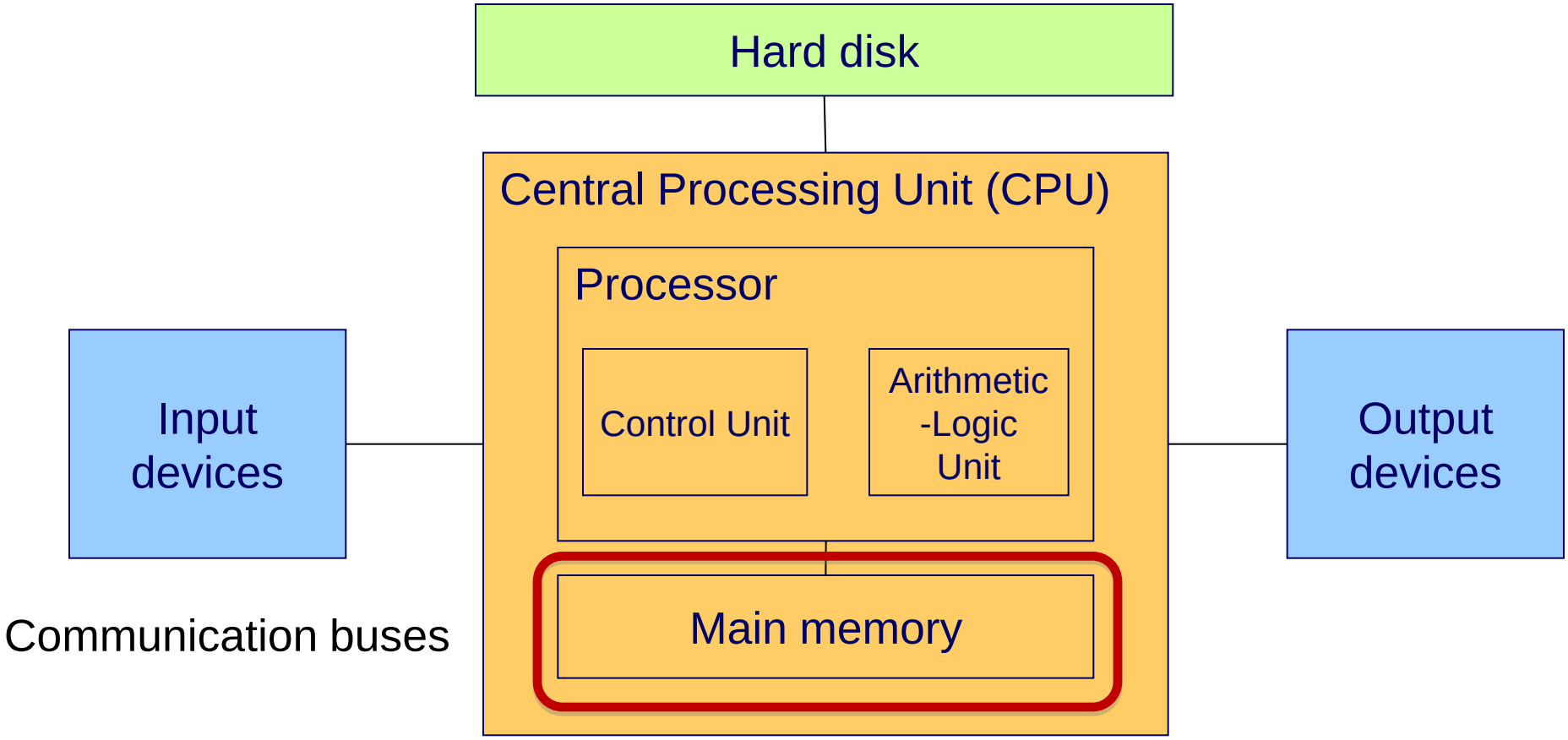
2.2. Components of the computer



2.2.1. Main memory

The **main memory** stores information that **is being processed by the computer or has been recently produced**

- Data
- Instructions

Very fast access, read/write

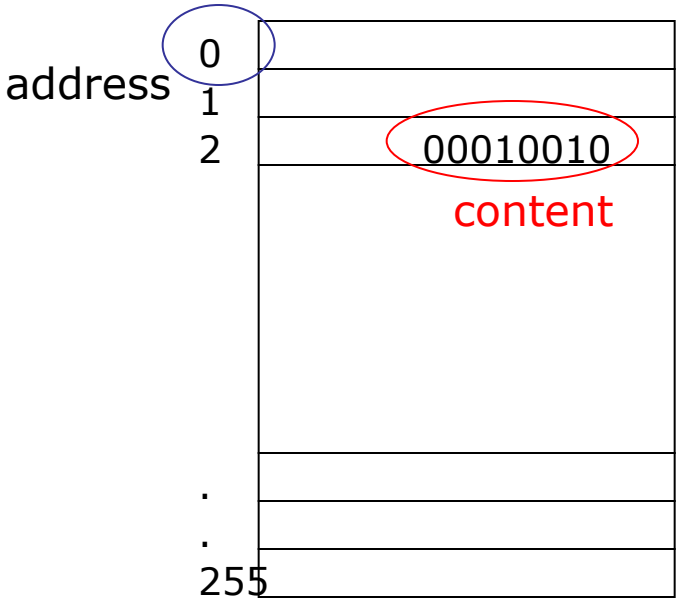
Usually, two types are distinguished

- Read-only memory (**ROM**)
  - Recorded by the manufacturer
  - Permanent
  - Contains programs and data relevant to the operating system that need to be accessible
- Random-access memory (**RAM**)
  - Used by the programs to store and retrieve data
  - Volatile (the contents are lost when the computer is turned off)
  - Contains the programs that are being currently executed by the CPU and associated data

2.2.1. Main memory

Logically arranged as a list of cells with consecutive position numbers

- Each cell stores several bits
- Cells are also named “memory words”
- A word is identified by its position number (the *address*), which indicates the order in the list



RAM memory

Random Access Memory

Used to store programs, data, and part of the operating system

It is volatile (contents are lost when the computer is turned off)

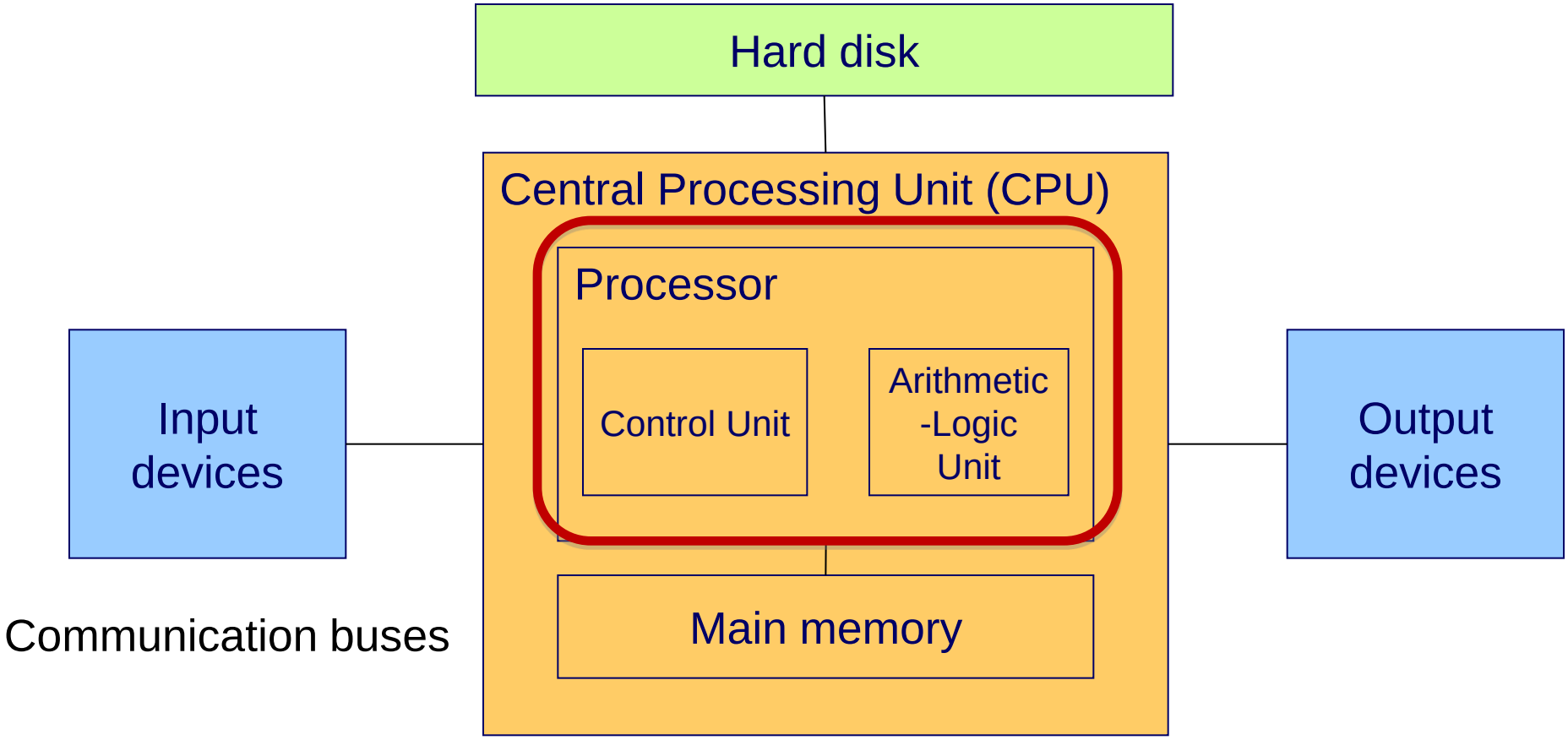
Read/write

The more RAM memory the computer has, the more programs can be in execution at the same time and the larger programs can be stored in memory

Extensible (SIMM modules)

Source: Wikipedia [link]

2.1. Components of the computer



The **processor** is the core component of the computer

It includes

- **Control Unit**
  - Interprets the instructions and control their execution
- **Arithmetic-Logic Unit**
  - Performs basic arithmetical and logic operations
    - Addition, substraction, …
    - Logical AND, OR, …

Control Unit

- Manages the functioning of the computer
- Executes the instructions stored in the main memory
- Basic functions
  - Analyzes the state of the other units
  - Fetch program instructions from the main memory
  - Generate electric control signals to the other units to perform the operations required by the instruction that is being executed
- Composed of
  - Registers
  - Decoder
  - Clock

2.2.2. Processor – Control Unit

Registers

Small memory slot to store data and instructions temporarily

Program counter (or Instruction Pointer): Contains the memory address of the next instruction

Instruction register: Contains the instruction being executed

Decoder

Translates the instruction into machine language and executes it

Clock generator

Generates clock signals at a fixed frequency

Each clock pulse starts the execution of a machine instruction

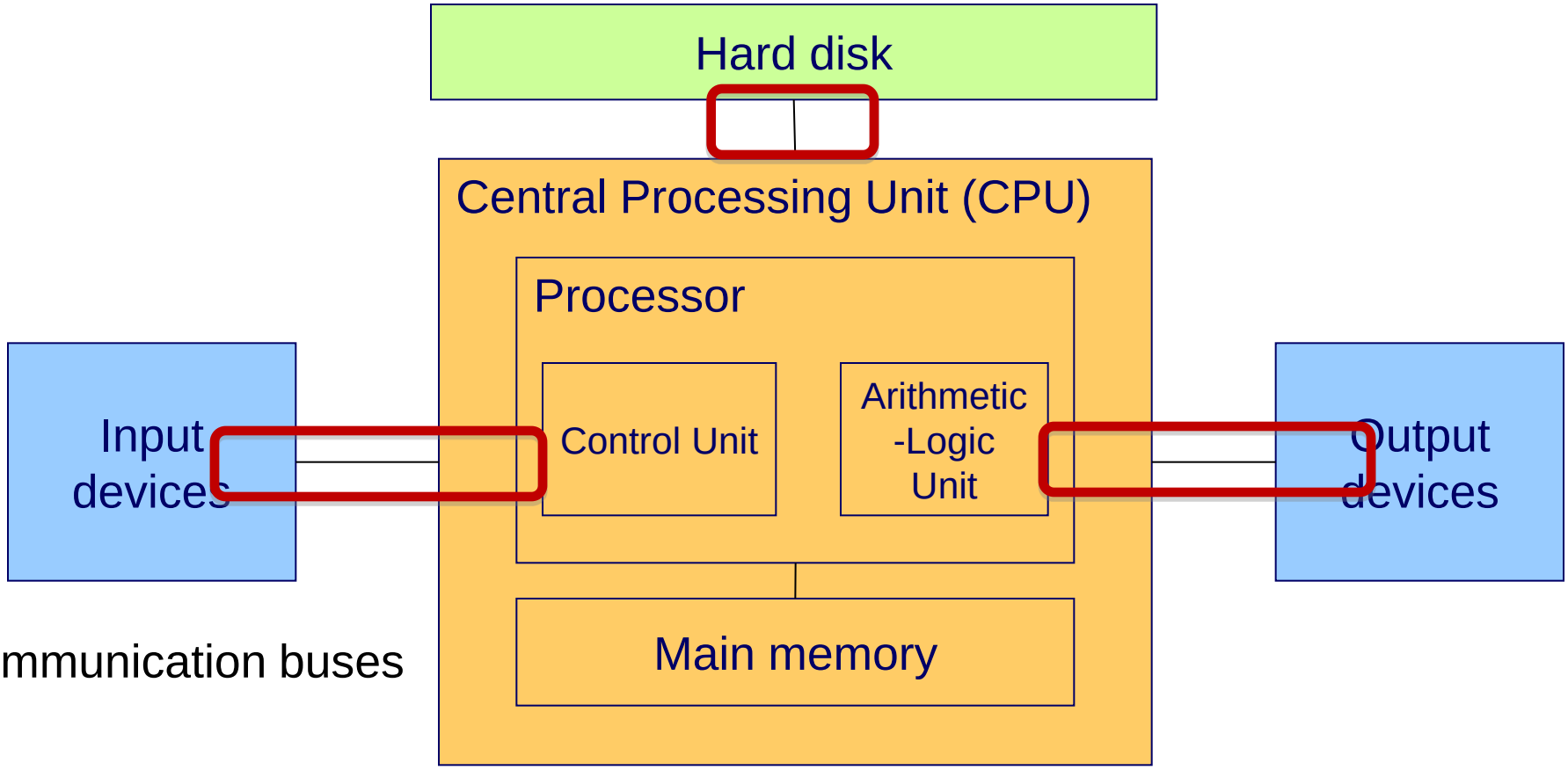
The number of pulses per second determines the speed of the computer. Clock speed is measured in hertzs

200 Mhz = 200 millions of elemental instructions per second

Arithmetic-Logic Unit (ALU)

- Perform arithmetic (addition, substraction, etc.) and bitwise logic (and, or, etc.) operations
- Data used by the ALU must be stored in the main memory
- The ALU fetches data to be operated to ALU registers
  - First operator, Second operator, Result
- The ALU is composed by elemental circuits: AND, OR, NOT gates

2.2. Components of the computer



Communication buses

2.2.3. Buses

Communication buses are electrical circuits that connect the control components of the computer

- Information: data, addresses, or instructions
- Transmitted in parallel
- Bus width: number of *wires* = number of bits that can be simultaneously transmitted

Three types of buses

- **Control bus**, to transmit orders to the components of the system
- **Address bus**, to transmit addresses
  - e.g. Address of a memory cell to write, or address of a peripheral to send data
- **Data bus**, to transmit data between the components of the system

Program execution encompasses the following steps:

The control unit fetches the instruction to be executed from the main memory (the address where this instruction is stored is retrieved from the program counter)

The instruction is stored in the instruction register. The instruction has two parts: the operation code (i.e., what operation it is) and the memory address of the operators (i.e., where are allocated the values to operate)

The control unit sets connections through the system buses

It fetches from the main memory the data to process, if needed (e.g., it fetches the values from the address specified in the structions and stores them in the registers of the ALU)

Order to the components (e.g., the ALU) to perform operations by sending control signals and data

If the instruction provides new data as result, they are stored in the main memory

The program counter is increased and the next instruction is processed

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   - Other peripherals
   - Computer networks and the Internet

2.3. Data storage

Peripherals are devices to allow the computer to communicate with people and other computers to acquire, store, or transmit data.

Types:

- **Storage**: hard disk, magnetic tape, optical disk, CD-ROM, DVD
- **Input**: keyboard, scanner, optical reader
- **Output**: monitor, printer

Peripherals communicate with the processor through ***channels***

A channel is an electronic device with two parts:

- Memory or buffer: data to be processed
- Control unit: executes instructions

2.3.1. Storage peripherals

Storage peripherals are used to store massive information

- **Magnetic units**
  - Data are stored by means of changes in the polarization of a magnetic surface
  - Floppy disks, hard disks, magnetic tape
- **Optical units**
  - They based in the optical properties of the materials (light reflection)
  - CD-ROM, DVD
- **Solid state units**
  - Data is stored in integrated circuits
  - Flash memory

Storage units can be also classifed as:

- **Undetachable**
  - Hard disk
- **Detachable**
  - Floppy disk, CD-ROM, DVD, Flash memory

Magnetic units

Magnetic **tape**

- Thin magnetizable coating (iron oxide or chromium dioxide) on a narrow strip of plastic
- Information is encoded as polarized points on tracks parallels to the axis of the tape
- Sequential storage
- Currently, it is used for very massive storage with non-frequent access (e.g. backups)

Magnetic **disks**

- Most common direct-access storage support
- Physical foundation similar to magnetic tapes
  - Hard disk
  - Floppy disk

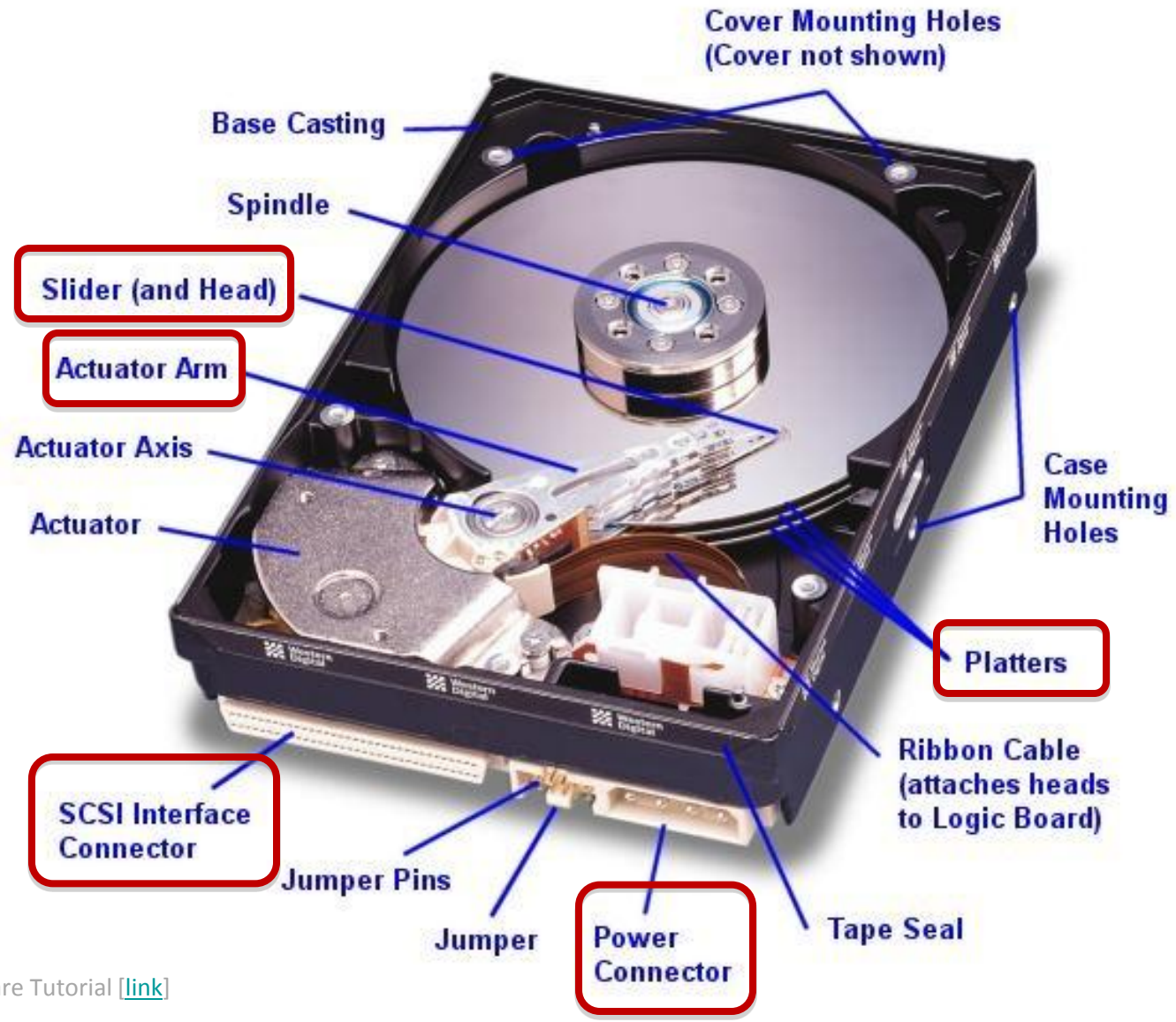
Hard disk

- Group of 1-4 platters sealed inside a protecting case
- Platters are metallic or are covered with magnetizable material (two sides)
- An electrical engine make the platters spin at constant speed
- Reading / writing heads
  - Ferrite core on a mechanical arm
  - A head is used on each magnetized side
  - Arms move forward and backward to reach atrack on the platter
- '1' is stored when the polarization has one direction, '0' in the other case

http://youtu.be/Wiy_eHdj8kg

Info

2.3.1. Storage peripherals – Hard disk



Source: The PC Hardware Tutorial [link]

Optical units

Transparent plastic disc (polycarbonate)

Data layer –data to be read with a laser beam

Metalic layer –reflects the beam back to the reader sensor

Materials of the data and the metalic layers are different for different kind of discs

Source: Wikimedia Commons [link]

Optical units

Information encoding

Data is stored as micro *grooves* (pits)

One single spiral groove, starting from the center of the disc

Holes (pits) and flat zones (lands) have different reflection properties

- The sensor measures the energy of the laser beam reflected on the disc surface to distinguish pit and lands (two states)

'0' and '1' are not directly represented with lands and pits

- A pit means that there is a state change (from 0 to 1 and 1 to 0)
- A land represents a zone with no change of state (may be 0 or 1)
- The number of pits is reduced ➔ Writing is faster

Optical units

Capacity

The capacity of DVDs is larger because *grooves* are smaller

Laser wavelength is shorter

Blu Ray has an even shorter wavelength

Multi-layer discs

A second physical layer is created inside the disc

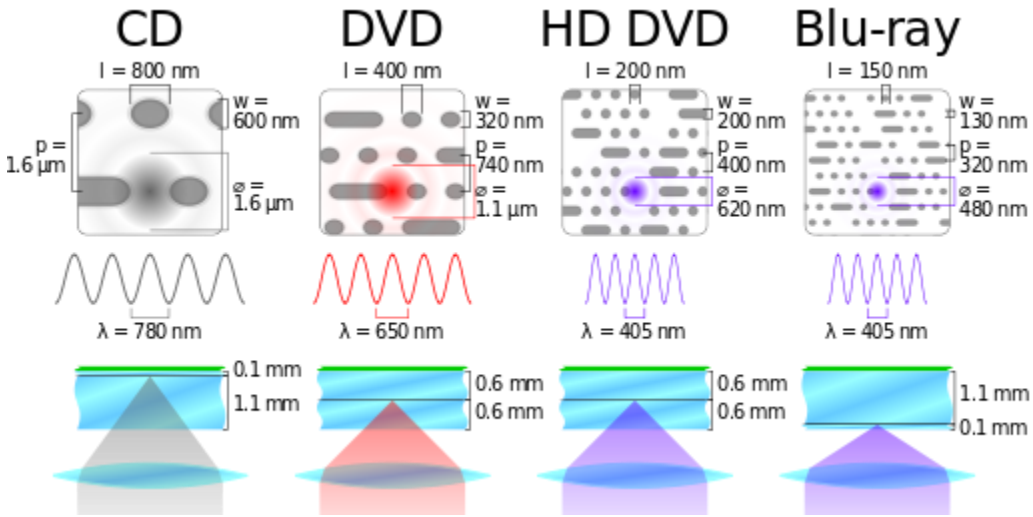
The outer layer is semi-transparent

The laser beam access to the second layer through the first layer

Larger capacity

Info

2.3.2. Storage peripherals – Optical units



Source: Wikipedia [link]

Optical units

Read-only (CD-ROM and DVD-ROM)

- Data is physically carved on the poly-carbonate
- Metallic layer is aluminum
- Audio CDs have the same physical structure, but different data format

Writable (CD-R, DVD-R)

- Data layer is an organic material that can be altered with the laser
- Metallic layer is gold, silver, or silver alloy
- After carving the organic material, it cannot be changed again
- Used for backups

Optical units

Rewritable (CD-RW, DVD-RW, DVD+RW, DVD+RAM)

Data layer is a metallic-alloy coating that can be changed

Crystallization changes with heat

The data layer is altered with the heat of the laser beam. The *grooves* are flattened, so the laser beam can be applied to record new data

+RW and –RW are two different encoding formats promoted by different associations of companies

Solid state units

Also called flash memory

Detachable storage devices that use solid state devices (integrated circuits) instead of optical or magnetic technology

No mechanical part –everything is electronic

Pros: Faster; longer life

Cons: Less capacity for a unit of the same size of a hard disk; cost per megabyte is higher

Solid state units

USB Flash drives (pen drives)

- Solid state memory that is plugged in the USB port
- A pencil-sized device can store more than 256GB

USB drive
Source: Wikipedia [link]

Memory cards

- Used for portable devices
- Different types:
  - SD: Secure Digital (normal, mini, micro)
  - CF: Compact Flash
  - XD: XD-Picture Card
  - MMC: Multimedia Card

Comparison of different SD card sizes
Source: Wikipedia [link]

MP3 Players use solid state units

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     - **Ouput**
     - Input
   - Computer networks and the Internet

Output peripherals

- Monitor
- Printer

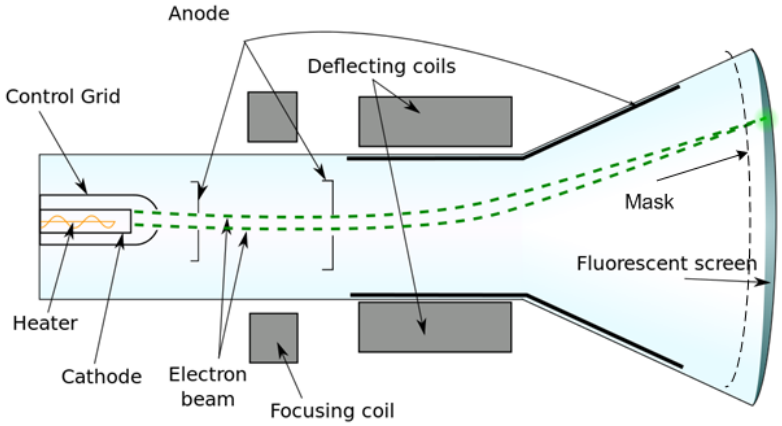
Monitor: Types

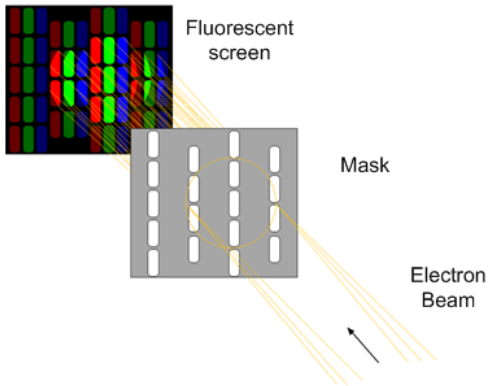
- Cathode Ray Tube (CRT)
- Liquid Crystal Display (LCD)

- Pixel
  - Smaller image unit printable on the screen

Info

2.4.1. Output peripherals - CRT





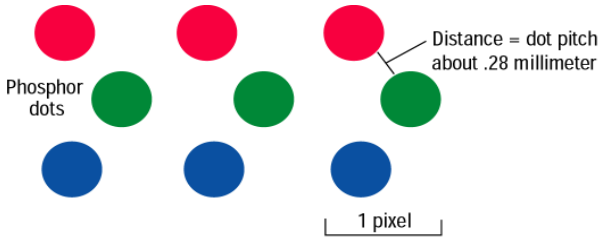
Cathode Ray Tube (CRT)

Vacuum tube

The image is generated when an electron beam comes in contact with a fluorescent screen

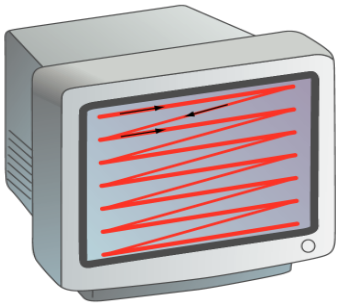
Three electron guns (RGB) and phosphor points with three colors (RGB)

Human eye mixes the points to create colors



http://videos.howstuffworks.com/howstuffworks/144-how-tv-works-video.htm

Cathode Ray Tube (CRT)



Refresh rate

60 Hz, 75 Hz (refresh per second)

Graphical controller (video card)

The output to the monitor is managed by the video card

The video card has memory

The number of colors and the resolution depends on the card

The more colors, the better look of the images

The number of colors is correlated to the size of the memory:

256 colors ⇿ 8 bits per pixel

16 millions of colors ⇿ 24 bits per pixel

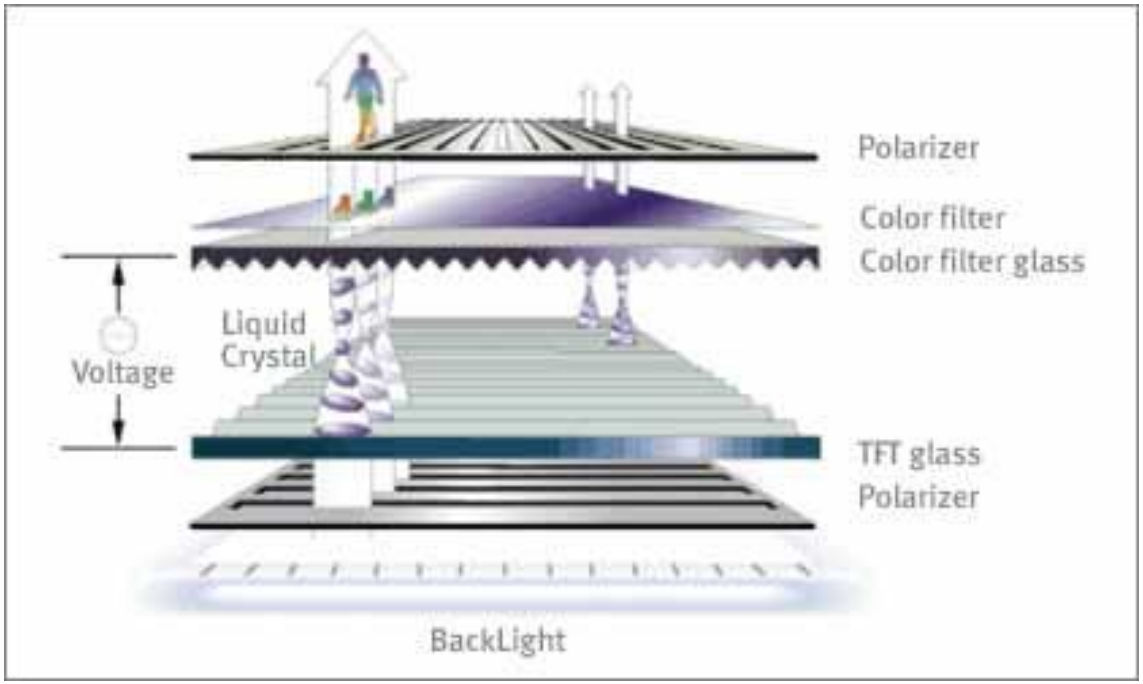
Liquid Crystal Display (LCD)

- Structure
  - http://youtu.be/jiejNAUwcQ8
  - A layer of molecules –liquid crystal, it can change the direction of light
  - aligned between two transparent electrodes –conductors
  - and two polarizing filters –without the liquid crystal, the light stops after the first filter
- The liquid crystal do not emit light. Since there is not enough contrast between the images and the background, the screen requires a back light
- TFT (Thin Film Transistor) is a kind of LCD that allows higher refresh frequencies

Liquid Crystal Display (LCD)

Color LCDs

Pixels are divided into three sub-pixels, each one used for a basic color (RGB), by using three filters



Source: Wikimedia Commons [link]

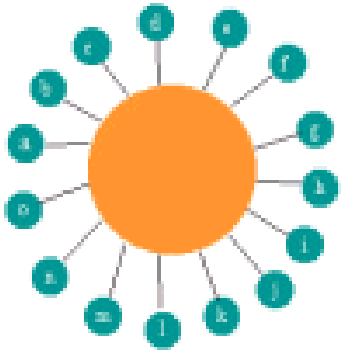
Printer

Impact printer

Impact on an inked strip to transfer ink to the paper and create a character (similar to a typewriter)

Daisy wheel

Wheel with carved character



Dot-matrix

Several pins create the character

Printer

Non-impact printer

- Writing is done with thermal, electrostatic or chemical techniques
- They use liquid ink or toner
  - Inkjet
  - Thermal
  - Laser
- More silent and faster

Inkjet printers

- Propel droplets of ink onto the paper to form the characters
- Similar to dot-matrix, but changing the pins for tiny tubes that propel the ink
- Mobile head that moves horizontally on the paper
- The ink deposit is located on the head

- The piezoelectric crystal creates a vibration on the ink container by applying a voltage difference
- The droplet is driven by electrostatic devices

Thermal printers

- Selectively heating of regions of special heat-sensitive paper
- Slow, require special paper
- Similar to dot-pin, but they heat the paper instead of making impacts
- Used in receipts (credit cards, etc.)

Laser printers

Similar to a copy machine; they use toner (dry ink) and a rotating drum

The drum is charged with electrostatic energy

The page is drawn in the drum with a laser beam

- The laser removes the charge of the points that will not be printed

Toner particles are then electrostatically picked up by the drum's charged areas

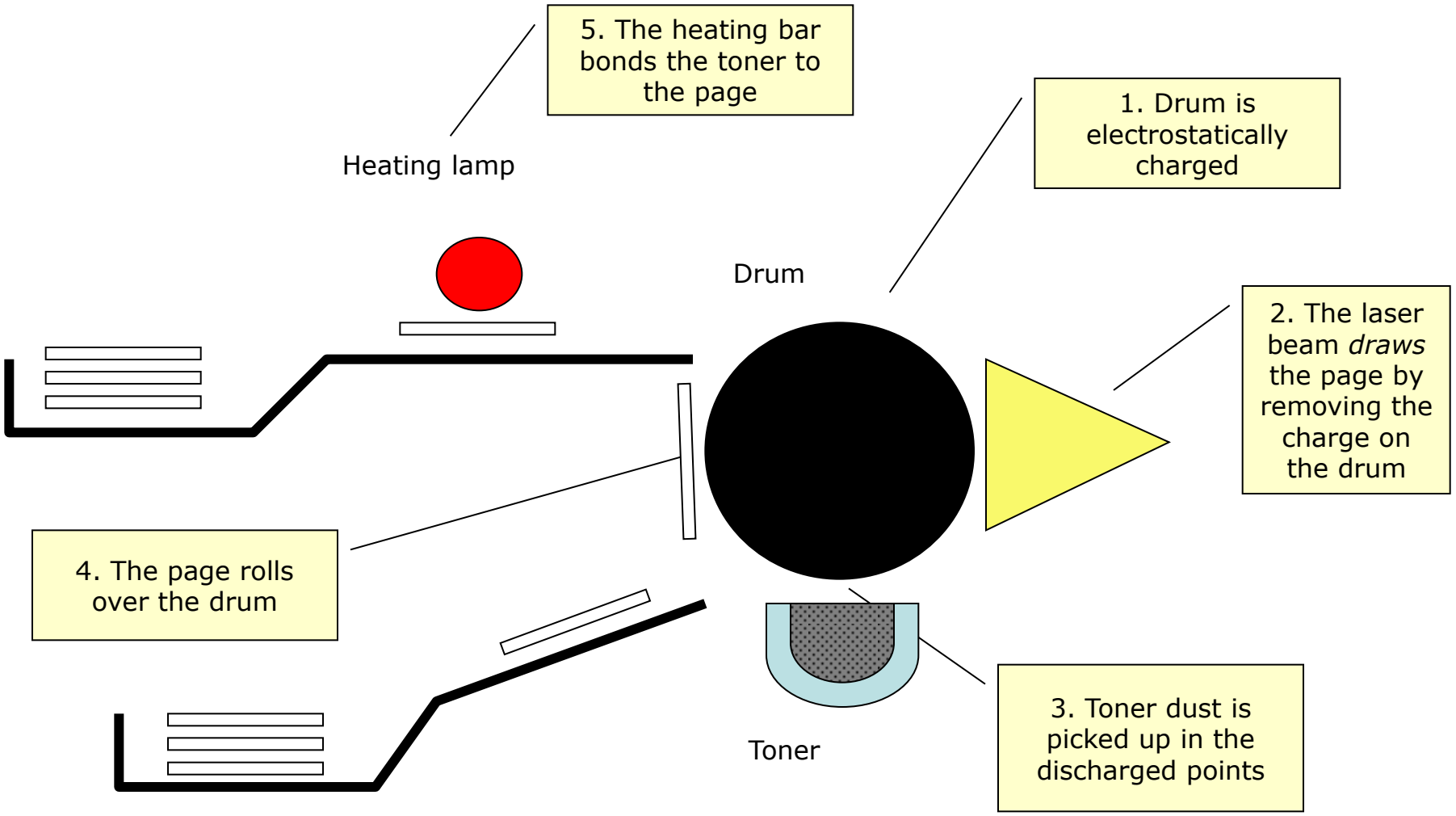
The drum prints the image onto paper by direct contact and heat, which fuses the ink to the paper

Faster, high quality

Full pages are printed (memory is required)

Info

2.4.3. Output peripherals - Printer



Outline

1. Logic support: Software
   - Programming languages
   - *Compilation and translation* programs
   - Operating systems
2. **Physical support: Hardware**
   - Computer architecture
   - Components
   - Data storage
   - **Other peripherals**
     - **Ouput**
     - **Input**
   - Computer networks and the Internet

Keyboard

Mouse

Joystick

Scanner

Barcode reader

Magnetic reader

Keyboard

Switches connected to a microprocessor that monitors their state

Mechanical keyboard

Small springs under the keys to return to the initial position

The key, when pressed, make a contact with the metal of the circuit of the keyboard and closes the circuit –it opens when the key is released by the spring

Membrane keyboard

Rubber layer instead of springs

When the key is pressed, the rubber presses a conductive layer with a metal end, which makes a contact with the circuit of the keyboard

Mouse

Mechanical mouse

- Moving the mouse turns the inner ball, and consequently, the horizontal and the vertical rollers
- The movement (x and y axis) is transmitted

Trackball

- The ball is directly moved; the mouse is static

Optical mouse

- Uses a LED (light-emitting diode) that emits an infra-red beam
- The beam is reflected on the surface and detected back by a photosensor
- The movement (x and y axis) is interpreted from the reflection of the light

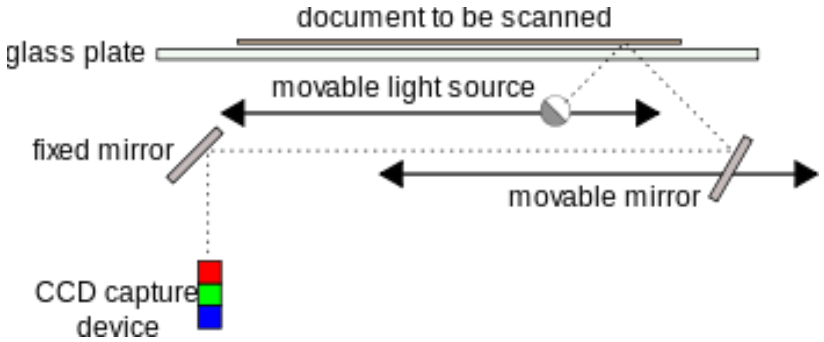
Info

2.4.5. Input peripherals - Mouse

Source: Wikipedia [link]

Scanner

- Used to digitalize paper documents
- Photosensor with several photoelectric cells
- The documents is lightened
- The light is reflected and detected back by the cells (colours or greyscale)
- The resolution of the scanner is the number of points (individual cells) that are contained in a square inch



Source: Wikipedia [link]

Industrial interfaces

Input (sensors)

Devices that provide an electrical signal measuring some property of the observed object. The signal is digitalized and used as the input of the computer

- Thermo-resistors
- Pressure sensors
- Humidity sensors
- Volume of flow sensors

Output (actuators)

Relays (electromagnetic switch)

Electro valves (valves activated with electric signals)

Engines

Connections

Ports

Communication link to connect the computer with peripherals (keyboard, printer, etc.) or other computers

Basic types

- Parallel port
- Serial port
- New I/O ports (USB)

Parallel port

- Bits are transmitted through different wires
- If the transmission unit is a byte, the parallel cable will have 8 wires, plus additional lines to send control information (e.g., the channel is free or not)
- Obsolete

Connections

Ports

Serial port

Bits are transmitted through a single wire (one at once)

Before starting the communication, some information is exchanged between the sender and the receiver (hand-shaking): transfer speed (bits/second), number of bits per word, parity checking (redundant code)

Communication between computers or with a modem

USB (Universal Serial Bus)

Update on the classical serial port

Higher transfer speed

Unified connection technology: different types of devices can be plugged (keyboard, mouse, printer, camera, phone, etc.)

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Computer network

Group of autonomous computers interconnected by communication channels to share information

Channel: wired or wireless

Specific hardware (modem or network card) and software (communication program) is required

Two types of networks

- LAN: Local Area Network
- WAN: Wide Area Network

Internet

http://youtu.be/7_LPdttKXPc

Net of networks: network composed by interconnecting computer networks around the world

Each computer is identified with an address (IP address)

Information is transmitted according to a set of rules (protocols): the TCP/IP protocols

Features:

- Decentralized >> no central index
- Non hierarchical >> all the computers are equal
- Heterogeneous >> different types of computers (PCs, large systems)
- O.S. Independent >> computers can be connected without regard of the operating system

History of the Internet

http://www.youtube.com/watch?v=9hIQjrMHTv4

Cold War

- Computer networks based on phone and radio connections
- Vulnerable network
  - Depends on the conditions of the channel
  - If a link is interrupted, the net is out

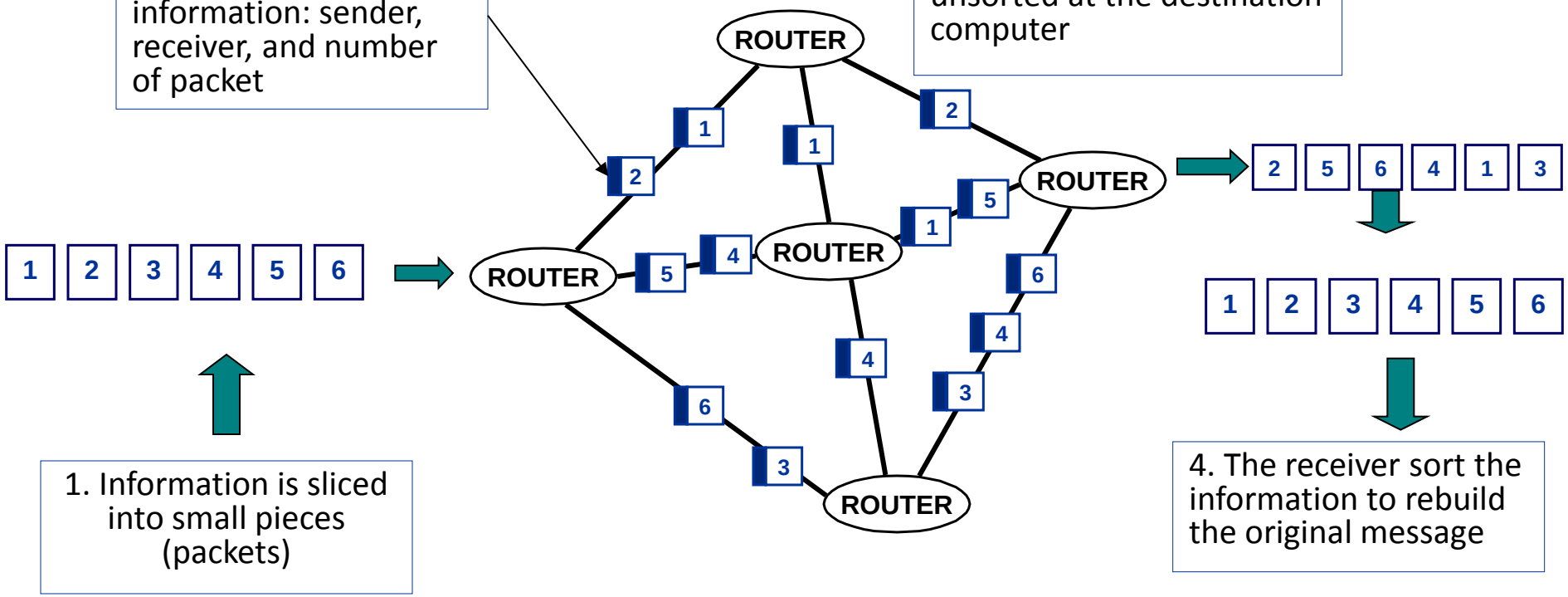
1969

- DARPA (Advanced Research Projects Agency), an agency of the US Department of Defence, connected four remote computers (ARPAnet)
- *Packet switching*
  - Messages are sliced in the sender and rebuilt in the receiver
  - All the packets of the message do not have to take the same path from the sender to the receiver

Packet switching

3. Packets are transmitted from computer to computer towards the destination. The path may be different for two packets. Packets may be unsorted at the destination computer

2. Each packet is attached a header with information: sender, receiver, and number of packet



1. Information is sliced into small pieces (packets)

4. The receiver sort the information to rebuild the original message

send

receive

Internet

Communication Protocol

Rules or conventions agreed by two computer systems to interchange information without errors

TCP/IP Protocol

Core protocol of the Internet used to interchange information

IP (Internet Protocol)

Rules to find the path to the destination

It does not specify packet latency and order in the transmission

TCP (Transmission Control Protocol)

Guarantees that the packets at the source reach the destination without errors to rebuilt the original message

Internet

IP Address

Each node of the net (computer) has an address

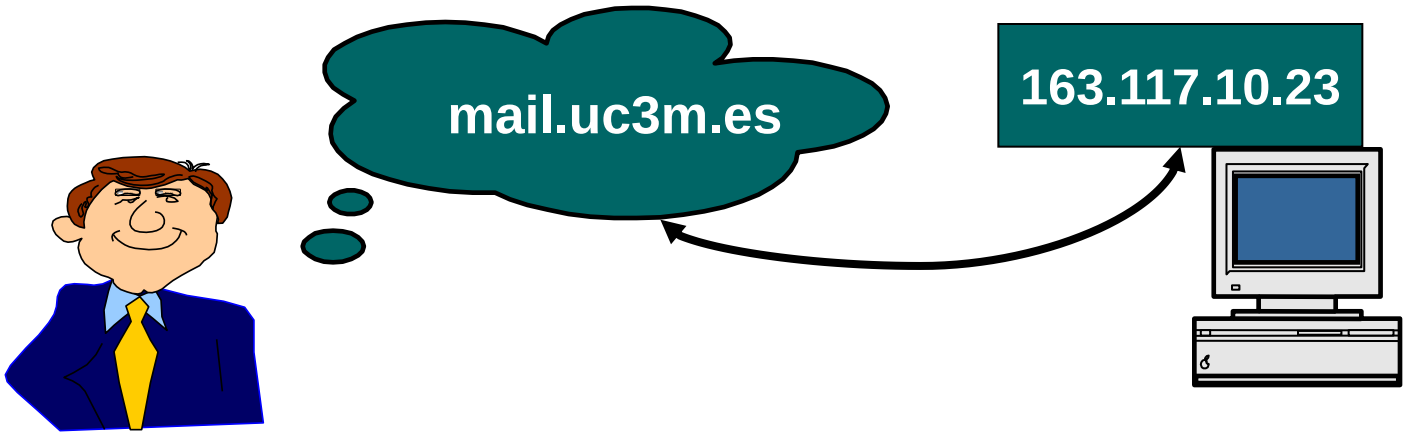
Addresses are unique: each connected machine has a different address

Numeric internal representation: four numbers separated by a dot: 163.117.10.23

Domain Name

Readable name assigned to a IP: mail.uc3m.es

2.5. Computer networks and the Internet



DNS: Domain Name System

Internet

Applications

- World Wide Web
- E-Mail
- File transfer (ftp)
- Remote access (ssh)
- Instant messaging
- VoIP (voice over IP)

Internet

E-Mail

Message-exchange with other users of the network

Text and attached files

http://www.youtube.com/watch?v=YBzLPmx3xTU

Internet

World Wide Web

http://www.youtube.com/watch?v=qv0XCaUkfNk

Documents (files) distributed in servers allocated around the world with links between them

Multimedia documents: text, images, sound, video, etc.

HTML: Hypertext Markup Language

- Standard language to describe web pages
- The presentation is independent of the operating system
- Links allow navigation between web pages by clicking on them

HTPP: Hypertext Transfer Protocol

- Protocol based on TCP/IP to send and retrieve information to the WWW
- HTTP address or URL (Uniform Resource Locator): readable identifier of a resource of a computer
- E.g.: http://www.uc3m.es/uc3m/matriculanuevos-cuando.html

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