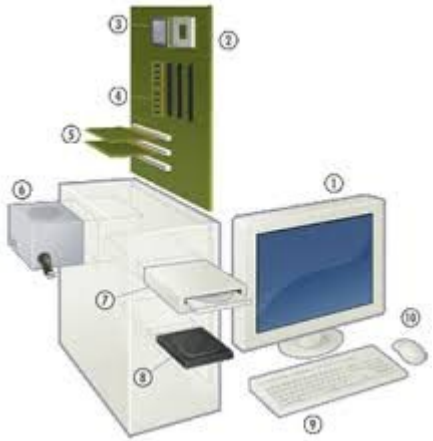
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Computer Architecture



Context and Motivation

- To better understand a software system, it is mandatory understand two elements:
  - The computer as a basic building block for the application
  - The operating system as intermediate layers between applications and the computer
- In this session, we will address the computer internals
  - How a computer is designed
  - Get acquainted with the basic "**Von Neumann**" computational model

Outiline

- Computers' history
- The hardware architecture in a computer
  - **Von Neumann's** architecture
- Modern HW architectures

Computer definition

According to RAE (Real Academia de la Lengua Española):

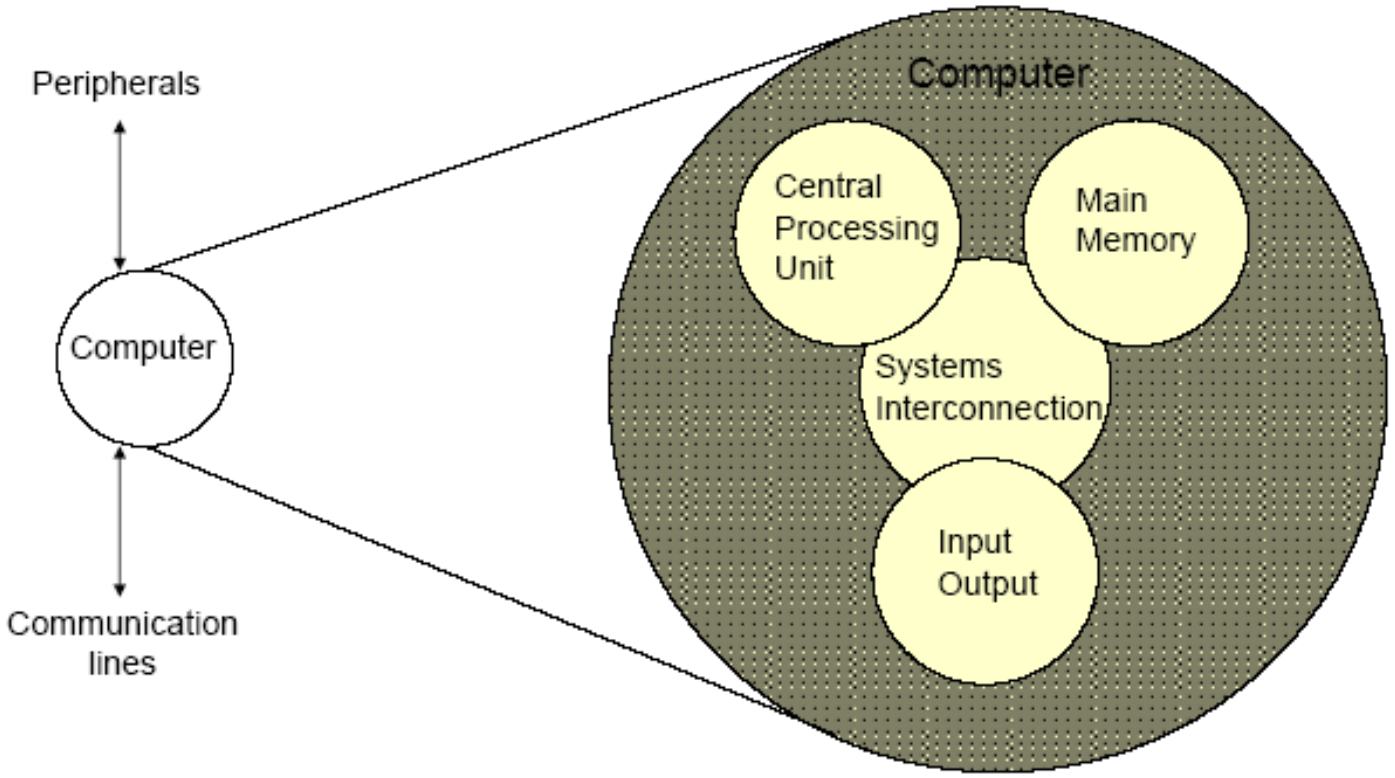
> Electronic machine, analogical or digital, composed of a high-capacity memory and methods to manage information, able to solve mathematical and logic problems by using informatics **programs**.

According to Stallings

> **Programmable** electronic digital machine for automatic information processing, able to receive it, manage it via processes and to output the results of such operations.

Computer Organization and Architecture: Designing for Performance . **William Stallings** ISBN: 0-13-185644-8
Publisher: Prentice Hall

(Hw) Structure of a computer

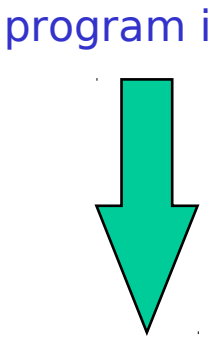


Concepts

- A **digital computer** is a machine that may solve problems running certain statements
- A **program** is a sequence of statements.
- The electronic circuits in each computer manage a limited number of statements (very simple statements)
- **Machine language** is the set of basic statements in an computer.
- Using machine langue is difficult and tedious
- Solution:

  Given L1, the machine language

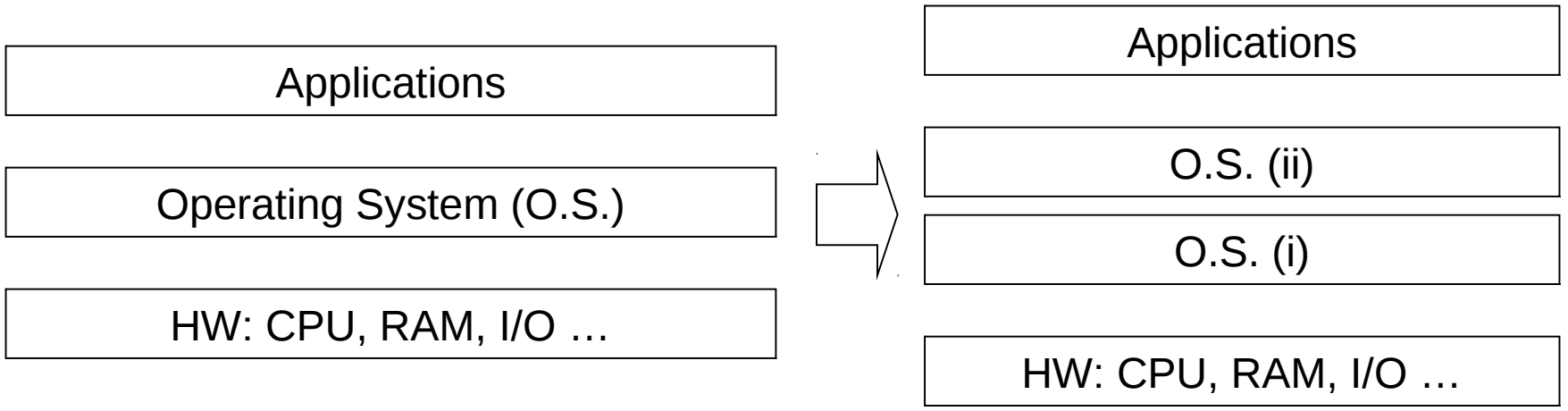
  And L2 a simpler language



Compilation (compiler)

Interpretation (interpret

Hw and Sw



(i) – Task managers, memory managers, I/O device drivers
(ii) – File systems, command interpreter, user interfaces, programming APIs.

→ In this presentation, the focus is set on HW issues

Computer's History

- Some generations and their technologies:

  … - 1945: Mechanical systems and electro-mechanics

  1945 – 1955: Vacuum valves , boards.

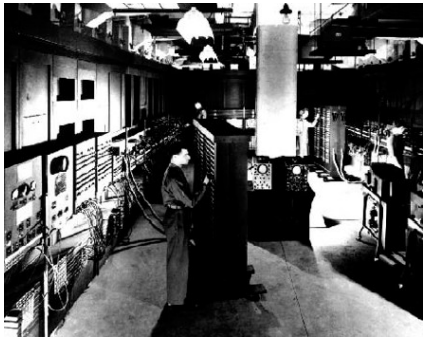
  1955 – 1965: Transistors and batch systems

  1965 – 1980: Integrated circuits and multiprogramming

  Since 1980: Personal computers



Difference Engine (1822)



ENIAC
(1946)

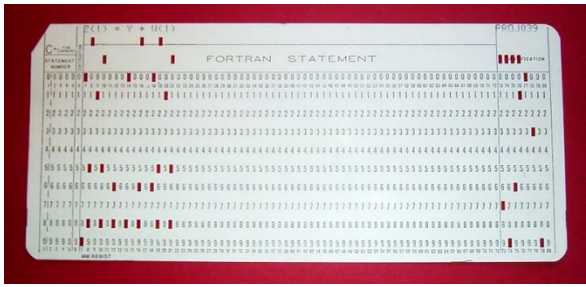
IBM 704 (1955)

- **First comercial machine with floating point hardware (5kFLOPS).**



Compilers

- Enabled high-level programming development and their translation to the machine processor statement model.
- First compiler: FORTRAN (1957)
  - **Primer compiler for IBM 704 (Formula Translator)**
- Mouse invention (1964)





Intel breaks into

- Founded in 1968
- Bell Labs developed the C language (1972) to write UNIX

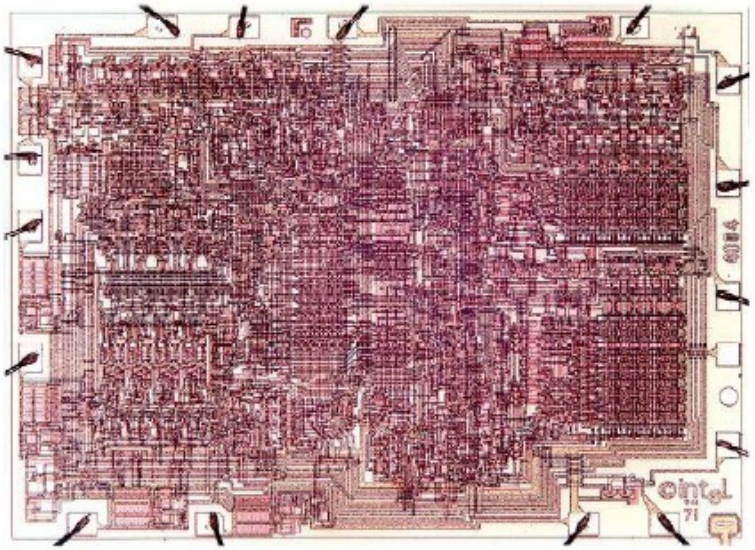


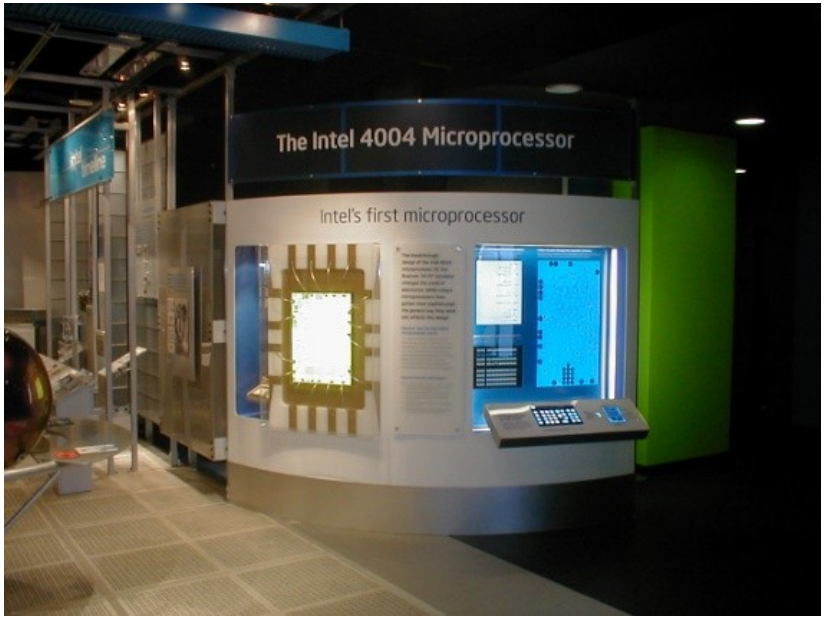
```
#include <stdio.h>
    main()
    {
      for(;;)
      printf("Hello world..."\n);
    }
```

The first chip



- Intel 4004 (1971)

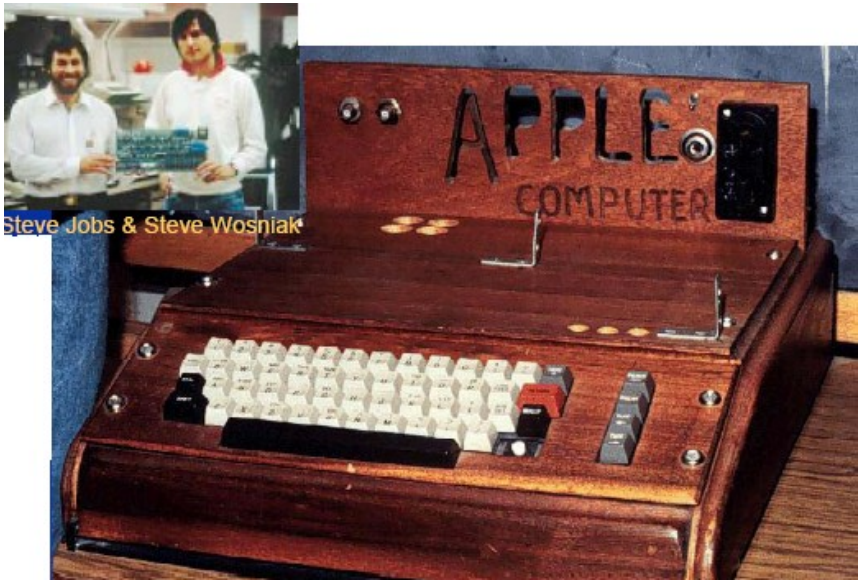




Apple

- Apple I (1976)

  - Price: 666,66 $



Microsoft

- In1978



PC’s inception

- in1981

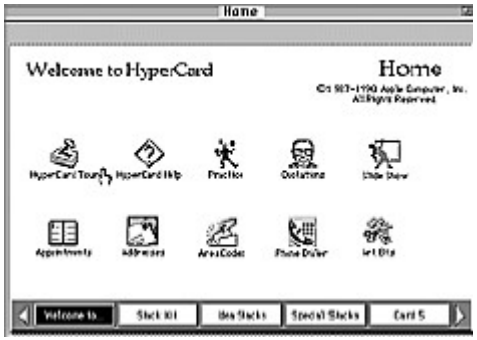


First multimedia systems

- In1984 Sony creates the CD



And graphical interfaces





Macintosh (1984)

Graphical User Interfaces

- X Windows for UNIX (1984)



- An also Windows (latter)



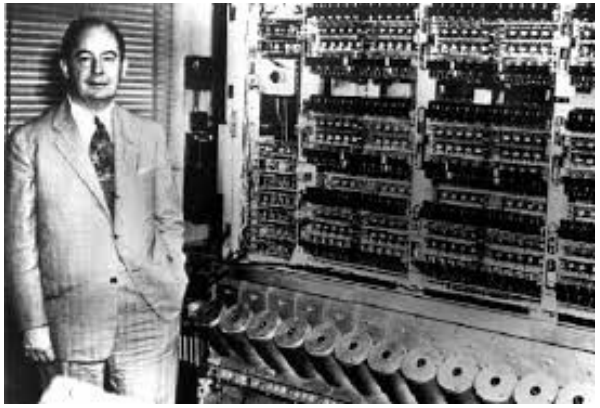
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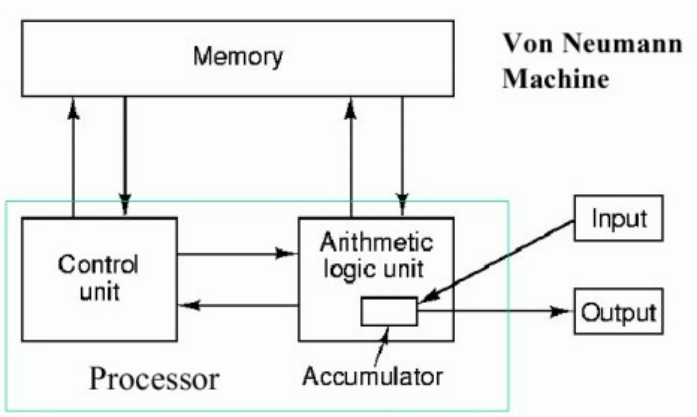
- Computers' history
- The hardware architecture in a computer
  - **Von Neumann's** architecture
- Modern HW architectures

Von Neumann's machine

- The basic model for the computer architecture was set by **Von Neumann** in 1945 by Von Neumann (Pennsylvania University).

"…Given that the final device **will be a general purpose machine**, it will have to contain certain **fundamental organs** related to arithmetic, the storage memory, control and the communication with the human operator, ..".





Von Neumann's machine

- **Main memory:** it is a unit that that consists of cells, that are identified by a direction. All cells share the same size and are used for storing data and instructions
- **Arithmetic-logic unit**: it allows a set of fundamental instructions such as add, subtract, AND, OR, etc
- **Control unit**: it will be in charge of reading, one after another all machine instructions, and of generating all control signals required for the computer works
- **E/S devices:** in charge of transferring information with the external units called peripherals

Stored program and general purpose

“ … The machine should be able of storing not only all digital information for a computation […] but it should be able to **store instructions that rule** the routine to be carried out on numerical data . […] To have a general purpose machine, it should be possible to instruct the such a way that it may carry out any computation set in numerical terms. Therefore, it should be some organ able to store these program commands …”

Currently, all this refers to instructions.

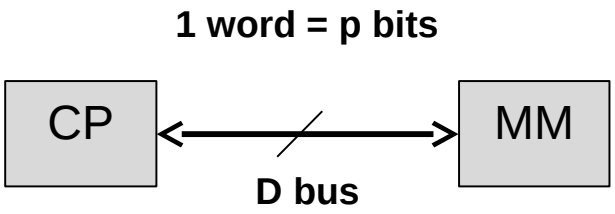
- The set of different instructions that may be executed in a computer is called instruction set.

Instructions

- Computers are able to run a series of simple instructions, such as adds, subtracts, information moves, etc
- All these instructions are executed on a “**clock tick**” that dictates which is the next instruction to be executed
- Generally, one instruction is a processing command, forcing a set of preliminary requirements
- In any case, the two previous steps force a timed switch execution

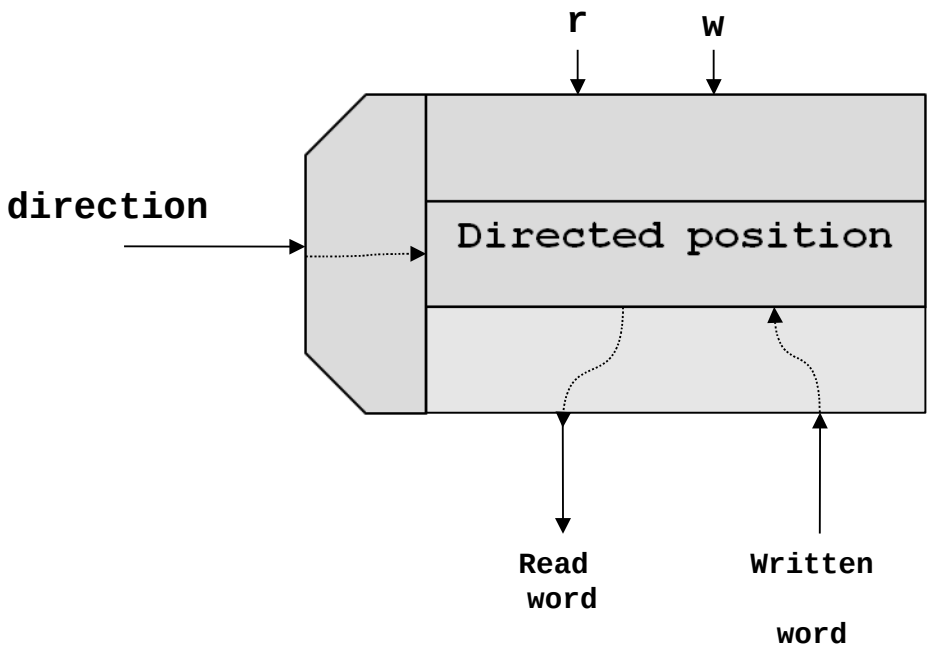
Memory

- The memory subsystem stores program instructions and also data (Princeton architecture)
- The memory should offer direct access, called also random access.
- The minimum storage element is the bit
- A memory point is a physical mechanism in charge of storing a bit



Memory (II)

- Reading and writing functionalities:



Memory (III)

- Data to be stored in memory

  -Directions or «pointers» and unsigned integers:

  d bits for 2^d addresses

  -Integer numbers (signed):

  binary (or decimal, BCD)

  n bits for an extension covering from -2^{n-1} to $2^{n-1} -1$

  -Real numbers:

  Floating-point format

  n bits for the extension and precision

  -Characters:

  ASCII, or ISO Latin1 (8 bits) or Unicode (one or more bytes)

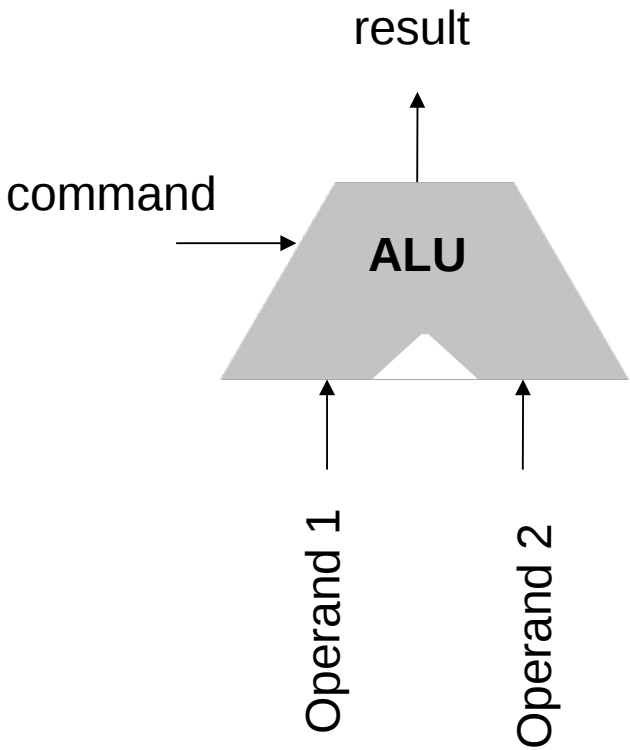
- Note: Only the two first make sense in the Von Neumann machine

Arithmetic-Logic Unit (ALU)

"… Given that the device is to going to be a computer machine, it should have an arithmetic organ that allows performing certain basic arithmetic commands. It should be able of adding, subtracting, multiplying, dividing, …"

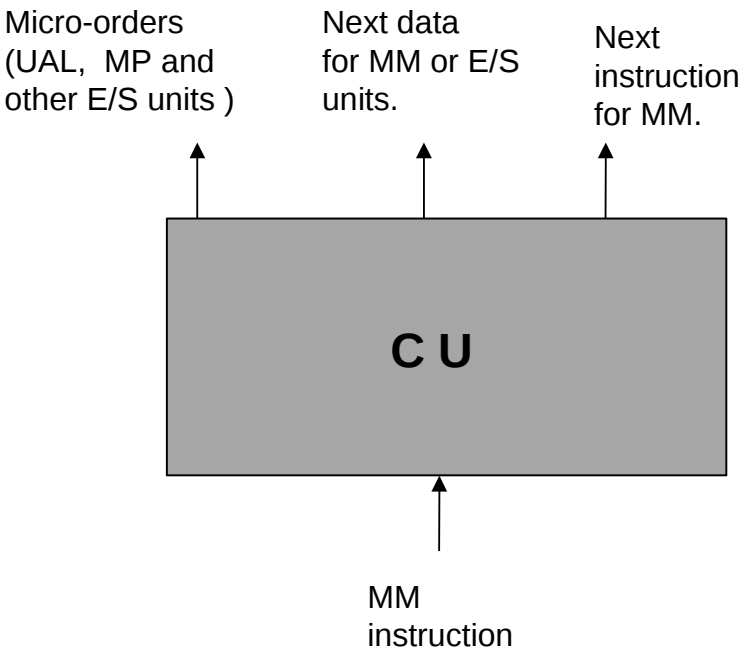
- The ALU may include logic commands too.
- Hardware vs. Software choice:

  many functions may be implemented in i) **hardware** or in ii) **software**.



Control Unit

"… If memory is for commands is a simple storage organ, then it should be another in charge of running this instructions stored in memory. This organ will be called the control .."



Control Unit (II)

"… It has to be possible to extract number from any part of the memory in any moment. However, in the case of instructions, the treatement should be more methodic, because control instructions may be arranged in a lineal sequence. As a result, the control will be usually ***build in such a way that it comes from the n memory position to the n+1 for the next instruction*** *…".*

- Another aspect: instruction modification.
  - Useful to explore several memory positions.
  - Not used (today).

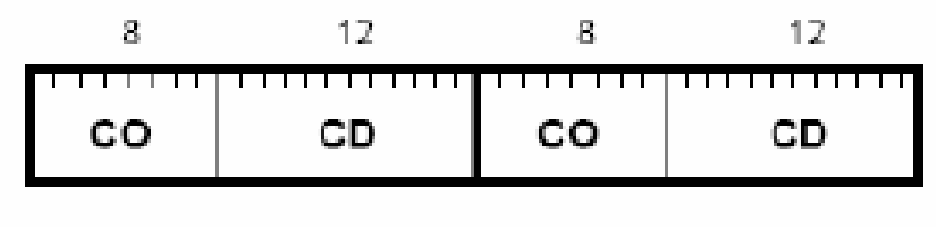
Input /Output devices

"… Lastly, it should be devices, that are the input and output organ, by which the operator and the machine communicate themselves …"

- The input and output units, devices and peripherals may be many (and of different kinds).

Instructions format

- Data representation: in binary, with 40 bits.

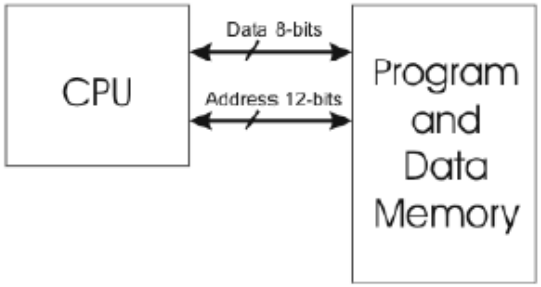


- Instructions set:

  Add, subtract,…

  2^8 (256) instructions per byte

- Address space: 2^{12} = 4096 words

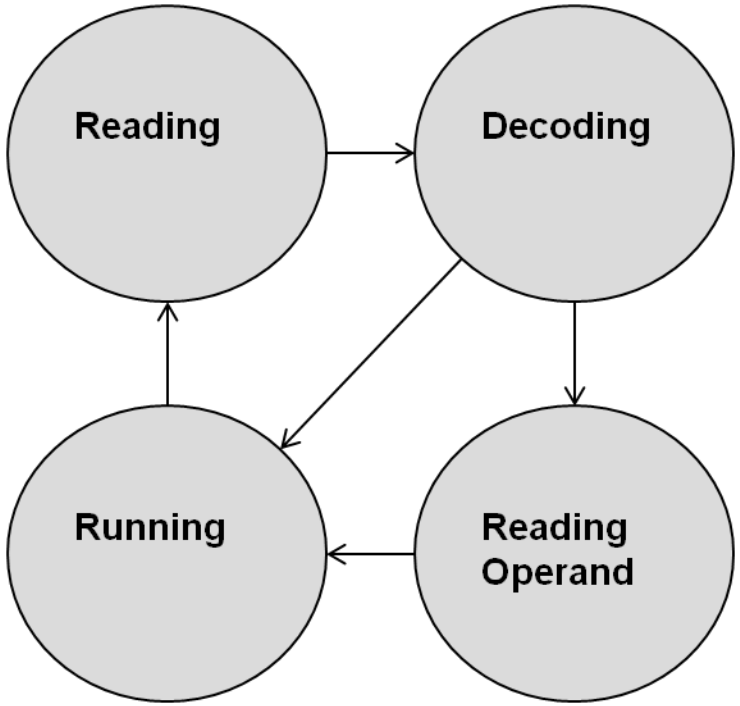


Running an instruction

- The running phases of an instruction are the following:
  1. The **Control Unit** indicates to the **Main Memory**, the next instruction to the executed
  2. The C. U. receives the command, and determines its corresponding operands (if there is any operands) and their location.
  3. Under the control of the C. U and A.L.U performs the command and stores the result in its destination
  4. After executing the instruction, **the program counter is incremented** and executes the next instruction

Running an instruction

- Other names (more recent, but similar) :
  1. Search phase or **fetch**
  2. Decodification phase
  3. Execution phase/ results storage
  4. Program counter increment

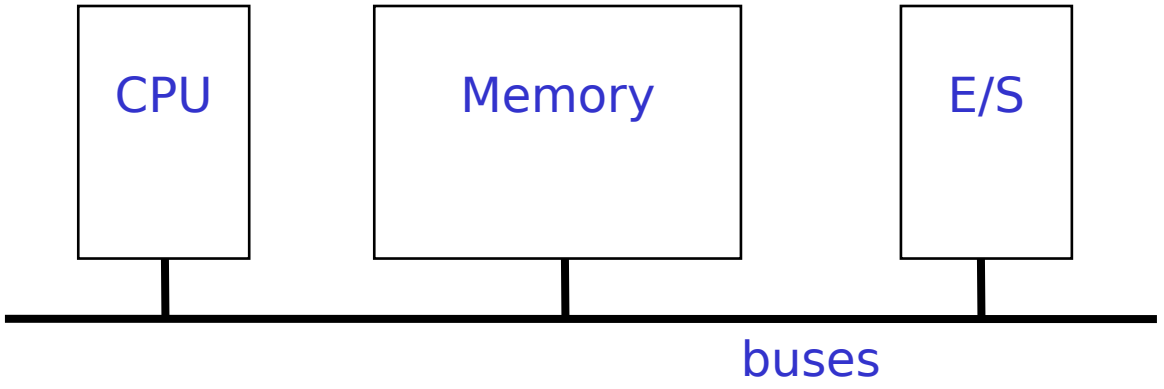


Advantages and Drawbacks in Von Neumann architecture

- It allows code automodification
- Electronic hardware “easy” (in design terms)
- Instructions and data recovered sequentially (Von neumann Bottleneck)

- Are all are architectures similar to Von Neumann’s one?

  Roughly speaking, all are based in this simple models (but with some evolution).

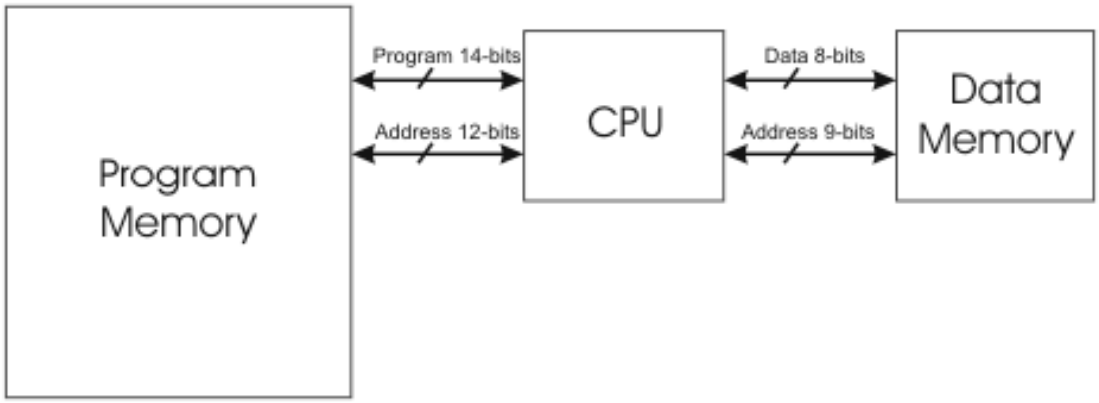


Harvard Architecture

- Advantages and drawbacks

  Usefull for ***pipelining***

  - One instruction may be executed when the following is searched in program memory



Outiline

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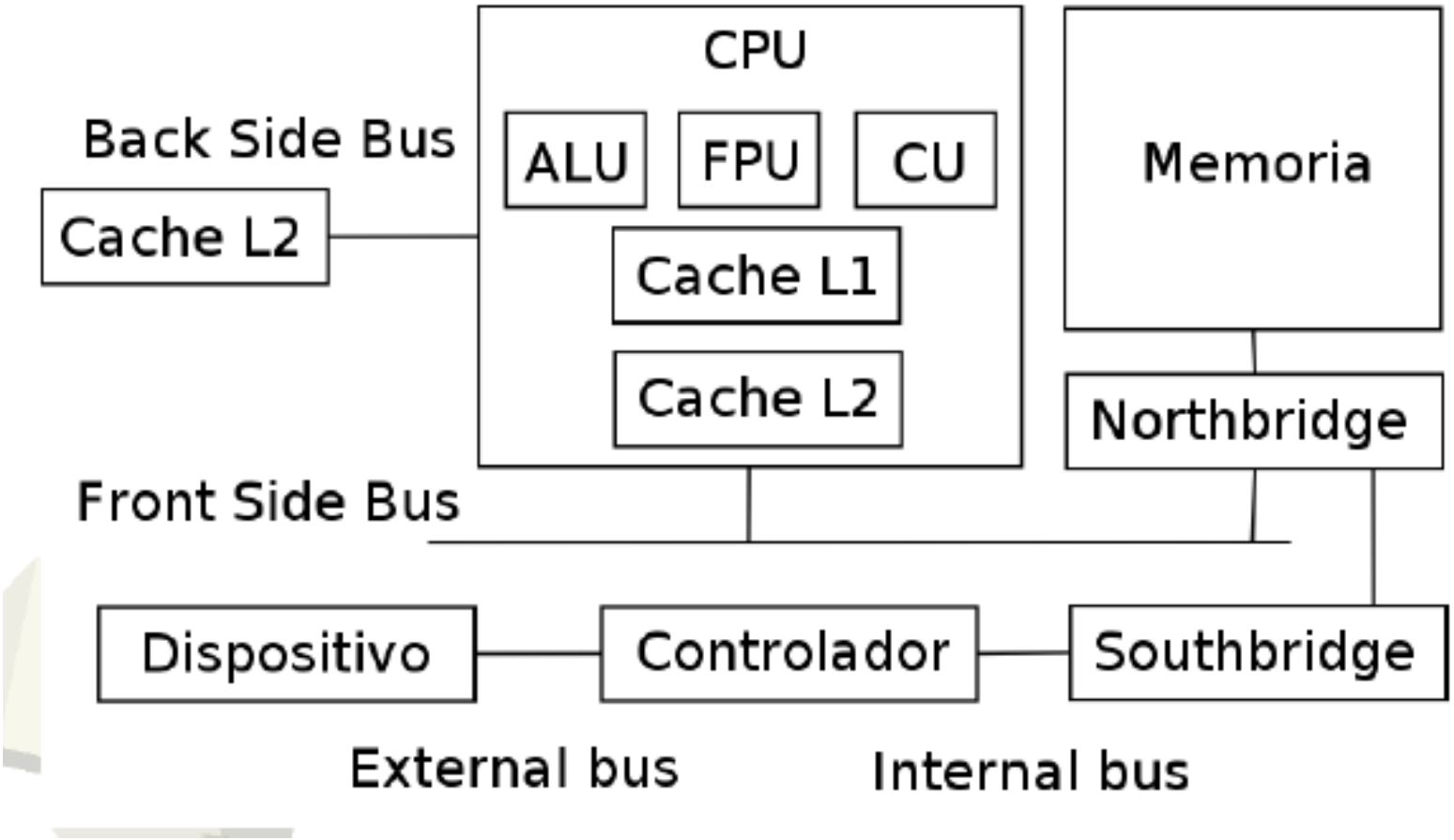
Differents types of CU: Instruction set

CISC: Complex Instruction Set Computer, more than 80 different instructions, some of them, may be require several clock cycles for its exection.

RISC: Reduced Instruction Set Computer, reduced set of instructions, very simple instructions that may be run in a reduced number of clock cycles.

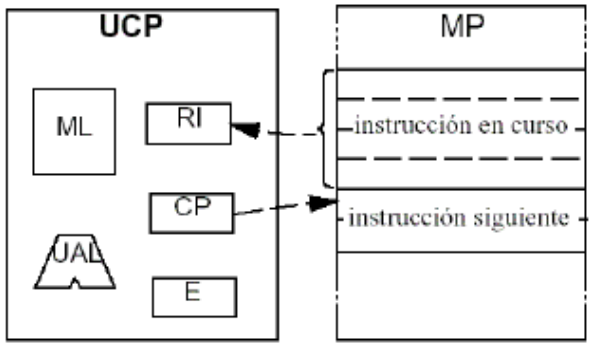
SISC: Specific Instruction Set Computer, for specific applications very dependant from the application.

A modern architecture



Registros de la UCP

- Arithmetic (formely accumulators)
- For addresses (index, base, etc.)
- General purpuse (arranged in a local memory)
- State (with Z, V, N, C indicator)
- Program counter
- Others available (micro architecture)



A modern architecture (II)

Front Side Bus

- EV6 (Athlon y Alpha), GTL+/AGTL+ (Intel)

Internal bus – Parallel

- ISA, EISA, VESA, MCA, PCI, AGP

Internal bus – Serial

- PCI Express (PCIe), I2C, HyperTransport

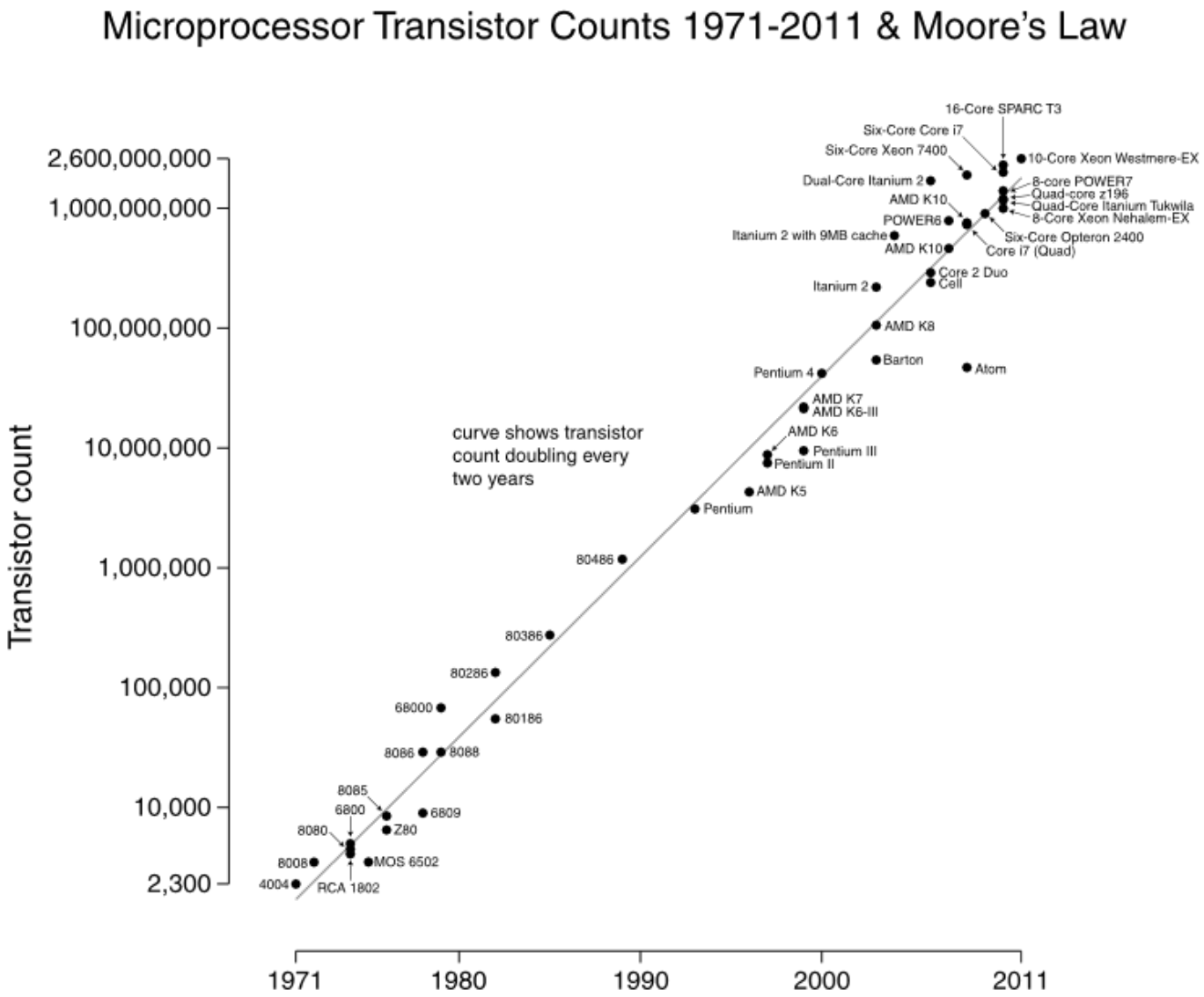
External bus – Parallel

- ATA (aka IDE, EIDE, ATAPI), SCSI, PCMCIA

External bus – Serial

- SATA, USB, IEEE 1394 (FireWire)

Moore's Law


Microprocessor Transistor Counts 1971-2011 & Moore's Law
Transistor count
2,600,000,000
1,000,000,000
100,000,000
10,000,000
1,000,000
100,000
10,000
2,300
1971
1980
1990
2000
2011
curve shows transistor count doubling every two years
16-Core SPARC T3
Six-Core Core i7
Six-Core Xeon 7400
10-Core Xeon Westmere-EX
Dual-Core Itanium 2
8-core POWER7
Quad-core z196
AMD K10
Quad-Core Itanium Tukwila
POWER6
8-Core Xeon Nehalem-EX
Itanium 2 with 9MB cache
Six-Core Opteron 2400
AMD K10
Core i7 (Quad)
Core 2 Duo
Cell
Itanium 2
AMD K8
Barton
Pentium 4
Atom
AMD K7
AMD K6-III
AMD K6
Pentium III
Pentium II
AMD K5
Pentium
80486
80386
80286
68000
80186
8086
8088
8085
6800
6809
8080
Z80
8008
MOS 6502
4004
RCA 1802

Moore's Law (II)

Processor:

- 2X speed each 1.5 years; 1000X in the last decade

Memory:

- DRAM capacity: > 2x every 1.5 years; 1000X in the last decade
- Cost per bit: improves 25% every year

Disc:

- Capacity: > 2X in size each 1.5 years.
- Cost per bit: improves 60% every year.
- 200X in last decade.

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Thanks