Chapter 1

Electronics

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CENTRE DE RECHERCHE

2021-2022

HISTORY OF ELECTRICITY

From the stone age to the digital age

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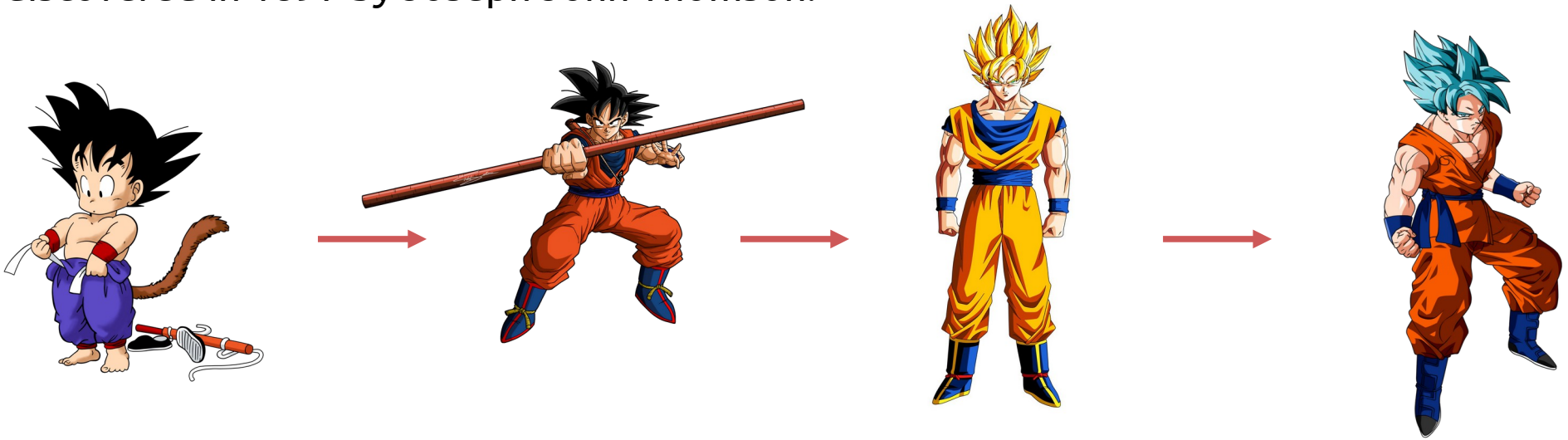
One upon a time…

The humankind has been through different stages through ages. The first main progress was the control of fire (between 2 M and 125,000 years ago) and another major step was the agriculture (about 11,000 BC) using control of water.

Some electric effects have been described by Thales in about 600 BC, but electricity really became a research subject in the 17th century and the electron has been discovered in 1897 by Joseph John Thomson.



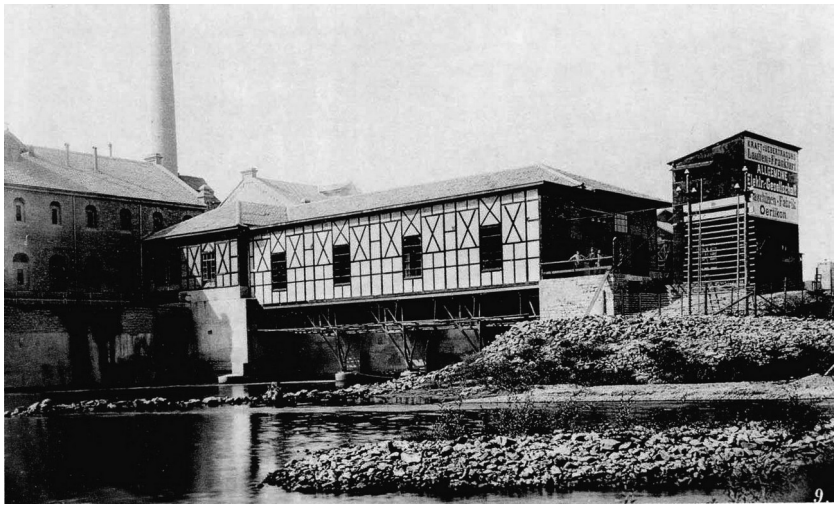
Electrical engineering: electricity as a power source

At first electricity was used for **its energy aspect only**.

Electrical machines were used to convert power from its electrical form to a mechanical form, and *vice versa*. Indeed, electricity easily converts to another form and is also easily transportable in comparison to other forms of energy.

Electrical battery
A. Volta, 1799

Induction machine
H. Pixii, 1832

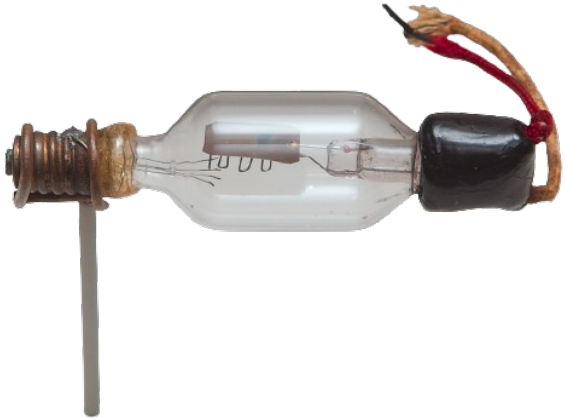


High voltage line (Mühlgraben-Frankfurt)
Mühlgraben, 1891

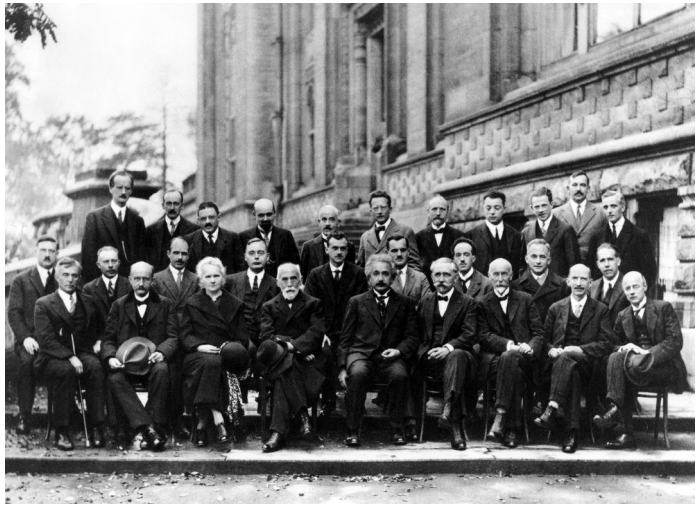
As the electron is discovered in 1897, a new field of research is open with the objective of **controlling the electrons flow so that it can contain information**.

Vacuum tubes are the first components capable of controlling the electrons flow.

John Ambrose Fleming
Vacuum tube inventor
(diode, 1904)

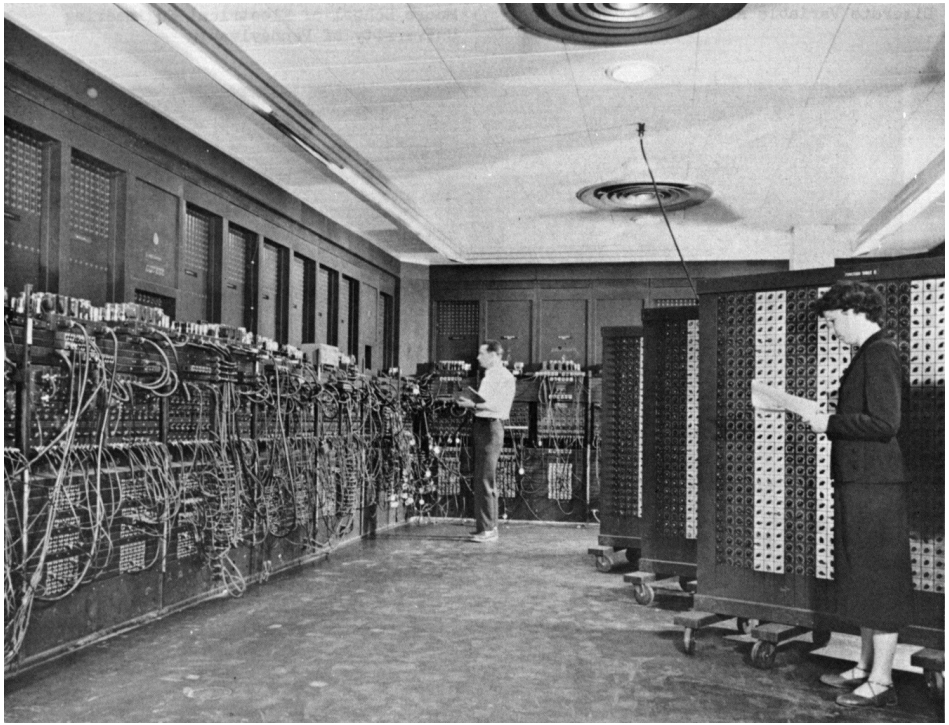


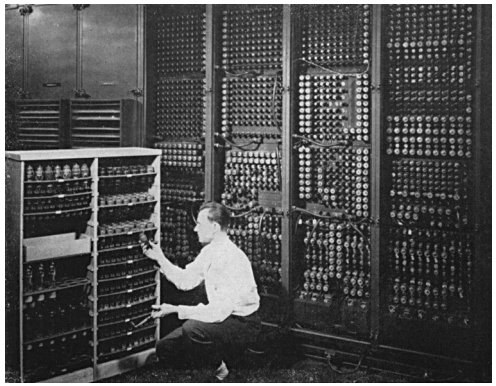
Audion (triode)
Lee de Forest (1906)



5th Solvay conference, 1927
Subject « electrons and photons »
17 / 29 (will) have Nobel prize

The apotheosis of the use of vacuum tubes is the ENIAC (*Electronic Numerical Integrator And Computer*) in 1945, which is the **first fully-electronic computer**.





The first six programmers of the ENIAC are female mathematicians (1944-1955).

100 000 add/s
357 mul/s
38 div/s
116 h : longest working time with no failure

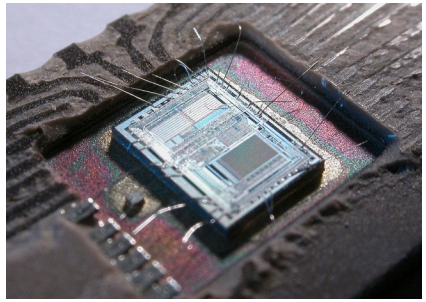
17 468 vacuum tubes
7 200 diodes
70k resistors + 10k capacitors
5M hand-made welds
167 m², 30 tons
150 kW

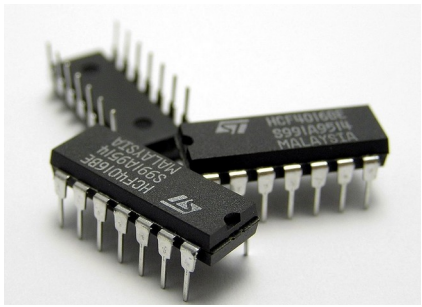
Electronics: the rise of semi-conductors

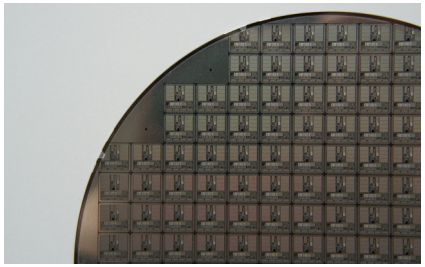
The discovery of semi-conductors and associated technical progress brought humankind to another revolution: after agriculture and energy, information processing is now within everybody's reach!

The **Bipolar Junction Transistor** (1947) and the **MOS Field-Effect Transistor** (1960) are the keystone of all digital circuit, especially due to **Integrated Circuits** (TI, 1958).

First bipolar junction transistor (1947)
Bardeen[2], Schokley, Brattain (Bell Labs), Nobel in 1956







Summary

We saw that electricity was first use as an energy source. This field of study is called **electrical engineering** (fr: *électrotechnique*) and won't be part of your curriculum.

Indeed you will focus on using the electrons flow as an information source by studying electronics (fr: *électronique*). This subject is large and can be split into two categories:

- **Analogue electronics** (*électronique analogique*), which is about signals with continuously varying values
- **Digital electronics** (*électronique numérique*), which applies to signals with discrete values

Note that you can also use others categories: AC vs. DC, Low-Frequency vs. High-Frequency, …

ANALOGUE ELECTRONICS

On the use of analogue signals in electrical circuits

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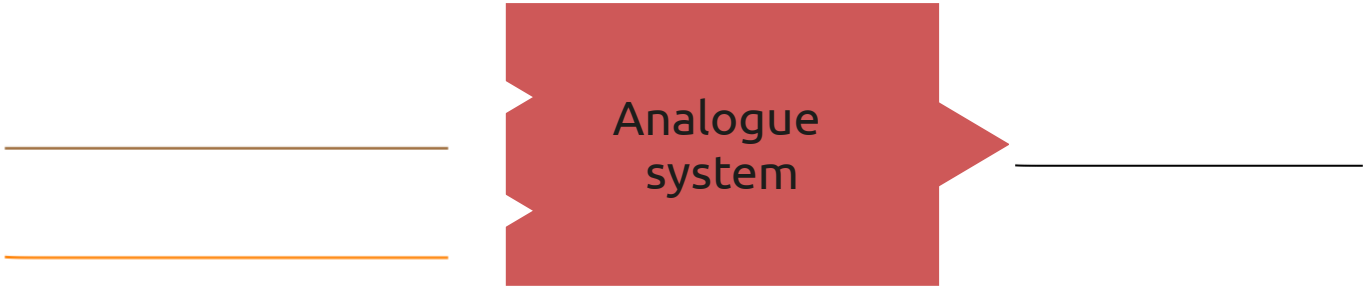
Analogue electronics is the subject that deals with electrical system using **continuously variable signals** (voltage, current, load, …).

This contrasts with digital electronics, in which signals are quantified.

Analogue signals can be very sensitive to environmental conditions (temperature, noise, electromagnetic disturbances, …).



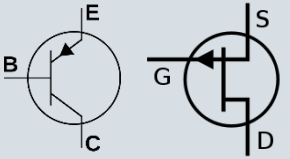
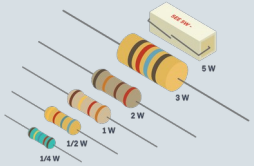
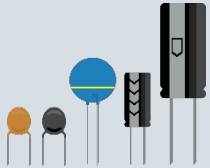
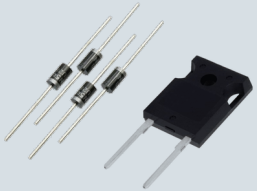
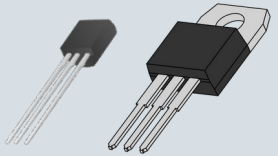
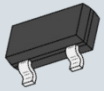
Fields of application

Analogue electronics are being less and less used in comparison to digital electronics. However it still remains as some functions cannot be realised using digital blocs.

The main (research and commercial) fields of applications for today's analogue electronics are :

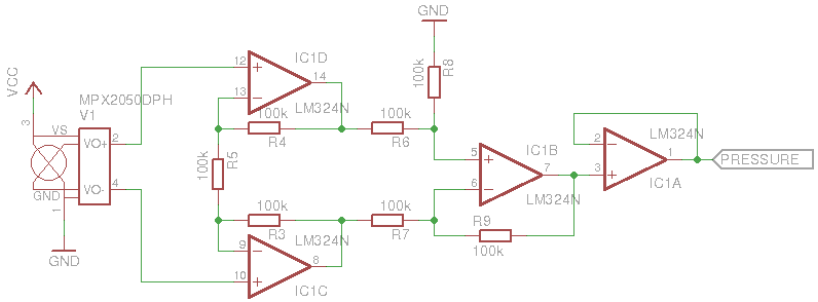
- Instrumentation and measurements
- Electrical power conversion and storage (power electronics)
- Telecommunications (antenna, radio-frequencies, hyper-frequencies, …)
- PCB design (Printed Circuit Board)
- Audio electronics

Analogue circuit design is based on understanding and associating active and passive components. There are only few categories for those components, but the huge number of references is due to some specialized versions of them.

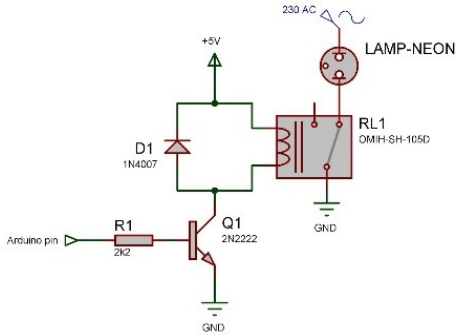
	Resistor	Capacitor	Inductor	Diode	Transistor
Symbol					
Through-hole packages					
Surface Mount packages					

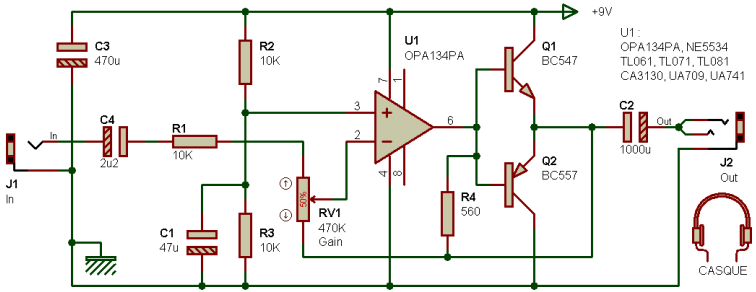
Here are some basic electrical circuits you might already know:

Instrumentation amplifier (INA)

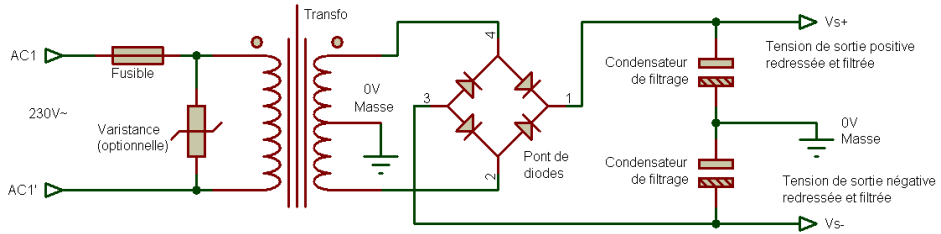


Relay command





Class-A audio amplifier



Linear power supply

DIGITAL ELECTRONICS

Digital signals and their use in electronic circuits

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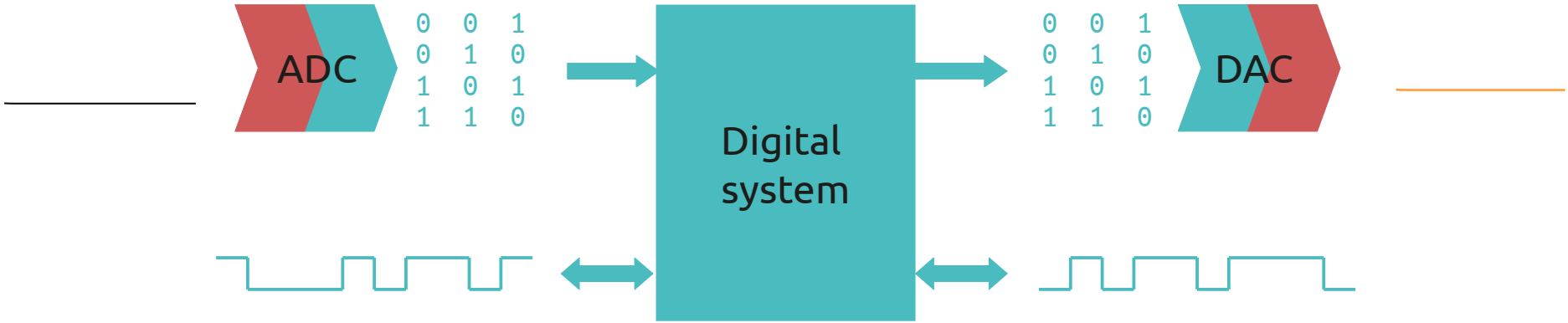
Digital signals use a sequence of discrete values, with a minimum of two for binary signals. Discrete values make signals less sensitive to disturbances. Digital signals can be considered as more reliable and robust than analogue signals.

Binary values can be easily stored and processed, especially when associated to Boole algebra and combinatory and sequential logic.



Digital vs. Analogue

Most of today's systems use digital data instead of analogue. That is because digital signals have important advantages when compared to analogue signals:

- Digital data is easier to store, in greater density
- All digital signals can be processed with nearly one device (processor)
  - Filters, data processing, encryption, …
  - Which leads to reduction of PCB size and increase of performances
- When quantified, data is much more immune to noise
  - Can be used in a disturbed environment
  - Data can be sent further away

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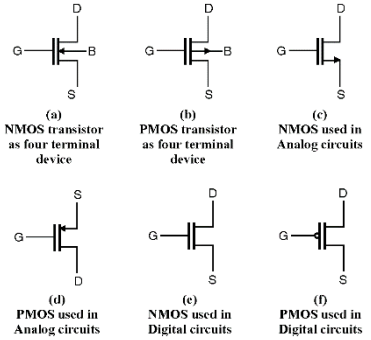
However we must be aware of digital limitations:

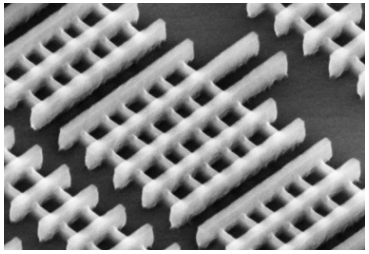
- Signals cannot be all digitised (at least not directly)
  - e.g. high-frequency signals (4G, 5G, …)
  - Physical phenomena are analogue variations of the environment → use of analogue sensor and conditioner
- Digitisation brings loss of information
  - Loss of amplitude information,
  - Loss of time information
  - Loss of spatial information (images)
- Sometimes signals need to be converted back to analogue
  - When output is an analogue actuator, a telecommunication stage, ...

Digital systems rely on the use of **transistors in commutation mode**.

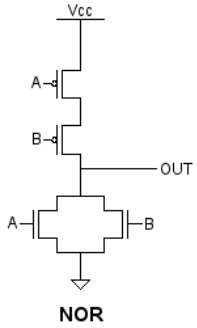
Transistors are combined to build logic gates and latches, which are then used to build application-specific digital systems.

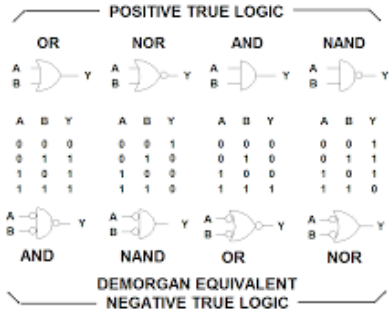
MOS Transistors

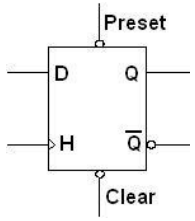




Logic gates, latches







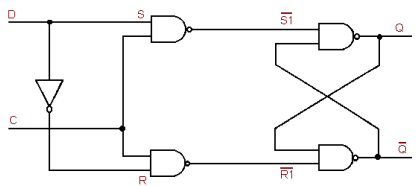
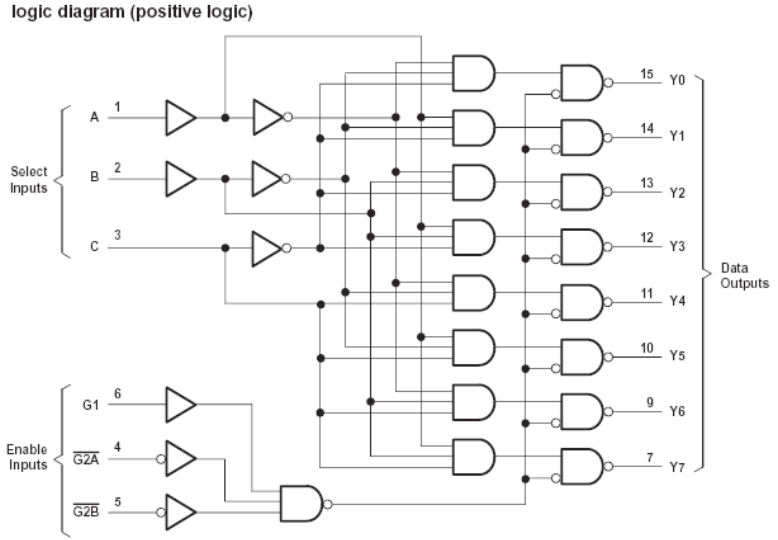


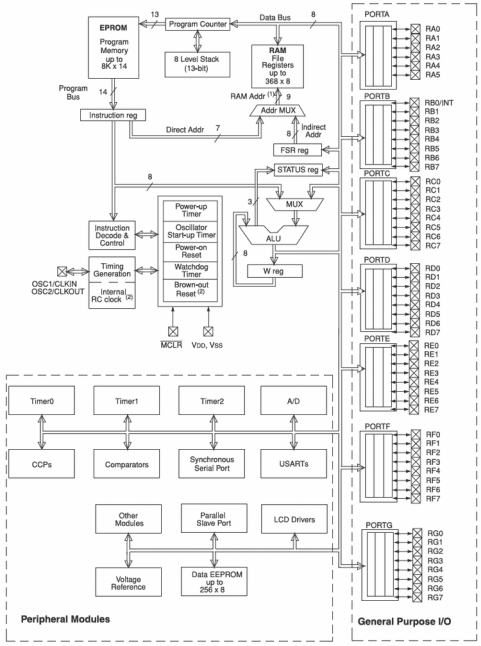
Fig. 7. - Structure d'une bascule D latch.

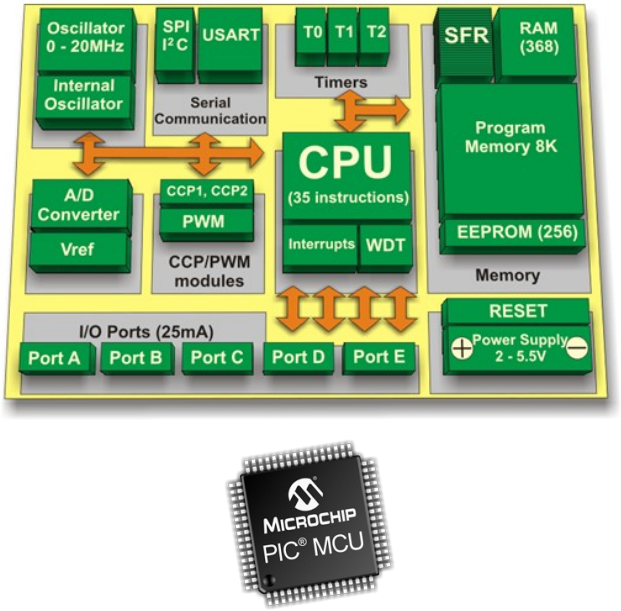
Specialized circuit

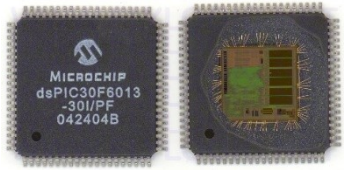


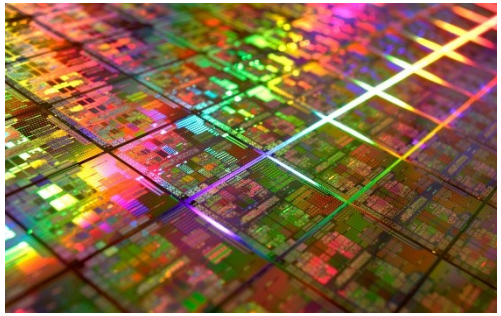
Specialized-function blocs can be built as a single **Integrated Circuits (IC)**. But they can also be interconnected with communication buses and make more complex circuits.

Modern processors are a perfect example for that, as they now contain different specialized blocs that were before dispatched in separated Integrated Circuits.



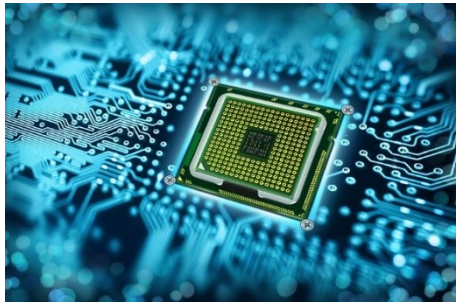
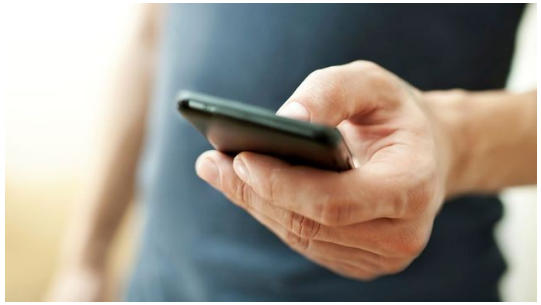






Digital electronic circuits are widely used in current (mostly embedded) systems, especially for supervision and processing applications.

Estimations state that everybody uses indirectly about 200 processors each day, without being aware.

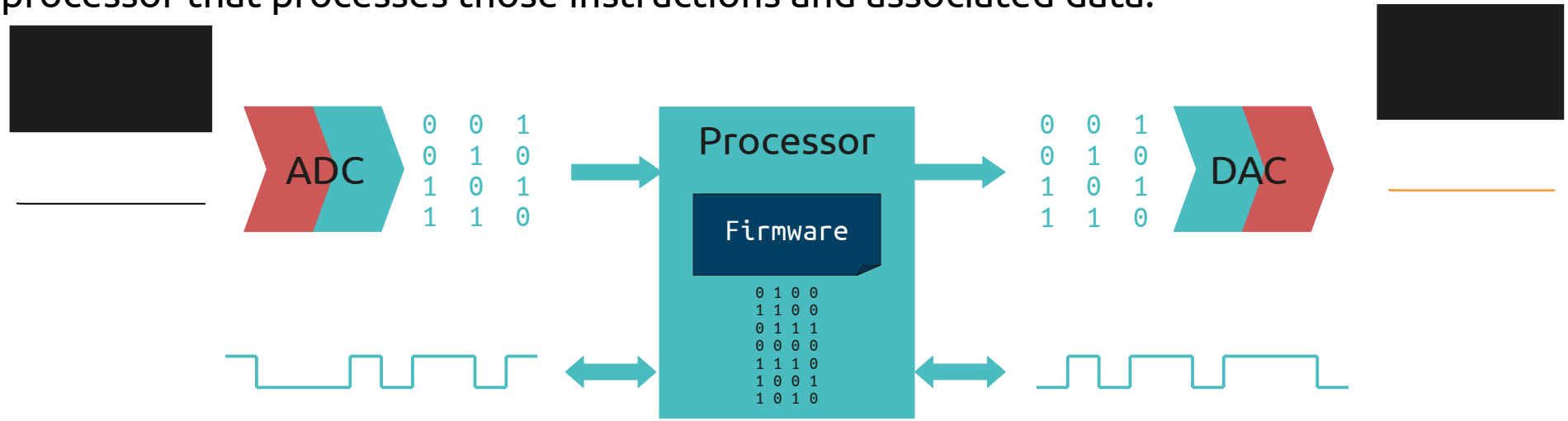




Digital electronic systems are **designed to control an application** (Fr: *supervision*), or even **perform specific process onto signals**.

More precisely, **CPU-based processors are the devices in charge**. They run sequential programs that contain a sequence of instructions.

The **CPU (Central Processing Unit, *Unité Centrale de Traitement*)** is the part of the processor that processes those instructions and associated data.



EMBEDDED SYSTEMS

A part of history

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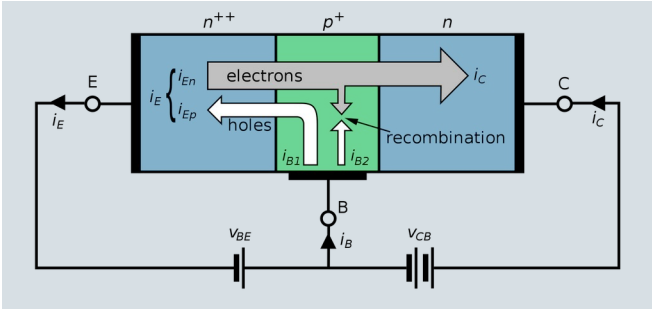
Bref rappel (cf cours de Systèmes embarqués)

1947: Invention du Transistor à Jonction Bipolaire →

par Bardeen, Schokley et Brattain (Bell labs), Lauréats du Prix Nobel

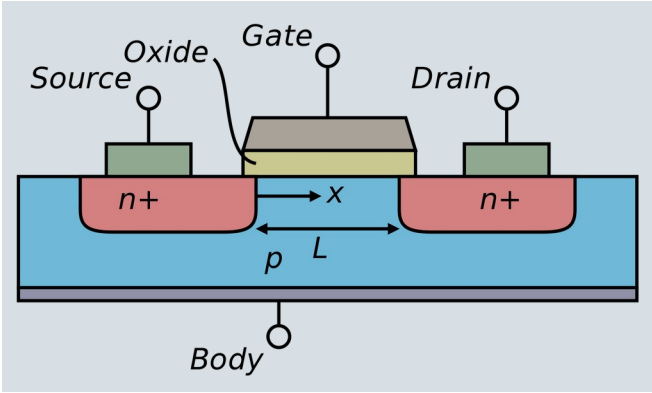


1958/1959: Création des Circuits Intégrés

par Texas Instruments (IC hybride), puis Fairchild (vrai IC monolithique)

1960: Invention du Transistor à Effet de Champ MOS →

par Mohammed Atalla et Dawon Kahng



Premier processeur

Le premier processeur commercial est le 4004, annoncé par Intel le 15 novembre 1971.

En réalité, l'armée américaine avait déjà développé un processeur en juin 1970, gardé secret pour le F-14.

À titre de comparaison, la mission Apollo 11 s'est déroulée deux ans plus tôt !

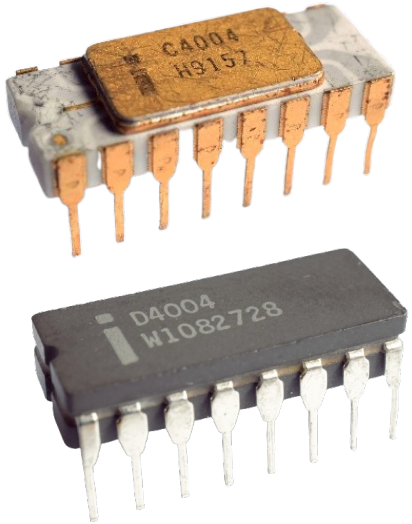
Le 4004 possède 2 300 transistors gravés en 10 µm.

C'est un processeur 4 bits, à 16 broches.

Son ISA compte 45 instructions,
dont du saut conditionnel et de l'appel de fonction.

Cadencé à 740 kHz, il peut alors réaliser 90 kIPS.

Le tout pour la modique somme de 60 $!



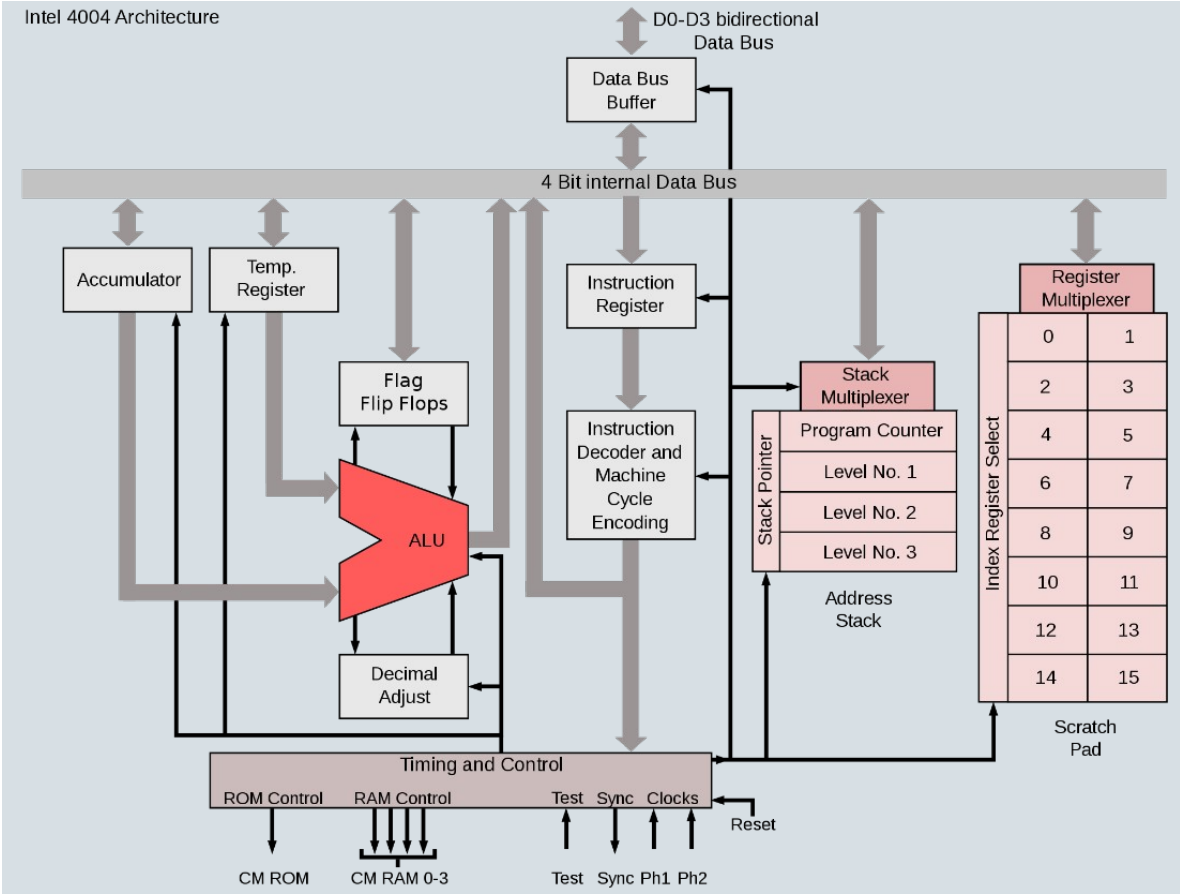
Intel 4004

L'architecture du 4004 reste la base de tous les processeurs modernes.

À comparer avec le PIC18 une fois son architecture étudiée !

Pour les fans de transistors, le schéma est visible ici :

https://www.framboise314.fr/le-microprocesseur-a-50-ans-intel-4004/



Intel 4004

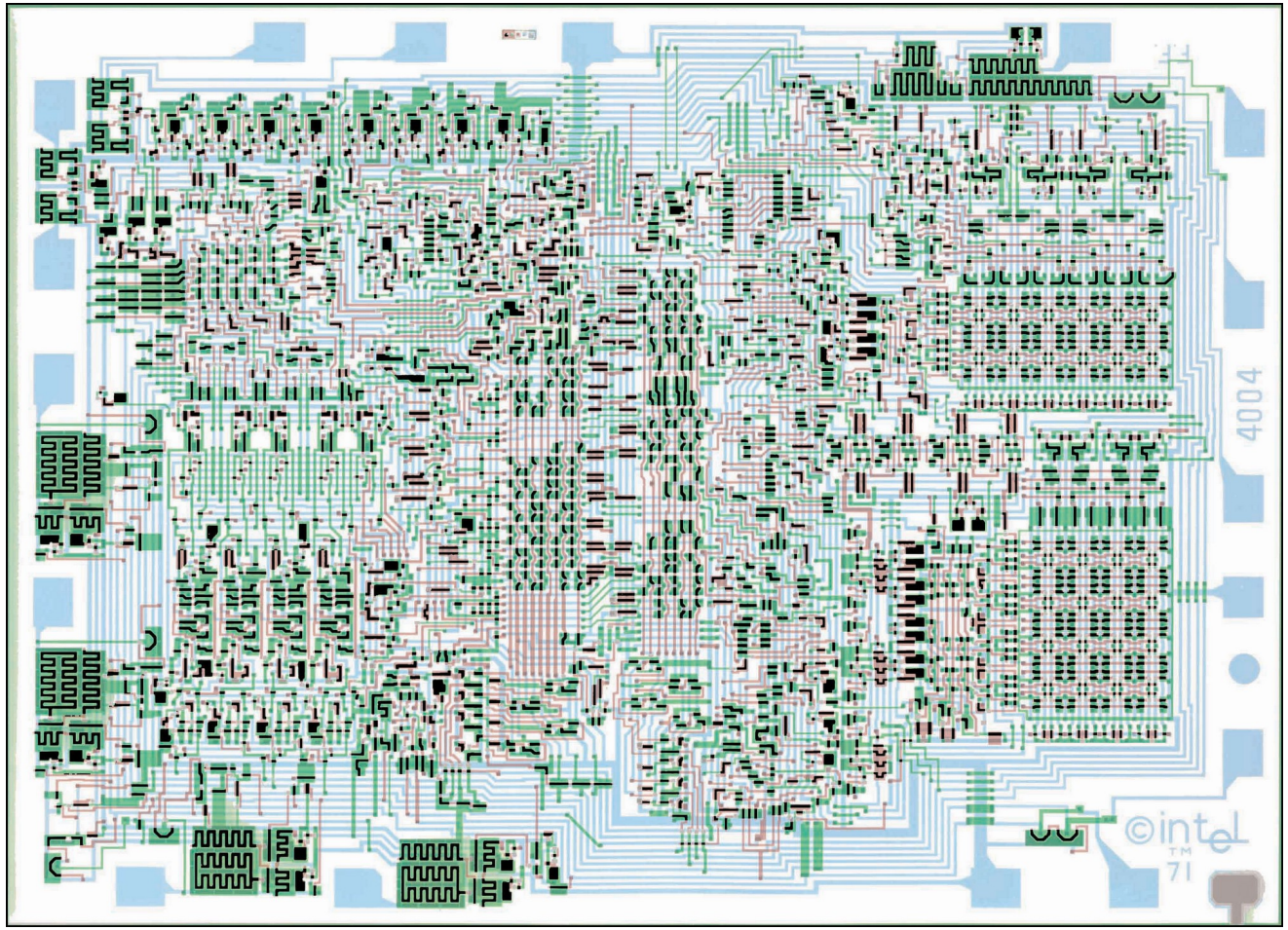


Schéma d'implantation.

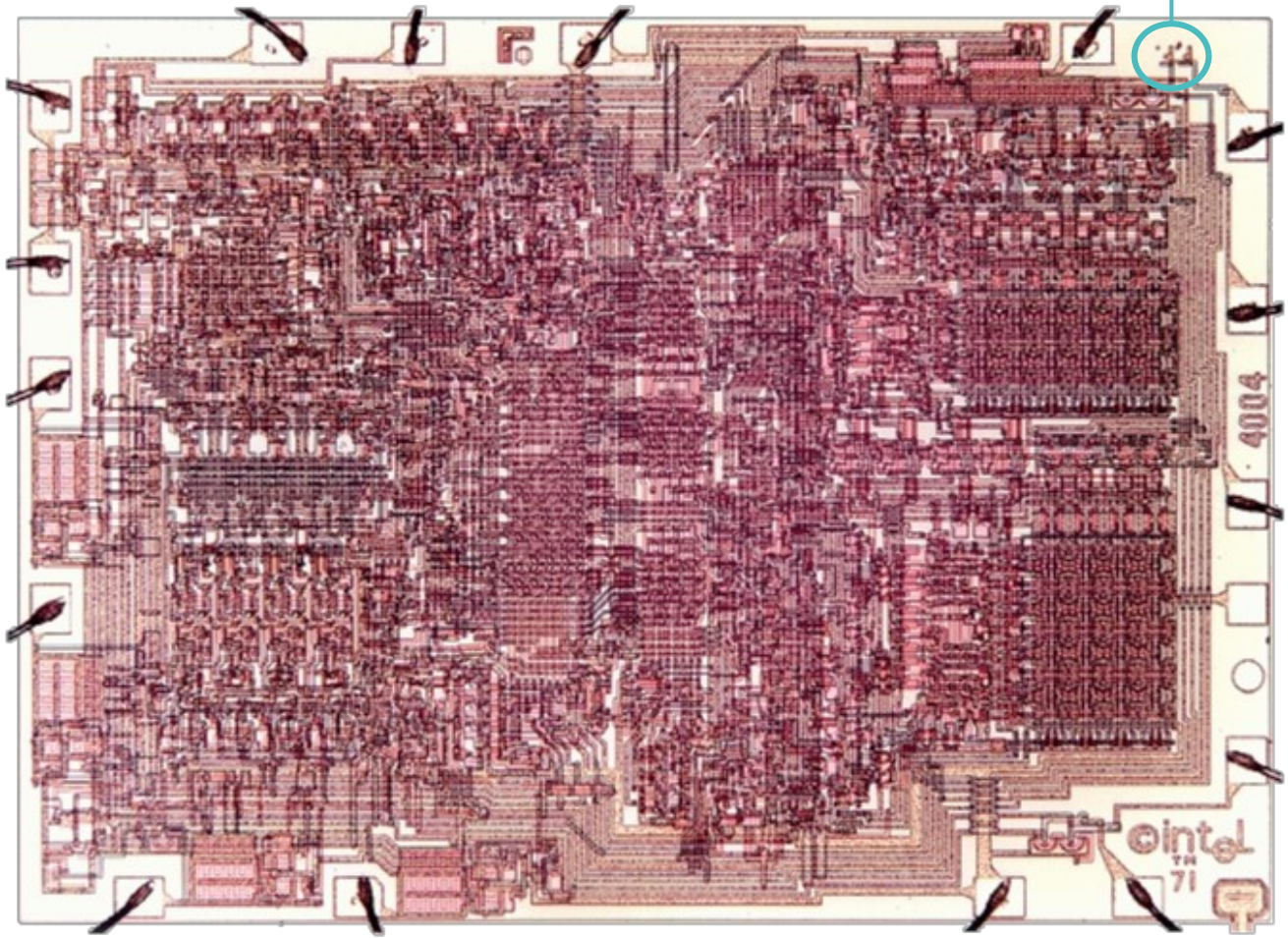
Objectif :

Polariser, assembler les 2300 transistors pour réaliser les différentes fonctions logiques.

À l'époque, pas d'outil informatique : tout ce travail est fait à la main !

DIVERSITÉ DES ARCHITECTURES PROCESSEUR

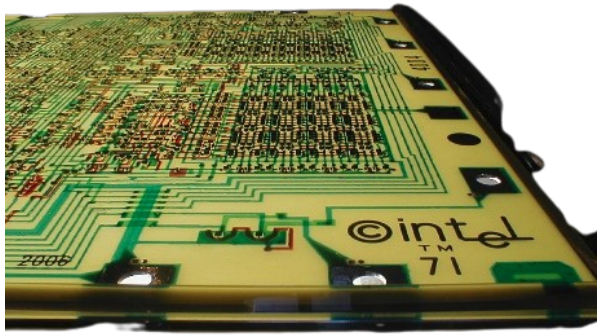
Intel 4004



Initiales de Federico Faggin, concepteur du 4004, 8008, 4040 et 8080 !

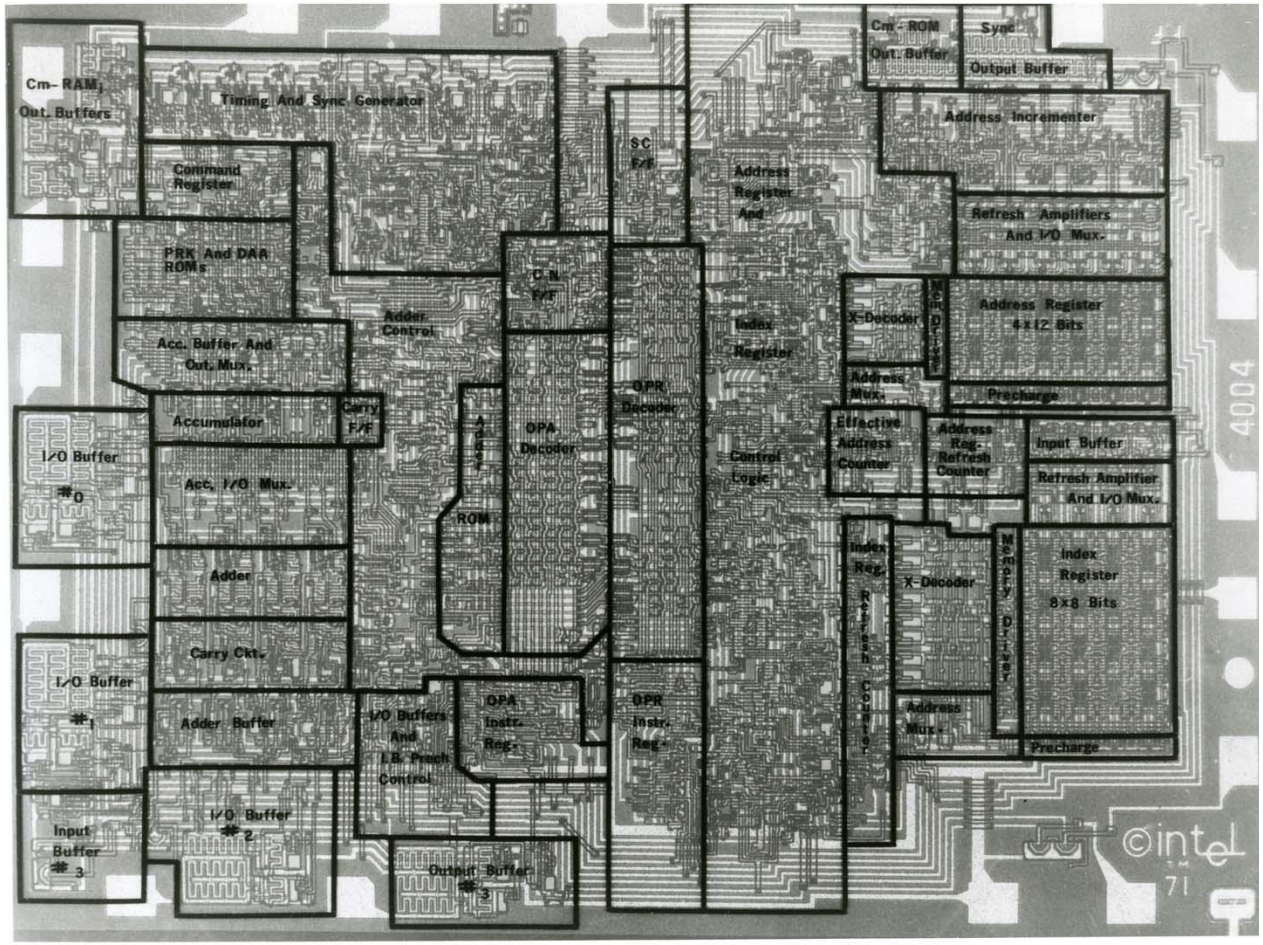
Photographie par MEB.

On voit encore les fils d'or reliant les pads du die aux broches du boîtier.



DIVERSITÉ DES ARCHITECTURES PROCESSEUR

Intel 4004



Découpage du schéma d'implantation en blocs fonctionnels.

Simulation à 6 cycles par seconde (90 kIPS IRL) :

https://www.youtube.com/watch?v=0Fixr39X8S4

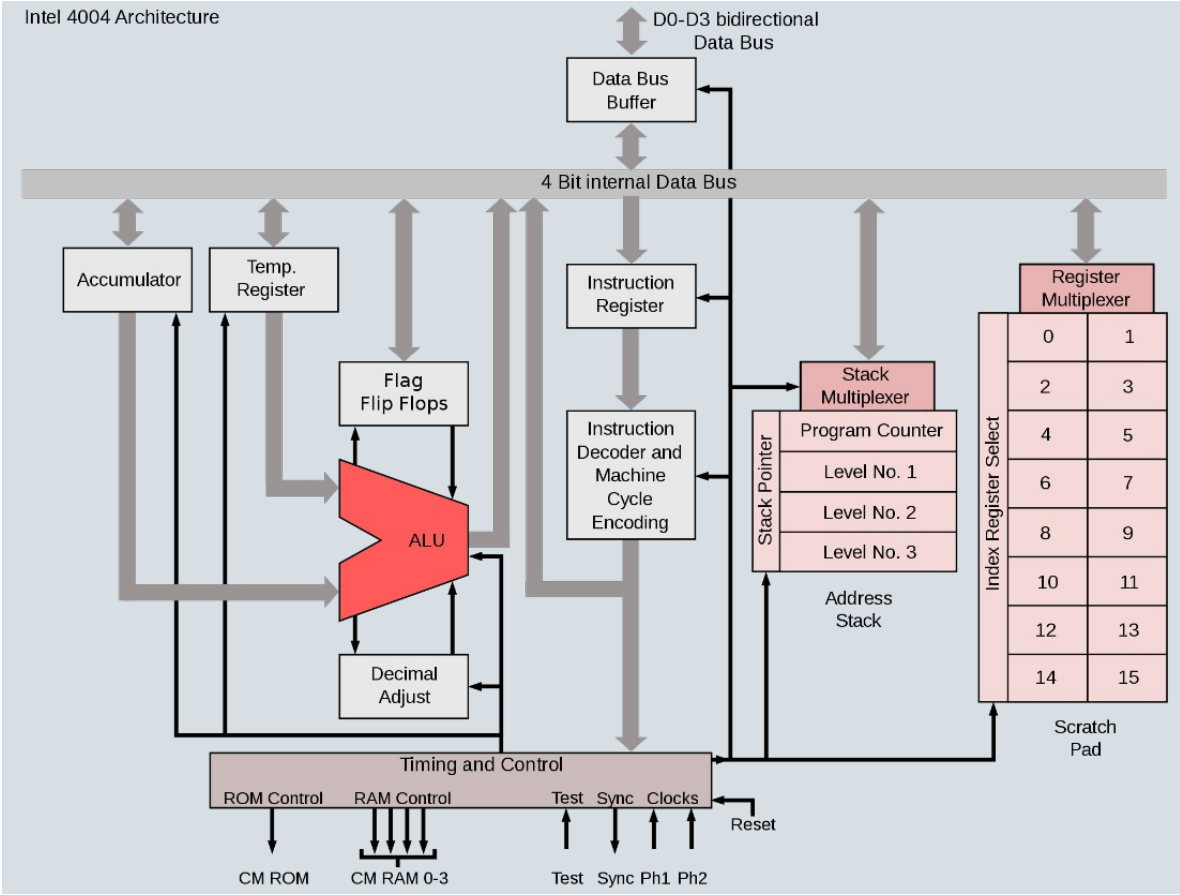
Intel 4004

L'architecture du 4004 reste la base de tous les processeurs modernes.

À comparer avec le PIC18 une fois son architecture étudiée !

Pour les fans de transistors, le schéma est visible ici :

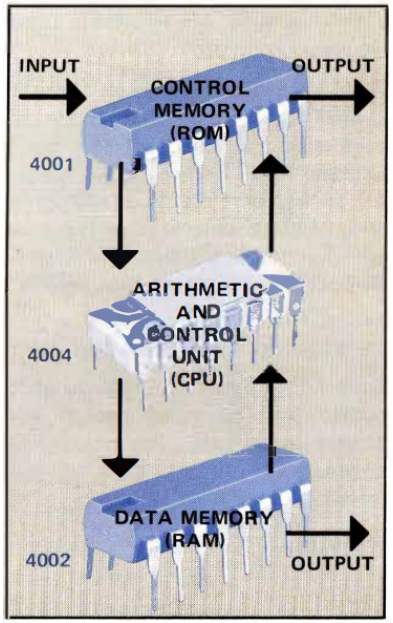
https://www.framboise314.fr/le-microprocesseur-a-50-ans-intel-4004/



Intel 4004

Le 4004 a été conçu pour une machine à calculer de *Busicom Corporation (la 141-PF)*.

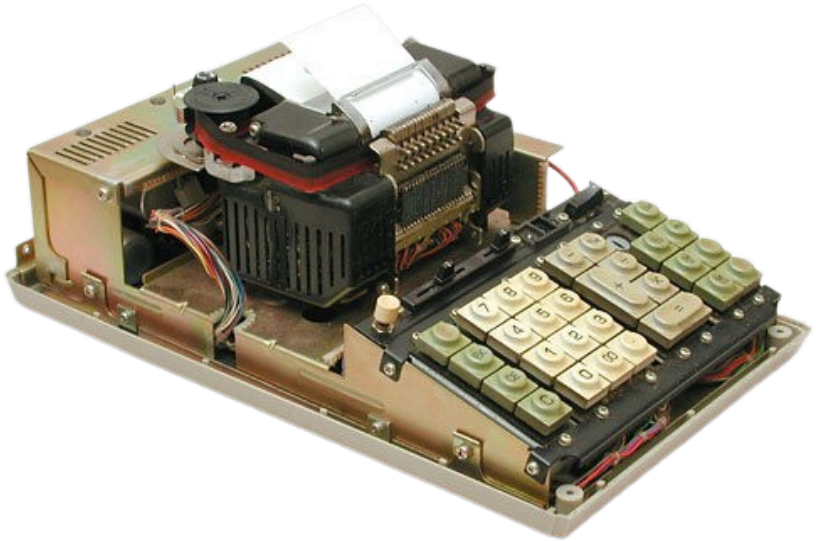
Il est alors associé à d'autres composants pour former le **chipset Intel MCS-4**.




```
4001 : 256 x 8 bit ROM
4002 : 320 bit RAM
4003 : 10 bit shift register
4004 : 4 bit CPU
```

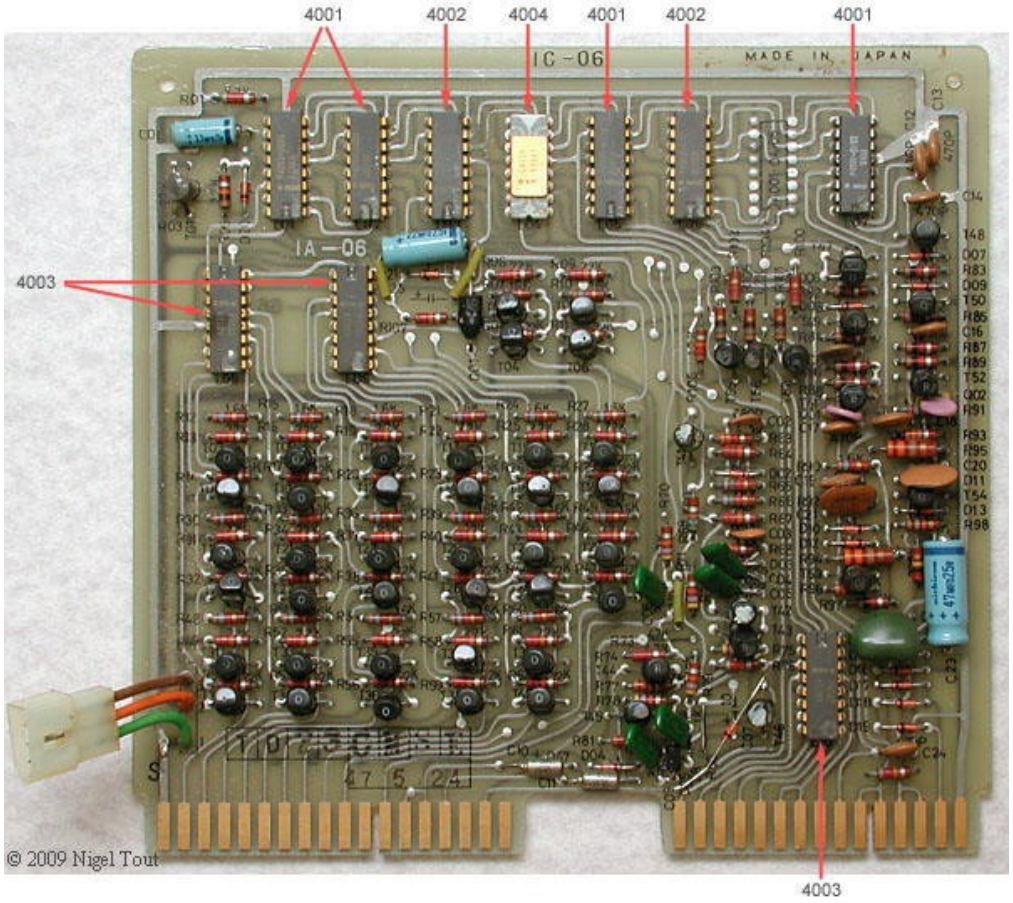
Source : http://ieeemilestones.ethw.org/images/2/2d/Ref2-Intel_MCS-4_DataSheet.pdf

Intel 4004



Busicom 141-PF (ou NCR-18-36)

Bloc d'alimentation au fond,
PCB unique en dessous.



Source : http://www.vintagecalculators.com/html/busicom_141-pf.html

Intel Core 10e génération

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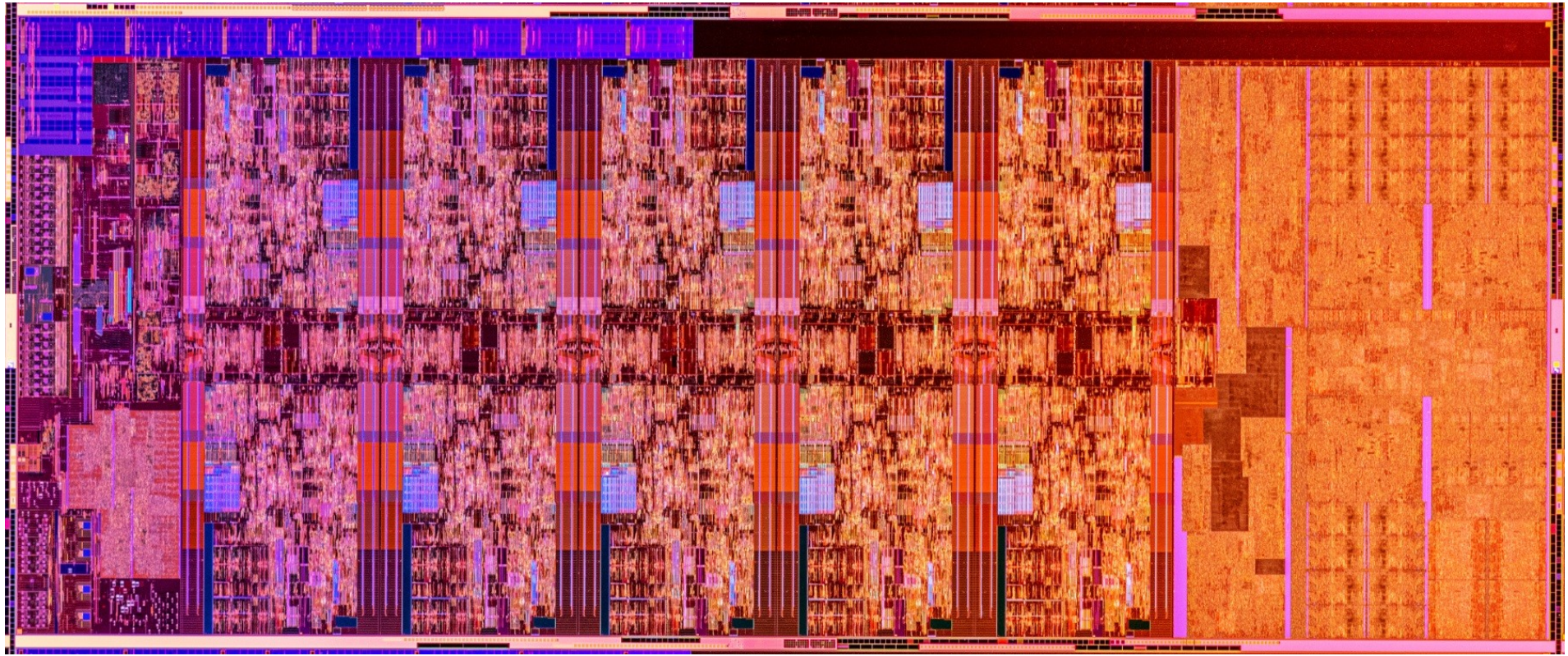
Intel® Core™ i9-10900K Processor

2e trimestre 2020
14 nm (estimé à 7 milliards de transistors)
10 coeurs, 5.30 GHz, 460.8 GFlops



EMBEDDED SYSTEMS

Architecture

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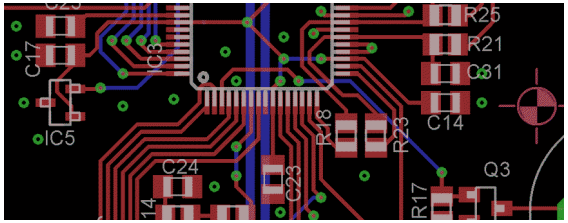
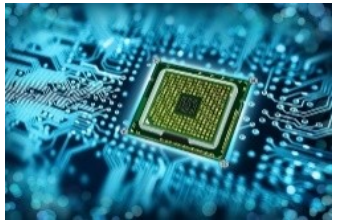
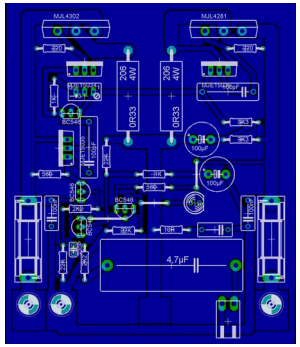
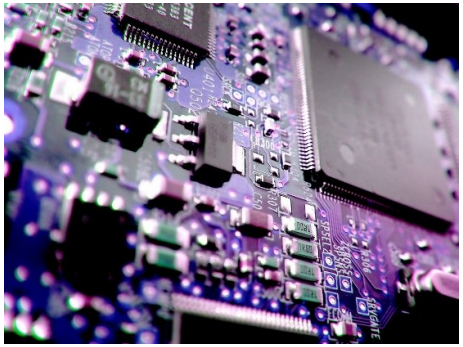
By mixing scientific skills in applied mathematics (control and signal processing), applied physics, analogue and digital electronics, computer science, … we can build complex embedded systems.

We'll see soon enough that most of today's systems are called "embedded systems".







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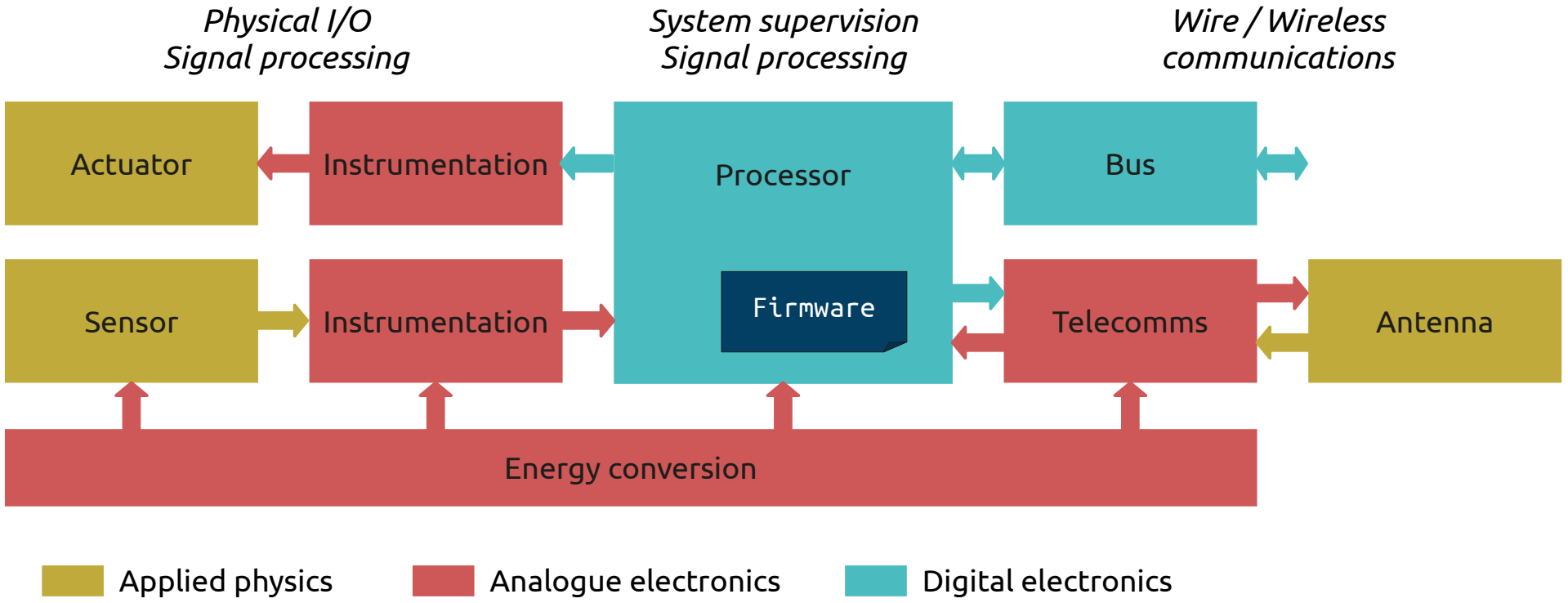
Generic architecture of an electronic system



An embedded system is the product of an electronic and information system specifically designed for a need.

Its opposite is the computer, which aims for genericity and has been designed for a variety of uses.

The design process of an embedded system usually follows these requirements:

- cost (production volume),
- power consumption and dissipation (battery life),
- determinism (real-time system),
- Sturdiness.

This class will not talk about all the listed elements of embedded systems. In fact you will see most of them in other classes.

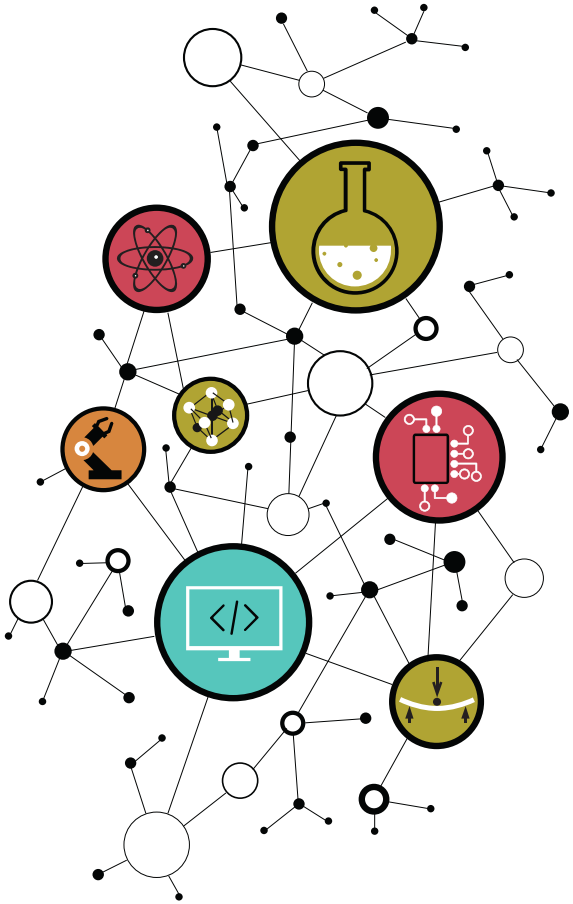
First, we'll take a brief look at different processors architectures.

Then we'll focus on one precise architecture: **MCUs (Micro-Controller Units, *micro-contrôleurs*)**, with a direct application to Microchip's PIC18 MCU.

The reason why we study MCUs only is that this is the most popular processor choice when it comes to embedded systems.

The other processor architectures (DSP, GPP, FPGA, SoC, …) will also have their dedicated classes.

CONTACT



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