ESCAPE 824064

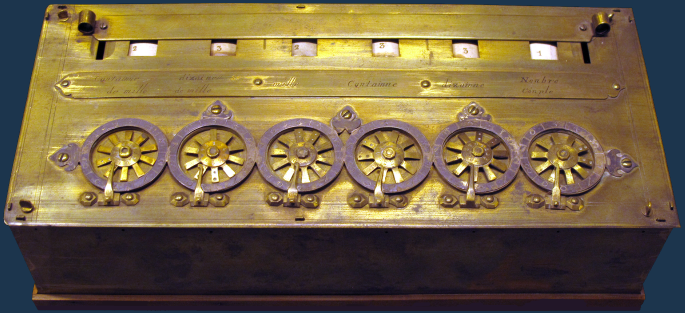
Laboratoire d'Annecy de Physique des Particules

From Barrel Organ to Quantum Computing

Pierre Aubert

Pascaline

Invented in **1645**



- Addition
- Subtraction
- Multiplication
- Division

Barrel Organ

1820 (first was made in 1502)

- Short Melodies
- Cumbersome barrel, not easy to change

Barrel Organ

1820 (first was made in 1502)

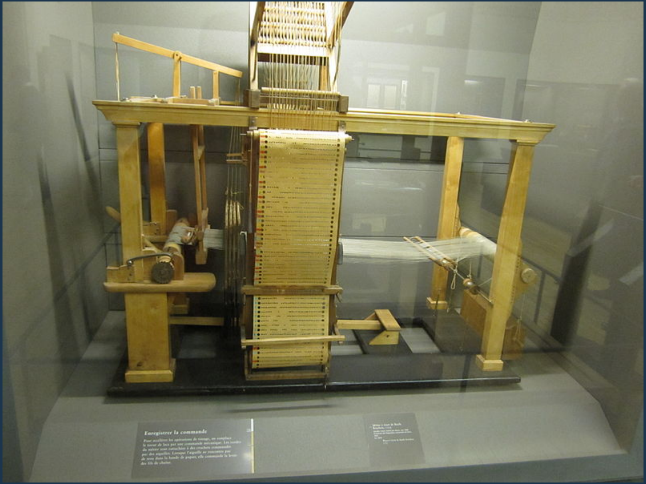
- Short Melodies
- Cumbersome barrel, not easy to change

Basile Bouchon : 1725, perforated ribbon
Jean-Baptiste Falcon : 1728, perforated paper tape

- Longer Melodies
- Small and easy to change

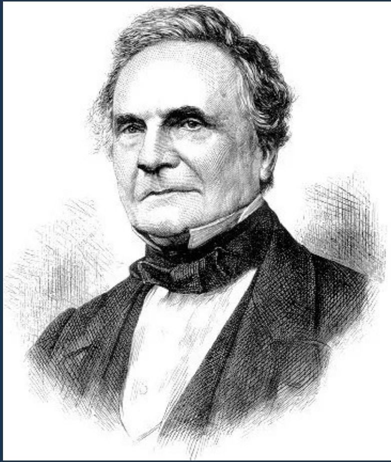
Loom

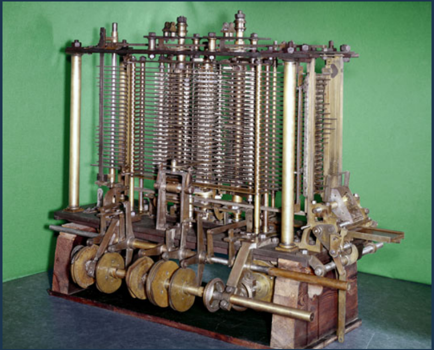
Basile Bouchon : 1725, perforated ribbon



Charles Babbage

Charles Babbage (1791 - 1871)





- Input (data and instructions) with perforated paper tape
- Data transfert and ordering for execution
- Operations on numbers
- Storage of intermediate results

Ada Lovelace

Ada Lovelace (1815 - 1852)

- Formalised **Charles Babbage**'s ideas
- Realised the **first** program

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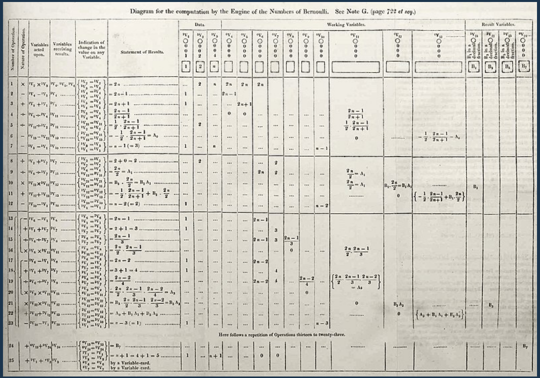


1842 : Computation of **Bernoulli numbers**

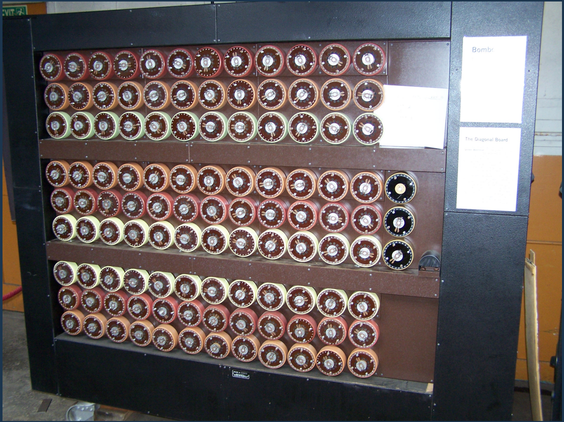
LAPP
Laboratoire d'Annecy de Physique des Particules

Alan Turing

Alan Turing (1912 - 1954)

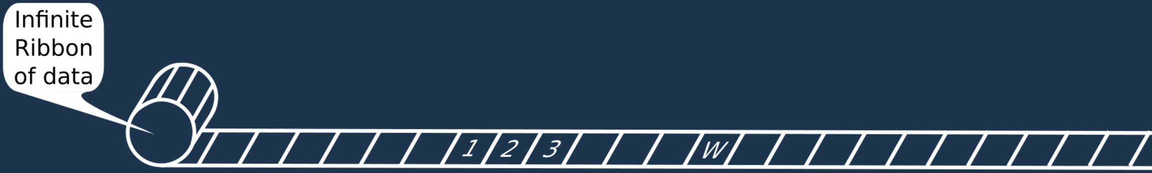
- Computer Scientist
- Logical
- Cryptoanalyst
- Theoretical biologist

The Bombe machine



Turing Machine

Turing Machine



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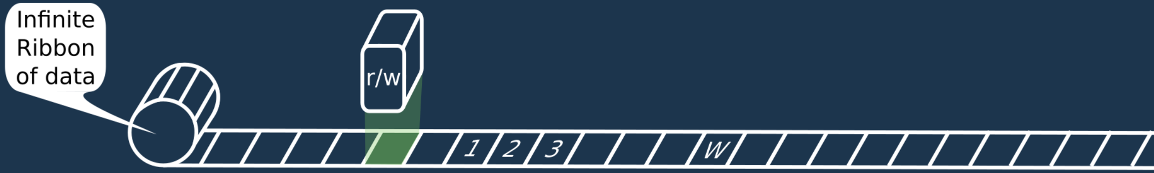
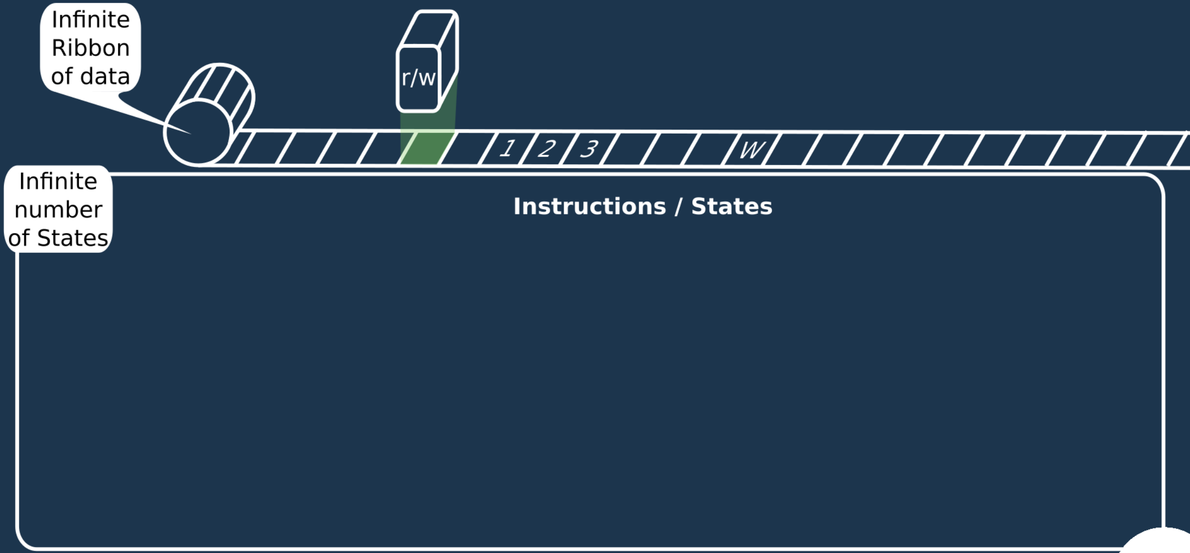


Turing Machine

Instructions / States

Turing Machine



Turing Machine

Infinite Ribbon of data

Infinite number of States

Instructions / States

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State 2

Go Left
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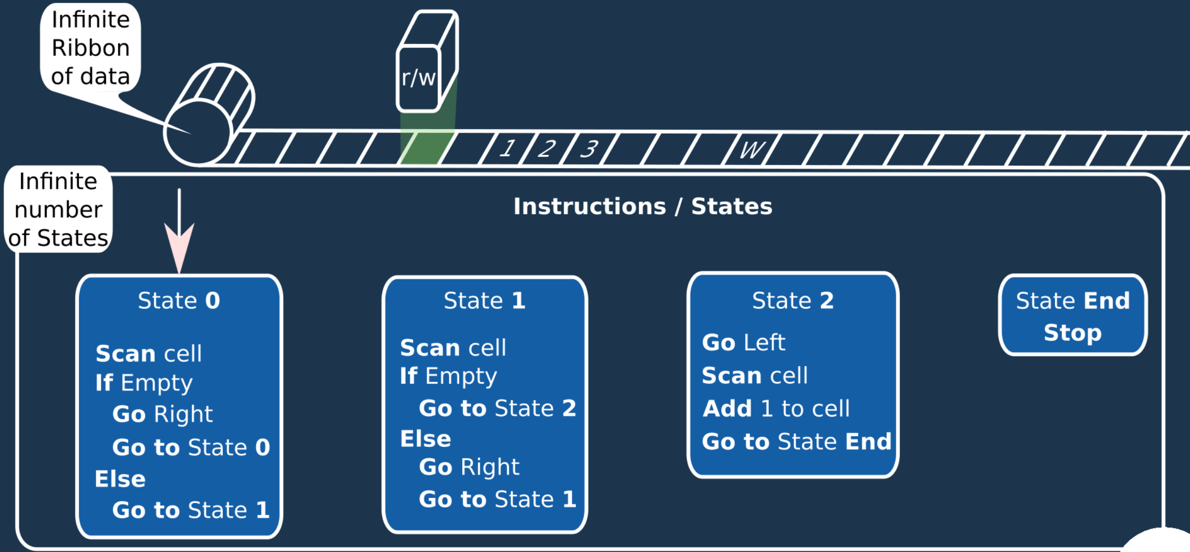

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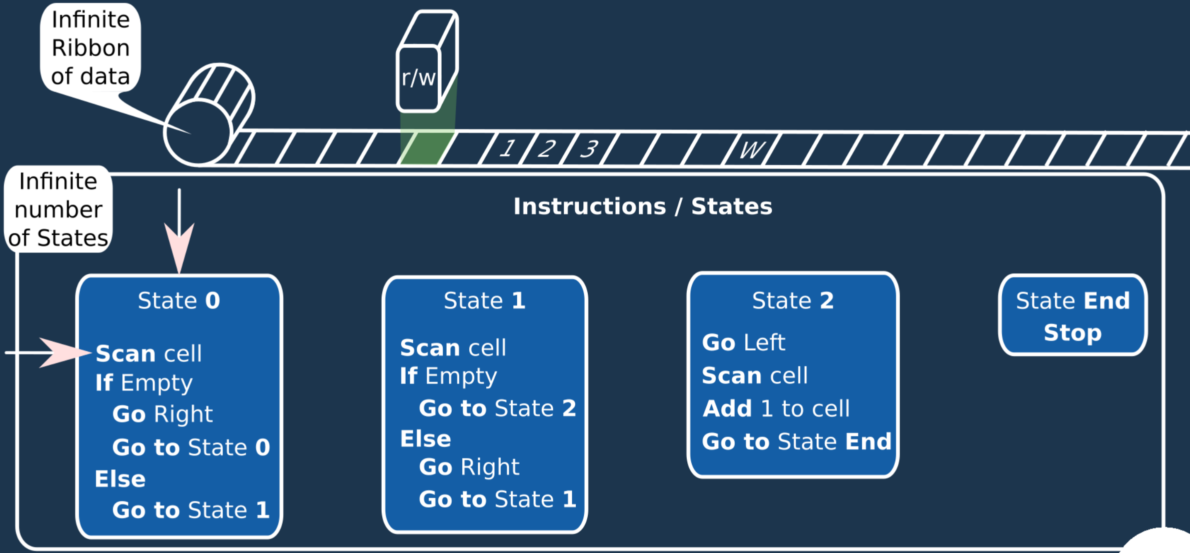

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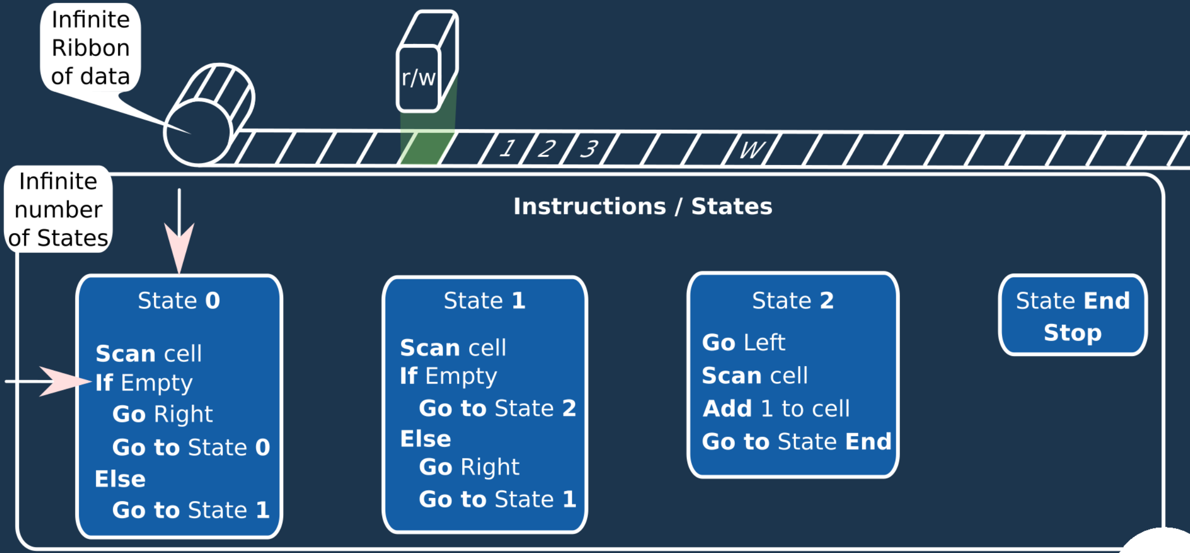

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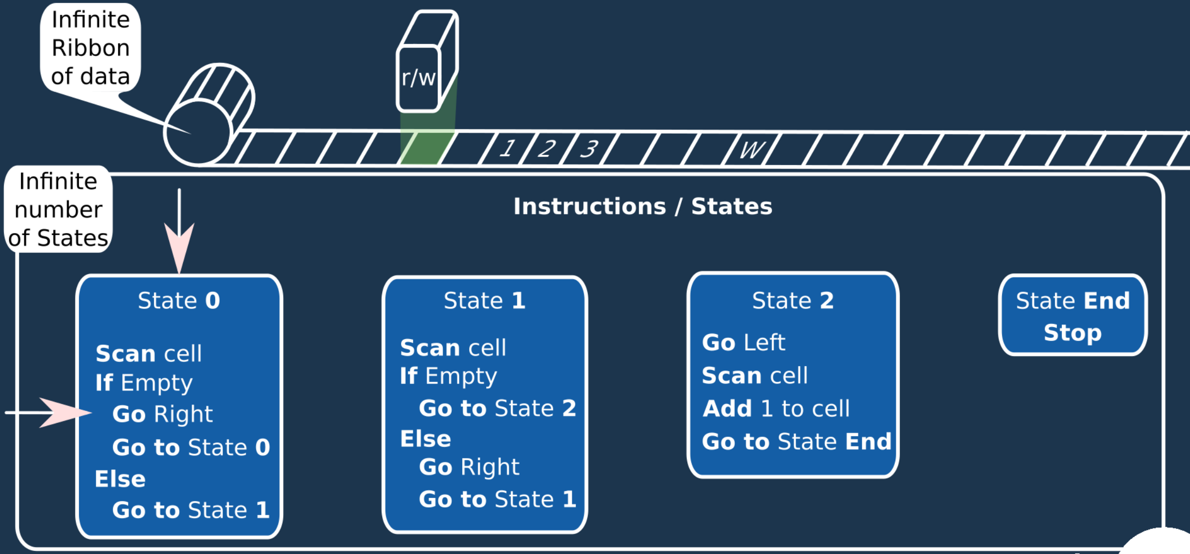

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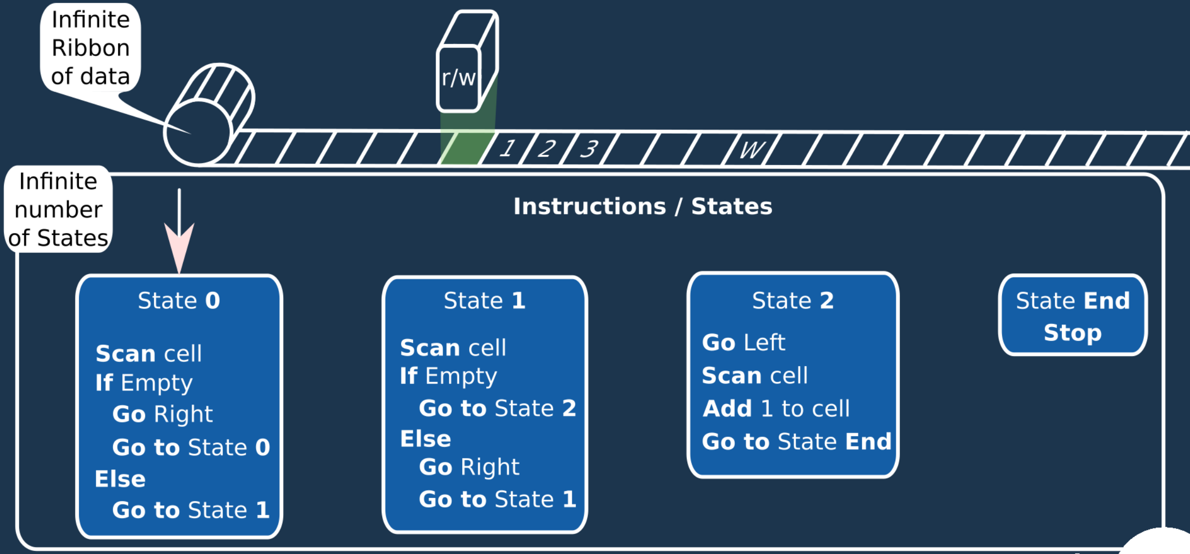

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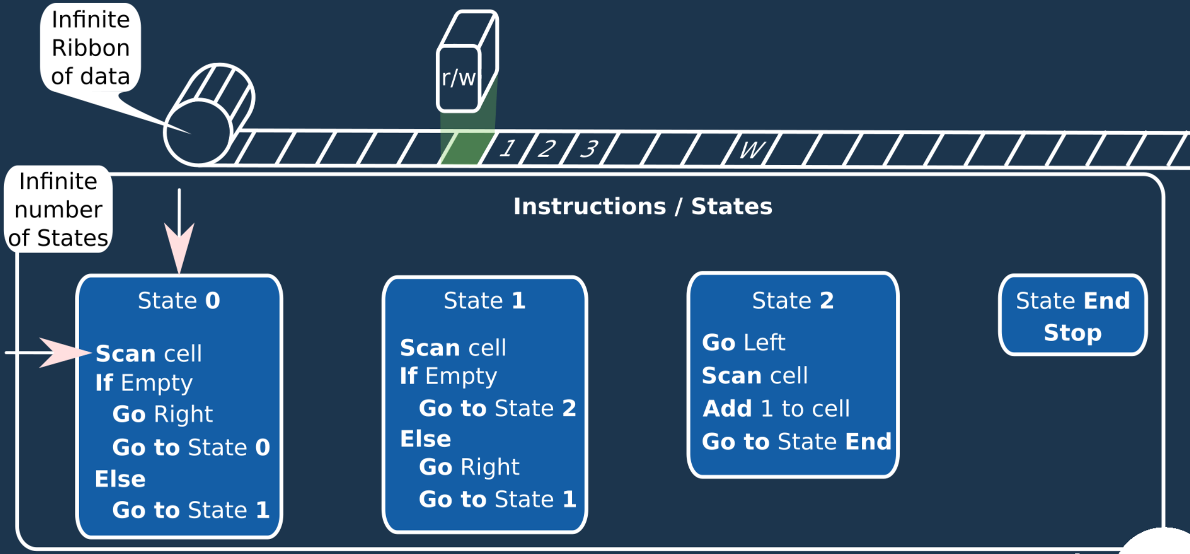

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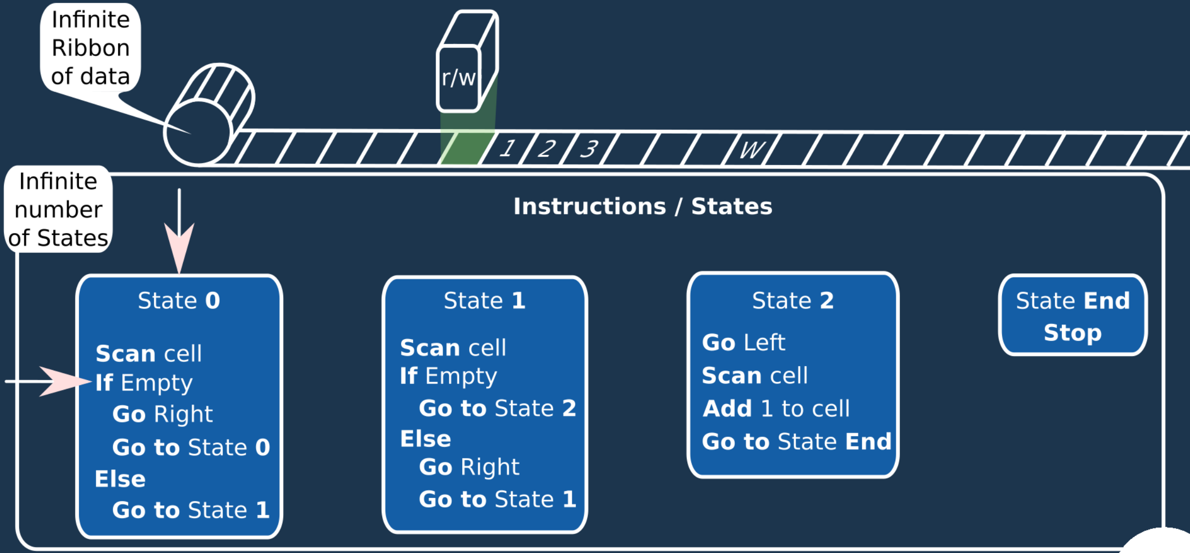

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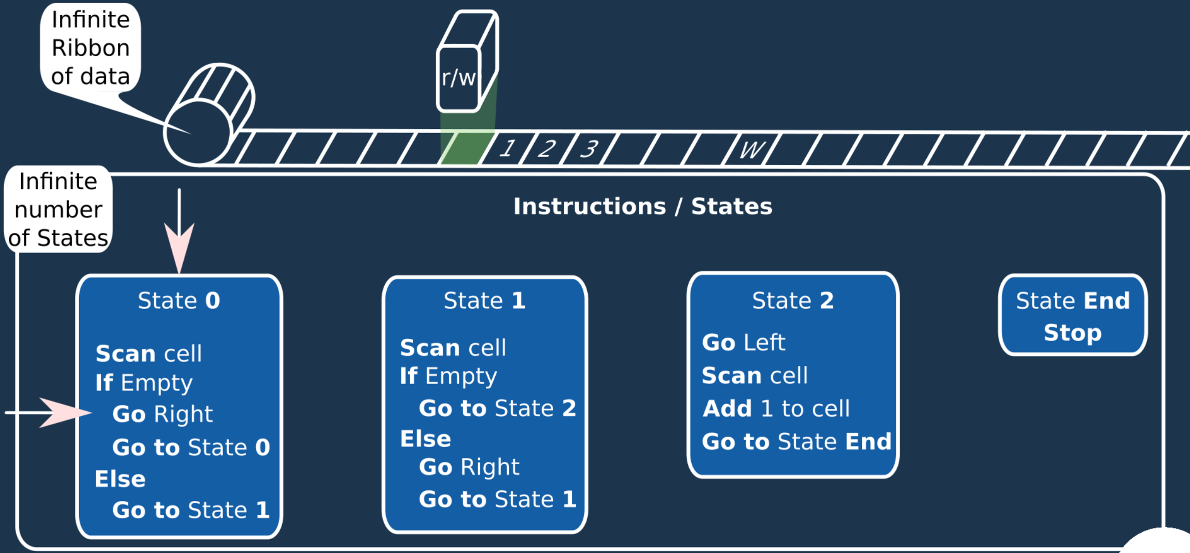

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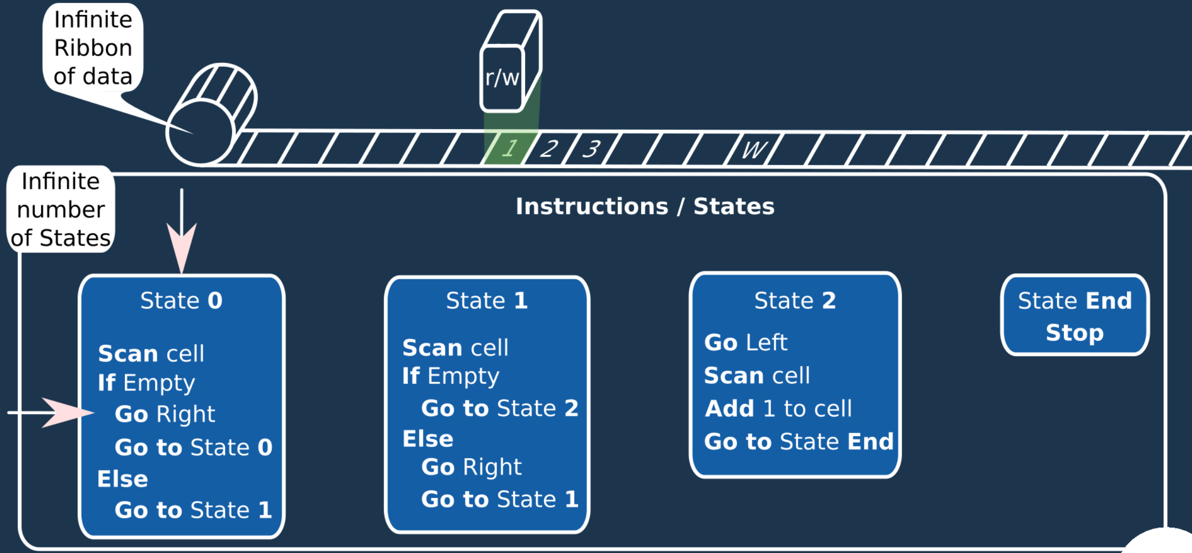

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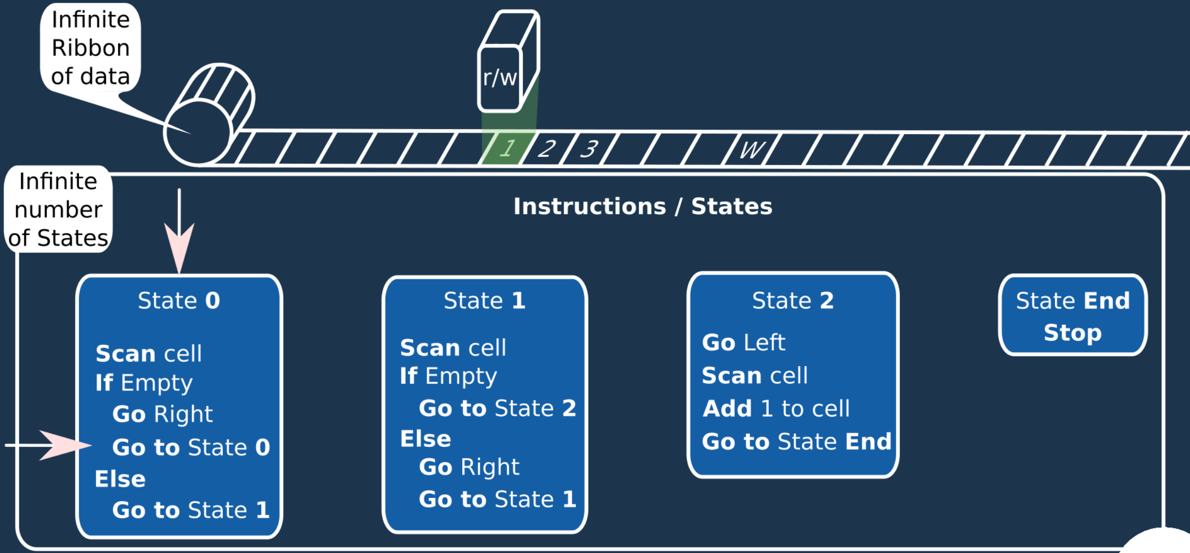

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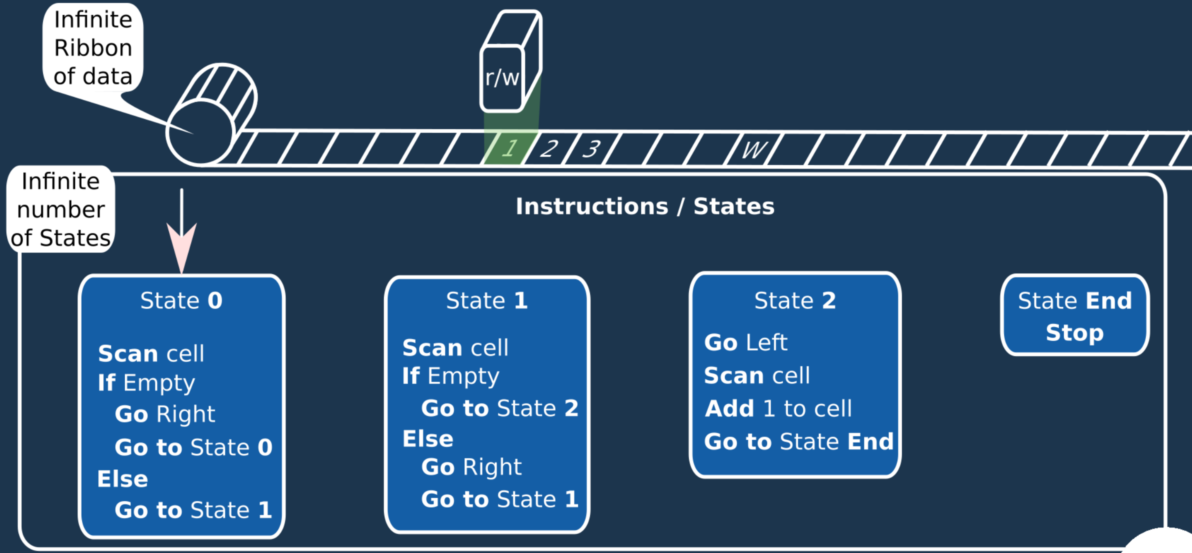

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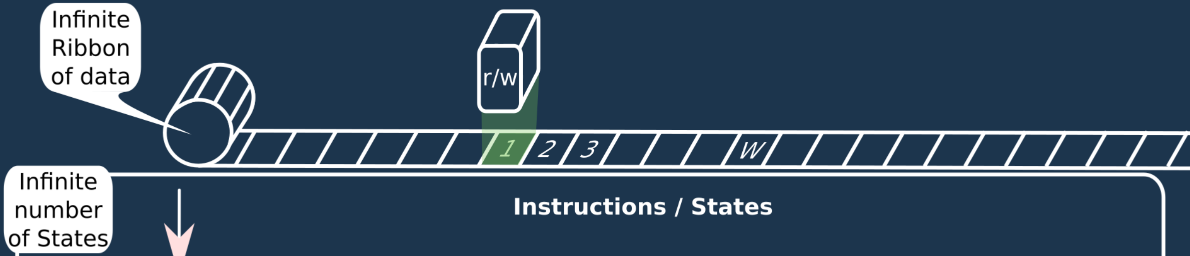

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State End

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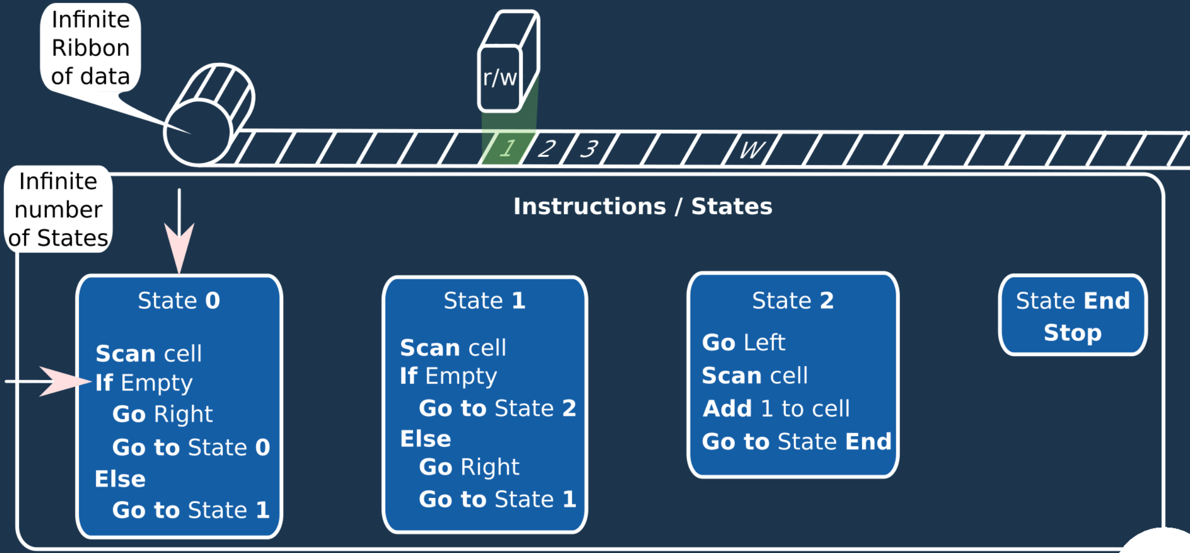

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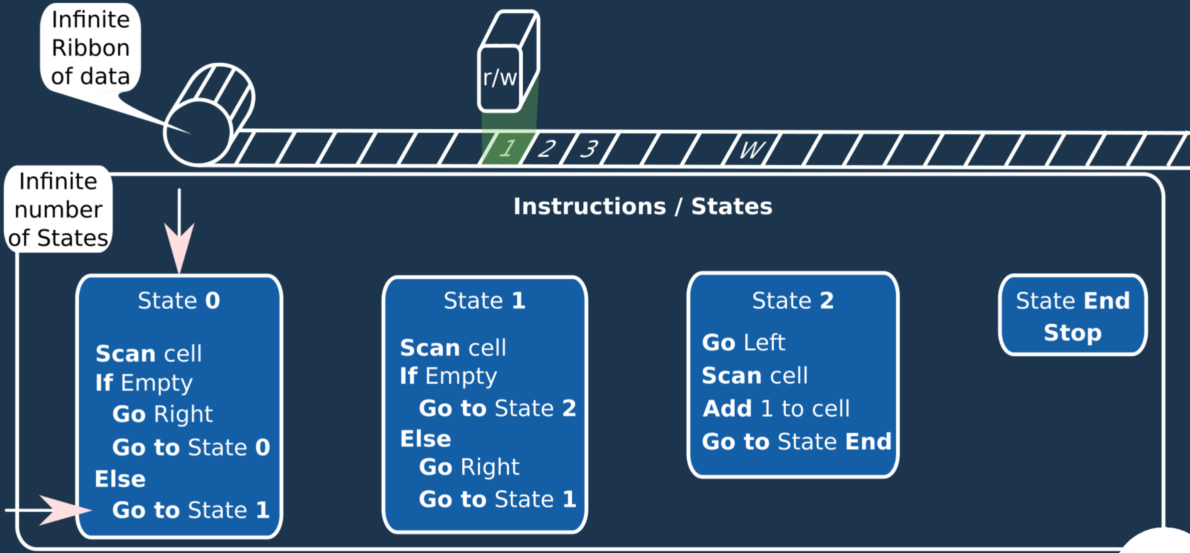

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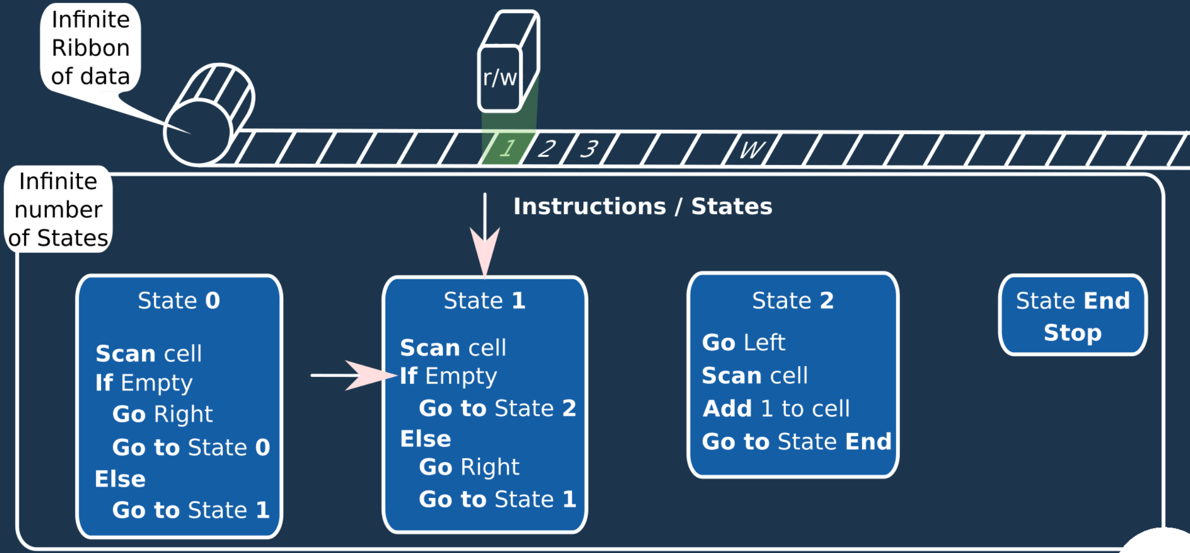

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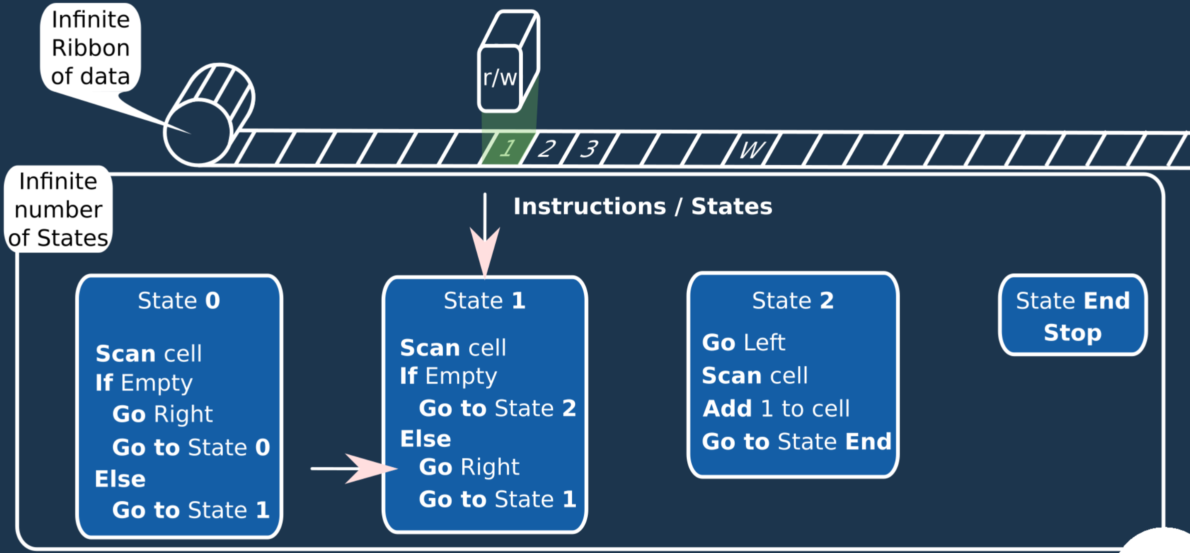

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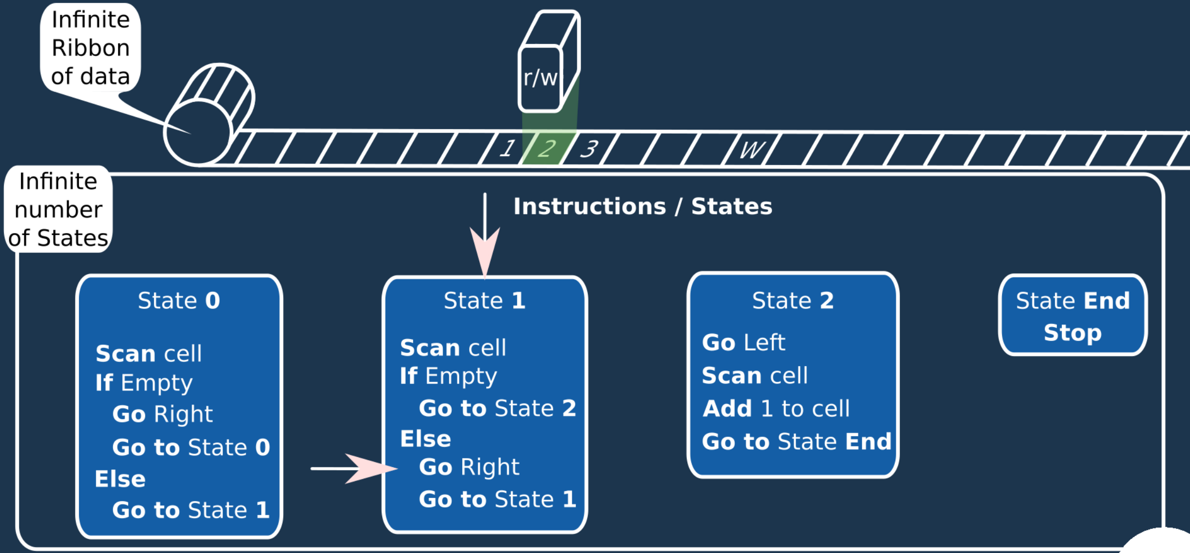

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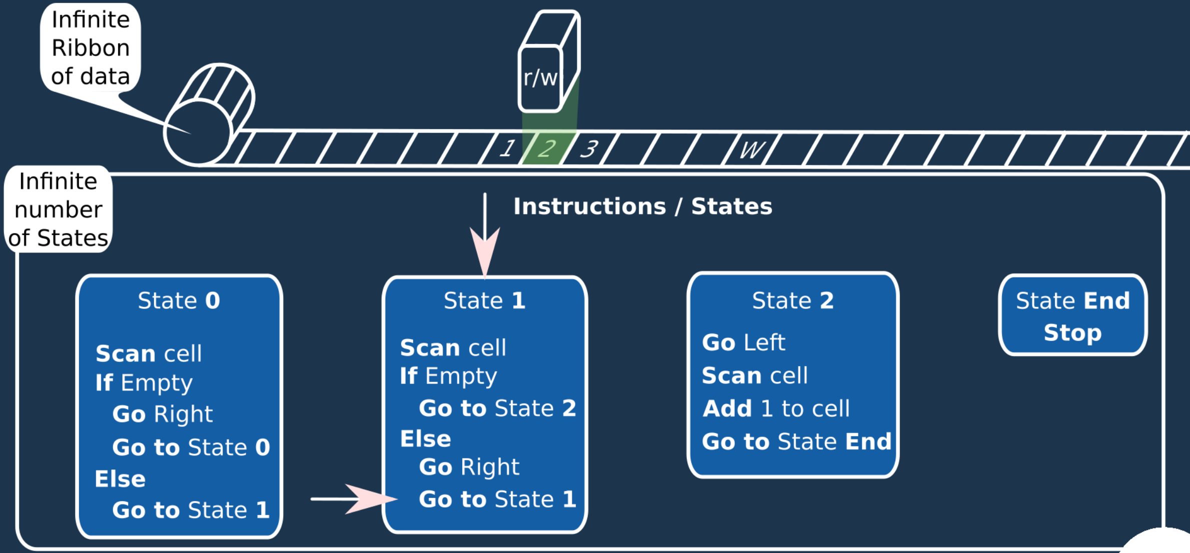

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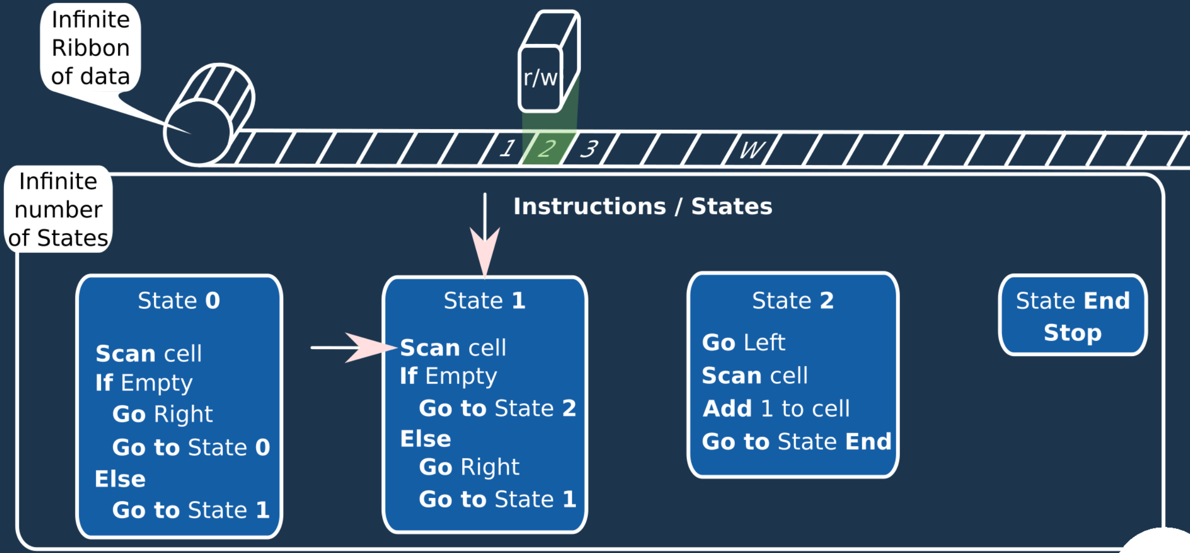

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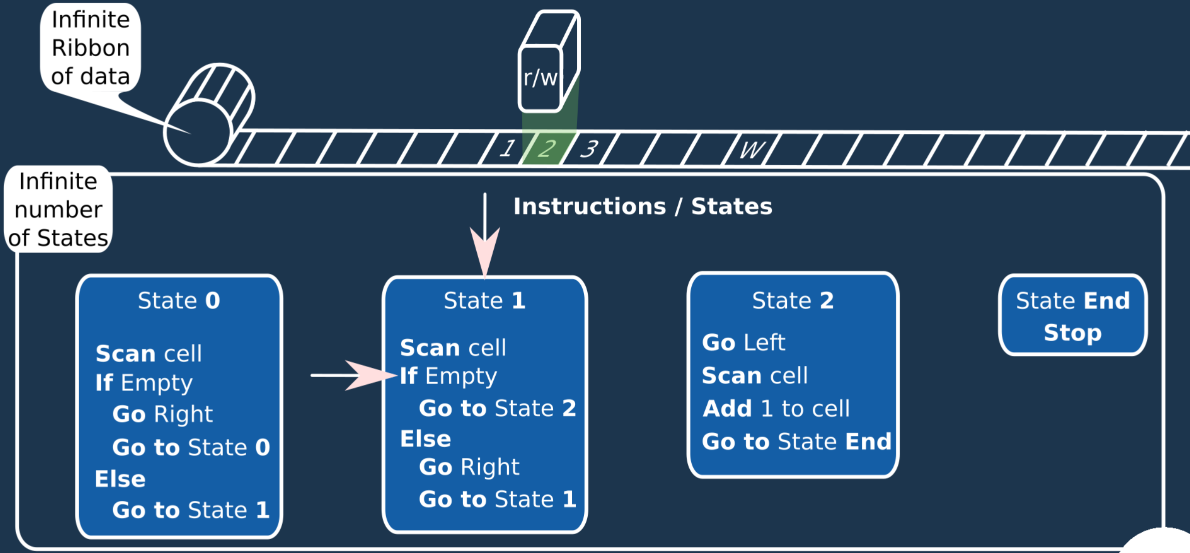

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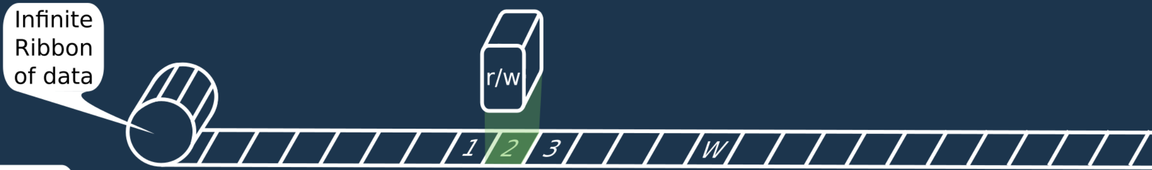

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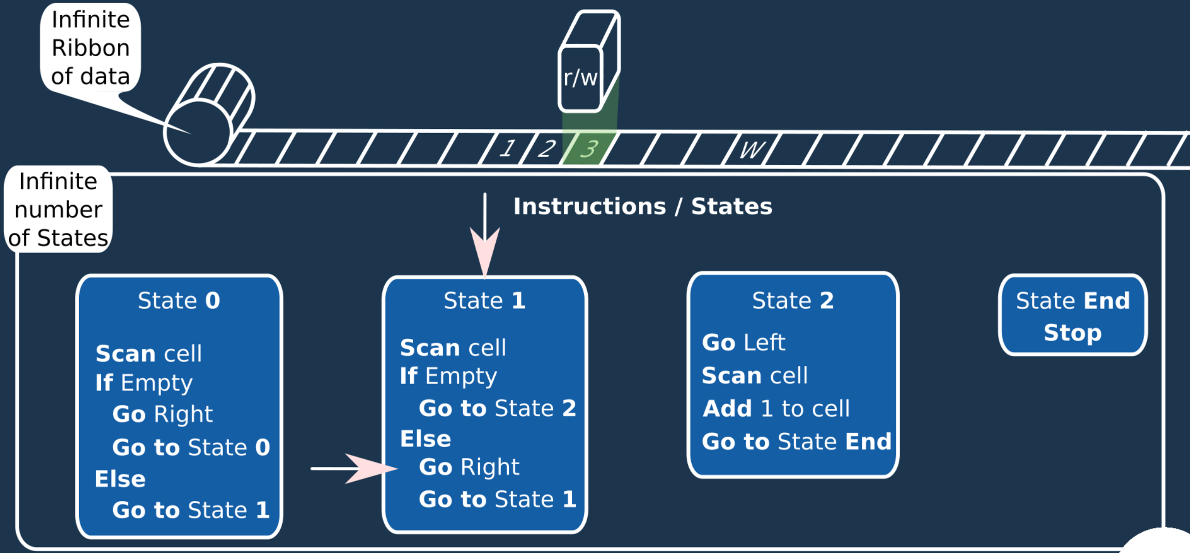

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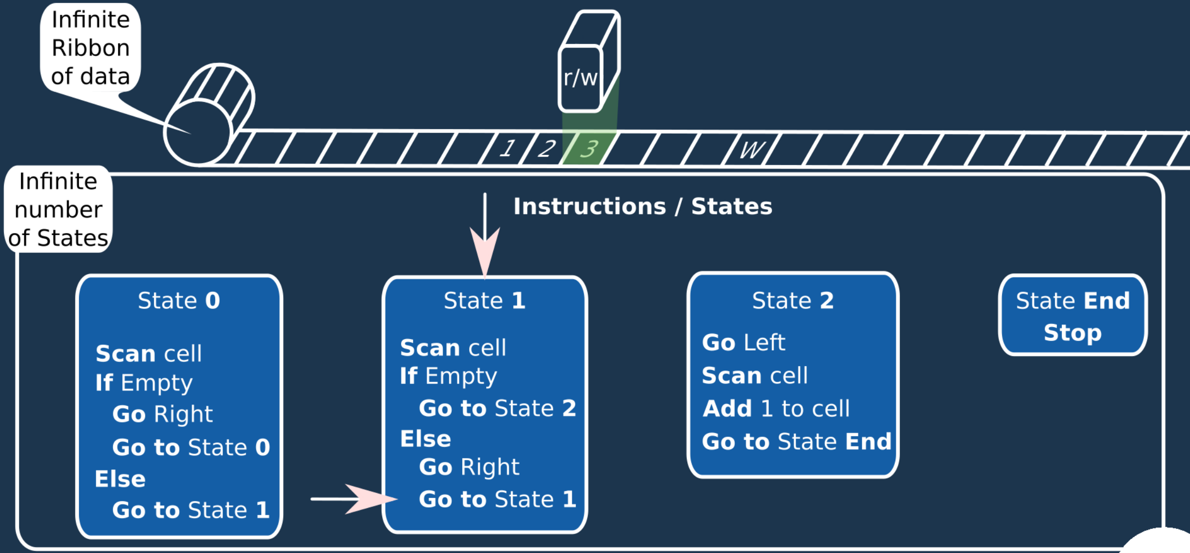

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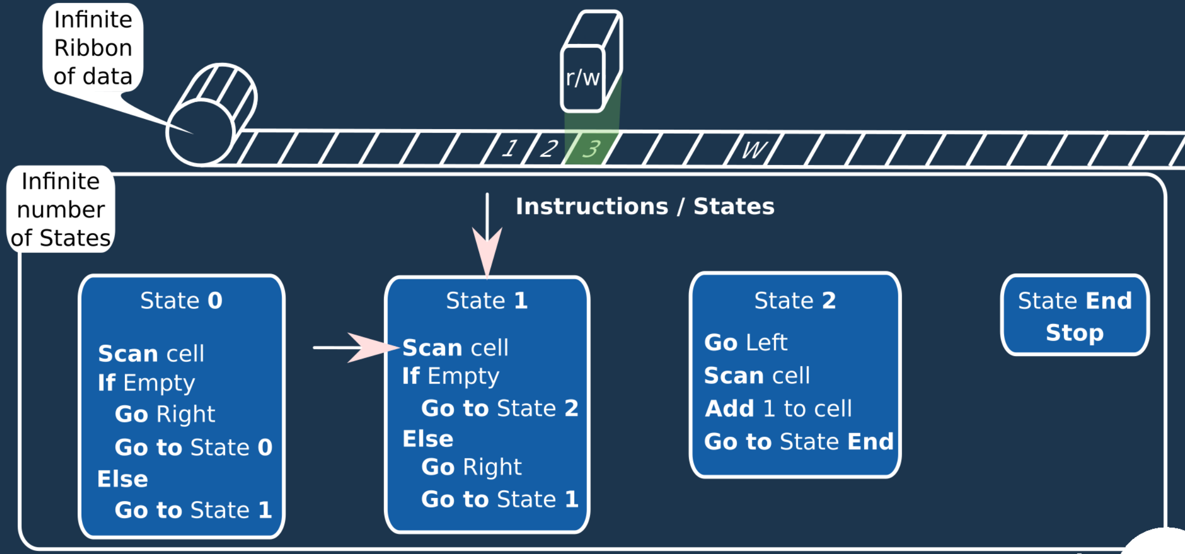

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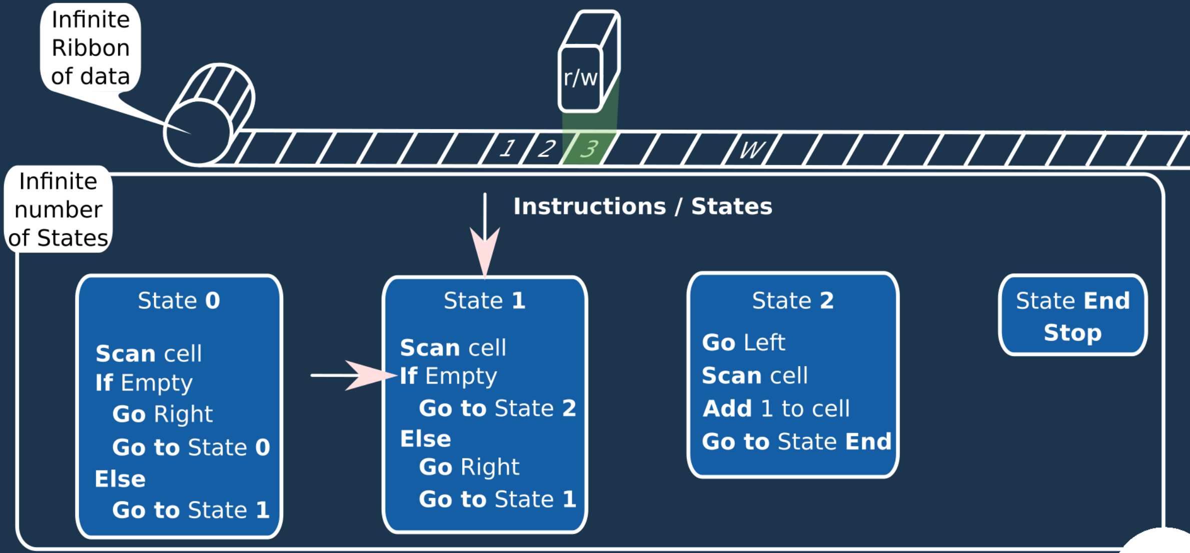

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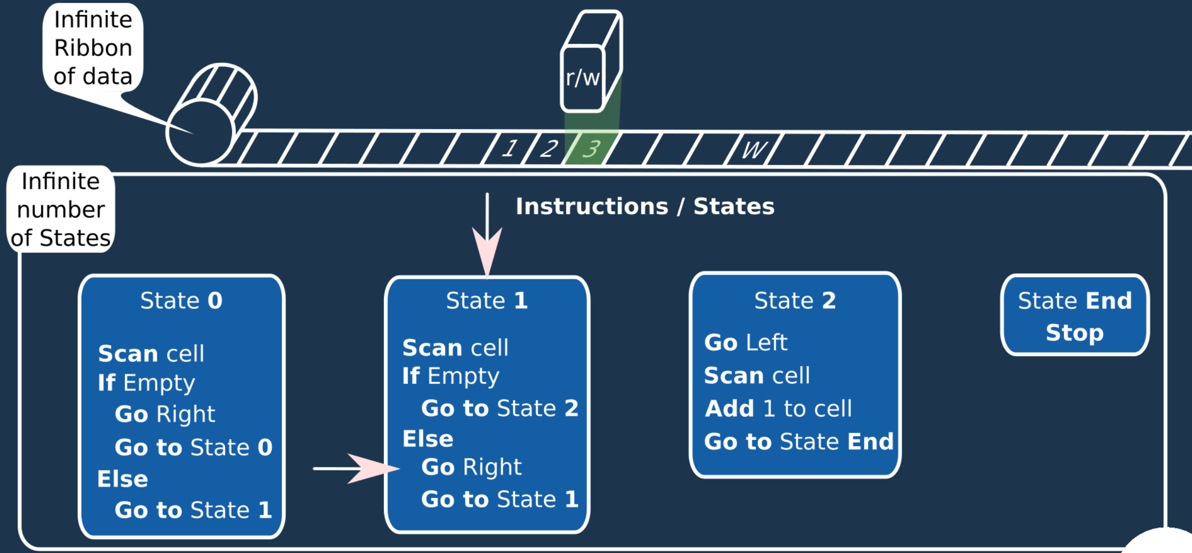

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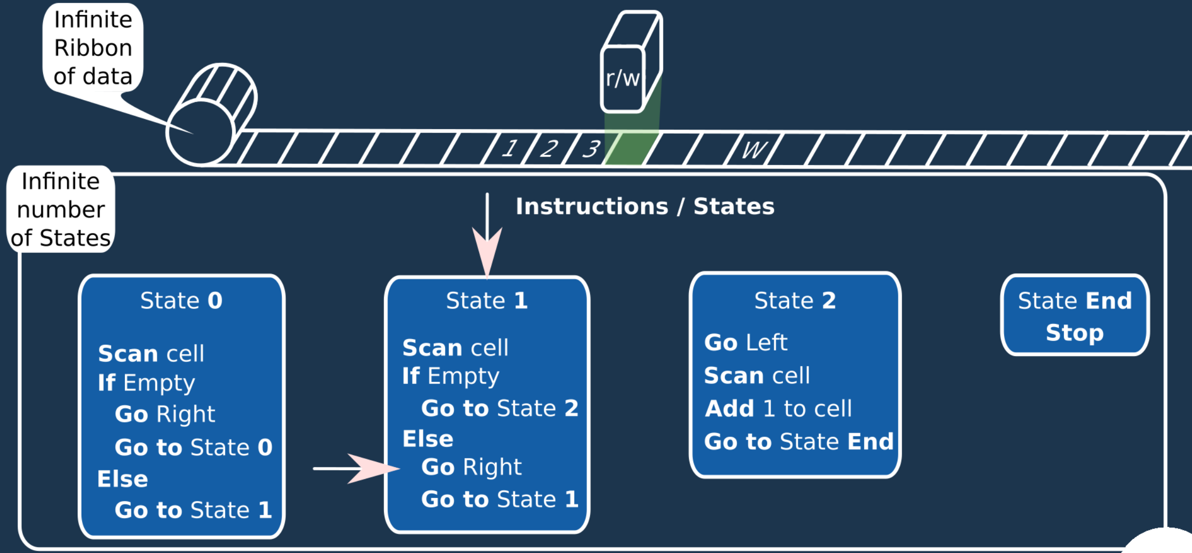

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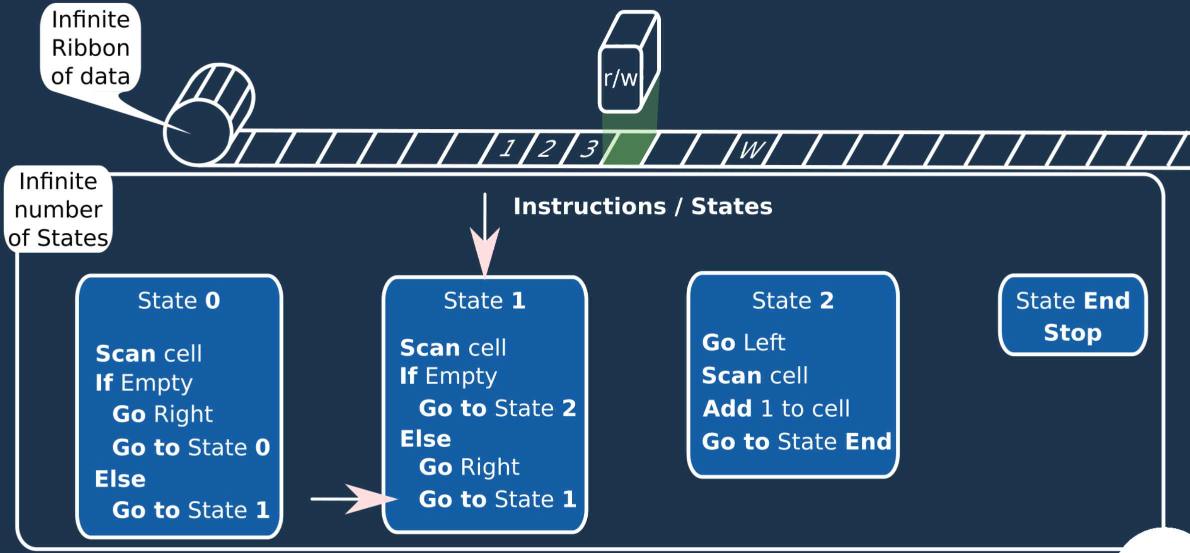

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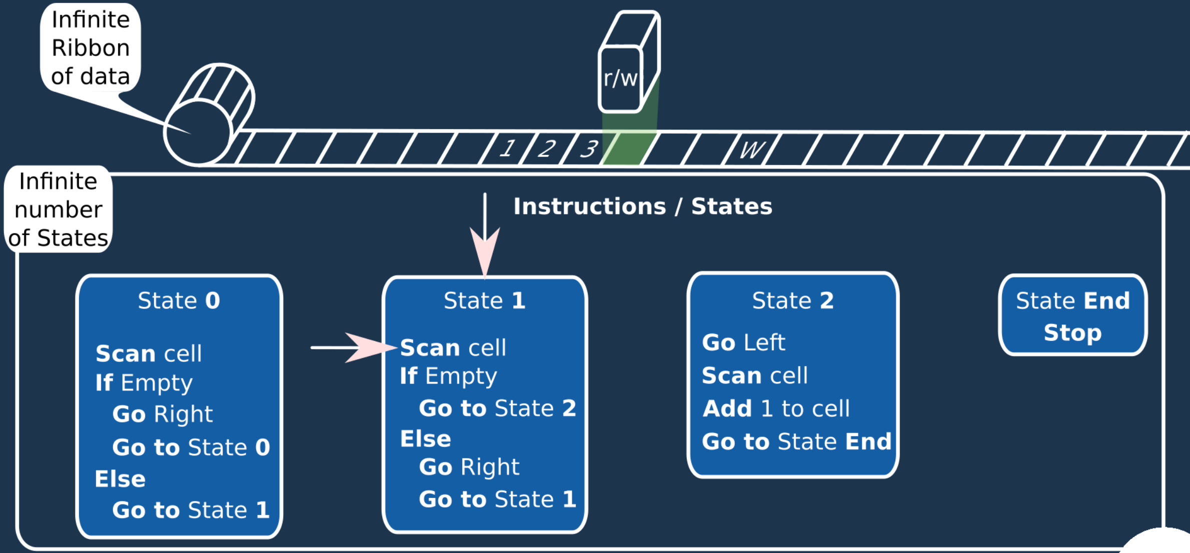

Turing Machine

Infinite Ribbon of data

Infinite number of States

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State 2
Go Left
Scan cell
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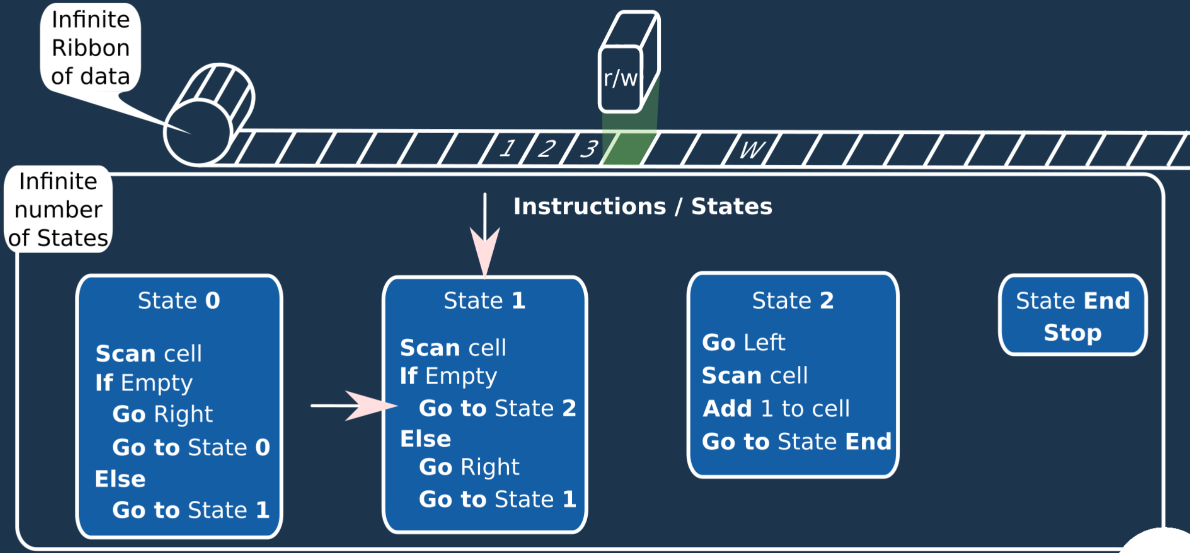
State **End**
Stop

Turing Machine



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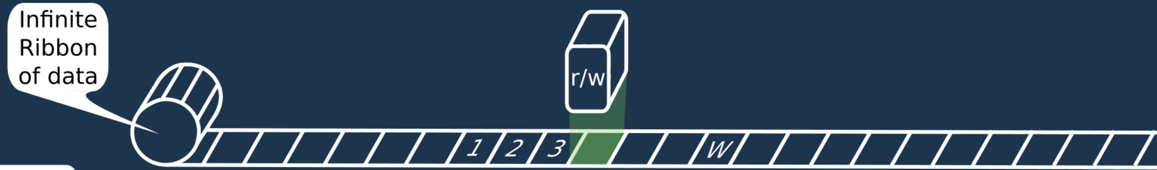

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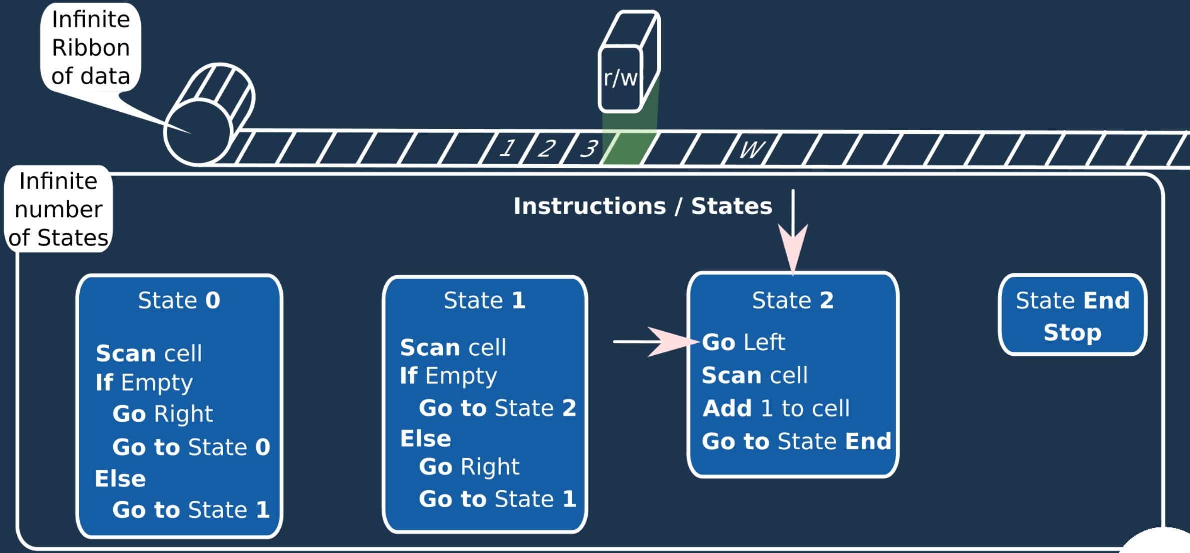

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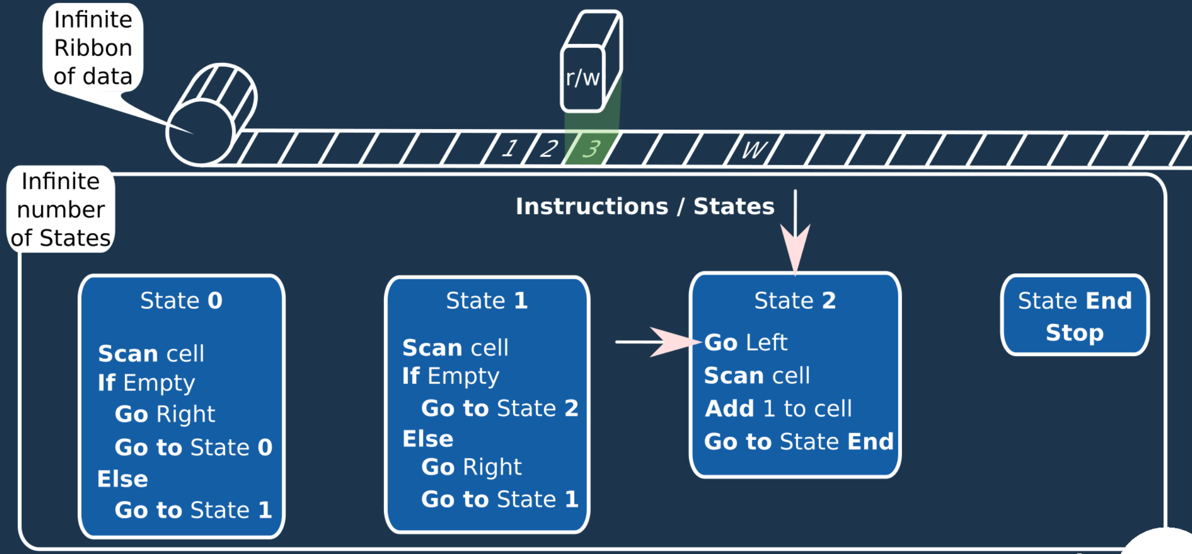

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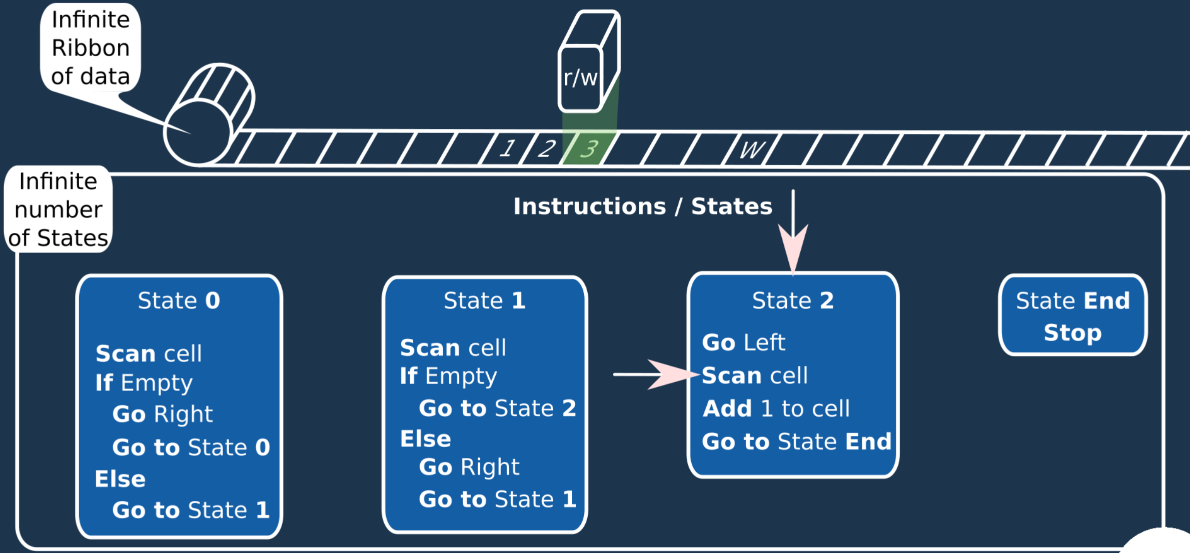

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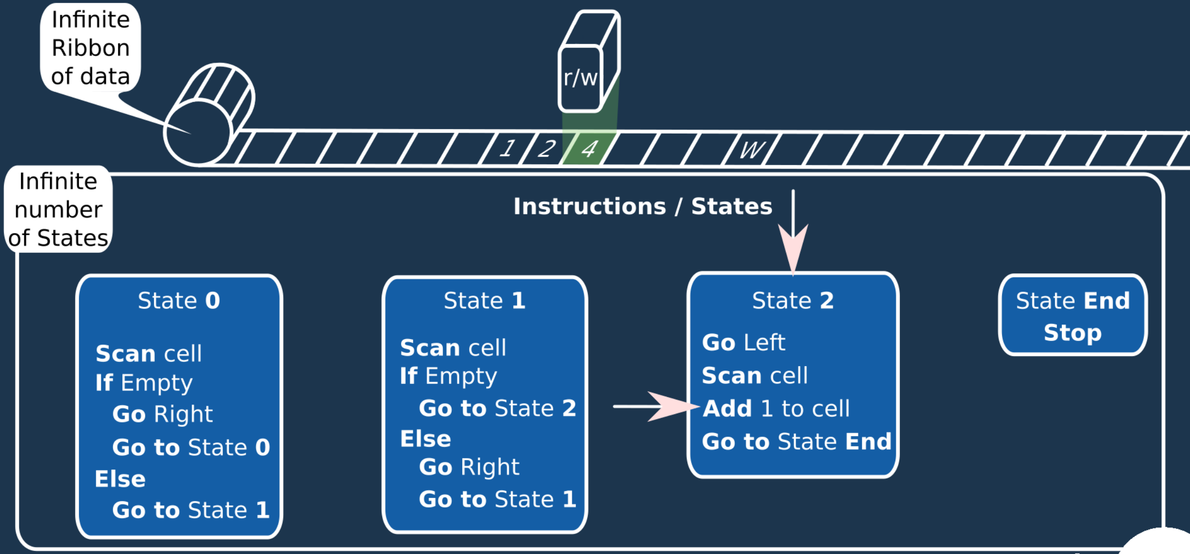

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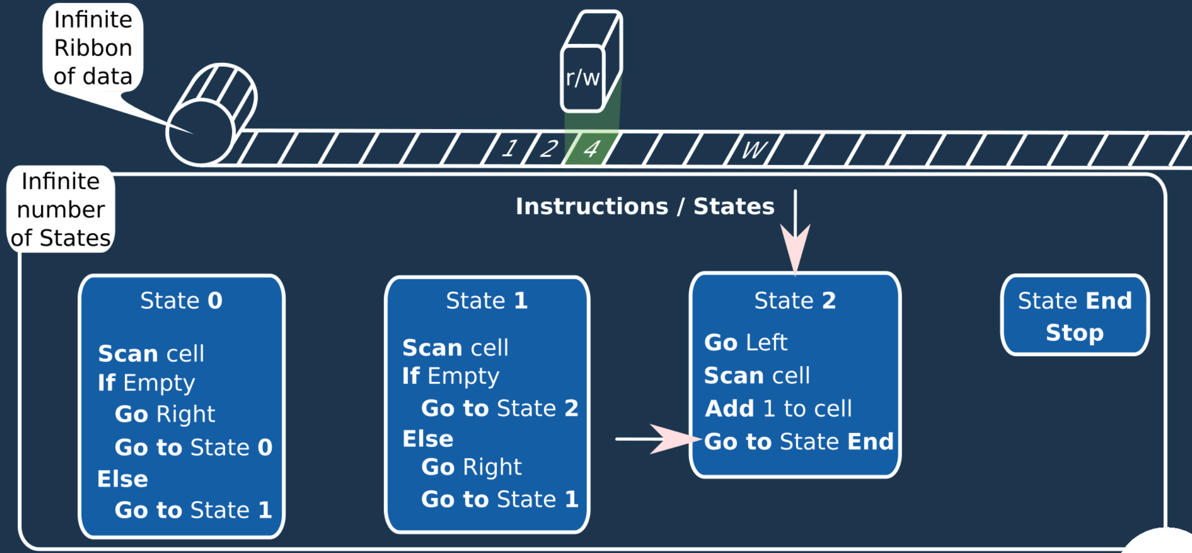

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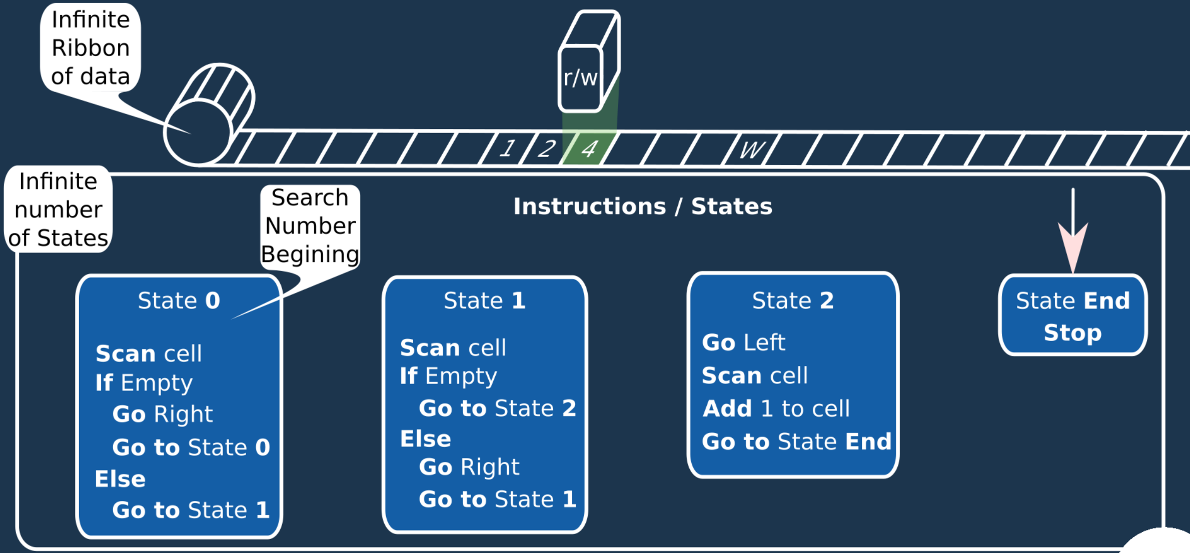

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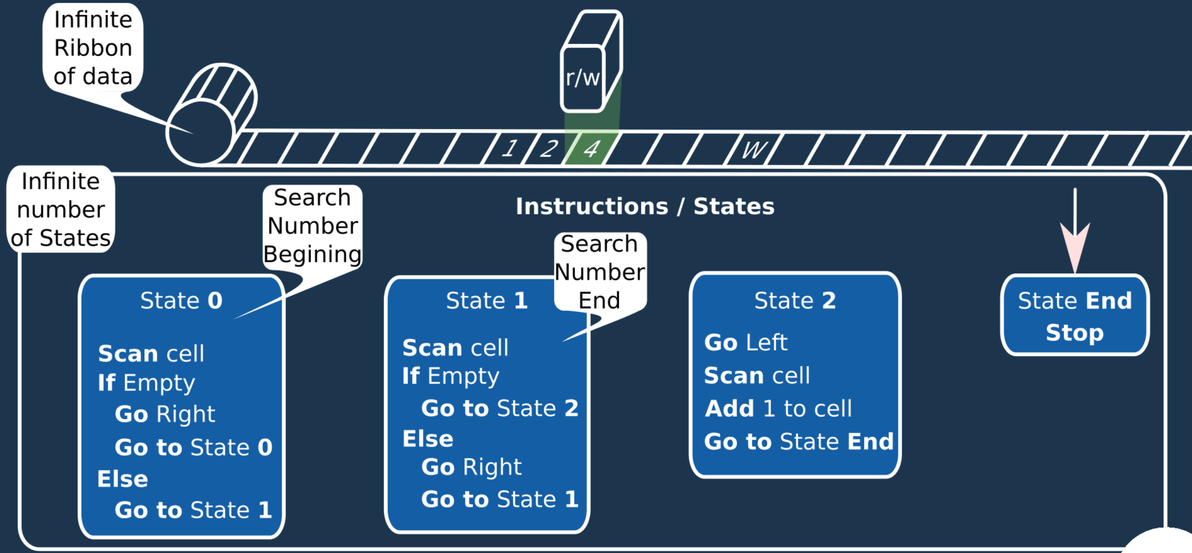

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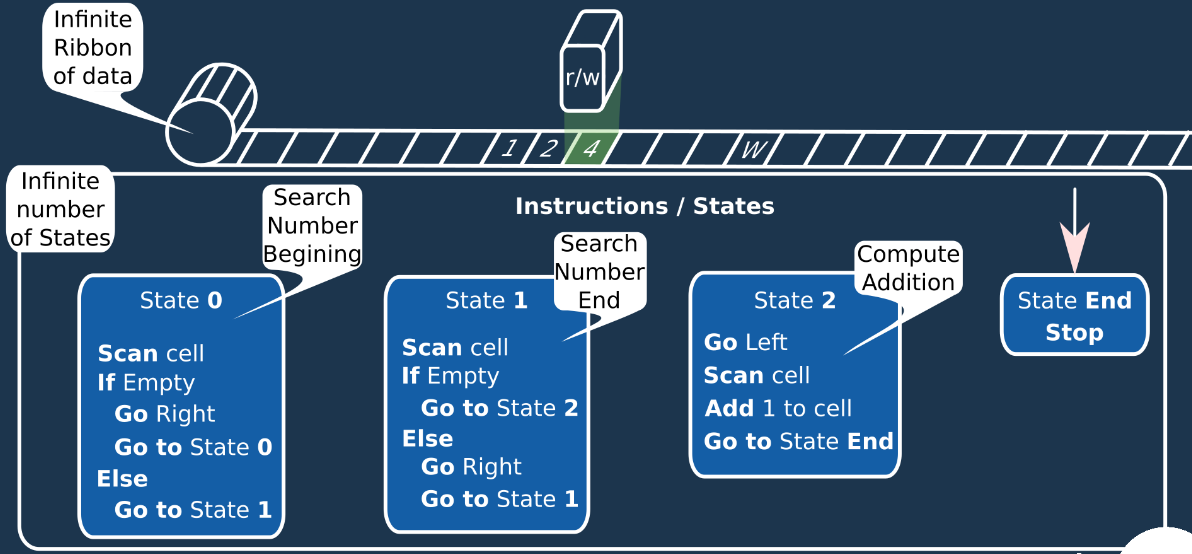

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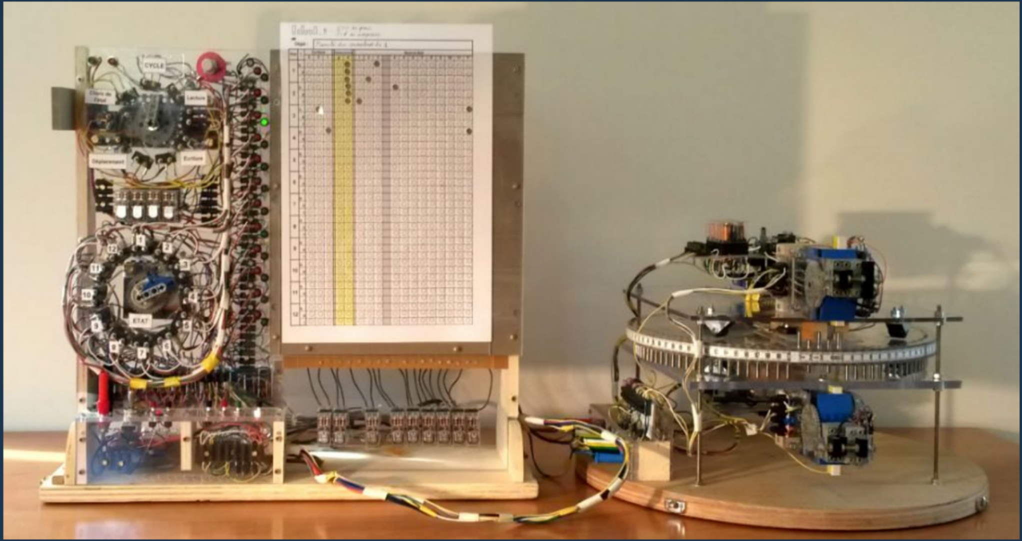

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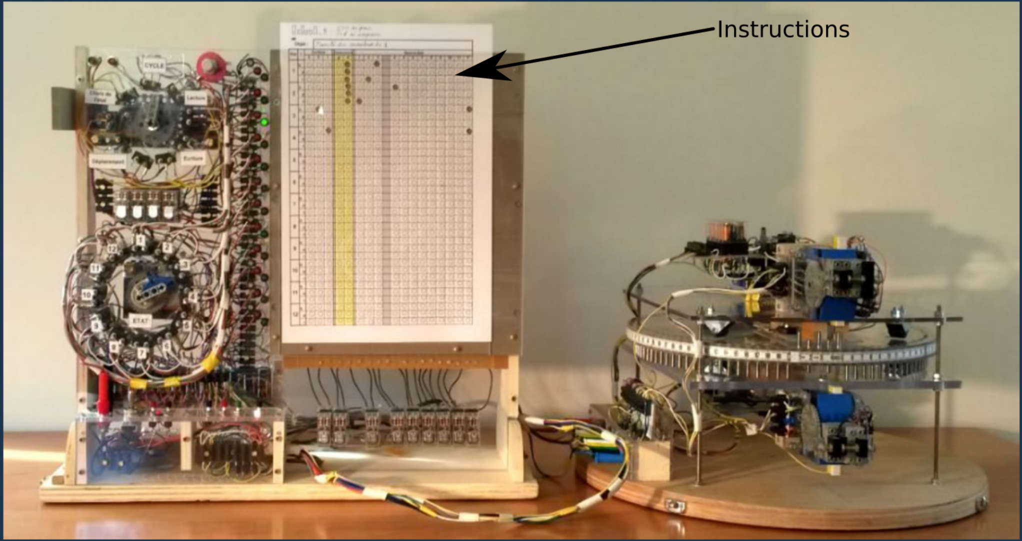

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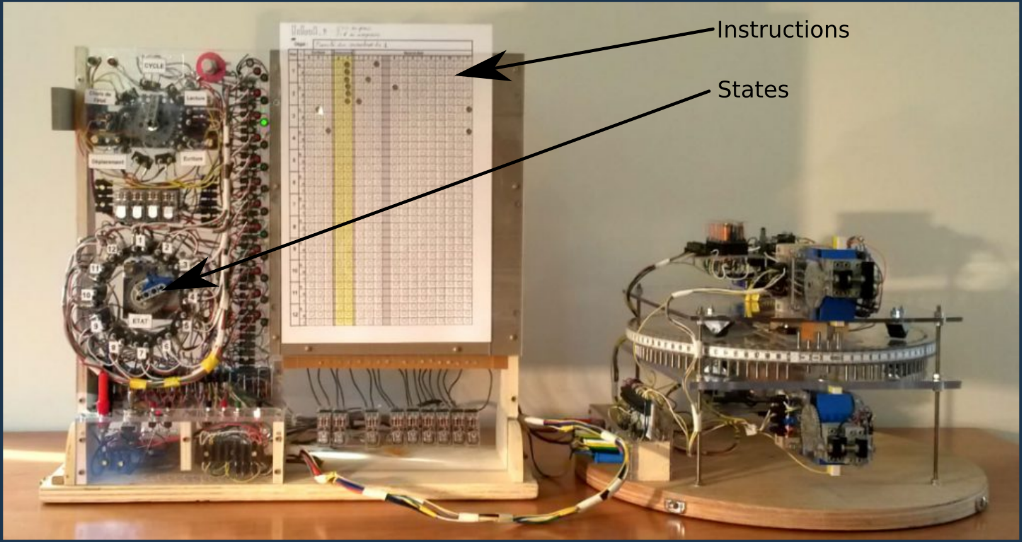

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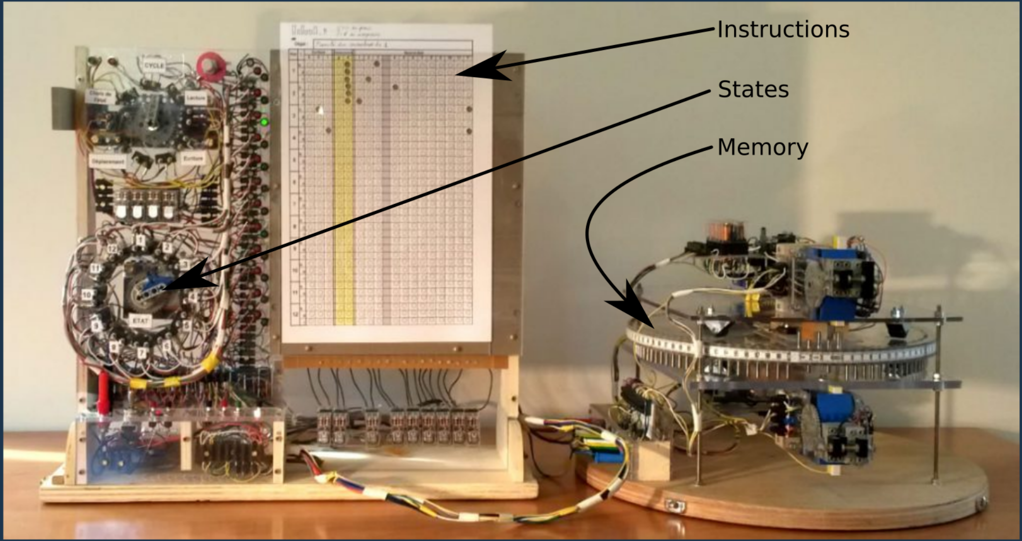

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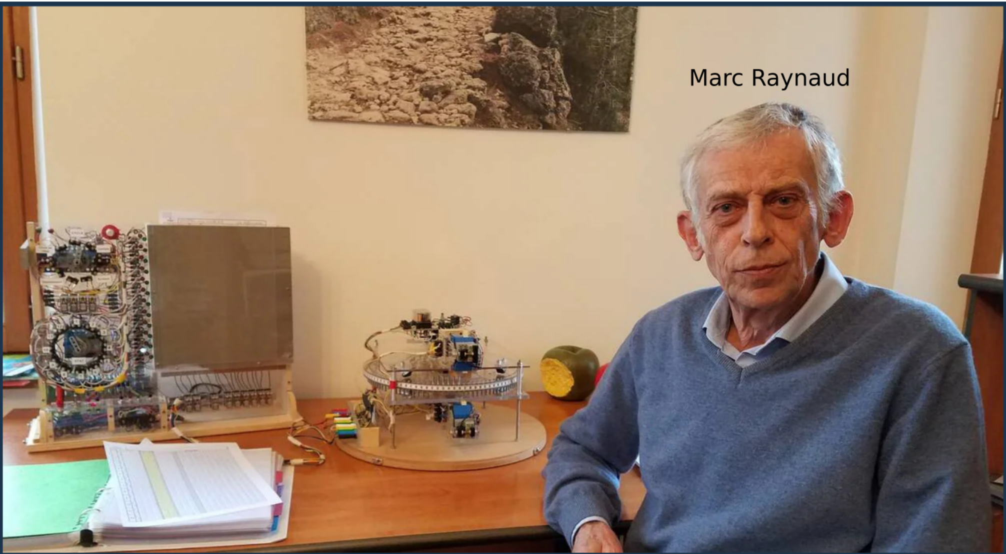
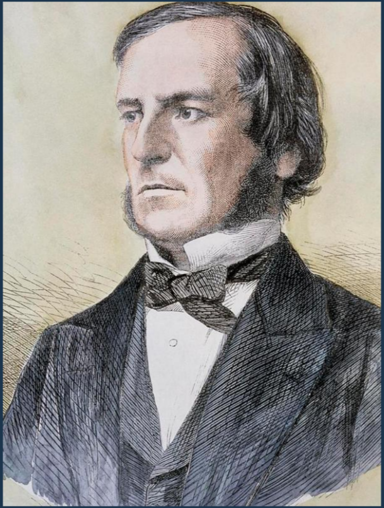


Georges Boole

Georges Boole (1815 - 1864)



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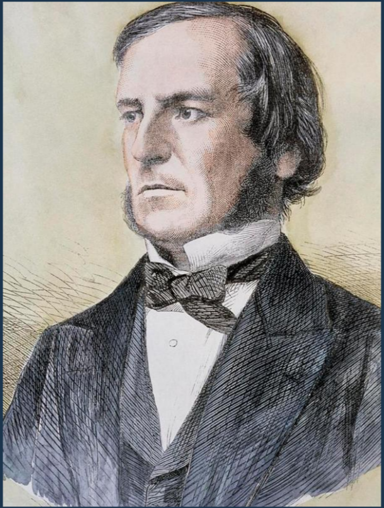
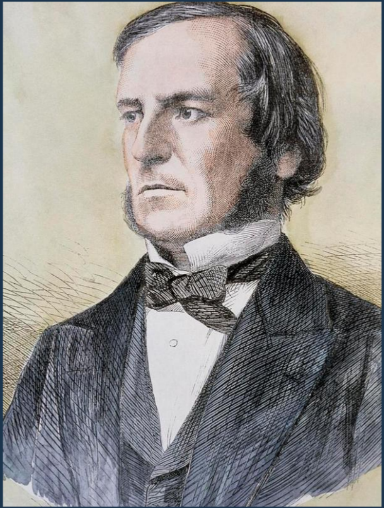


Number from basis **10** in basis **2** :

Georges Boole

Georges Boole (1815 - 1864)



Number from basis **10** in basis **2** :

74 = 70 + 4

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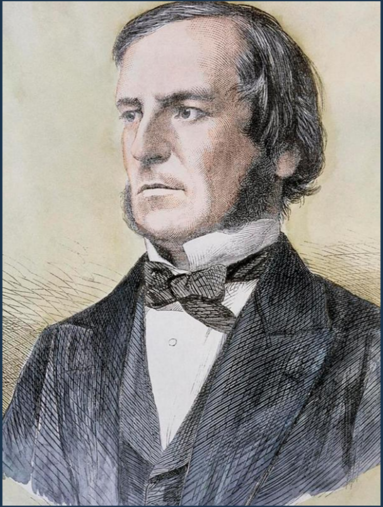

Number from basis **10** in basis **2** :

$$74 = 70 + 4$$
$$= \mathbf{7}\times 10^1 + \mathbf{4}\times 10^0$$

Georges Boole

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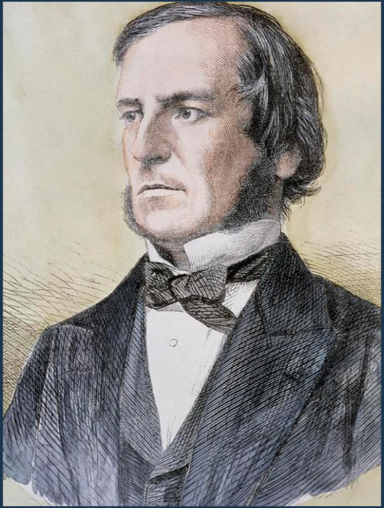

Number from basis **10** in basis **2** :

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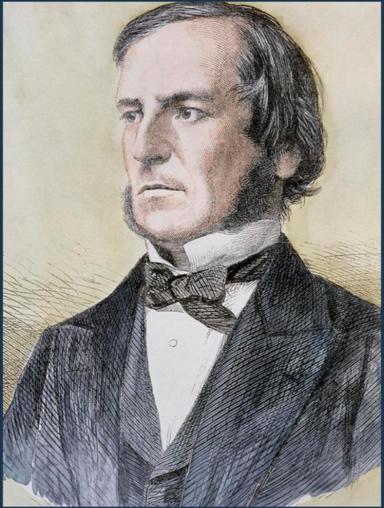

Number from basis **10** in basis **2** :

$$74 = 70 + 4$$
$$= \mathbf{7}\times 10^1 + \mathbf{4}\times 10^0$$
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$$= \mathbf{1}\times 2^6 + \mathbf{1}\times 2^3 + \mathbf{1}\times 2^1$$

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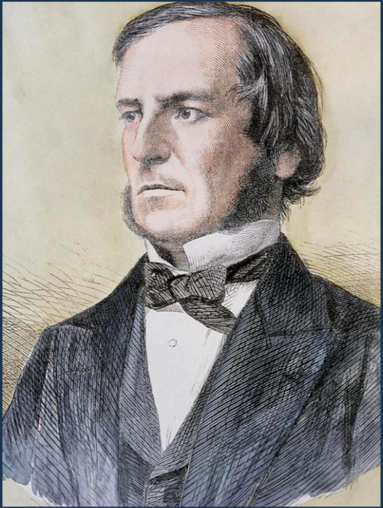

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&= \mathbf{1}\times 2^6 + \mathbf{0}\times 2^5 + \mathbf{0}\times 2^4 + \mathbf{1}\times 2^3 + \mathbf{0}\times 2^2 + \mathbf{1}\times 2^1 + \mathbf{0}\times 2^0
\end{aligned}
$$

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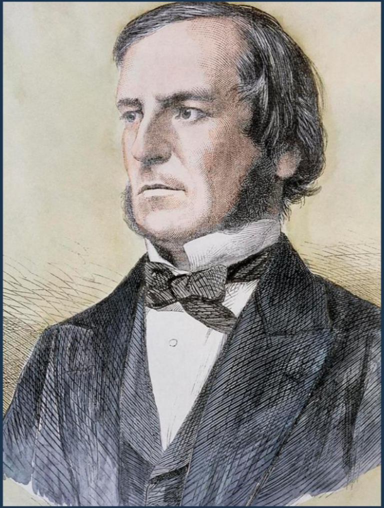

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$$74_{10} = 1001010_2$$

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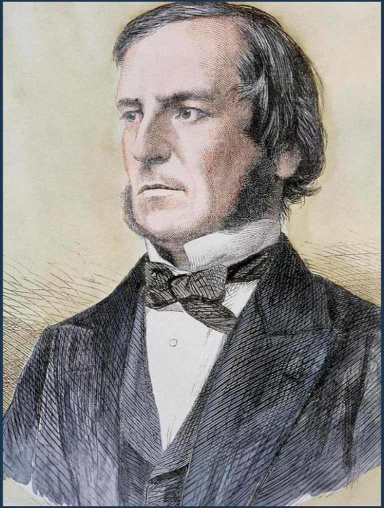

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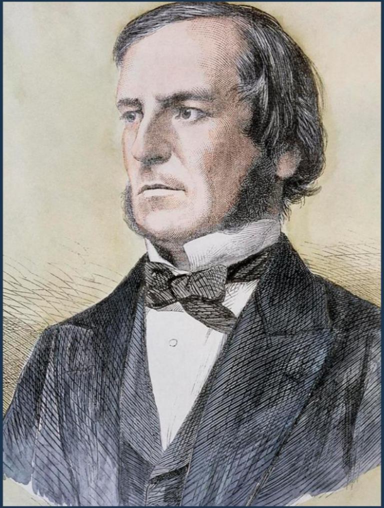
74_{10} &= 1001010_2
\end{aligned}
$$

Computing on basis **2**

Georges Boole

Georges Boole (1815 - 1864)



Number from basis **10** in basis **2** :

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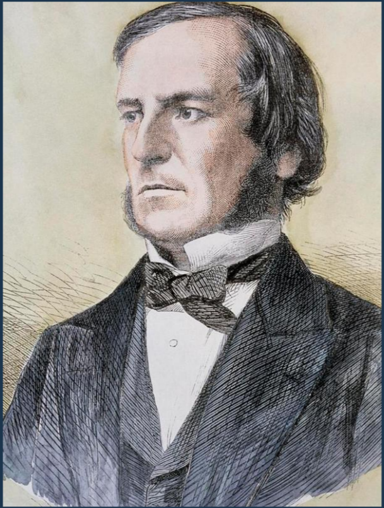
Computing on basis **2**

AND

Georges Boole

Georges Boole (1815 - 1864)



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74_{10} &= 1001010_2
\end{aligned}
$$

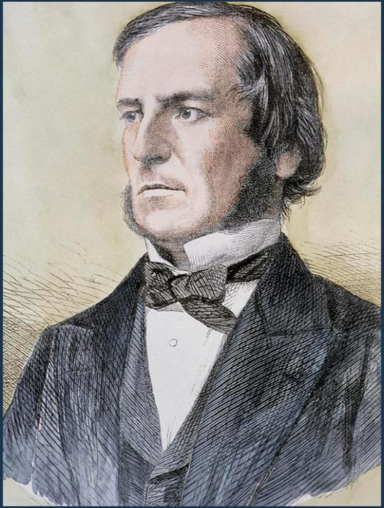
Computing on basis **2**

AND

OR

Georges Boole

Georges Boole (1815 - 1864)



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$$74_{10} = 1001010_2$$

Computing on basis **2**

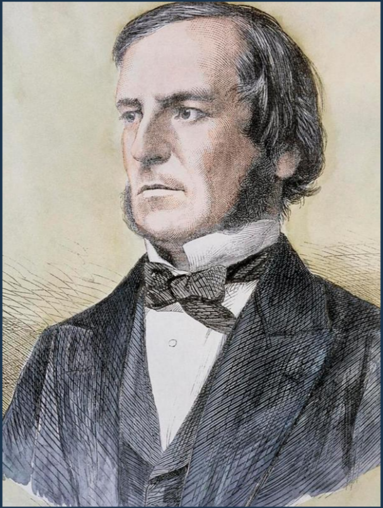
AND

OR

XOR

Georges Boole

Georges Boole (1815 - 1864)



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74_{10} &= 1001010_2
\end{aligned}
$$

Computing on basis **2**

AND

OR

XOR

NOT

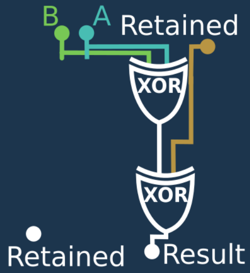
Boolean Addition

Boolean Addition

Boolean Addition

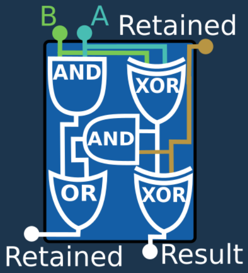
Boolean Addition

Boolean Addition

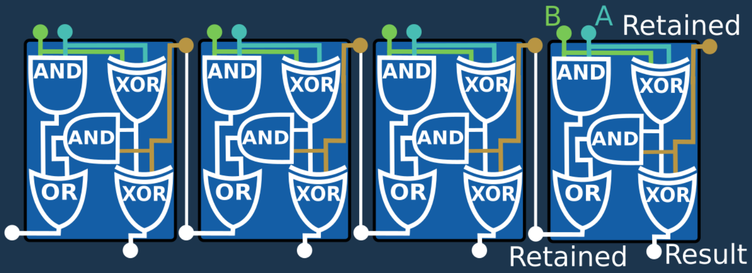


Boolean Addition

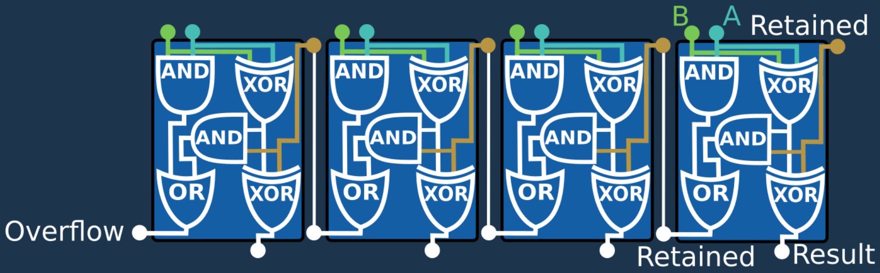
Boolean Addition



Boolean Addition

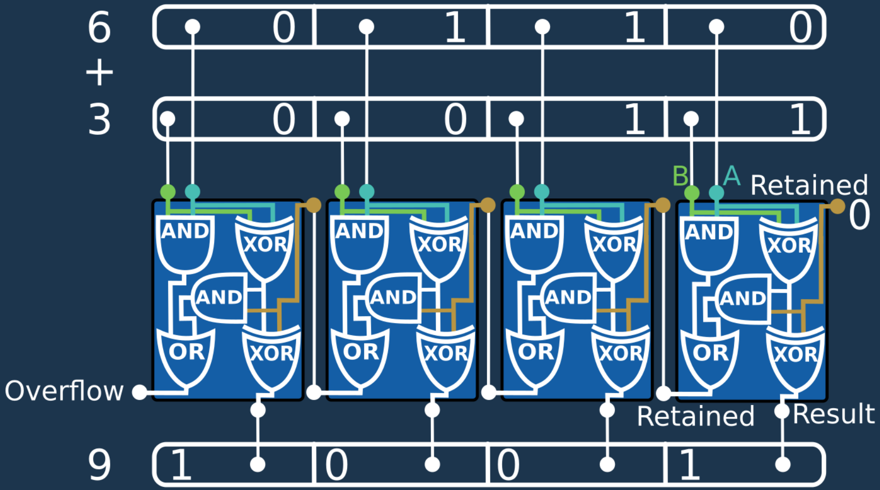


Boolean Addition



LAPP Laboratoire d'Annecy de Physique des Particules

Boolean Addition



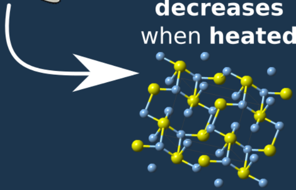
From Switch to Transistor

Switch

Switch

Michael Faraday
(1791 - 1867)

1833
Silver sulfide
Ag_2S resistance
decreases
when **heated**



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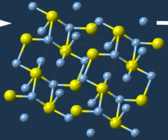


John A Fleming
(1849 - 1945)

1904

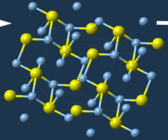
Vacuum
Tube

From Switch to Transistor

Switch

Michael Faraday (1791 - 1867)

1833
Silver sulfide
Ag_2S resistance **decreases** when **heated**



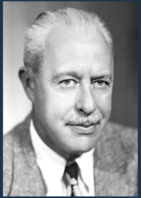
John A Fleming (1849 - 1945)

1904

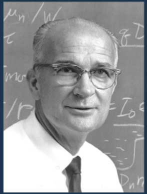
Vacuum Tube

John Bardeen (1908 - 1991)

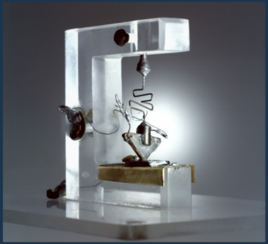
Walter H Brattain (1902 - 1987)



William Shockley (1910 - 1989)



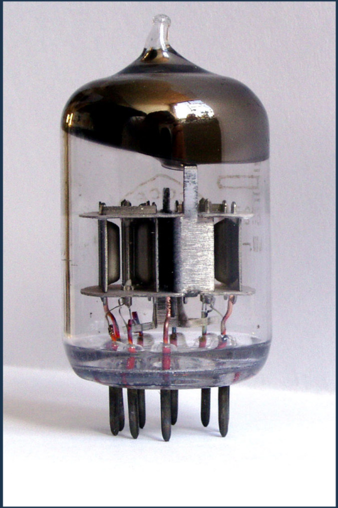
1947



Transistor

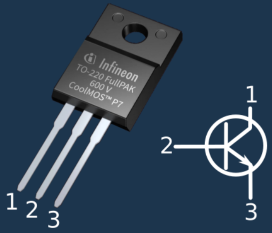
From Switch to Transistor

1904



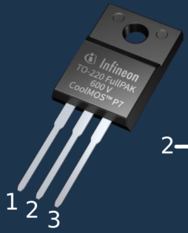
1947

From Transistor to Logical Gates


Infineon
TO-220 FullPAK
600 V
CoolMOS™ P7
1
2
3
1
2
3

From Transistor to Logical Gates

Convention :
- **0**V : **0**
- **5**V : **1**



From Transistor to Logical Gates

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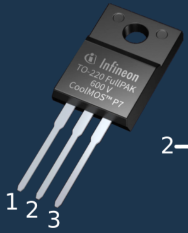
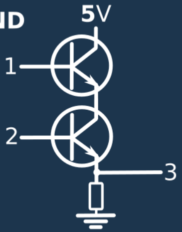


AND



From Transistor to Logical Gates

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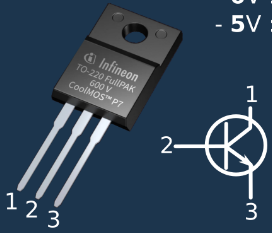

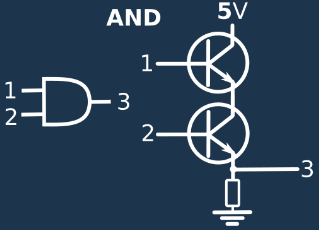

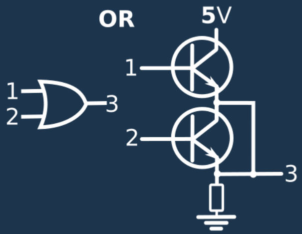

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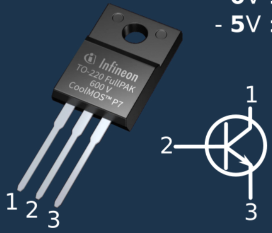
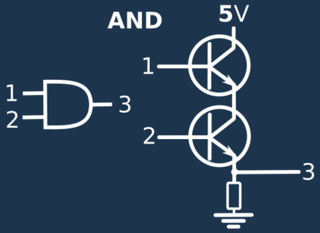
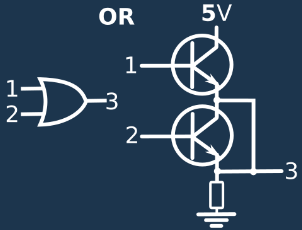


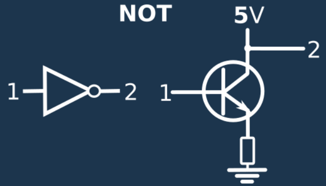
AND



OR



NOT



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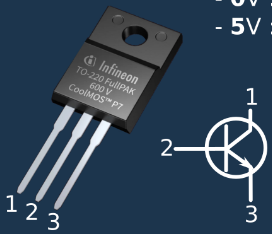
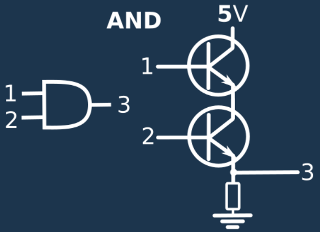
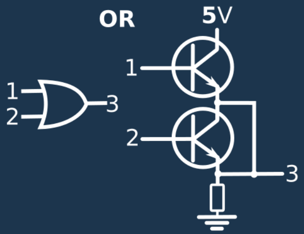
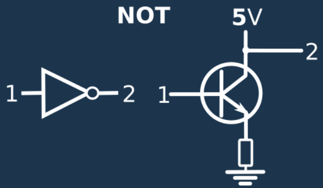
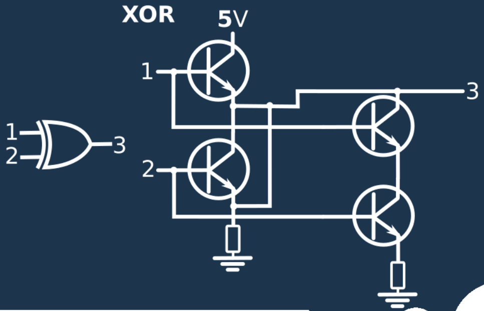










From Transistor to CPU

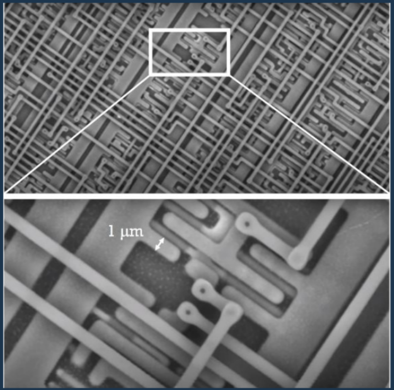
From Transistor to CPU

Transistor (3 cm)

From Transistor to CPU

Transistor (3 cm)

Transistor view from
Scanning electronic microscope



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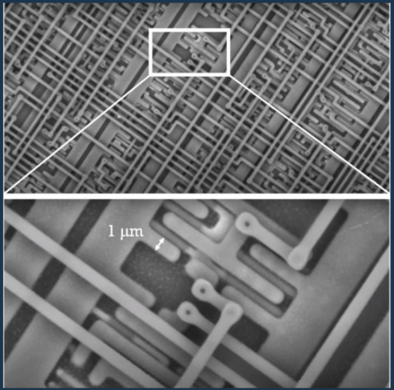
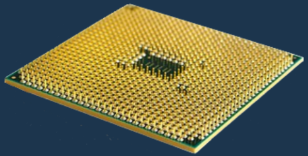


CPU (few cm)

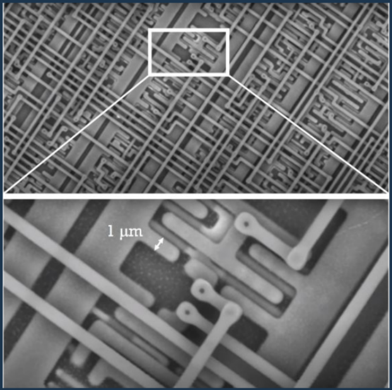


~ 1 billion transistors

From Transistor to CPU

Transistor (3 cm)

Transistor view from
Scanning electronic microscope



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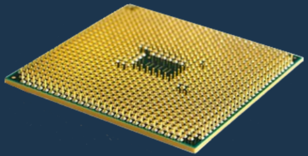
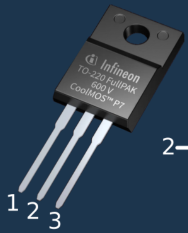


~ 1 billion transistors

Nowaday : **4** nm

Last **AMD Instinct MI300** :
146B Transistors

Memory for intermediate results



Convention :
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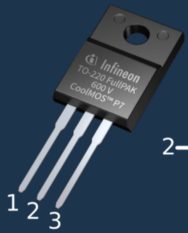
Memory for intermediate results



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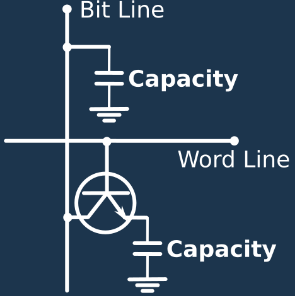
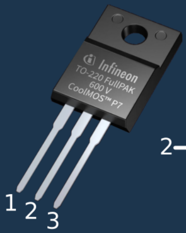
Dynamic Random Access Memory



Memory for intermediate results



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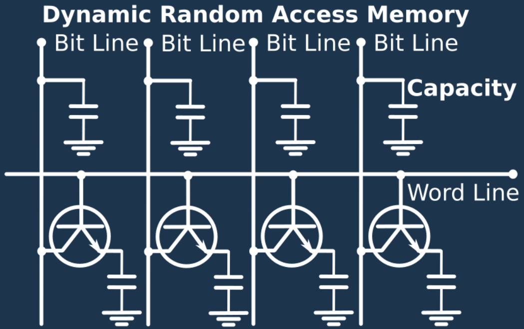
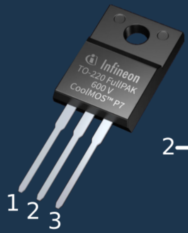


Memory for intermediate results



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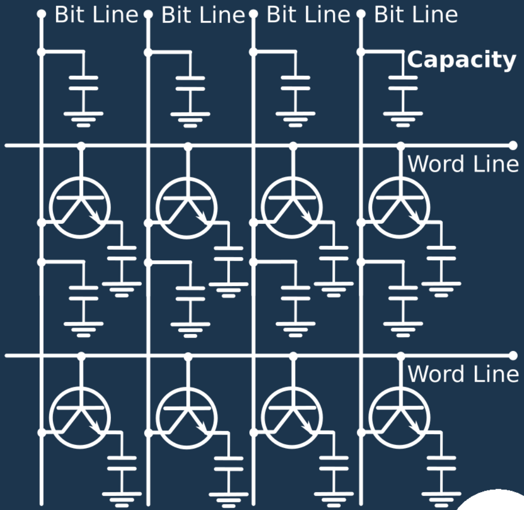
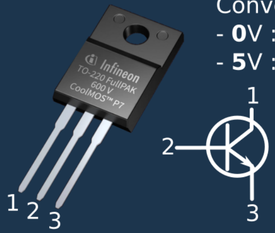


Memory for intermediate results



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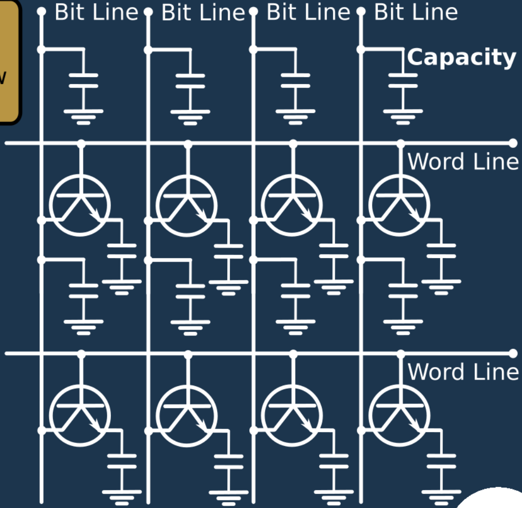
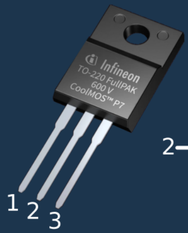
High density but need to be refreshed every few milisecond

Dynamic Random Access Memory



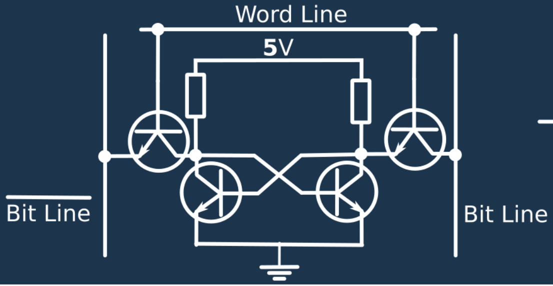
Memory for intermediate results



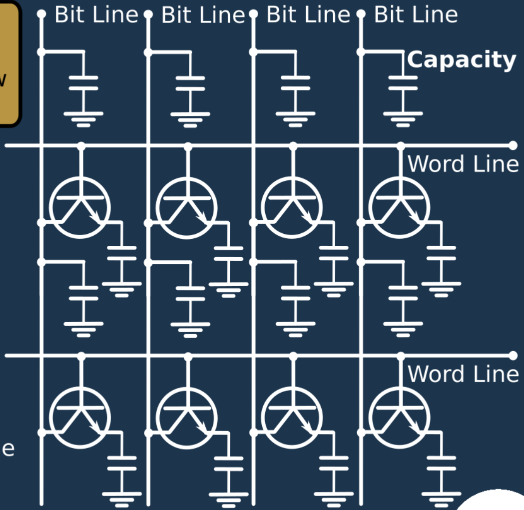
Convention :
- **0**V : **0**
- **5**V : **1**

High density but need to be refreshed every few milisecond

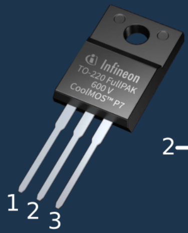
Static Random Access Memory



Dynamic Random Access Memory



Memory for intermediate results



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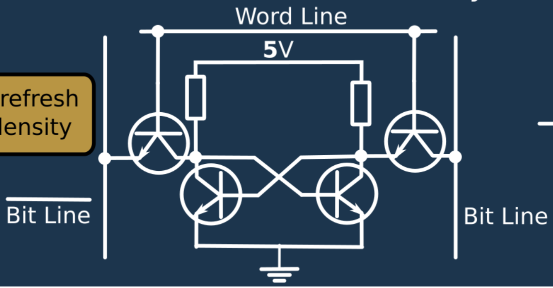
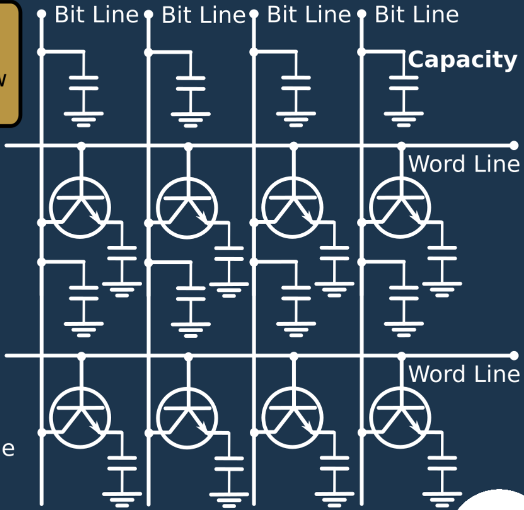


No need to refresh
but lower density

Dynamic Random Access Memory



Storage Memory

Long term information **storage**

Storage Memory

Long term information **storage**

Storage Memory

Long term information **storage**

Not easy to use

Storage Memory

Long term information **storage**

Not easy to use

Oberlin Smith
(1840 - 1926)

1888 : first
magnetic recording

Storage Memory

Long term information **storage**

Not easy to use

Oberlin Smith
(1840 - 1926)

1888 : first
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Fritz Pfleumer
(1881 - 1945)

1928 : first magnetic
tape recorder

Storage Memory

Long term information **storage**

Not easy to use

Video **H**ome **S**ystem

Oberlin Smith
(1840 - 1926)

1888 : first
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Fritz Pfleumer
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1928 : first magnetic
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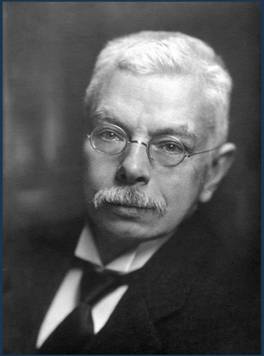
Storage Memory

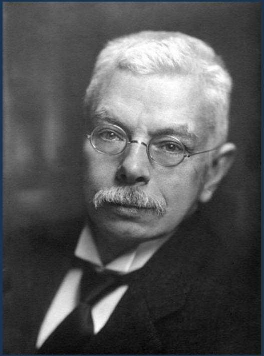
Pieter Zeeman
(1865 - 1943)



Storage Memory

1896 : What happens to the **spectrum** of an atom in a **magnetic field** ?

Pieter Zeeman
(1865 - 1943)



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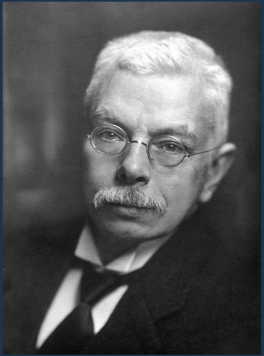
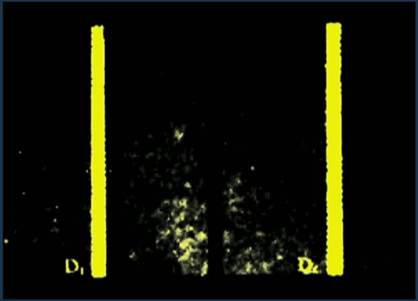


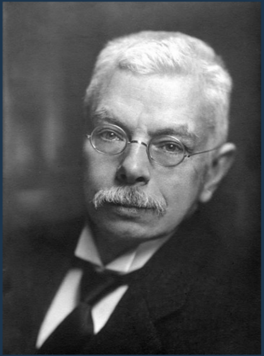
Sodium Spectrum



No magnetic field

1896 : What happens to the **spectrum** of an atom in a **magnetic field** ?

Pieter Zeeman
(1865 - 1943)



Sodium Spectrum

With **magnetic field**

Storage Memory

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Pieter Zeeman
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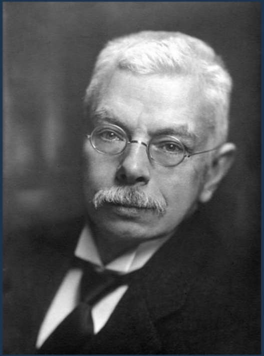

Enrik Lorentz
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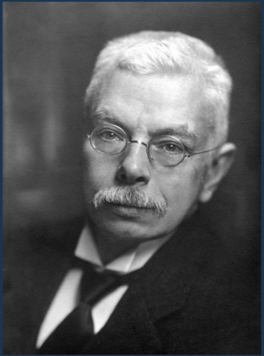
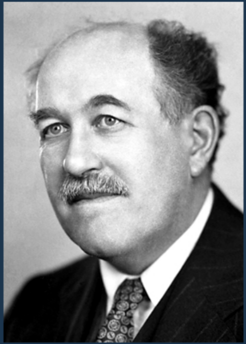


Enrik Lorentz (1853 - 1928)

Otto Stern (1888 - 1969)

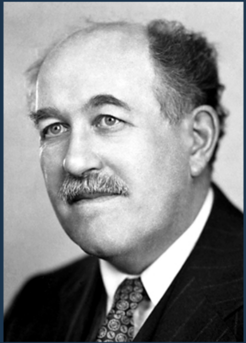


Walther Gerlach (1889 - 1979)

Storage Memory

1896 : What happens to the **spectrum** of an atom in a **magnetic field** ?

Otto Stern (1888 - 1969)



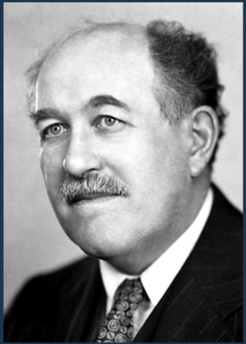
Walther Gerlach (1889 - 1979)

Storage Memory

1896 : What happens to the **spectrum** of an atom in a **magnetic field** ?

Stove

Otto Stern
(1888 - 1969)



Walther Gerlach
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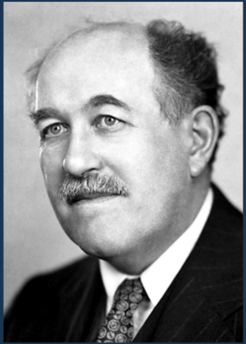
Storage Memory

Otto Stern
(1888 - 1969)



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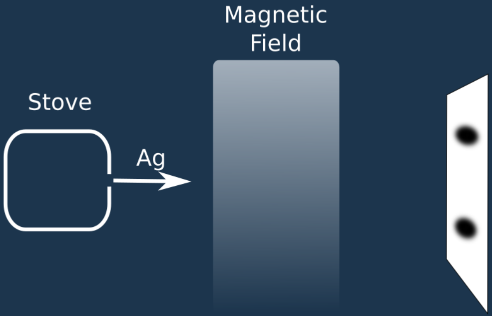
Storage Memory



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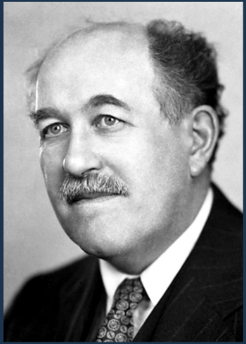

Walther Gerlach
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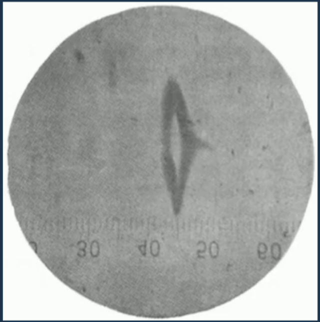
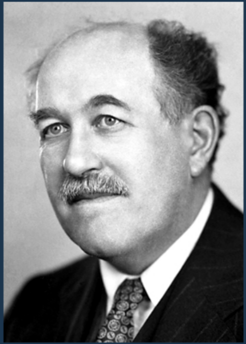
Storage Memory



Atom is quantized

Otto Stern
(1888 - 1969)



Walther Gerlach
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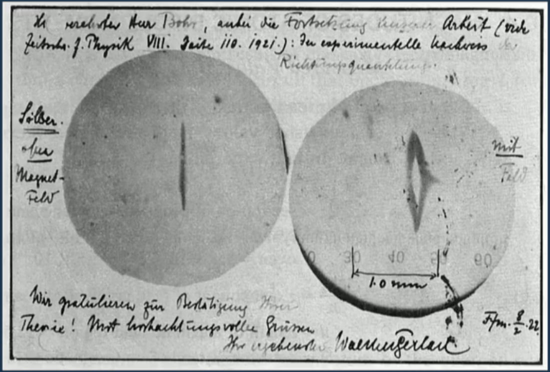
Storage Memory



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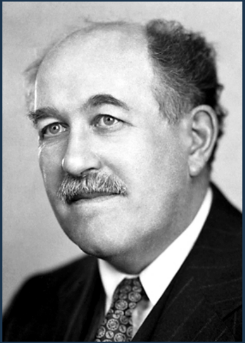

Walther Gerlach
(1889 - 1979)

Storage Memory

Wolfgang Pauli (1900 - 1958)	George Uhlenbeck (1900 - 1988)	Samuel Goudsmit (1902 - 1978)

Atom is a **quantum magnet**

Storage Memory

Wolfgang Pauli
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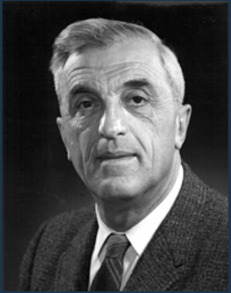
Atom is a **quantum magnet**

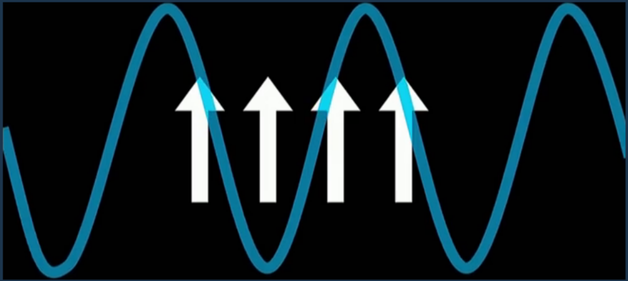
Felix Bloch
(1905 - 1983)



1946 : How behaves an electron in a metal ?

Storage Memory

Spin resonance with microwaves



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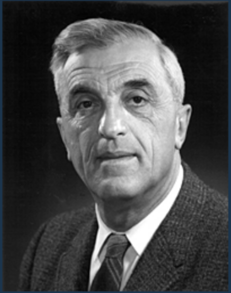

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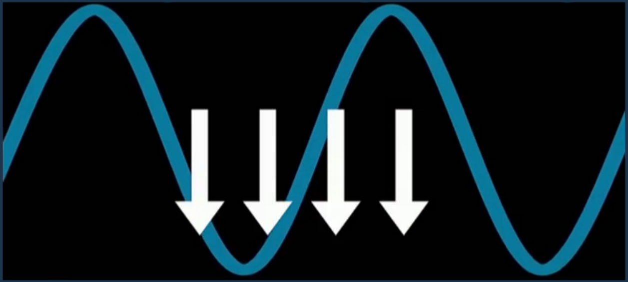

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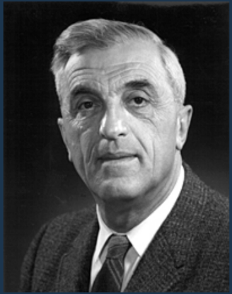

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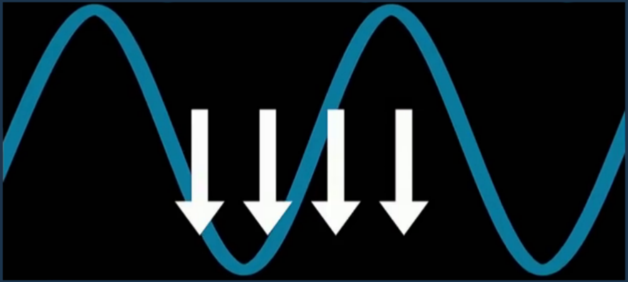
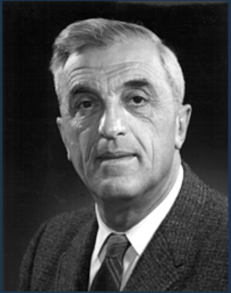


The right frequency **flips** the **spin**

Felix Bloch
(1905 - 1983)



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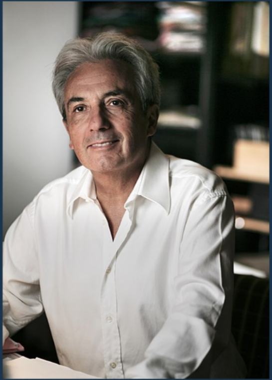
Storage Memory

Albert Fert
(1938 -)



1988 : Can **spins** be manipulated with **electric currents** ?

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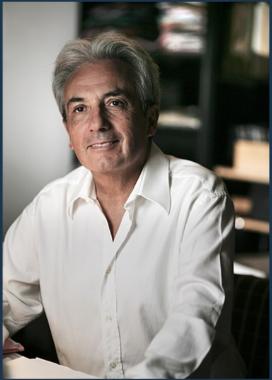

1988 : Can **spins** be manipulated
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Spintronics

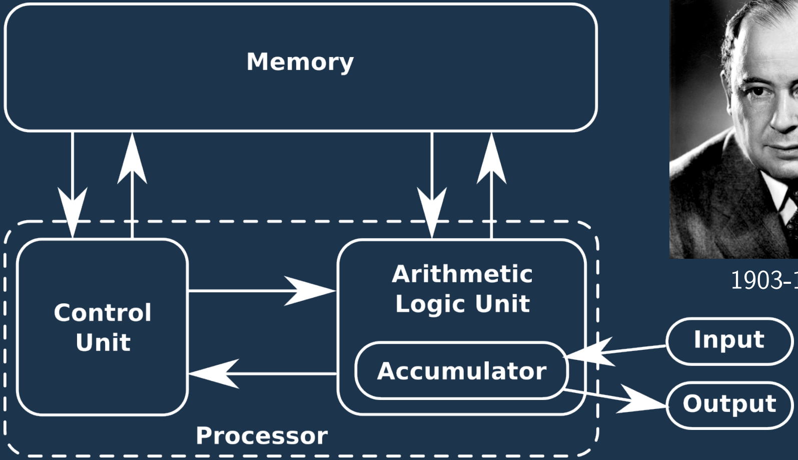
Use **spins** to **store information**

Giant **m**agneto**r**esistance (GMR)

Used is all Reading head of **H**ard **D**isk **D**rive

Computing Processing Unit (CPU)

John Von Neumann architecture (1945)



1903-1957

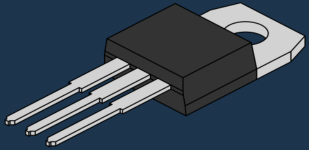
Grace Hopper

Grace Hopper (1906 - 1992)

- Developed First Compiler
- **Cobol** language

COBOL PROGRAMMING

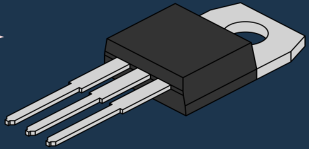
Transistor



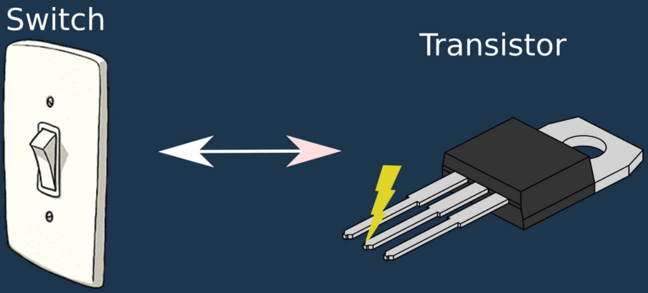
From Transistor to Computing Hardware

Switch

Transistor



From Transistor to Computing Hardware



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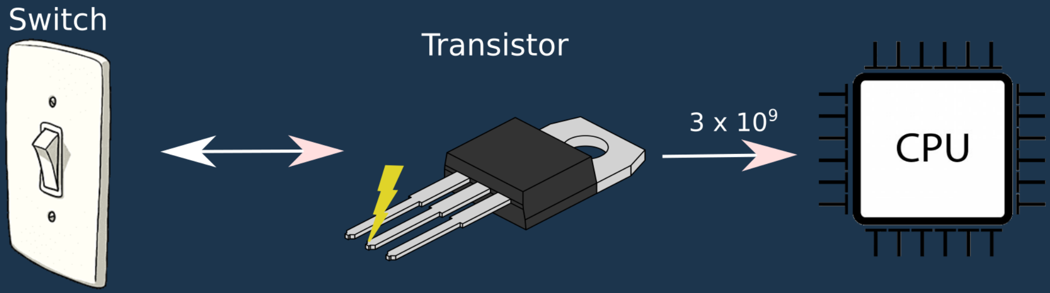
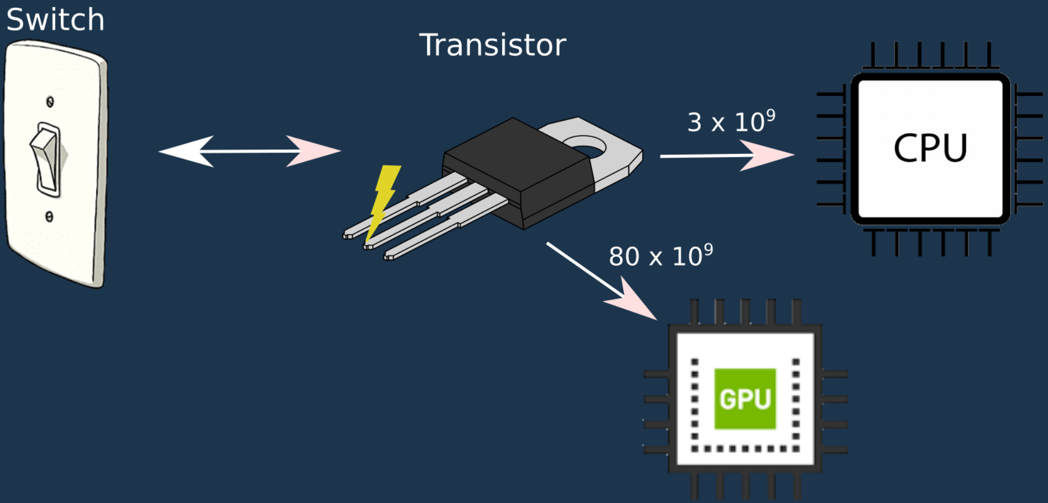
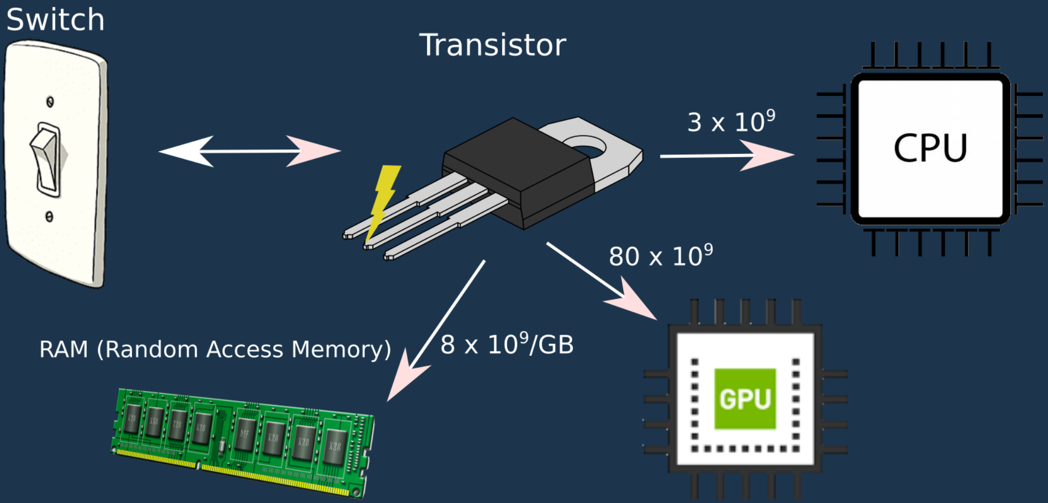


From Transistor to Computing Hardware

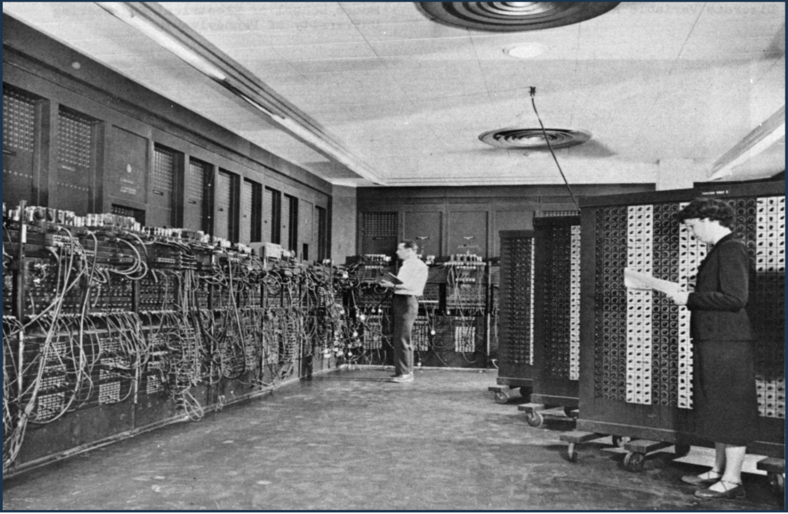


From Transistor to Computing Hardware



ENIAC

1945



Electronic
Numerical
Integrator
And
Computer

Input/Output with perforated paper

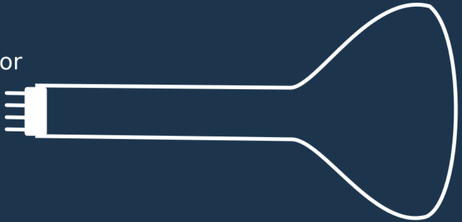
Cathode Ray Tube

Boris Rosing (1869 - 1933)

Cathode Ray Tube

Boris Rosing (1869 - 1933)

Invented in **1907**

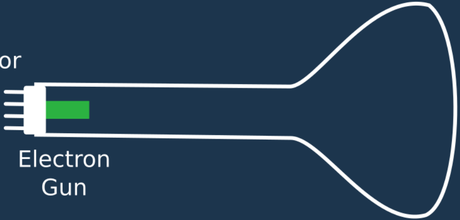


LAPP
Laboratoire d'Annecy de Physique des Particules

Cathode Ray Tube

Invented in **1907**

Boris Rosing (1869 - 1933)



Cathode Ray Tube

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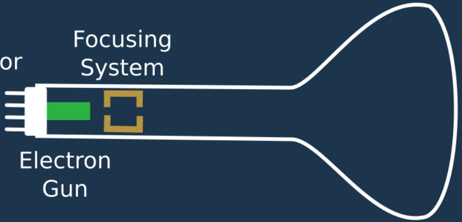

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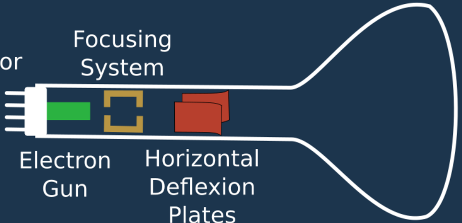

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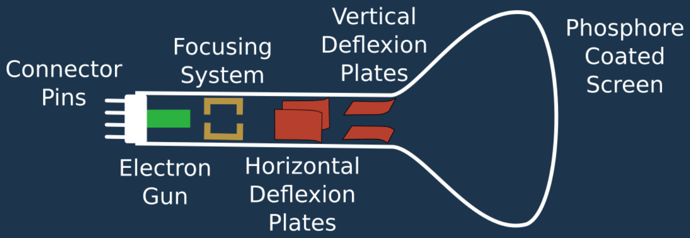

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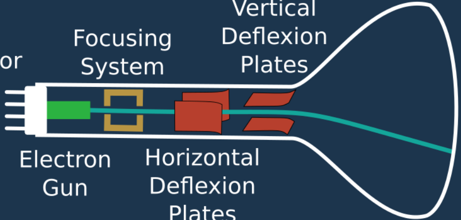

Cathode Ray Tube

Invented in **1907**

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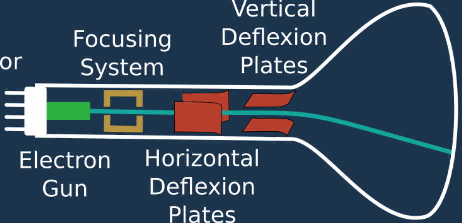
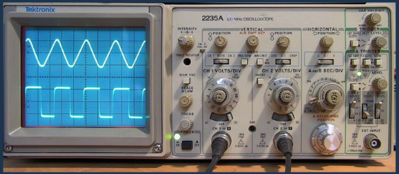


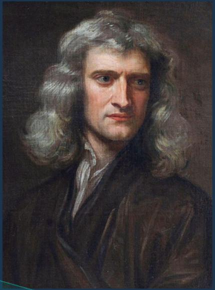
Oscilloscope

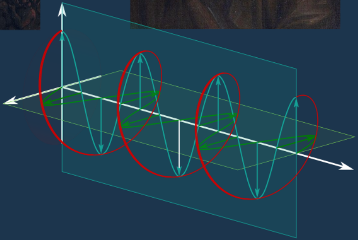


Television

Light Polarization

Rasmus Bartholin (1625 - 1698)	Christian Huygens (1629 - 1695)	Isaac Newton (1642 - 1727)	Augustin Fresnel (1788 - 1827)





Liquid Crystal

Otto Lehmann (1855 - 1922)

1888 : **Liquid Crystal** discovery

Liquid Crystal

Otto Lehmann (1855 - 1922)

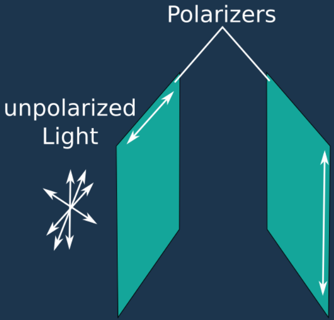
unpolarized
Light

1888 : **Liquid Crystal** discovery

Liquid Crystal

Otto Lehmann (1855 - 1922)

1888 : **Liquid Crystal** discovery



Liquid Crystal

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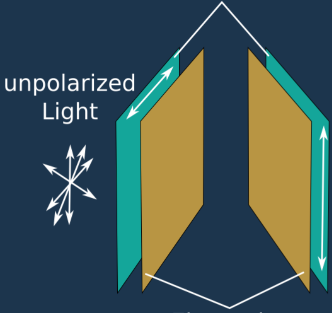

1888 : **Liquid Crystal** discovery

Liquid Crystal

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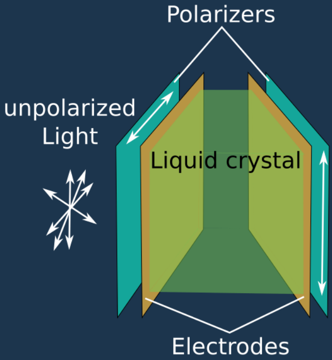

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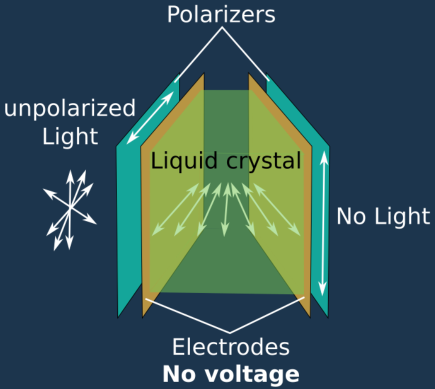

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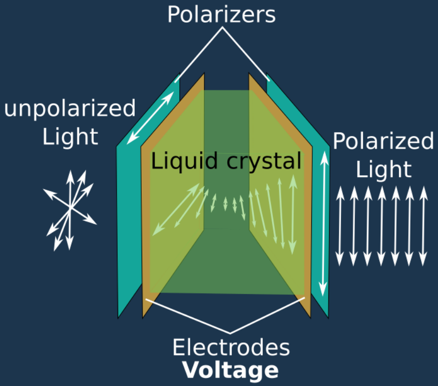

1888 : **Liquid Crystal** discovery

Liquid Crystal

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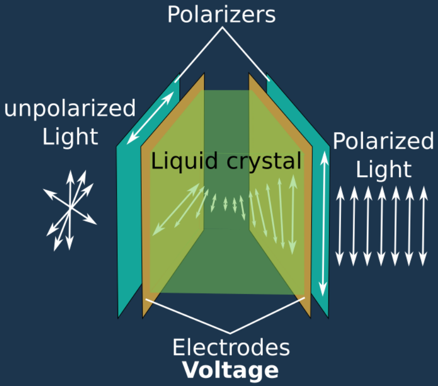
1888 : **Liquid Crystal** discovery



One colored pixel

Liquid Crystal

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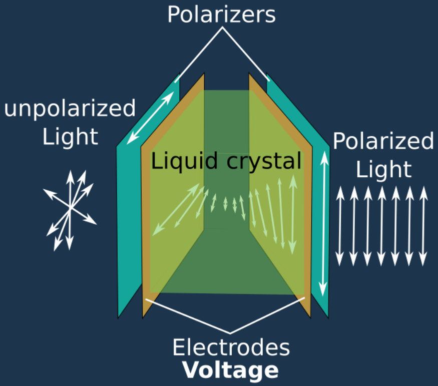


One colored pixel

Modern screen

Liquid **C**rystal **D**isplay (LCD)

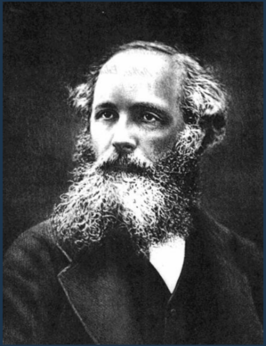
Electromagnetism

André-Marie Ampère
(1775 - 1836)

Carl Friedrich Gauss
(1777 - 1855)

Michael Faraday
(1791 - 1867)

James Clerk Maxwell
(1831 - 1879)



Wireless Telegraphy

Samuel Morse
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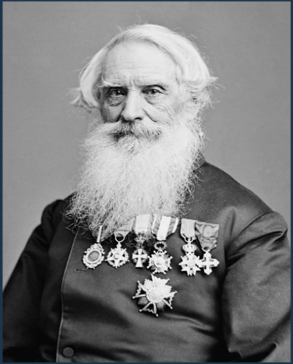

- Electric **telegraph**
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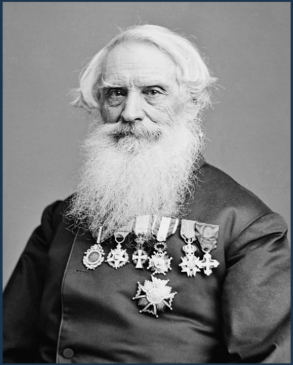

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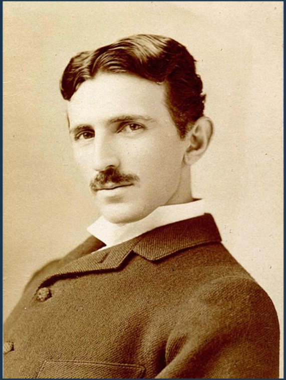

One of the first to make
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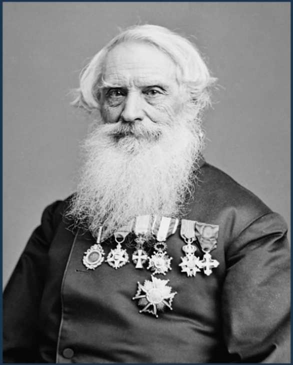

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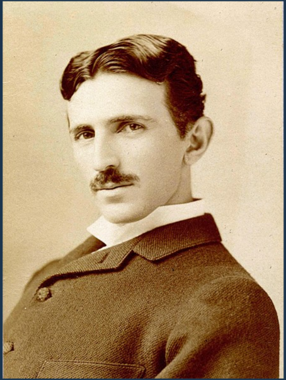

One of the first to make
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Guglielmo Marconi
(1874 - 1937)

One of the inventors of :
- **Radio**
- **Wireless telegraphy**

Safer wireless communication

Hedy Lamarr (1914 - 2000)

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Vincente Minnelli, 1946

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Solution :
- **Change channel** on the fly

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Solution :
- **Change channel** on the fly

- First use by **military**
- Basis of **Wifi** communication

Optic Fiber

Jacques Babinet
(1794 - 1872)

Daniel Colladon
(1802 - 1893)

First Light guide using refraction
in 1840s

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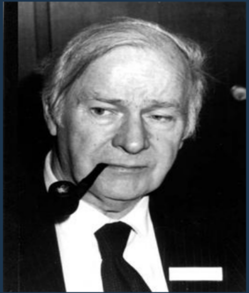

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1953 : First **image transmission**
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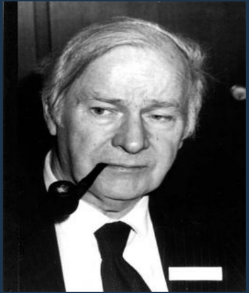

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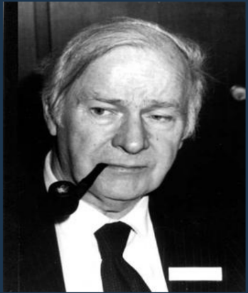

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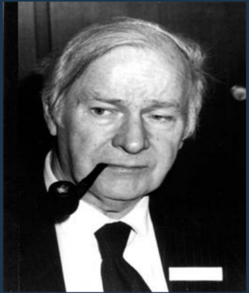

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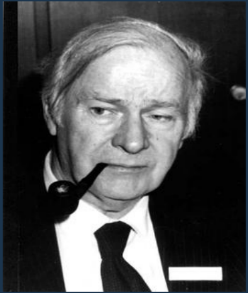

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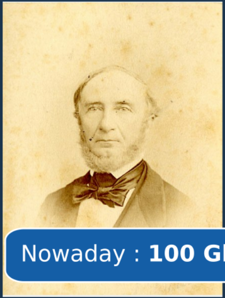

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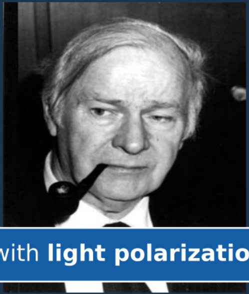

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Nowaday : **100 Gbit/s** with **light polarization**

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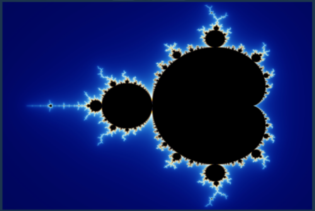
Fractals

Benoît Mandelbrot
(1924 - 2010)



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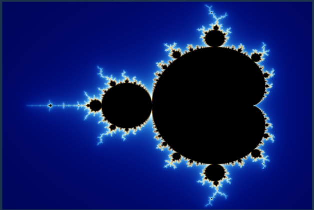

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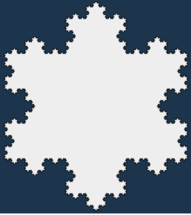

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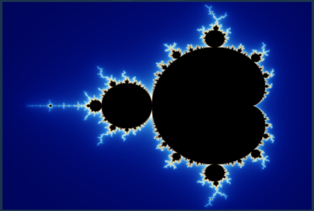

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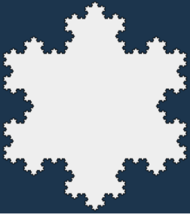
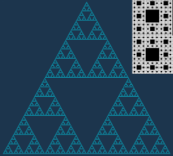
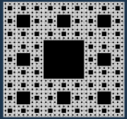


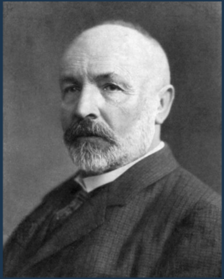
Wacław Sierpiński
(1882 - 1969)

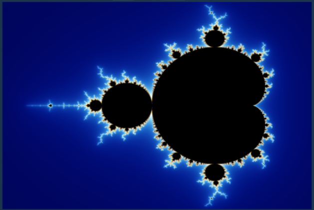


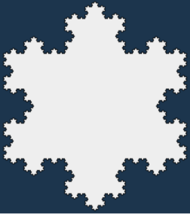


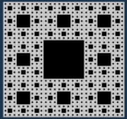
Fractals

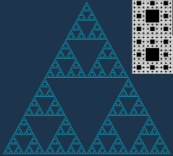
Benoît Mandelbrot (1924 - 2010)	Helge von Koch (1870 - 1924)	Wacław Sierpiński (1882 - 1969)	Georg Cantor (1845 - 1918)





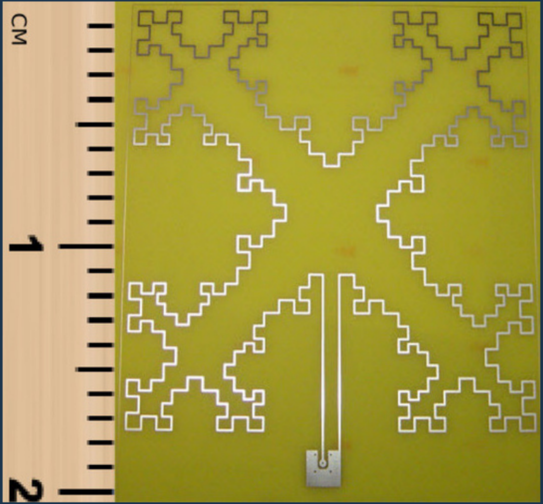






Fractals

Multiband / **wideband** antenna



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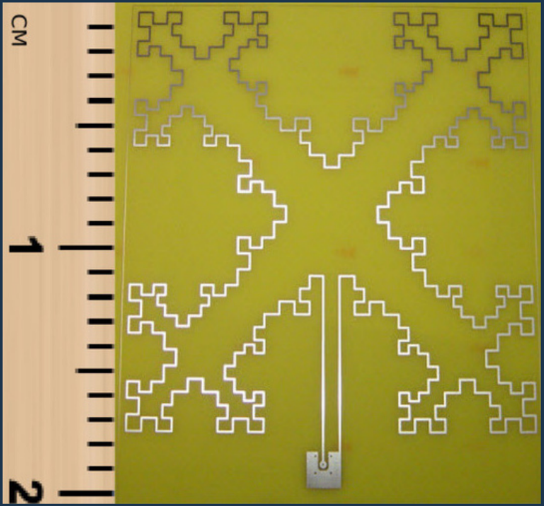
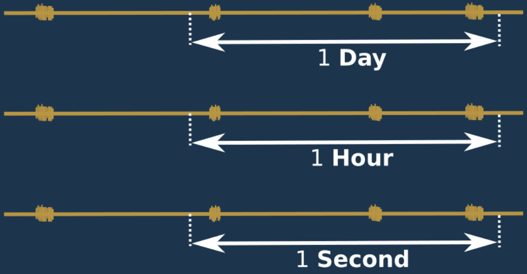


Denoising commnunications

First **IBM** data transmission *via* **telegraphic wires**

Mandelbrot found :
noise is a **self repeated pattern**



Classical Computer : Time Scale

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Pascaline (1645) -> **computer** (1945)

300 years

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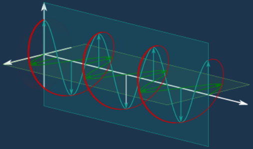

267 years

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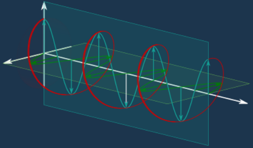

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Zeeman Effect (1896) -> **Hard Disk Drive** (1988)

92 years

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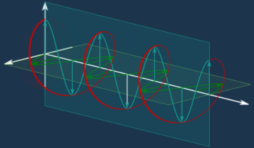

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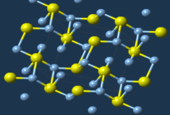

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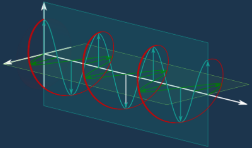

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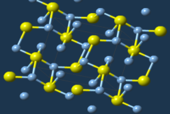
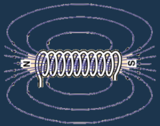


114 years

Electromagnetism (1860) -> **Wifi** (1997)



137 years

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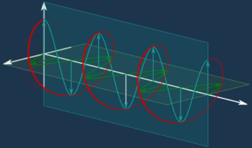

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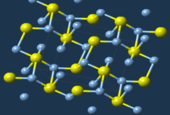
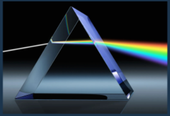
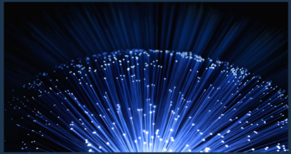


114 years

Light Guide (1840) -> **Optic Fiber** (1953)



113 years



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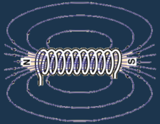

137 years

(Some) Involved people

44

Quantum Physics

Quantum Physics

Describes the behaviour of the matter at **microscopic** scale (electron, photon, atom, etc)

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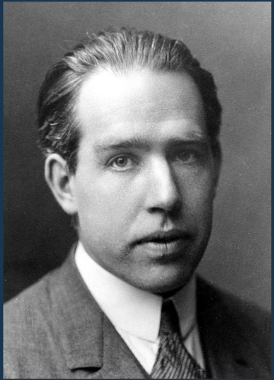
Quantum States

Niels Bohr (1885 - 1962)



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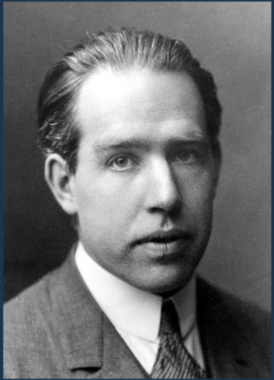
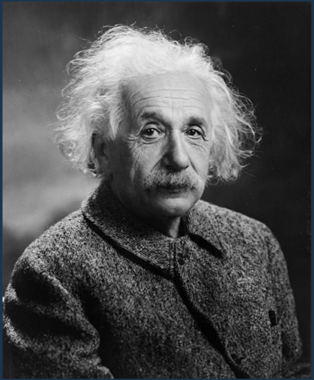


Photo-electric effect

Albert Einstein (1879 - 1955)



LAPP Laboratoire d'Annecy de Physique des Particules

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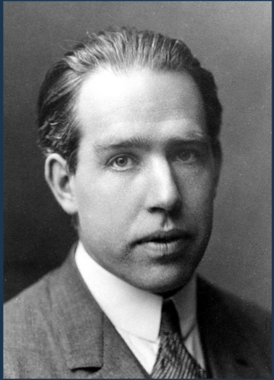

LASER

Light
Amplification by
Stimulated
Emission of
Radiation

Photo-electric effect

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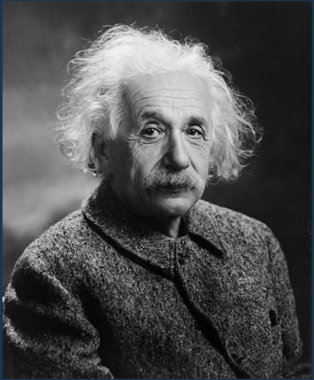

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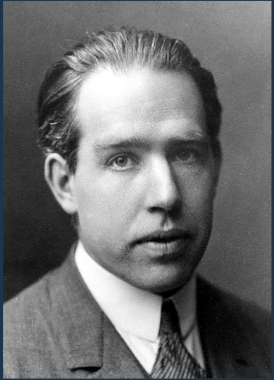

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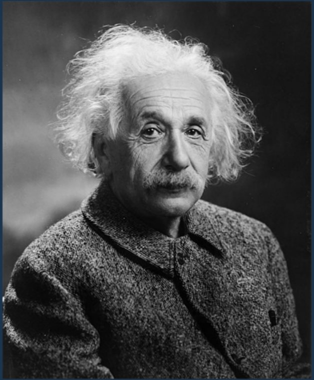

Photovoltaic panels

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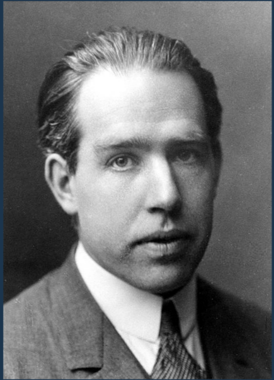

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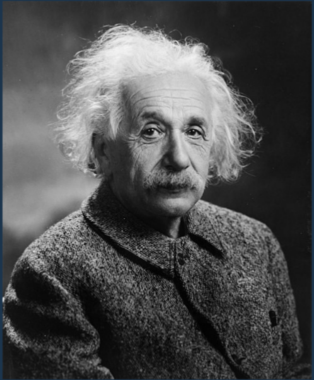

Photovoltaic panels

Very good **accuracy** according to **experiments**

Quantum Physics : Non trivial properties

Quantum Physics : Non trivial properties

Quantum Superposition

Quantum Superposition

Example : **Strontium**

Quantum Superposition

Example : **Strontium**

Quantum Superposition

Example : **Strontium**

Non excited AND **excited**

Quantum Superposition

Example : **Strontium**

Non excited **Excited**

Non excited AND **excited**

Quantum entanglement

Quantum Physics : Non trivial properties

Quantum Superposition

Example : **Strontium**

Non excited **Excited**

Non excited AND **excited**

Quantum entanglement

Particle

State **Up**

State **Down**

Quantum Physics : Non trivial properties

Quantum Superposition

Example : **Strontium**

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Quantum entanglement

Particle

State **Up** Both State **Down**

Quantum Physics : Non trivial properties

Quantum Superposition

Example : **Strontium**

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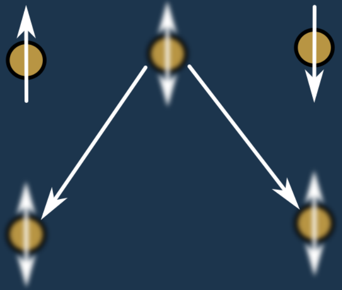
Non excited AND **excited**

Quantum entanglement

Particle

State **Up** Both State **Down**



Quantum Physics : Non trivial properties

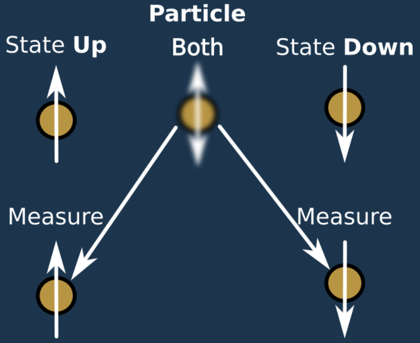
Quantum Superposition

Example : **Strontium**

Non excited **Excited**

Non excited AND **excited**

Quantum entanglement

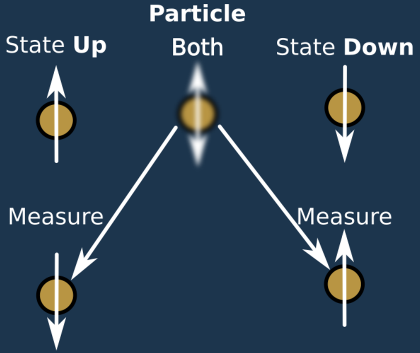


Quantum Physics : Non trivial properties

Quantum Superposition

Example : **Strontium**

Quantum entanglement



Quantum Physics : Non trivial properties

Quantum Superposition

Example : **Strontium**

Non excited **Excited**

Non excited AND **excited**

Quantum entanglement

Alain Aspect (1947 -)

Entangled particles do not send information to each other

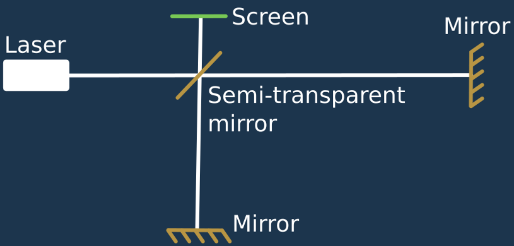
Interferometer

Interferometer

Albert Michelson (1852 - 1931)

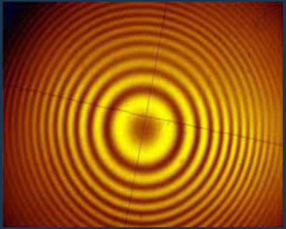
Interferometer

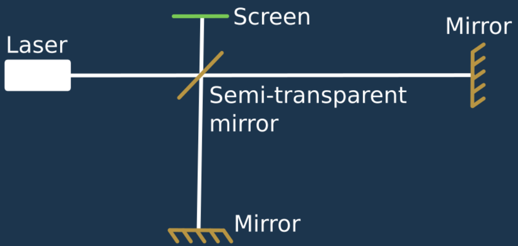
Albert Michelson (1852 - 1931)



Interferometer

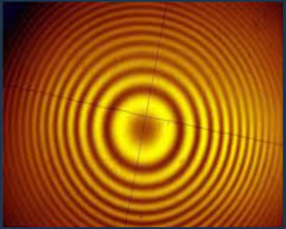
Albert Michelson (1852 - 1931)



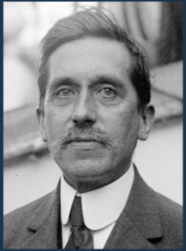


Interferometer

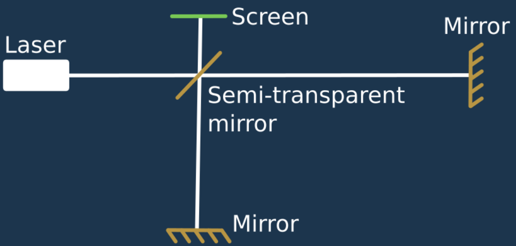
Albert Michelson (1852 - 1931)



Charles Fabry (1867 - 1945)

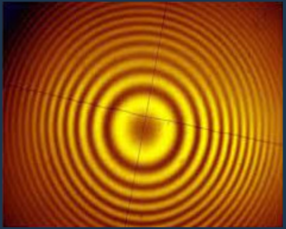


Alfred Perot (1863 - 1925)



Interferometer

Albert Michelson (1852 - 1931)



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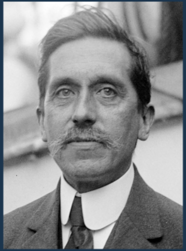

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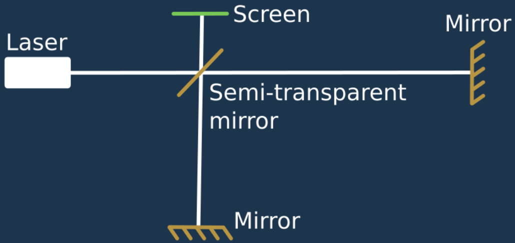
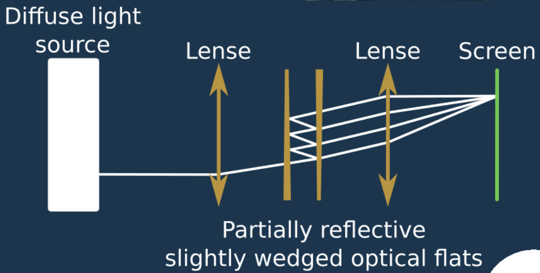
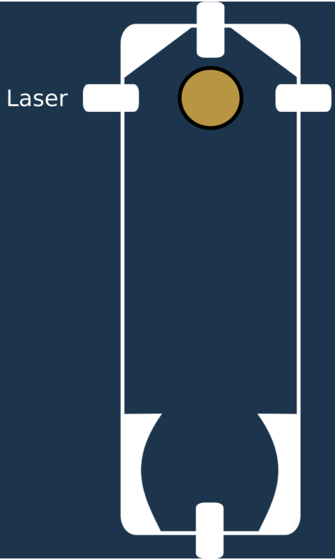




Atomic Interferometer

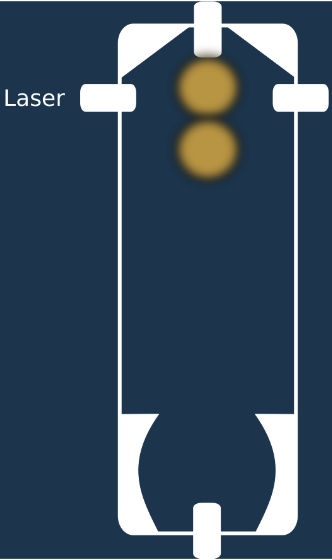
Application using **quantum superposition**

Atomic Interferometer



Application using **quantum superposition**

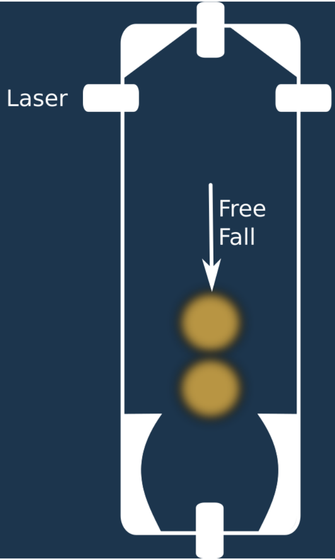
Atomic Interferometer

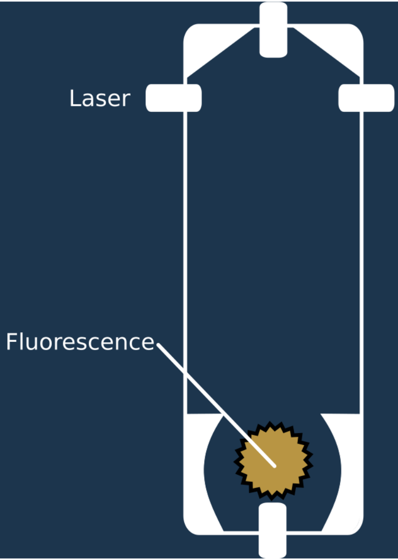


Application using **quantum superposition**

Atomic Interferometer

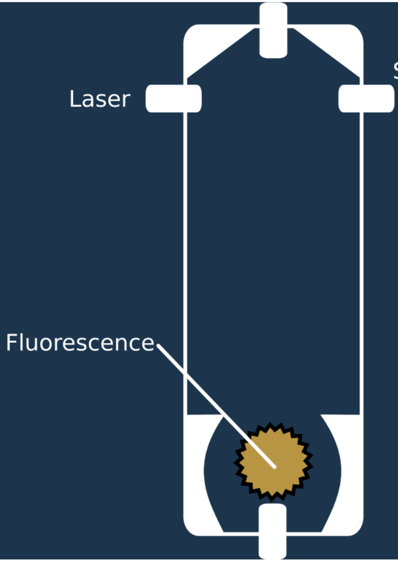
Application using **quantum superposition**





Application using **quantum superposition**

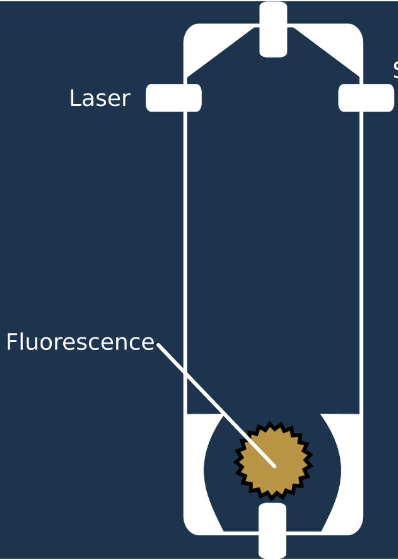
Atomic Interferometer



Application using **quantum superposition**

Sensitivity : few µGal ~ 10 nm/s^2

Atomic Interferometer



Application using **quantum superposition**

Sensitivity : few µGal ~ 10 nm/s^2

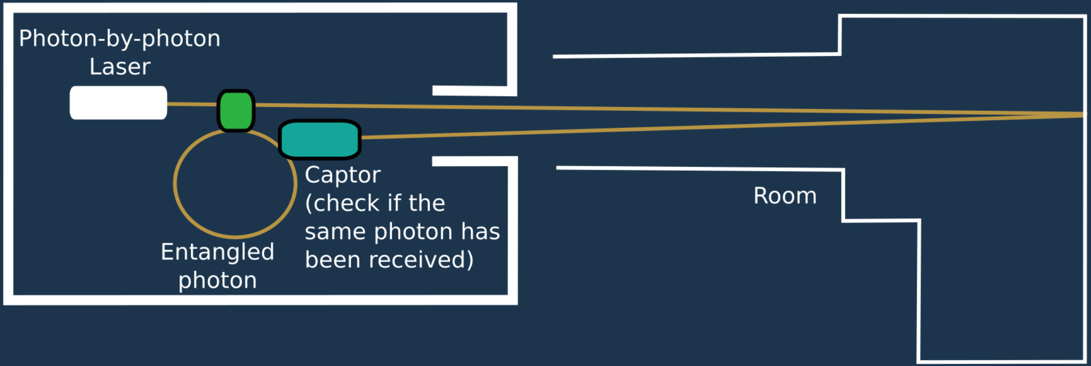
Muquans gravimeter on **Etna**

Quantum Imaging with entangled photons

Application using **Quantum Entanglement**

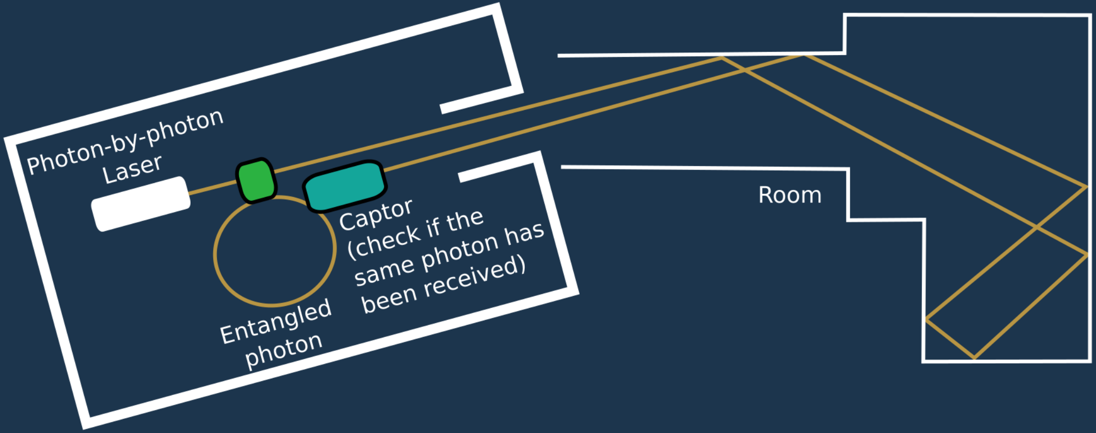
Quantum Imaging with entangled photons

Application using **Quantum Entanglement**



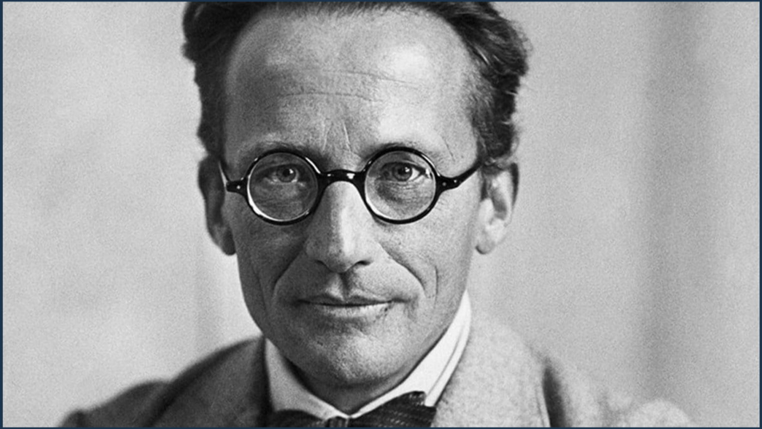
Quantum Imaging with entangled photons

Application using **Quantum Entanglement**



Quantum Computer

Erwin Schrödinger (1887 - 1961)



Why not simulate
quantum phenomena
with other
quantum phenomena ?

Quantum Computing

Computing with **quantum physics** ?

Computing with **other things** than **0** and **1** ?

Peter Shor (1959 -)

Factorization into **prime** numbers

Quantum Computing : how to store data ?

Quantum Computing : how to store data ?

States Convention :

Quantum Computing : how to store data ?

States Convention :

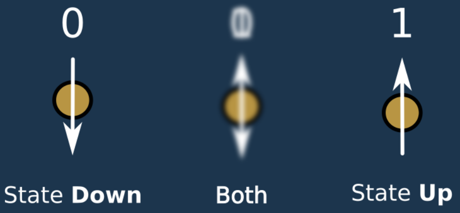
0

State **Down**

Quantum Computing : how to store data ?

States Convention :

States Convention :



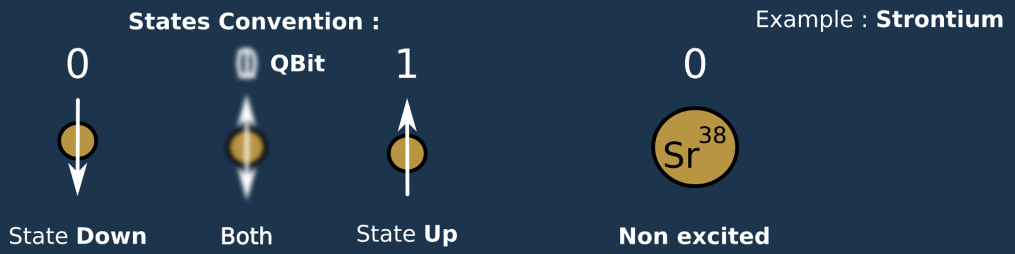
States Convention :

Quantum Computing : how to store data ?

States Convention :

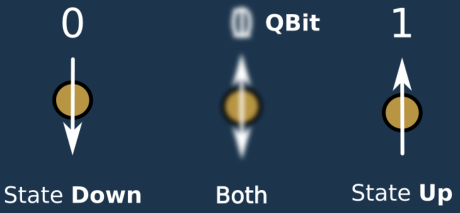
Example : **Strontium**

Quantum Computing : how to store data ?



Quantum Computing : how to store data ?

States Convention :



Example : **Strontium**

Quantum Computing : how to store data ?

States Convention :

State **Down** | Both | State **Up**

Example : **Strontium**

Non excited | **Non excited** AND **excited** | **Excited**

Quantum Computing : how to store data ?

States Convention :

0 **QBit** 1

State **Down** | Both | State **Up**

Example : **Strontium**

0 1

Non excited | **Non excited** AND **excited** | **Excited**

Nb Combinations : **2**

Quantum Computing : how to store data ?

States Convention :

Example : **Strontium**

Nb Combinations : 4

Quantum Computing : how to store data ?

States Convention :

State **Down** | Both | State **Up**

Example : **Strontium**

Non excited | **Non excited** AND **excited** | **Excited**

Nb Combinations : **8**

Quantum Computing : how to store data ?

States Convention :

0 | QBit | 1

State **Down** | Both | State **Up**

Example : **Strontium**

0 | 1

Non excited | **Non excited** AND **excited** | **Excited**

Nb Combinations : 16

Quantum Computing : how to store data ?

States Convention :

0 **QBit** 1

State **Down** Both State **Up**

Example : **Strontium**

0 1

Non excited | **Non excited** AND **excited** | **Excited**

Nb Combinations : 32

Quantum Computing : how to store data ?

States Convention :

0 | QBit | 1

State **Down** | Both | State **Up**

Example : **Strontium**

0 | 1

Non excited | **Non excited** AND **excited** | **Excited**

Nb Combinations : 64

Quantum Computing : how to store data ?

States Convention :

0 **QBit** 1

State **Down** | Both | State **Up**

Example : **Strontium**

0 1

Non excited | **Non excited** AND **excited** | **Excited**

Nb Combinations : 128

Quantum Computing : how to store data ?

States Convention :

State **Down** | Both | State **Up**

Example : **Strontium**

Non excited | **Non excited** AND **excited** | **Excited**

Nb Combinations : 256

Quantum Computing : how to store data ?

States Convention :

0 **QBit** 1

State **Down** | Both | State **Up**

Example : **Strontium**

0 1

Non excited | **Non excited** AND **excited** | **Excited**

One Quantum Object

Nb Combinations : 256

Quantum Computing : how to store data ?

States Convention :

0 | **QBit** | 1

State **Down** | Both | State **Up**

Example : **Strontium**

0 | | 1

Non excited | **Non excited** AND **excited** | **Excited**

One Quantum Object

Nb Combinations : 256

Adding one **QBit** doubles the memory capacity

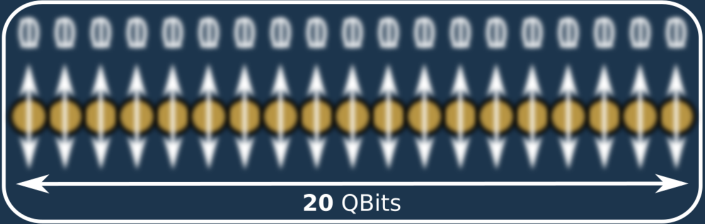
Quantum Computing : word search ?

Search **one word** in a list of **1 million words**

Quantum Computing : word search ?

Search **one word** in a list of **1 million words**

List in **QBits**



Quantum Computing : word search ?

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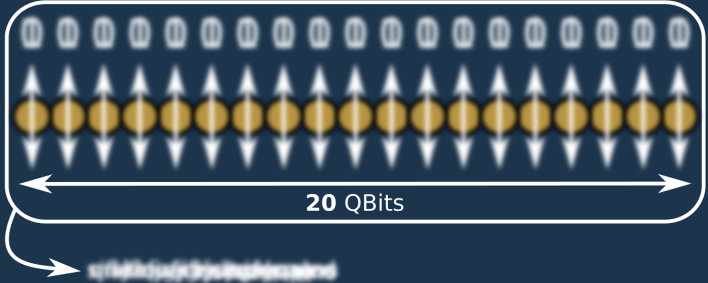

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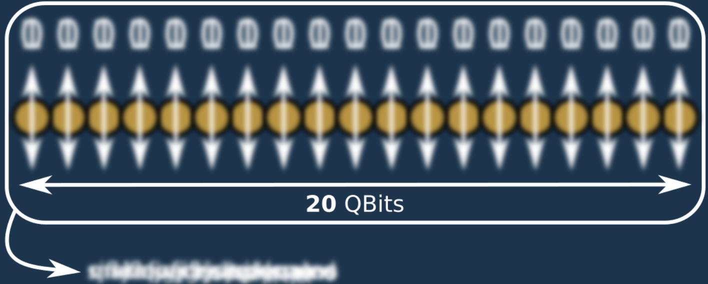
List in **QBits**

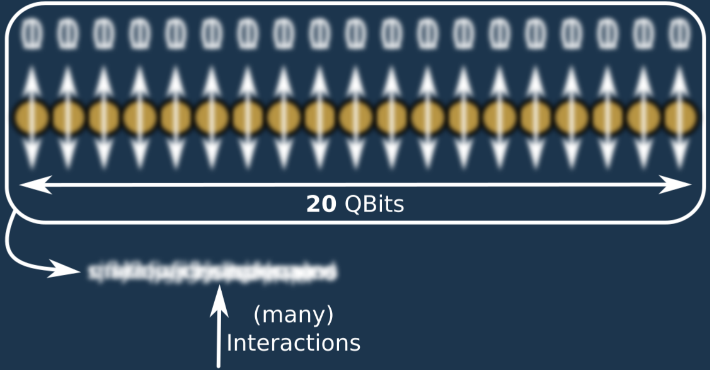


Search word : .omputer

Quantum Computing : word search ?

Search **one word** in a list of **1 million words**

List in **QBits**



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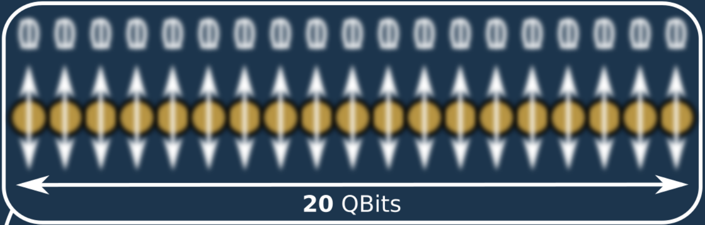

(many)
Interactions

Search word : .omputer

Quantum Computing : word search ?

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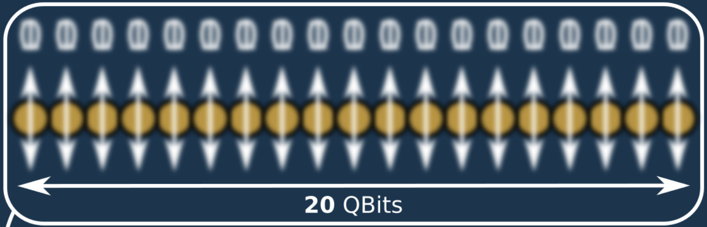

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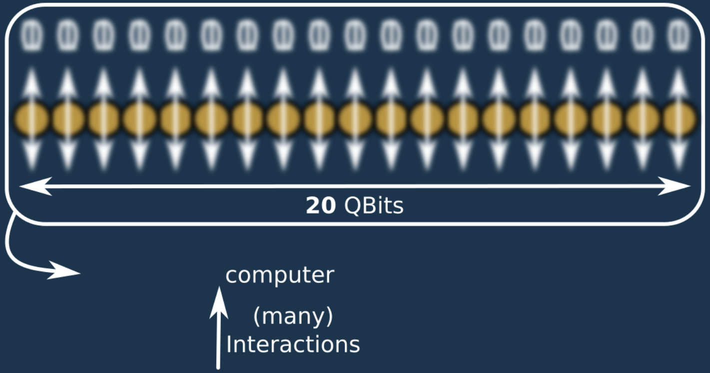

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Quantum Computing : word search ?

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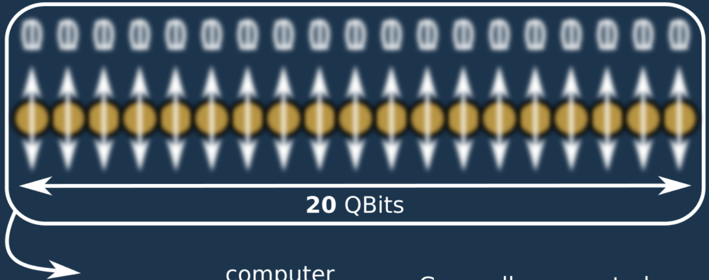
List in **QBits**



computer

(many)
Interactions

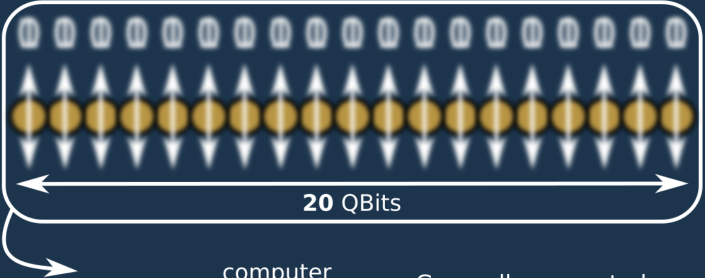
Search word : .omputer

Generally presented :
- **1000** computations instead of **1 million** for classical computers

Quantum Computing : word search ?

Search **one word** in a list of **1 million words**

List in **QBits**



computer

(many) Interactions

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Generally presented :
- **1000** computations instead of **1 million** for classical computers

Classic computer approach

Quantum Computing : word search ?

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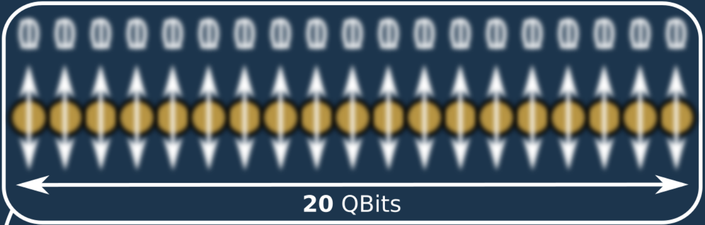

computer

(many)

Interactions

Search word : .omputer

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Classic computer approach

- Build **dictionary** with reversed keys

Quantum Computing : word search ?

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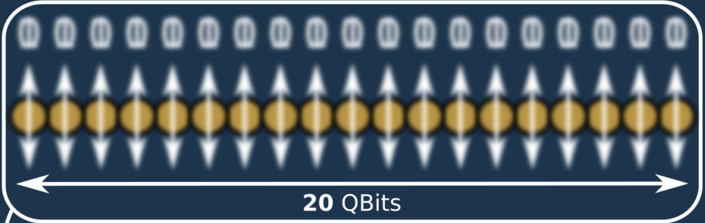
List in **QBits**



computer

(many) Interactions

Search word : .omputer

Generally presented :
- **1000** computations instead of **1 million** for classical computers

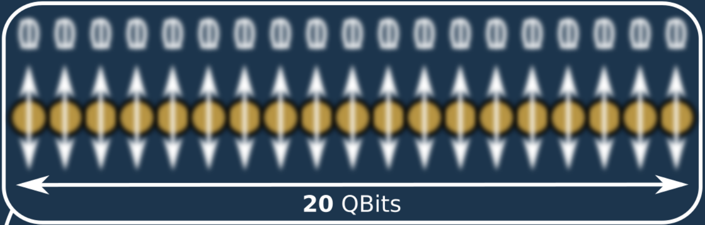
Classic computer approach

- Build **dictionary** with reversed keys
- Get the word in **20** computations by **dichotomy**

Quantum Computing : word search ?

Search **one word** in a list of **1 million words**

List in **QBits**



computer

(many)
Interactions

Search word : .omputer

Better search : .om.ut.r

Generally presented :
- **1000** computations instead of **1 million** for classical computers

Classic computer approach

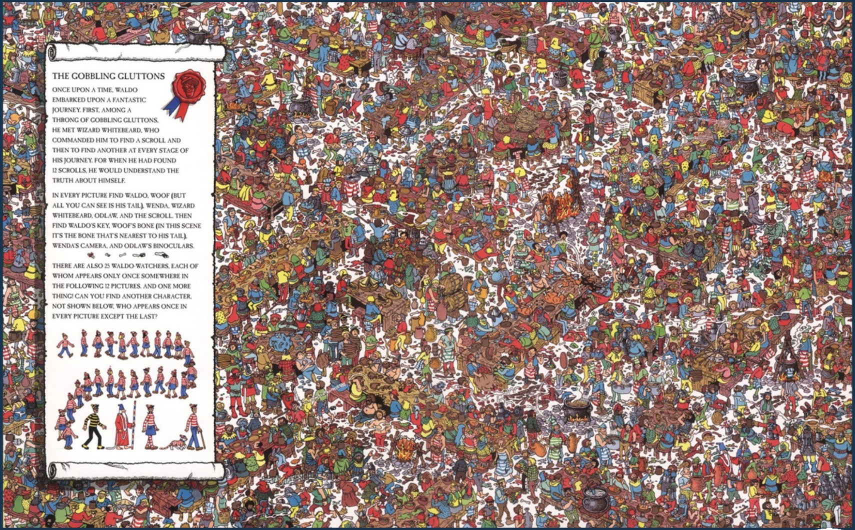
- Build **dictionary** with reversed keys

- Get the word in **20** computations by **dichotomy**

Where is **waldoo** ?

Quantum computing : pattern search

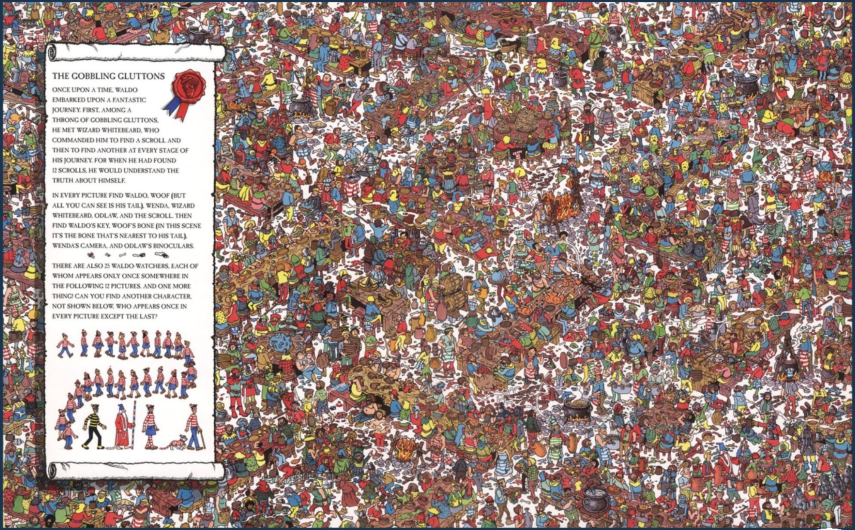
Where is **waldoo** ?



Quantum computing : pattern search

Where is **waldoo** ?

Blur what is **not waldoo**



Destructive / Constructive interferences

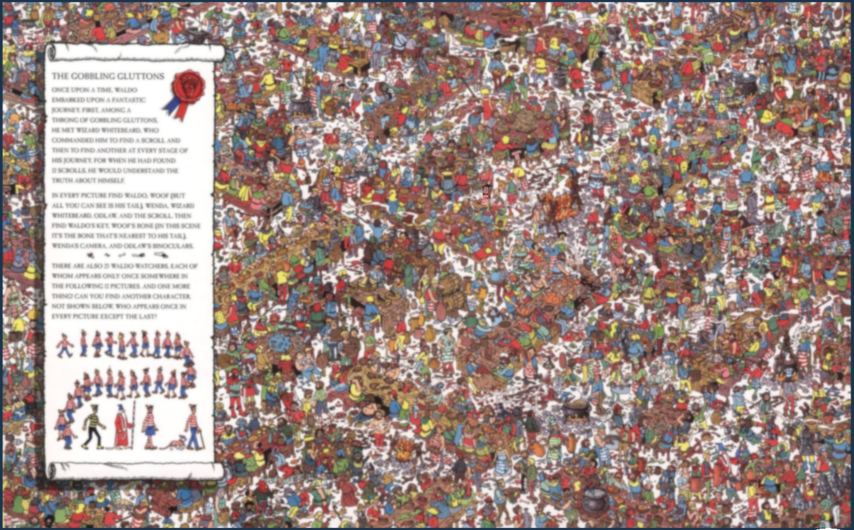
Quantum computing : pattern search

Where is **waldoo** ?

⊗

Blur what is **not waldoo**

Destructive / Constructive interferences



Quantum computing : pattern search

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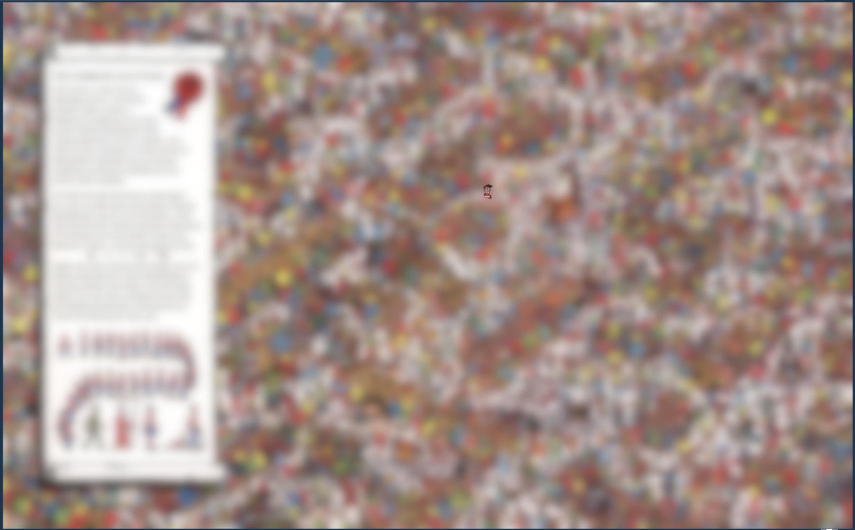

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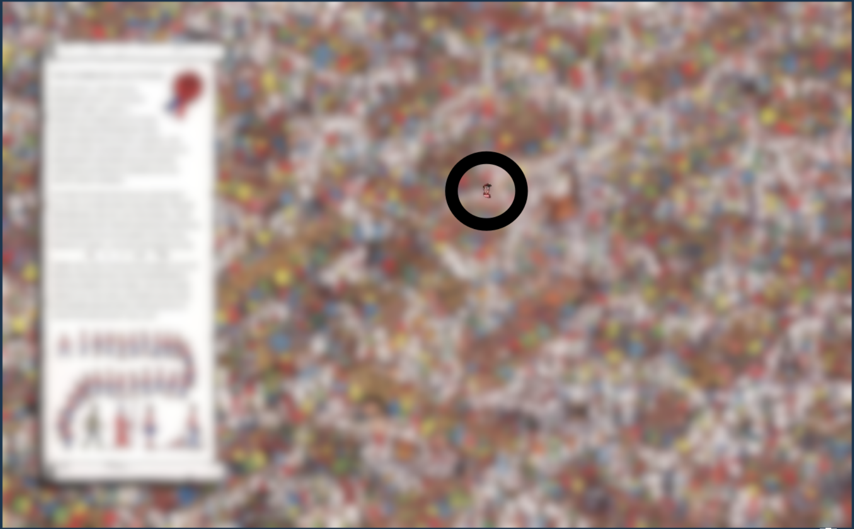


Destructive / Constructive interferences

Quantum Superposition

Ion Trapped quantum computer

Quantum Superposition

Strontium

Non excited **Excited**

Non exited AND excited

Laboratoire d'Annecy de Physique des Particules

Ion Trapped quantum computer

Quantum Superposition

Strontium **Mercury**

Non excited **Excited**

Non excited **Excited**

Non exited AND excited

Non excited AND **excited**

Ion Trapped quantum computer

Quantum Superposition

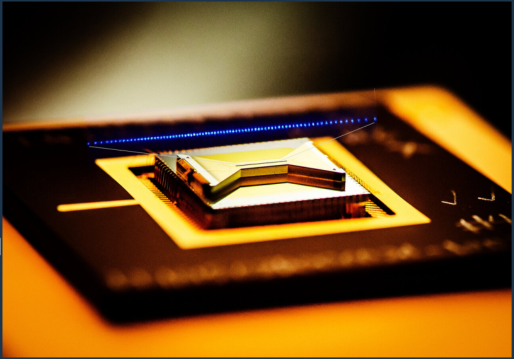
	Strontium		**Mercury**	
	Non excited	**Excited**	**Non excited**	**Excited**
	Sr^{38}	Sr^{38}	Hg^{80}	Hg^{80}

Non exited AND excited

Sr^{38}

Non excited AND **excited**

Hg^{80}



Photonic quantum computer

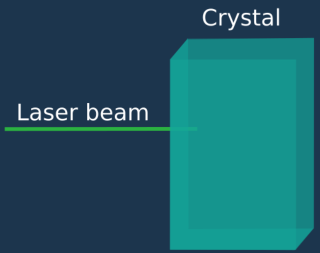
States superposition

States superposition

Laser beam

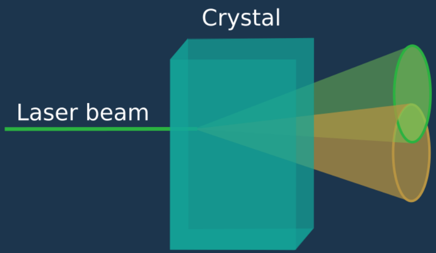
Photonic quantum computer

States superposition



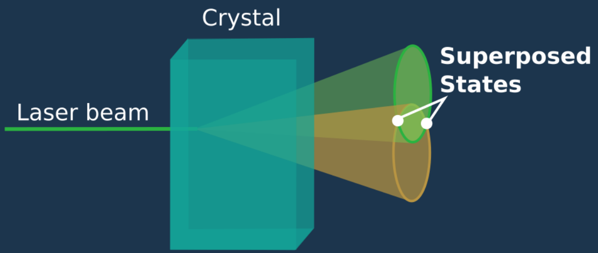
Photonic quantum computer

States superposition



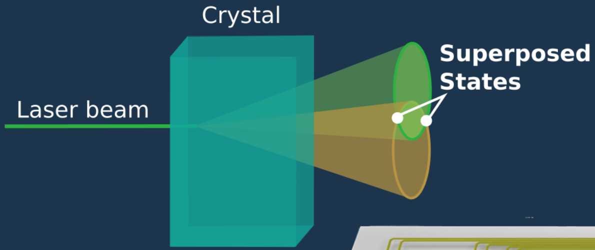
Photonic quantum computer

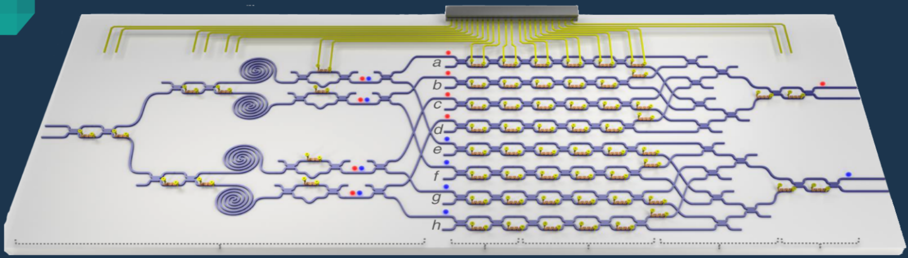
States superposition



Photonic quantum computer

States superposition





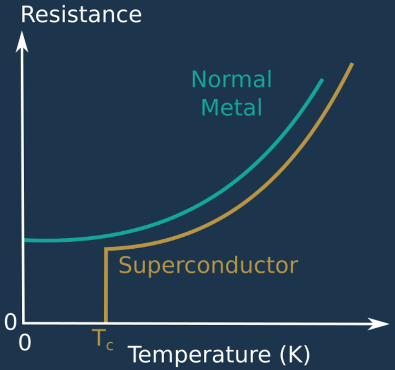
Superconductivity

Heike Kammerlingh Onnes
(1853 - 1926)

Superconductivity

Discovery in **1911** with **Mercury**

Heike Kammerlingh Onnes
(1853 - 1926)



Superconductivity

Heike Kammerlingh Onnes
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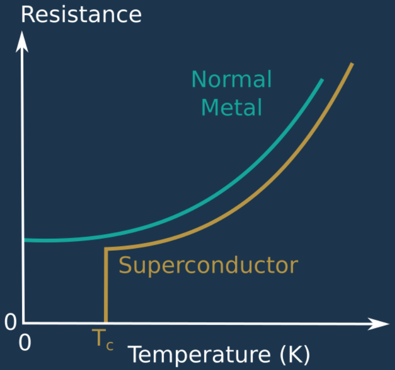
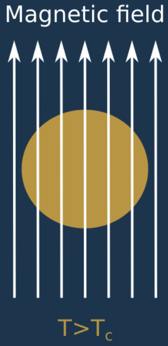
Discovery in **1911** with **Mercury**





Superconductivity

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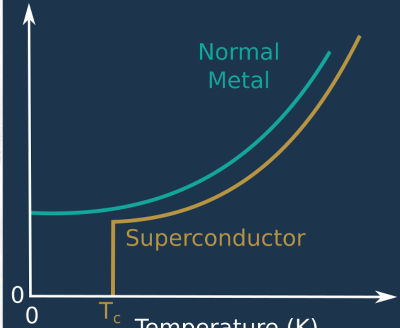
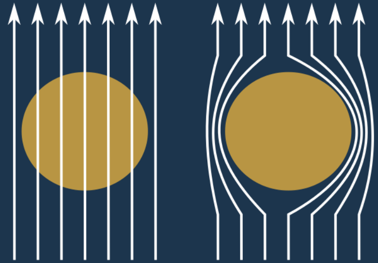
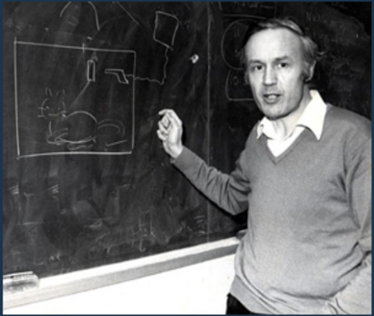
Discovery in **1911** with **Mercury**





Superconductor quantum computing

Anthony James Leggett
(1938 -)



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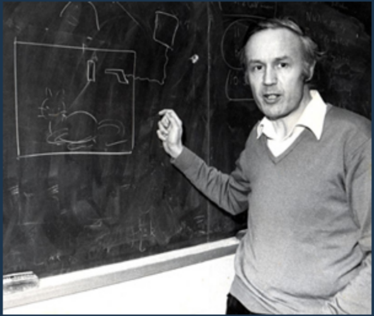
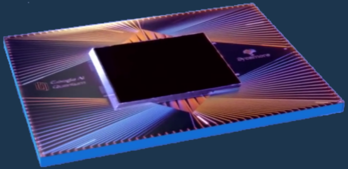


Google Sycamore Chip
2019



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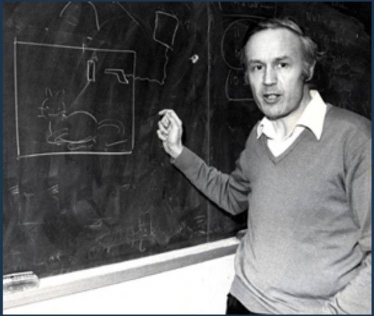

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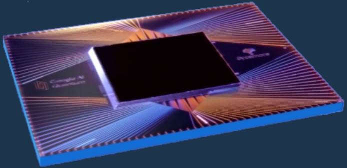

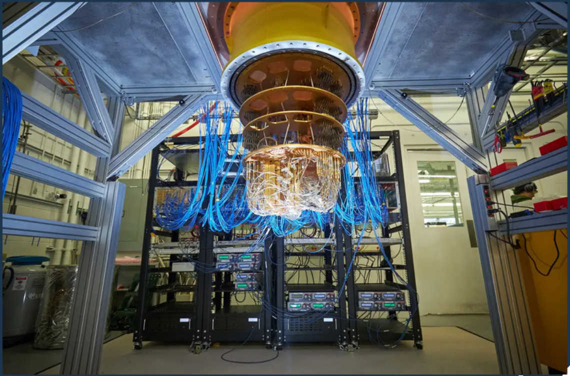

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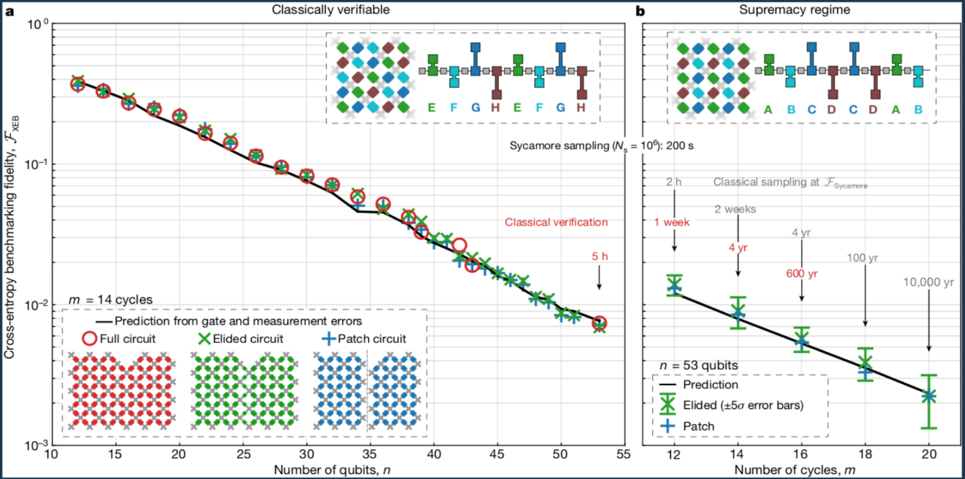

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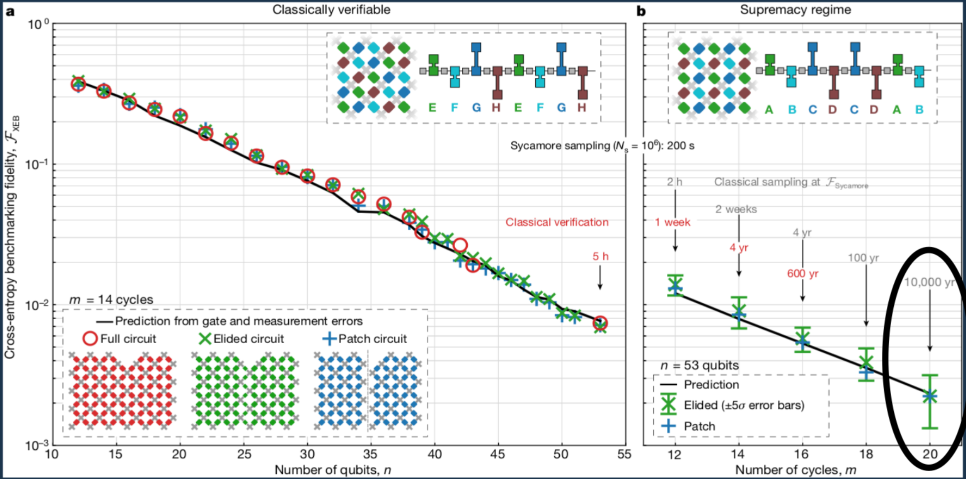
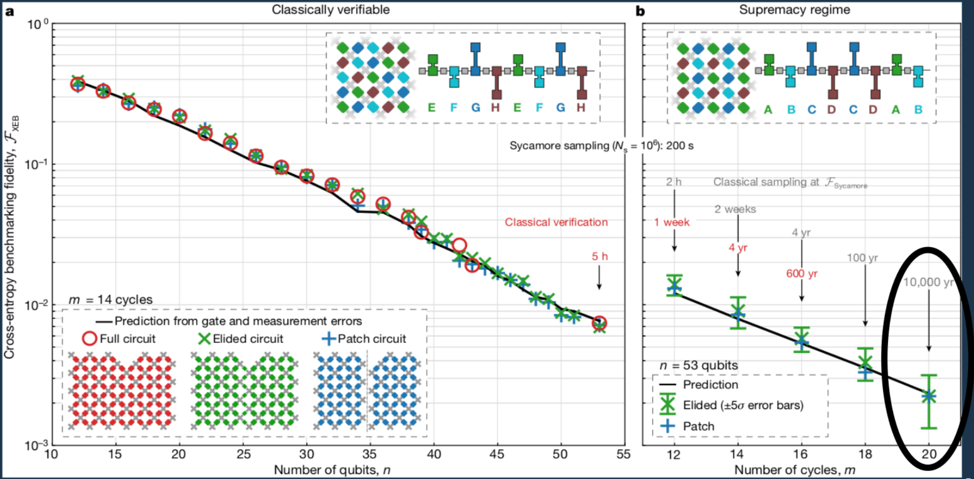


Superconductor quantum computing

Likelihood of different outcomes from a quantum version of a **random-number generator**



Quantum computing applications

Quantum computing applications

Find string
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Factorization in primes numbers

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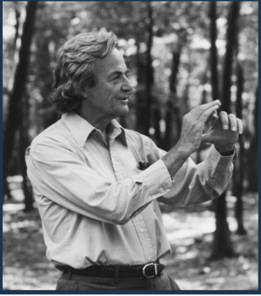

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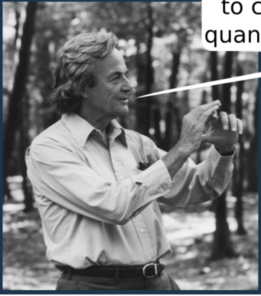
It would be a pitty to compute with quantum computer



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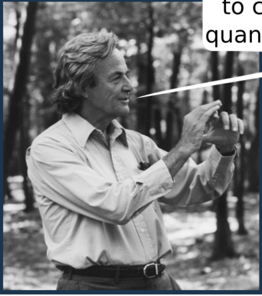

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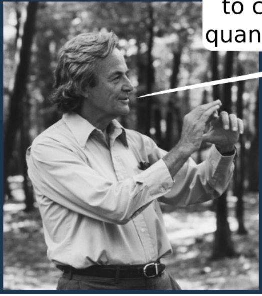

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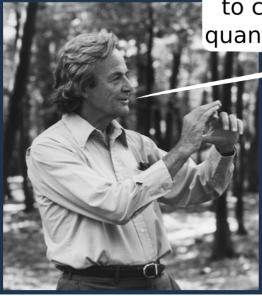

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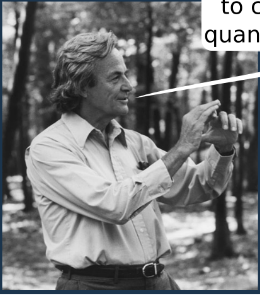

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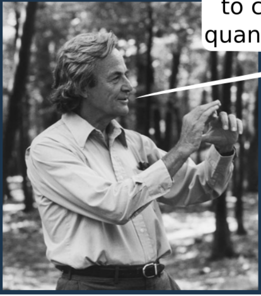

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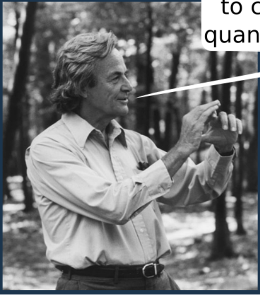

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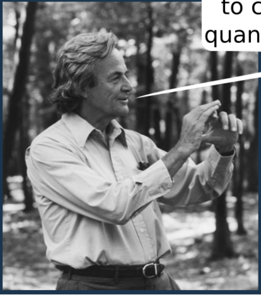

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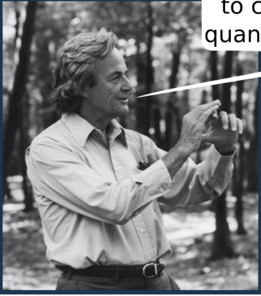

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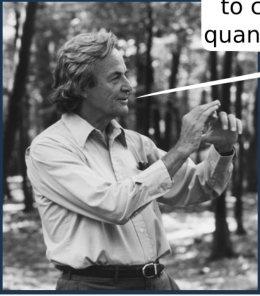

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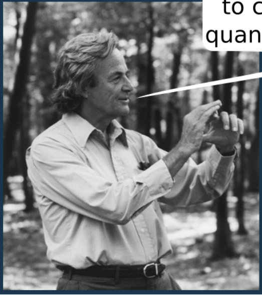

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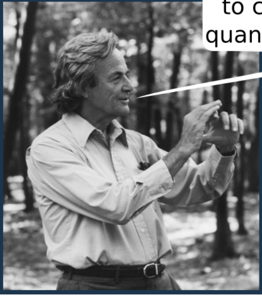

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Too many errors (**1** over **1000** computations)

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Need **1 000 000** computations to get a result

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Nowadays : **300-400** atoms entangled

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10 000 atoms needed

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Quantum Computer time scale

Almost 40 years for every aspect :

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  - Levitation of Baryum atom : **1990**
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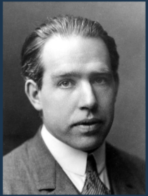
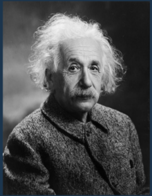
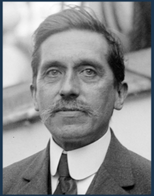
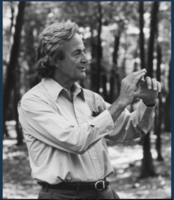
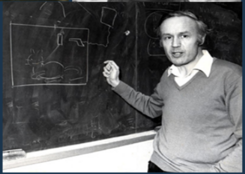
- **Theory** :
  - First ideas : **1979-1981**
  - First algorithms : **some years ago**

Laboratoire d'Annecy de Physique des Particules

(Some) Involved people


56 + previous people