ESCAPE 824064



From Barrel Organ to Quantum Computing

Pierre Aubert











Pascaline

Invented in $\mathbf{1645}$



- Addition
- Subtraction
- Multiplication
- Division

Pierre Aubert, From Barrel Organ to Quantum Computing

Blaise Pascal (1623 - 1662)



Barrel Organ

1820 (first was made in 1502)



- Short Melodies
- Cumbersome barrel, not easy to change



Barrel Organ

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- Short Melodies
- Cumbersome barrel, not easy to change

Pierre Aubert, From Barrel Organ to Quantum Computing

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



- Longer Melodies
- Small and easy to change



Loom

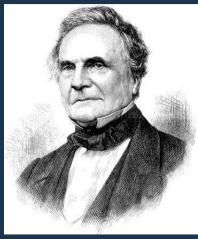
Basile Bouchon : 1725, perforated ribbon





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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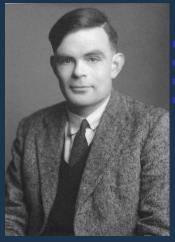
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1842 : Computation of Bernoulli numbers



Alan Turing

Alan Turing (1912 - 1954)



- Computer Scientist
- Logicial
- Cryptoanalyst
- Theoretical biologist



The Bombe machine





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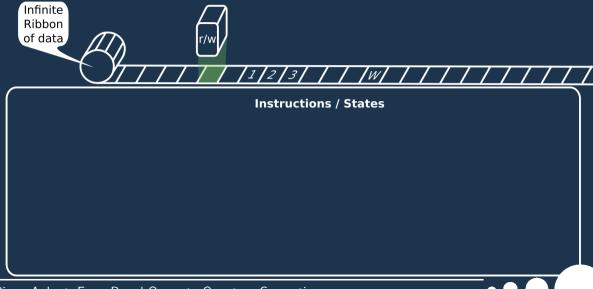




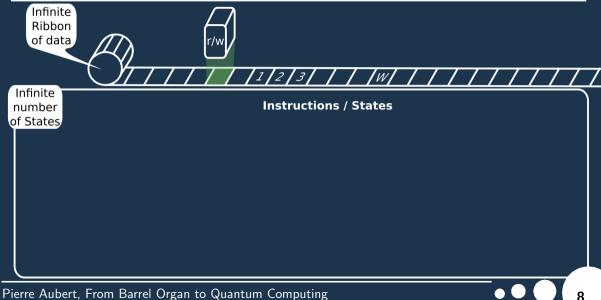




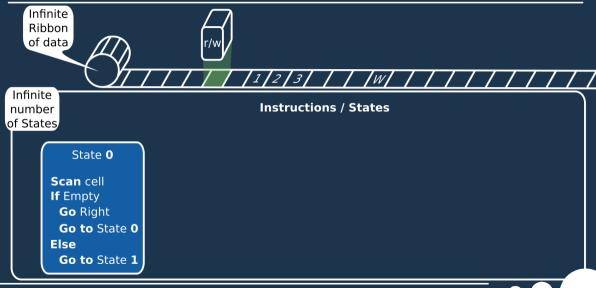




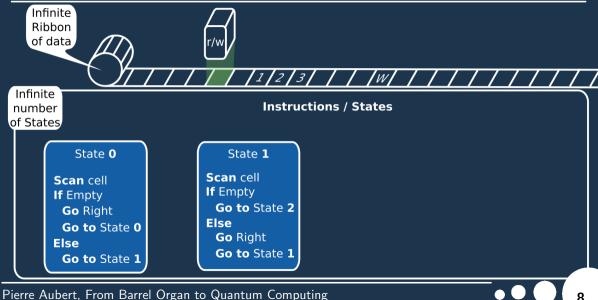




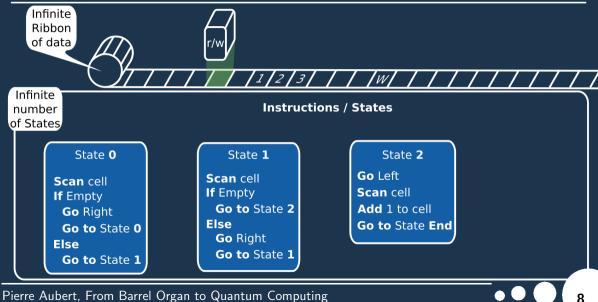




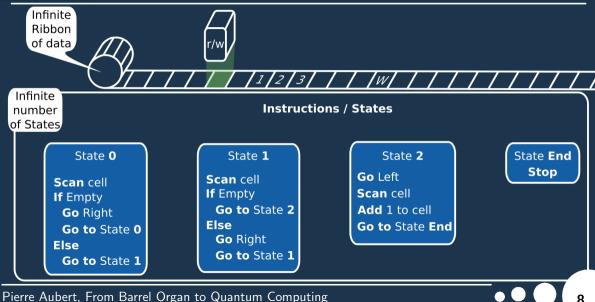




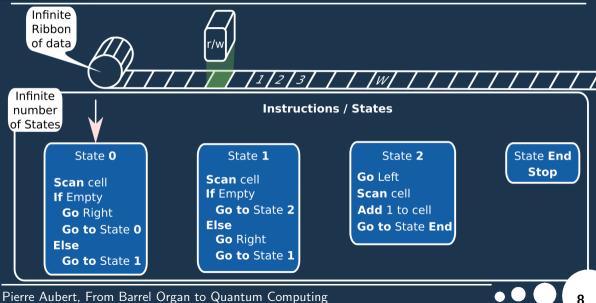




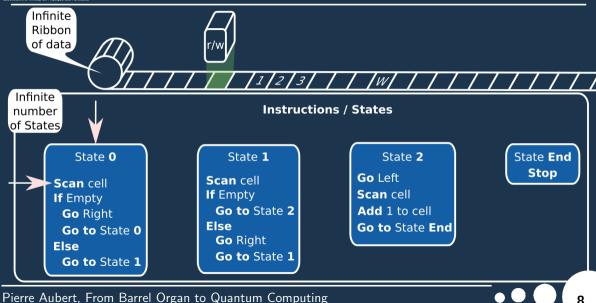




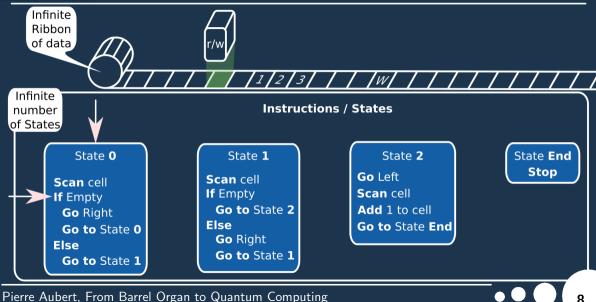




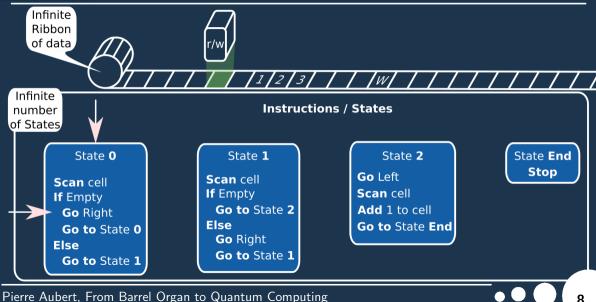




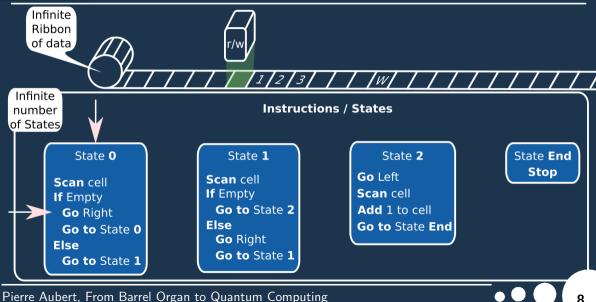




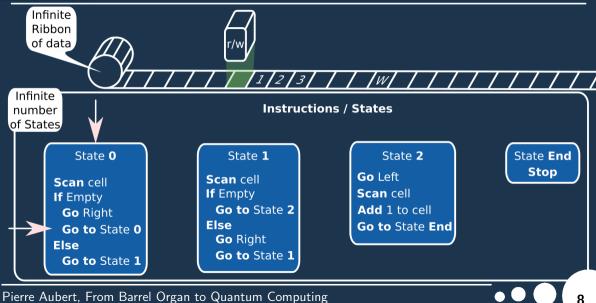




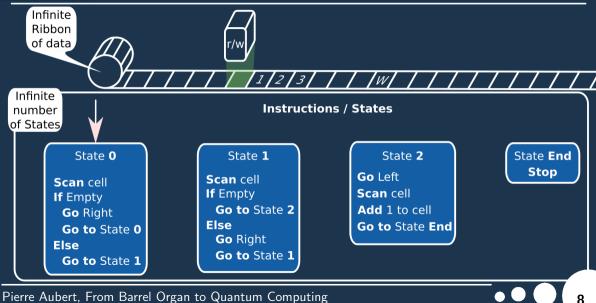




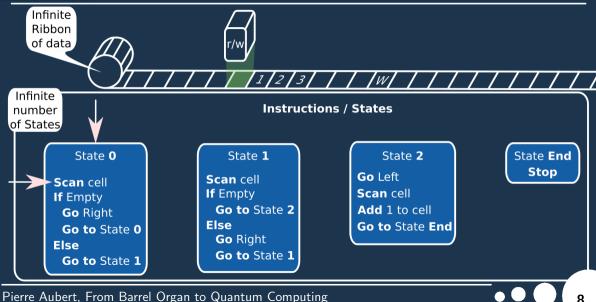




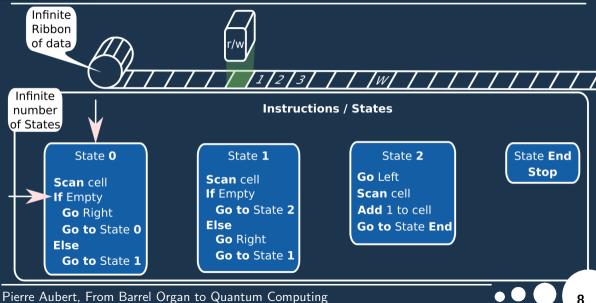




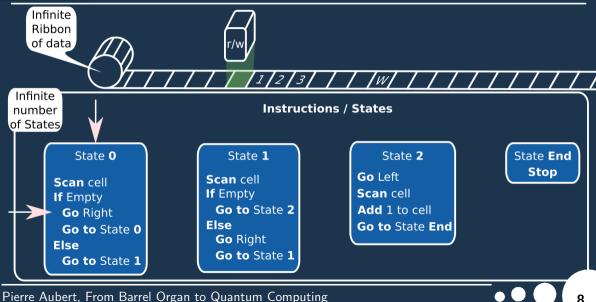


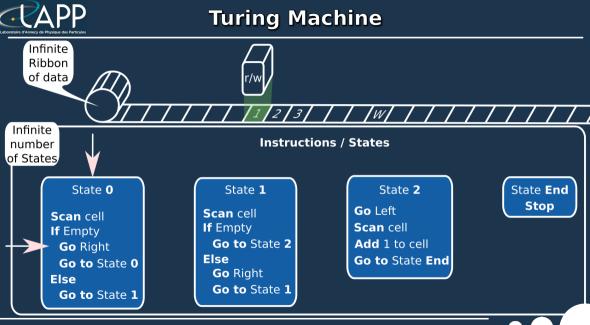


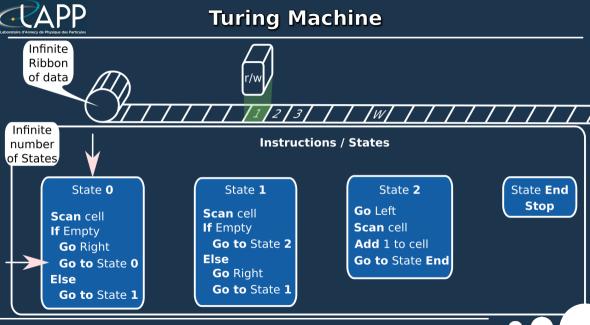


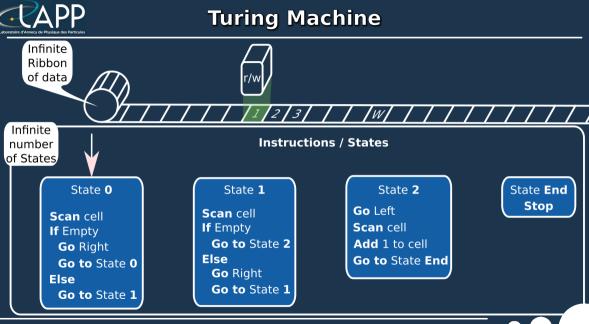


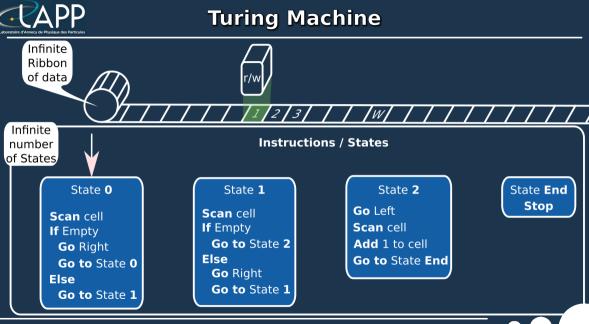


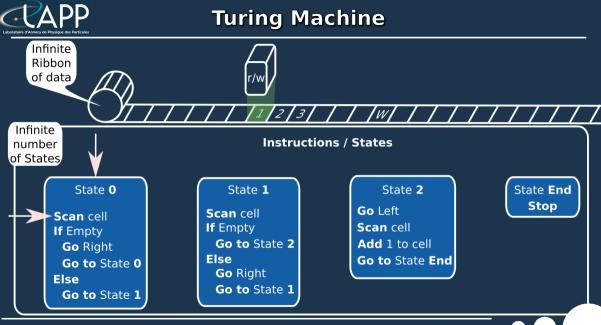


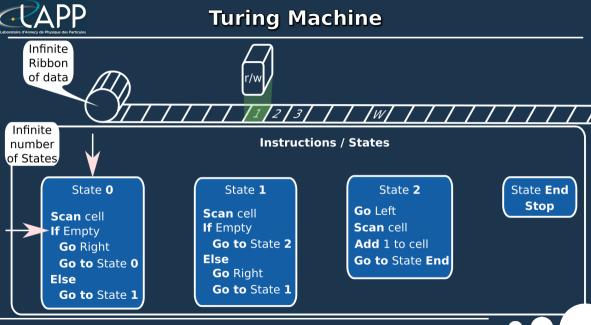


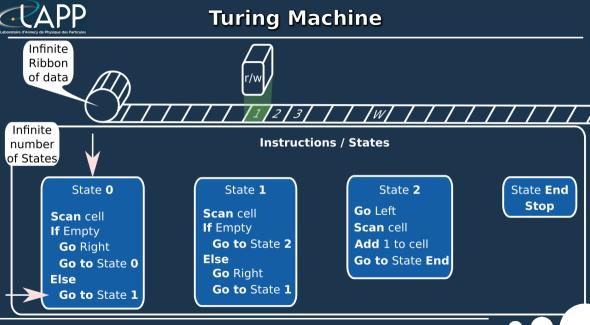




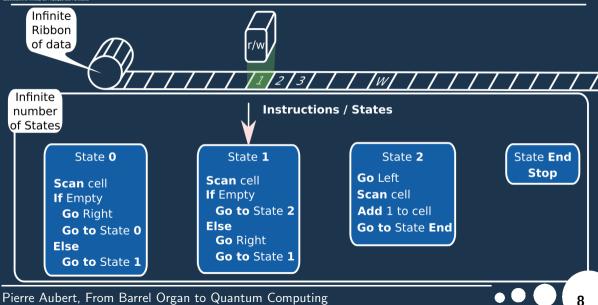




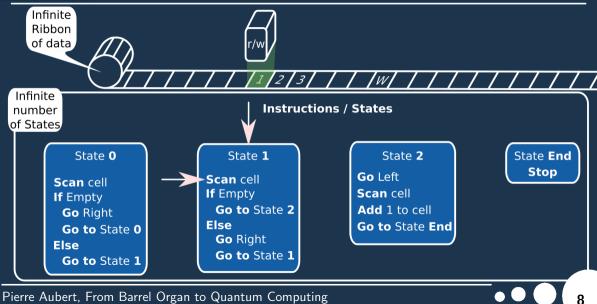




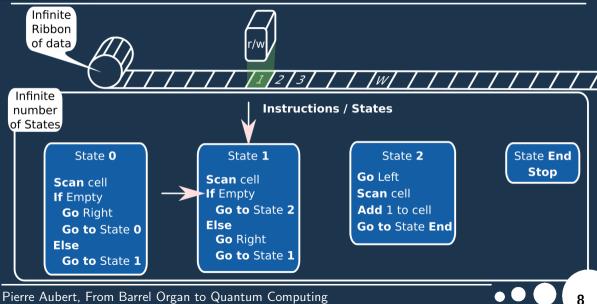




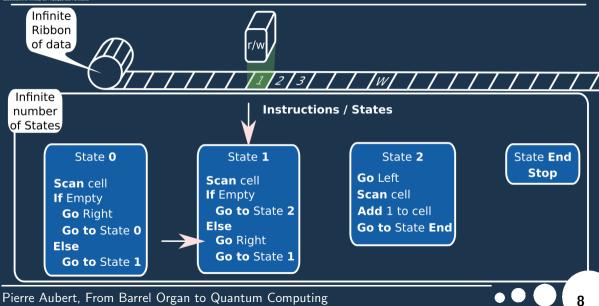




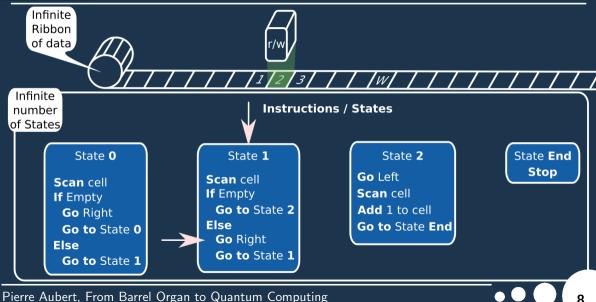




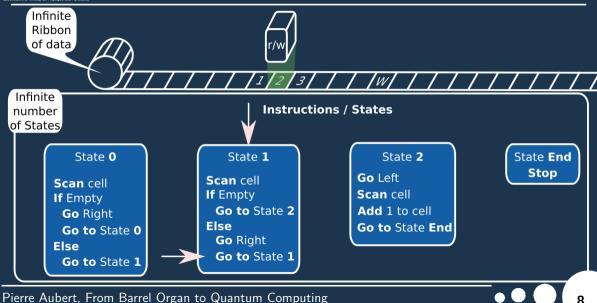




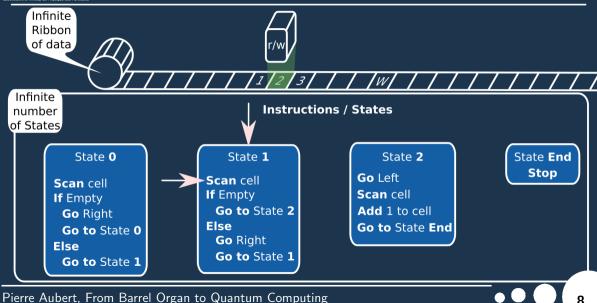




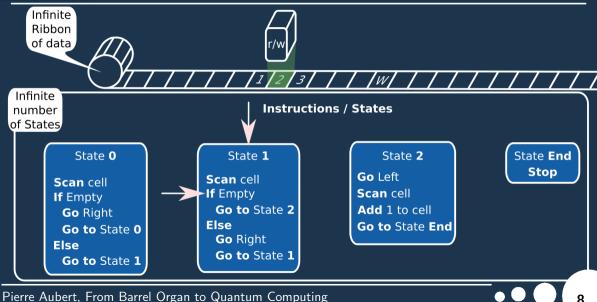




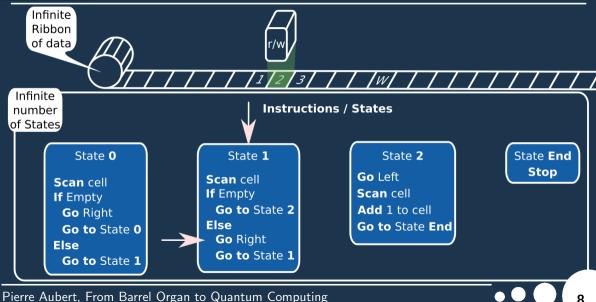




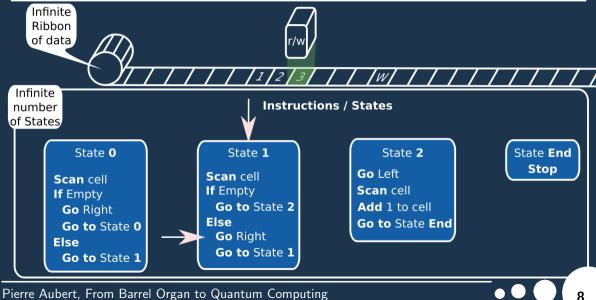




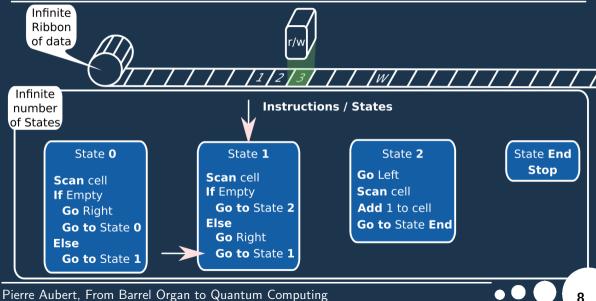




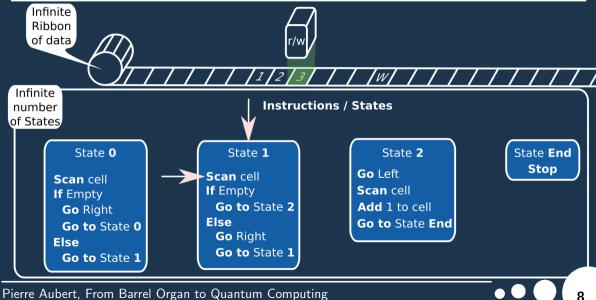




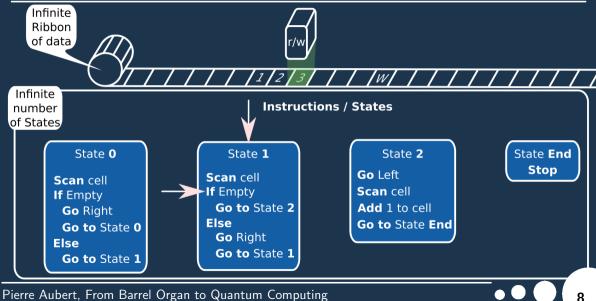




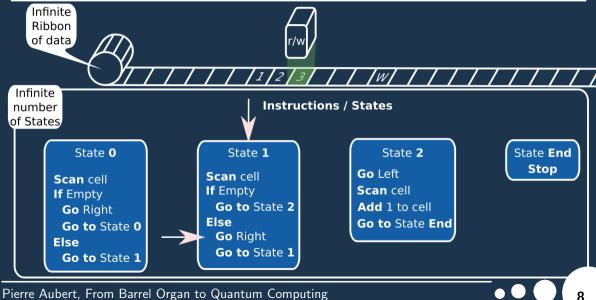




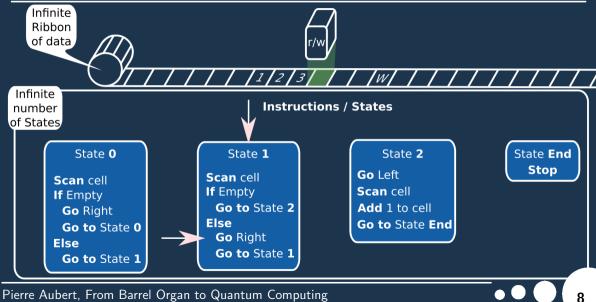




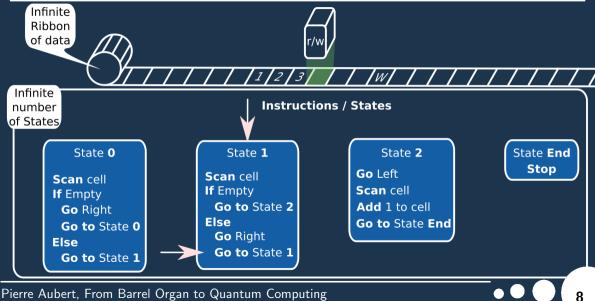




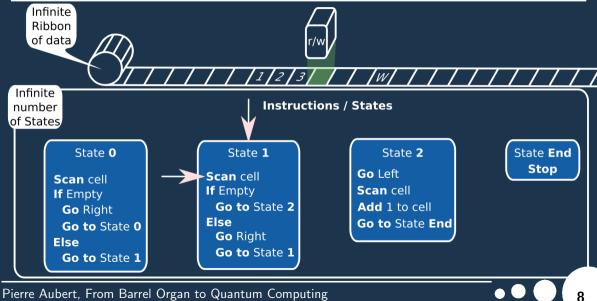




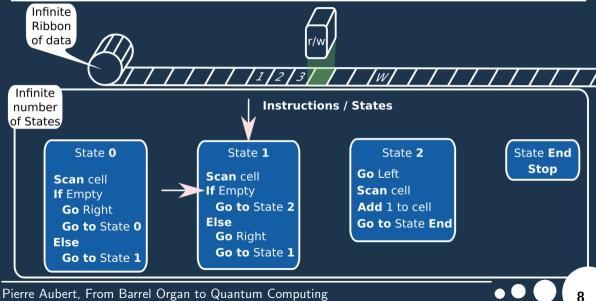




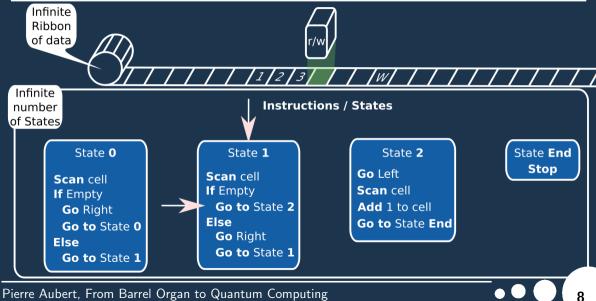




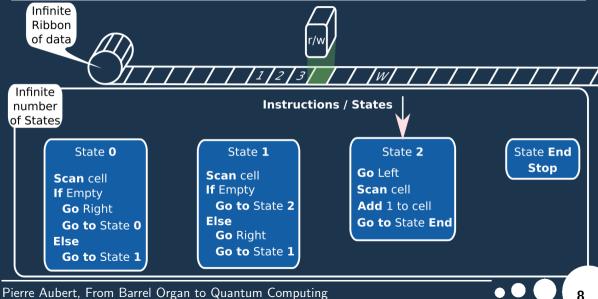




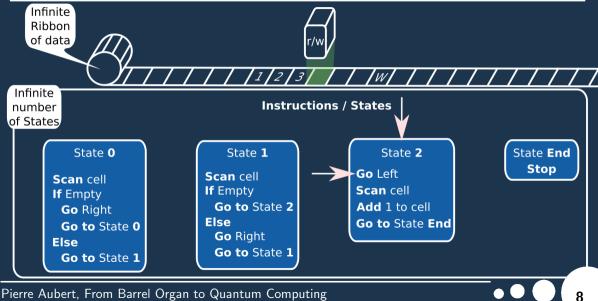




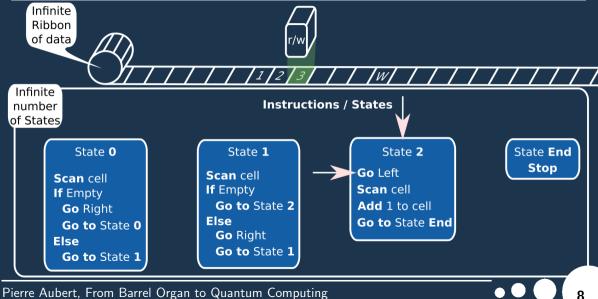




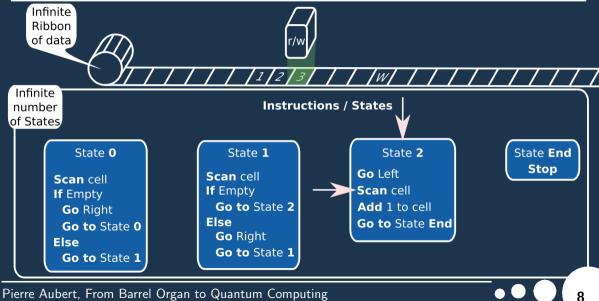




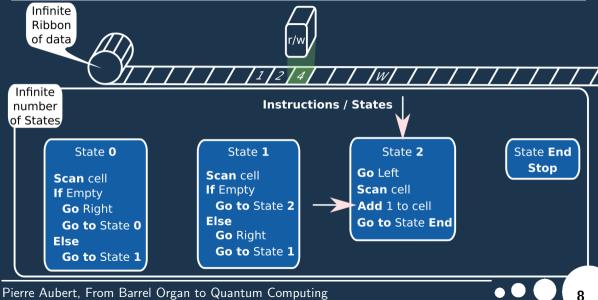




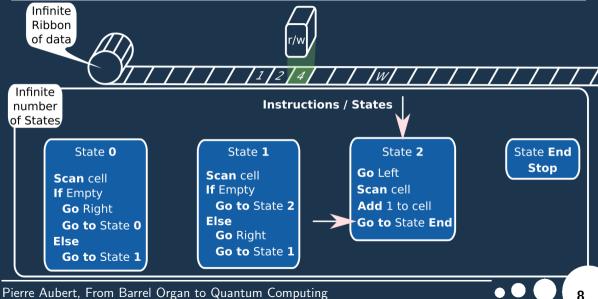




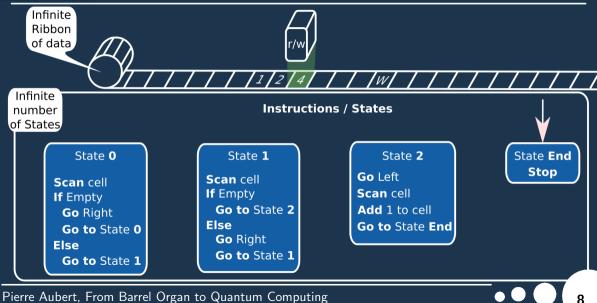




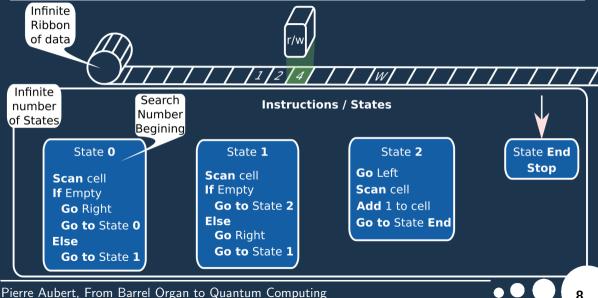




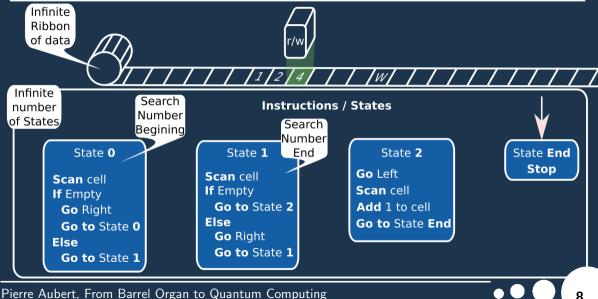




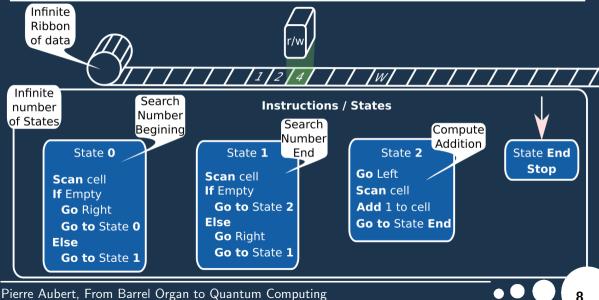




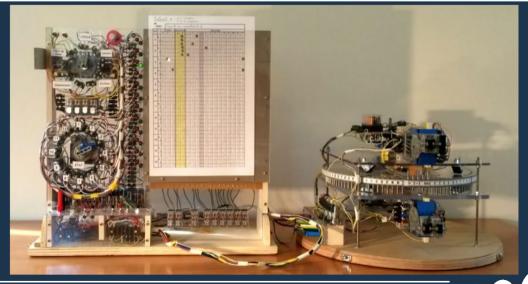








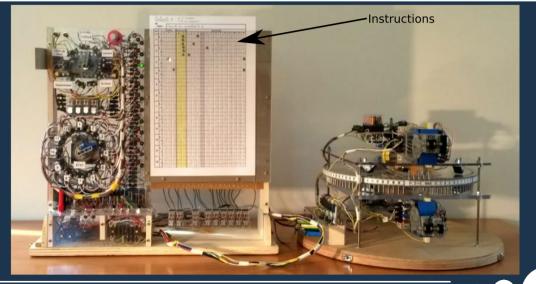




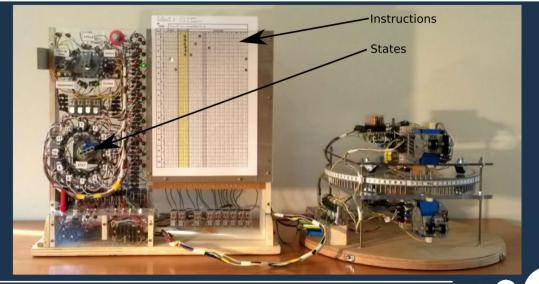
Pierre Aubert, From Barrel Organ to Quantum Computing

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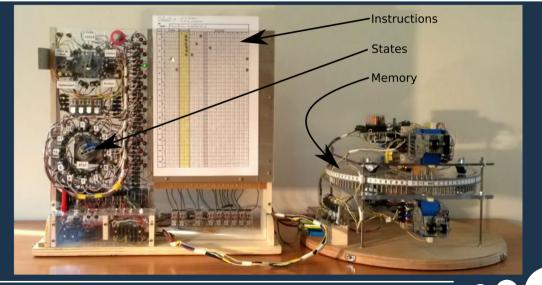
















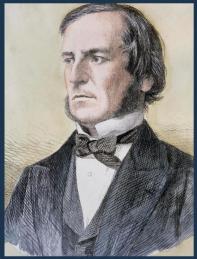
Pierre Aubert, From Barrel Organ to Quantum Computing



Georges Boole

10

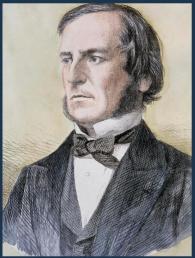
Georges Boole (1815 - 1864)





Georges Boole

Georges Boole (1815 - 1864)



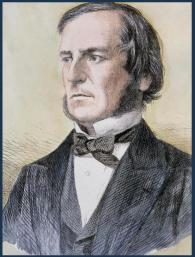
Number from basis 10 in basis 2 :

10



Georges Boole

Georges Boole (1815 - 1864)



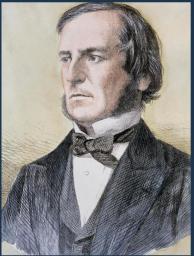
Number from basis 10 in basis 2 :

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74 = 70 + 4



Georges Boole (1815 - 1864)



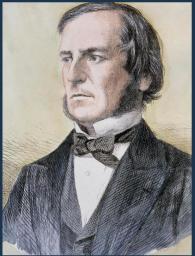
Number from basis 10 in basis 2 :

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



Georges Boole (1815 - 1864)



Number from basis 10 in basis 2 :

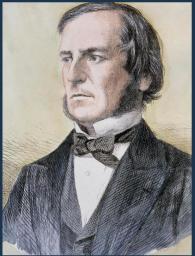
10

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

= 64 + 8 + 2



Georges Boole (1815 - 1864)



Number from basis 10 in basis 2 :

10

$$74 = 70 + 4$$

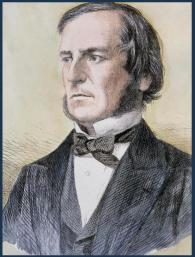
= **7**×10¹ + **4**×10⁰

$$= 64 + 8 + 2$$

 $= \mathbf{1} \times 2^6 + \mathbf{1} \times 2^3 + \mathbf{1} \times 2^1$



Georges Boole (1815 - 1864)

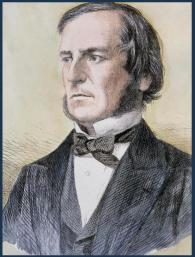


Number from basis 10 in basis 2 :

- 74 = 70 + 4
 - = **7**×10¹ + **4**×10⁰
 - = 64 + 8 + 2
 - $= \mathbf{1} \times 2^6 + \mathbf{1} \times 2^3 + \mathbf{1} \times 2^1$
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Georges Boole (1815 - 1864)



Number from basis 10 in basis 2 :

$$=$$
 7×10¹ + **4**×10⁰

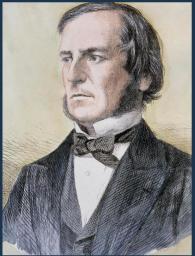
$$= 64 + 8 + 2$$

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Georges Boole (1815 - 1864)



Number from basis 10 in basis 2 :

$$74 = 70 + 4$$

$$=$$
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$$= 64 + 8 + 2$$

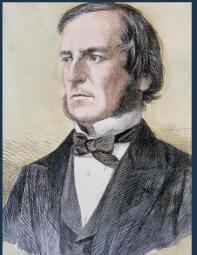
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Computing on basis 2



Georges Boole (1815 - 1864)



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

$$74 = 70 + 4$$

$$=$$
 7×10¹ + **4**×10⁰

$$= 64 + 8 + 2$$

$$= \mathbf{1} \times 2^6 + \mathbf{1} \times 2^3 + \mathbf{1} \times 2^1$$

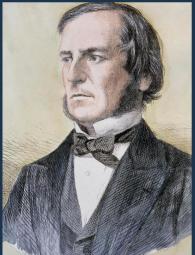
 $= \mathbf{1} \times 2^{6} + \mathbf{0} \times 2^{5} + \mathbf{0} \times 2^{4} + \mathbf{1} \times 2^{3} + \mathbf{0} \times 2^{2} + \mathbf{1} \times 2^{1} + \mathbf{0} \times 2^{0}$ 74₁₀ = 1001010₂

Computing on basis **2**

AND



Georges Boole (1815 - 1864)



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

$$74 = 70 + 4$$

$$=$$
 7×10¹ + **4**×10⁰

$$= 64 + 8 + 2$$

$$= \mathbf{1} \times 2^6 + \mathbf{1} \times 2^3 + \mathbf{1} \times 2^1$$

 $= \mathbf{1} \times 2^{6} + \mathbf{0} \times 2^{5} + \mathbf{0} \times 2^{4} + \mathbf{1} \times 2^{3} + \mathbf{0} \times 2^{2} + \mathbf{1} \times 2^{1} + \mathbf{0} \times 2^{0}$ 74₁₀ = 1001010₂

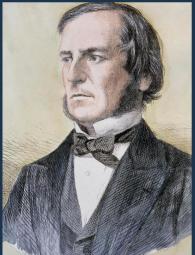
Computing on basis **2**

AND

OR



Georges Boole (1815 - 1864)



74 = 70 + 4= 7×10¹ + 4×10⁰ = 64 + 8 + 2 = 1×2⁶+1×2³+1×2¹ = 1×2⁶+0×2⁵+0×2⁴+1×2³+0×2²+1×2¹+0×2⁰ 74₁₀ = 1001010₂

Number from basis 10 in basis 2 :

Computing on basis 2

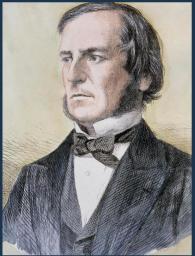




XOR



Georges Boole (1815 - 1864)



74 = 70 + 4= 7×10¹ + 4×10⁰ = 64 + 8 + 2 = 1×2⁶+1×2³+1×2¹ = 1×2⁶+0×2⁵+0×2⁴+1×2³+0×2²+1×2¹+0×2⁰ 74₁₀ = 1001010₂

Number from basis 10 in basis 2 :

Computing on basis 2





11





11







11







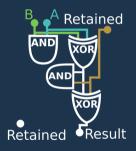
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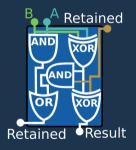
11





11





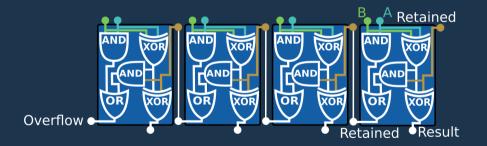
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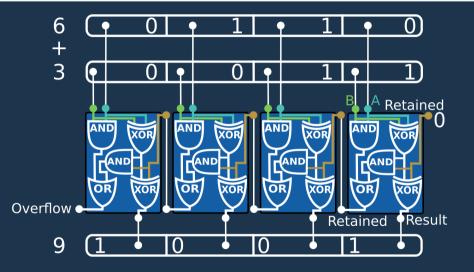
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11





11



From Switch to Transistor



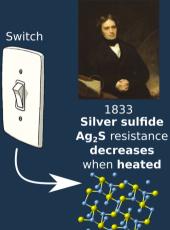






From Switch to Transistor

Michael Faraday (1791 - 1867)





Switch

From Switch to Transistor

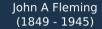


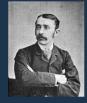
1833

Silver sulfide

Ag₂S resistance

decreases when heated





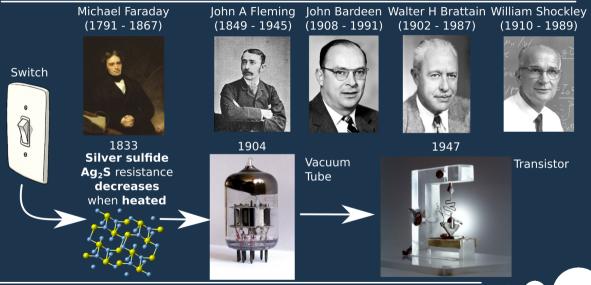
1904



Vacuum Tube

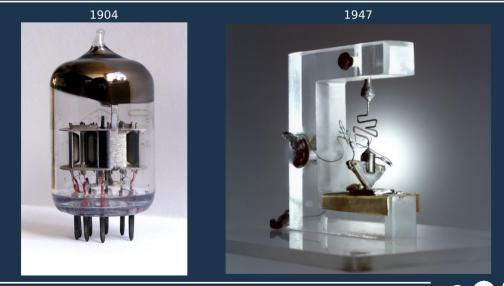


From Switch to Transistor





From Switch to Transistor





13



13



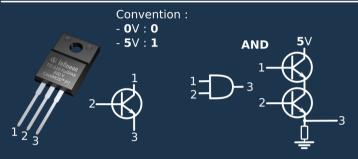


13

Convention : - 0V : 0 - 5V : 1 $2 - \frac{1}{3}$

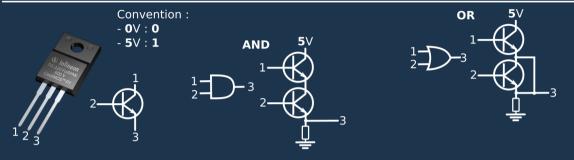


13



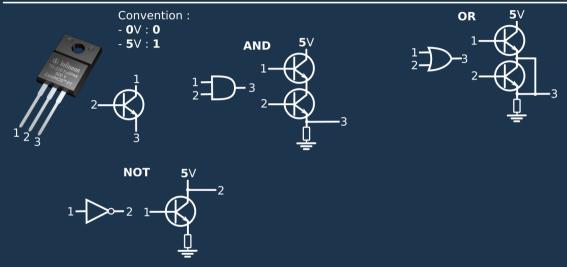


13

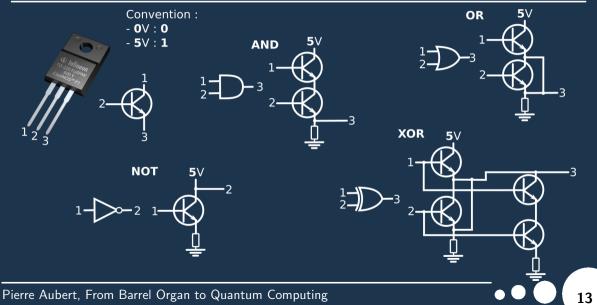




13









From Transistor to CPU

14



From Transistor to CPU

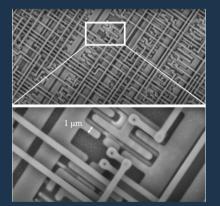






From Transistor to CPU

Transistor view from Scanning electronic microscope



Transistor (3 cm)

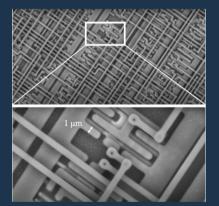


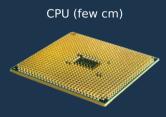


Transistor (3 cm)

From Transistor to CPU

Transistor view from Scanning electronic microscope



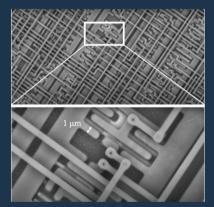


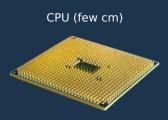
 \sim 1 billion transistors



From Transistor to CPU

Transistor view from Scanning electronic microscope





~ 1 billion transistors Nowaday : **4** nm

Last AMD Instinct MI300 : 146B Transistors



Transistor (3 cm)





15

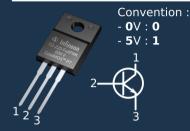
Convention : $- \mathbf{0} \lor : \mathbf{0}$ $- \mathbf{5} \lor : \mathbf{1}$ $1 \xrightarrow{2}{3}$

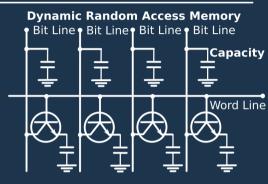


15



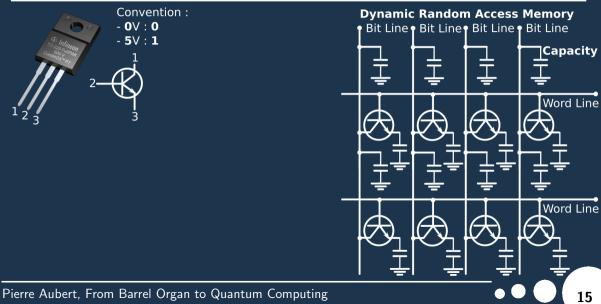




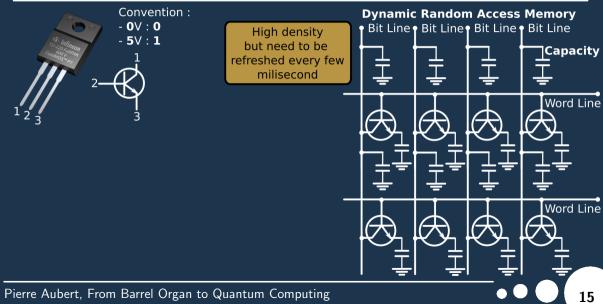


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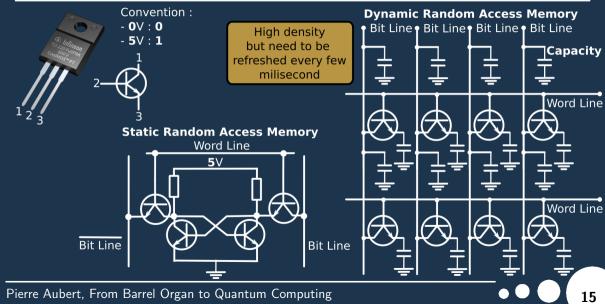




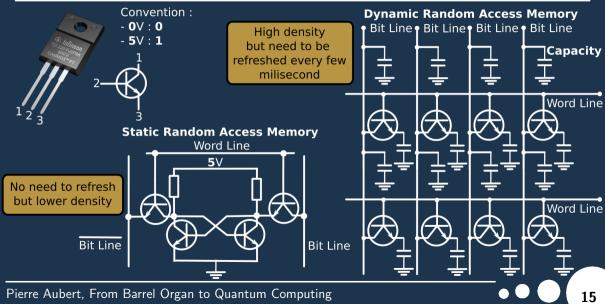














16

Long term information storage



16

Long term information storage





16

Long term information storage





Long term information storage



Oberlin Smith (1840 - 1926)



1888 : first magnetic recording

16



Long term information storage

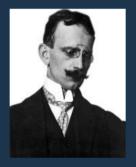


Oberlin Smith (1840 - 1926)



1888 : first magnetic recording

Fritz Pfleumer (1881 - 1945)



1928 : first magnetic tape recorder



Long term information storage



Video Home System



Oberlin Smith (1840 - 1926)



1888 : first magnetic recording

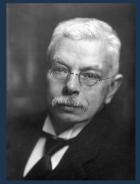
Fritz Pfleumer (1881 - 1945)



1928 : first magnetic tape recorder



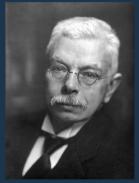
Pieter Zeeman (1865 - 1943)





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

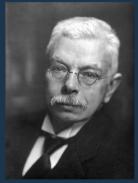
Pieter Zeeman (1865 - 1943)



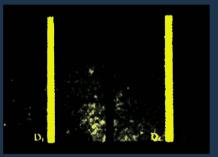


1896 : What happens to the spectrum of an atom in a magnetic field ?

Pieter Zeeman (1865 - 1943)



Sodium Spectrum

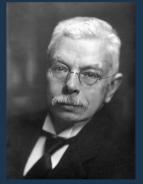


No magnetic field



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

Pieter Zeeman (1865 - 1943)



Sodium Spectrum



With magnetic field



1896: What happens to the **spectrum** of an atom in a **magnetic field** ?Pieter ZeemanEnrik Lorentz(1865 - 1943)(1853 - 1928)





1896 : What happens to the **spectrum** of an atom in a **magnetic field**? Enrik Lorentz Otto Stern Pieter Zeeman

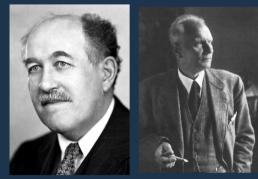
(1865 - 1943)





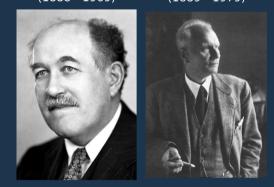
(1888 - 1969)

Walther Gerlach (1889 - 1979)



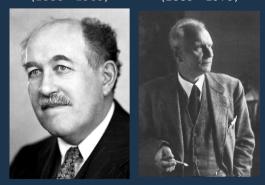


1896 : What happens to the **spectrum** of an atom in a **magnetic field** ? Otto Stern Walther Gerlach (1888 - 1969) (1889 - 1979)





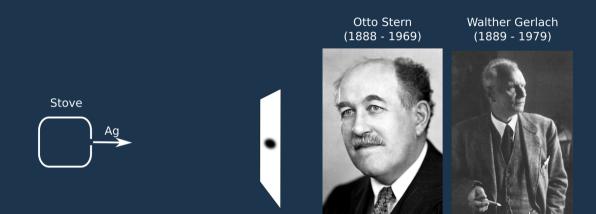
1896 : What happens to the **spectrum** of an atom in a **magnetic field** ? Otto Stern Walther Gerlach (1888 - 1969) (1889 - 1979)



Stove











Pierre Aubert, From Barrel Organ to Quantum Computing

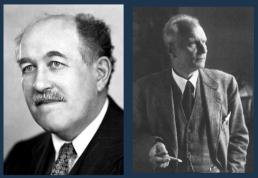
17





Atom is quantized

Otto Stern (1888 - 1969) Walther Gerlach (1889 - 1979)





Otto Stern Walther Gerlach (1888 - 1969)(1889 - 1979) the words das have Porter, autre sie Fortretering august arter (vich Jubrites of Myrith MII. Jaile 110. 1921) : In copriminant la karderes Richt Tryp queschlauser filler due Magnet Glat Win gratitieren zur Nedatigung Herr Theorie ! Most borkacht ungestelle Prime Herrie West borkacht ungestelle Prime 1.0 mm Fm. 8.22 Waenugerlant

Atom is quantized





Atom is a quantum magnet





Atom is a quantum magnet

Felix Bloch (1905 - 1983)

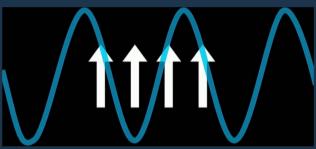


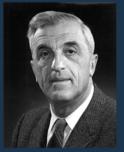
1946 : How behaves an electron in a metal ?



Felix Bloch (1905 - 1983)

Spin resonance with microwaves



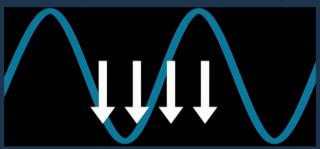


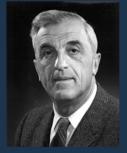
1946 : How behaves an electron in a metal ?



Felix Bloch (1905 - 1983)

Spin resonance with microwaves



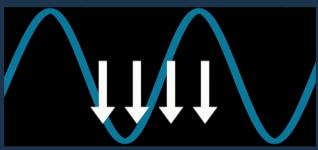


1946 : How behaves an electron in a metal ?

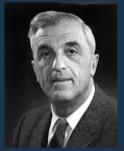


Felix Bloch (1905 - 1983)

Spin resonance with microwaves



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



1946 : How behaves an electron in a metal ?



Albert Fert (1938 -)



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



Albert Fert (1938 -)



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

Spintronics

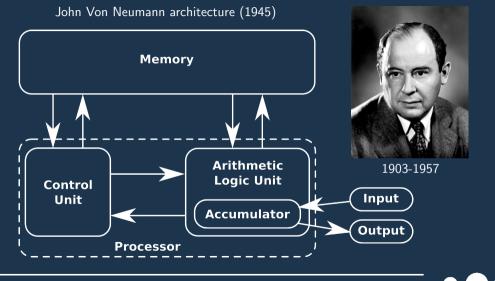
Use spins to store information

Giant magnetoresistance (GMR)

Used is all Reading head of Hard Disk Drive







18



Grace Hopper

Grace Hopper (1906 - 1992)



- Developed First Compiler
- Cobol language

19

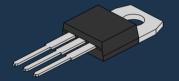


From Transistor to Computing Hardware

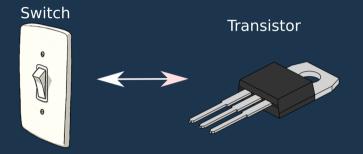


From Transistor to Computing Hardware

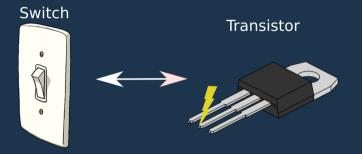
Transistor



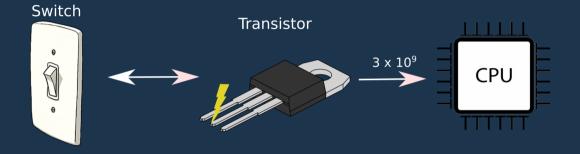






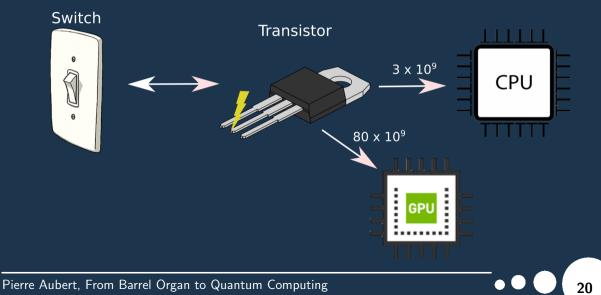


PP From Transistor to Computing Hardware

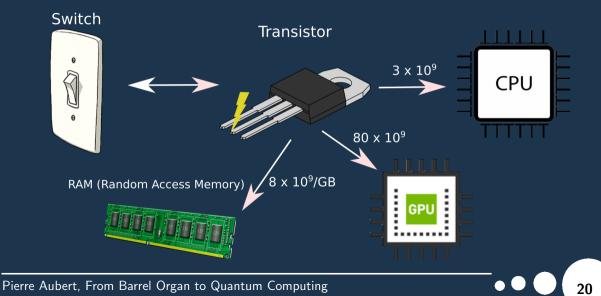


20

PP From Transistor to Computing Hardware



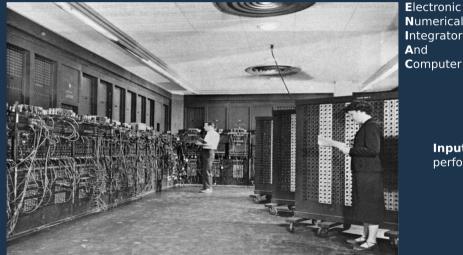
PP From Transistor to Computing Hardware







1945



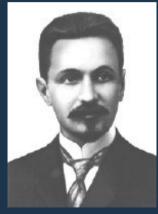
Numerical Integrator Computer

Input/Output with perforated paper

21

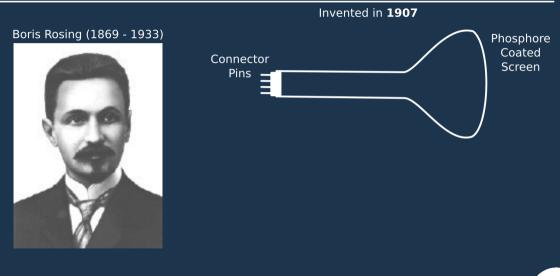


Boris Rosing (1869 - 1933)

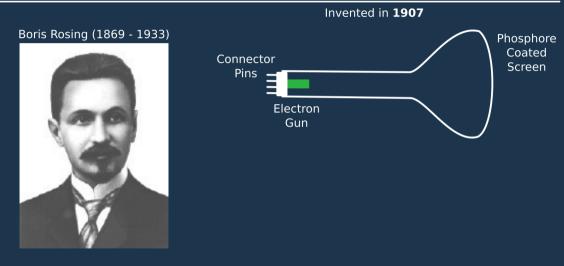




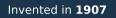


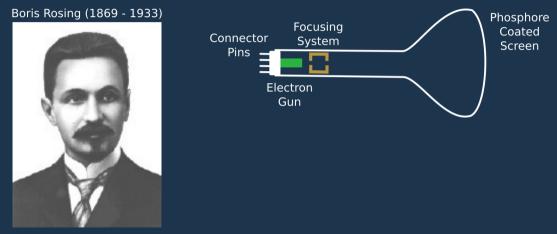




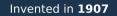




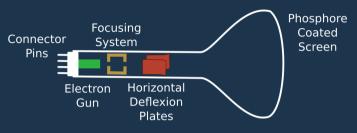




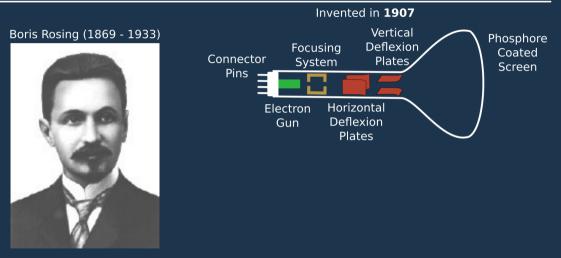




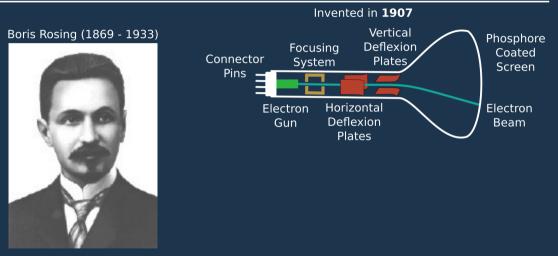
Boris Rosing (1869 - 1933)



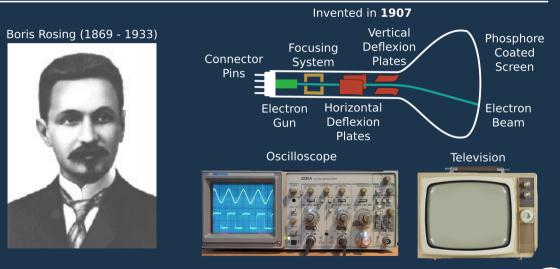






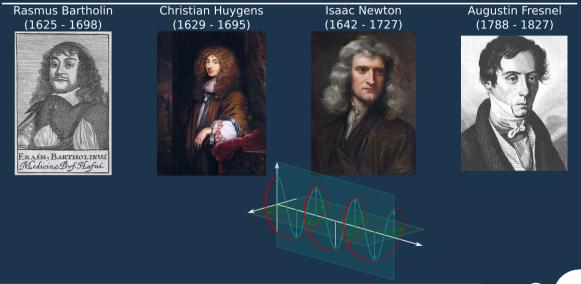








Light Polarization

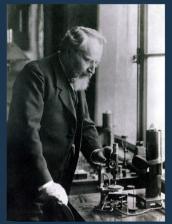


23



24

Otto Lehmann (1855 - 1922)



1888 : Liquid Crystal discovery



Otto Lehmann (1855 - 1922)



1888 : Liquid Crystal discovery

Light



unpolarized





unpolarized Light Polarizers

Otto Lehmann (1855 - 1922)



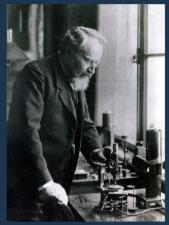
1888 : Liquid Crystal discovery

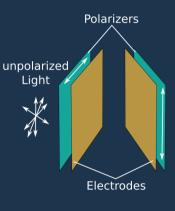






Otto Lehmann (1855 - 1922)



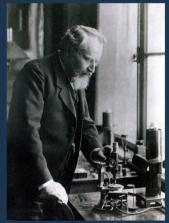


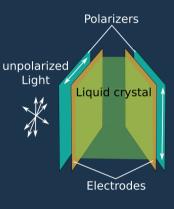
24

1888 : Liquid Crystal discovery



Otto Lehmann (1855 - 1922)





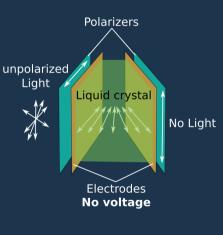
24

1888 : Liquid Crystal discovery



Otto Lehmann (1855 - 1922)



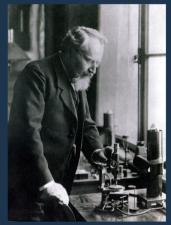


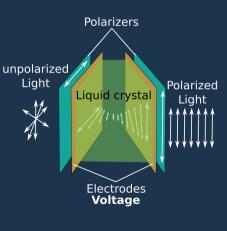
24

1888 : Liquid Crystal discovery



Otto Lehmann (1855 - 1922)

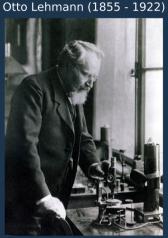


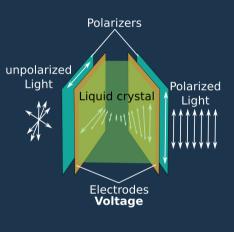


24

1888 : Liquid Crystal discovery







One colored pixel

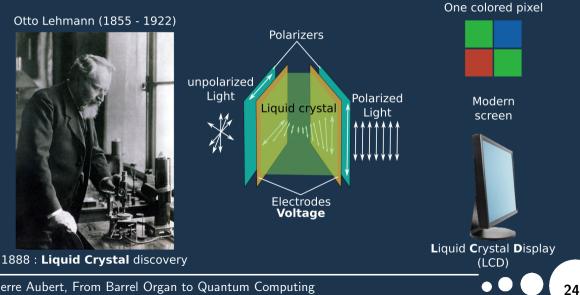


1888 : Liquid Crystal discovery

Pierre Aubert, From Barrel Organ to Quantum Computing

24







Electromagnetism



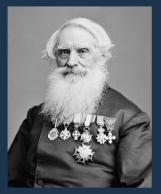




Wireless Telegraphy

26

Samuel Morse (1791 - 1872)

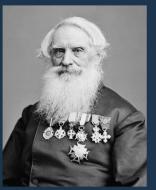


- Electric telegraphMorse alphabet
- Pierre Aubert, From Barrel Organ to Quantum Computing



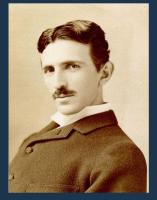
Wireless Telegraphy

Samuel Morse (1791 - 1872)



Electric telegraphMorse alphabet

Nikola Tesla (1856 - 1943)



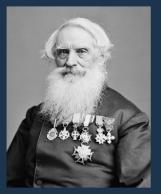
One of the first to make wireless communications

26



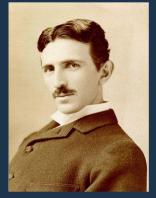
Wireless Telegraphy

Samuel Morse (1791 - 1872)



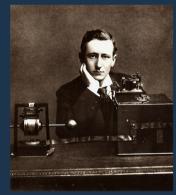
Electric telegraphMorse alphabet

Nikola Tesla (1856 - 1943)



One of the first to make wireless communications

Guglielmo Marconi (1874 - 1937)



One of the inventors of : - Radio - Wireless telegraphy





Hedy Lamarr (1914 - 2000)





Hedy Lamarr (1914 - 2000)





Hedy Lamarr (1914 - 2000)



Vincente Minnelli, 1946



Pierre Aubert, From Barrel Organ to Quantum Computing

27



Hedy Lamarr (1914 - 2000)



Wireless communications can be easly intercepted

Vincente Minnelli, 1946





Hedy Lamarr (1914 - 2000)



Wireless communications can be easly intercepted

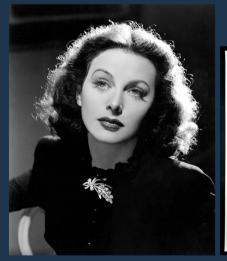
Vincente Minnelli, 1946



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



Hedy Lamarr (1914 - 2000)



Wireless communications can be easly intercepted

Vincente Minnelli, 1946



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

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





Optic Fiber

28

Jacques Babinet (1794 - 1872)



Daniel Colladon

(1802 - 1893)

First Light guide using refraction in 1840s



Harold Horace Hopkins (1918 - 1994)



Jacques Babinet

(1794 - 1872)



Daniel Colladon

First Light guide using refraction in 1840s 1953 : First **image transmission** (75 cm fiber) with **several thousand fibers**

28



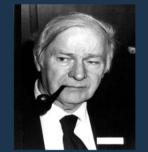


Jacques Babinet



Daniel Colladon

Harold Horace Hopkins (1918 - 1994)



Sir Charles Kao Kuen (1933 - 2018)



First Light guide using refraction in 1840s 1953 : First **image transmission** 1965 : **impurities** could (75 cm fiber) be removed with **several thousand fibers** (attenuation **20 dB/km**)



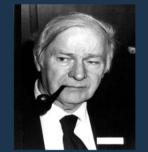


lacques Babinet



Daniel Colladon

Harold Horace Hopkins (1918 - 1994)



Sir Charles Kao Kuen (1933 - 2018)



First Light guide using refraction in 1840s

 1953 : First image transmission
 1965 : impurities could

 (75 cm fiber)
 be removed

 with several thousand fibers
 (attenuation 20 dB/km)

1970 : Robert D. Maurer, Donald Keck, Peter C. Schultz, and Frank Zimar : first optic fiber at 20 dB/km



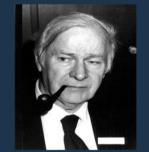


lacques Babinet



Daniel Colladon

Harold Horace Hopkins (1918 - 1994)



Sir Charles Kao Kuen (1933 - 2018)



First Light guide using refraction in 1840s

 1953 : First image transmission
 1965 : impurities could

 (75 cm fiber)
 be removed

 with several thousand fibers
 (attenuation 20 dB/km)

1970 : Robert D. Maurer, Donald Keck, Peter C. Schultz, and Frank Zimar : first optic fiber at **20 dB/km** 1981 : first **40 km** transmission (**4 dB/km**)



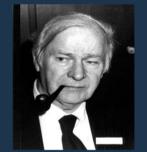


lacques Babinet



Daniel Colladon

Harold Horace Hopkins (1918 - 1994)



Sir Charles Kao Kuen (1933 - 2018)



First Light guide using refraction in 1840s

 1953 : First image transmission
 1965 : impurities could

 (75 cm fiber)
 be removed

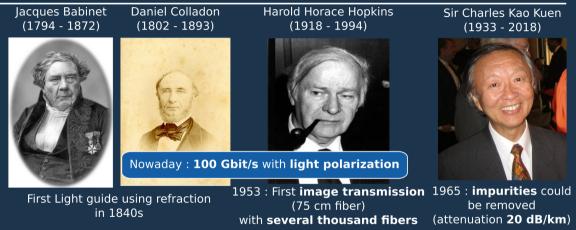
 with several thousand fibers
 (attenuation 20 dB/km)

1970 : Robert D. Maurer, Donald Keck, Peter C. Schultz, and Frank Zimar : first optic fiber at 20 dB/km

1981 : first 40 km transmission (4 dB/km)

1987 : 2 teams, David N. Payne , Emmanuel Desurvire, first 70 - 150 km transmission



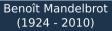


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Helge von Koch

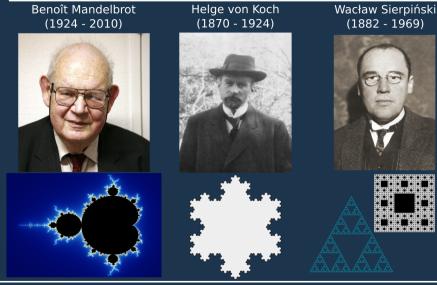
(1870 - 1924)



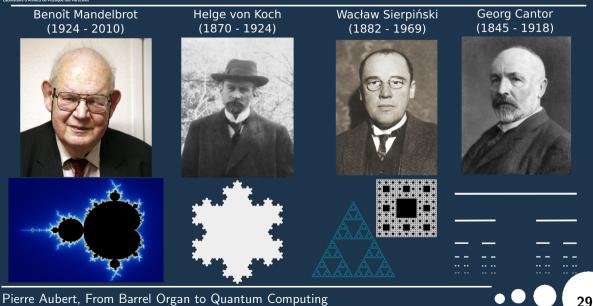




29

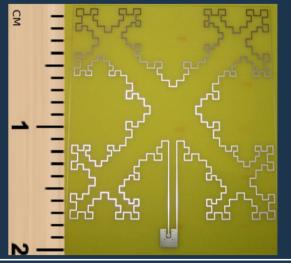








Multiband / wideband antenna

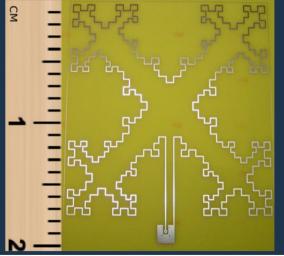


Pierre Aubert, From Barrel Organ to Quantum Computing

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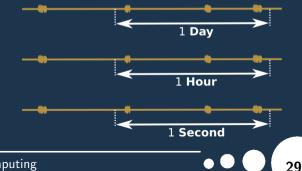
Multiband / wideband antenna



Denoising communications

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

Mandelbrot found : noise is a self repeated pattern





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30



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

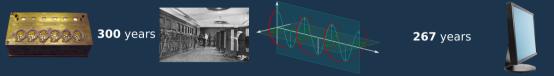






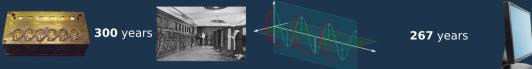


Pascaline (1645) -> computer (1945) Light Polarization (1650s) -> Liquid Crystal Display (1971)





Pascaline (1645) -> computer (1945) Light Polarization (1650s) -> Liquid Crystal Display (1971)



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



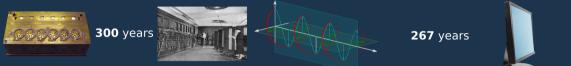
92 years







Pascaline (1645) -> computer (1945) Light Polarization (1650s) -> Liquid Crystal Display (1971)



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



92 years



Silver sulfide (1833) -> Transistor (1947)

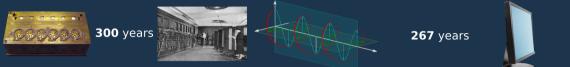


114 years





Pascaline (1645) -> computer (1945) Light Polarization (1650s) -> Liquid Crystal Display (1971)



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



92 years



Silver sulfide (1833) -> Transistor (1947)



114 years

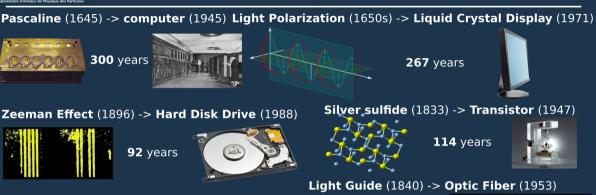


Electromagnetism (1860) -> Wifi (1997)









Electromagnetism (1860) -> Wifi (1997)







30



(Some) Involved people



31



32



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





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

Quantum States

Niels Bohr (1885 - 1962)





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

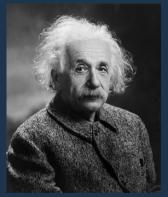
Quantum States

Niels Bohr (1885 - 1962)



Photo-electric effect

Albert Einstein (1879 - 1955)





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

Quantum States Niels Bohr (1885 - 1962)

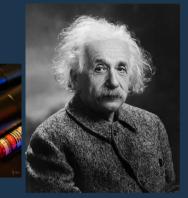


LASER

Light Amplification by Stimulated Emission of Radiation

Photo-electric effect

Albert Einstein (1879 - 1955)







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

Quantum States Niels Bohr (1885 - 1962)



LASER

Light Amplification by Stimulated Emission of Radiation Photo-electric effect

Albert Einstein (1879 - 1955)

Photovoltaic panels



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

Quantum States Niels Bohr (1885 - 1962)



LASER

Light Amplification by Stimulated Emission of Radiation Photo-electric effect

Albert Einstein (1879 - 1955)

Photovoltaic panels

Very good accuracy according to experiments

Pierre Aubert, From Barrel Organ to Quantum Computing

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Pierre Aubert, From Barrel Organ to Quantum Computing

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Quantum Superposition

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J



Quantum Superposition

Example : Strontium





Quantum Superposition

Example : Strontium







Quantum Superposition

Example : Strontium



Non excited AND excited







Quantum Superposition

Quantum entanglement

Example : Strontium



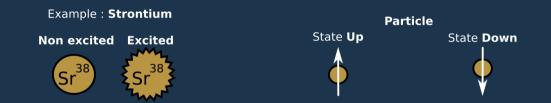
Non excited AND excited





Quantum Superposition

Quantum entanglement



Non excited AND excited





Quantum Superposition

Quantum entanglement





Non excited AND excited

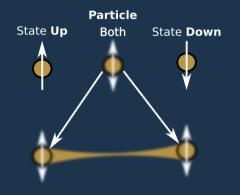




Quantum Superposition

Quantum entanglement



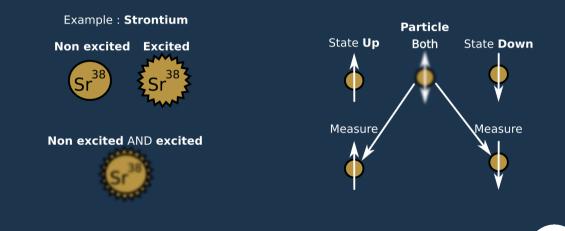




Quantum Physics : Non trivial properties

Quantum Superposition

Quantum entanglement

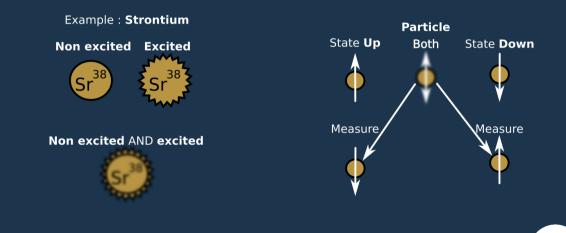




Quantum Physics : Non trivial properties

Quantum Superposition

Quantum entanglement





Quantum Physics : Non trivial properties

Quantum Superposition

Example : Strontium

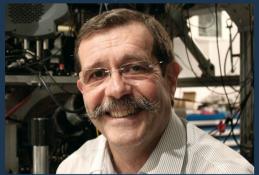


Non excited AND excited



Quantum entanglement

Alain Aspect (1947 -)



Entangled particles do not send information to each other



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34



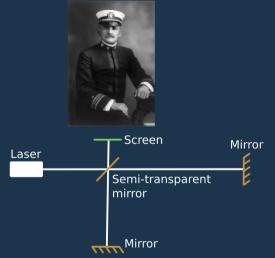
Albert Michelson (1852 - 1931)







Albert Michelson (1852 - 1931)

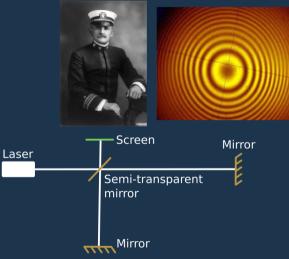


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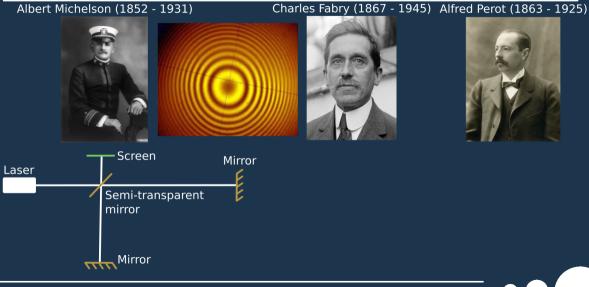
Albert Michelson (1852 - 1931)



Pierre Aubert, From Barrel Organ to Quantum Computing

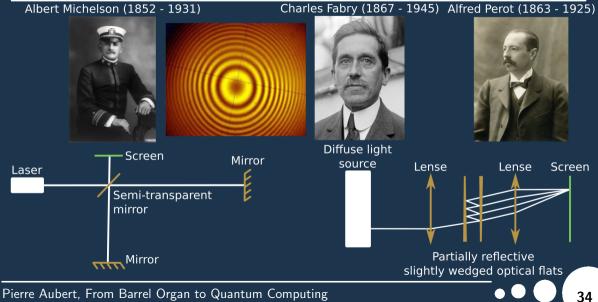
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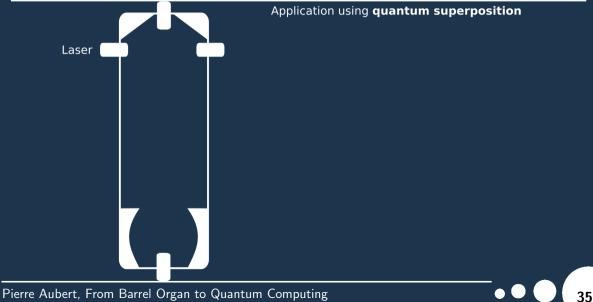


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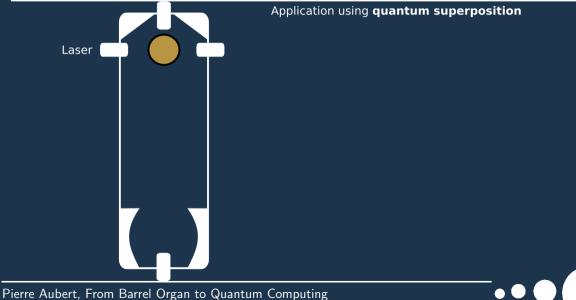






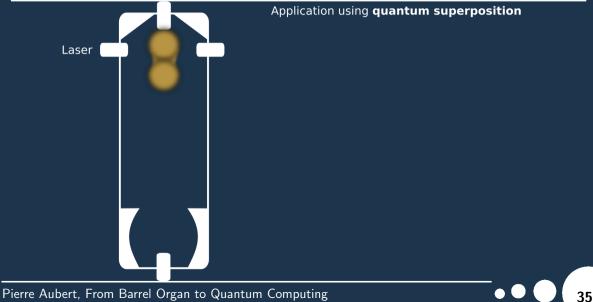




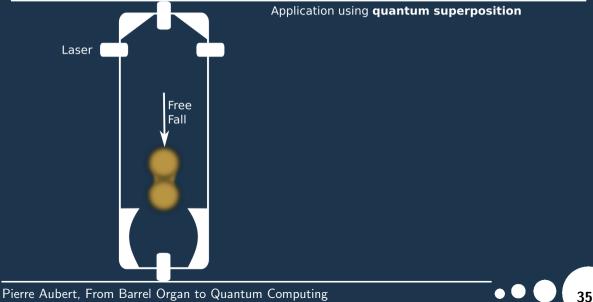


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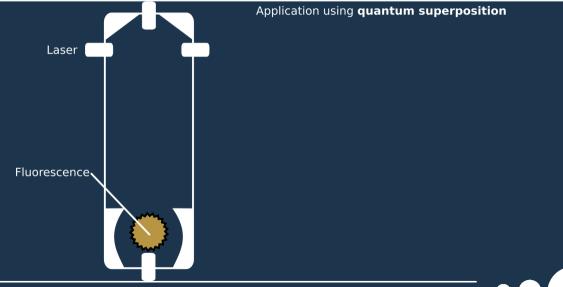








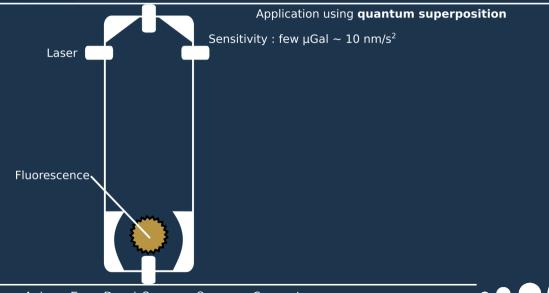




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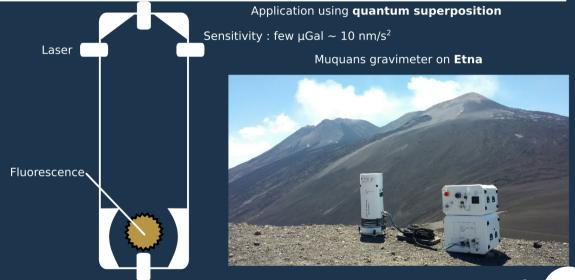
35





35





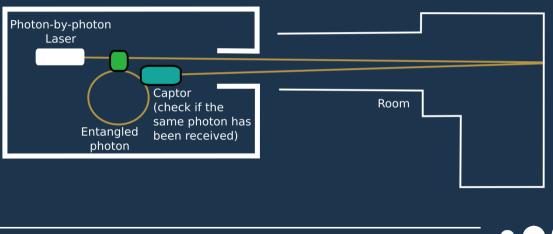
CAPP Quantum Imaging with entangled photons

Application using **Quantum Entanglement**





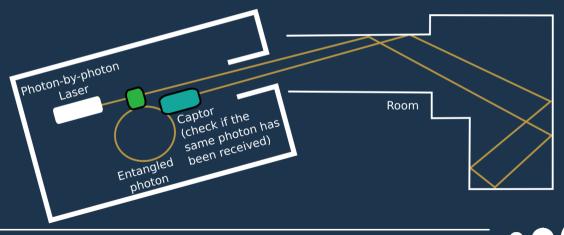
Application using **Quantum Entanglement**



CAPP Quantum Imaging with entangled photons

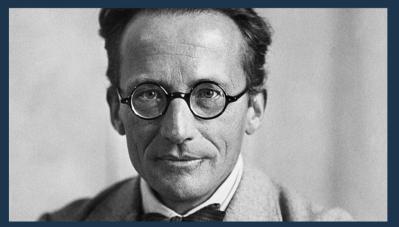
Application using Quantum Entanglement

36





Erwin Schrödinger (1887 - 1961)



Why not simulate quantum phenomena with other quantum phenomena ?



Real Fluid Mechanics



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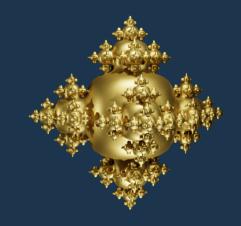
37



Real Volume "Computation"

Real Fluid Mechanics



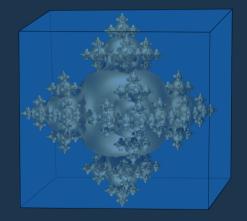




Real Volume "Computation"

Real Fluid Mechanics



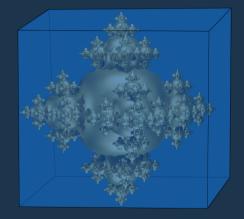




Real Volume "Computation"

Real Fluid Mechanics





Measure : **overflowed water**





Quantum Computing

Computing with quantum physics ?

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





Quantum Computing

Peter Shor (1959 -)



Factorization into prime numbers

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38



39



States Convention :



States Convention :



State **Down**





Quantum Computing : how to store data ?

States Convention :



State **Up**





Quantum Computing : how to store data ?

States Convention :















Example : Strontium

O Quantum Computing : how to store data ?





Quantum Computing : how to store data ?



Quantum Computing : how to store data ?

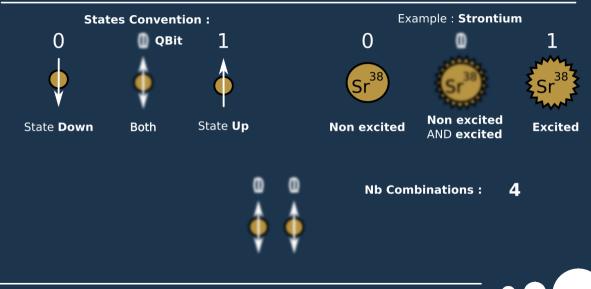


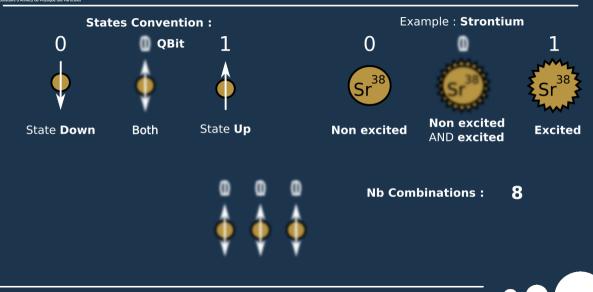
Pierre Aubert, From Barrel Organ to Quantum Computing

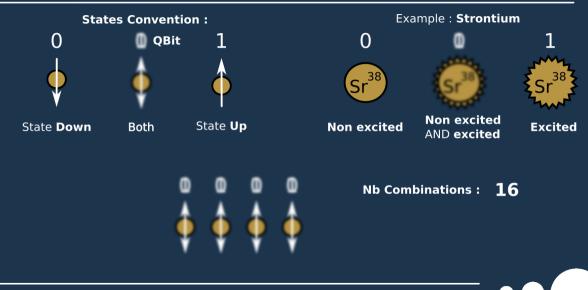
39

39



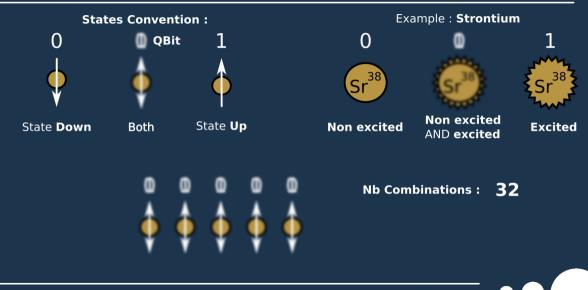


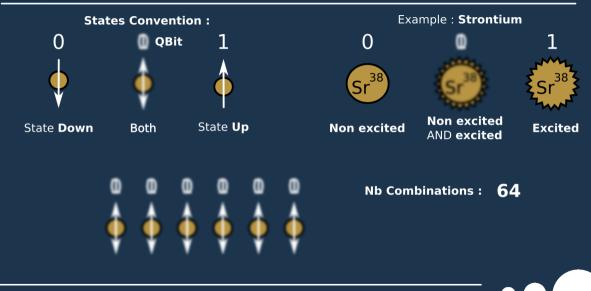


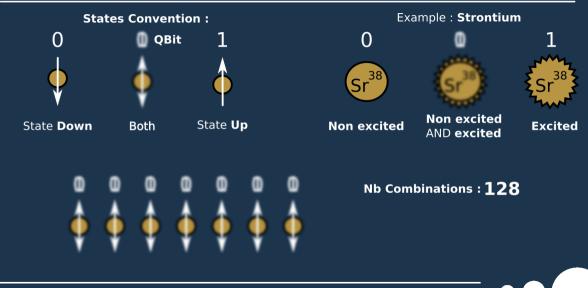


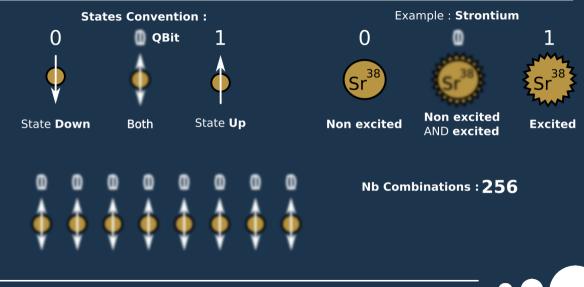
Pierre Aubert, From Barrel Organ to Quantum Computing

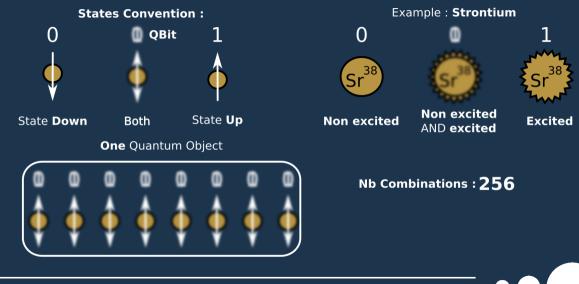
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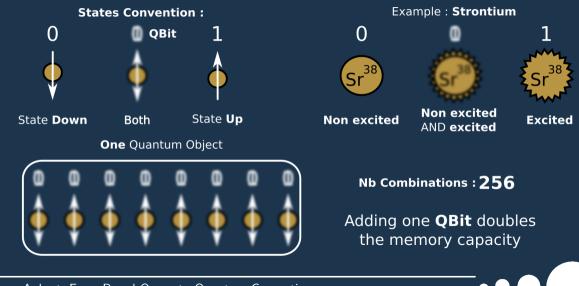










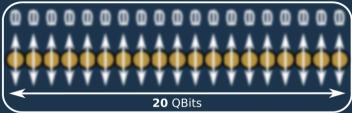




Search one word in a list of 1 million words



Search one word in a list of 1 million words List in QBits





Search one word in a list of 1 million words List in QBits





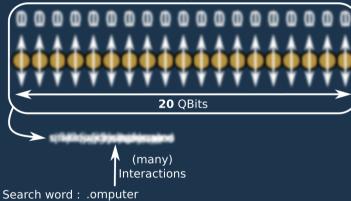
Search one word in a list of 1 million words List in QBits



Search word : .omputer

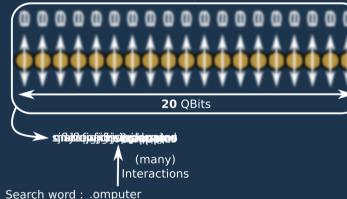


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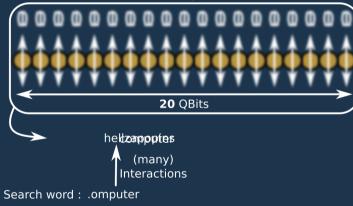


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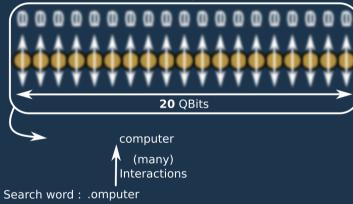


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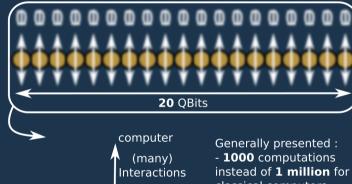


Search one word in a list of 1 million words List in QBits





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



Search word : .omputer

classical computers





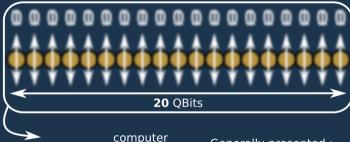
computer (many) Interactions

Search word : .omputer

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



Search one word in a list of 1 million words List in QBits



Classic computer approach

- Build **dictionary** with reversed keys

(many) Interactions

Search word : .omputer

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



Search one word in a list of 1 million words List in QBits



Classic computer approach

- Build **dictionary** with reversed keys

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

Search word : .omputer

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

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(manv)

Interactions



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 ?



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Where is **waldoo**?





IN EVERY PICTURE FIND WALDO, WOOF (BUT ALL YOU CAN SEE IS HIS TAIL), WENDA, WIZARD WHITEREARE OLAVE, AND THE SCIOLE THEN FIND WALDO'S KEY, WOOF'S BONE (DI THES SCINE IT'S THE BONE THAT'S NEAREST TO HIS TAIL, WINDA'S CAMERA, AND OOL/W'S INNOCULARS

THERE ARE ALSO 25 WALDO WATCHERS, EACH OF WHOM AFFEARS ONLY ONCE SOMEWHERE IN THE FOLLOWING 12 HICTURES AND ONE MORE THENGTON TO FIND ANOTHER CHARACTER, NOT SHOWN BELOW, WHO AFFEARS ONCE IN EVERY FOLLOWE EXCEPT THE LAST?







Where is **waldoo**?

THE COBBLING CLUTTONS ONCI UPON A THE WALD DIMENSIO UPON A TANKATIC DOLMAN THE UPON A TANKATIC DIMENSION OF DEMINISCI AND THEN TO THE ANALY AND A TANKAT AND THE NO THE ANALY AND A TANKAT AND A TANKAT THE AND A TANKAT AND A TANKAT AND A TANKAT AND A TANKAT THE AND A TANKAT TANKAT AND A TANK

IN EVERY PICTURE FIND WALDO, WOOF (BUT ALL YOU CAN SEE IS HIS TAB, WENDA, WEARD WHITEREARD DOLW, AND THE SCIOLL THEN FIND WALDO'S KEY, WOOF'S BONE (IN THIS SCENE IT'S THE BONE THAT'S NEAREST TO HIS TAB, WENDA'S CAMERA, AND ODLAW'S BINOCULARS.

THERE ARE ALSO IS WALLOW WATCHEES LACH OF WHOM APPEARS ONLY ONCE SOMEWHERE IN THE FOLLOWING IP PICTURES AND ONE MORE THENG CAN YOU FIND ANOTHER CHARACTER. NOT SHOWN BELOW, WHO APPEARS ONCE IN EVERY PICTURE EXCEPT THE LAST?

Destructive / Constructive interferences

Pierre Aubert, From Barrel Organ to Quantum Computing

Blur what

is **not**

waldoo





Where is waldoo ?

IN EVERY PECTURE IND WALDO, WOOF (BUT ALL YOU CAN BEE IS HIS TAIL) WENDA, WEARD WHITEBEARD, ORLAW, AND THE SCHOLL THEN FIND WALDO'S KEY, WOOF'S BONE (IN THIS SCENE IT'S THE BONE THAT'S NEAREST TO HIS TAIL) WENDA'S CAMERA, AND ORLAW'S BINOCULARS.

THERE ARE ALSO IS WALLOW WITCHERE, LACH OF WHOM APPLANS ONLY ONCE SOMEWHERE IN THE FOLLOWING I PRCTURES AND ONE MORE THENG CAN YOU FIND ANOTHER CHARACTER, NOT SHOPEN ELLOW, WHO APPLANS ONCE IN FYRAT PRCTURE EXCEPT THE LAST?

Destructive / Constructive interferences

Pierre Aubert, From Barrel Organ to Quantum Computing

Blur what

is not waldoo





Where is waldoo ?

Blur what is not waldoo

Destructive / Constructive interferences THE COMMENDER OF STATES OF

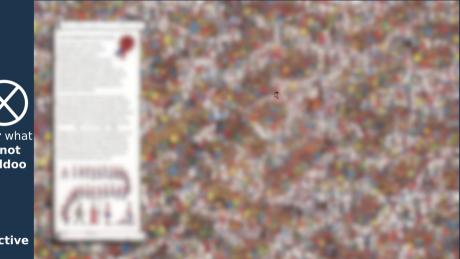




Where is **waldoo**?



Destructive / Constructive interferences

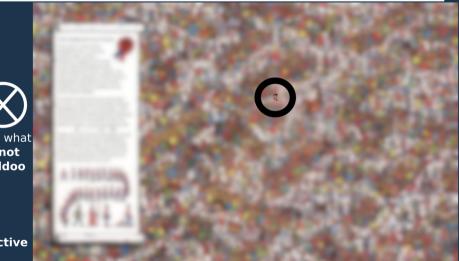




Where is **waldoo**?



Destructive / Constructive interferences







Quantum Superposition





Quantum Superposition

Strontium



Non exited AND excited







Quantum Superposition

Strontium

Mercury

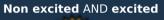
Non excited Excited





Non exited AND excited









Quantum Superposition

Strontium

Mercury

Non excited Excited



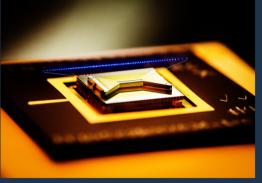
Non excited Excited



Non exited AND excited



Non excited AND excited







Photonic quantum computer

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•••



Photonic quantum computer

States superposition

Pierre Aubert, From Barrel Organ to Quantum Computing



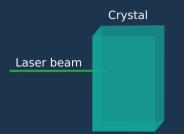


States superposition

Laser beam



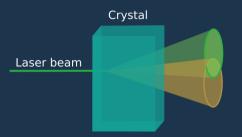
States superposition







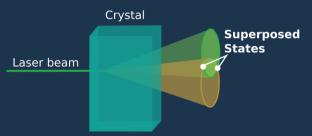
States superposition







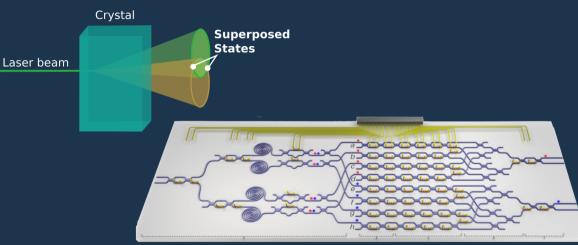
States superposition













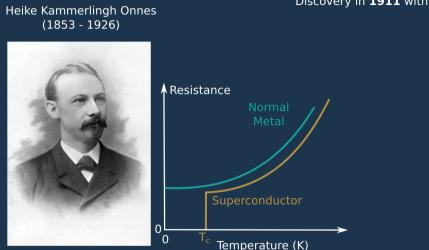
Heike Kammerlingh Onnes (1853 - 1926)



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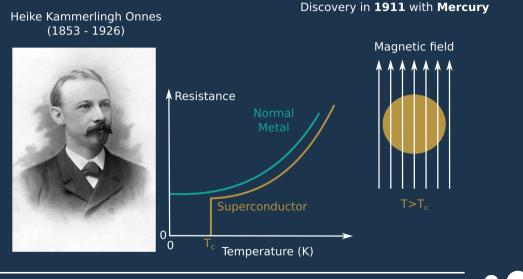


Discovery in 1911 with Mercury

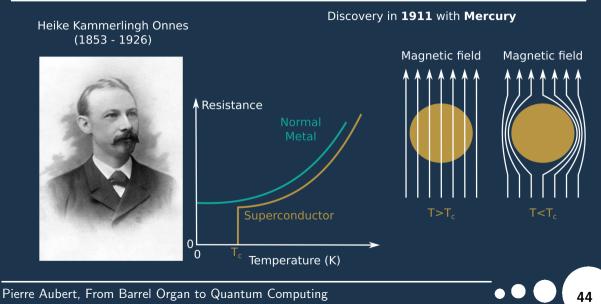
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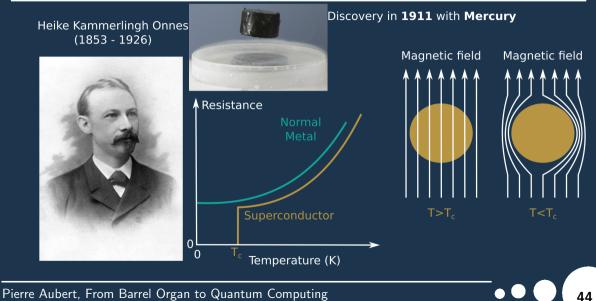






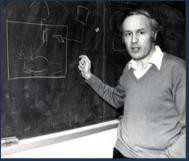








Anthony James Leggett (1938 -)



Metal with **giant quantic wave** is similar as an atom !





Anthony James Leggett (1938 -)



Metal with **giant quantic wave** is similar as an atom !

Google Sycamore Chip 2019



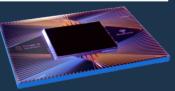


Anthony James Leggett (1938 -)



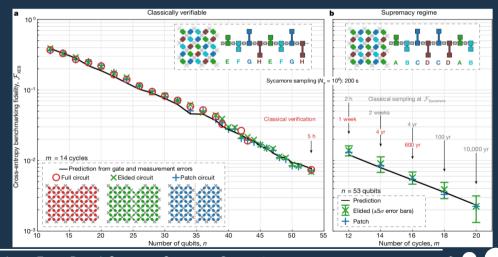
Metal with **giant quantic wave** is similar as an atom !

Google Sycamore Chip 2019



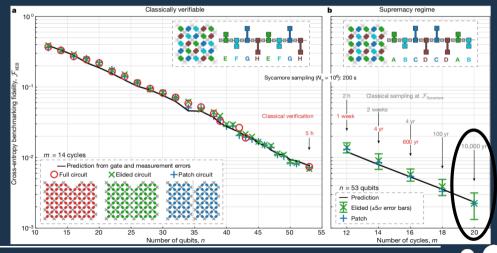






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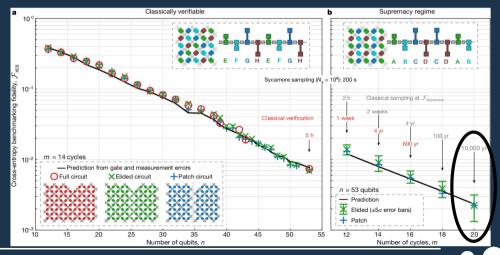




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Likelihood of different outcomes from a quantum version of a random-number generator



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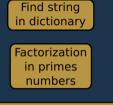
Factorization in primes numbers





Quantum cryptography





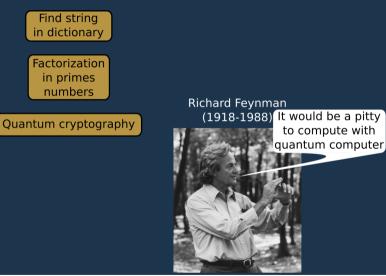
Quantum cryptography

Richard Feynman (1918-1988)

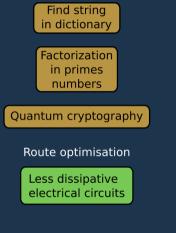


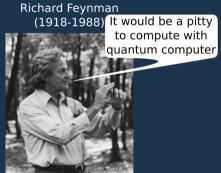




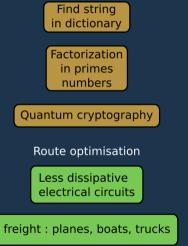


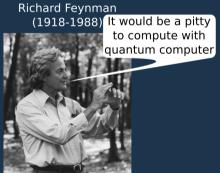




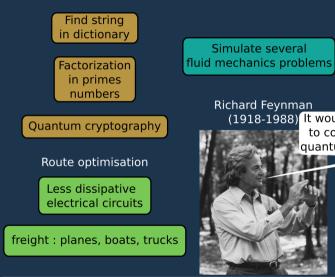










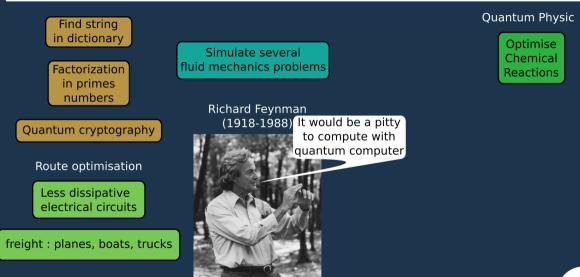


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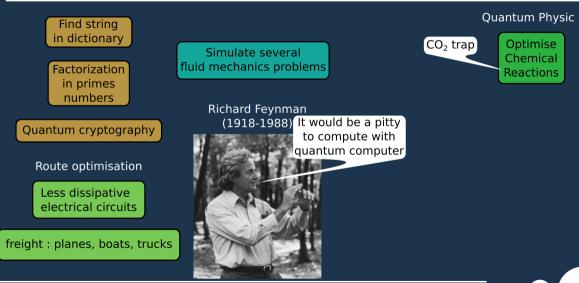
Richard Feynman (1918-1988) It would be a pitty to compute with quantum computer

Simulate several

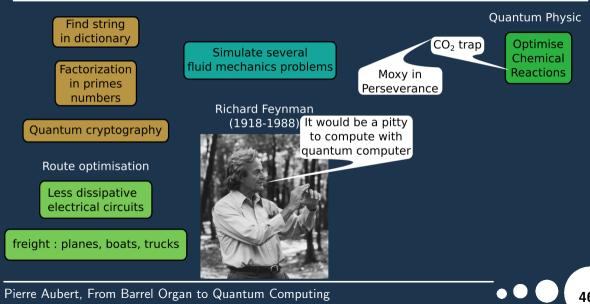




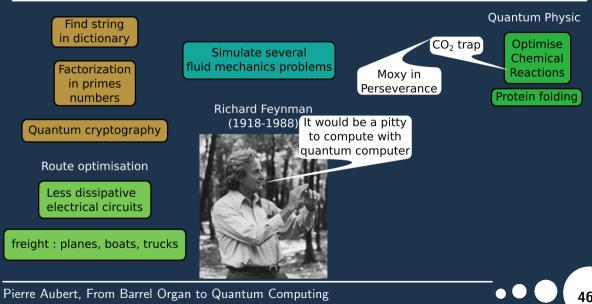




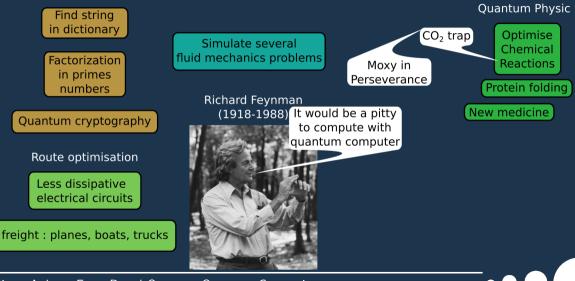




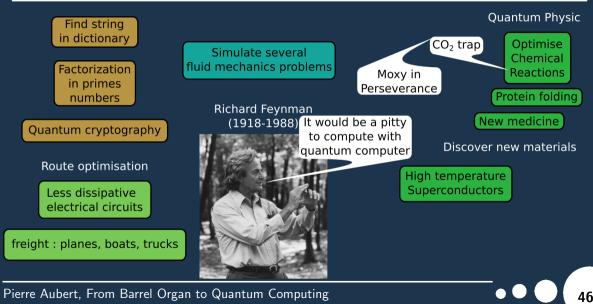




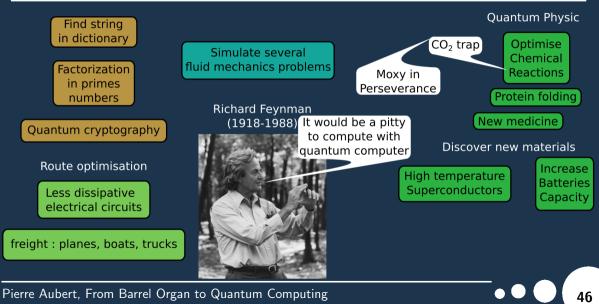




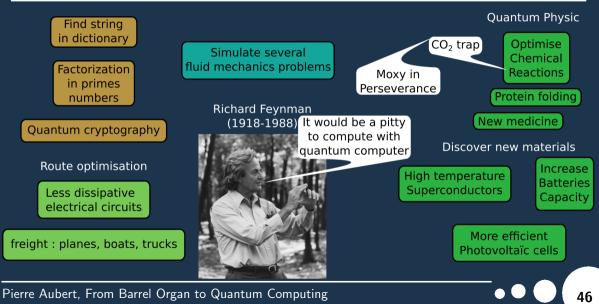














Quantum Computer Issues

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Quantum Computer Issues

Too many errors (1 over 1000 computations)

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Too many errors (1 over 1000 computations)

Need 1 000 000 computations to get a result



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On classical computer : less than one error on $\mathbf{10}^{24}$ computations



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Peter Shor (1959 -)



Error correction with entanglement On classical computer : less than one error on ${\bf 10}^{\rm 24}$ computations



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Error correction with entanglement



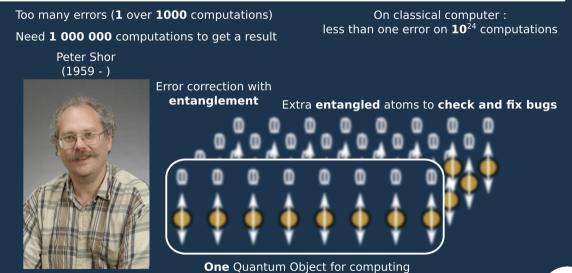
One Quantum Object for computing

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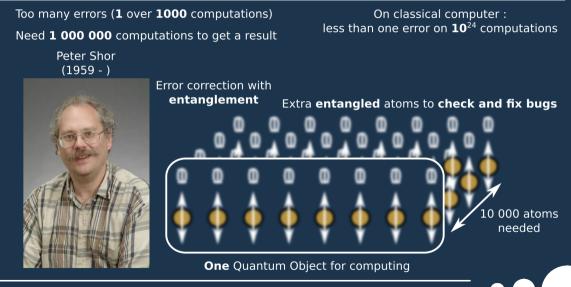
On classical computer : less than one error on ${\bf 10}^{\rm 24}$ computations

47





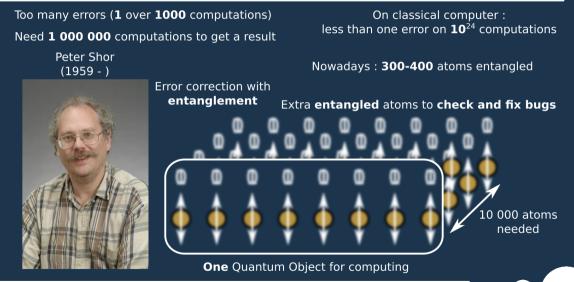




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Almost 40 years for every aspect :



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- Superconductors :
 - Anthony Legett : 1980
 - First computers : 2019
- Theory :
 - First ideas : 1979-1981
 - First algorithms : **some years ago**





(Some) Involved people





56 + previous people







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