

Introduction to Quantum Computing:

A demo with IBM
Qiskit

V2 - Benoît Prieur - CC0 - BarCamp Yerevan  - 24-25 June 2023



Quantum Physics

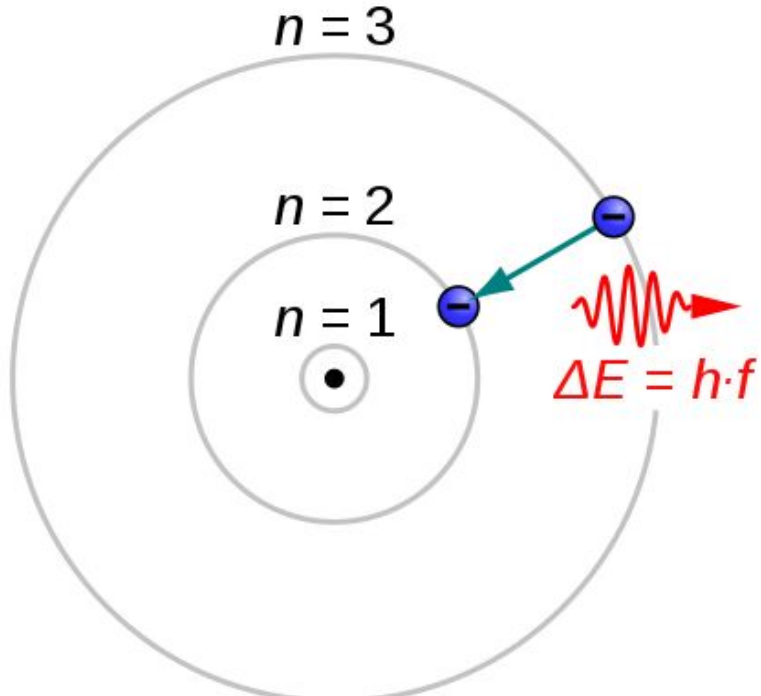
- Physics of the infinitely small
- Counter-intuitive, as opposed to classical physics/mechanics
- Probabilistic world (not determinist)



Subatomic world, few particles

- Atom
 - Nucleus: **Neutron**, **Proton (+1)**
 - **Electron (-1)**
- Light: Wave–particle duality, **Photon**

1st counter-intuitive phenomenon: levels of energy “quanta”



- Electron absorption or emit is done according to quantified energy levels
- Etymology: “Quanta”



Understand Quantum Computing

Understand (at least) Three concepts:

- Superposition
- Measurement
- Entanglement



Heisenberg's uncertainty principle

- If we know (precisely) the position of a particle, we cannot know (precisely) its speed. And reciprocally
- First approach to **quantum superposition**
- The measurement disturbs the measured value (conventional mechanical counter-analogy)

Schrödinger's cat



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Wave function

Classical Mechanics

Newton's laws of motion

$$\sum \vec{F}_i = m\vec{a}$$

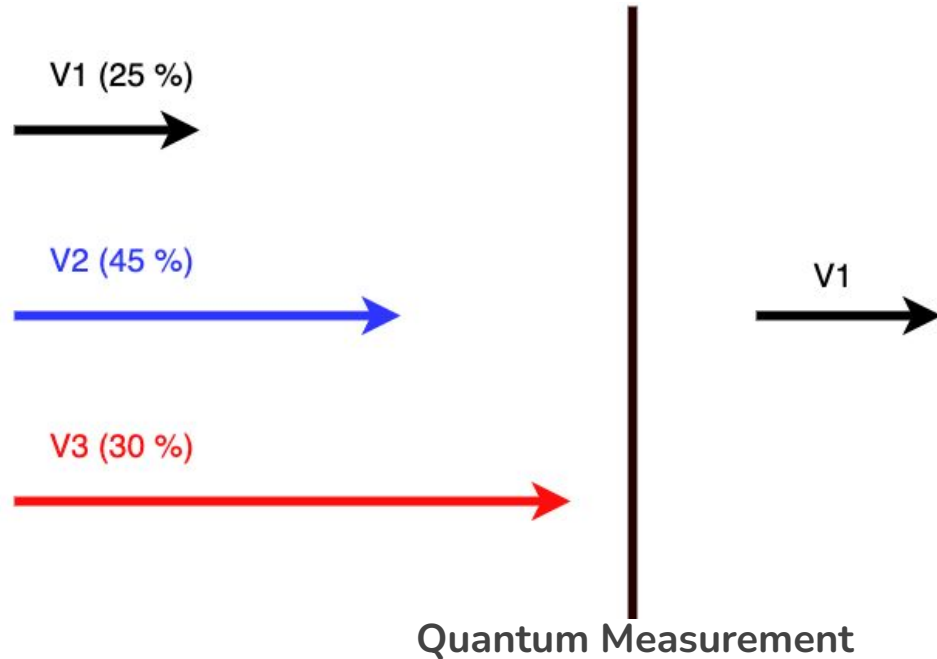
Quantum Mechanics

Schrödinger equation

$$i\hbar \frac{d}{dt} |\Psi(t)\rangle = \hat{H} |\Psi(t)\rangle$$

Quantum superposition and bracket notation

$$|\Psi\rangle = 25\% |V1\rangle + 45\% |V2\rangle + 30\% |V3\rangle$$





Quantum superposition and bracket notation (II)

Qubit 1



$$|qubit1\rangle = a.|0\rangle + b.|1\rangle$$



Qubit 2



$$|qubit1\rangle = a.|00\rangle + b.|10\rangle + c.|01\rangle + d.|11\rangle$$

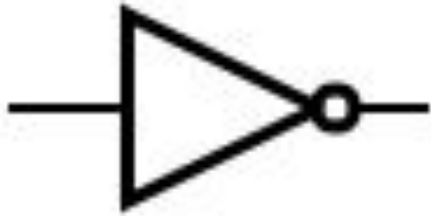


Qubit 3



$$|qubit1\rangle = a.|000\rangle + b.|001\rangle + c.|010\rangle + d.|100\rangle + e.|110\rangle + f.|011\rangle + g.|101\rangle + h.|111\rangle$$

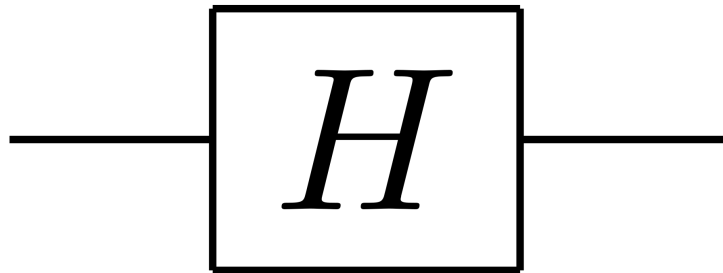
Logic Gates analogy



Entrée	Sortie
a	L
0	1
1	0

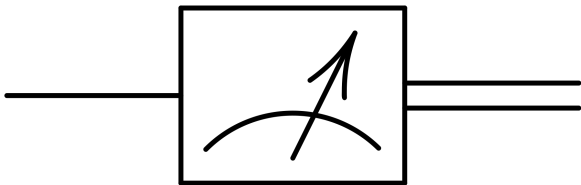
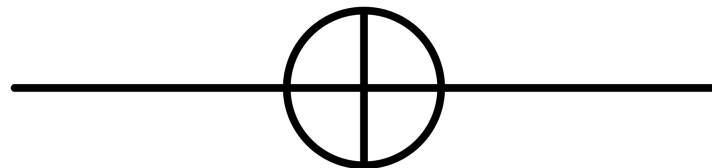


Quantum gates

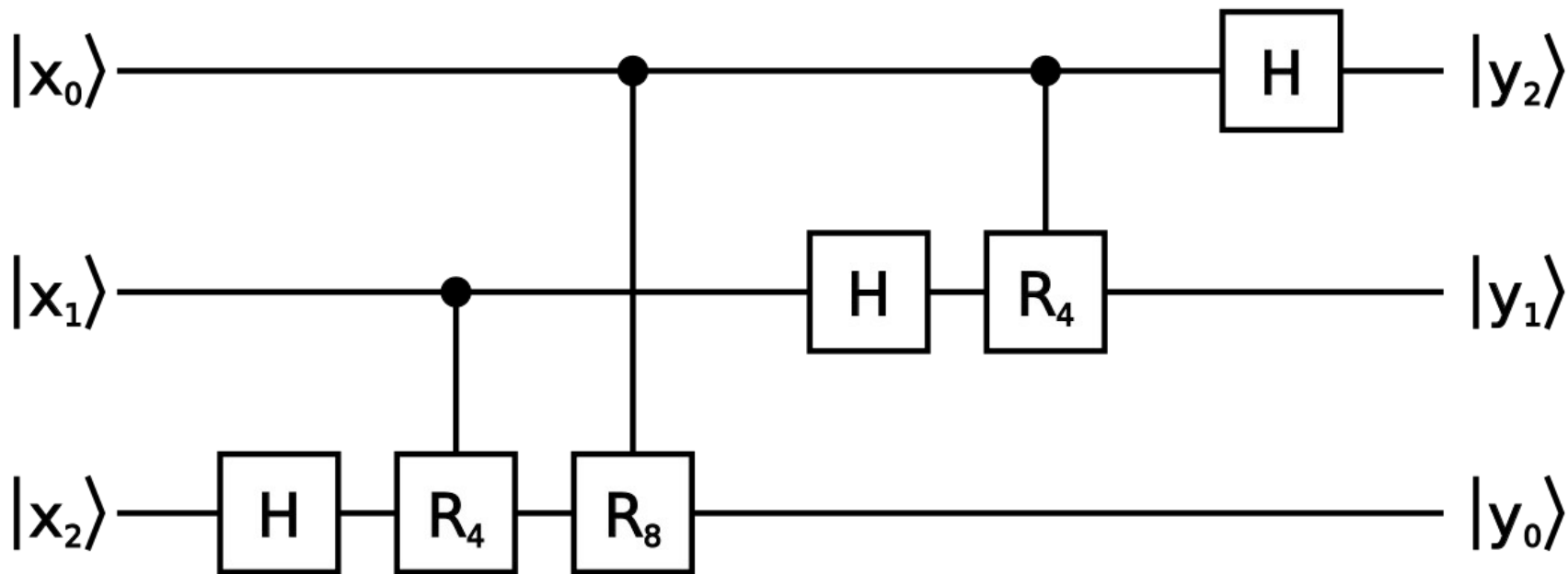


$$H = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}.$$

$$X = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}$$



Quantum circuit and Quantum gates





Quantum simulator vs Quantum computer

- **Quantum computers:** Photon polarization, Electron Spin, Cold atoms (quantum state: energy levels)
- **Quantum simulators:** combinatorial use, about 16 GB of RAM for 30 qubits
 - Qiskit, Microsoft Quantum, Cirq (Google), myQLM
 - HPC approach: business already a reality (NP-complete Problems Instances, Combinatorics industry).



Quantum entanglement

- Phenomenon: Two particles form a bound system, quantum states dependent on each other regardless of the distance between them.
- Paradox EPR (speed of light)




Quantum entanglement (II)

- Bohr-Einstein debates:
 - Local deterministic theory with hidden variables (Einstein)
 - Bell's inequalities, violated if no hidden variables
 - Aspect's experiment (1982, absence of hidden variables)
 - An application in quantum computing: quantum teleportation



IBM Qiskit, a demo

- IBM Quantum solution, using a Python-like language
- Cloud:
<https://quantum-computing.ibm.com/>
- Online: code, composer, access to various Quantum Simulators & Real computers queues



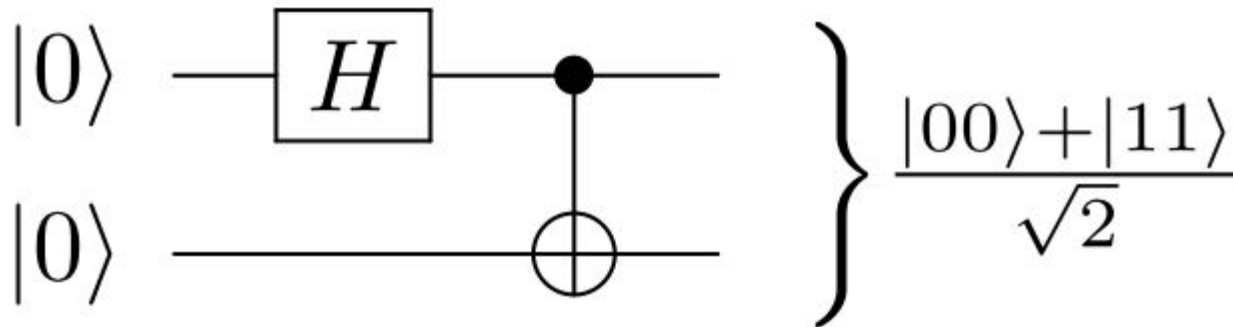
Bell States, maximum 2-qubits intrication

$$|\Phi^+\rangle = \frac{1}{\sqrt{2}}(|0\rangle_A \otimes |0\rangle_B + |1\rangle_A \otimes |1\rangle_B) \quad (1)$$

$$|\Phi^-\rangle = \frac{1}{\sqrt{2}}(|0\rangle_A \otimes |0\rangle_B - |1\rangle_A \otimes |1\rangle_B) \quad (2)$$

$$|\Psi^+\rangle = \frac{1}{\sqrt{2}}(|0\rangle_A \otimes |1\rangle_B + |1\rangle_A \otimes |0\rangle_B) \quad (3)$$

$$|\Psi^-\rangle = \frac{1}{\sqrt{2}}(|0\rangle_A \otimes |1\rangle_B - |1\rangle_A \otimes |0\rangle_B) \quad (4)$$



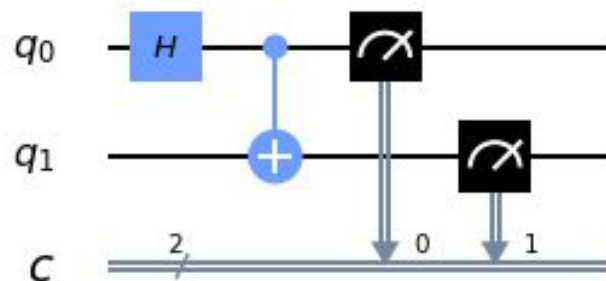
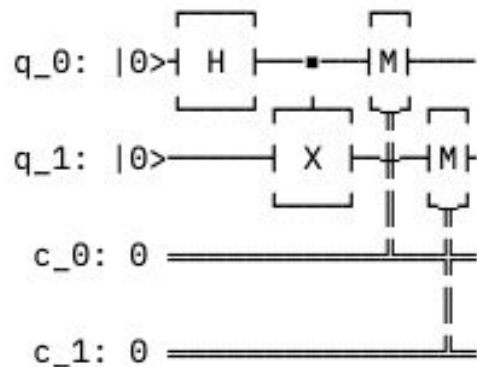
```

%matplotlib inline
import qiskit
from qiskit import(
    IBMQ,
    ClassicalRegister,
    QuantumCircuit,
    QuantumRegister,
    QuantumCircuit,
    execute,
    Aer)
import numpy as np
from qiskit.visualization import plot_histogram

circuit = QuantumCircuit(2, 2)
circuit.h(0)
circuit.cx(0, 1)
circuit.measure([0,1], [0,1])

# Circuit
circuit.draw()
print(circuit)
circuit.draw(output='mpl', filename='circuit.png')

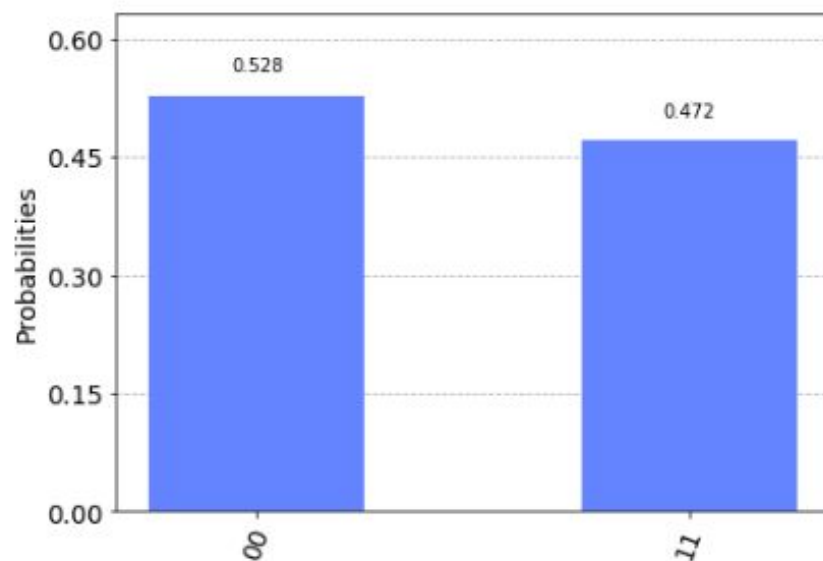
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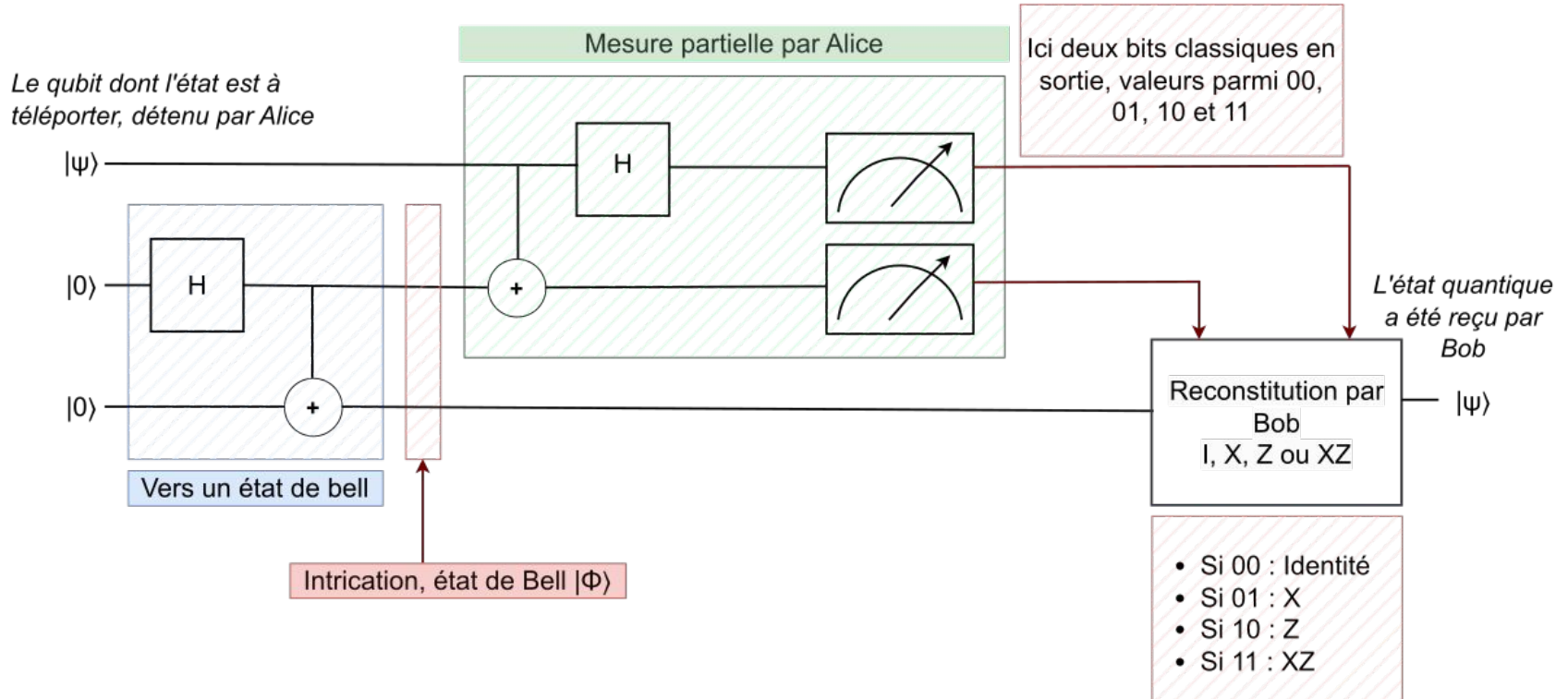
Entrée [29]

```
simulator = Aer.get_backend('qasm_simulator')  
job = execute(circuit, simulator, shots=1000)  
result = job.result()  
counts = result.get_counts(circuit)  
print("\nRésultats :", counts)  
plot_histogram(counts)
```

Résultats : {'11': 472, '00': 528}



Quantum teleportation: an example of usage of the previous Bell State





Questions, discussion

Շատ շնորհակալություն :)