# Introduction to Quantum Computing Workshop

23rd October 2019

QUANTUM COMPUTING ASSOCIATION
EPFL

# Outline

- Learn fundamental concepts of quantum computing
- Register on the IBM Q Experience platform
- Experiment with Qiskit, the Python package to program on IBM’s machines

# Fundamentals of Quantum Computing

# Quantum Bits

- Notation is different!

$$|0\rangle \quad |1\rangle$$

- Act like our bits in the classical world, but in quantum systems
- Follow the laws of quantum mechanics

Why would it be useful?

- Using laws of QM may give us additional power of computation

# Superposition

- A qubit can be a 0 or 1, or a **mix** of both

$$\alpha|0\rangle + \beta|1\rangle \longrightarrow \begin{bmatrix}\alpha \\ \beta\end{bmatrix}$$

**Interpretation**: $|0\rangle$ with probability $|\alpha|^2$ and $|1\rangle$ with probability $|\beta|^2$

**Example**: $\frac{|0\rangle + |1\rangle}{\sqrt{2}}$ is $|0\rangle$ with probability $\frac{1}{2}$ and $|1\rangle$ with probability $\frac{1}{2}$

- Linear algebra is our best friend in quantum computation

# Measurements

- How to make sense of qubits in the classical world?
- How to read qubits if they are in superposition?
- Measurements allow us to force a qubit to “collapse” into a 0 or 1

# More qubits

Everything we saw generalizes to systems with many qubits

$$\frac{|00\rangle + |11\rangle}{\sqrt{2}}$$

$$\frac{|010\rangle + |011\rangle + |001\rangle}{\sqrt{3}}$$

$$|010000\rangle$$

$$\frac{|00\rangle + |01\rangle + |10\rangle + |11\rangle}{2}$$

# Quantum entanglement

?

*“Quantum entanglement is a physical phenomenon that occurs when pairs or groups of particles are generated, interact, or share spatial proximity in ways such that the quantum state of each particle cannot be described independently of the state of the others, even when the particles are separated by a large distance. “*

*Wikipedia*

# Entanglement: an example

$$\frac{|00\rangle + |11\rangle}{\sqrt{2}}$$

# Entanglement: an example

$$\frac{|00\rangle + |11\rangle}{\sqrt{2}}$$

$Q_1$

Alice

$Q_2$

Bob

# Entanglement: an example

$$\frac{|00\rangle + |11\rangle}{\sqrt{2}}$$

$B_1 = 0$

Alice

$Q_2$

Bob

Alice knows what the value of Bob's qubit will be!

# Entanglement: an example

$$\frac{|00\rangle + |11\rangle}{\sqrt{2}}$$

$B_1 = 0$

Alice

$B_2 = 0$

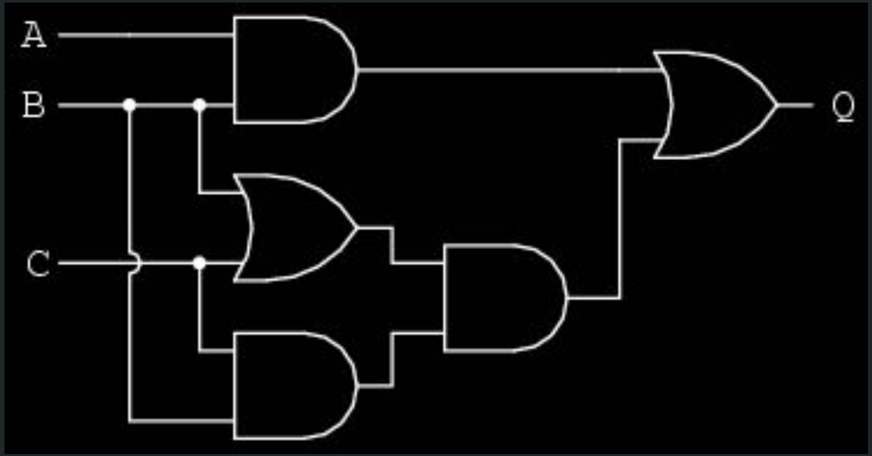
Bob

Alice knows what the value of Bob's qubit will be!

# Computing with Qubits

# Circuits

- Input bits are given
- Wires carry the information (bits)
- Gates transform the bits
- Wire at the end contains the output




https://sub.allaboutcircuits.com/images/04287.png

# Quantum Gates

- Remember qubits can be represented as vectors, so transformations (gates) can be represented as matrices

- Used to transform qubits

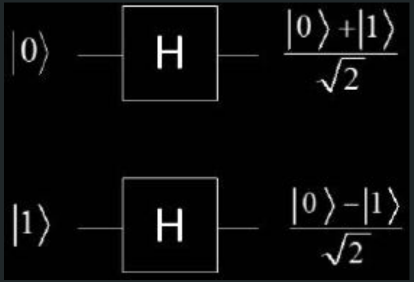
  Interesting since:

  - It can create superpositions
  - It can be applied to qubits which are in a superposition

# Quantum Gates: Single Qubit

- Not-Gate (X gate)

$$X|0\rangle = |1\rangle \text{ and } X|1\rangle = |0\rangle$$




- Hadamard gate

$$H|0\rangle = \frac{|0\rangle + |1\rangle}{\sqrt{2}} \text{ and } H|1\rangle = \frac{|0\rangle - |1\rangle}{\sqrt{2}}$$

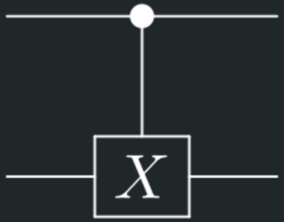
https://www.researchgate.net/profile/Daniel_Ciocirlan/publication/263046229/figure/fig3/AS:296567878766594@1447718700257/the-Hadamard-gate.png

# Quantum Gates: Multiple Qubits

- Controlled gates

Controlled gates act on two or more qubits, where one or more qubits act as a control for some operation

https://en.wikipedia.org/wiki/Quantum_logic_gate




- Controlled Not-Gate (C-X gate)

  Second qubit is flipped only if first one is $|1\rangle$

$$CX|00\rangle = |00\rangle,\ CX|01\rangle = |01\rangle,$$
$$CX|10\rangle = |11\rangle,\ CX|11\rangle = |10\rangle$$

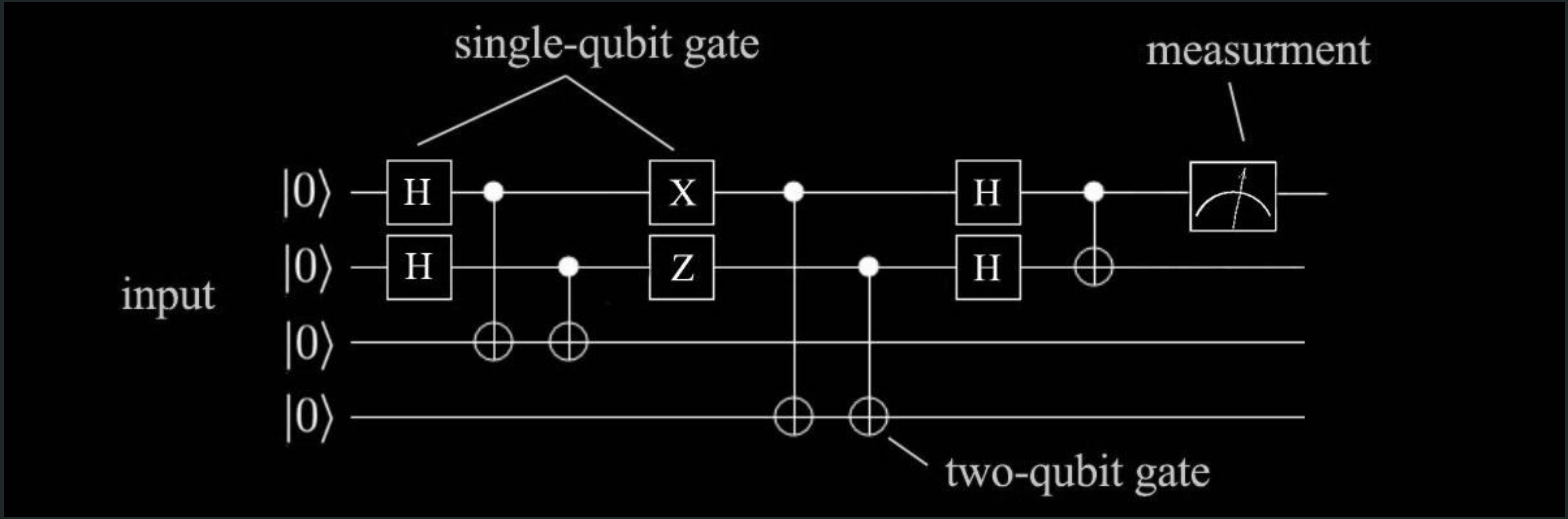
# Measurements

- We want to have classical bits to read the output of the quantum circuit

- Measurements are a kind of gate

https://upload.wikimedia.org/wikipedia/commons/thumb/2/2b/Qcircuit_measure-arrow.svg/225px-Qcircuit_measure-arrow.svg.png

# Quantum Circuits Recap




https://medium.com/@jonathan_hui/qc-programming-with-quantum-gates-8996b667d256

# Summary

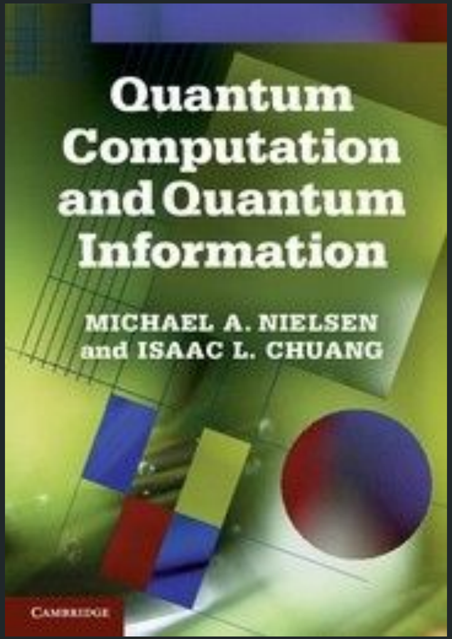
Use qubits to perform computation, using properties like:

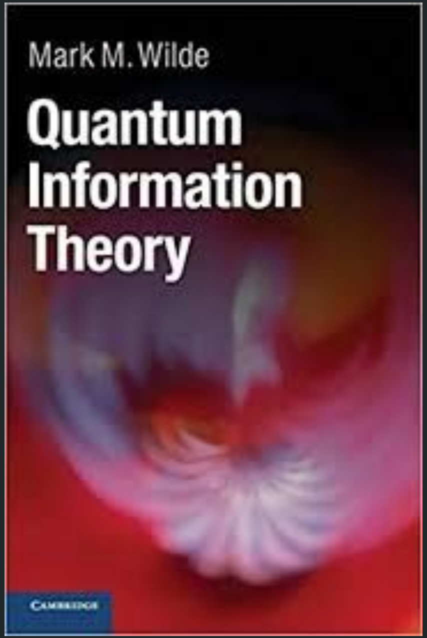
- Superposition
- Entanglement

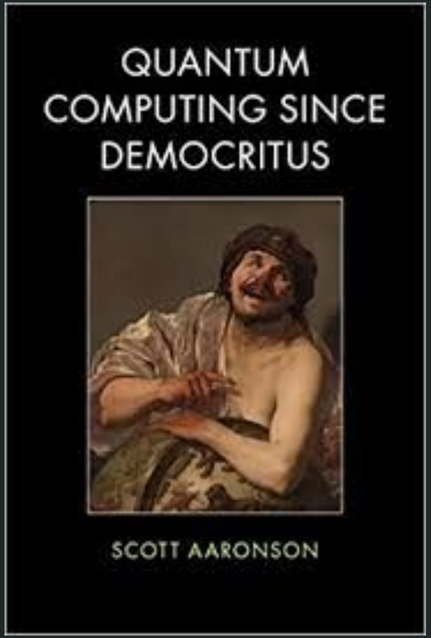
Process these qubits in a circuit using:

- Gates (transformations)
- Measurements (get back classical bits)

# References and Further Reading




and many others...

# Introduction to Programming on Quantum Computers

# Platforms Available

rigetti

IBM

Microsoft

XANADU

Google

and more...

# Get the workshop's material

- Today we will use IBM's Qiskit Python package

- Go to https://tinyurl.com/yxet2ryc in order to get the Jupyter notebook for the workshop.

*Note: you don't need to install anything on your computer, just download the notebook!*

# Sign up for the IBM Q Experience

Go to https://quantum-computing.ibm.com/login and create an account (you can connect with Google, Facebook, … if you want)

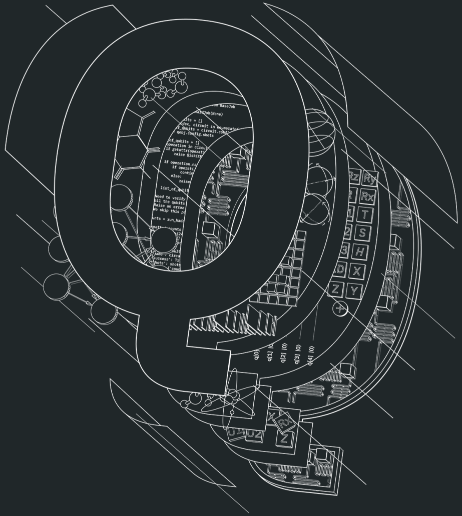
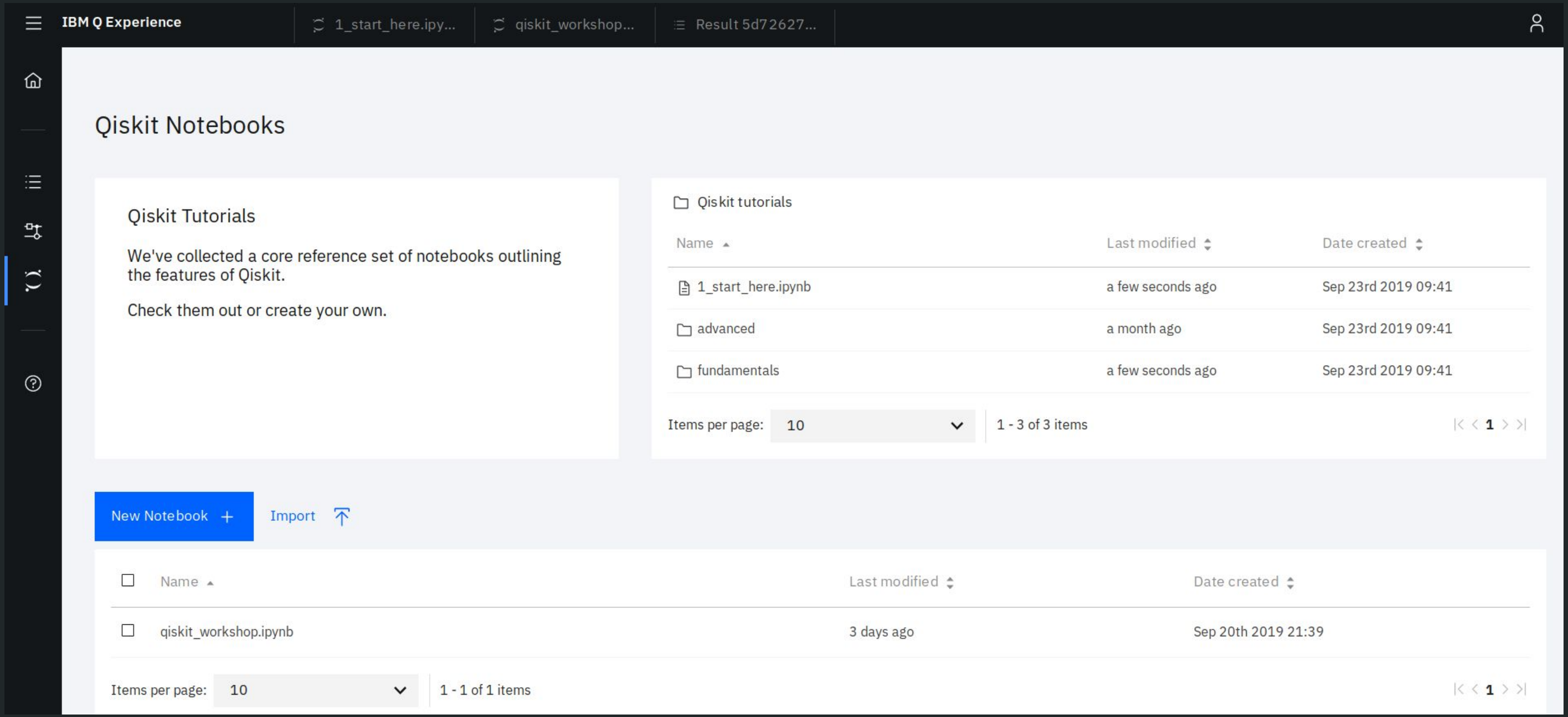


Image from [https://www.ibm.com/quantum-computing]

# Import the Jupyter Notebook



# Last point

- You can get the slides at ?
- Feedback form