Programming a Quantum Computer - I
(Introduction To Quantum Computing)

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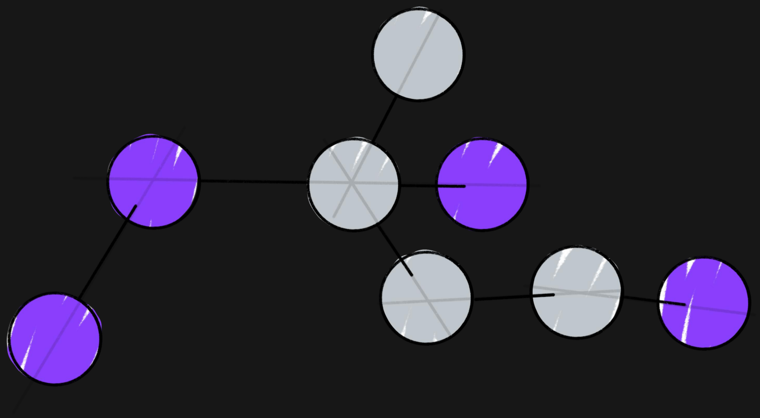
Qiskit Advocate



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About Me

I am a computer science undergraduate, interested in the field of Quantum Computing.

I am a IBM Qiskit Advocate and founder of Qftics.

I am particularly interested in simplifying complex Quantum Computing Concepts for general masses to better understand.

I have experience in coding with Qiskit , Strawberry Field and Pennylane.

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SCHEDULE

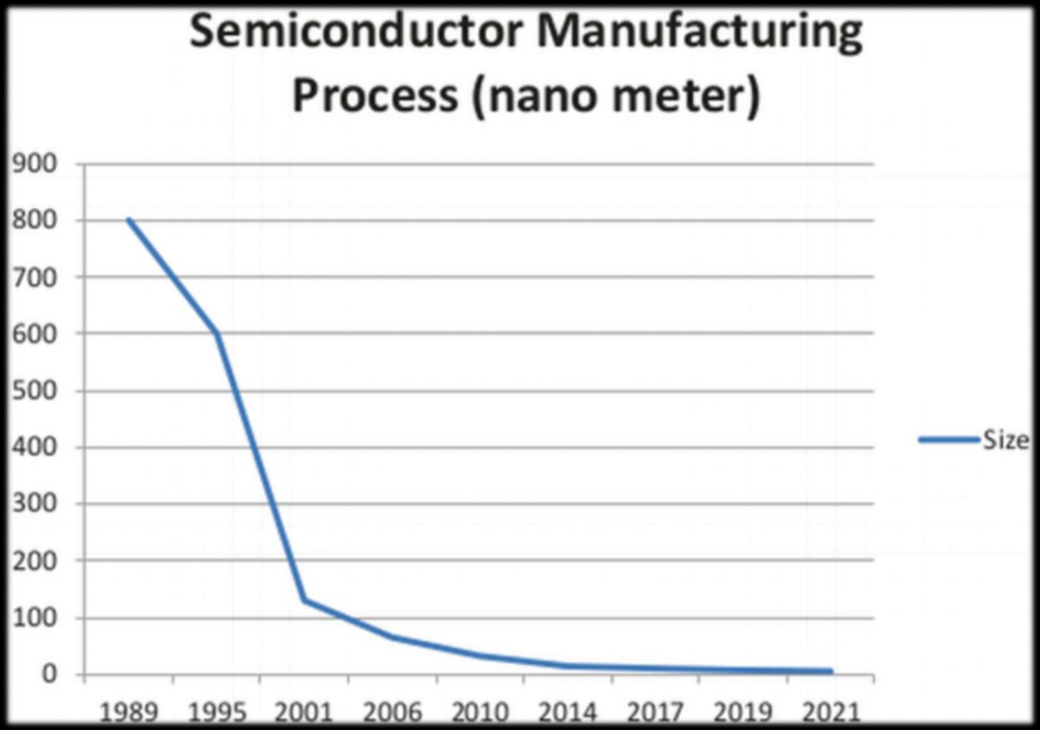
- Overview
- Quantum Computing Concepts
- Quantum Algorithm
- Quantum Teleportation
- Qiskit Implementation
- Use Cases Of Quantum Computing

Overview

Why Go Quantum?

- Moores Law , Slowing down in 2020

  (The graph almost flatenning)
- Transistors cannot be made smaller , due to the laws of Quantum Mechanics taking over.
- **Post Silicon Era**



What is a Quantum Computer?

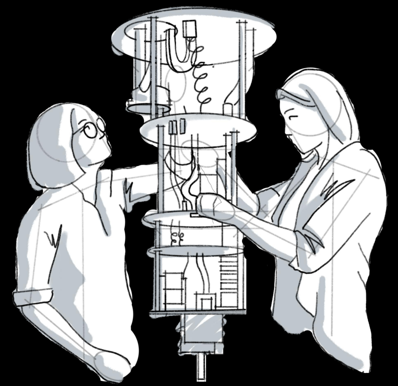
- A Quantum Computer makes use of the natural laws of quantum mechanics to perform a calculation.

¿Why do we want a Quantum Computer?

Performance: Solving Problems much faster than a classical computer.

Impossible Problems : There are problems that can not be run with full fidelity in a classical system.

80 years of Quantum History



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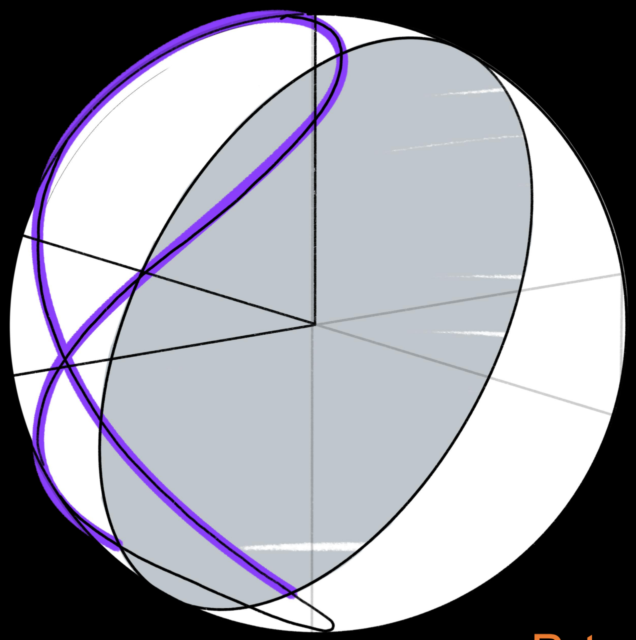
The spark of quantum computing was struck by Richard Feynman.

With this, he outlined the possibility to exponentially outpace classical computers. However, it took more than 10 years until a special algorithm was created to change the view on quantum computing, the Shor Algorithm(1994) , followed by Grovers Algorithm(1996).

Twenty years later, in 2017, IBM presented the first commercially usable quantum computer, raising the race to another level.

What’s a Quantum Bit or Qubit?

- A qubit is the quantum concept of a bit.



- It’s not any element or device. A qubit is a logical concept that can be implemented on a wide range of different systems with quantum behaviour

- As a bit, a single qubit can represent two states 0 and 1

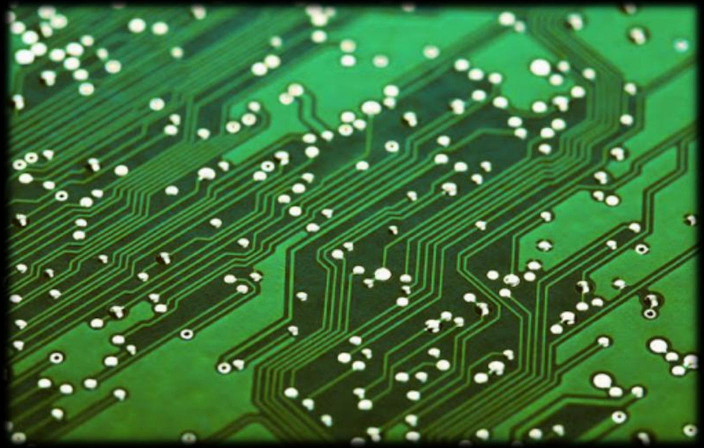
But additionally a qubit is able to manage all possible combinations among base states 0 and 1

$$|\psi\rangle = \alpha|0\rangle + \beta|1\rangle$$

The Power Of Quantum Computer

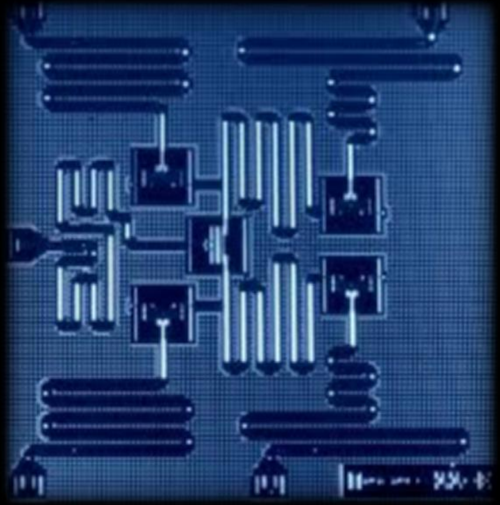
Classical Computing

The potential power of a classical computer doubles everytime you double the number of transistors.



Quantum Computing

The potential power of a quantum computer doubles everytime you add one additional Qubit.



Quantum vs Classical Computer

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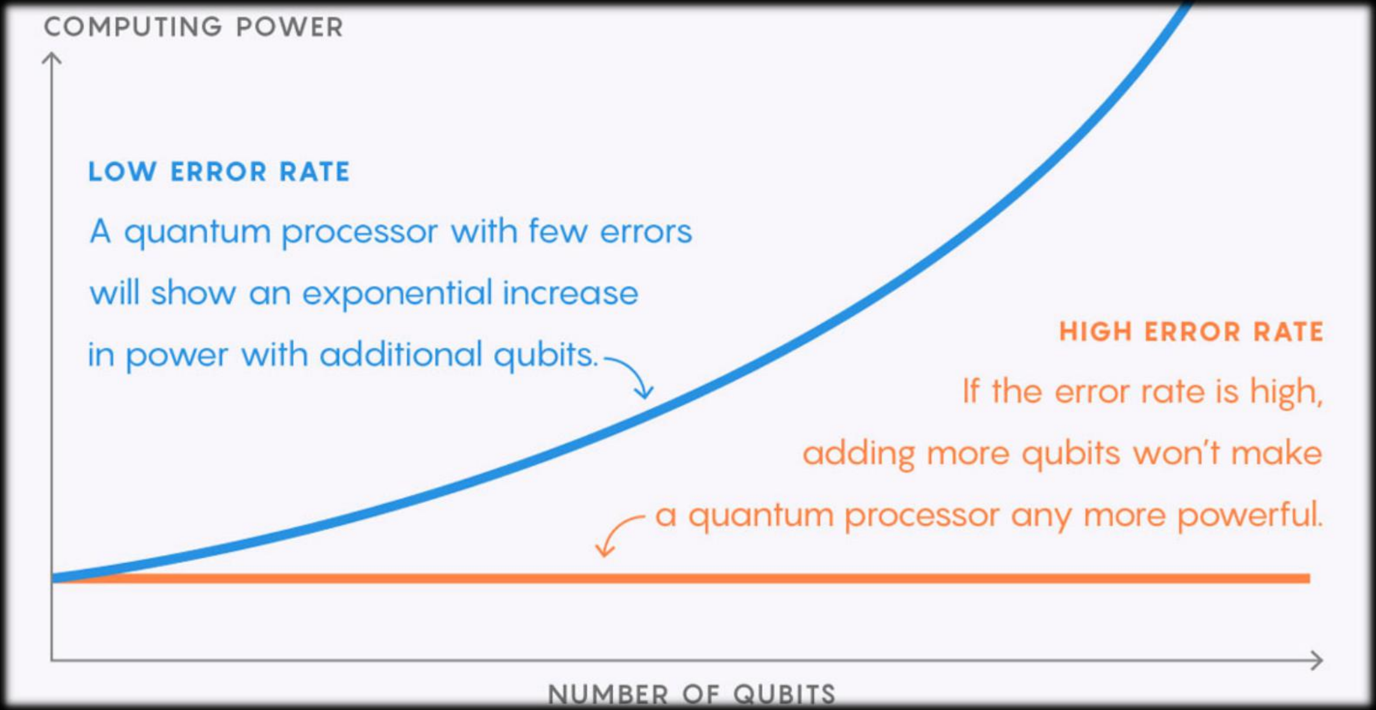
Source: Caltech Entrepreneurs Forum, Feb 23, 2019

	Classical	Quantum
Basic Unit	Binary Bit (1 or 0)	**Qbit** (vector)
Computing	Logical Operation	**Unitary** Operation
Description	Truth Table (True/False)	**Unitary** Matrix
Direction	Most Gates Run Forward	Gates are Reversible
Copying	Easy	Impossible
Noise	Minimal w/Error Correction	**Quantum Error Correction** (Very Difficult)
Storage	n-bit storage holds 1 value. from 0 to 2**n - 1	n-qbits storage holds 2**n values
Computation	n-bit processor = 1 operation	n-qbit processor = 2**n operations

Where We Stand Today?

NISQ Era

- Gate Model（IBM，Google，Alibaba，Rigetti）
- Topological Model（Microsoft）
- Annealing Model（DWave，Google）



Quantum Computing Concepts

Quantum Physics

Quantum physics is hard because, like Einstein's theory of relativity, it requires internalizing ideas that are simple but very counterintuitive.

The counterintuitive ideas one must accept are

1. A physical system in a perfectly definite state can still behave randomly.

2. Two systems that are too far apart to influence each other can nevertheless behave in ways that, though individually random, are somehow strongly correlated.

Basic Concepts in Quantum Mechanics

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The Uncertainty Principle

Every time a measurement is made on the system , the system is changed by that that measurement.

States Superposition

An state exists in all the possible configurations of the configuration space

Quantum Entanglement

EPR Paradox – There's a relationship among the features of the entangled elements.

Decoherence

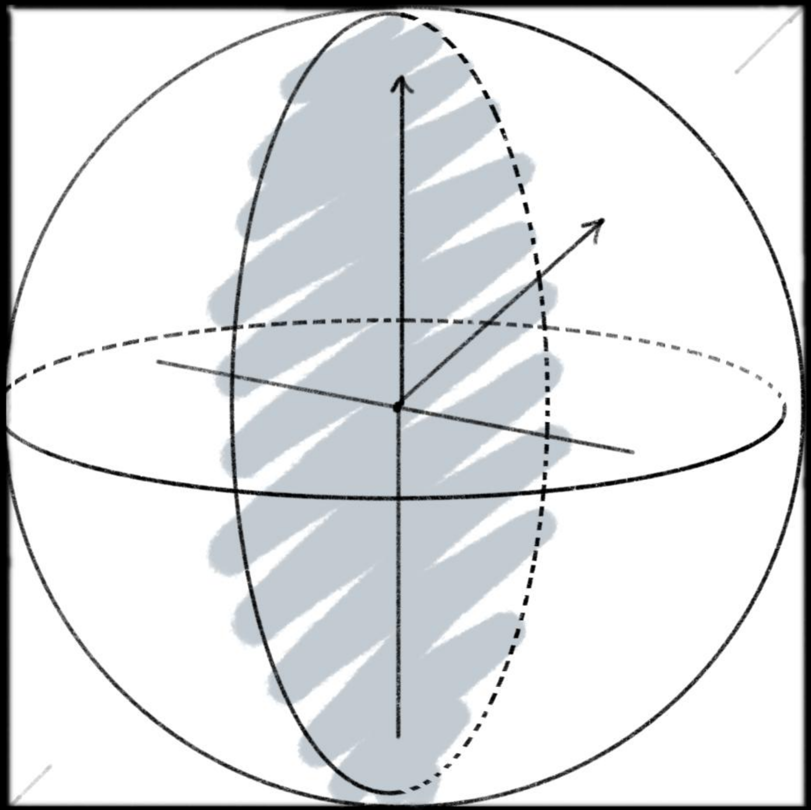
In a coherent state made up of several elements, all the quantum features are alive and the system appear as one quantum system. Decoherence gives back individual identity to each system component

Quantum Computer Main Features

1. Uses Quantum Bits (Qubits)
2. Works with Quantum Parallelism
3. Entanglement
4. Keeps coherence

What makes Qubit special?

A classical bit can either be 0 or 1 at a time.



Quantum Mechanics allows us to have a superposition of both 0 and 1 , with thier respective amplitudes , the square which denote the probability of it being in state 0 or 1.
The fun thing about Qubits is you can use any physical system with two distinguishable basis states as a Qubit.

$$|\psi\rangle = \alpha|0\rangle + \beta|1\rangle$$

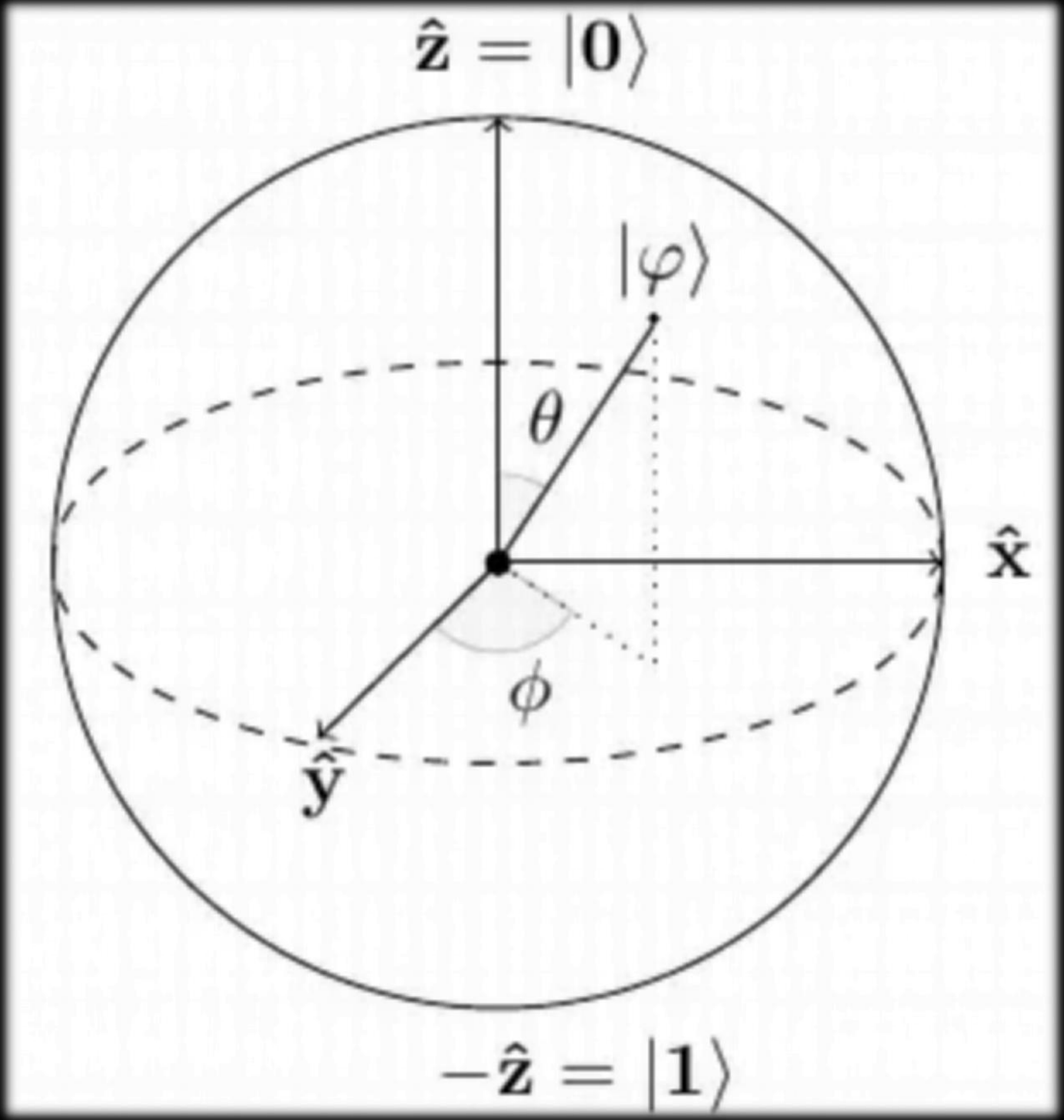
$$\begin{pmatrix} \alpha \\ \beta \end{pmatrix}$$

$$|\alpha|^2 + |\beta|^2 = 1$$

Where α,β $\in \mathbb{C}^2$

Bloch Sphere

$$|\psi\rangle = \cos\frac{\theta}{2}|0\rangle + e^{i\phi}\sin\frac{\theta}{2}|1\rangle$$



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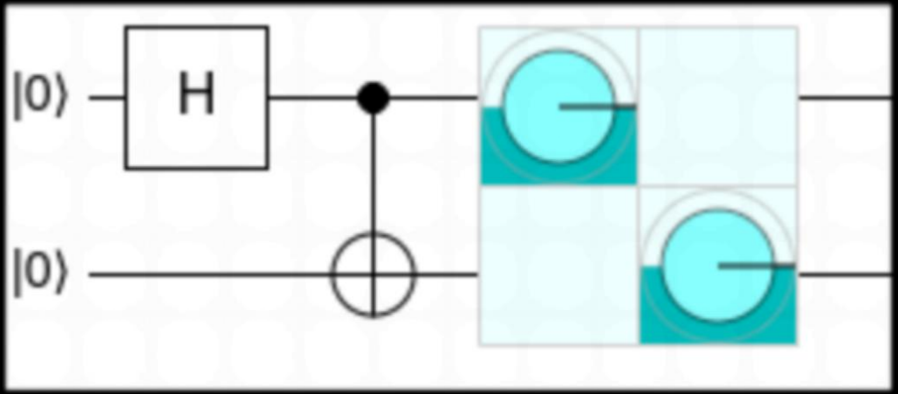
Quantum Computing In a Nutshell

Quantum Computer = Superposition + Interference

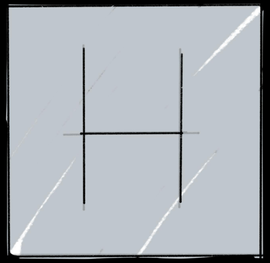
1. Start with a Qubit/Qubits in a initial state.(Say , |0>)
2. Run the Qubit/Qubits through a circuit (Containing Quantum Gates) creating the right **interference** , to reach as close to the recquired state as possible.
3. Measure the final state and get solution.



Quantum Operations

Quantum Gates

- A basic quantum gate works on one or more qubits.
- It's equivalent to digital circuits logical gates.



Properties

1. Quantum Gates are reversible
2. Mathematically they are represented by unitary matrixes
3. All qubits on which they act must retain their quantum identity.

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Some Quantum Gates

Single Qubit Gates

X-gate

$$\boxed{X} \quad \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}$$

Y-gate

$$\boxed{Y} \quad \begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix}$$

Z-gate

$$\boxed{Z} \quad \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$$

H-gate
(AKA Hadamard Gate)

$$\boxed{H} \quad \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix}$$

T-gate
($\sqrt[4]{Z}$-gate)

$$\boxed{T} \quad \begin{pmatrix} 1 & 0 \\ 0 & e^{i\pi/4} \end{pmatrix}$$

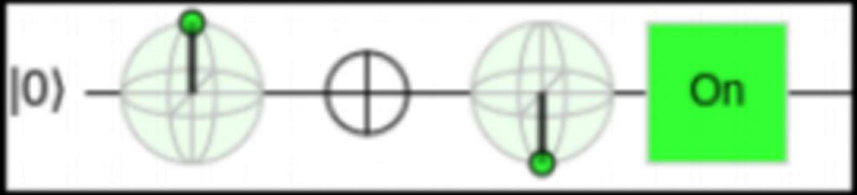
R_ϕ-gate
(phase shift)

$$\boxed{R_\phi} \quad \begin{pmatrix} 1 & 0 \\ 0 & e^{i\phi} \end{pmatrix}$$

How Quantum Gates changes the state of a Qubit:

$$\frac{1}{\sqrt{2}}\begin{pmatrix}1 & 1\\ 1 & -1\end{pmatrix} \times \begin{pmatrix}1 & 0\\ 0 & -1\end{pmatrix} \times \frac{1}{\sqrt{2}}\begin{pmatrix}1 & 1\\ 1 & -1\end{pmatrix} = \begin{pmatrix}0 & 1\\ 1 & 0\end{pmatrix}$$

$$\begin{pmatrix}0 & 1\\ 1 & 0\end{pmatrix} \times \begin{pmatrix}1\\ 0\end{pmatrix} = \begin{pmatrix}0\\ 1\end{pmatrix}$$



Multi Qubit System

(Tensor Product)

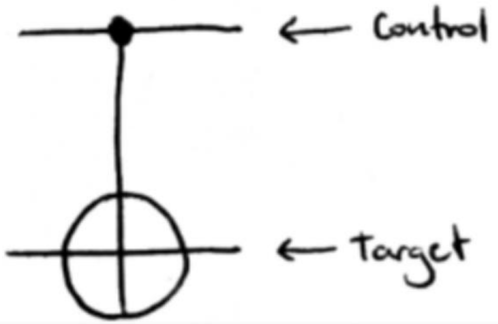
$$\begin{pmatrix}\alpha\\ \beta\end{pmatrix} \otimes \begin{pmatrix}\gamma\\ \delta\end{pmatrix} = \begin{pmatrix}\alpha\begin{pmatrix}\gamma\\ \delta\end{pmatrix}\\ \beta\begin{pmatrix}\gamma\\ \delta\end{pmatrix}\end{pmatrix} = \begin{pmatrix}\alpha\gamma\\ \alpha\delta\\ \beta\gamma\\ \beta\delta\end{pmatrix}$$

$$\begin{pmatrix}1\\ 0\end{pmatrix} \otimes \begin{pmatrix}0\\ 1\end{pmatrix} = \begin{pmatrix}1\begin{pmatrix}0\\ 1\end{pmatrix}\\ 0\begin{pmatrix}0\\ 1\end{pmatrix}\end{pmatrix} = \begin{pmatrix}0\\ 1\\ 0\\ 0\end{pmatrix}$$

Two Qubit Gates

CNOT - gate

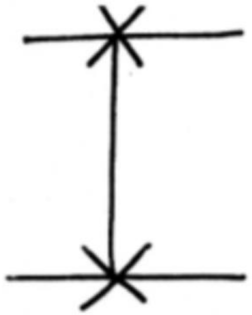
Flips the target bit if the control bit is |1>



$$\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{pmatrix}$$

SWAP - gate

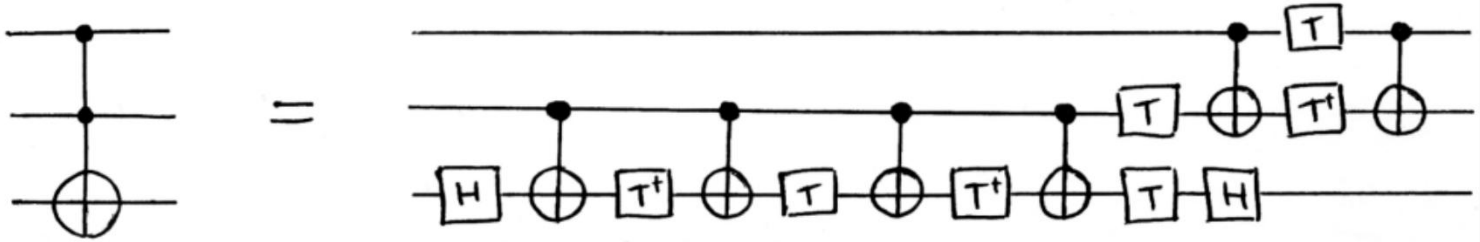
Swaps the states of the two qubits (useful in actual machines)



$$\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

Larger Gates

Toffoli Gate



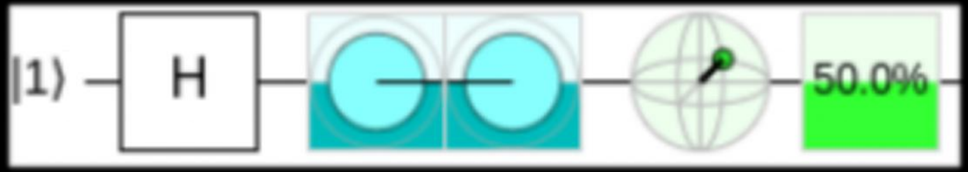
Quantum Superposition

In common experience a coin facing up has a definite value: it is a head or a tail. Even if you don't look at the coin you trust that it must be a head or tail.

In quantum experience the situation is more unsettling: material properties of things do not exist until they are measured. Until you "look" (measure the particular property) at the coin, as it were, it has no fixed face up.

Superposition Of |0> :

Superposition Of |1> :



Quantum Entanglement

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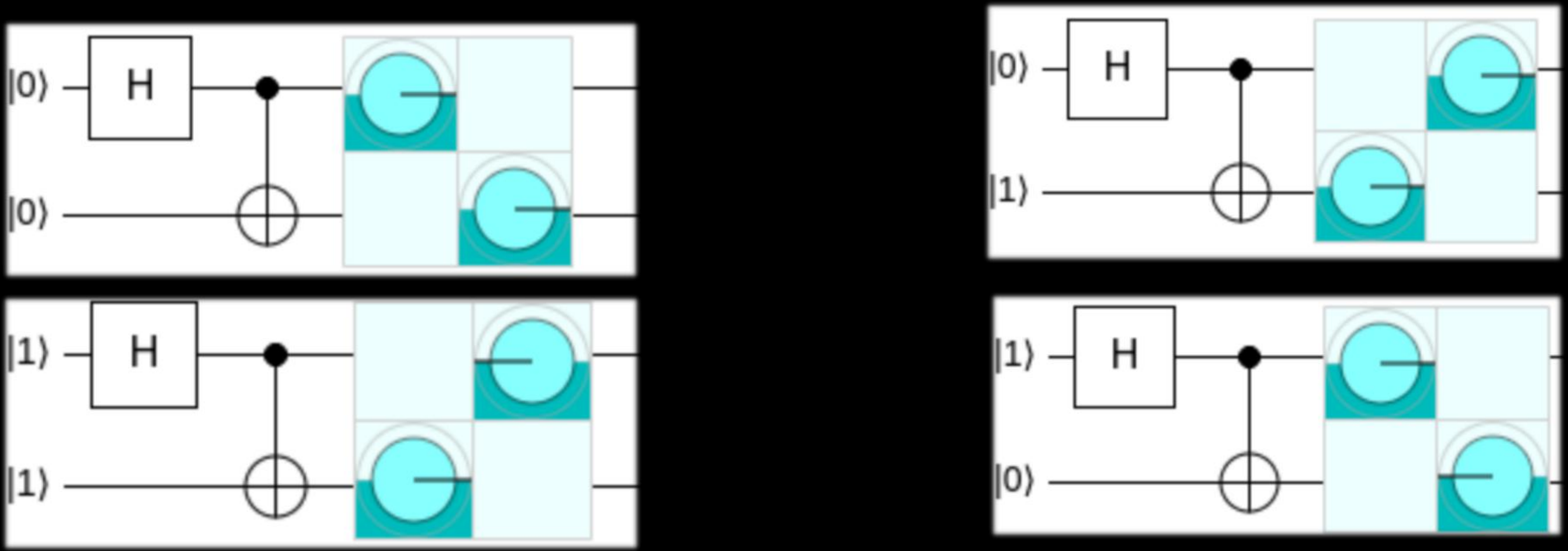
The individual constiuents or particles cannot be fully described or considered without taking into account the entire entangled system. Measurement of one part of the entangled quantum system will ‘collapse‘ the system.

Namely, locally interaction on one constituent will affect the other constituents, even if the pieces of the entangled system are separated by large distances.

Bell Pairs (2-Qubit Entangled Pairs):



Quantum Teleportation

Quantum Teleportation

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We all have seen Teleportation in action , well in movies atleast.

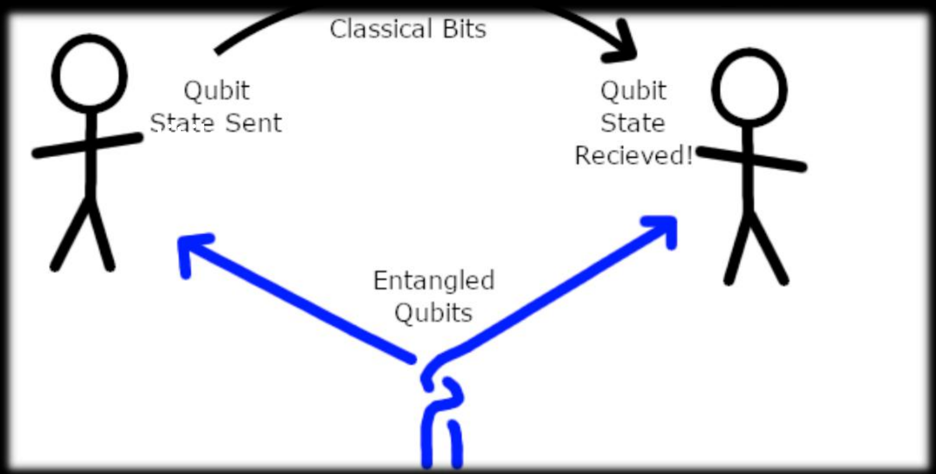
Well Quantum Mechanics allow you to do exactly that , the only catch being we are teleporting Qubits instead of physical objects.

The Only Tool we need is
Superposition and Entanglement

Scenario

Ritik wants to send quantum information to Jai. Specifically, suppose he wants to send the qubit state $|\psi\rangle = \alpha|0\rangle + \beta|1\rangle$. This entails passing on information about α and β to Jai.

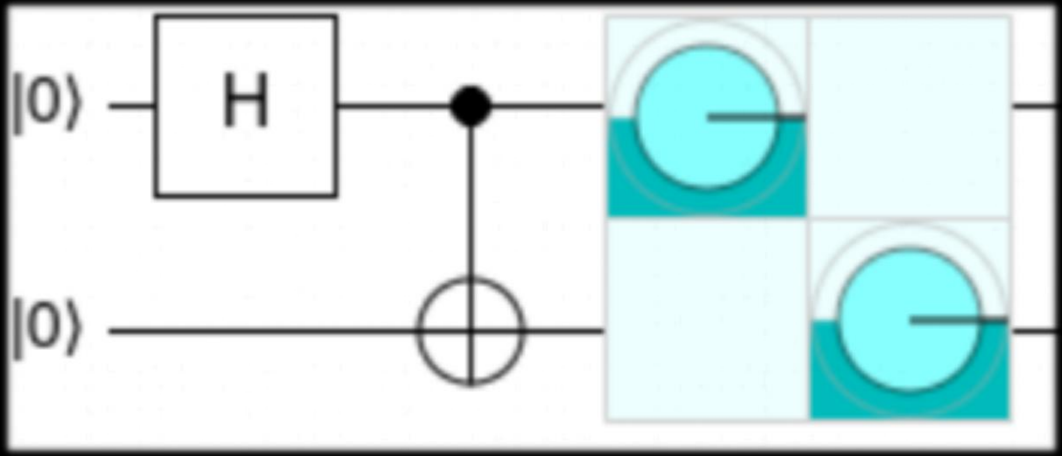
By taking advantage of two classical bits and an entangled qubit pair, Ritik can transfer the state $|\psi\rangle$ to Jai. We call this teleportation because, at the end, Jai will have $|\psi\rangle$ and Ritik won't anymore.



Step 1:

I create an entangled pair of qubits and gives one to Ritik and one to Jai.

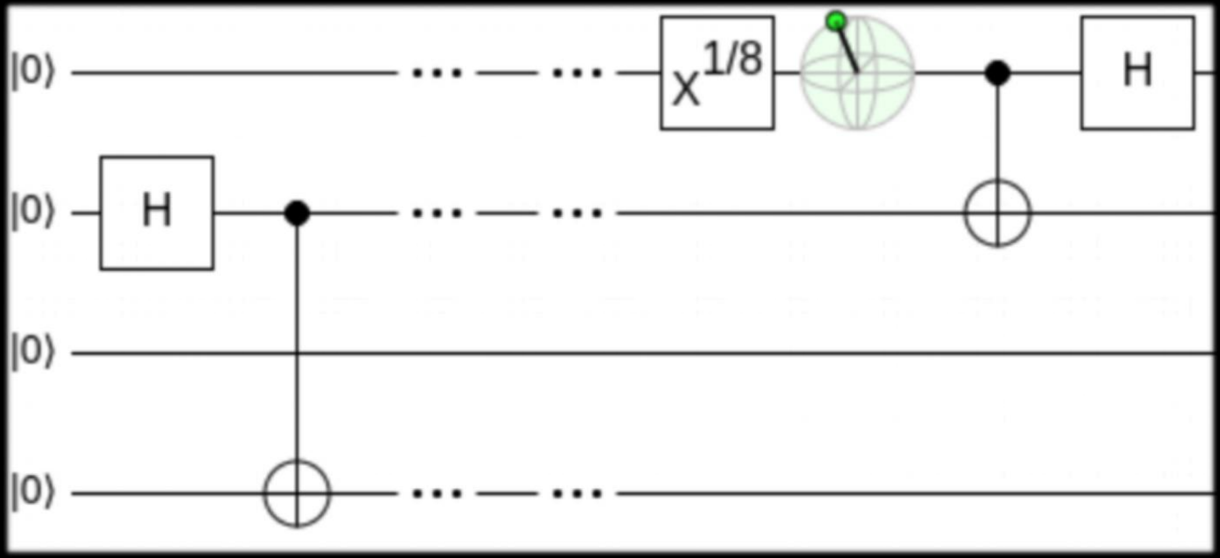
The pair I create is a special pair called a Bell pair. In quantum circuit language, the way to create a Bell pair between two qubits is to first transfer one of them to the X-basis ($|+\rangle$ and $|-\rangle$) using a Hadamard gate, and then to apply a CNOT gate onto the other qubit controlled by the one in the X-basis.



Step 2:

Ritik applies a CNOT gate to his entangled Qubit , controlled by $|\psi\rangle$(the qubit he is trying to send Jai).

Then Ritik applies a Hadamard gate to $|\psi\rangle$.

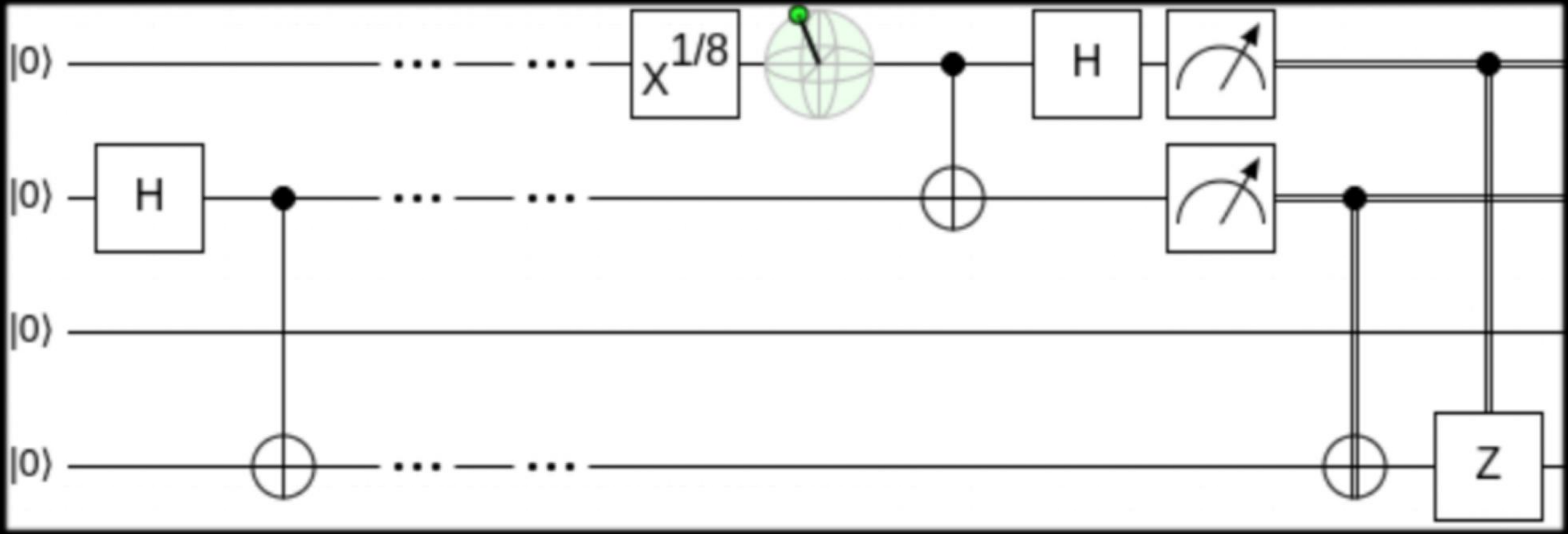


Step 3:

Next, Ritik applies a measurement to both qubits that he owns,

q1 (one of the entangled qubit) and $|\psi\rangle$, and stores this result in two classical bits. He then sends these two bits to Jai.

(Or lets say he called Jai and told the value of measurements)



Step 4:

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Jai, who already has the qubit $q2$(second entangled Qubit) , then applies the following gates depending on the state of the classical bits:

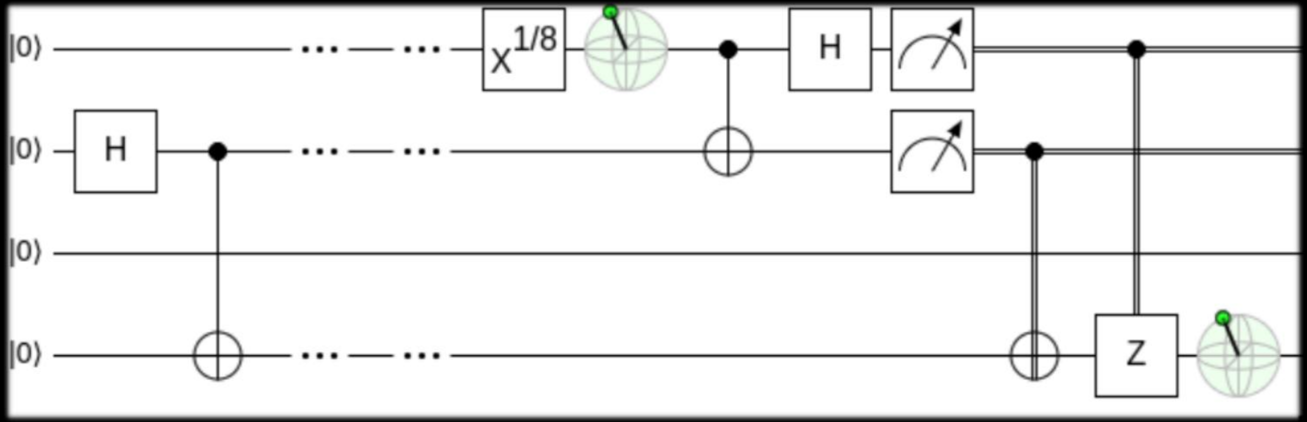
$00 \rightarrow$ Do nothing

$01 \rightarrow$ Apply X gate

$10 \rightarrow$ Apply Z gate

$11 \rightarrow$ Apply ZX gate

(Note that this transfer of information is purely classical.)



Things stopping us from reaching “Quantum Supremacy”

- Noise
- Decoherence
- Error Propogation
- Expensive Hardware

Use Cases Of Quantum Computing

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Quantum Computing Use Cases

Cryptography

Quantum computers are famous for code-breaking, but their real power may lie in making cloud computing more secure. Based on laws of physics, quantum computers have the potential to keep private data safe from snoops and hackers, no matter where it is stored or processed.

Medicine & Materials

A quantum computer mimics the computing style of nature, allowing it to simulate, understand and improve upon natural things—like molecules, and their interactions and compounds-better than a classical computer. This ability could lead to new medical advances and materials discovery.

Machine Learning

Quantum machine learning is an exciting and new area. Research indicates that quantum computing could significantly accelerate machine learning and data analysis tasks, such as training of classical Boltzmann machines, or topological analysis of big data. .

Searching Big Data

A machine that can search the ever-growing amount of data being created, and locate connections within it, could have tremendous impact across many industries. Quantum computing offers the possibility of doing this significantly faster than classical computers. Further research will lead to the realization of this capability

Questions … ?

Qftics

Just Another Quantum Computing Community

www.qftics.com

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THANK Q

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