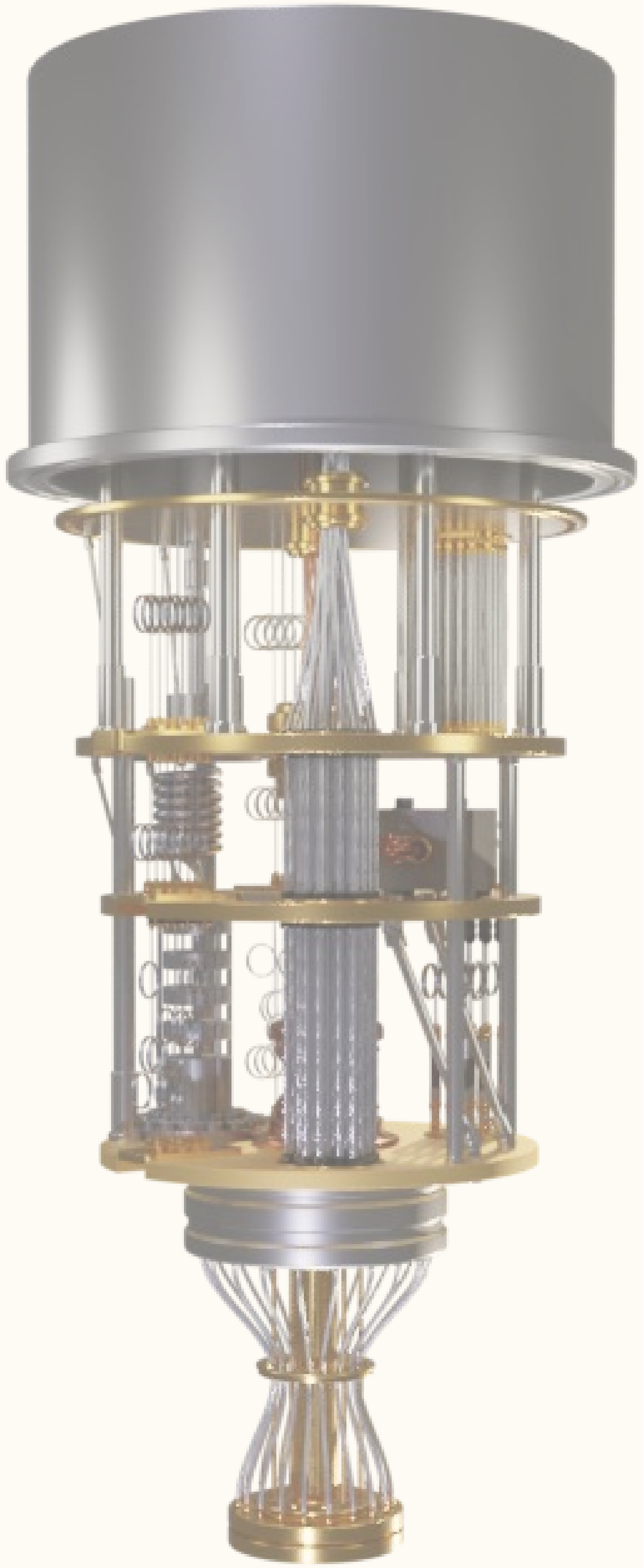
QUANTUM
COMPUTING CLUB

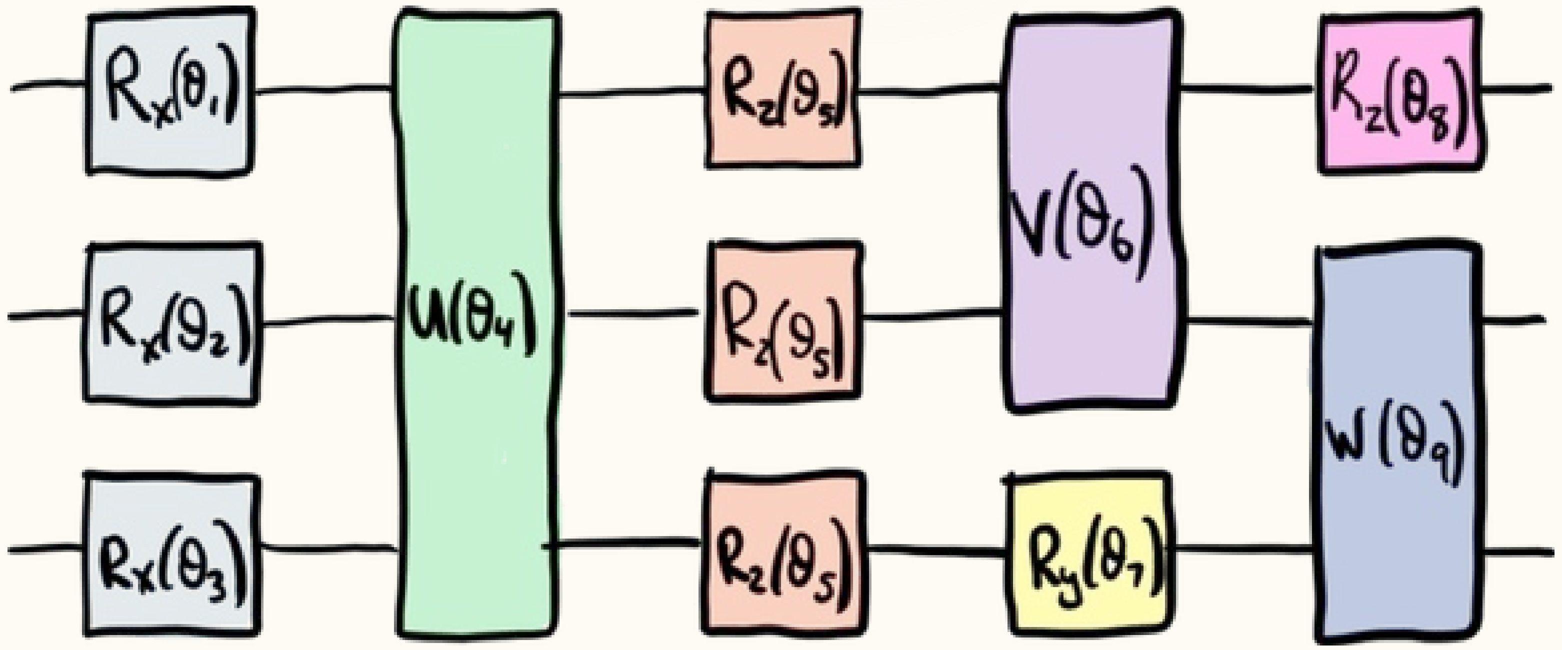
Introduction to Quantum Computing: From Qubits to Circuits

Quantum Computing Club Yachay Tech

By Gabriel Balarezo

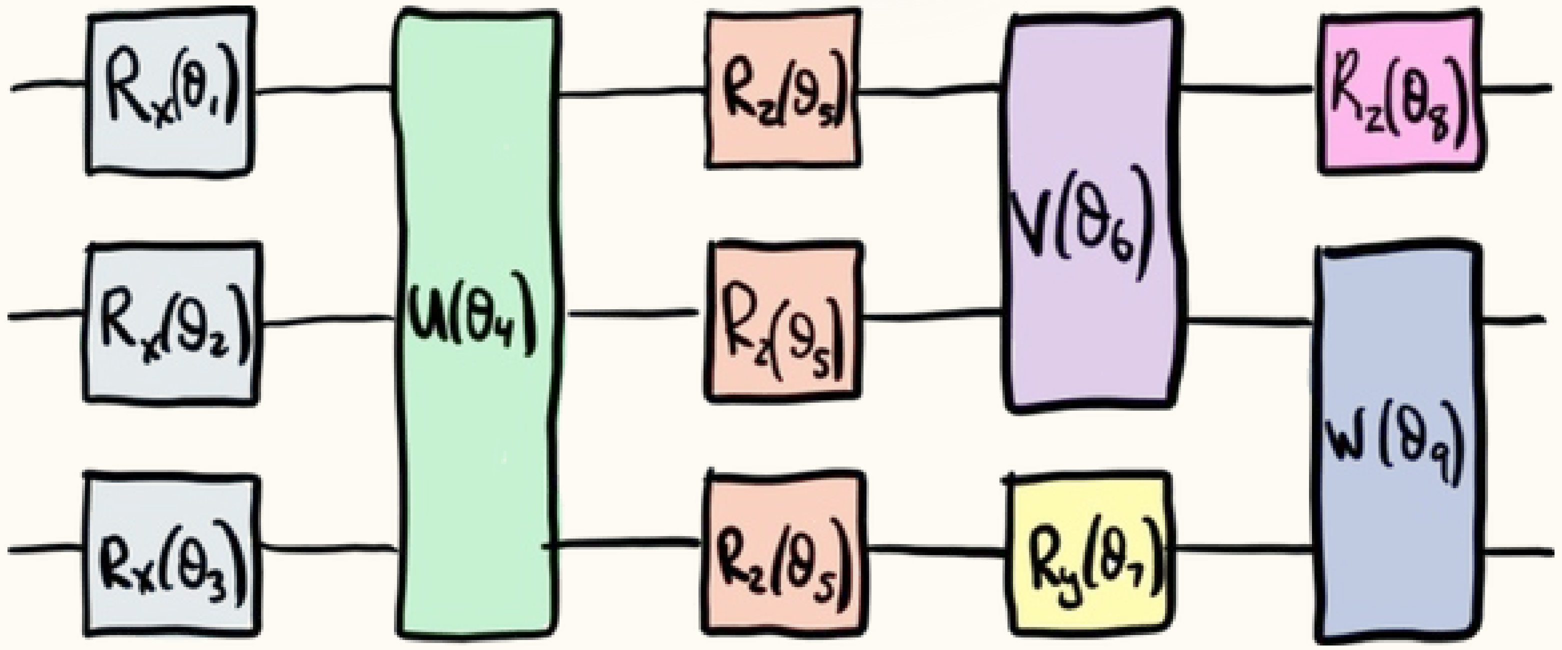


Overview


$R_x(\theta_1)$
$R_x(\theta_2)$
$R_x(\theta_3)$
$U(\theta_4)$
$R_z(\theta_5)$
$R_z(\theta_5)$
$R_z(\theta_5)$
$V(\theta_6)$
$R_y(\theta_7)$
$R_z(\theta_8)$
$W(\theta_9)$

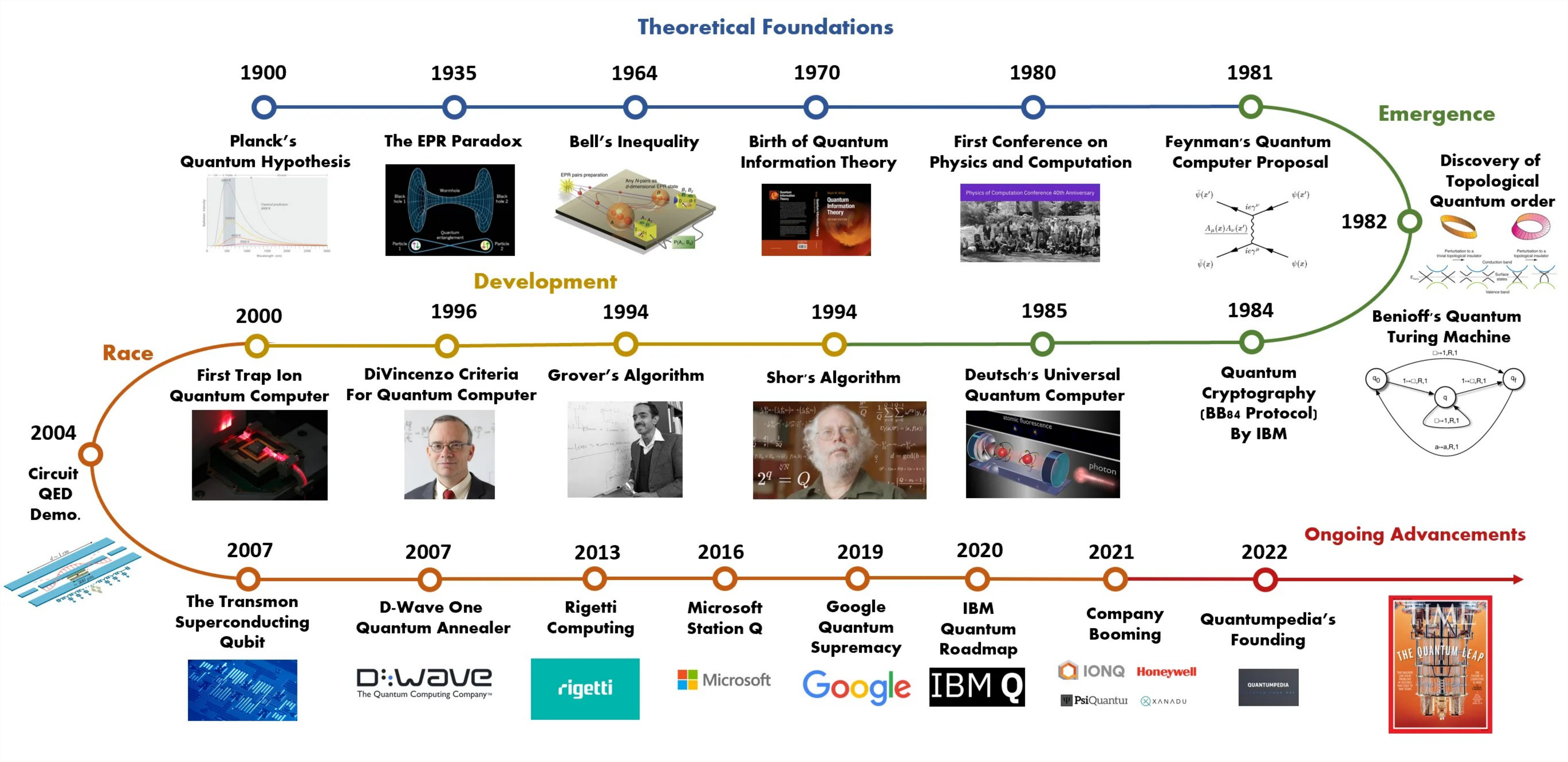
Overview

- Introduction to Quantum Computing
- Quantum Bits and Superposition
- Entanglement
- Quantum Gates and Circuits



Roadmap

Roadmap



Theoretical Foundations
1900
Planck's Quantum Hypothesis
1935
The EPR Paradox
1964
Bell's Inequality
1970
Birth of Quantum Information Theory
1980
First Conference on Physics and Computation
1981
Feynman's Quantum Computer Proposal
Emergence
1982
Discovery of Topological Quantum order
1984
Benioff's Quantum Turing Machine
Quantum Cryptography (BB84 Protocol) By IBM
Development
1985
Deutsch's Universal Quantum Computer
1994
Shor's Algorithm
1994
Grover's Algorithm
1996
DiVincenzo Criteria For Quantum Computer
2000
First Trap Ion Quantum Computer
Race
2004
Circuit QED Demo.
2007
The Transmon Superconducting Qubit
2007
D-Wave One Quantum Annealer
2013
Rigetti Computing
2016
Microsoft Station Q
2019
Google Quantum Supremacy
2020
IBM Quantum Roadmap
2021
Company Booming
2022
Quantumpedia's Founding
Ongoing Advancements
D-Wave The Quantum Computing Company
rigetti
Microsoft
Google
IBM Q
IONQ
Honeywell
PsiQuantum
XANADU
QUANTUMPEDIA
TIME
THE QUANTUM LEAP

Introduction

What is quantum computing?

Quantum computing uses quantum mechanics to process information in ways classical computers cannot.

What is quantum computing?

Quantum computing uses quantum mechanics to process information in ways classical computers cannot.

Classical vs. Quantum

What is quantum computing?

Quantum computing uses quantum mechanics to process information in ways classical computers cannot.

Classical vs. Quantum

Classical bits

What is quantum computing?

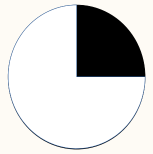
Quantum computing uses quantum mechanics to process information in ways classical computers cannot.

Classical vs. Quantum

Classical bits

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

Quantum bits (Qubit)



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

What is quantum computing?

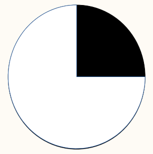
Quantum computing uses quantum mechanics to process information in ways classical computers cannot.

Classical vs. Quantum

Classical bits

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

Quantum bits (Qubit)



$\alpha|0\rangle + \beta|1\rangle$ ...superposition!!

What is quantum computing?

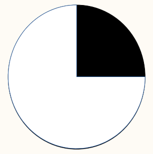
Quantum computing uses quantum mechanics to process information in ways classical computers cannot.

Classical vs. Quantum

Classical bits

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

Quantum bits (Qubit)



$\alpha|0\rangle + \beta|1\rangle$ ...superposition!!

How do we represent a Qubit?

What is quantum computing?

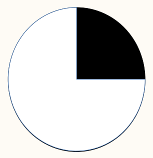
Quantum computing uses quantum mechanics to process information in ways classical computers cannot.

Classical vs. Quantum

Classical bits

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

Quantum bits (Qubit)



$\alpha|0\rangle + \beta|1\rangle$ ...superposition!!

How do we represent a Qubit?

Basis states

$$|0\rangle = \begin{bmatrix} 1 \\ 0 \end{bmatrix}$$

$$|1\rangle = \begin{bmatrix} 0 \\ 1 \end{bmatrix}$$

What is quantum computing?

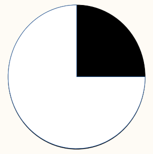
Quantum computing uses quantum mechanics to process information in ways classical computers cannot.

Classical vs. Quantum

Classical bits

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

Quantum bits (Qubit)



$\alpha|0\rangle + \beta|1\rangle$ ...superposition!!

How do we represent a Qubit?

Basis states

$$|0\rangle = \begin{bmatrix} 1 \\ 0 \end{bmatrix}$$

$$|1\rangle = \begin{bmatrix} 0 \\ 1 \end{bmatrix}$$

Quantum state

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

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

α and β can be complex!

What is quantum computing?

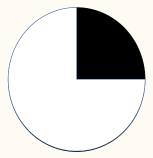
Quantum computing uses quantum mechanics to process information in ways classical computers cannot.

Classical vs. Quantum

Classical bits

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

Quantum bits (Qubit)



$\alpha|0\rangle + \beta|1\rangle$ ...superposition!!

How do we represent a Qubit?

Basis states

$$|0\rangle = \begin{bmatrix} 1 \\ 0 \end{bmatrix}$$

$$|1\rangle = \begin{bmatrix} 0 \\ 1 \end{bmatrix}$$

Quantum state

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

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

α and β can be complex!

$\Longrightarrow$

What is quantum computing?

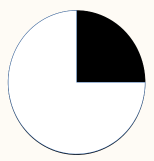
Quantum computing uses quantum mechanics to process information in ways classical computers cannot.

Classical vs. Quantum

Classical bits

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

Quantum bits (Qubit)



$\alpha|0\rangle + \beta|1\rangle$ ...superposition!!

How do we represent a Qubit?

Basis states

$$|0\rangle = \begin{bmatrix} 1 \\ 0 \end{bmatrix}$$

$$|1\rangle = \begin{bmatrix} 0 \\ 1 \end{bmatrix}$$

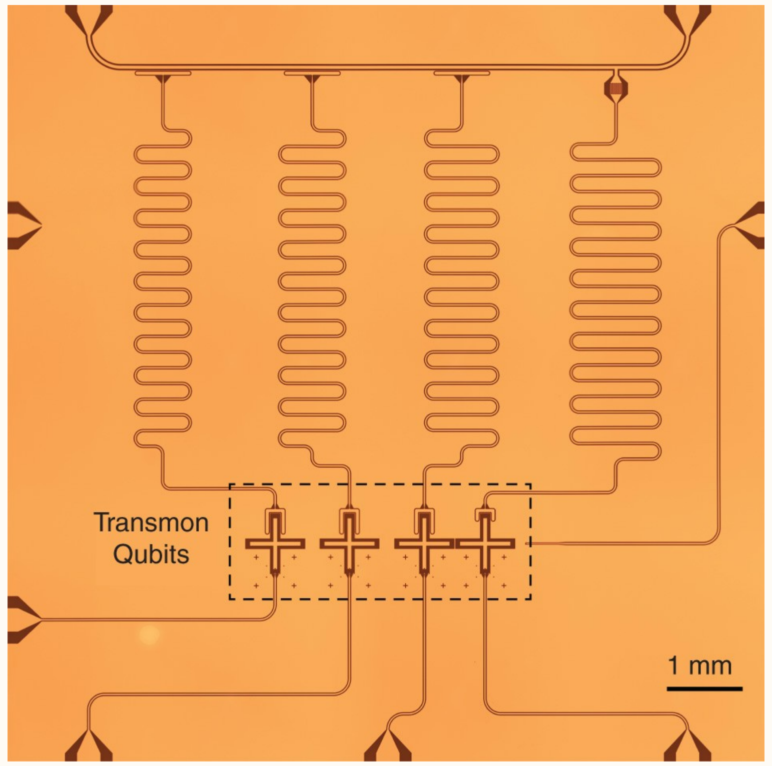
Quantum state

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

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

α and β can be complex!

$\Longrightarrow$



Superposition

Superposition

Qubits and Superposition

Quantum superposition is a fundamental principle in **quantum mechanics** that describes how a quantum system can exist in multiple states simultaneously until it is observed!

Qubits and Superposition

Quantum superposition is a fundamental principle in **quantum mechanics** that describes how a quantum system can exist in multiple states simultaneously until it is observed!

Why is it important?

Qubits and Superposition

Quantum superposition is a fundamental principle in **quantum mechanics** that describes how a quantum system can exist in multiple states simultaneously until it is observed!

Why is it important?

1) ***Parallelism:*** quantum computers can explore many possibilities at once. With n qubits, we can represent 2^n states simultaneusly.

Qubits and Superposition

Quantum superposition is a fundamental principle in **quantum mechanics** that describes how a quantum system can exist in multiple states simultaneously until it is observed!

Why is it important?

1) ***Parallelism:*** quantum computers can explore many possibilities at once. With n qubits, we can represent 2^n states simultaneusly.
2) ***Speedup:*** this allows quantum computers to outperform classical counterparts by exploiting all possible solutions in parallel.

Qubits and Superposition

Quantum superposition is a fundamental principle in **quantum mechanics** that describes how a quantum system can exist in multiple states simultaneously until it is observed!

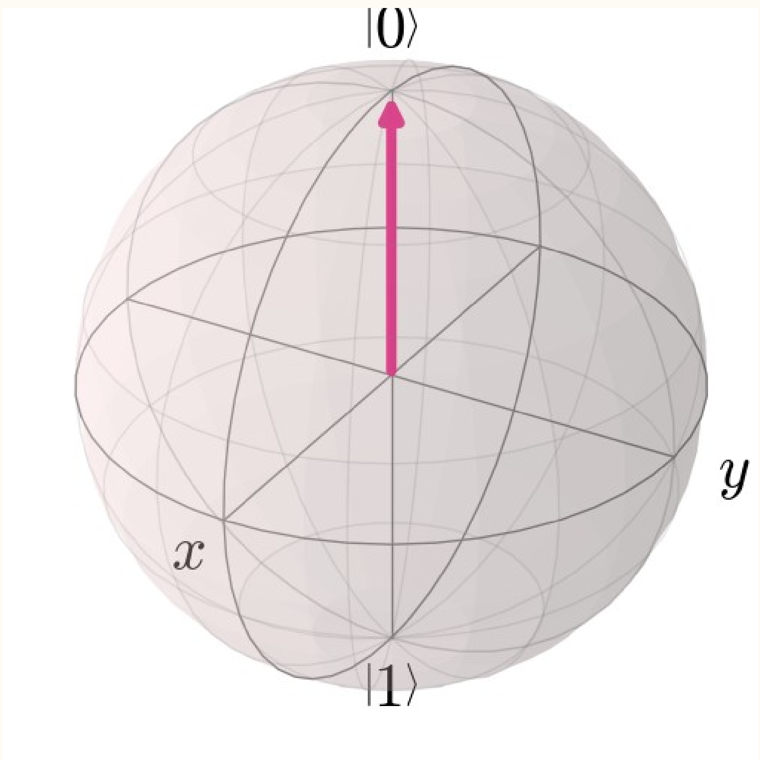
Why is it important?

1) ***Parallelism:*** quantum computers can explore many possibilities at once. With n qubits, we can represent 2^n states simultaneusly.
2) ***Speedup:*** this allows quantum computers to outperform classical counterparts by exploiting all possible solutions in parallel.
3) ***Interference:*** works by boosting correct results and suppressing wrong ones.

Superposition

Qubits and Superposition

Quantum superposition is a fundamental principle in **quantum mechanics** that describes how a quantum system can exist in multiple states simultaneously until it is observed!



Why is it important?

1) ***Parallelism:*** quantum computers can explore many possibilities at once. With n qubits, we can represent 2^n states simultaneusly.
2) ***Speedup:*** this allows quantum computers to outperform classical counterparts by exploiting all possible solutions in parallel.
3) ***Interference:*** works by boosting correct results and suppressing wrong ones.

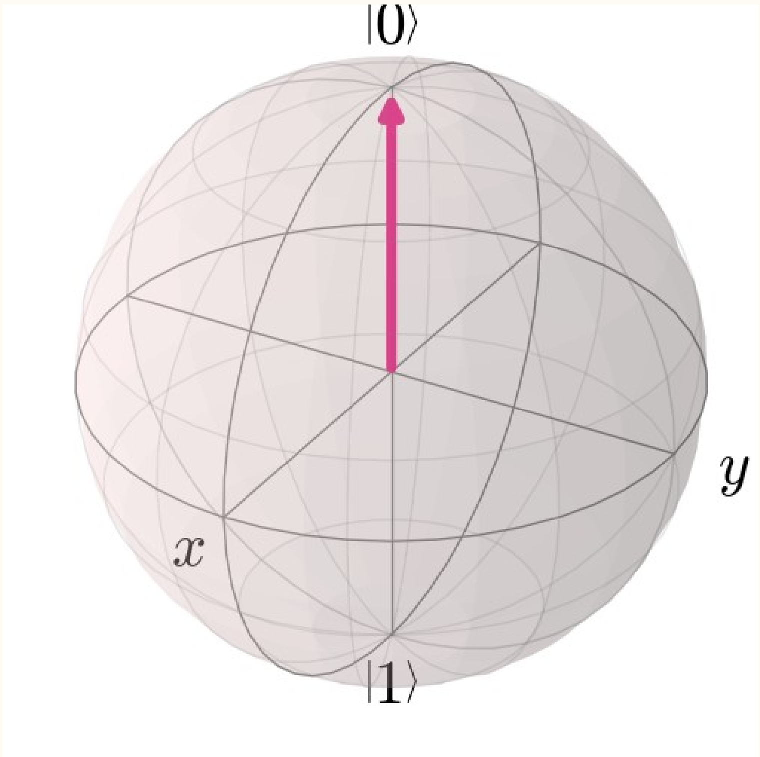
Superposition

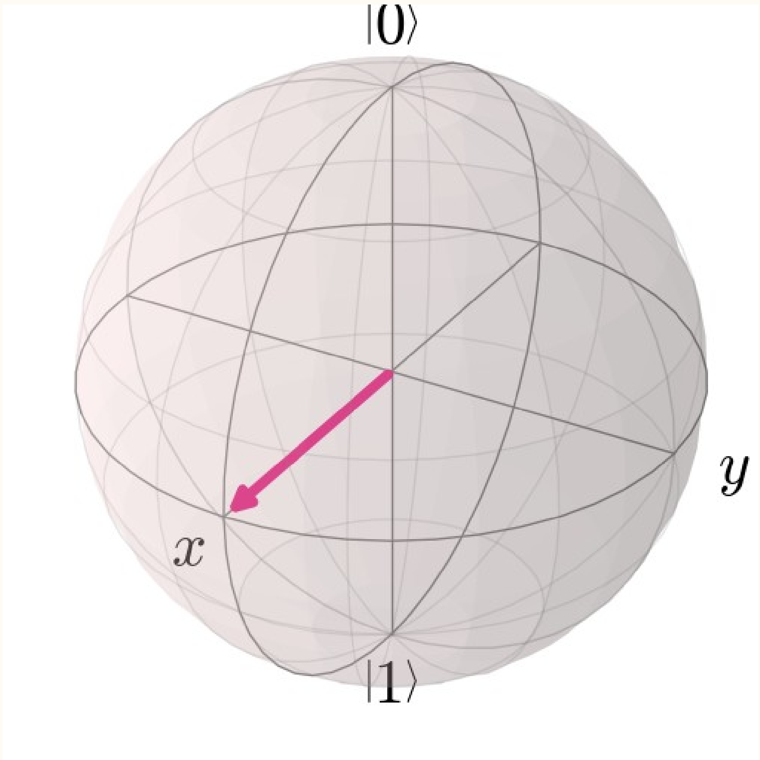
Qubits and Superposition

Quantum superposition is a fundamental principle in **quantum mechanics** that describes how a quantum system can exist in multiple states simultaneously until it is observed!

Why is it important?

1) ***Parallelism:*** quantum computers can explore many possibilities at once. With n qubits, we can represent 2^n states simultaneusly.
2) ***Speedup:*** this allows quantum computers to outperform classical counterparts by exploiting all possible solutions in parallel.
3) ***Interference:*** works by boosting correct results and suppressing wrong ones.





Entanglement

What is entanglement?

It is a **quantum phenomenon** where **two or more qubits** become linked. Measuring the state of one of them instantly determines the state of the other!

What is entanglement?

It is a **quantum phenomenon** where **two or more qubits** become linked. Measuring the state of one of them instantly determines the state of the other!

Why is it important?

Entanglement

What is entanglement?

It is a **quantum phenomenon** where **two or more qubits** become linked. Measuring the state of one of them instantly determines the state of the other!

Why is it important?

1) *Quantum Teleportation.*

Entanglement

What is entanglement?

It is a **quantum phenomenon** where **two or more qubits** become linked. Measuring the state of one of them instantly determines the state of the other!

Why is it important?

1) *Quantum Teleportation.*
2) *Quantum Error Correction*

Entanglement

What is entanglement?

It is a **quantum phenomenon** where **two or more qubits** become linked. Measuring the state of one of them instantly determines the state of the other!

Why is it important?

1) *Quantum Teleportation.*
2) *Quantum Error Correction*
3) *Parallelism*

Entanglement

What is entanglement?

It is a **quantum phenomenon** where **two or more qubits** become linked. Measuring the state of one of them instantly determines the state of the other!

Why is it important?

1) *Quantum Teleportation.*
2) *Quantum Error Correction*
3) *Parallelism*
4) *Quantum Cryptography*

Entanglement

What is entanglement?

It is a **quantum phenomenon** where **two or more qubits** become linked. Measuring the state of one of them instantly determines the state of the other!

Why is it important?

1) *Quantum Teleportation.*
2) *Quantum Error Correction*
3) *Parallelism*
4) *Quantum Cryptography*

Bell states

Entanglement

What is entanglement?

It is a **quantum phenomenon** where **two or more qubits** become linked. Measuring the state of one of them instantly determines the state of the other!

Why is it important?

1) *Quantum Teleportation.*
2) *Quantum Error Correction*
3) *Parallelism*
4) *Quantum Cryptography*

Bell states

$$|\Phi^+\rangle = \frac{1}{\sqrt{2}}\left(|00\rangle + |11\rangle\right)$$

Entanglement

What is entanglement?

It is a **quantum phenomenon** where **two or more qubits** become linked. Measuring the state of one of them instantly determines the state of the other!

Why is it important?

1) *Quantum Teleportation.*
2) *Quantum Error Correction*
3) *Parallelism*
4) *Quantum Cryptography*

Bell states

$$|\Phi^+\rangle = \frac{1}{\sqrt{2}}\left(|00\rangle + |11\rangle\right) \qquad |\Phi^-\rangle = \frac{1}{\sqrt{2}}\left(|00\rangle - |11\rangle\right)$$

What is entanglement?

It is a **quantum phenomenon** where **two or more qubits** become linked. Measuring the state of one of them instantly determines the state of the other!

Why is it important?

1) *Quantum Teleportation.*
2) *Quantum Error Correction*
3) *Parallelism*
4) *Quantum Cryptography*

Bell states

$$|\Phi^+\rangle = \frac{1}{\sqrt{2}}\left(|00\rangle + |11\rangle\right)$$

$$|\Phi^-\rangle = \frac{1}{\sqrt{2}}\left(|00\rangle - |11\rangle\right)$$

$$|\Psi^+\rangle = \frac{1}{\sqrt{2}}\left(|01\rangle + |10\rangle\right)$$

Entanglement

What is entanglement?

It is a **quantum phenomenon** where **two or more qubits** become linked. Measuring the state of one of them instantly determines the state of the other!

Why is it important?

1) *Quantum Teleportation.*
2) *Quantum Error Correction*
3) *Parallelism*
4) *Quantum Cryptography*

Bell states

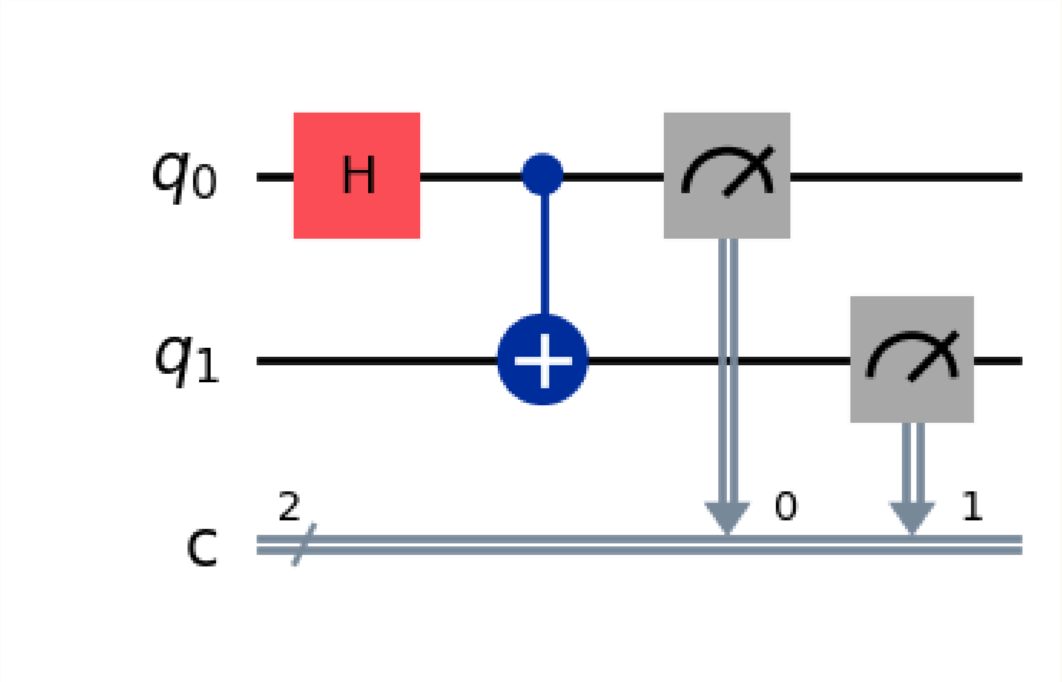
$$|\Phi^+\rangle = \frac{1}{\sqrt{2}}(|00\rangle + |11\rangle) \qquad |\Phi^-\rangle = \frac{1}{\sqrt{2}}(|00\rangle - |11\rangle)$$

$$|\Psi^+\rangle = \frac{1}{\sqrt{2}}(|01\rangle + |10\rangle) \qquad |\Psi^-\rangle = \frac{1}{\sqrt{2}}(|01\rangle - |10\rangle)$$

Entanglement

What is entanglement?

It is a **quantum phenomenon** where **two or more qubits** become linked. Measuring the state of one of them instantly determines the state of the other!



Why is it important?

1) *Quantum Teleportation.*
2) *Quantum Error Correction*
3) *Parallelism*
4) *Quantum Cryptography*

Bell states

$$|\Phi^+\rangle = \frac{1}{\sqrt{2}}\left(|00\rangle + |11\rangle\right) \qquad |\Phi^-\rangle = \frac{1}{\sqrt{2}}\left(|00\rangle - |11\rangle\right)$$

$$|\Psi^+\rangle = \frac{1}{\sqrt{2}}\left(|01\rangle + |10\rangle\right) \qquad |\Psi^-\rangle = \frac{1}{\sqrt{2}}\left(|01\rangle - |10\rangle\right)$$

Entanglement

What is entanglement?

It is a **quantum phenomenon** where **two or more qubits** become linked. Measuring the state of one of them instantly determines the state of the other!

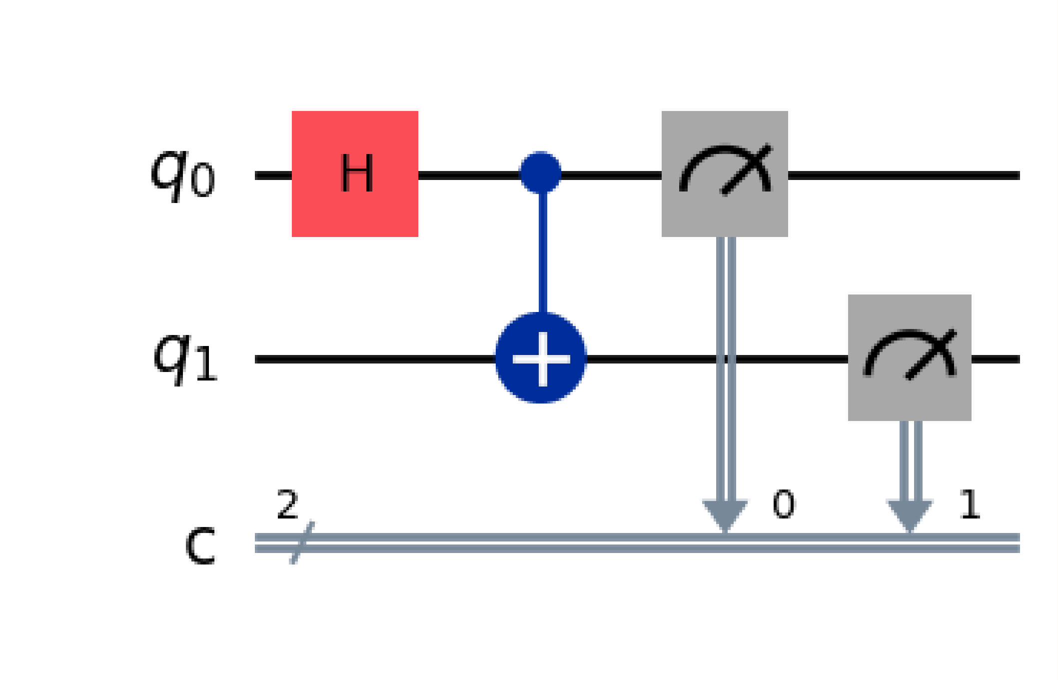
Why is it important?

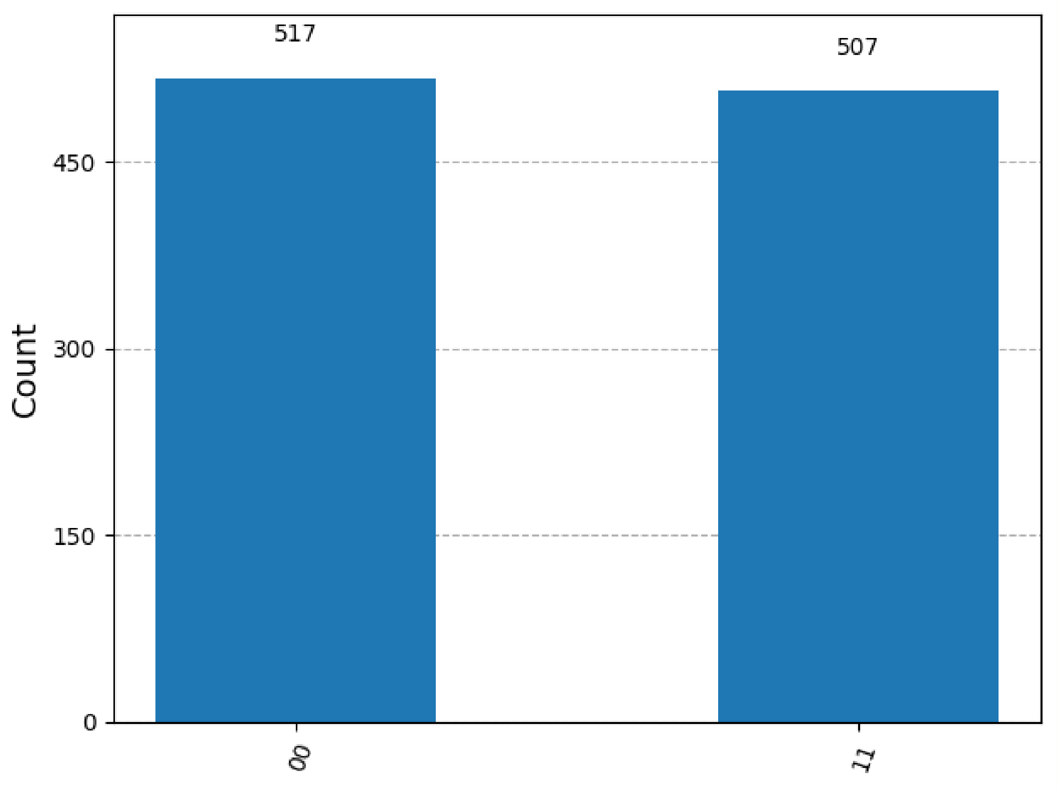
1) *Quantum Teleportation.*
2) *Quantum Error Correction*
3) *Parallelism*
4) *Quantum Cryptography*

Bell states

$$|\Phi^+\rangle = \frac{1}{\sqrt{2}}(|00\rangle + |11\rangle) \qquad |\Phi^-\rangle = \frac{1}{\sqrt{2}}(|00\rangle - |11\rangle)$$

$$|\Psi^+\rangle = \frac{1}{\sqrt{2}}(|01\rangle + |10\rangle) \qquad |\Psi^-\rangle = \frac{1}{\sqrt{2}}(|01\rangle - |10\rangle)$$

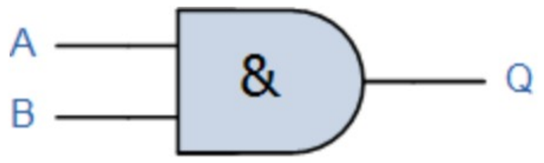




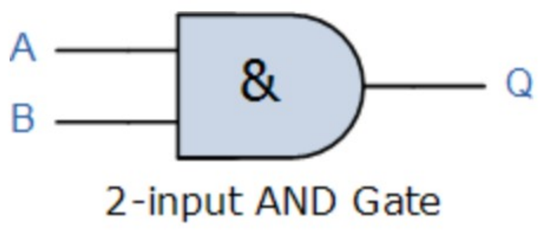
Quantum Gates

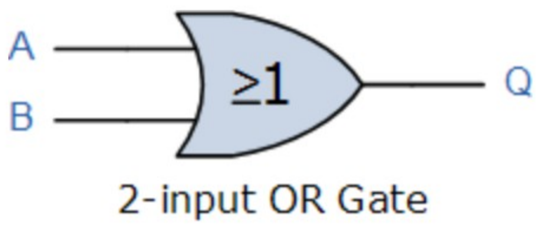
Classical Logic Gates

Classical Logic Gates

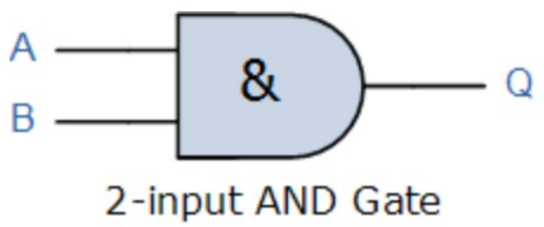
Symbol	Truth Table		
 2-input AND Gate	A	B	Q
	0	0	0
	0	1	0
	1	0	0
	1	1	1
Boolean Expression Q = A.B	Read as A AND B gives Q		

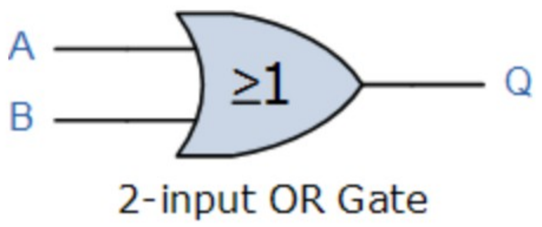
Classical Logic Gates

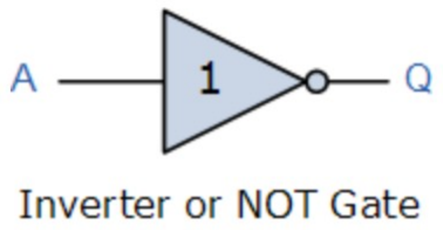
Symbol	Truth Table		
	A	B	Q
	0	0	0
	0	1	0
	1	0	0
	1	1	1
Boolean Expression Q = A.B	Read as A AND B gives Q		

Symbol	Truth Table		
	A	B	Q
	0	0	0
	0	1	1
	1	0	1
	1	1	1
Boolean Expression Q = A+B	Read as A OR B gives Q		

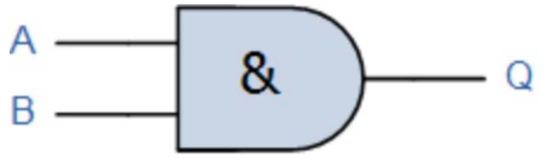
Classical Logic Gates

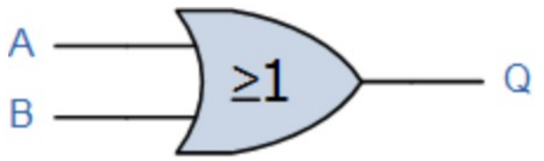
Symbol	Truth Table		
	A	B	Q
	0	0	0
	0	1	0
	1	0	0
	1	1	1
Boolean Expression Q = A.B	Read as A AND B gives Q		

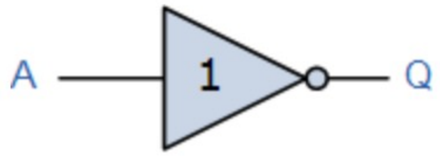
Symbol	Truth Table		
	A	B	Q
	0	0	0
	0	1	1
	1	0	1
	1	1	1
Boolean Expression Q = A+B	Read as A OR B gives Q		

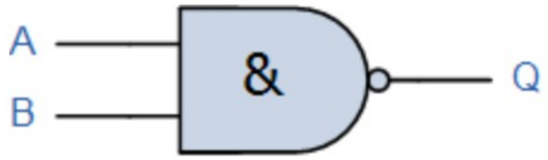
Symbol	Truth Table	
	A	Q
	0	1
	1	0
Boolean Expression Q = NOT A or $\overline{A}$	Read as inversion of A gives Q	

Classical Logic Gates

Symbol	Truth Table		
	A	B	Q
 2-input AND Gate	0	0	0
	0	1	0
	1	0	0
	1	1	1
Boolean Expression Q = A.B	Read as A AND B gives Q		

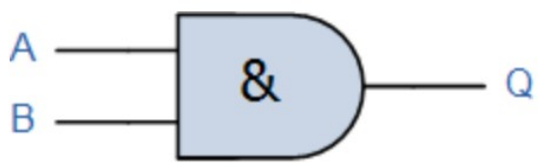
Symbol	Truth Table		
	A	B	Q
 2-input OR Gate	0	0	0
	0	1	1
	1	0	1
	1	1	1
Boolean Expression Q = A+B	Read as A OR B gives Q		

Symbol	Truth Table	
	A	Q
 Inverter or NOT Gate	0	1
	1	0
Boolean Expression Q = NOT A or $\overline{A}$	Read as inversion of A gives Q	

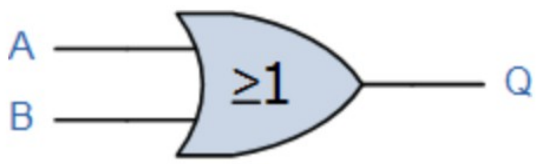
Symbol	Truth Table		
	A	B	Q
 2-input NAND Gate	0	0	1
	0	1	1
	1	0	1
	1	1	0
Boolean Expression Q = $\overline{A.B}$	Read as A AND B gives NOT-Q		

Quantum Gates

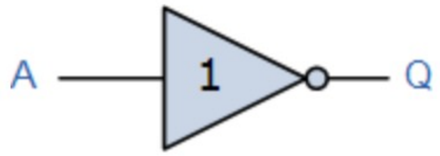
Classical Logic Gates



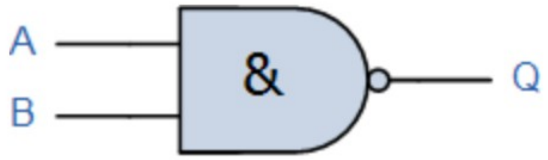
Symbol	Truth Table		
	A	B	Q
2-input AND Gate	0	0	0
	0	1	0
	1	0	0
	1	1	1
Boolean Expression Q = A.B	Read as A AND B gives Q		



Symbol	Truth Table		
	A	B	Q
2-input OR Gate	0	0	0
	0	1	1
	1	0	1
	1	1	1
Boolean Expression Q = A+B	Read as A OR B gives Q		



Symbol	Truth Table	
	A	Q
Inverter or NOT Gate	0	1
	1	0
Boolean Expression Q = NOT A or $\overline{A}$	Read as inversion of A gives Q	



Symbol	Truth Table		
	A	B	Q
2-input NAND Gate	0	0	1
	0	1	1
	1	0	1
	1	1	0
Boolean Expression Q = $\overline{A.B}$	Read as A AND B gives NOT-Q		

Quantum Gates

Quantum Gates

How to we manipulate Qubits?

How to we manipulate Qubits?

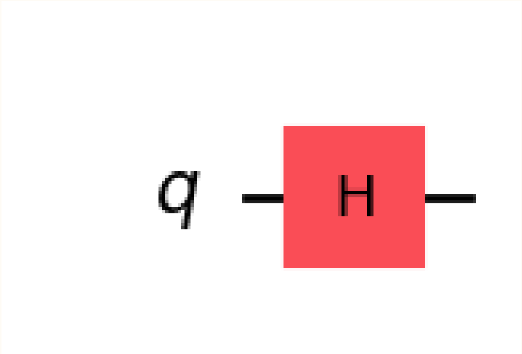
Quantum Gates! Represented by unitary matrices $\mathcal{U}^{\dagger}\mathrm{U} = 1$

Quantum Gates

How to we manipulate Qubits?

Quantum Gates! Represented by unitary matrices $\mathcal{U}^{\dagger}\mathrm{U} = 1$

Hadamard Gate $\frac{1}{\sqrt{2}}\begin{bmatrix}1 & 1\\ 1 & -1\end{bmatrix}$



$\implies$

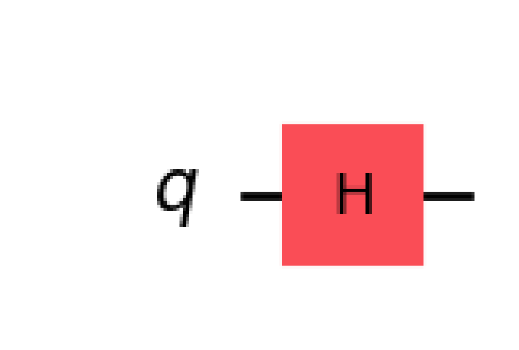
$$H|0\rangle = \tfrac{1}{\sqrt{2}}(|0\rangle + |1\rangle)$$
$$H|1\rangle = \tfrac{1}{\sqrt{2}}(|0\rangle - |1\rangle)$$

Quantum Gates

How to we manipulate Qubits?

Quantum Gates! Represented by unitary matrices $\mathcal{U}^\dagger \mathrm{U} = 1$

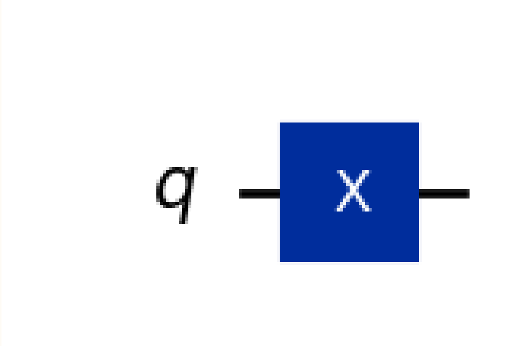
Hadamard Gate $\frac{1}{\sqrt{2}}\begin{bmatrix}1 & 1\\1 & -1\end{bmatrix}$



$\Longrightarrow$

$$H\left|0\right\rangle = \tfrac{1}{\sqrt{2}}(\left|0\right\rangle + \left|1\right\rangle)$$
$$H\left|1\right\rangle = \tfrac{1}{\sqrt{2}}(\left|0\right\rangle - \left|1\right\rangle)$$

Pauli X Gate $\begin{bmatrix}0 & 1\\1 & 0\end{bmatrix}$



$\Longrightarrow$

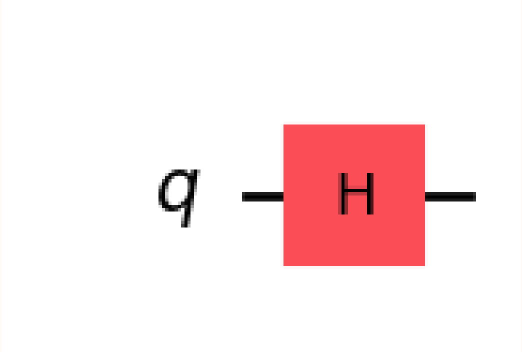
$$X\left|0\right\rangle = \left|1\right\rangle$$
$$X\left|1\right\rangle = \left|0\right\rangle$$

Quantum Gates

How to we manipulate Qubits?

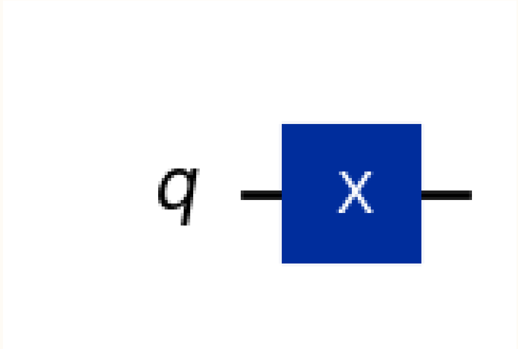
Quantum Gates! Represented by unitary matrices $\mathcal{U}^{\dagger}\mathrm{U} = 1$

Hadamard Gate $\frac{1}{\sqrt{2}}\begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}$



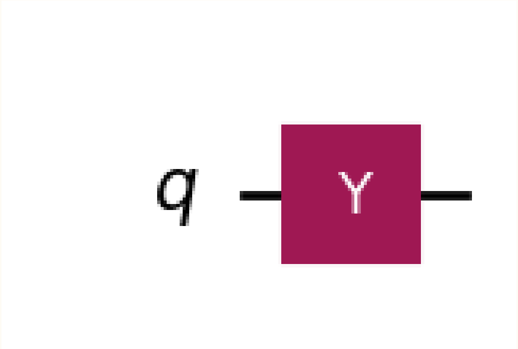
$$\implies \begin{aligned} H\,|0\rangle &= \tfrac{1}{\sqrt{2}}(|0\rangle + |1\rangle) \\ H\,|1\rangle &= \tfrac{1}{\sqrt{2}}(|0\rangle - |1\rangle) \end{aligned}$$

Pauli X Gate $\begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}$



$$\implies \begin{aligned} X\,|0\rangle &= |1\rangle \\ X\,|1\rangle &= |0\rangle \end{aligned}$$

Pauli Y Gate $\begin{bmatrix} 0 & -i \\ i & 0 \end{bmatrix}$



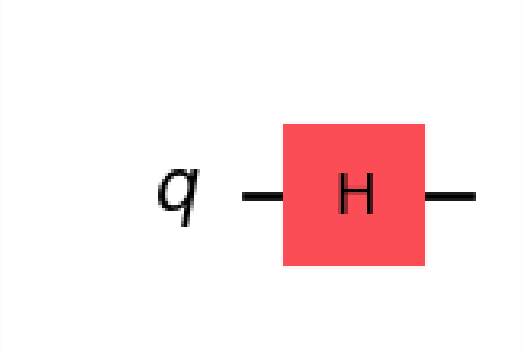
$$\implies \begin{aligned} Y\,|0\rangle &= i|1\rangle \\ Y\,|1\rangle &= -i|0\rangle \end{aligned}$$

Quantum Gates

How to we manipulate Qubits?

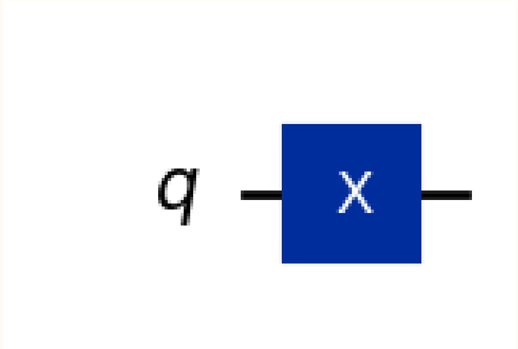
Quantum Gates! Represented by unitary matrices $\mathcal{U}^{\dagger}\mathrm{U} = 1$

Hadamard Gate $\frac{1}{\sqrt{2}}\begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}$



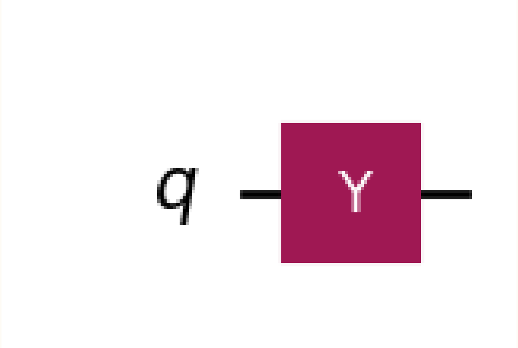
$$\Longrightarrow \quad H\left|0\right\rangle = \frac{1}{\sqrt{2}}(\left|0\right\rangle + \left|1\right\rangle)$$
$$H\left|1\right\rangle = \frac{1}{\sqrt{2}}(\left|0\right\rangle - \left|1\right\rangle)$$

Pauli X Gate $\begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}$



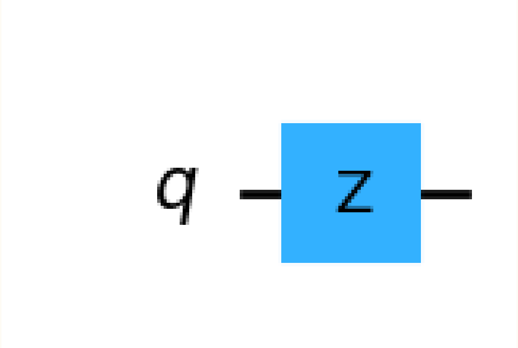
$$\Longrightarrow \quad X\left|0\right\rangle = \left|1\right\rangle$$
$$X\left|1\right\rangle = \left|0\right\rangle$$

Pauli Y Gate $\begin{bmatrix} 0 & -i \\ i & 0 \end{bmatrix}$



$$\Longrightarrow \quad Y\left|0\right\rangle = i\left|1\right\rangle$$
$$Y\left|1\right\rangle = -i\left|0\right\rangle$$

Pauli Z Gate $\begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix}$



$$\Longrightarrow \quad Z\left|0\right\rangle = \left|0\right\rangle$$
$$Z\left|1\right\rangle = -\left|1\right\rangle$$

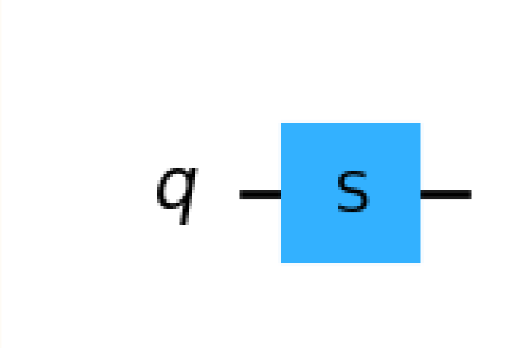
Quantum Gates

Wait… we have more of them!!

Wait… we have more of them!!

S Gate

$$\begin{bmatrix} 1 & 0 \\ 0 & i \end{bmatrix}$$

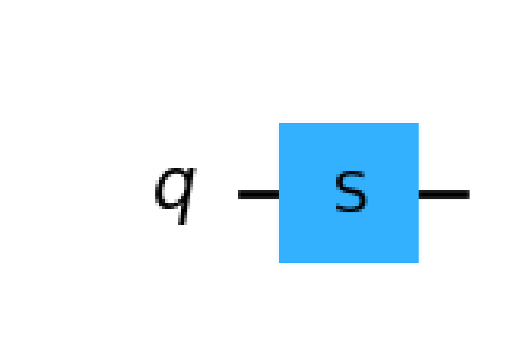


$$\implies \begin{aligned} Z\left|0\right\rangle &= \left|0\right\rangle \\ Z\left|1\right\rangle &= -\left|1\right\rangle \end{aligned}$$

Wait… we have more of them!!

S Gate

$$\begin{bmatrix} 1 & 0 \\ 0 & i \end{bmatrix}$$



$$\implies \begin{aligned} Z\left|0\right\rangle &= \left|0\right\rangle \\ Z\left|1\right\rangle &= -\left|1\right\rangle \end{aligned}$$

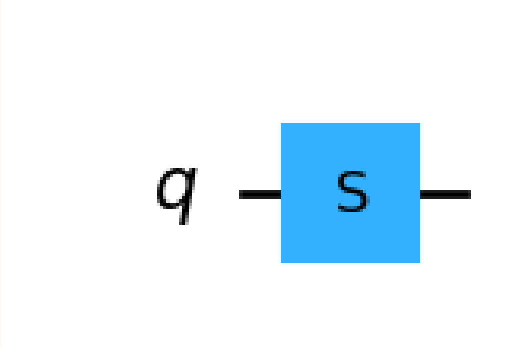
Multi-qubit gates!

Quantum Gates

Wait… we have more of them!!

S Gate

$$\begin{bmatrix} 1 & 0 \\ 0 & i \end{bmatrix}$$

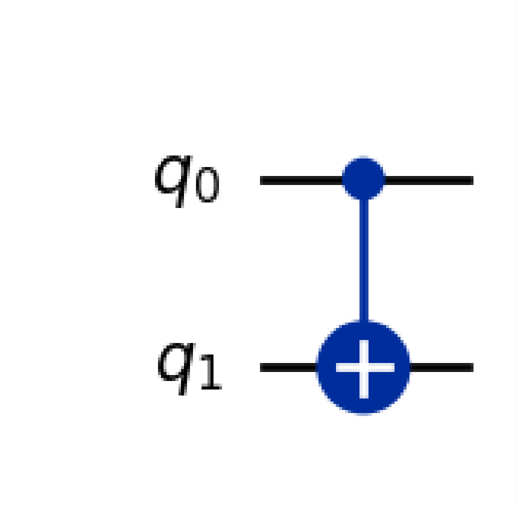


$$\implies \begin{aligned} Z\,|0\rangle &= |0\rangle \\ Z\,|1\rangle &= -|1\rangle \end{aligned}$$

Multi-qubit gates!

CNOT Gate

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

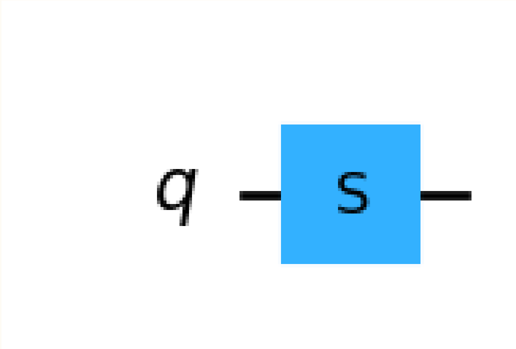


$\implies$ Flips the state of q1 if q0's state is 1. Entanglement!!

Wait… we have more of them!!

S Gate

$$\begin{bmatrix} 1 & 0 \\ 0 & i \end{bmatrix}$$

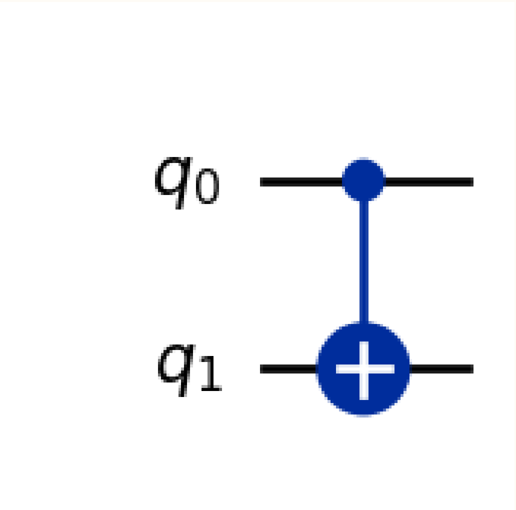


$$\Longrightarrow \quad Z\,|0\rangle = |0\rangle \qquad Z\,|1\rangle = -|1\rangle$$

Multi-qubit gates!

CNOT Gate

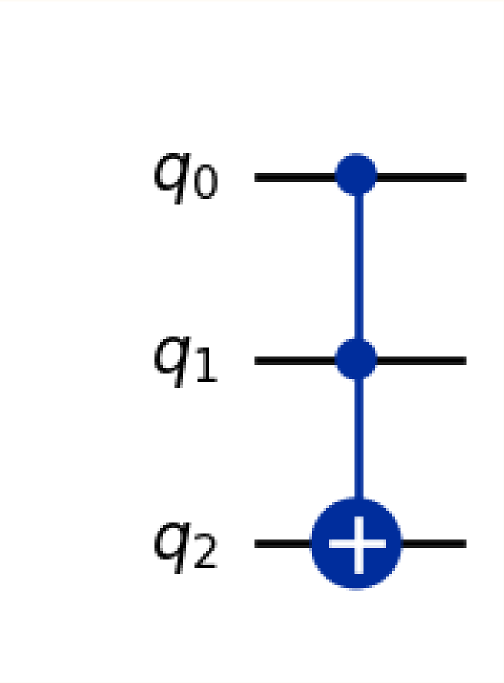
$$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{bmatrix}$$



$\Longrightarrow$ Flips the state of q1 if q0's state is 1. Entanglement!!

Toffoli Gate

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



$\Longrightarrow$ Flips q2 only and if only q0 and q1 are in 1 state! Universal gate!

Wait… we have more of them!!

Multi-qubit gates!

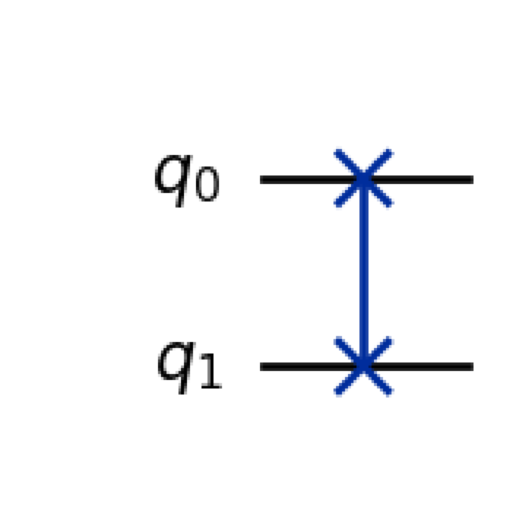
Quantum Gates

Wait… we have more of them!!

Multi-qubit gates!

SWAP Gate

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



$\Longrightarrow$ Swaps q0 and q2 states.

Quantum Circuits

What is a Quantum Circuit?

Sequence of building blocks that carry out elementary operations, called gates!

What is a Quantum Circuit?

Sequence of building blocks that carry out elementary operations, called gates!

Key components

What is a Quantum Circuit?

Sequence of building blocks that carry out elementary operations, called gates!

Key components

1) ***Qubits:*** *wires that carry quantum information.*

What is a Quantum Circuit?

Sequence of building blocks that carry out elementary operations, called gates!

Key components

1) ***Qubits:*** *wires that carry quantum information.*
2) ***Gates:*** *unitary operators.*

What is a Quantum Circuit?

Sequence of building blocks that carry out elementary operations, called gates!

Key components

1) ***Qubits:*** *wires that carry quantum information.*
2) ***Gates:*** *unitary operators.*
3) ***Measurement:*** *extract classical information.*

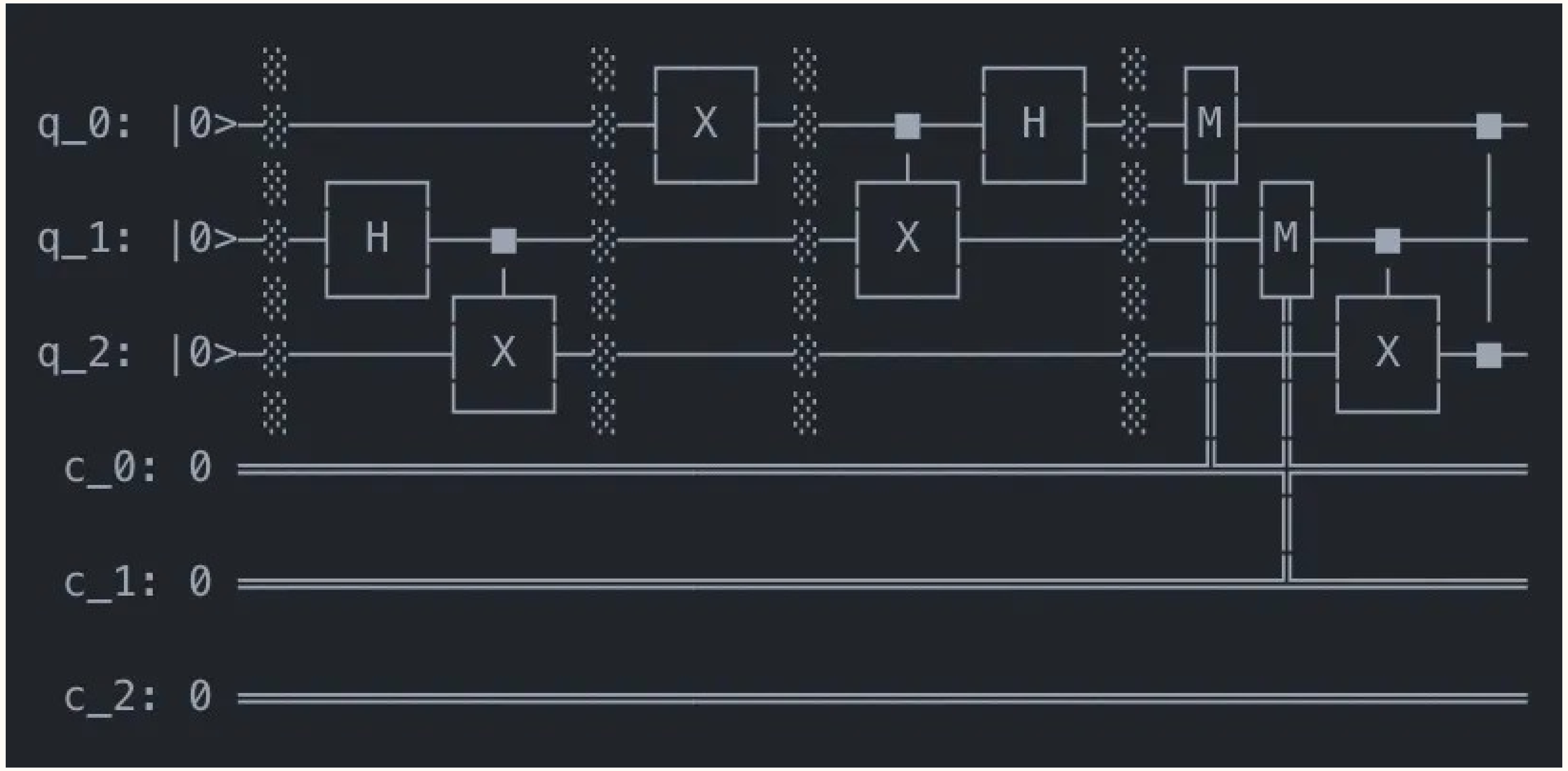
Quantum Circuits

What is a Quantum Circuit?

Sequence of building blocks that carry out elementary operations, called gates!

Key components

1) ***Qubits:*** *wires that carry quantum information.*
2) ***Gates:*** *unitary operators.*
3) ***Measurement:*** *extract classical information.*



Coding time!!!