Getting started with IBM-Qiskit

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IQCQ-2024, UPES

Outline of Talk

- Prerequisites from Quantum Mechanics : BraKet Notation, statevectors, qubits, Bloch sphere ~ (Git Repo : pre-quantum circuit warmup) .
- Getting started with IBMQ Qiskit, logins via IBMid and google colab jupyter notebooks (slides).
- IBMQ-composer : quantum circuit creation, basic gates (Hadamard, CNOT, X and Z gates) , Example: Bell state (slides and IBMQ composer)
- Introduction to quantum circuits, various single and multi-qubits gates and measurements (slides, IBMQ composer and Git Repo : Single and Multi Qubit circuit)
- Visualisation of statevectors on Bloch sphere, quantum simulators (Git Repo : Single and Multi Qubit circuit).
- Computational (z-basis) and Hadamard Basis (x-basis) measurements (Git Repo : Bloch Visualization and Quantum Fourier Transform)
- Quantum Fourier transform : Basic Circuit and visualization (Git Repo : Bloch Visualization and Quantum Fourier Transform)
- Quantum Teleportation : Basic circuit and visualization (Git Repo :Quantum Teleportation)

Qiskit : Brief Intro

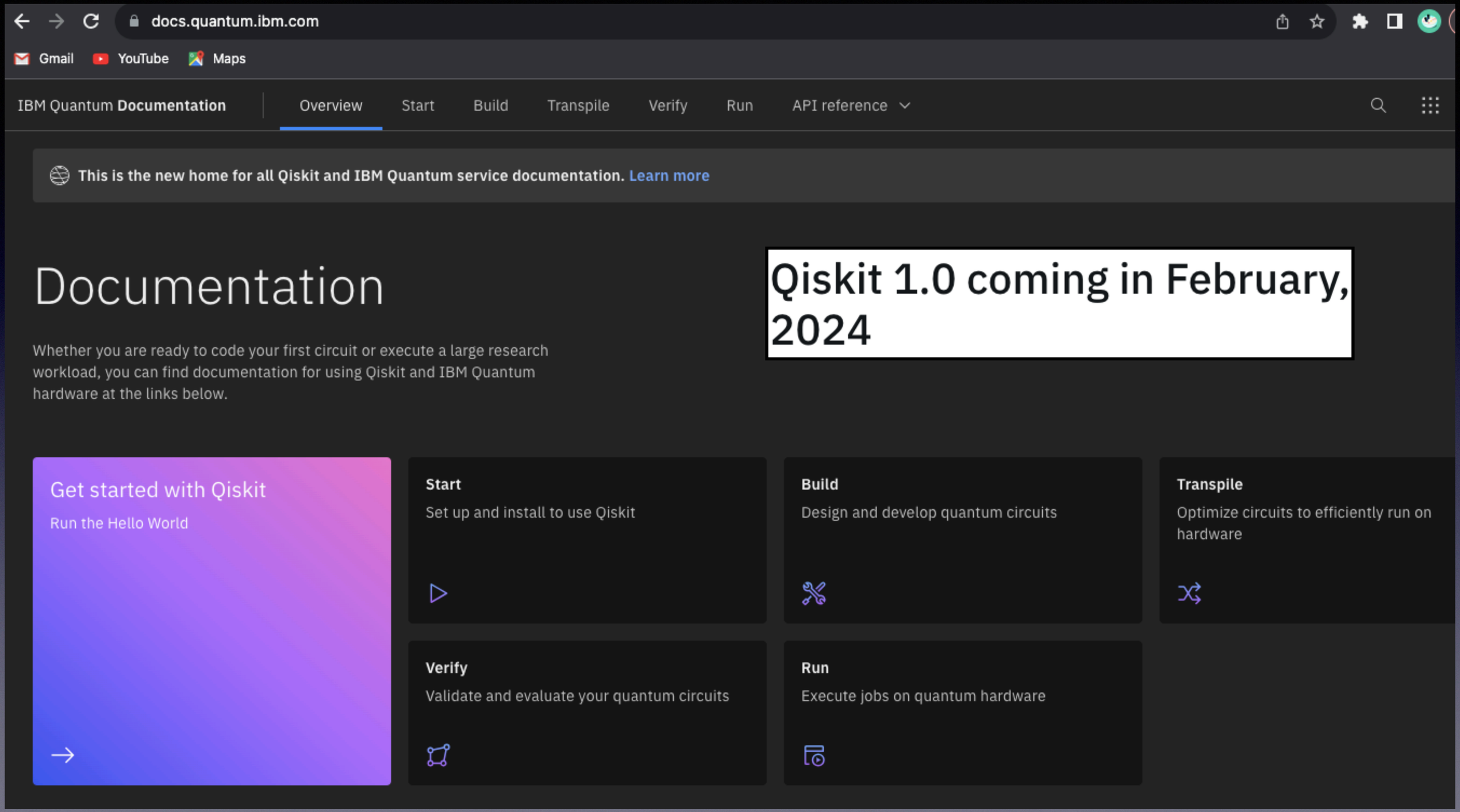
Qiskit

IBM Quantum Spring Challenge

May 17, 2023 at 6:30 PM (local) — May 25, 2023 at 2:30 AM (local)

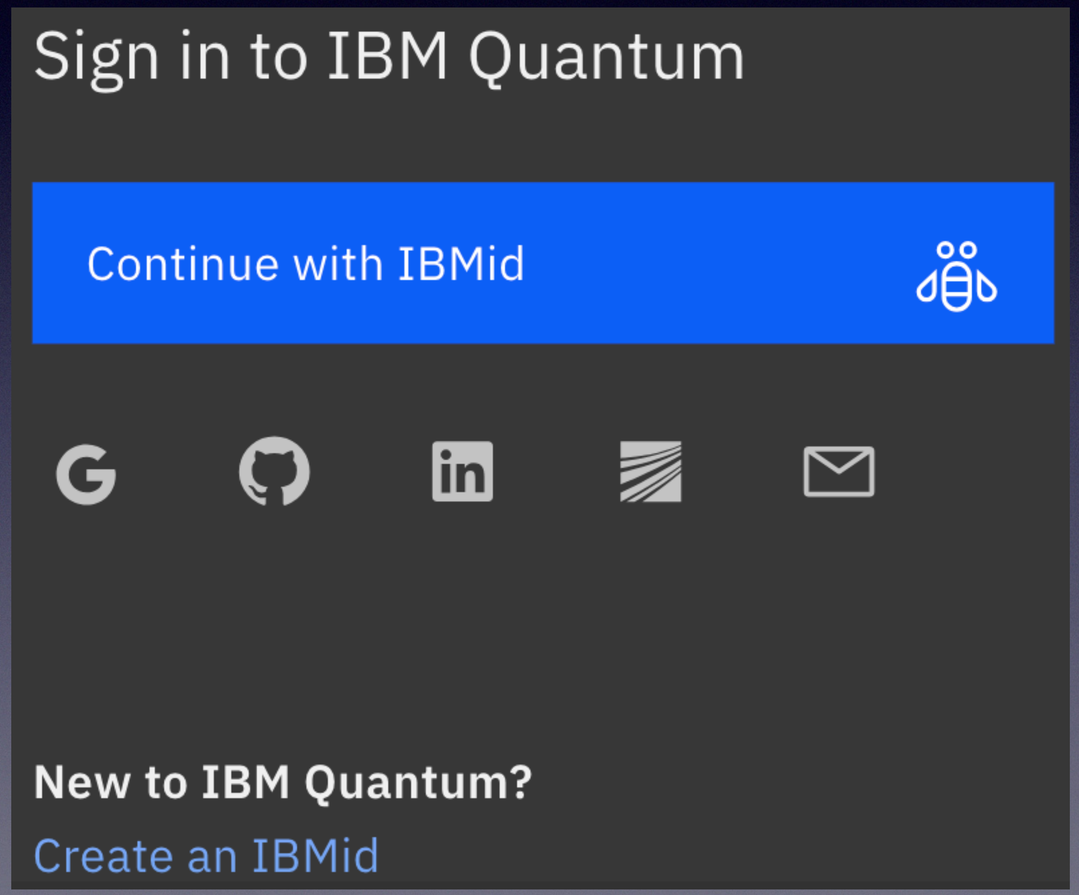
- **Open-source Python-based software development kit developed by IBM Research, 2016.**
- **Creation, manipulation of quantum circuits, design of algorithms, quantum programs and running on IBM-quantum simulators and cloud-based real quantum processors (quantum computers).**
- **Popularization and Training : Qiskit Textbook, numerous Jupiter notebooks, Qiskit Global Summer Schools, Spring and Autumn Challenges, Fall Fest etc..**
- **Certification: IBM-certified developer and Qiskit Advocate.**

https://github.com/qiskit-community/ibm-quantum-challenge-spring-2023, https://quantum.ibm.com/, https://research.ibm.com/blog/quantum-roadmap-2033, https://www.ibm.com/roadmaps/quantum/2024/, https://www.ibm.com/training/badge/qiskit-advocate


docs.quantum.ibm.com
Gmail
YouTube
Maps
IBM Quantum Documentation
Overview
Start
Build
Transpile
Verify
Run
API reference
This is the new home for all Qiskit and IBM Quantum service documentation. Learn more
Documentation
Whether you are ready to code your first circuit or execute a large research workload, you can find documentation for using Qiskit and IBM Quantum hardware at the links below.
Qiskit 1.0 coming in February, 2024
Get started with Qiskit
Run the Hello World
Start
Set up and install to use Qiskit
Build
Design and develop quantum circuits
Transpile
Optimize circuits to efficiently run on hardware
Verify
Validate and evaluate your quantum circuits
Run
Execute jobs on quantum hardware

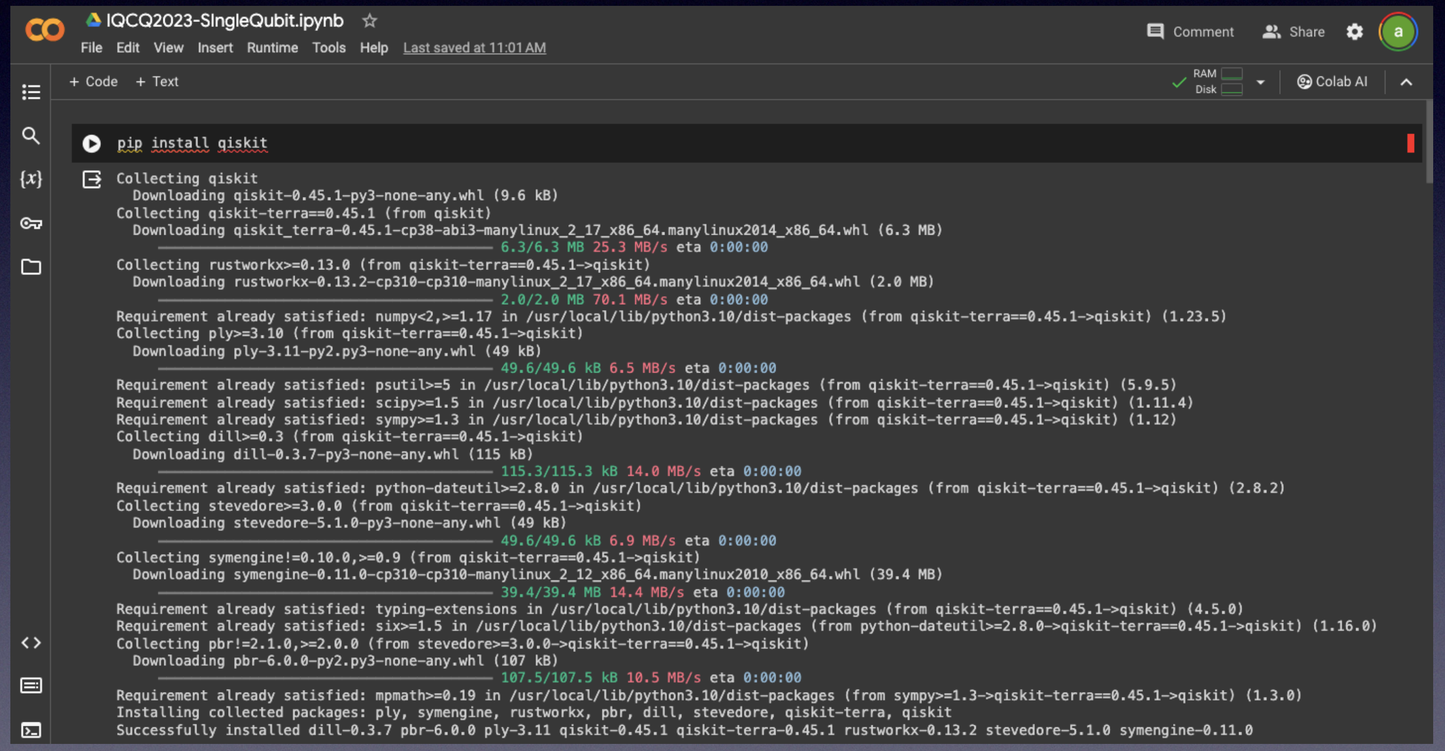
Getting Started : with IBMid

- **Login with IBMid**
- **If you don’t have an account, create one.**
- **If you do just login. It is free of cost to create circuits and run of simulators.**
- **https://quantum.ibm.com/**



Getting Started : with Google Colab

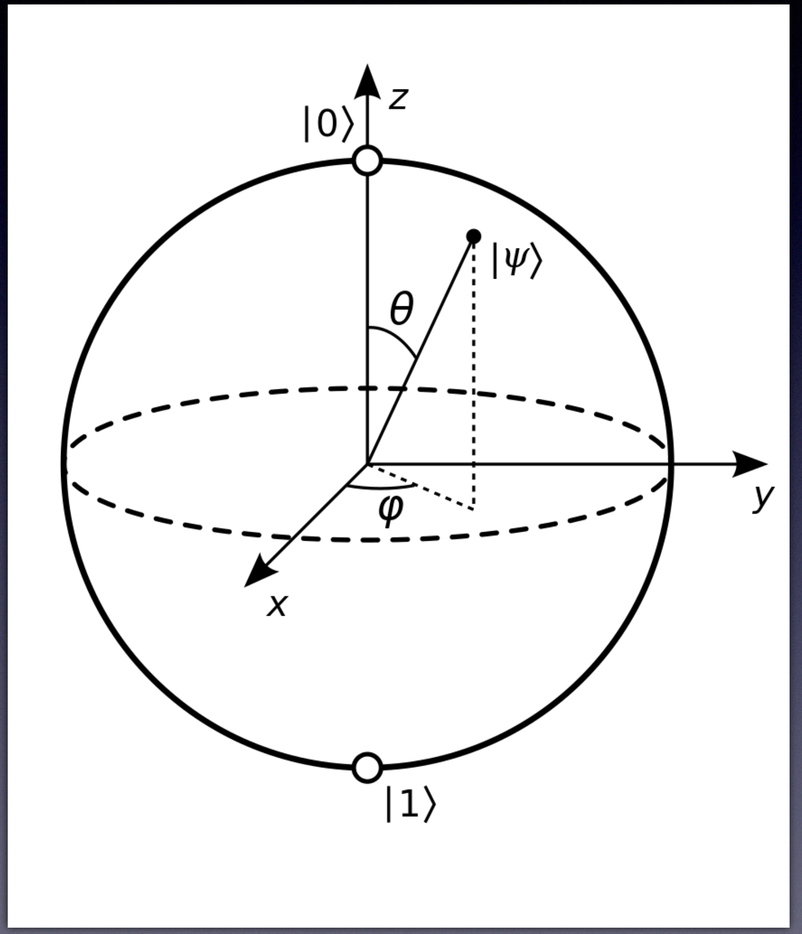
- Hosted Jupyter Notebook service by Google
- Particularly useful in teaching purposes, file can be directly saved into GitHub.
- Install Qiskit and other dependencies like matplotlib, runtime etc with the following on the colab Jupyter Notebook.
- pip install qiskit, pip install qiskit-ibm-runtime (depends), pip install matplotlib.



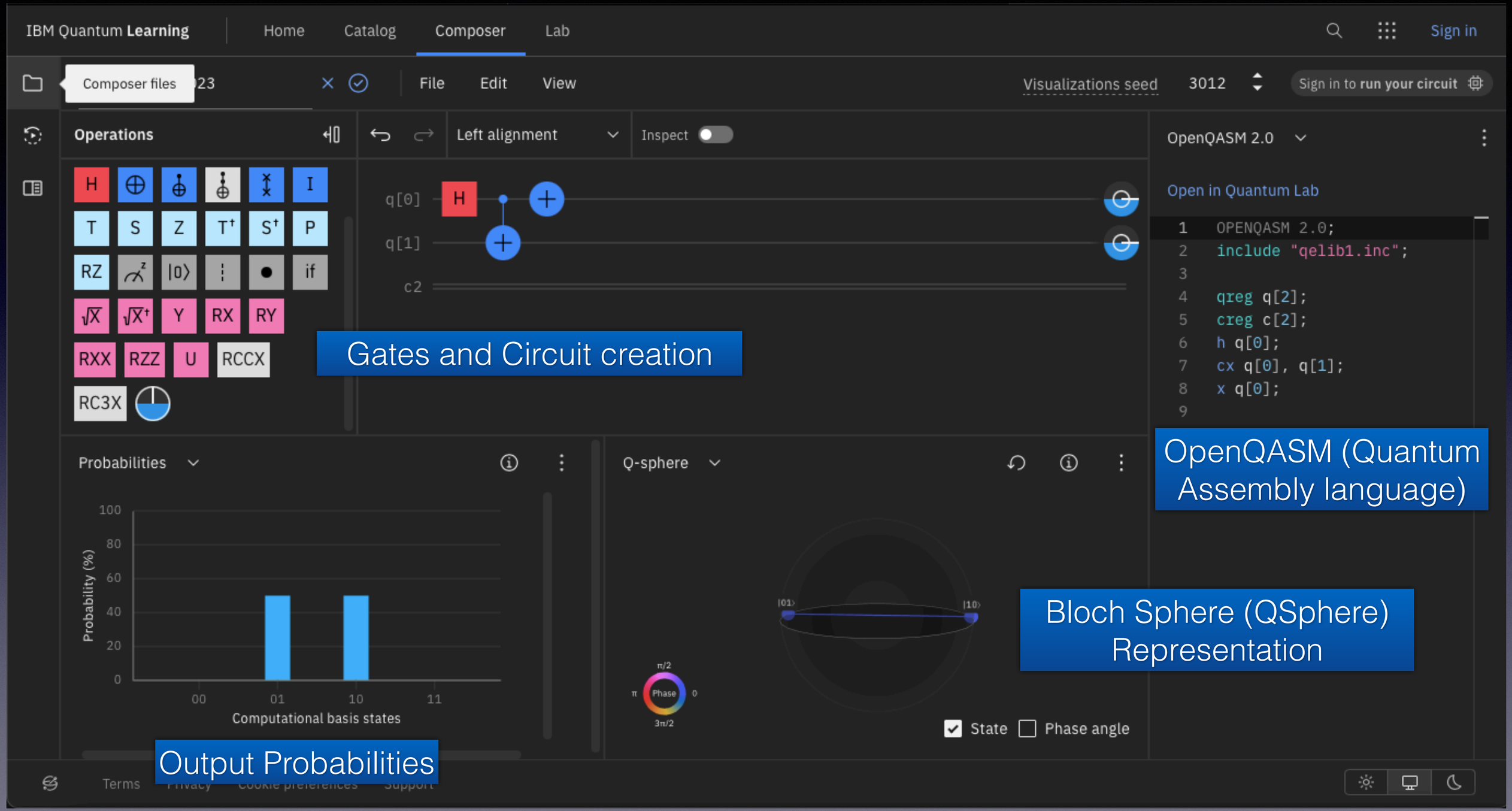
- https://github.com/sayana25/IQCQ-UPES-2023

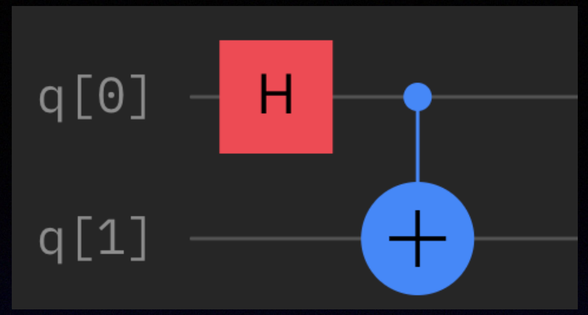
Pre-req from QM

- Statevector $\rightarrow |\psi\rangle$, ψ is a wave function.
- BraKet Notation $\rightarrow |0\rangle, \langle 1|$
- A “qubit” is the basis of quantum information~ two-level quantum systems.
- Any pure state $|\psi\rangle$ of a two-level quantum system can be written as a superposition of the basis vectors $|0\rangle$ and $|1\rangle$ i.e. $\alpha|0\rangle + \beta|1\rangle$.
- Any point on the Bloch sphere represents a pure state.
- In terms of these angles,
  $|\psi\rangle = \cos(\theta/2)|0\rangle + e^{i\phi}\sin(\theta/2)|1\rangle$

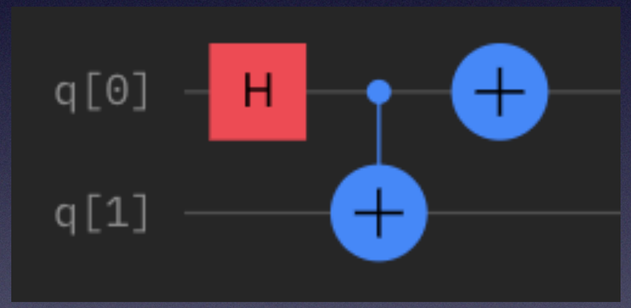


IBMQ-composer


IBM Quantum Learning
Home
Catalog
Composer
Lab
Sign in
Composer files
File
Edit
View
Visualizations seed
3012
Sign in to run your circuit
Operations
Left alignment
Inspect
H
I
T
S
Z
P
RZ
if
Y
RX
RY
RXX
RZZ
U
RCCX
RC3X
q[0]
q[1]
c2
Gates and Circuit creation
OpenQASM 2.0
Open in Quantum Lab
1 OPENQASM 2.0;
2 include "qelib1.inc";
3
4 qreg q[2];
5 creg c[2];
6 h q[0];
7 cx q[0], q[1];
8 x q[0];
9
OpenQASM (Quantum Assembly language)
Probabilities
Probability (%)
100
80
60
40
20
0
00
01
10
11
Computational basis states
Output Probabilities
Q-sphere
|01⟩
|10⟩
π/2
π
Phase
0
3π/2
State
Phase angle
Bloch Sphere (QSphere) Representation
Terms

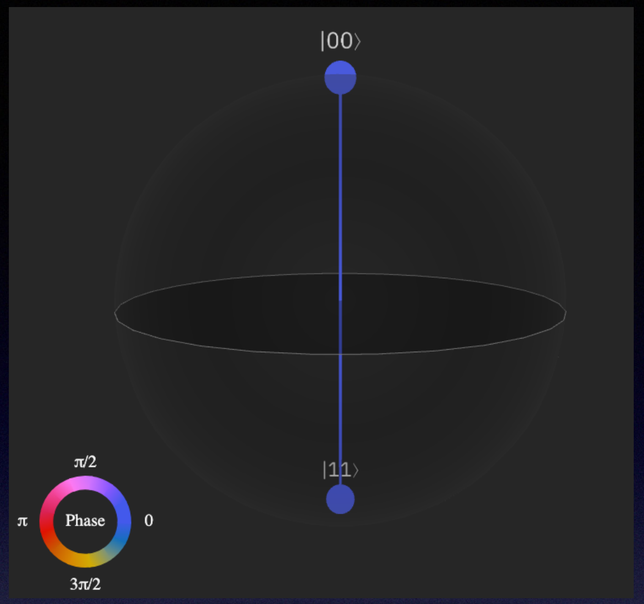


Bell state $|\phi^+\rangle : \frac{1}{\sqrt{2}}(|00\rangle + |11\rangle)$

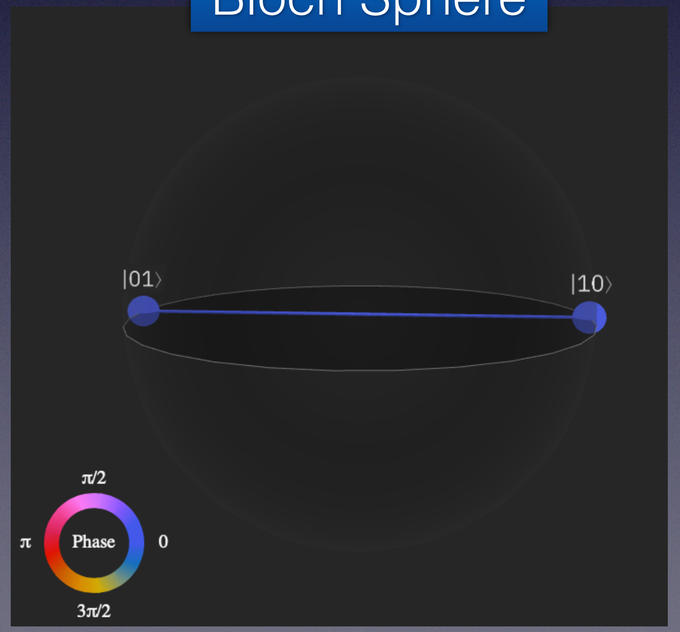


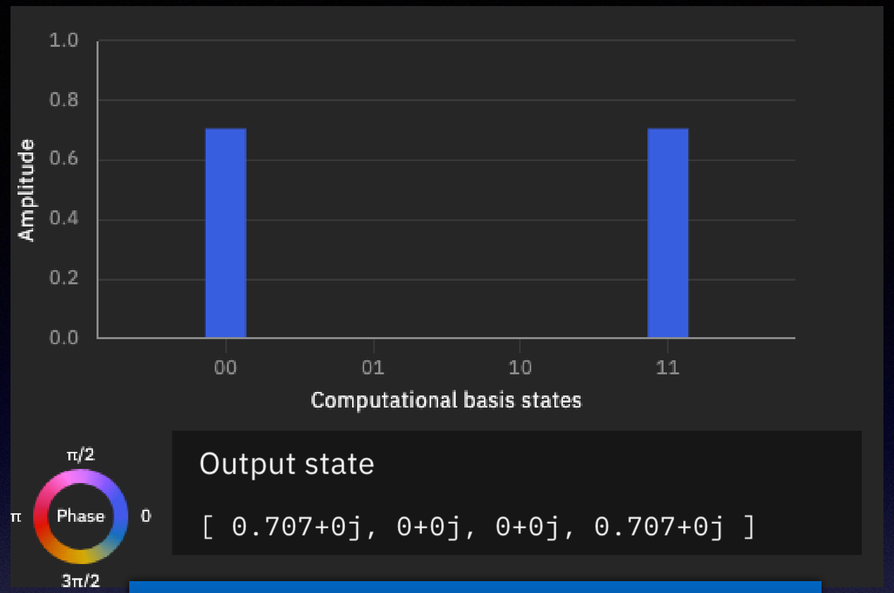
Bell state $|\psi^+\rangle : \frac{1}{\sqrt{2}}(|01\rangle + |10\rangle)$

Can you create the other bell states in the composer? Try out!

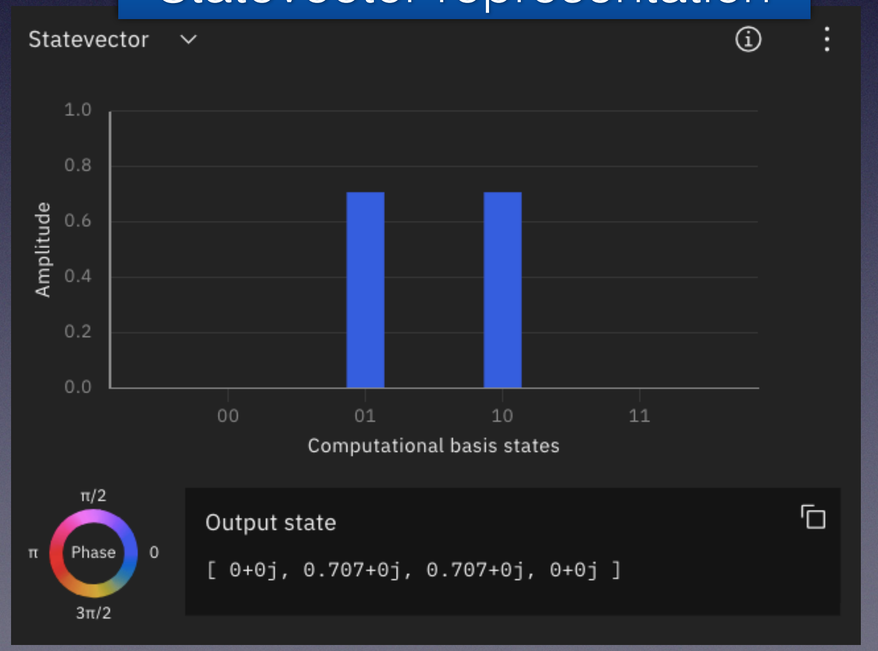


Bloch Sphere



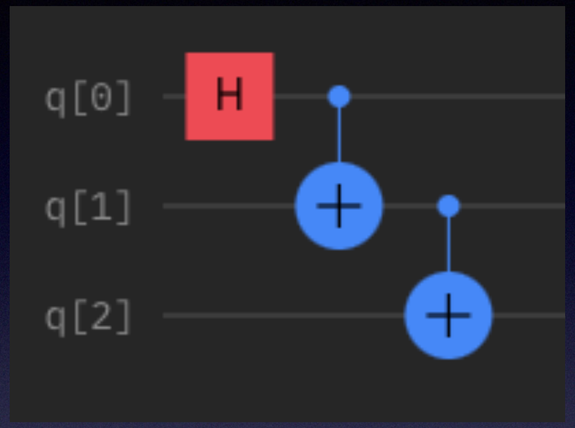


Statevector representation

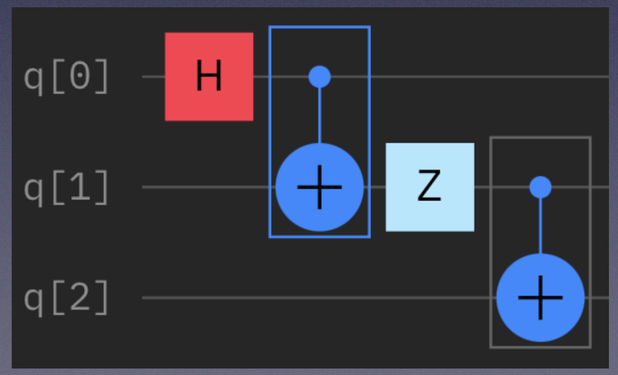


Creating the GHZ state (IBM-Q composer)

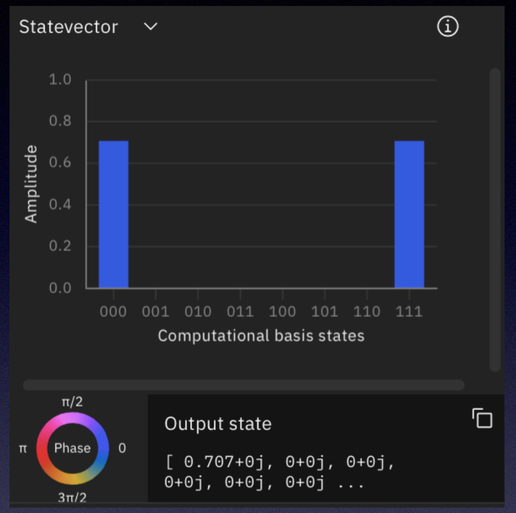
- It is an entangled state for 3 qubits.
- Named after Greenberger–Horne–Zeilinger
- N-qubit generalisation also available.

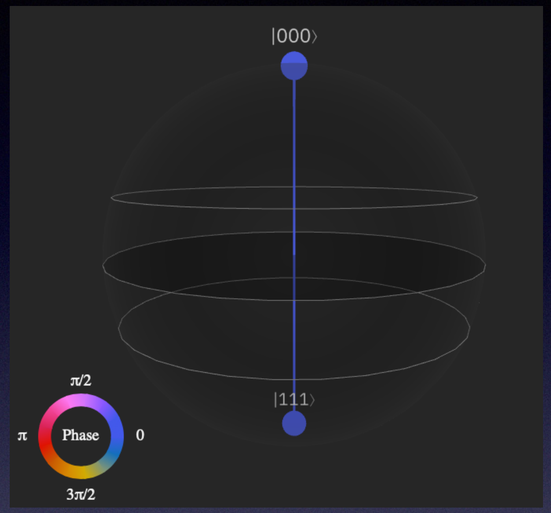


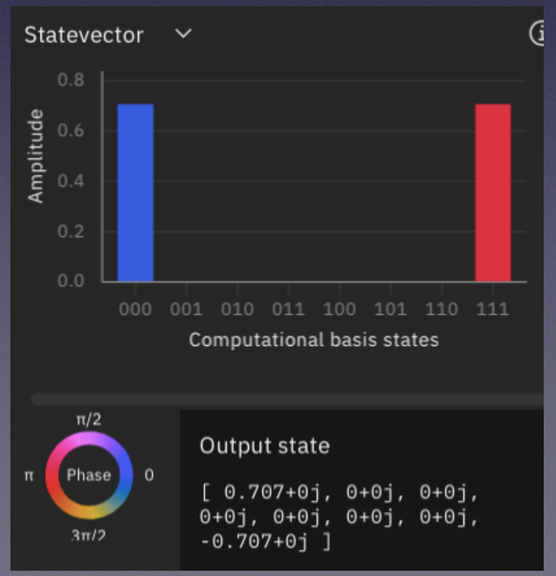
$$|GHZ\rangle = \frac{1}{\sqrt{2}}(|000\rangle + |111\rangle)$$

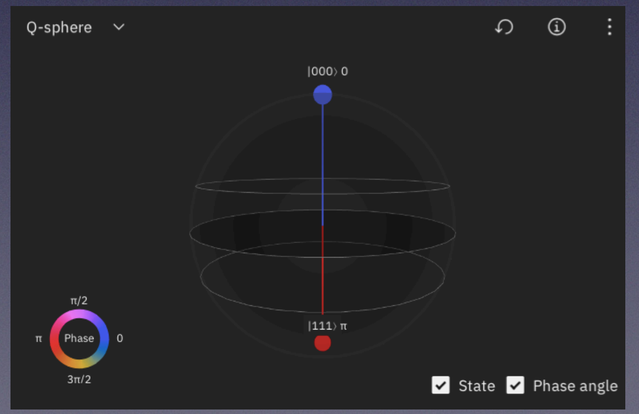


$$|GHZ + phase\rangle = \frac{1}{\sqrt{2}}(|000\rangle - |111\rangle)$$





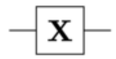
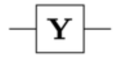
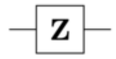
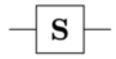
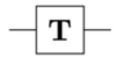
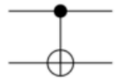
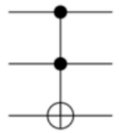




QISKIT

Single and Multi Qubits gates

- Gates are quantum unitary operations.
- Unitary matrices : $UU^\dagger = I = U^\dagger U$.
- N-qubit gates give rise to matrices of size $2^N \times 2^N$.
- For a single qubit, unitary gates are rotations on the surface of the Bloch Sphere.
- **Bell states ~** quantum states of **two** qubits, simple examples of quantum entanglement.
- Applications in Super dense coding, Quantum teleportation, quantum key distribution etc..

Operator	Gate(s)	Matrix
Pauli-X (X)		$\begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}$
Pauli-Y (Y)		$\begin{bmatrix} 0 & -i \\ i & 0 \end{bmatrix}$
Pauli-Z (Z)		$\begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix}$
Hadamard (H)		$\frac{1}{\sqrt{2}}\begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}$
Phase (S, P)		$\begin{bmatrix} 1 & 0 \\ 0 & i \end{bmatrix}$
$\pi/8$ (T)		$\begin{bmatrix} 1 & 0 \\ 0 & e^{i\pi/4} \end{bmatrix}$
Controlled Not (CNOT, CX)		$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{bmatrix}$
Controlled Z (CZ)		$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & -1 \end{bmatrix}$
SWAP		$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$
Toffoli (CCNOT, CCX, TOFF)		$\begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$

https://doi.org/10.48550/arXiv.1707.03429, https://calumholker.medium.com/an-introduction-to-quantum-computing-ee6bffff0ab4,Nielsen & Chuang 2010,

Quantum Fourier transform (QFT)

- Quantum counterpart of classical Fourier transform or the discrete Fourier transform.
- Effectively a change of basis from computational (Z-basis) to the Fourier (Hadamard/X) basis.
- H-gate is the single-qubit QFT, transforms Z-basis ($|0\rangle, |1\rangle$) states to X-basis ($|+\rangle, |-\rangle$) states .
- key step in many quantum algorithms and most significantly in the Shor's factorization algorithm, related to period finding and factorization of prime which builds the basis of security or classical encryption.
- Yields **exponential advantage** over classical computational methods

https://github.com/Qiskit/textbook/blob/main/notebooks/ch-algorithms/quantum-fourier-transform.ipynb

Quantum Teleportation

- Teleportation is a cornerstone of quantum information theory.
- Discovered by Bennett, Brassard, Crepeau, Josza, Peres and Wootters, experimentally realized through many recent and older experiments*.
- Protocol in quantum communication ~ transfer of quantum information from qubit to another.
- Utilizes entangled bell states to transfer quantum information from one qubit to another.
- Fundamental importance in the study of quantum information and quantum computation.
- No violation of the No-cloning theorem or of the theory of relativity.

https://github.com/qiskit-community/qiskit-community-tutorials/blob/master/Coding_With_Qiskit/ep5_Quantum_Teleportation.ipynb, https://github.com/qiskit-community/qiskit-community-tutorials/blob/master/awards/teach_me_quantum_2018/intro2qc/7.Quantum%20teleportation.ipynb, https://calumholker.medium.com/an-introduction-to-qiskit-with-quantum-teleportation-e76a507d69b5, Nielsen & Chuang, 2010.

Thank you !

Prequel to the Quantum Fourier transform : Classical Discrete Fourier transform

- Classical Fourier transform (CFT) & discrete version (DFT) ~ related Fast Fourier transform (FFT) have huge implications in all of STE.
- DFT maps a sequence of N complex numbers, $x = \{x_0, x_1 \ldots x_{n-1}\}$, into another, $y = \{X_0, X_1 \ldots X_{n-1}\}$, such that, $y_k = \sum_{k=0}^{N-1} x_n e^{-\frac{i2\pi}{N}kn}$, k = 0,1,2…$N-1$.
- An N-point DFT maybe expressed as a transformation : $y = Wx$, where, W is the DFT matrix.

https://www.authorea.com/users/311310/articles/442033-a-comparison-of-quantum-and-traditional-fourier-transform-computations