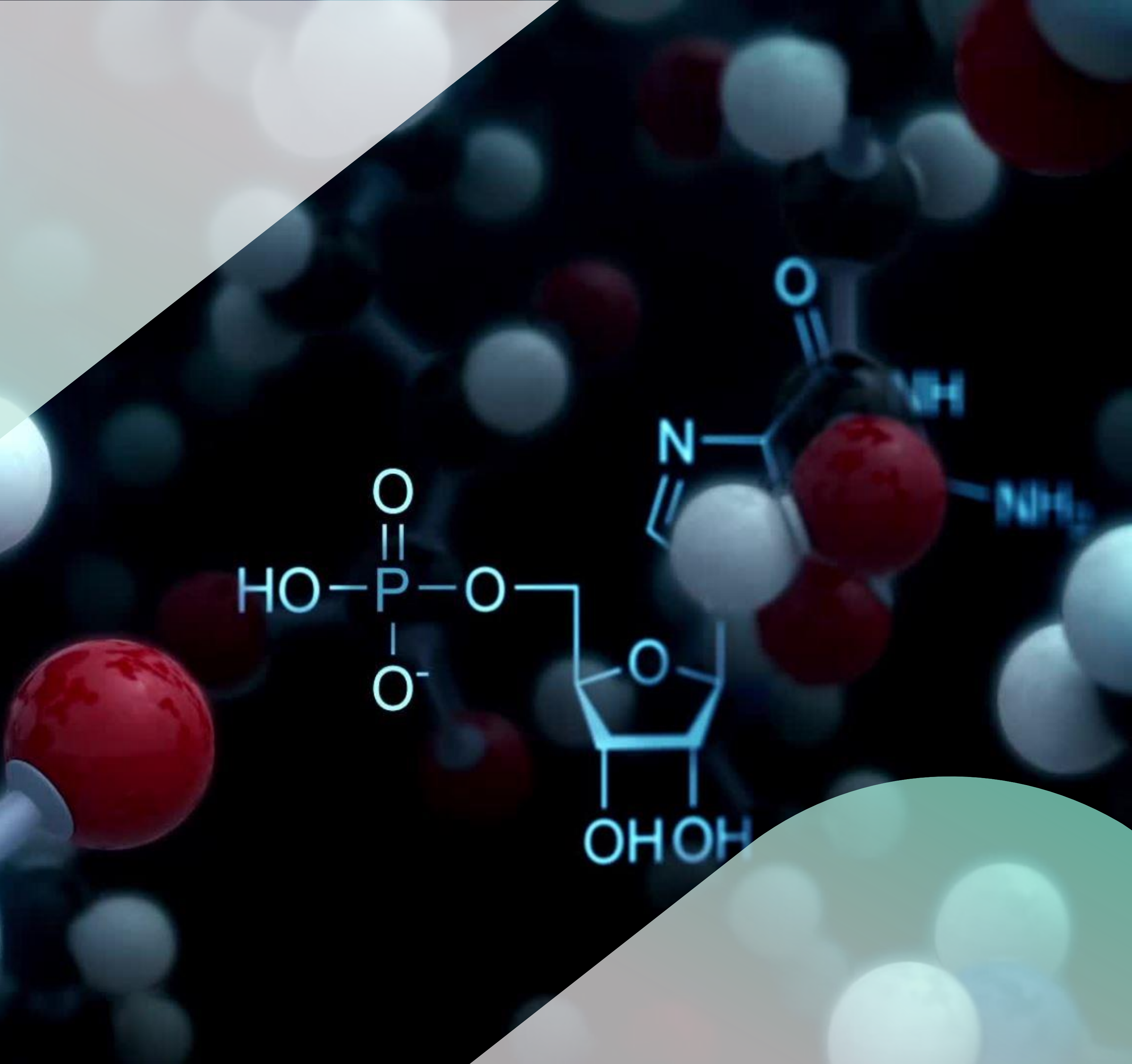
DL-2 Red
Why Quantum ML Matters

4850-03 Fall 2023

Christopher Dargan

Hyunmo Kim

Patricia Reimao



Classical Computing

Architecture:

- Binary System
- Von Neumann

Processing:

- Boolean Logic
- Algorithms (e.g., sorting, searching)

Limitations:

- Complexity of certain problems (e.g., factorization)

Quantum Computing

Principles of Quantum Mechanics:

- Superposition
- Entanglement

Qubits

Quantum Gates and Operations

Quantum Algorithms (e.g., Deutsch-Jozsa algorithm)

Comparing Classical vs Quantum

Similarities:

- Both involve information processing
- Can perform mathematical operations and computations

Differences:

- Superposition and Entanglement in Quantum Computing
- Exponential parallelism vs sequential processing in Classical Computing
- Complexity of algorithms (e.g., factoring, optimization problems)

Classical Bit vs Quantum Bit

- A ***bit*** is the basic unit of information in classical computing
- Classical bits have two possible states: {0, 1}
- Determinant by nature

- A ***qubit*** is a basic unit of quantum information used in quantum computing
- Quantum bits utilize the superposition of classical bits.
- Nondeterministic by nature

Classical Bit Vector Representation

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

Quantum Bit Vector Representation

$$|\psi\rangle = \alpha|0\rangle + \beta\,|1\rangle = \alpha\begin{bmatrix}1\\0\end{bmatrix} + \beta\begin{bmatrix}0\\1\end{bmatrix}$$

$$\alpha = e^{i\chi}a, \beta = e^{i\phi}b$$

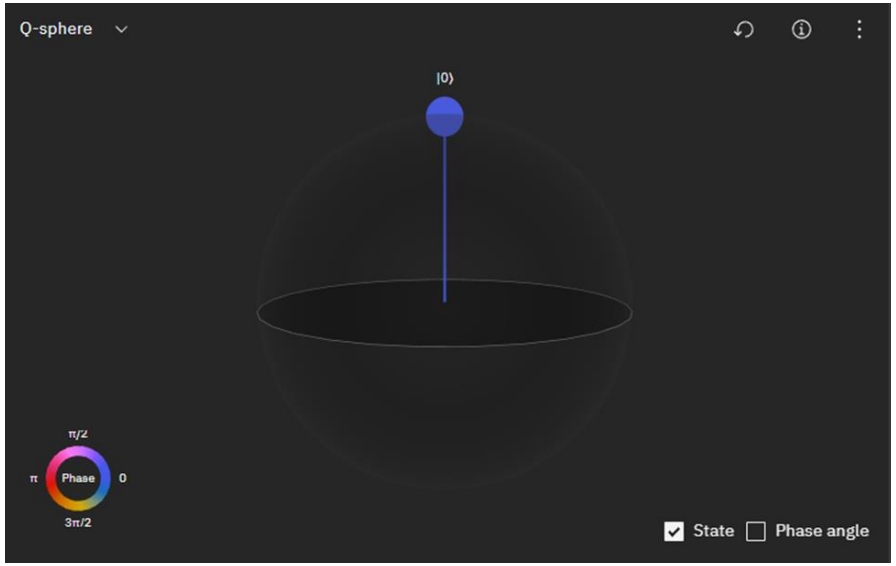
Quantum Bit - Superposition

- A qubit is indeterminate having no intrinsic value
- Qubit is determined by the superposition of the two state bits $|0\rangle$ and $|1\rangle$
- Metaphorically speaking the qubit is simultaneously in both the $|0\rangle$ and $|1\rangle$ state with a probability of being in the two distinct states given by terms

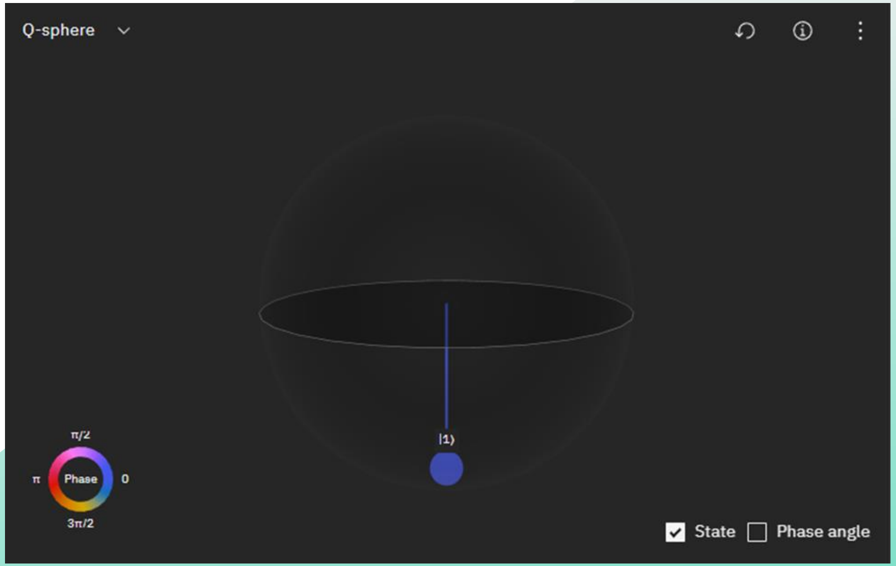
Qubit $$|\psi\rangle = \alpha|0\rangle + \beta\,|1\rangle = \alpha \begin{bmatrix}1\\0\end{bmatrix} + \beta \begin{bmatrix}0\\1\end{bmatrix}$$

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

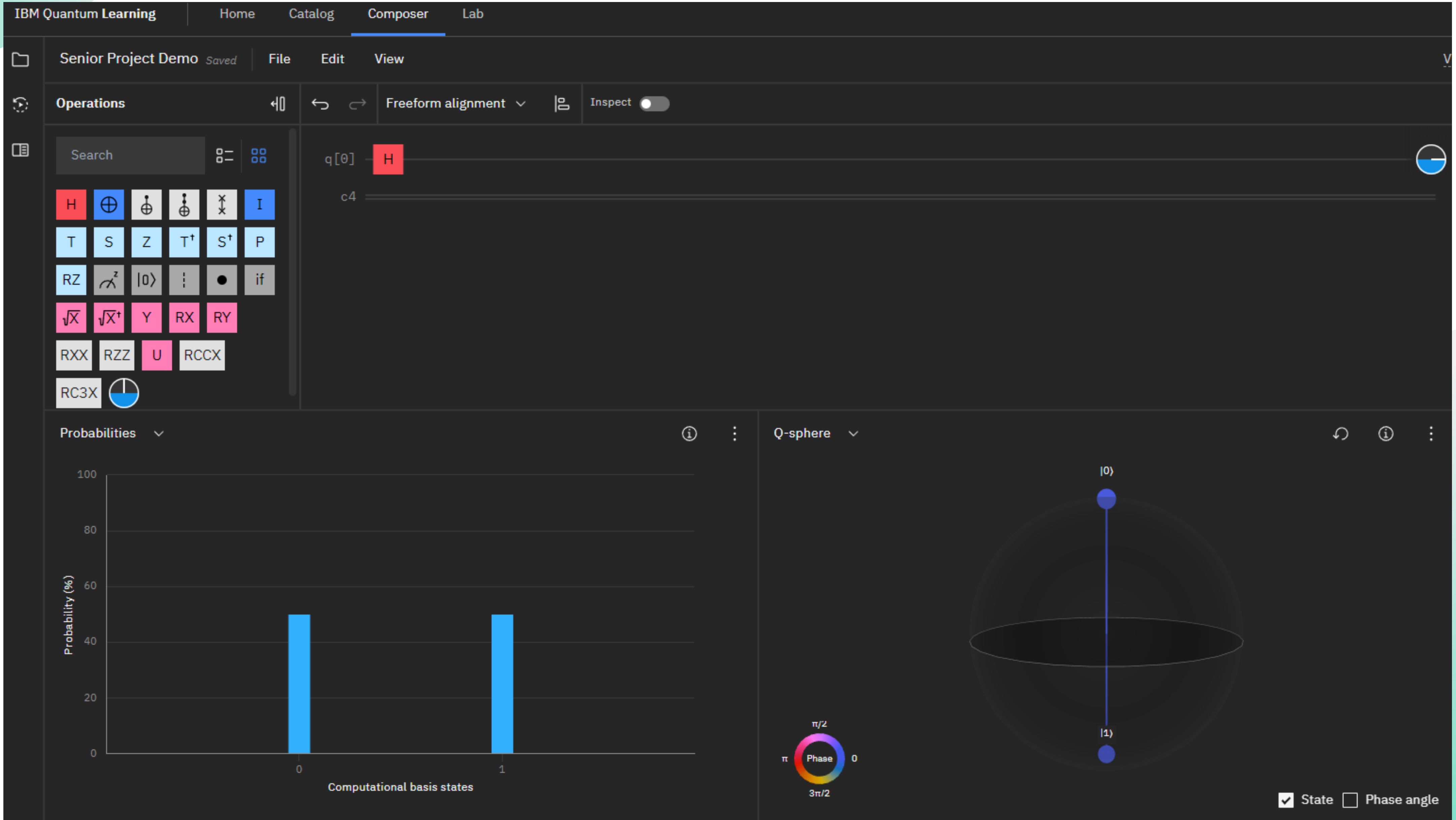
Qubit $|0\rangle$ - IBM Quantum Composer



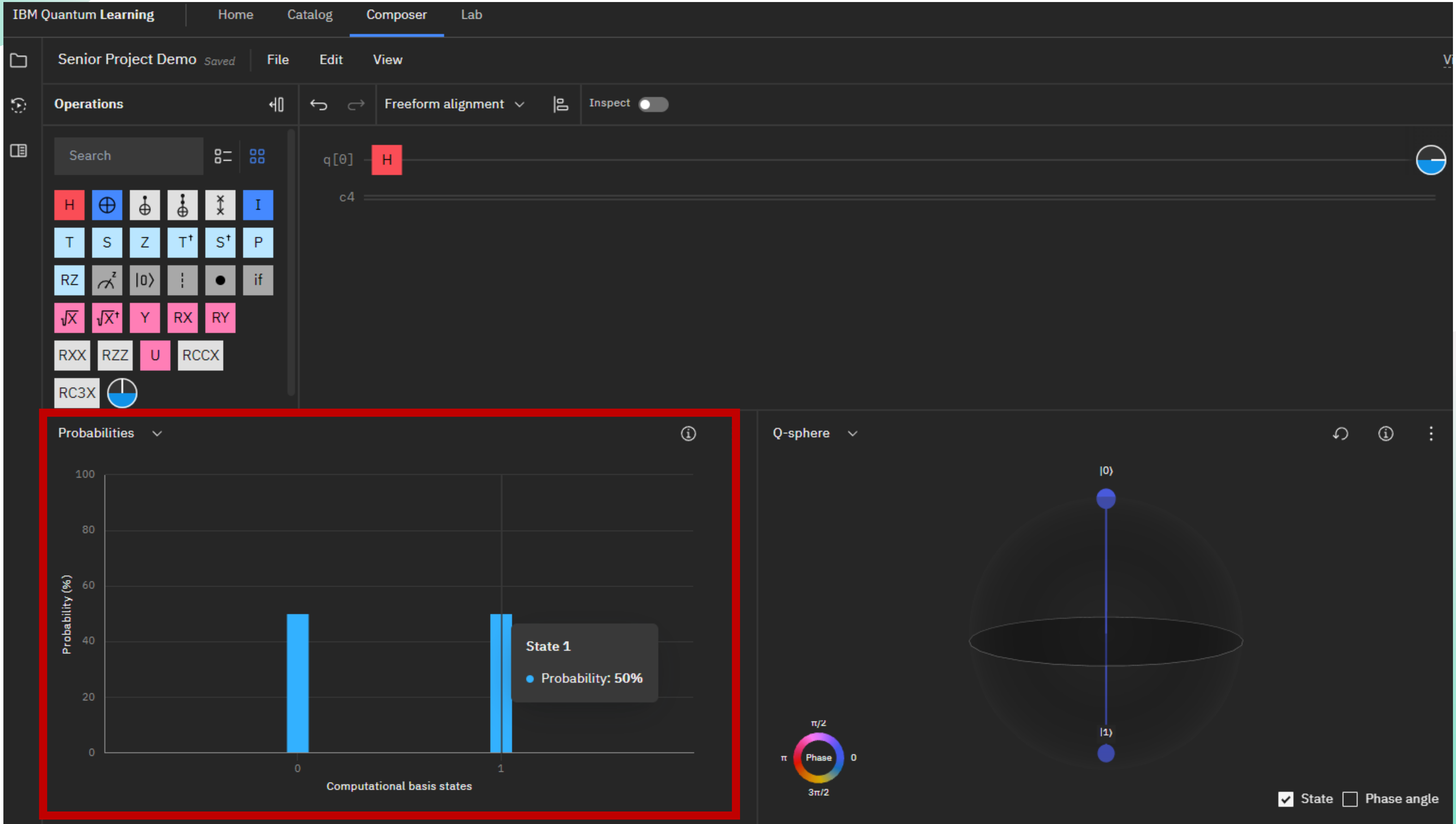
Qubit $|1\rangle$ - IBM Quantum Composer



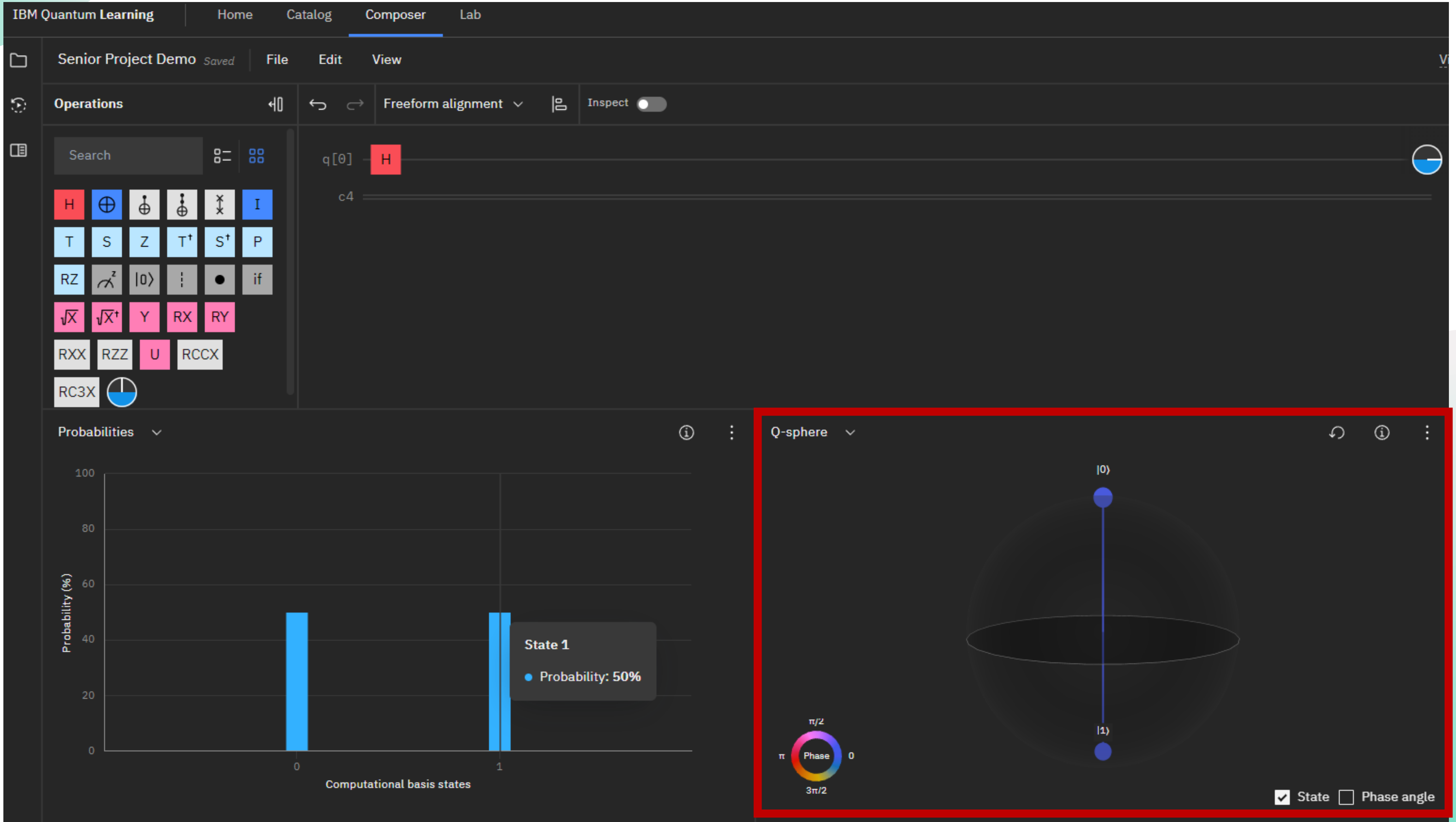
Quantum Bit - Superposition



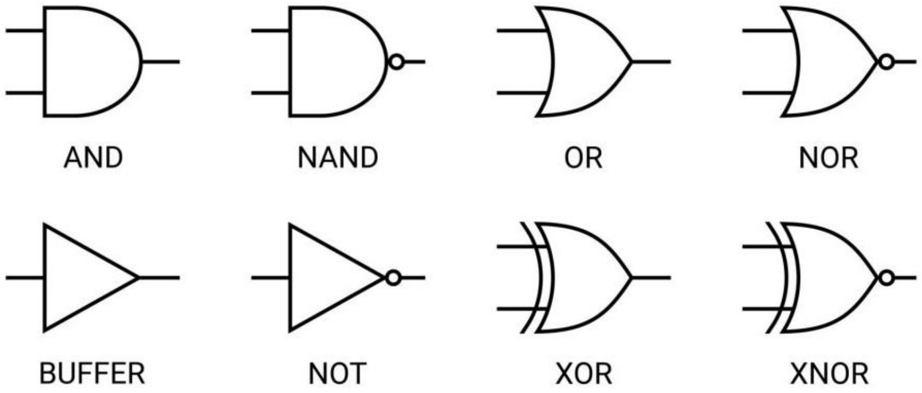
Quantum Bit - Superposition



Quantum Bit - Superposition



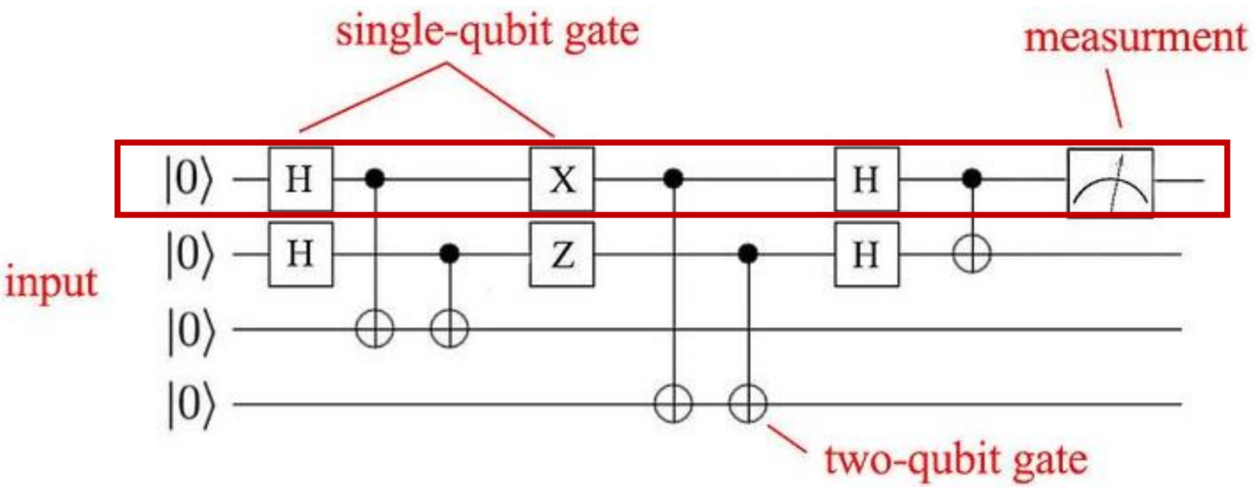
Classical Logic Gates



Quantum Gates

Operator	Gate(s)		Matrix
Pauli-X (X)	$\boxed{X}$	$\oplus$	$\begin{bmatrix}0 & 1\\1 & 0\end{bmatrix}$
Pauli-Y (Y)	$\boxed{Y}$		$\begin{bmatrix}0 & -i\\i & 0\end{bmatrix}$
Pauli-Z (Z)	$\boxed{Z}$		$\begin{bmatrix}1 & 0\\0 & -1\end{bmatrix}$
Hadamard (H)	$\boxed{H}$		$\frac{1}{\sqrt{2}}\begin{bmatrix}1 & 1\\1 & -1\end{bmatrix}$
Phase (S, P)	$\boxed{S}$		$\begin{bmatrix}1 & 0\\0 & i\end{bmatrix}$
$\pi/8$ (T)	$\boxed{T}$		$\begin{bmatrix}1 & 0\\0 & e^{i\pi/4}\end{bmatrix}$
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)	$\boxed{Z}$		$\begin{bmatrix}1&0&0&0\\0&1&0&0\\0&0&1&0\\0&0&0&-1\end{bmatrix}$
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)			$\begin{bmatrix}1&0&0&0&0&0&0&0\\0&1&0&0&0&0&0&0\\0&0&1&0&0&0&0&0\\0&0&0&1&0&0&0&0\\0&0&0&0&1&0&0&0\\0&0&0&0&0&1&0&0\\0&0&0&0&0&0&0&1\\0&0&0&0&0&0&1&0\end{bmatrix}$

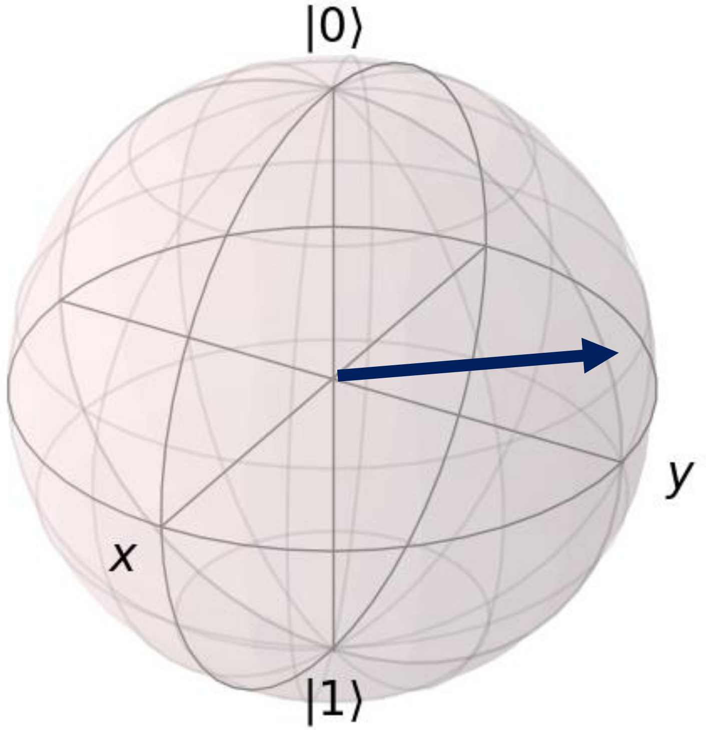
Example of quantum gates



Example of quantum circuit

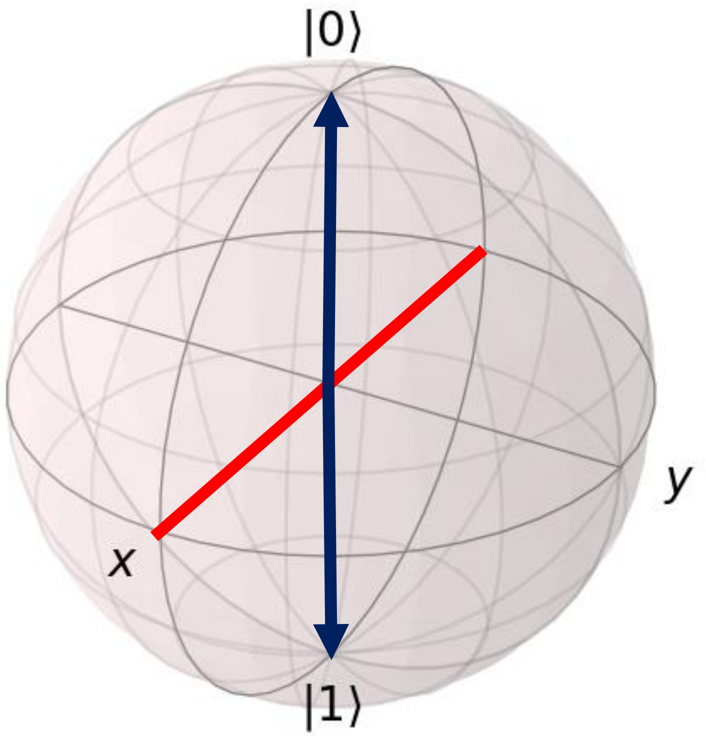
- Qubits don't represent 0 or 1
- Could be both 0 and 1 simultaneously (superposition)
- Think of quantum gates as changing probabilities through circuits

Bloch Sphere

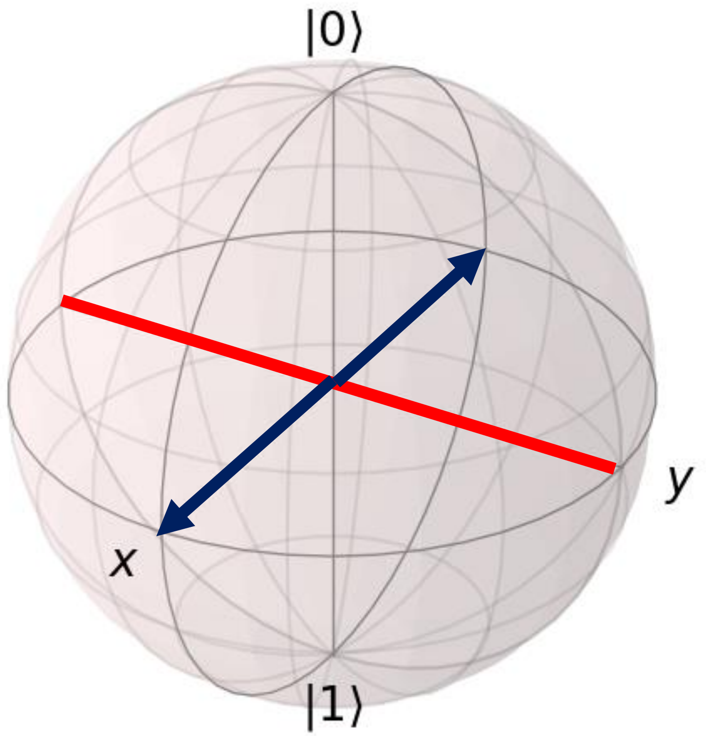


- Classical Logic Gate : Determines the state of 0 or 1 through the circuit
- Quantum Gate: Adjusts the probability of 0 or 1 coming through the circuit

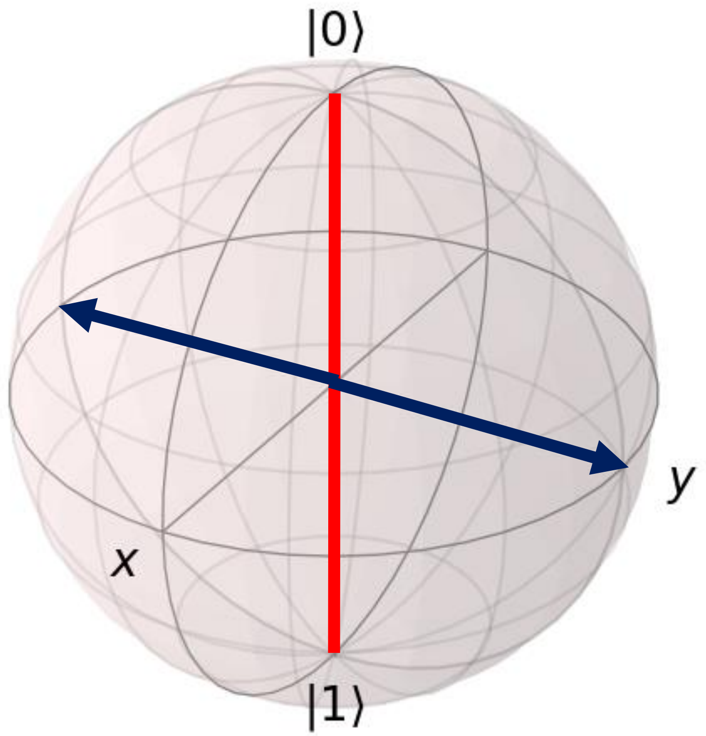
Single-Qubit Gates



Pauli-X Gate

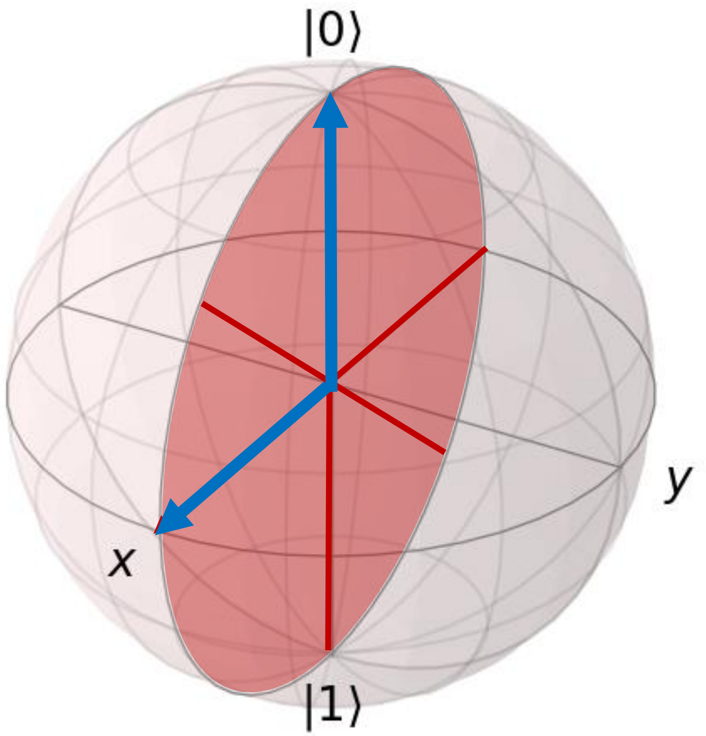


Pauli-Y Gate

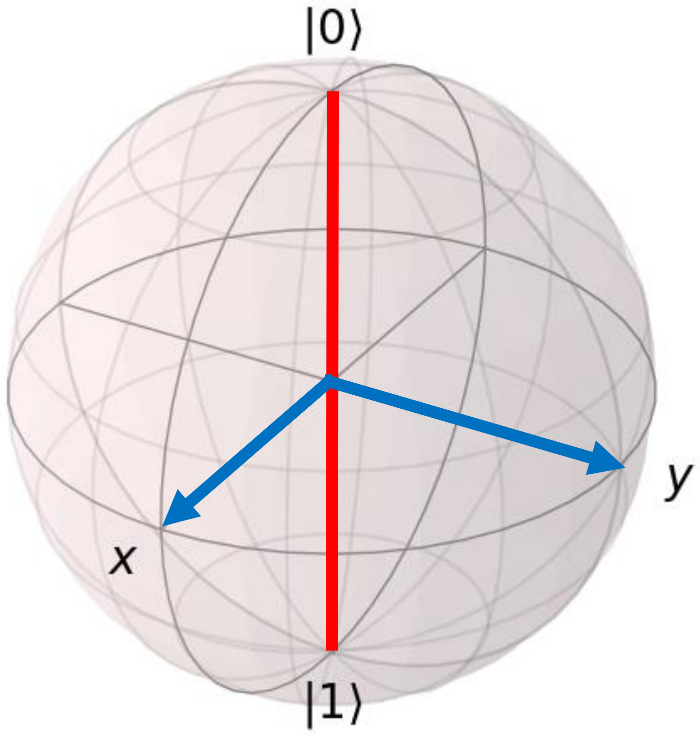


Pauli-Z Gate

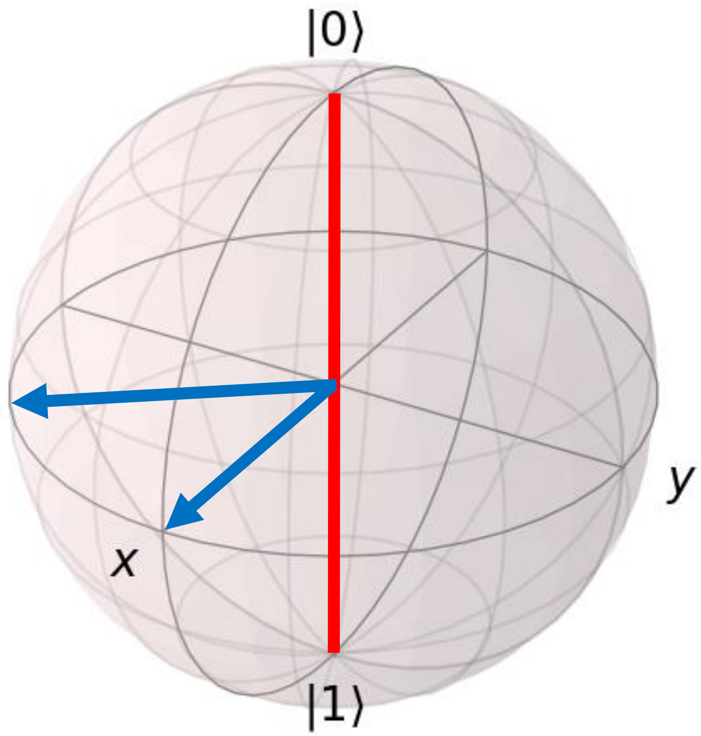
Single-Qubit Gates



Hadamard Gate

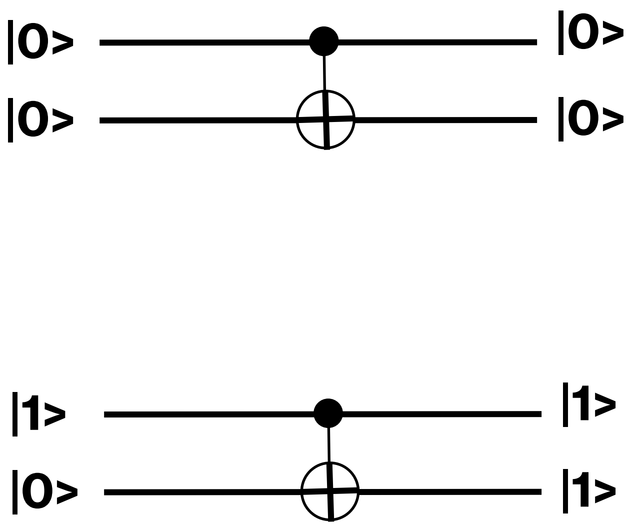


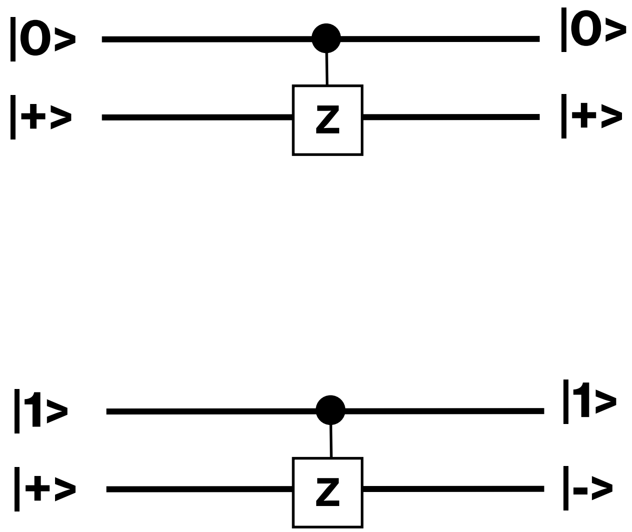
S Gate



T Gate

Multi-Qubit Gates

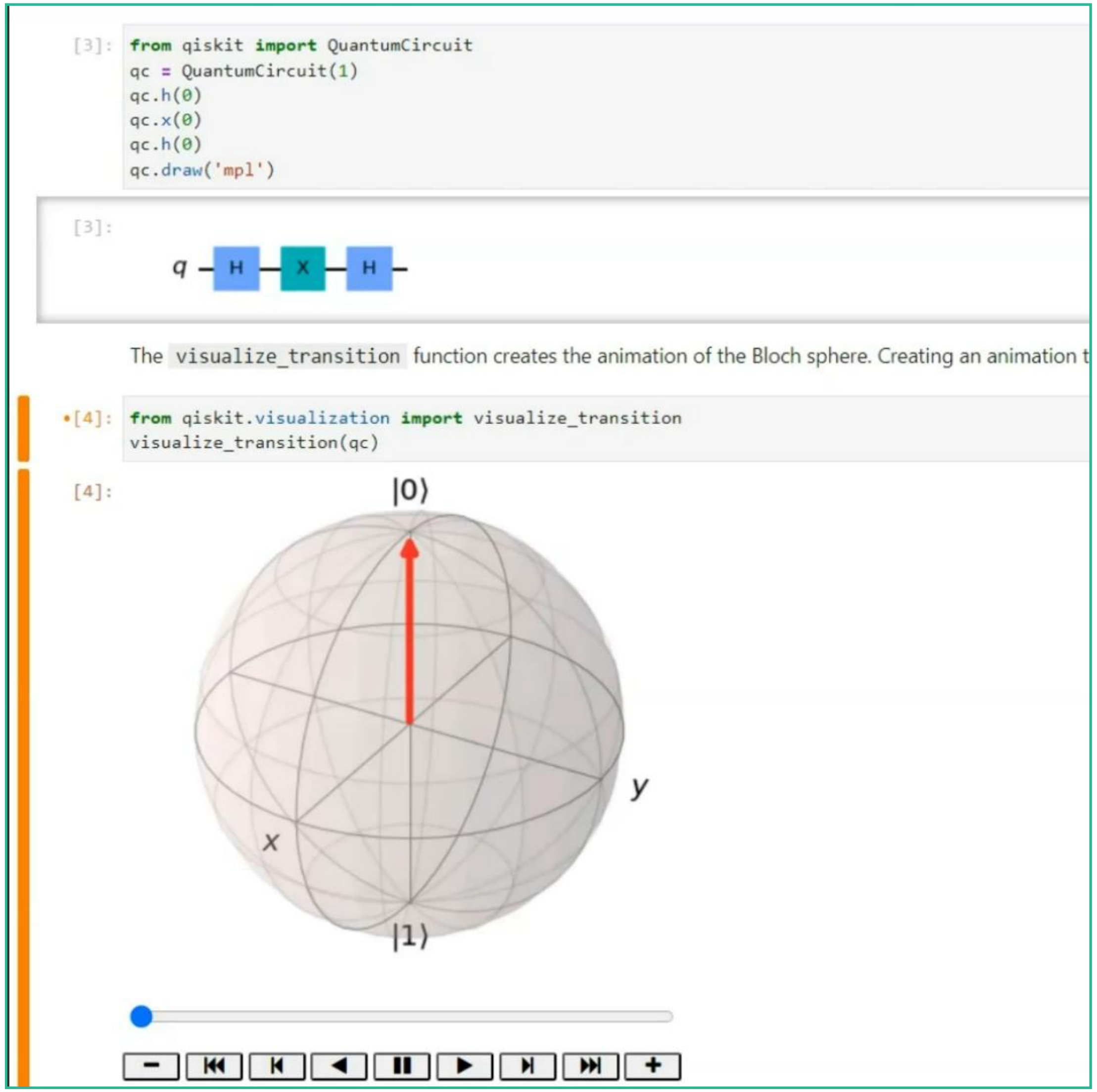


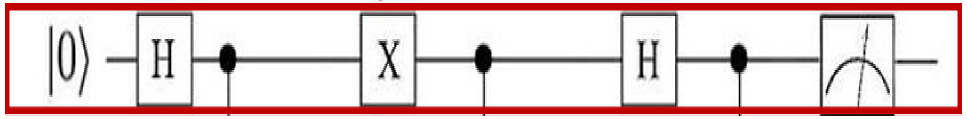


CNOT Gate

CZ Gate

Bloch Sphere





Conclusion

Classical Computing vs Quantum Computing

Quantum Algorithms - Deutsch-Jozsa

Classical Bits vs Quantum Bits

Qubit – Superposition

Classical Gates vs Quantum Gates

Bloch Sphere

Thank you