quantum logic gates

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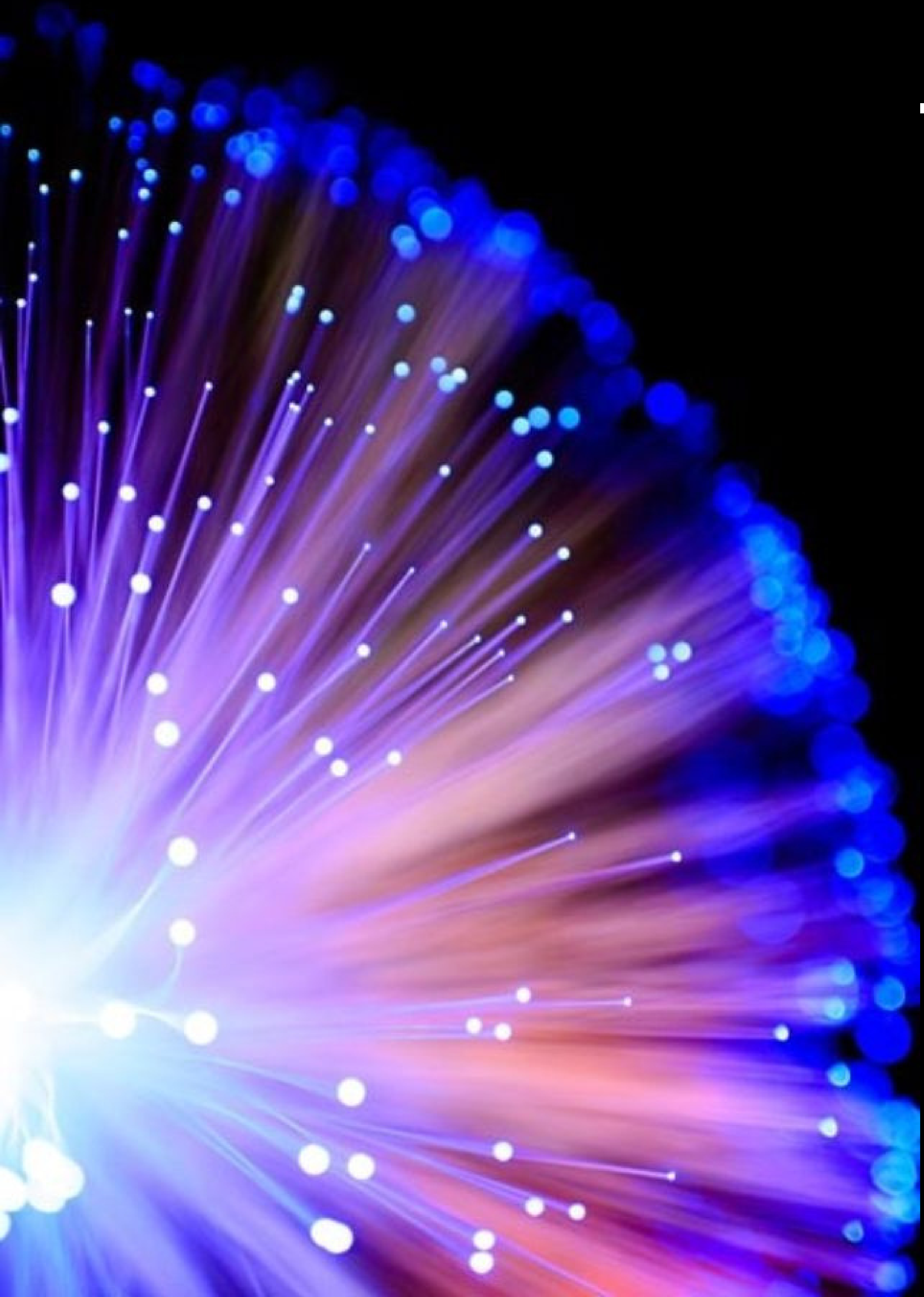


Contents

Introduction

1. Quantum logic gates are the basic building blocks of quantum computing, which is a field that explores the use of quantum-mechanical phenomena to perform computational tasks.
2. The key difference between classical and quantum logic gates is that classical gates operate on bits that have a binary value of either 0 or 1, while quantum gates operate on qubits (which are the fundamental unit of quantum information that can exist in a superposition of both 0 and 1 states.
3. Quantum gates can manipulate and exploit the entanglement of qubits, which is a quantum mechanical phenomenon where the state of one qubit depends on the state of another.

Introduction

4. This property allows quantum gates to perform operations that are not possible with classical gates, leading to computational speedups and novel applications in cryptography, simulation, and optimization.
5. Some of the most commonly used quantum logic gates include single-qubit gates like the Pauli-X gate and the Hadamard gate, and multi-qubit gates like the CNOT gate and the Toffoli gate.
6. Quantum algorithms are constructed by combining various quantum gates to perform specific computational tasks.
7. The development of quantum logic gates and quantum computing has the potential to revolutionize computing and solve problems that are currently intractable for classical computers.

Literature Survey

[1]. In this paper, authers demonstrate the feasibility of constructing universal quantum gates using a scalable semiconductor platform. They show that a combination of single-qubit rotations and two-qubit CNOT gates can be used to implement any quantum circuit, and demonstrate the implementation of a controlled-Z gate. The results demonstrate the potential of silicon-based qubits for the development of large-scale quantum computers.

[2]. This paper reports the successful implementation of a set of scalable quantum logic gates using trapped ions. They demonstrate the realization of single-qubit gates and a two-qubit entangling gate, showing high-fidelity gate operations. The results highlight the potential of trapped ions for the implementation of large-scale quantum computers with high gate fidelities.

Literature Survey

[3]. In this paper, authers present a new method for implementing efficient quantum gates on superconducting qubits. They introduce a gate optimization technique that enables high-fidelity single-qubit and two-qubit gates using only a few pulse parameters, reducing the complexity of the gate operation. The results demonstrate the potential for scalable and efficient quantum computation using superconducting qubits.

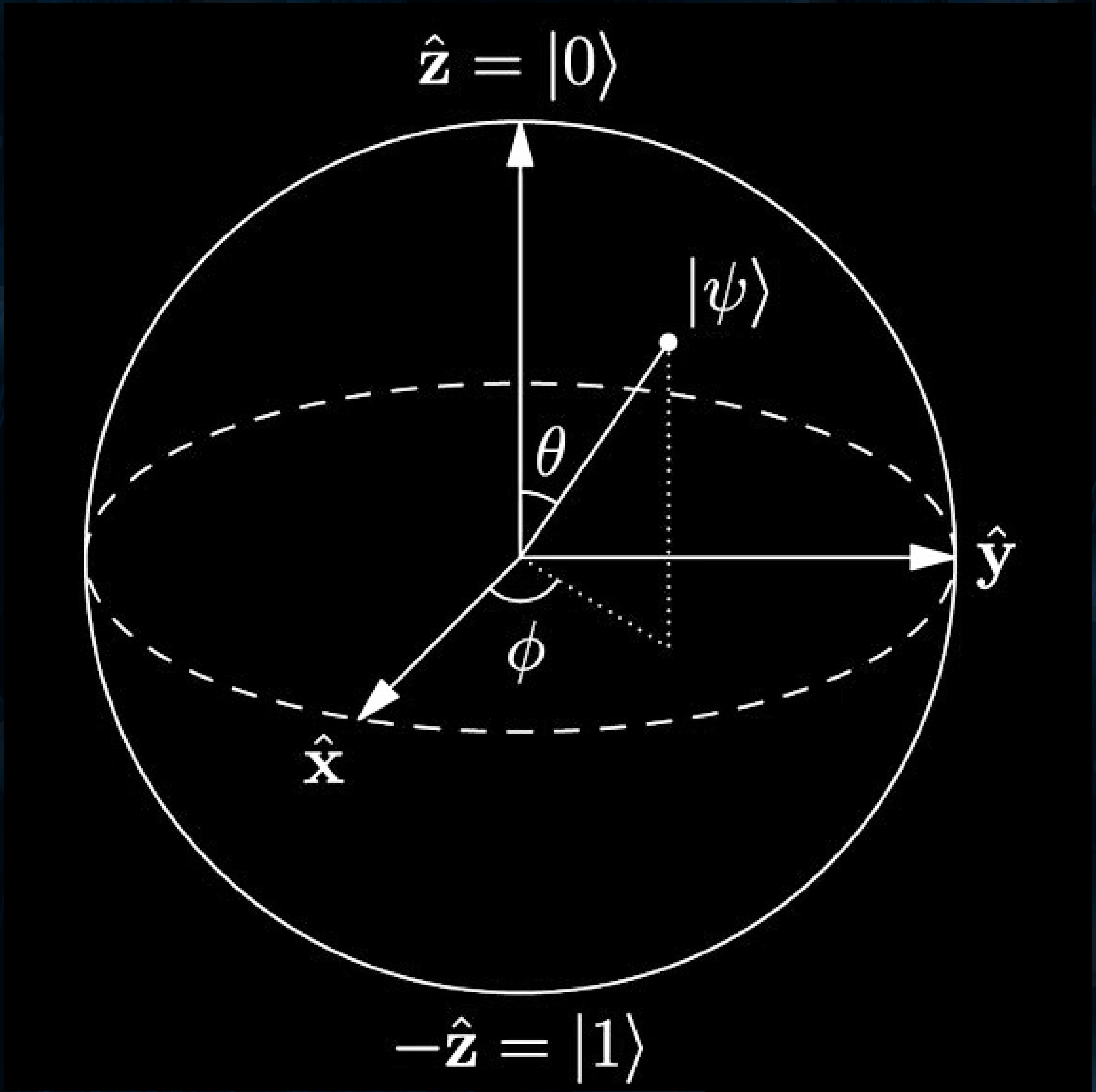
[4]. In this paper The authers introduce a new optimization algorithm that can efficiently search for optimal gate sequences with reduced gate counts, leading to faster gate operations and reduced decoherence. The results demonstrate the effectiveness of this approach for optimizing gates on various quantum hardware platforms. This approach has the potential to facilitate the development of more efficient and scalable quantum circuits.

Quantum Logic Gates

1. Quantum logic gates are the building blocks of quantum computing, just like classical logic gates are the building blocks of classical computing.
2. Quantum logic gates operate on qubits, which are the basic units of quantum information. Unlike classical bits, qubits can exist in a superposition of states, which allows for more powerful computational operations.
3. Quantum logic gates are used to implement quantum algorithms, which can solve certain problems faster than classical algorithms. Examples include Shor's algorithm for factoring large numbers and Grover's algorithm for searching an unsorted database.
4. The development of new quantum logic gates and their optimization is an active area of research in quantum computing.

Bloch Sphere

$$|\mathbf{0}> = \begin{pmatrix} \mathbf{1} \\ \mathbf{0} \end{pmatrix}$$



$$|\mathbf{1}> = \begin{pmatrix} \mathbf{0} \\ \mathbf{1} \end{pmatrix}$$

Bloch sphere showing the computational basis states |0 > and |1 >

Bloch Sphere

In the picture, the North pole corresponds to the pure state |0> and the South pole corresponds to the (orthogonal) pure state |1>. All other points on the surface of the Bloch sphere correspond to the superposition states of the form $|\psi>$ = $\alpha|0>$ + β $|1>$ for all possible values of the complex numbers α *and* β such that

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

An arbitrary point on the surface of the bloch sphere can be represented as:

$$|\Psi> = \mathrm{Cos}\frac{\theta}{2}\,|0> + e^{i\phi}\mathrm{Sin}\frac{\theta}{2}\,|1>$$

Quantum Logic 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)			$\begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \end{bmatrix}$

Single Qubit Gates

There are mainly 6 Single Qubit Gates:

1. **Pauli - X Gate**
2. **Pauli -Y Gate**
3. **Pauli - Z Gate**
4. **Hadamard Gate**
5. **Phase (S) Gate**
6. **T gate**

Single Qubit Gates

Pauli - X Gate:

This gate is synonymous with the classical(reversible) NOT gate.

Matrix representation:

$$X = U_{NOT} = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}$$

Hence,

$$U_{NOT}|0> = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}\begin{pmatrix} 1 \\ 0 \end{pmatrix} = \begin{pmatrix} 0 \\ 1 \end{pmatrix} = |1>$$

$$U_{NOT}|1> = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}\begin{pmatrix} 0 \\ 1 \end{pmatrix} = \begin{pmatrix} 1 \\ 0 \end{pmatrix} = |0>$$

Single Qubit Gates

Pauli - X Gate:

Therefore the truth table can be written as:

Input	Output
$\|0>$	$\|1>$
$\|1>$	$\|0>$
$\alpha\|0> + \beta\|1>$	$\alpha\|1> + \beta\|0>$

Single Qubit Gates

Pauli - Y Gate:

The Pauli Y gate can be considered as a bit and phase flip gate that causes rotation around the y-axis by π radianse.

Matrix representation:

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

Hence,

$$Y\,|0> = \begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix}\begin{pmatrix} 1 \\ 0 \end{pmatrix} = \begin{pmatrix} 0 \\ i \end{pmatrix} = i\begin{pmatrix} 0 \\ 1 \end{pmatrix} = i|1>$$

$$Y\,|1> = \begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix}\begin{pmatrix} 0 \\ 1 \end{pmatrix} = \begin{pmatrix} -i \\ 0 \end{pmatrix} = -i\begin{pmatrix} 1 \\ 0 \end{pmatrix} = -i|0>$$

Single Qubit Gates

Pauli - Y Gate:

Therefore the truth table can be written as:

Input	Output
$\|0>$	$i\|1>$
$\|1>$	$-i\|0>$
$\alpha\|0> + \beta\|1>$	$i\,\alpha\|1> -i\,\beta\|0>$

Single Qubit Gates

Pauli - Z Gate:

The Pauli - Z gate acts as identity on the state and multiplies the sign of the state by -1. It therefore flips the and states.

Matrix representation:

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

Hence,

$$Z\,|0> = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}\begin{pmatrix} 1 \\ 0 \end{pmatrix} = \begin{pmatrix} 1 \\ 0 \end{pmatrix} = |0>$$

$$Z\,|1> = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}\begin{pmatrix} 0 \\ 1 \end{pmatrix} = \begin{pmatrix} 0 \\ -1 \end{pmatrix} = -1\begin{pmatrix} 0 \\ 1 \end{pmatrix} = -|1>$$

Single Qubit Gates

Pauli - Z Gate:

Therefore the truth table can be written as:

Input	Output
$\|0>$	$\|0 >$
$\|1>$	$-\|1 >$
$\alpha\|0> + \beta\|1>$	$\alpha\|0> - \beta\|1>$

Single Qubit Gates

Hadamard Gate:

The Hadamard gate will give the superposition of two state vectors.

Matrix representation:

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

Hence,

$$H\,|0\rangle = \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix}\begin{pmatrix} 1 \\ 0 \end{pmatrix} = \frac{1}{\sqrt{2}}\begin{pmatrix} 1 \\ 1 \end{pmatrix} = \frac{1}{\sqrt{2}}\left[\begin{pmatrix} 1 \\ 0 \end{pmatrix} + \begin{pmatrix} 0 \\ 1 \end{pmatrix}\right] = \frac{1}{\sqrt{2}}(|0\rangle + |1\rangle) = |+\rangle$$

$$H\,|1\rangle = \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix}\begin{pmatrix} 0 \\ 1 \end{pmatrix} = \frac{1}{\sqrt{2}}\begin{pmatrix} 1 \\ -1 \end{pmatrix} = \frac{1}{\sqrt{2}}\left[\begin{pmatrix} 1 \\ 0 \end{pmatrix} - \begin{pmatrix} 0 \\ 1 \end{pmatrix}\right] = \frac{1}{\sqrt{2}}(|0\rangle - |1\rangle) = |-\rangle$$

Single Qubit Gates

Hadamard Gate:

Therefore the truth table can be written as:

Input	Output
$\|0>$	$\frac{1}{\sqrt{2}}(\|0> + \|1>) = \|+>$
$\|1>$	$\frac{1}{\sqrt{2}}(\|0> - \|1>) = \|->$
$\alpha\|0> + \beta\|1>$	$\frac{(\alpha+\beta)\|0>}{\sqrt{2}} + \frac{(\alpha-\beta)\|1>}{\sqrt{2}} = \alpha\|+> + \beta\|->$

Single Qubit Gates

Phase (S) Gate:

The Phase gate changes the phase of the high state qubit. Means that, it won't act with |0>

Matrix representation:

$$S = \begin{pmatrix} 1 & 0 \\ 0 & i \end{pmatrix}$$

Hence,

$$S\,|0\rangle = \begin{pmatrix} 1 & 0 \\ 0 & i \end{pmatrix}\begin{pmatrix} 1 \\ 0 \end{pmatrix} = \begin{pmatrix} 1 \\ 0 \end{pmatrix} = |0\rangle$$

$$S\,|1\rangle = \begin{pmatrix} 1 & 0 \\ 0 & i \end{pmatrix}\begin{pmatrix} 0 \\ 1 \end{pmatrix} = \begin{pmatrix} 0 \\ i \end{pmatrix} = i|1\rangle$$

Single Qubit Gates

Phase Gate:

Therefore the truth table can be written as:

Input	Output
$\|0>$	$\|0>$
$\|1>$	$i\|1>$
$\alpha\|0> + \beta\|1>$	$\alpha\|0> + i\beta\|1>$

Single Qubit Gates

T - Gate:

The T - gate is a rotation of π/4 around the Z-axis of the Bloch sphere.

Matrix representation:

$$T = \begin{pmatrix} 1 & 0 \\ 0 & e^{\frac{i\pi}{4}} \end{pmatrix}$$

Hence,

$$T|0> = \begin{pmatrix} 1 & 0 \\ 0 & e^{\frac{i\pi}{4}} \end{pmatrix} \begin{pmatrix} 1 \\ 0 \end{pmatrix} = \begin{pmatrix} 1 \\ 0 \end{pmatrix} = |0>$$

$$T|1> = \begin{pmatrix} 1 & 0 \\ 0 & e^{\frac{i\pi}{4}} \end{pmatrix} \begin{pmatrix} 0 \\ 1 \end{pmatrix} = \begin{pmatrix} 0 \\ e^{\frac{i\pi}{4}} \end{pmatrix} = e^{\frac{i\pi}{4}}|1>$$

Single Qubit Gates

T - Gate:

Therefore the truth table can be written as:

Input	Output
$\|0>$	$\|0 >$
$\|1>$	$e^{\frac{i\pi}{4}}\|1 >$
$\alpha\|0> + \beta\|1>$	$\alpha\|0 > + e^{\frac{i\pi}{4}}\beta\|1 >$

These are few of the most important Single Quibit Gates.

To get much more computational advantage we go for Multi Qubit Gates

Multi Qubit Gates

There are mainly 4 Multi Qubit Gates:

1. CNOT Gate
2. SWAP Gate
3. CZ Gate
4. Toffoli Gate

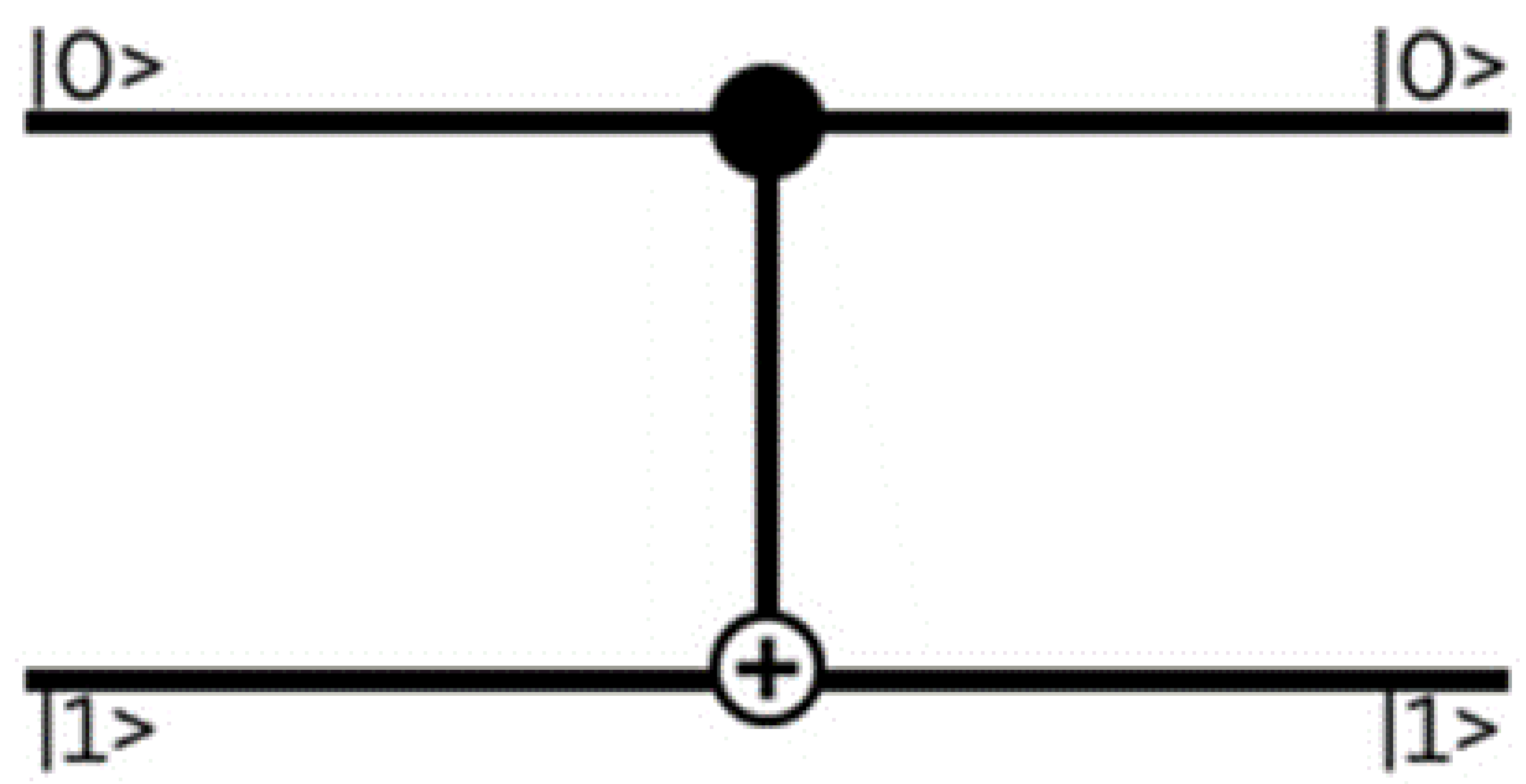
Unlike the Single Qubit Gates, The Multi Qubit Gates take combination of qubits obtained by the tensor product of two column vecors as input.

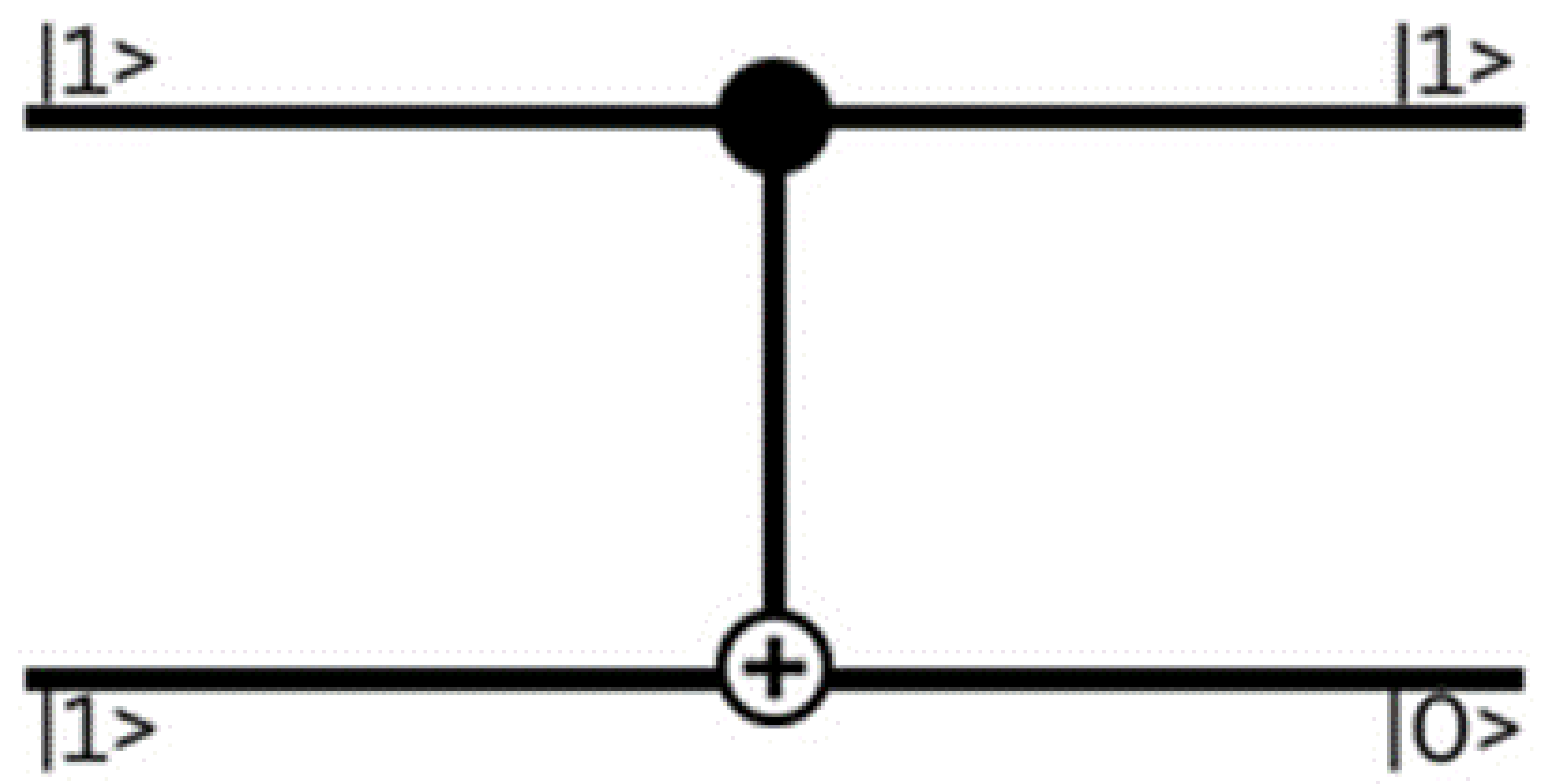
Multi Qubit Gates

CNOT (CX) Gate:

The CNOT gate is controlled NOT gate, which allows NOT gate to affect the target only when the control is in |1> state.

Circuit Diagram:





Multi Qubit Gates

CNOT Gate:

Therefore the truth table can be written as:

Input	Output
|00>	|00>
|01>	|01>
|10>	|11>
|11>	|10>
|AB>	B⊕A

Matrix Representation

$$CX = CNOT = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{pmatrix}$$

Multi Qubit Gates

CNOT Gate:

Examples for Proof:

$$CNOT\,|01> = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{pmatrix} \begin{pmatrix} 0 \\ 1 \\ 0 \\ 0 \end{pmatrix} = \begin{pmatrix} 0 \\ 1 \\ 0 \\ 0 \end{pmatrix} = |01>$$

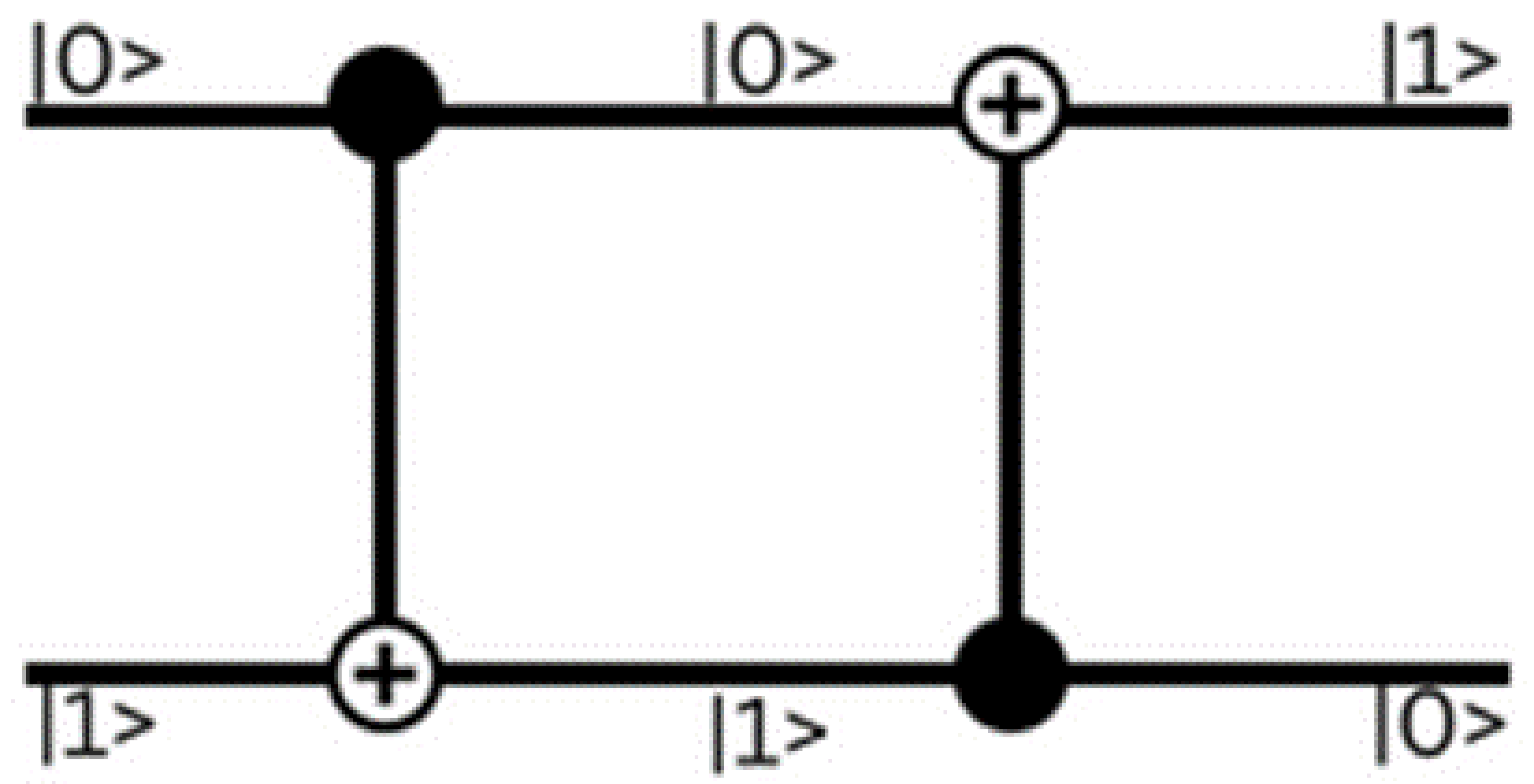
$$CNOT\,|01> = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{pmatrix} \begin{pmatrix} 0 \\ 1 \\ 0 \\ 0 \end{pmatrix} = \begin{pmatrix} 0 \\ 1 \\ 0 \\ 0 \end{pmatrix} = |01>$$

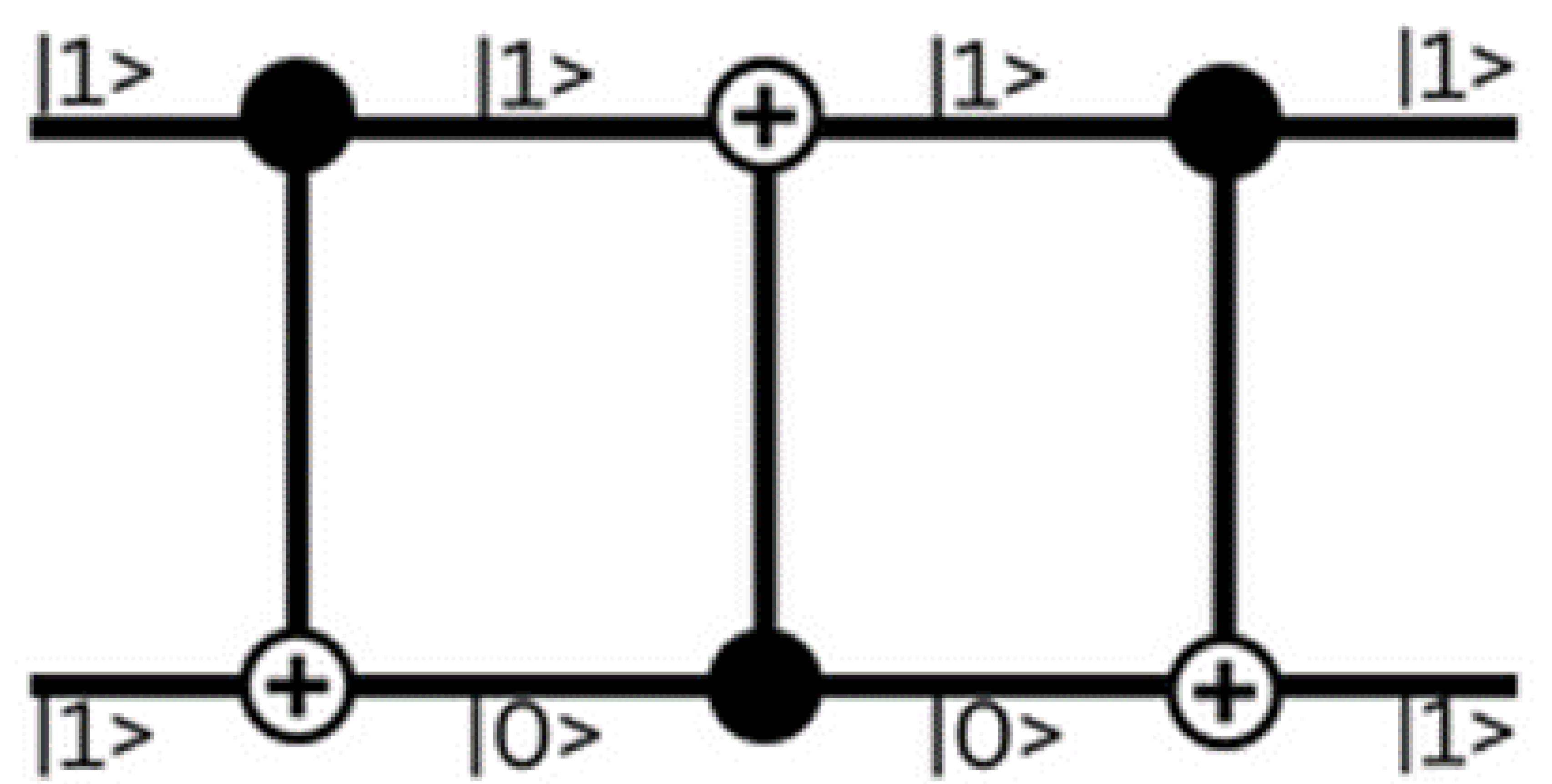
Multi Qubit Gates

SWAP Gate:

The SWAP gate is made up of many CNOT gates, which helps to interchange the input qubits.

Circuit Diagram:





Multi Qubit Gates

SWAP Gate:

Therefore the truth table can be written as:

Input	Output
|00>	|00>
|01>	|10>
|10>	|01>
|11>	|11>

Matrix Representation

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

Multi Qubit Gates

SWAP Gate:

Examples for Proof:

$$SWAP\,|01> = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} 0 \\ 1 \\ 0 \\ 0 \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \\ 1 \\ 0 \end{pmatrix} = |10>$$

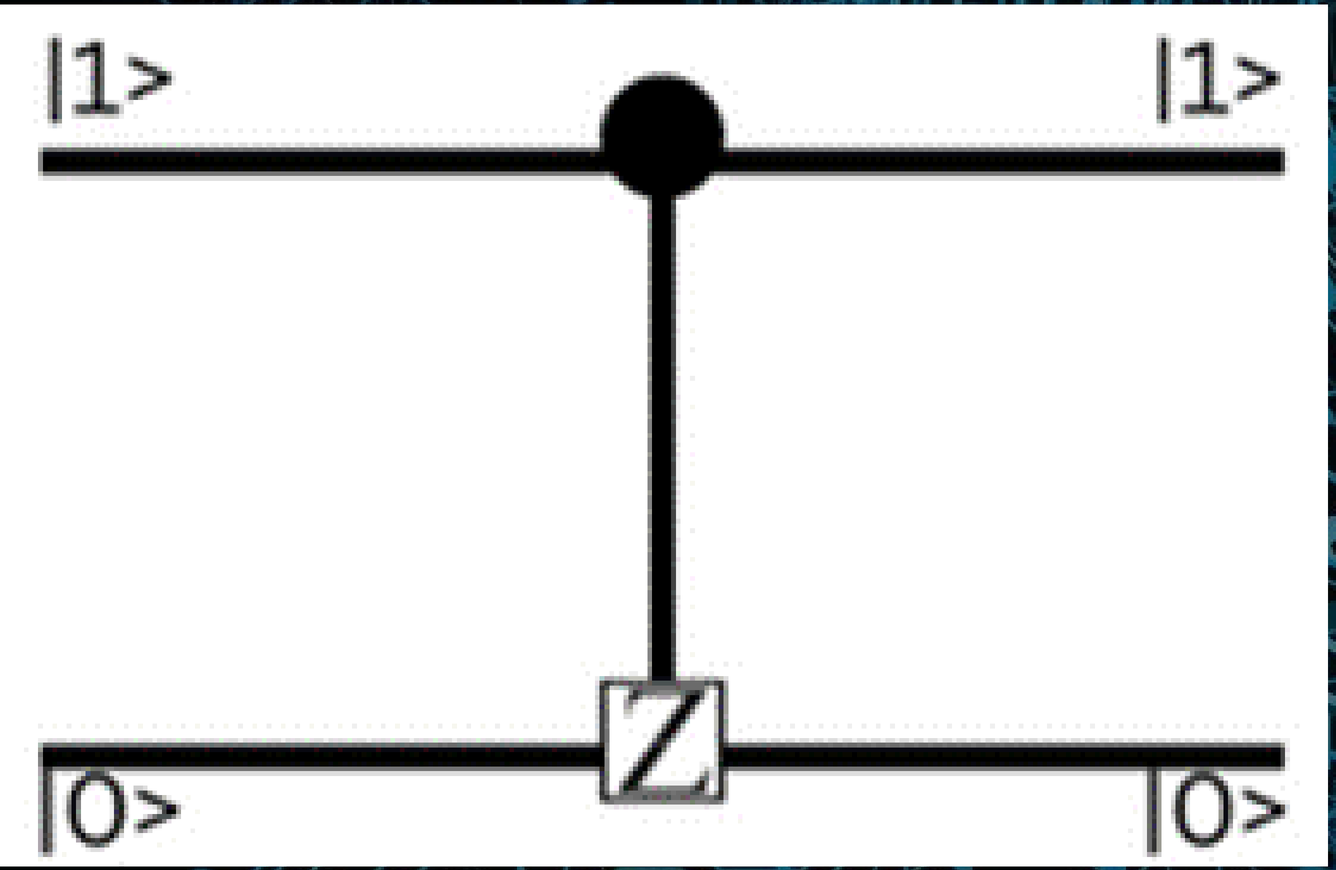
$$SWAP\,|10> = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} 0 \\ 0 \\ 1 \\ 0 \end{pmatrix} = \begin{pmatrix} 0 \\ 1 \\ 0 \\ 0 \end{pmatrix} = |01>$$

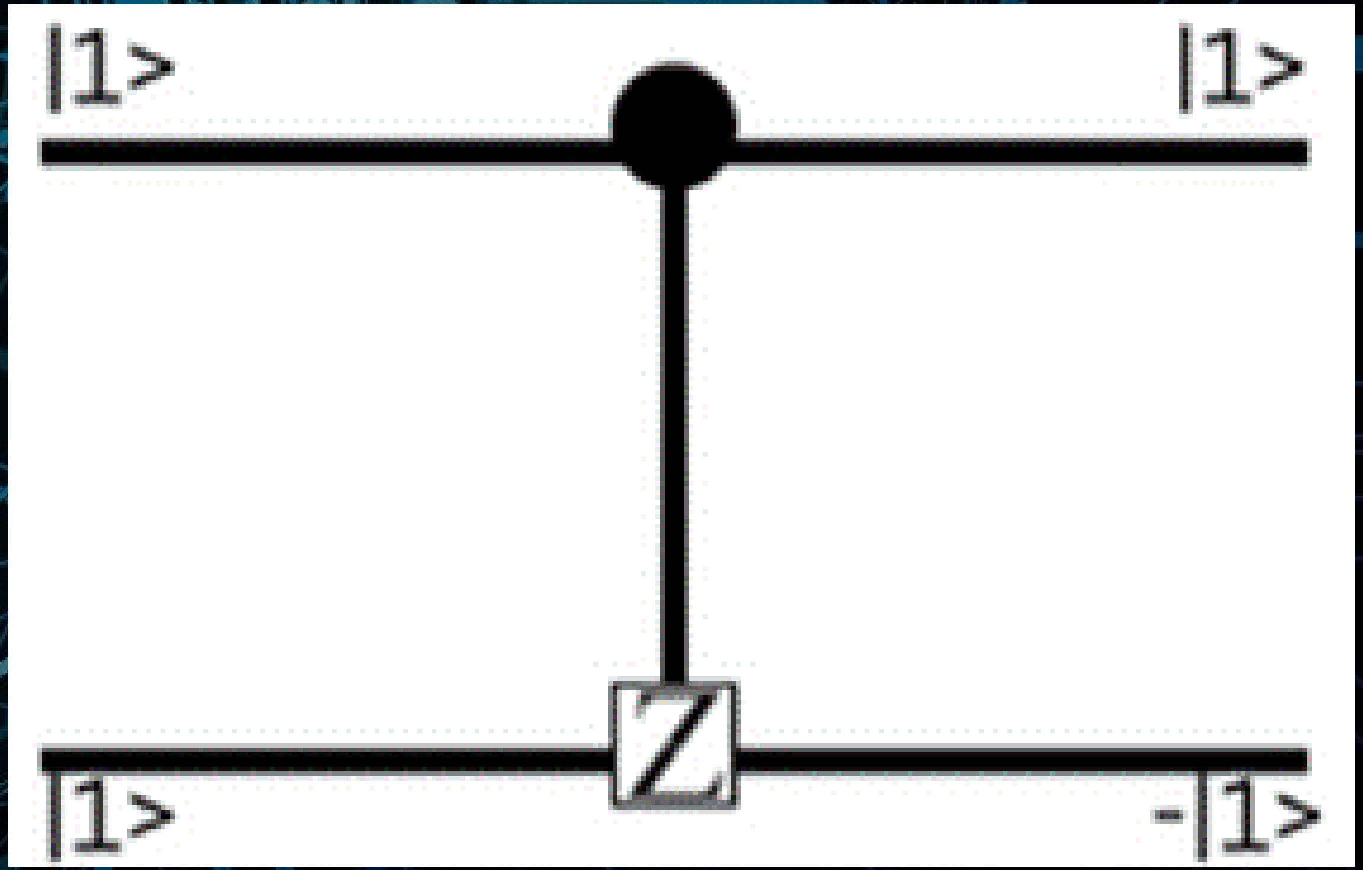
Multi Qubit Gates

CZ Gate:

The CZ gate is controlled Z gate, which allows Z gate to affect the target only when the control is in |11> state.

Circuit Diagram:





Multi Qubit Gates

CZ Gate:

Therefore the truth table can be written as:

Input	Output
|00>	|00>
|01>	|01>
|10>	|10>
|11>	−|11>

Matrix Representation

$$U_Z = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & -1 \end{pmatrix}$$

Multi Qubit Gates

CZ Gate:

Examples for Proof:

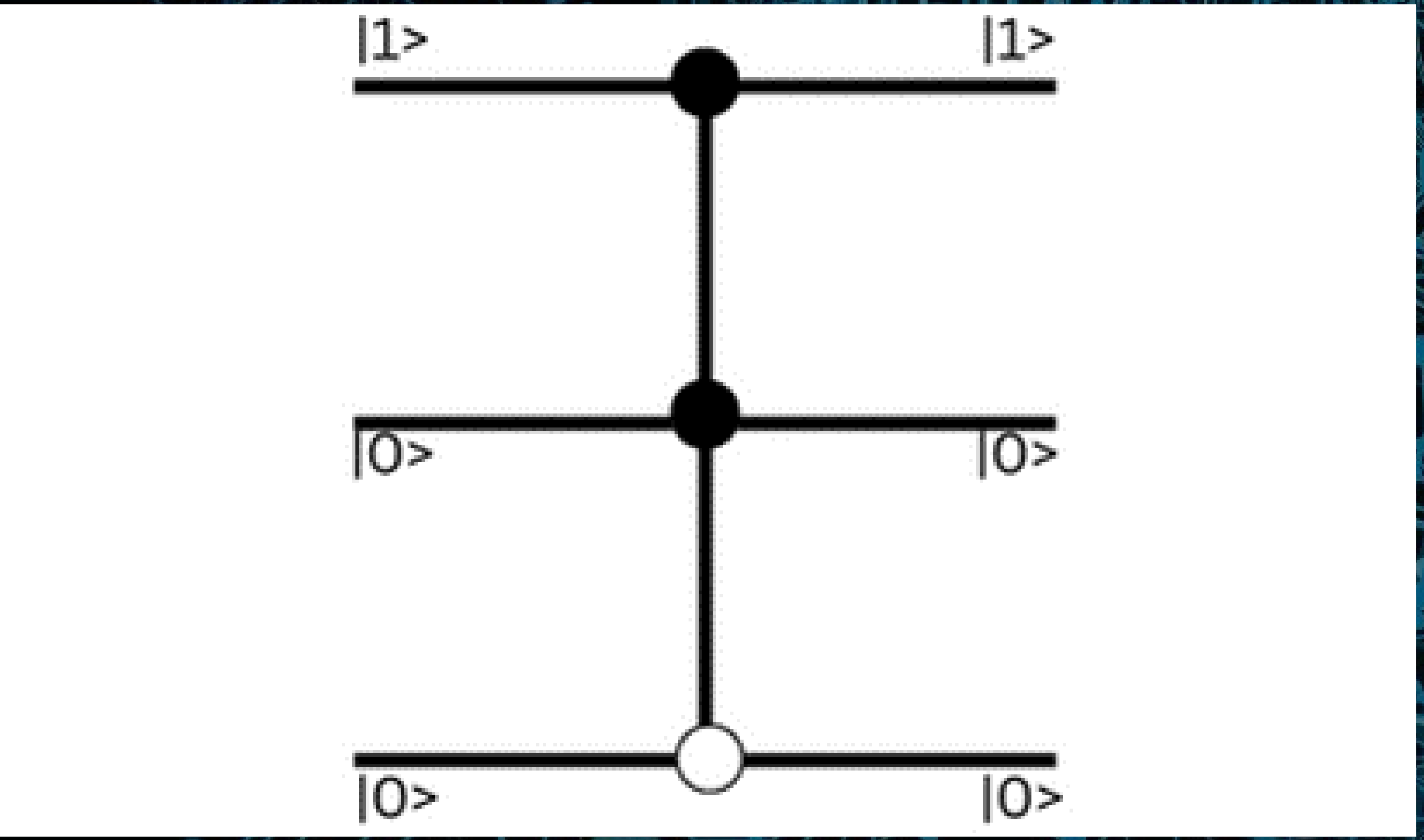
$$U_Z|01> = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & -1 \end{pmatrix} \begin{pmatrix} 0 \\ 1 \\ 0 \\ 0 \end{pmatrix} = \begin{pmatrix} 0 \\ 1 \\ 0 \\ 0 \end{pmatrix} = |01>$$

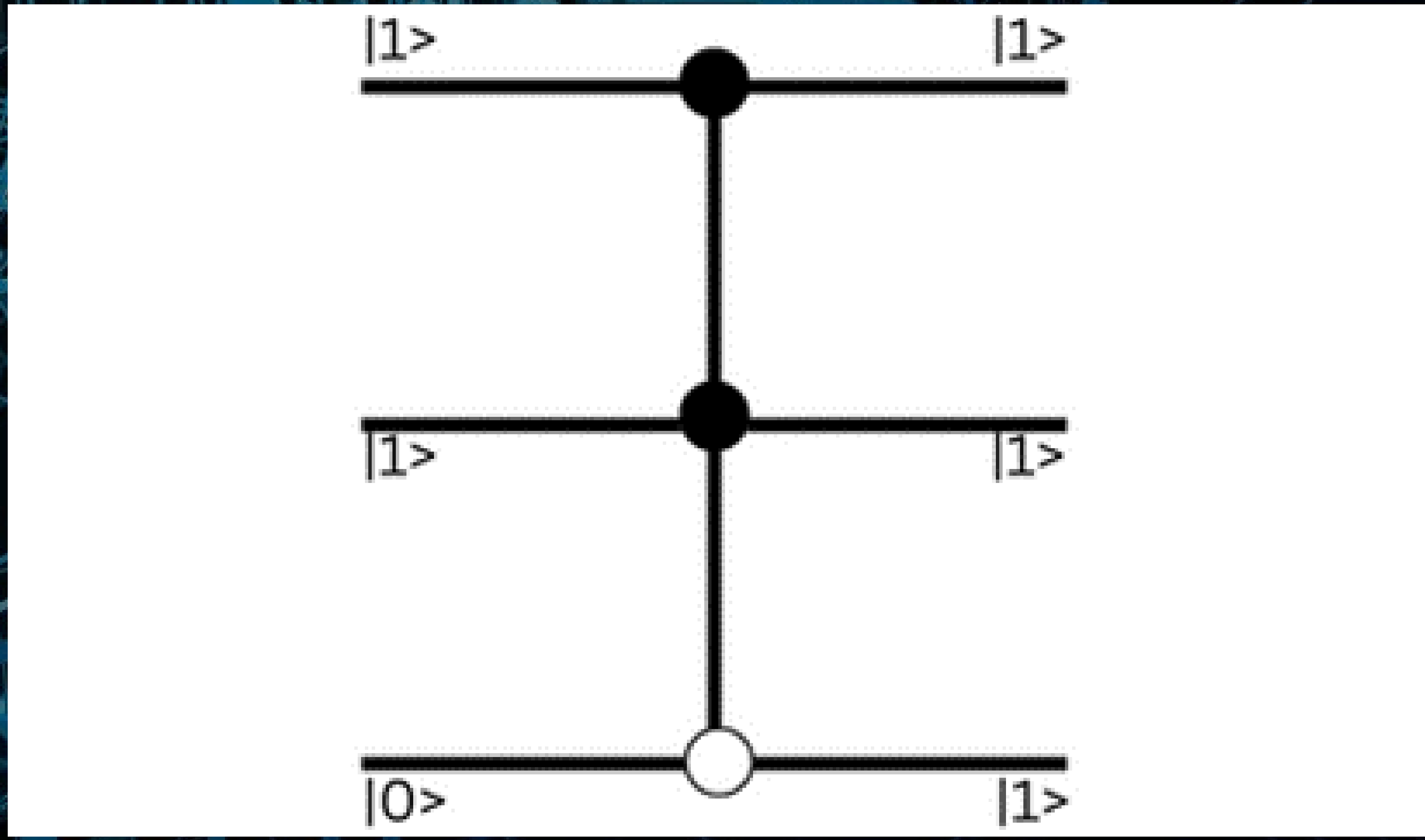
$$U_Z|11> = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & -1 \end{pmatrix} \begin{pmatrix} 0 \\ 0 \\ 0 \\ 1 \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ -1 \end{pmatrix} = -|11>$$

Multi Qubit Gates

Toffoli Gate:

The Toffoli gate is also called double controlled NOT gate, which takes 3 qubits combination as input. It allows NOT gate to affect the target only when both the controls are in |1> state.





Multi Qubit Gates

Toffoli Gate:

Therefore the truth table can be written as:

Input	Output
|000>	|000>
|001>	|010>
|010>	|001>
|011>	|011>
|100>	|100>
|101>	|101>
|110>	|111>
|111>	|110>

Matrix Representation

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

Multi Qubit Gates

Toffoli Gate:

Examples for Proof:

$$Toffoli\,|010> = \begin{pmatrix} 1&0&0&0&0&0&0&0\\ 0&1&0&0&0&0&0&0\\ 0&0&1&0&0&0&0&0\\ 0&0&0&1&0&0&0&0\\ 0&0&0&0&1&0&0&0\\ 0&0&0&0&0&1&0&0\\ 0&0&0&0&0&0&0&1\\ 0&0&0&0&0&0&1&0 \end{pmatrix} \begin{pmatrix} 0\\0\\1\\0\\0\\0\\0\\0 \end{pmatrix} = \begin{pmatrix} 0\\0\\1\\0\\0\\0\\0\\0 \end{pmatrix} = |010>$$

$$Toffoli\,|110> = \begin{pmatrix} 1&0&0&0&0&0&0&0\\ 0&1&0&0&0&0&0&0\\ 0&0&1&0&0&0&0&0\\ 0&0&0&1&0&0&0&0\\ 0&0&0&0&1&0&0&0\\ 0&0&0&0&0&1&0&0\\ 0&0&0&0&0&0&0&1\\ 0&0&0&0&0&0&1&0 \end{pmatrix} \begin{pmatrix} 0\\0\\0\\0\\0\\0\\1\\0 \end{pmatrix} = \begin{pmatrix} 0\\0\\0\\0\\0\\0\\0\\1 \end{pmatrix} = |111>$$

Applications and Results

1. Cryptography: Shor's algorithm, which is based on quantum logic gates, can be used to factor large numbers, which is the basis of many cryptographic protocols. This has significant implications for the security of modern communication systems.
2. Simulation: Quantum logic gates can be used to simulate complex quantum systems, such as molecules and materials, which is important for applications in drug discovery, materials science, and other fields.
3. Optimization: Quantum logic gates can be used to solve optimization problems, which are important in many areas, such as logistics, finance, and machine learning.
4. Machine Learning: Quantum logic gates can be used to implement quantum machine learning algorithms, which have the potential to provide exponential speedups over classical algorithms for certain problems.

Applications and Results

5.Quantum Communication: Quantum logic gates can be used to implement quantum key distribution protocols, which allow for secure communication between parties.

In terms of results, researchers have demonstrated the successful implementation of various quantum logic gates using physical systems such as superconducting qubits and trapped ions. These gates have been used to implement small-scale quantum algorithms and demonstrate proof-of-concept for quantum computing. Additionally, researchers are continually developing new quantum logic gates and improving their performance, which is crucial for building larger and more powerful quantum computers.

Drawbacks

- Very difficult to monitor their interactions.

- The quantum information will spread outside the quantum computer and be lost into the environment, thus spoiling the computation. This process is called de-coherence.

- The number of operations that can be performed before the information is lost due to de-coherency is therefore limited.

- Quantum chips must be kept at very low temperature to create super positions and entanglement of qubits

- The final output of the quantum computers is in the form of a probability. Hence repeated operations are required to get correct answer.

Conclusions

- Quantum logic gates are essential building blocks for quantum computing and enable the manipulation of quantum states, allowing for the implementation of quantum algorithms.
- The development of efficient and scalable quantum logic gates is crucial for the realization of fault-tolerant quantum computing systems that can perform complex calculations and solve problems beyond the capability of classical computers.
- Researchers are exploring new types of quantum logic gates and algorithms that can take advantage of the unique properties of quantum computing, such as entanglement and superposition, to solve problems in various fields, including cryptography, machine learning, and drug discovery.
- The continued progress in the development of quantum logic gates and related technologies has the potential to revolutionize various industries and scientific fields.

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Thank You