An Introduction to Quantum Natural Language Processing (QNLP)

Part 1 :

Brief Introduction to Quantum Computing

Outline of the lecture

Outline of the lecture

- Introduction to Quantum Computing

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- Introduction to Quantum Computing
- Properties of Quantum Computing

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- Properties of Quantum Computing
- Single Qubit Quantum Gates – X, Y, Z, H, Rz, Rx

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- Multi Qubit Quantum Gates – CX, CRz, CRx

Outline of the lecture

- Introduction to Quantum Computing
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- Single Qubit Quantum Gates – X, Y, Z, H, Rz, Rx
- Multi Qubit Quantum Gates – CX, CRz, CRx
- ZX Calculus Representation of Quantum Gates

Introduction to Quantum Computing

Classical vs Quantum

Introduction to Quantum Computing

Classical vs Quantum

Classical Computing	Quantum Computing
Based on the principles of classical mechanics	Based on the principles of quantum mechanics
Uses classical bits 0 & 1	Uses Quantum Bits called Qubits, where bits can be in superposition. Represented as |0> & |1> (Ket 0 & Ket 1) or <0| & <1| (Bra 0 & Bra 1)
Hardware is composed of CMOS circuits	Hardware varies such as superconducting qubits, ion traps, optical photons.
Consists of Central Processing Units, processing in sequential manner	Consists of Quantum Processing Units, processing in parallel

Introduction to Quantum Computing

Introduction to Quantum Computing Concludes

Properties of Quantum Computing

Properties of Quantum Computing

- Superposition

Properties of Quantum Computing

- Superposition
- Interference

Properties of Quantum Computing

- Superposition
- Interference
- Entanglement

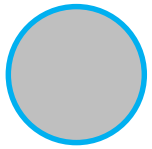
Properties of Quantum Computing

Superposition

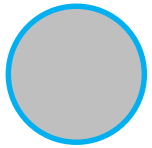
Properties of Quantum Computing

Superposition

Classical
Bit 1



Classical
Bit 0

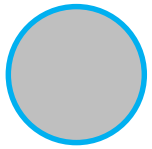


Properties of Quantum Computing

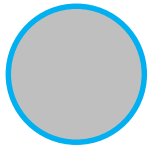
Superposition

Linear combination of quantum states or simultaneous occurrence of multiple quantum states! There can be 2^N states, where N is the number of qubits.

Classical
Bit 1



Classical
Bit 0



Properties of Quantum Computing

Superposition

Linear combination of quantum states or simultaneous occurrence of multiple quantum states! There can be 2^N states, where N is the number of qubits.

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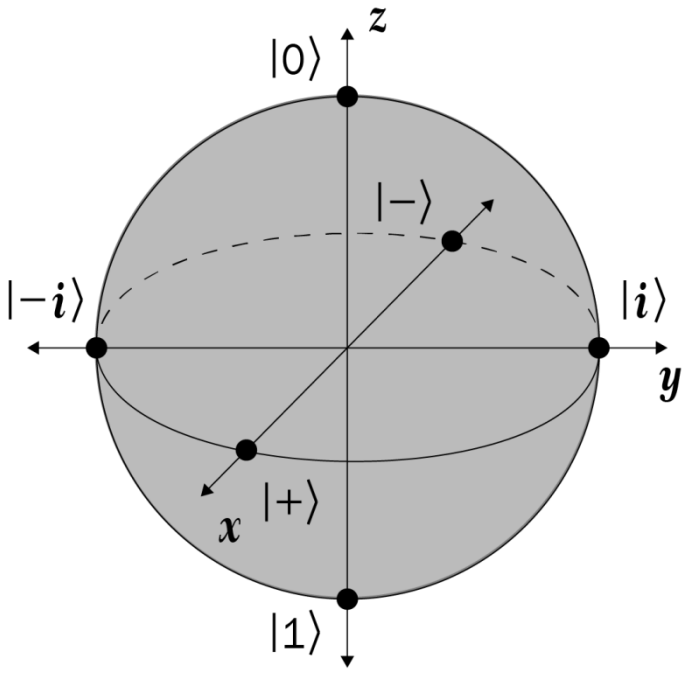

Classical
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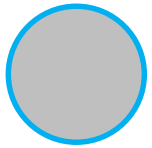


Properties of Quantum Computing

Interference

Properties of Quantum Computing

Interference

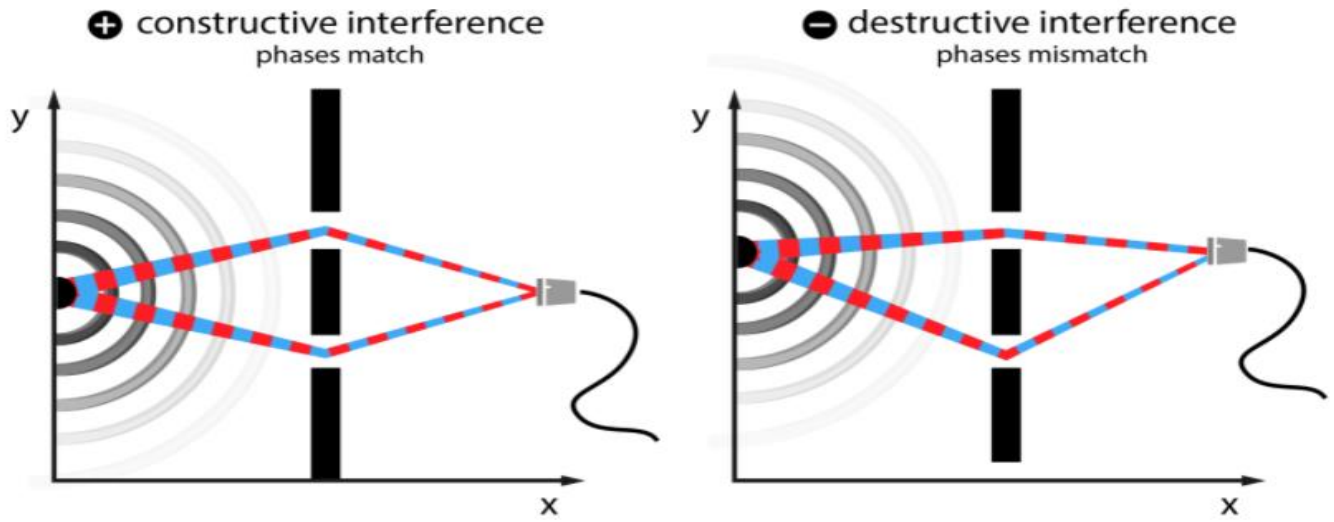
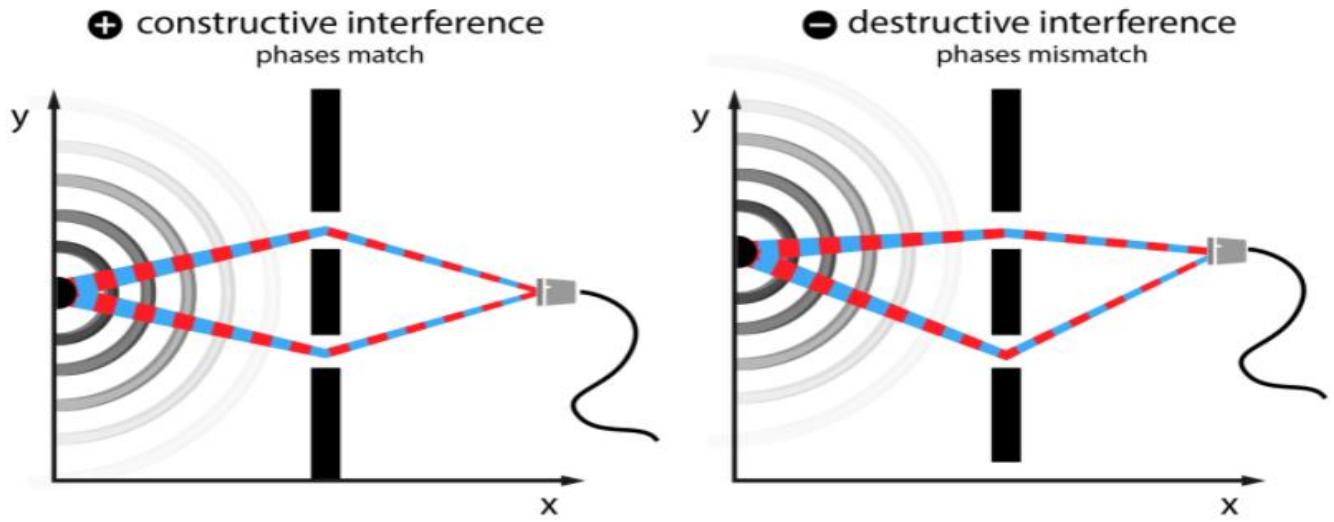


Image Source - https://physics.stackexchange.com/questions/170877/classical-and-semi-classical-vs-quantum-interferometry

Properties of Quantum Computing

Interference



Constructive or Destructive Interference leads to some quantum states having high probability of measurement

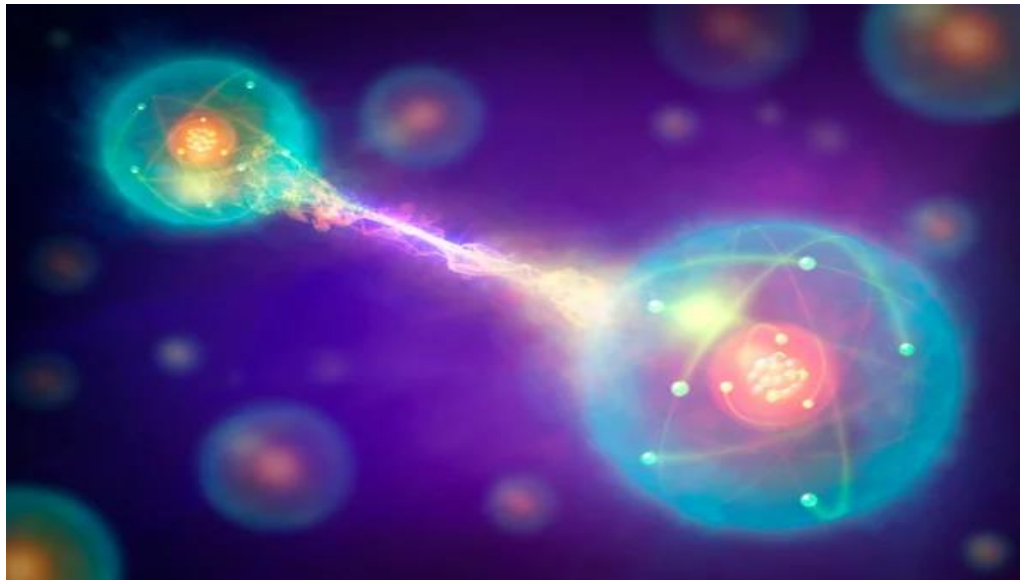
Image Source - https://physics.stackexchange.com/questions/170877/classical-and-semi-classical-vs-quantum-interferometry

Properties of Quantum Computing

Entanglement

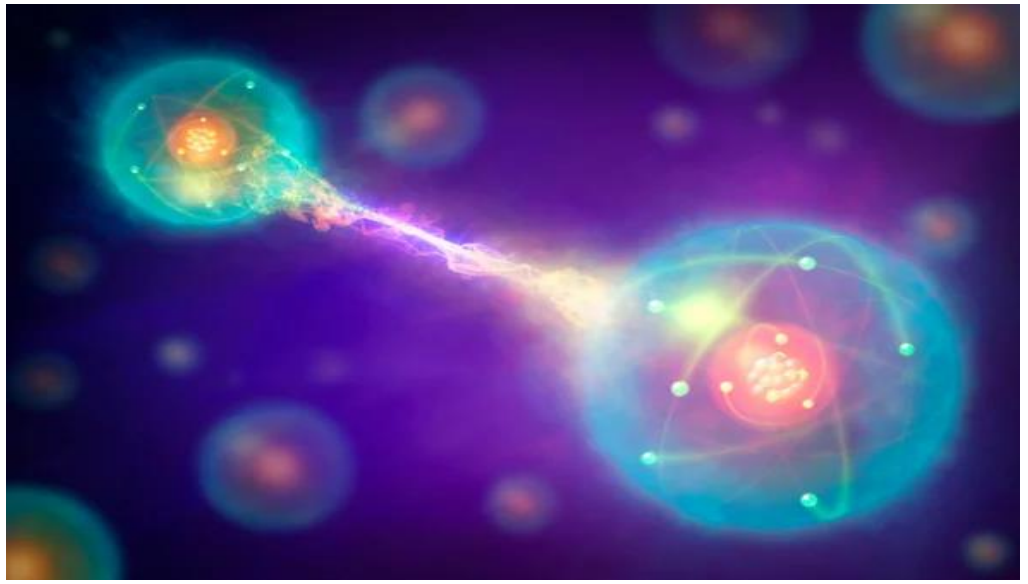
Properties of Quantum Computing

Entanglement



Properties of Quantum Computing

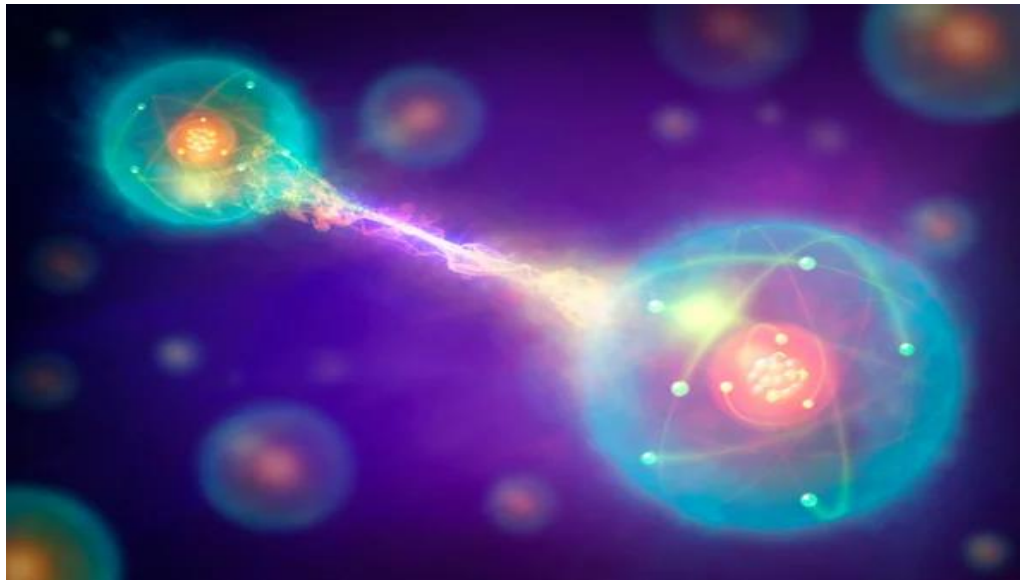
Entanglement



- Pairs or groups of qubits exist as a single quantum state such that their properties are correlated, even if the qubits are separated by a long distance!

Properties of Quantum Computing

Entanglement



- Pairs or groups of qubits exist as a single quantum state such that their properties are correlated, even if the qubits are separated by a long distance!

- If two particles are entangled, then measuring properties of 1st particle will give you information about the 2nd particle

Properties of Quantum Computing

Properties of Quantum Computing Concludes

Single Qubit Quantum Logic Gates

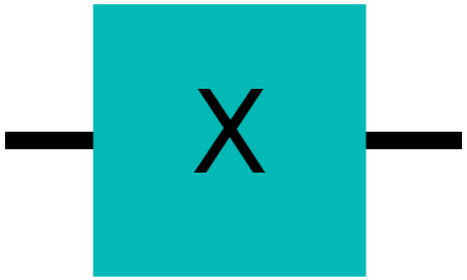
Single Qubit Quantum Logic Gates

Pauli X Gate

Single Qubit Quantum Logic Gates

Pauli X Gate

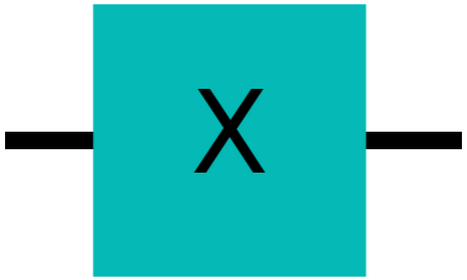
Gate Symbol



Single Qubit Quantum Logic Gates

Pauli X Gate

Gate Symbol



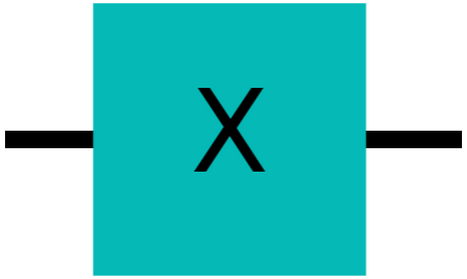
Gate Truth Table

Inputs	Outputs
|0>	|1>
|1>	|0>

Single Qubit Quantum Logic Gates

Pauli X Gate

Gate Symbol



Gate Operator

$$X = \sigma_x = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}$$

Gate Truth Table

Inputs	Outputs
|0>	|1>
|1>	|0>

Single Qubit Quantum Logic Gates

Pauli Y Gate

Single Qubit Quantum Logic Gates

Pauli Y Gate

Gate Symbol

Single Qubit Quantum Logic Gates

Pauli Y Gate

Gate Symbol

Gate Truth Table

Inputs	Outputs
|0>	i|1>
|1>	-i|0>

Single Qubit Quantum Logic Gates

Pauli Y Gate

Gate Symbol

Gate Operator

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

Gate Truth Table

Inputs	Outputs
|0>	i|1>
|1>	-i|0>

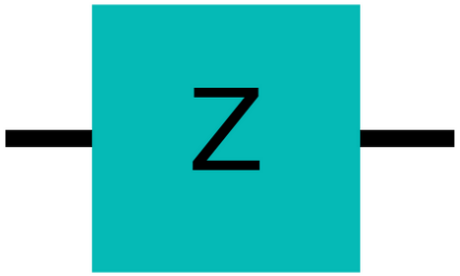
Single Qubit Quantum Logic Gates

Pauli Z Gate

Single Qubit Quantum Logic Gates

Pauli Z Gate

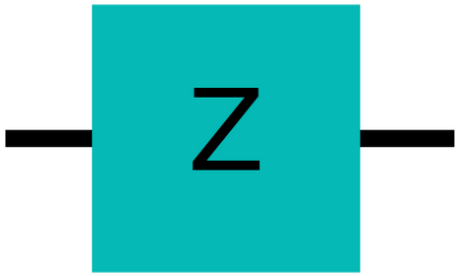
Gate Symbol



Single Qubit Quantum Logic Gates

Pauli Z Gate

Gate Symbol



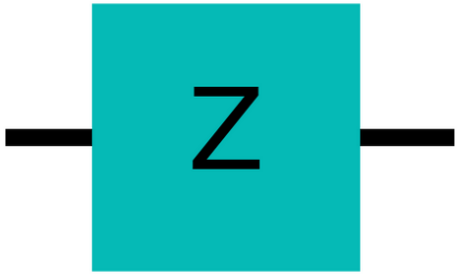
Gate Truth Table

Inputs	Outputs
|0>	|0>
|1>	-|1>

Single Qubit Quantum Logic Gates

Pauli Z Gate

Gate Symbol



Gate Operator

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

Gate Truth Table

Inputs	Outputs
|0>	|0>
|1>	-|1>

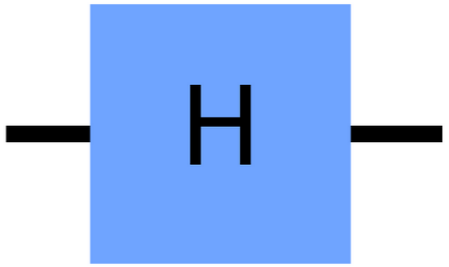
Single Qubit Quantum Logic Gates

Hadamard (H) Gate

Single Qubit Quantum Logic Gates

Hadamard (H) Gate

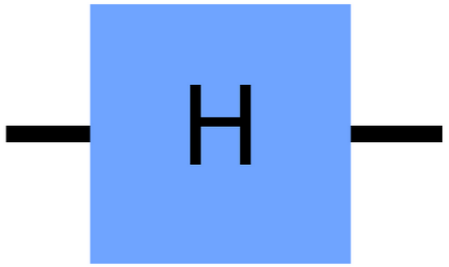
Gate Symbol



Single Qubit Quantum Logic Gates

Hadamard (H) Gate

Gate Symbol



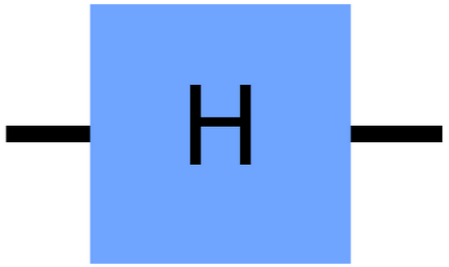
Gate Truth Table

Inputs	Outputs
|0>	$\|+\rangle = \frac{\|0\rangle + \|1\rangle}{\sqrt{2}}$
|1>	$\|-\rangle = \frac{\|0\rangle - \|1\rangle}{\sqrt{2}}$

Single Qubit Quantum Logic Gates

Hadamard (H) Gate

Gate Symbol



Gate Operator

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

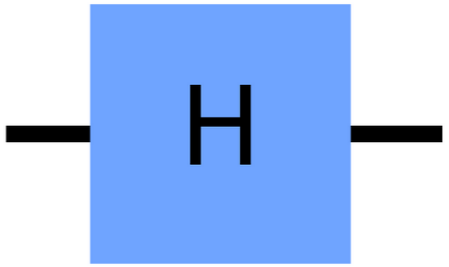
Gate Truth Table

Inputs	Outputs
|0>	$\|+\rangle = \frac{\|0\rangle + \|1\rangle}{\sqrt{2}}$
|1>	$\|-\rangle = \frac{\|0\rangle - \|1\rangle}{\sqrt{2}}$

Single Qubit Quantum Logic Gates

Hadamard (H) Gate

Gate Symbol



Gate Operator

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

Gate Truth Table

Inputs	Outputs
|0>	$\|+> = \frac{\|0> + \|1>}{\sqrt{2}}$
|1>	$\|-> = \frac{\|0> - \|1>}{\sqrt{2}}$

Hadamard gate is used to create superposition

Single Qubit Quantum Logic Gates

Parameterized Gate - Rz Gate

Single Qubit Quantum Logic Gates

Parameterized Gate - Rz Gate

Gate Symbol

Single Qubit Quantum Logic Gates

Parameterized Gate - Rz Gate

Gate Symbol

Gate Operator

$$\mathrm{Rz} = \begin{bmatrix} 1 & 0 \\ 0 & e^{i\varphi} \end{bmatrix}$$

Single Qubit Quantum Logic Gates

Parameterized Gate - Rz Gate

Gate Symbol

Gate Operator

$$\mathrm{Rz} = \begin{bmatrix} 1 & 0 \\ 0 & e^{i\varphi} \end{bmatrix}$$

Rotations around the Z axis of Bloch Sphere

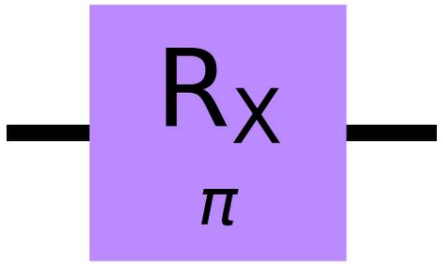
Single Qubit Quantum Logic Gates

Parameterized Gate - Rx Gate

Single Qubit Quantum Logic Gates

Parameterized Gate - Rx Gate

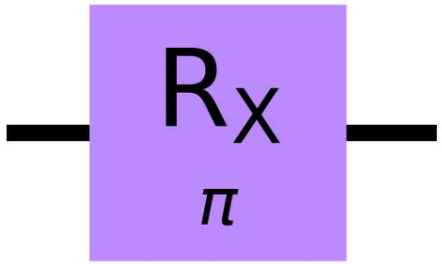
Gate Symbol



Single Qubit Quantum Logic Gates

Parameterized Gate - Rx Gate

Gate Symbol



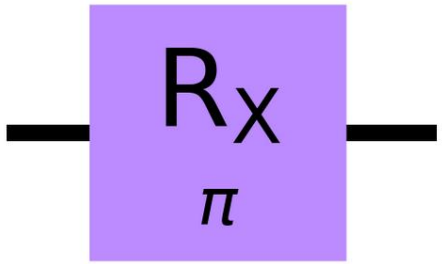
Gate Operator

$$\mathrm{Rx} = \begin{bmatrix} \cos\frac{\varphi}{2} & -i\sin\frac{\varphi}{2} \\ -i\sin\frac{\varphi}{2} & \cos\frac{\varphi}{2} \end{bmatrix}$$

Single Qubit Quantum Logic Gates

Parameterized Gate - Rx Gate

Gate Symbol



Gate Operator

$$\mathrm{Rx} = \begin{bmatrix} \cos\frac{\varphi}{2} & -i\sin\frac{\varphi}{2} \\ -i\sin\frac{\varphi}{2} & \cos\frac{\varphi}{2} \end{bmatrix}$$

Rotations around the X axis of Bloch Sphere

Single Qubit Quantum Logic Gates

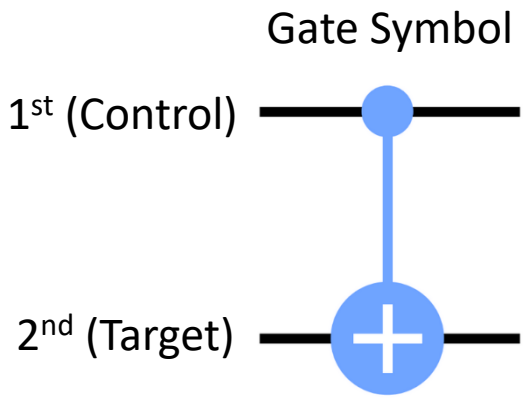
Single Qubit Quantum Gates Concludes

Multi Qubit Quantum Logic Gates

CNOT (CX) Gate

Multi Qubit Quantum Logic Gates

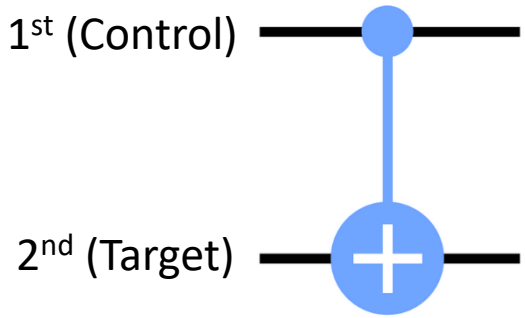
CNOT (CX) Gate



Multi Qubit Quantum Logic Gates

CNOT (CX) Gate

Gate Symbol



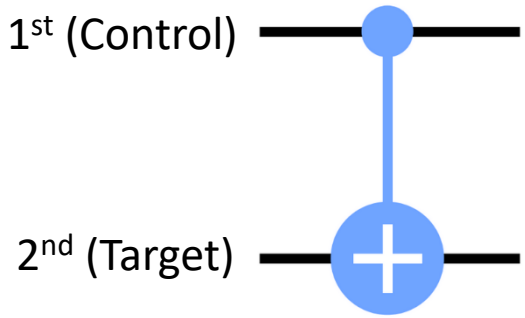
Gate Truth Table

Inputs **1st 2nd**	**Outputs** **1st 2nd**
|00>	|00>
|01>	|01
|10>	|11>
|11>	|10>

Multi Qubit Quantum Logic Gates

CNOT (CX) Gate

Gate Symbol



Gate Operator

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

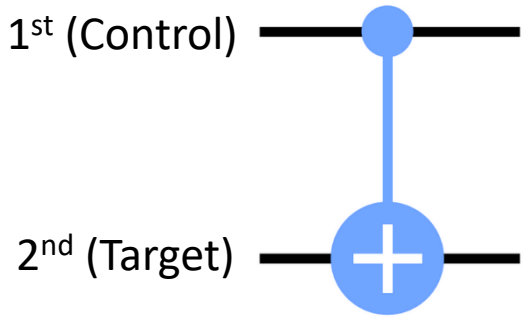
Gate Truth Table

Inputs **1st 2nd**	**Outputs** **1st 2nd**
|00>	|00>
|01>	|01
|10>	|11>
|11>	|10>

Multi Qubit Quantum Logic Gates

CNOT (CX) Gate

Gate Symbol



Gate Operator

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

Gate Truth Table

Inputs **1st 2nd**	**Outputs** **1st 2nd**
|00>	|00>
|01>	|01
|10>	|11>
|11>	|10>

CNOT Gate is used to create entanglement

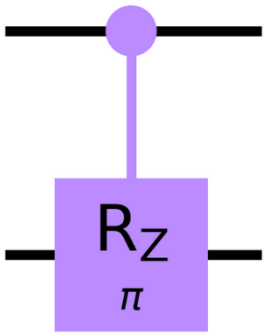
Multi Qubit Quantum Logic Gates

Parameterized Control Gate - CRz Gate

Multi Qubit Quantum Logic Gates

Parameterized Control Gate - CRz Gate

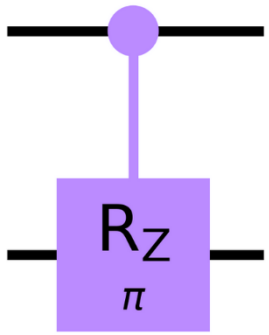
Gate Symbol



Multi Qubit Quantum Logic Gates

Parameterized Control Gate - CRz Gate

Gate Symbol



Gate Operator

$$\mathrm{CRz} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & e^{-i\frac{\lambda}{2}} & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & e^{i\frac{\lambda}{2}} \end{bmatrix}$$

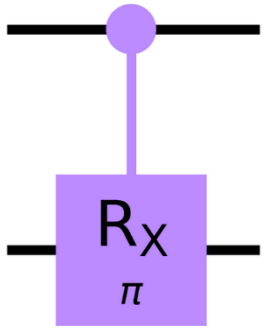
Multi Qubit Quantum Logic Gates

Parameterized Control Gate - CRx Gate

Multi Qubit Quantum Logic Gates

Parameterized Control Gate - CRx Gate

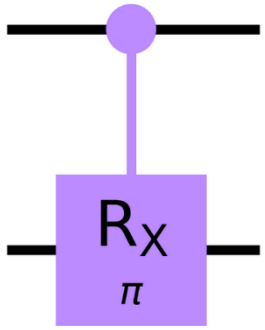
Gate Symbol



Multi Qubit Quantum Logic Gates

Parameterized Control Gate - CRx Gate

Gate Symbol



Gate Operator

$$\mathrm{CRx} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & cos\frac{\theta}{2} & 0 & -i\ sin\frac{\theta}{2} \\ 0 & 0 & 1 & 0 \\ 0 & -i\ sin\frac{\theta}{2} & 0 & cos\frac{\theta}{2} \end{bmatrix}$$

Multi Qubit Quantum Logic Gates

Multi Qubit Quantum Gates Concludes

ZX Calculus Representation of Quantum Gates

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- A graphical language which can represent quantum circuit diagrams as linear maps between qubits

ZX Calculus Representation of Quantum Gates

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- It consists of diagrammatic rewrite rules which assists in the reasoning of quantum circuits

ZX Calculus Representation of Quantum Gates

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- It consists of diagrammatic rewrite rules which assists in the reasoning of quantum circuits
- ZX-diagrams are generated by two basic generators – Z spiders and X spiders shown by white dots and grey dots respectively

ZX Calculus Representation of Quantum Gates

- A graphical language which can represent quantum circuit diagrams as linear maps between qubits
- It consists of diagrammatic rewrite rules which assists in the reasoning of quantum circuits
- ZX-diagrams are generated by two basic generators – Z spiders and X spiders shown by white dots and grey dots respectively
- ZX calculus can be used to convert string diagrams into quantum circuits which is useful for QNLP

ZX Calculus Representation of Quantum Gates

- A graphical language which can represent quantum circuit diagrams as linear maps between qubits
- It consists of diagrammatic rewrite rules which assists in the reasoning of quantum circuits
- ZX-diagrams are generated by two basic generators – Z spiders and X spiders shown by white dots and grey dots respectively
- ZX calculus can be used to convert string diagrams into quantum circuits which is useful for QNLP
- ZX calculus is complete i.e. different set of rewrite rules are complete for different families of linear maps

ZX Calculus Representation of Quantum Gates

Z & X Basis States

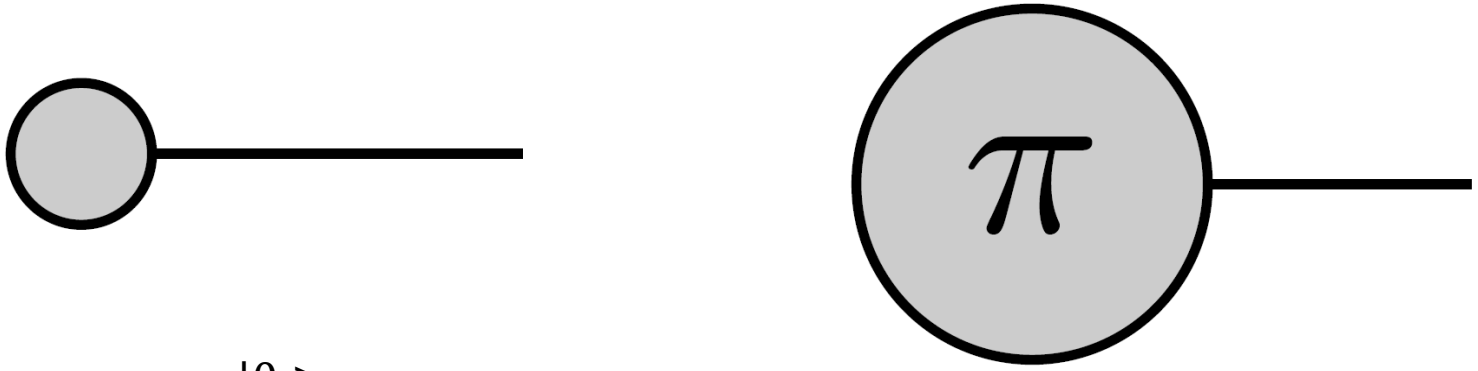
ZX Calculus Representation of Quantum Gates

Z & X Basis States

$|0>$

ZX Calculus Representation of Quantum Gates

Z & X Basis States



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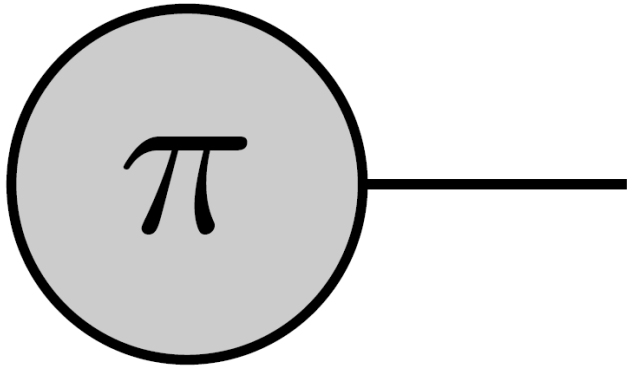
ZX Calculus Representation of Quantum Gates

Z & X Basis States

|0 >



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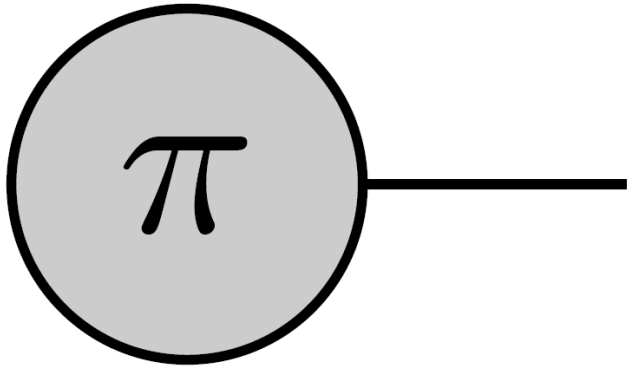
ZX Calculus Representation of Quantum Gates

Z & X Basis States

|0 >



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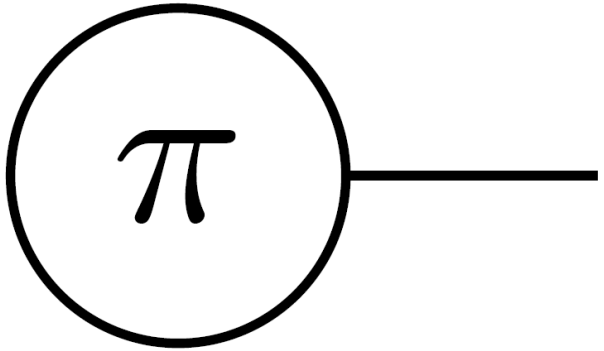

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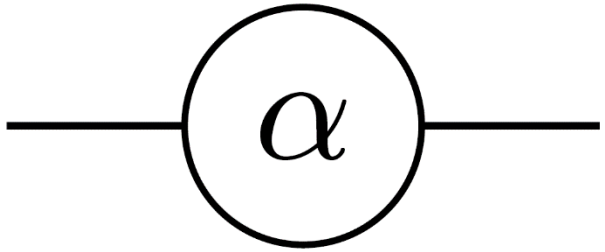
ZX Calculus Representation of Quantum Gates

Rz, Rx & CNOT Quantum Gates

ZX Calculus Representation of Quantum Gates

Rz, Rx & CNOT Quantum Gates



Rz Gate

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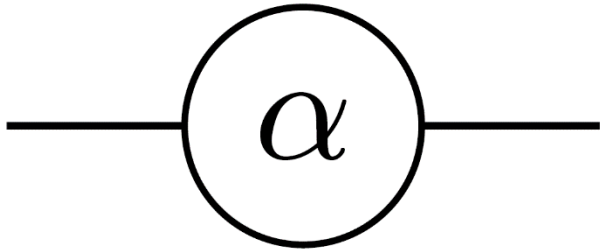
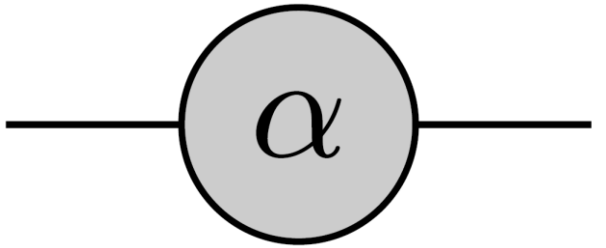
Rz, Rx & CNOT Quantum Gates



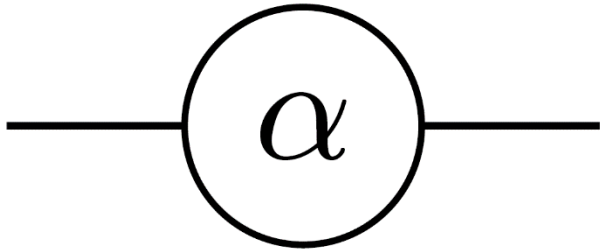
Rz Gate



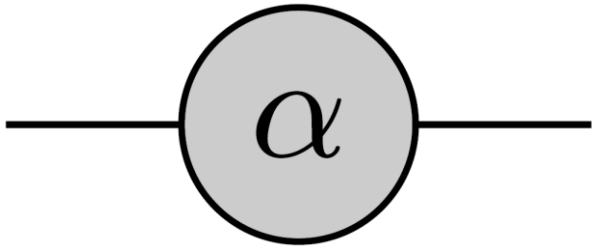
Rx Gate

ZX Calculus Representation of Quantum Gates

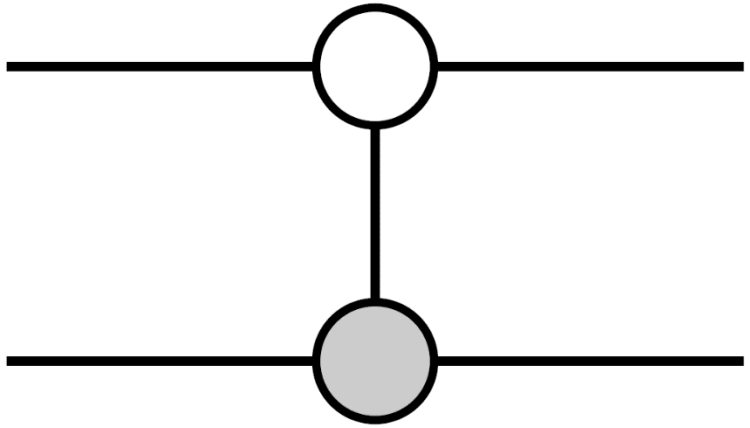
Rz, Rx & CNOT Quantum Gates



Rz Gate



Rx Gate



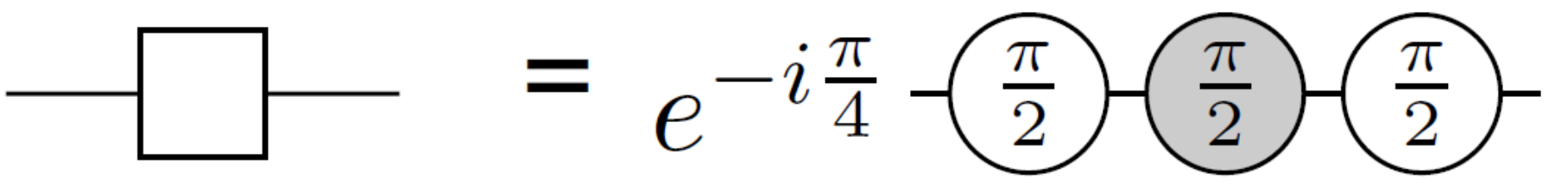
CNOT Gate

ZX Calculus Representation of Quantum Gates

Hadamard & Unitary Quantum Gates

ZX Calculus Representation of Quantum Gates

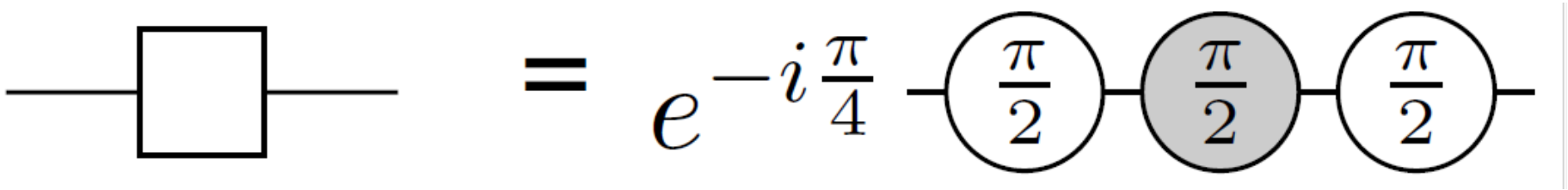
Hadamard & Unitary Quantum Gates



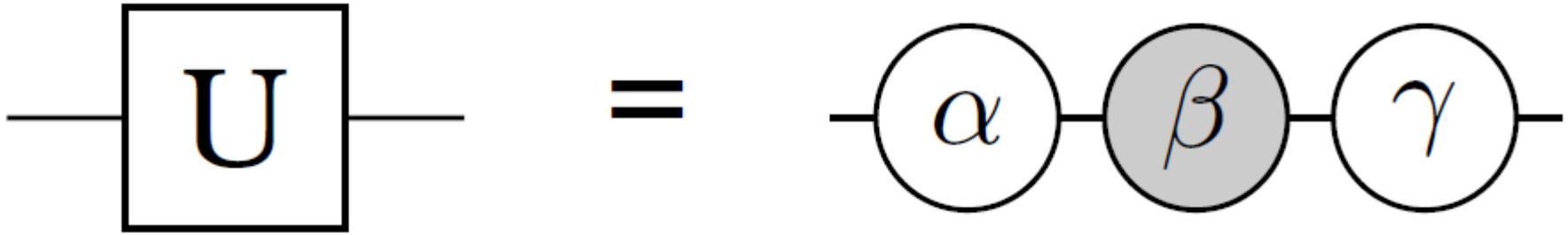
Hadamard Gate and its ZX components

ZX Calculus Representation of Quantum Gates

Hadamard & Unitary Quantum Gates



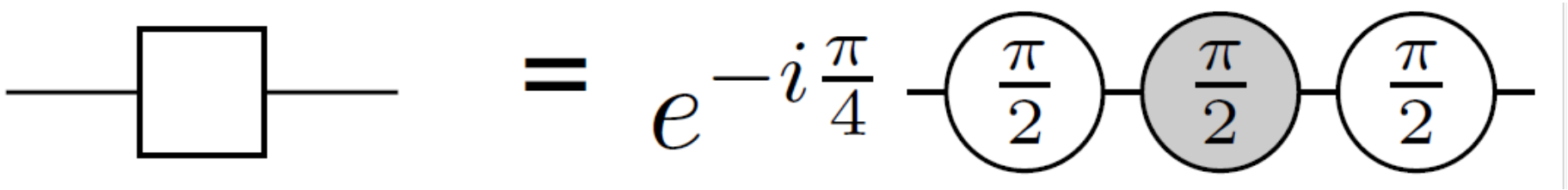
Hadamard Gate and its ZX components



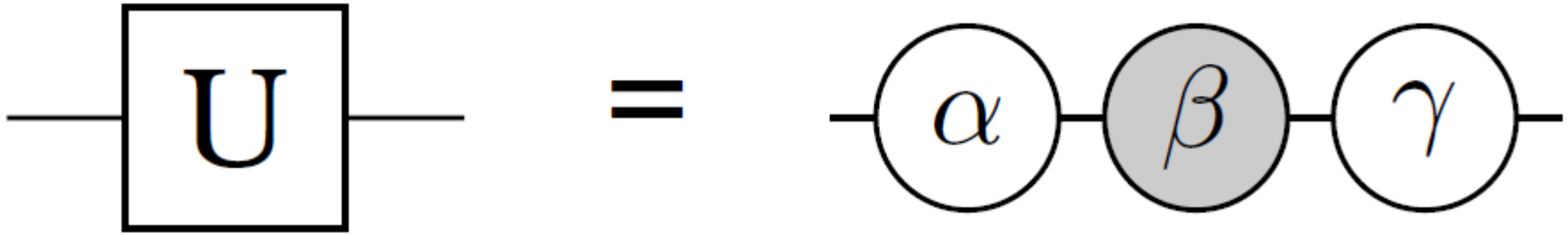
Unitary Gate or Parameterized Gate

ZX Calculus Representation of Quantum Gates

Hadamard & Unitary Quantum Gates



Hadamard Gate and its ZX components



Unitary Gate or Parameterized Gate

Unitary Gate can be used to make other quantum gates

ZX Calculus Representation of Quantum Gates

ZX Calculus Representation of Quantum Gates Concludes

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Thank you so much!