Turun yliopisto
University of Turku

Quantum Computing

Comp Coffee @ Tuorla, 2017-11-29

What is quantum computing?

- Quantum computers operate on qubits [*CUE*-bits]
- Two fundamental properties of qubits - superposition and entanglement\
- States are represented as vectors in Hilbert space (product $\langle \phi \mid \psi \rangle = \sum_i \phi_i^* \psi_i$)
- Two states: $\mid 0 \rangle$ (zero-ket) and $\mid 1 \rangle$ (one-ket)

$$\mid 0 \rangle = \begin{bmatrix} 1 \\ 0 \end{bmatrix}, \mid 1 \rangle = \begin{bmatrix} 0 \\ 1 \end{bmatrix}, \mid + \rangle = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 \\ 1 \end{bmatrix}, \mid - \rangle = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 \\ -1 \end{bmatrix},$$

$$\mid \circlearrowright \rangle = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 \\ i \end{bmatrix}, \mid \circlearrowleft \rangle = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 \\ -i \end{bmatrix}$$

What is quantum computing?

- Entangled state of two qubit system

$$\frac{1}{\sqrt{2}}(|00\rangle + |11\rangle)$$

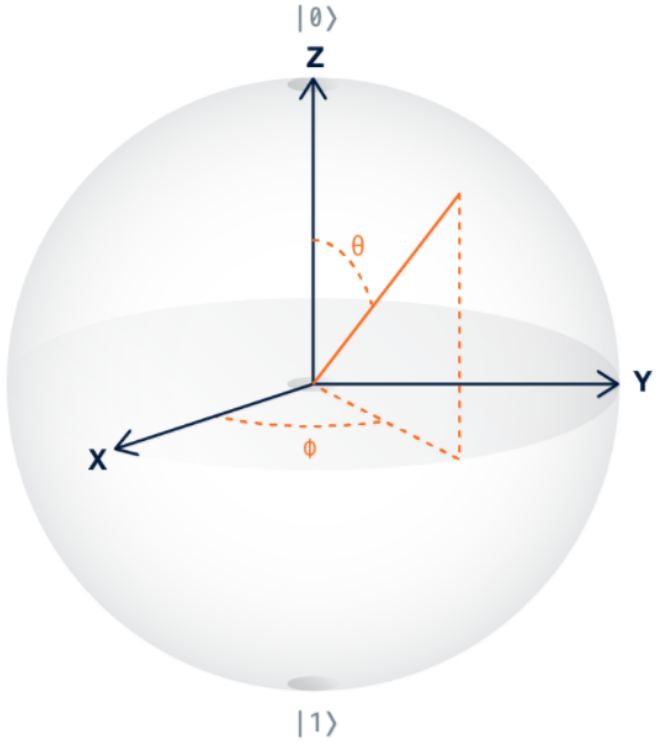
- Classical gates: **NOT, AND, OR**, also **XOR, NAND**
- Another important gate: **CNOT**, or controlled **NOT**

Quantum gates

- *Pauli* gates **X, Y, Z** (unary)
- *Clifford* gates **S, H, S** † (superpositions)
- Other gates from non-*Clifford* group
- Measurement gate that sends qubit value to a respective normal bit

Quantum gates

- $\mathbf{X} = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}$, rotation on π around x
- $\mathbf{Y} = \begin{bmatrix} 0 & -i \\ i & 0 \end{bmatrix}$
- $\mathbf{Z} = \begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix}$

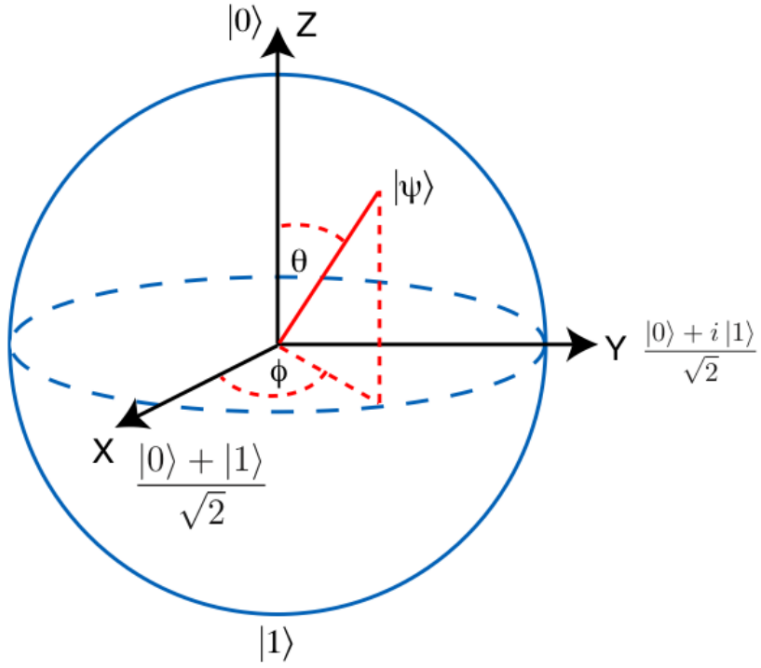


Quantum gates

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

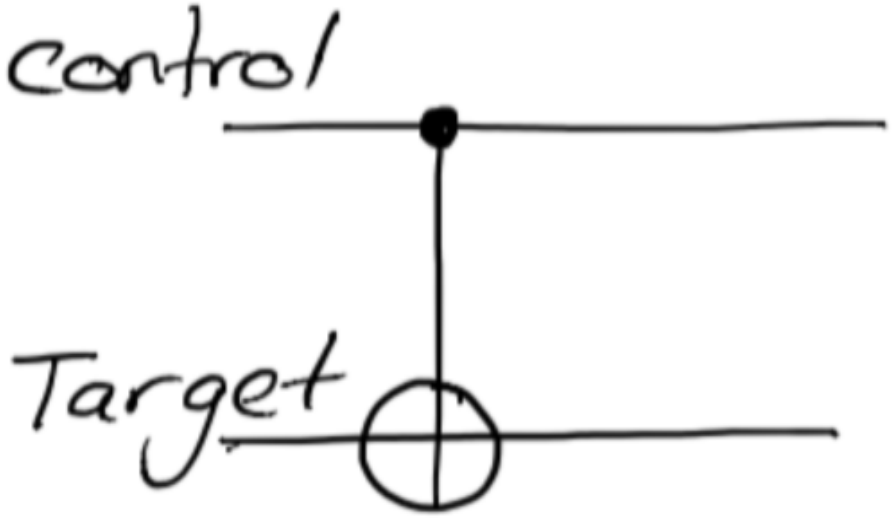
$\mathbf{H}$ applied to $|0\rangle$ gives $|+\rangle$

- $\mathbf{S} = \begin{bmatrix} 1 & 0 \\ 0 & i \end{bmatrix}$



CNOT two-qubit gate

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



- $|00\rangle \rightarrow |00\rangle$
- $|10\rangle \rightarrow |10\rangle$
- $|01\rangle \rightarrow |11\rangle$
- $|11\rangle \rightarrow |01\rangle$

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Go on and check it out!

IBM Quantum Experience