Quantum Machine Learning

Gennaro De Luca, PhD
Arizona State University

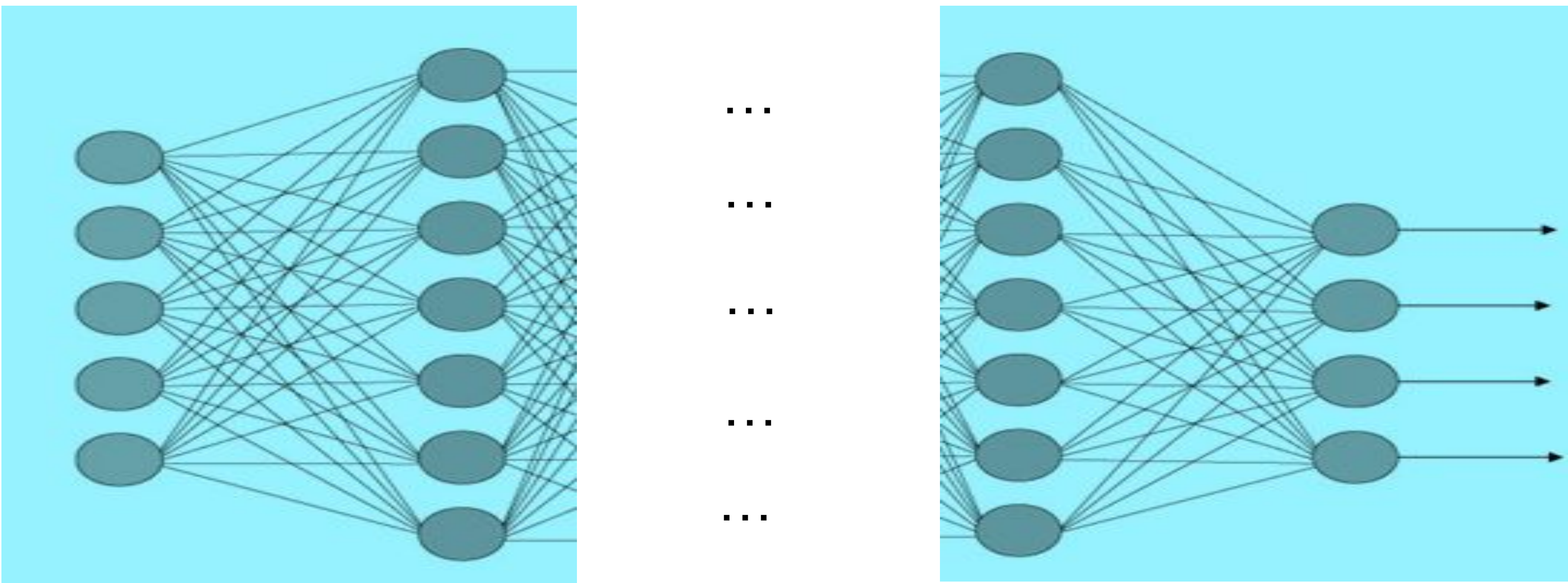
Ira A. Fulton Schools of Engineering
Arizona State University

Overview

- Artificial Neural Networks for Deep Learning
- Introduction to Quantum Computing
- Quantum Programming
- Quantum Machine Learning

Artificial Neural Networks Deep Learning

Input layer **Intermediate layers** **Output layer**

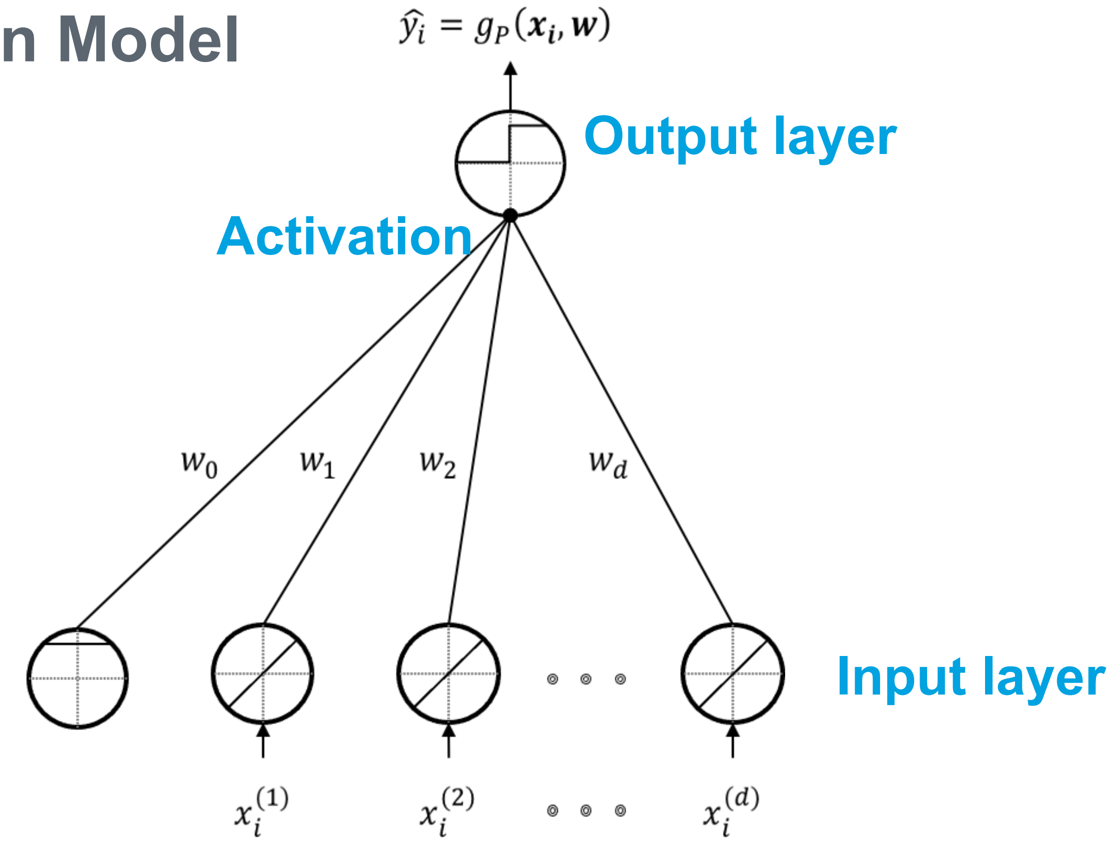


Building Artificial Neural Networks

What does this "neuron" do?

$$g_P(\boldsymbol{x}_i, \boldsymbol{w}) = \begin{cases} 1, & \text{if } \boldsymbol{w}^T \boldsymbol{x}_i > 0 \\ 0, & \text{otherwise} \end{cases}$$

The Perceptron Model



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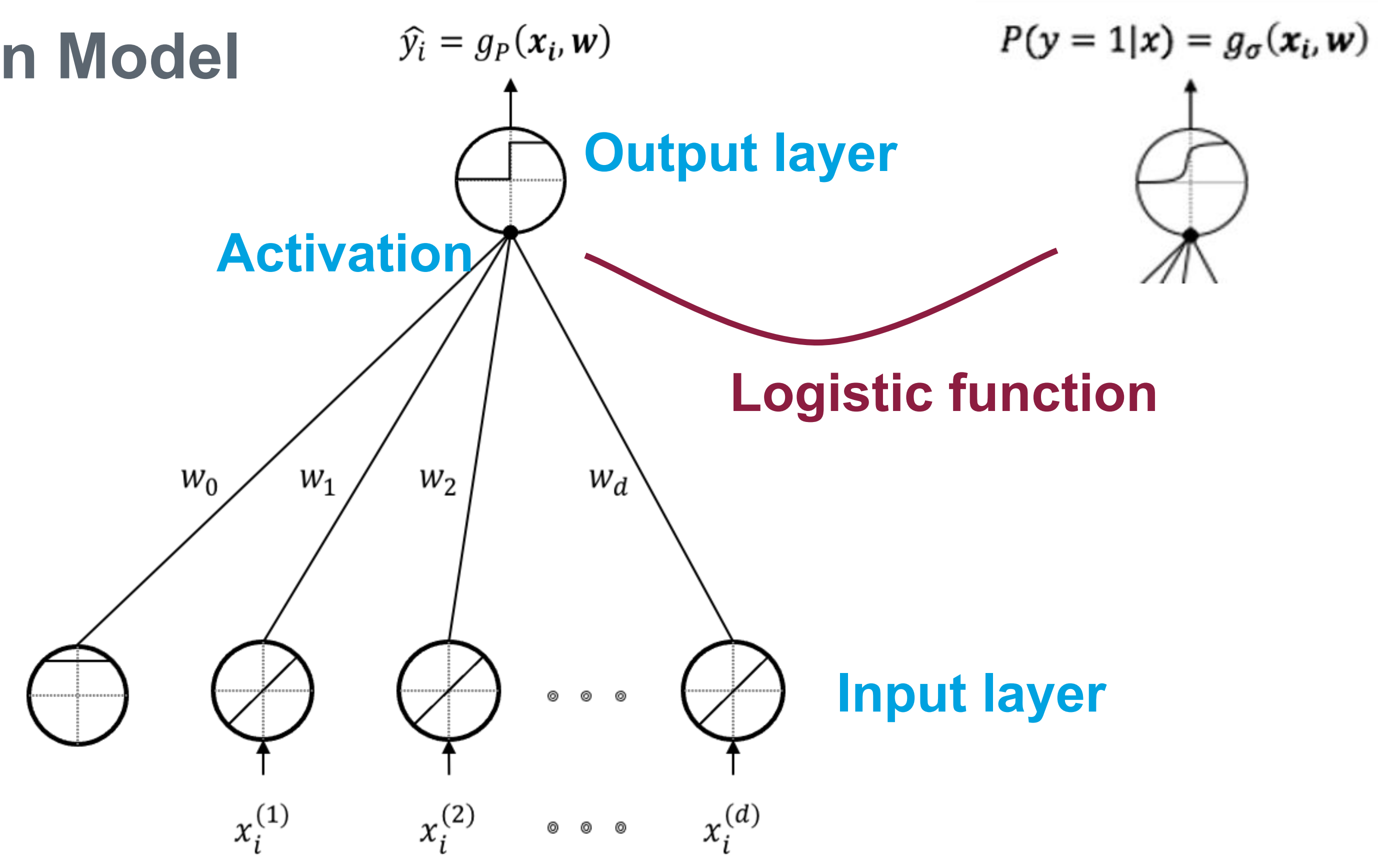


The Perceptron Learning Algorithm

Input:

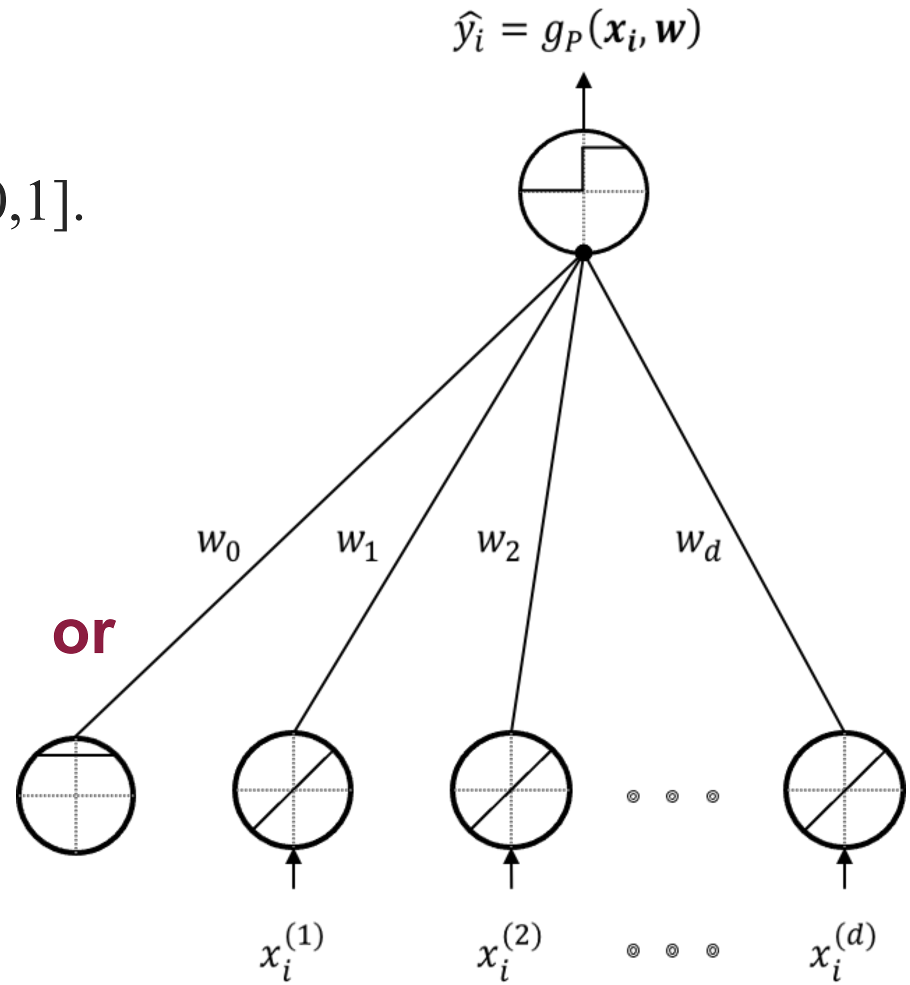
- Training set
  $D = \{(x_i, y_i),\ i \in [1,2,\ldots n]\}.\ y_i = [0,1].$

Initialization:

- Initialize the weights w(0) (and some thresholds)
- Weights may be set to 0

or

small random values



What is Quantum Computing?

- Quantum Computing (QC) involves qubits, with the special properties of superposition and entanglement.

- The computing capacity of quantum computers grows **exponentially** with the # of qubits.

- Electronic computer’s computing capacity grows **linearly** with the # of bits.

Quantum Computing Applications

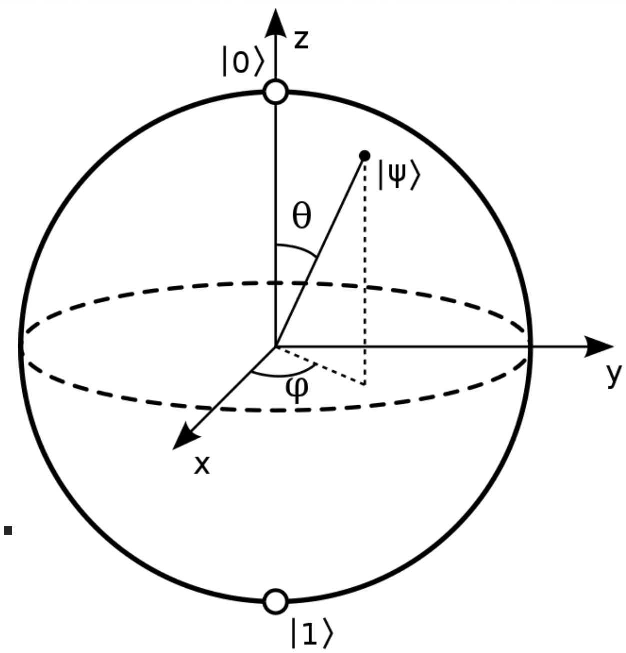
QC can be used where superpower is needed!

- Machine Learning
- Security: Can break the current security system
- Autonomous Decentralized Systems, with complex computing in real time
- Drug design and discovery
- Finance, …

Quantum Vs. Classical Computing

Qubits vs. Bits:

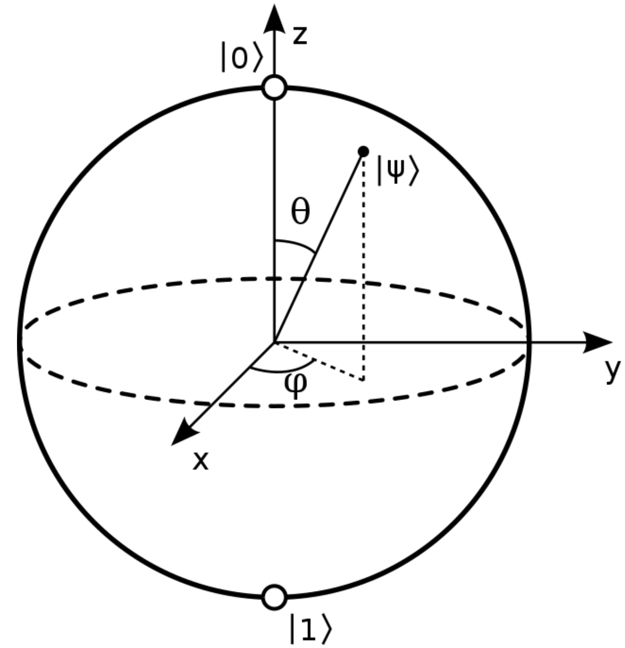
- Bits can be 0 or 1.
- A qubit stores a quantum state (point on the Bloch sphere).
- Qubits can be in a **superposition** of 0 and 1, but give a 0 or 1 when **measured**.



Quantum Vs. Classical Computing (cont'd)

Measurement:

- Classical bits are not probabilistic.
- Quantum bits change probabilistically when measured.



$$|\Phi\rangle = \alpha\,|0\rangle + \beta\,|1\rangle$$

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

$$P\,(|\Phi\rangle = |0\rangle) = |\alpha|^2$$

$$P\,(|\Phi\rangle = |1\rangle) = |\beta|^2$$

Quantum Entanglement

- The result of a measurement on one qubit can immediately determine the result if another qubit were to be measured.

$$|\Phi\rangle = 1/\sqrt{2}\ |00\rangle + 1/\sqrt{2}\ |11\rangle$$

- If the first qubit is measured, the second qubit's value is immediately known.
  - *Either **both** are 0 or **both** are 1.*

- The power of quantum computing comes from superposition and entanglement.

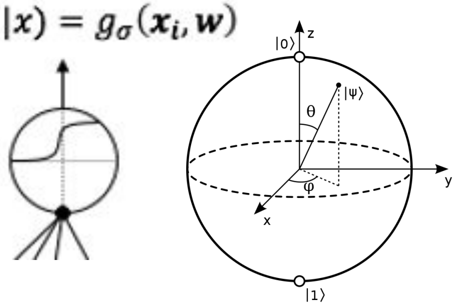
Quantum Programming

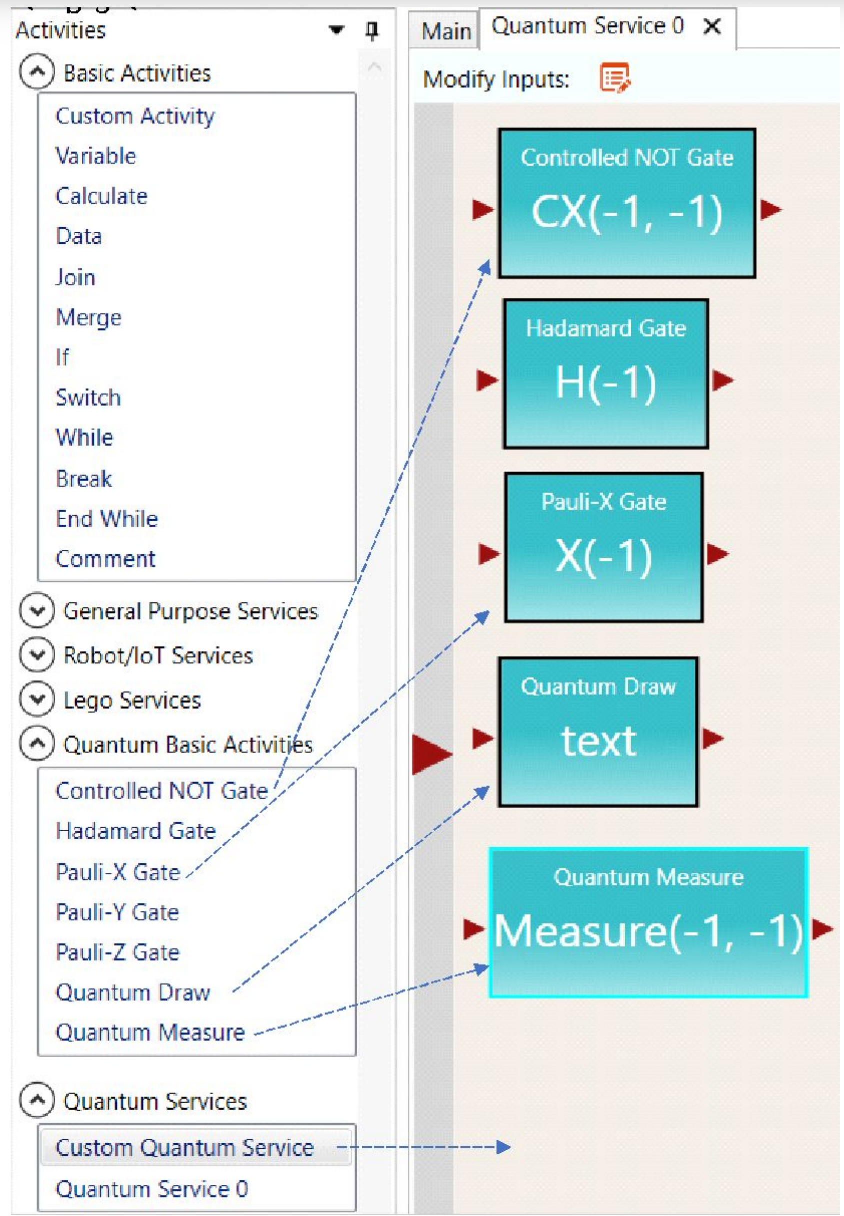
- **Quantum computing requires a new programming paradigm: Quantum Programming.**
- **Many text-based APIs exist, including IBM's Qiskit, Microsoft's Q#, and Google's Cirq.**
- **Several visual programming languages exist, including IBM's Circuit Composer and ASU VIPLE (Visual IoT/Robotics Programming Language Environment).**
  - Facilitate the introduction of quantum computing and quantum programming.

Quantum Programming in ASU VIPLE

Output layer $P(y = 1|x) = g_\sigma(\boldsymbol{x}_i, \boldsymbol{w})$

Activation

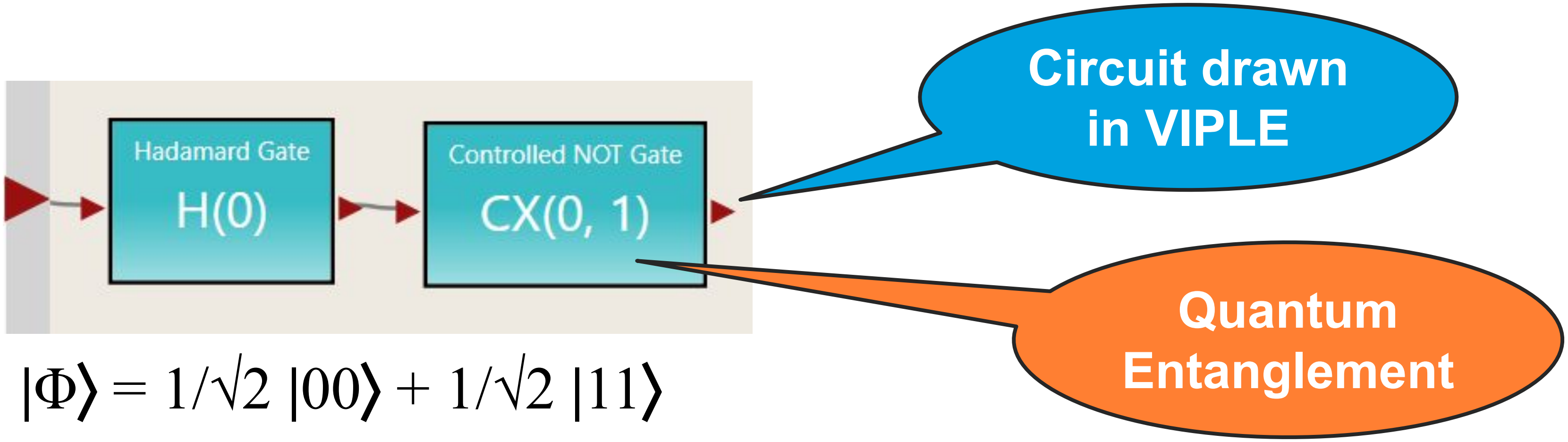




https://venus.sod.asu.edu/VIPLE/

VIP VISUAL IOT/ROBOTICS PROGRAMMING LANGUAGE ENVIRONMENT

Quantum Programming Example



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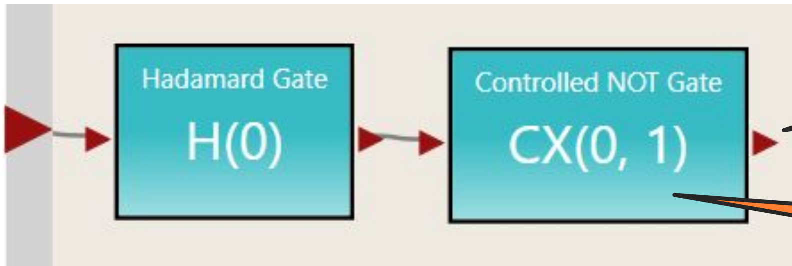
Quantum Programming Example

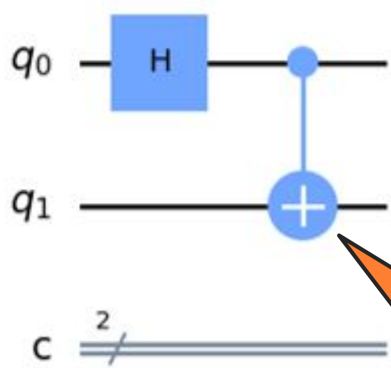


Circuit drawn in VIPLE

Quantum Entanglement

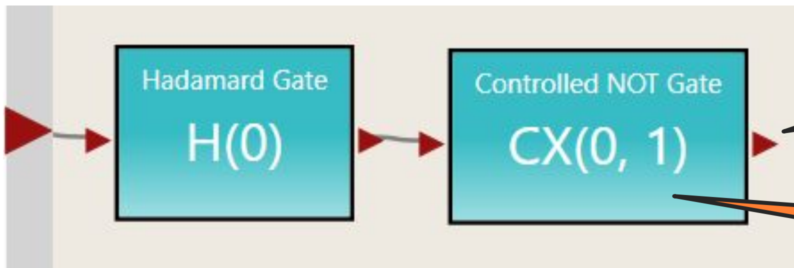
$$|\Phi\rangle = 1/\sqrt{2}\ |00\rangle + 1/\sqrt{2}\ |11\rangle$$

Circuit visualized in Qiskit backend



Quantum Entangle-ment

Quantum Programming Example



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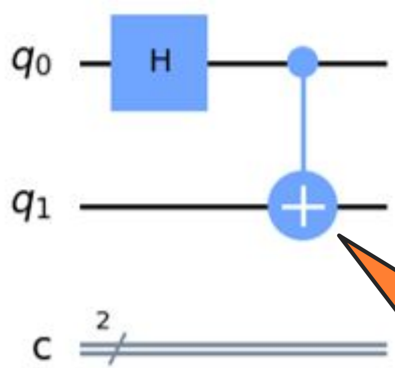

[0.7071067811865476+0j), 0j
0j, [0.7071067811865476+0j)]

Quantum Entangle-ment

Resulting probability amplitudes