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First steps in quantum ML using IBM QX

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Ph.D., Senior Data Scientist

Transistor computers. History of development.

1942

Mark 1

First electromechanical computer

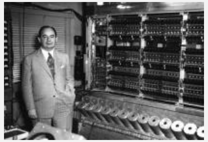
1943

Electronic vacuum tubes

1946

ENIAC

First computer using Vacuum Tubes



1949

EDSAC & EDVAC

First stored-program computers

1951

LEO & UNIVAC

First commercial computers

1951-1958

Vacuum tubes + Punch cards + Rotating magnetic drums

1959-1963

Transistors with semiconductors + Magnetic tape, discs and cores

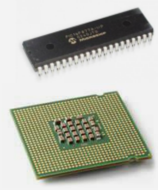
1977

Apple II

First mass-produced personal computer

1979- present

Microprocessors & CPUs



1981

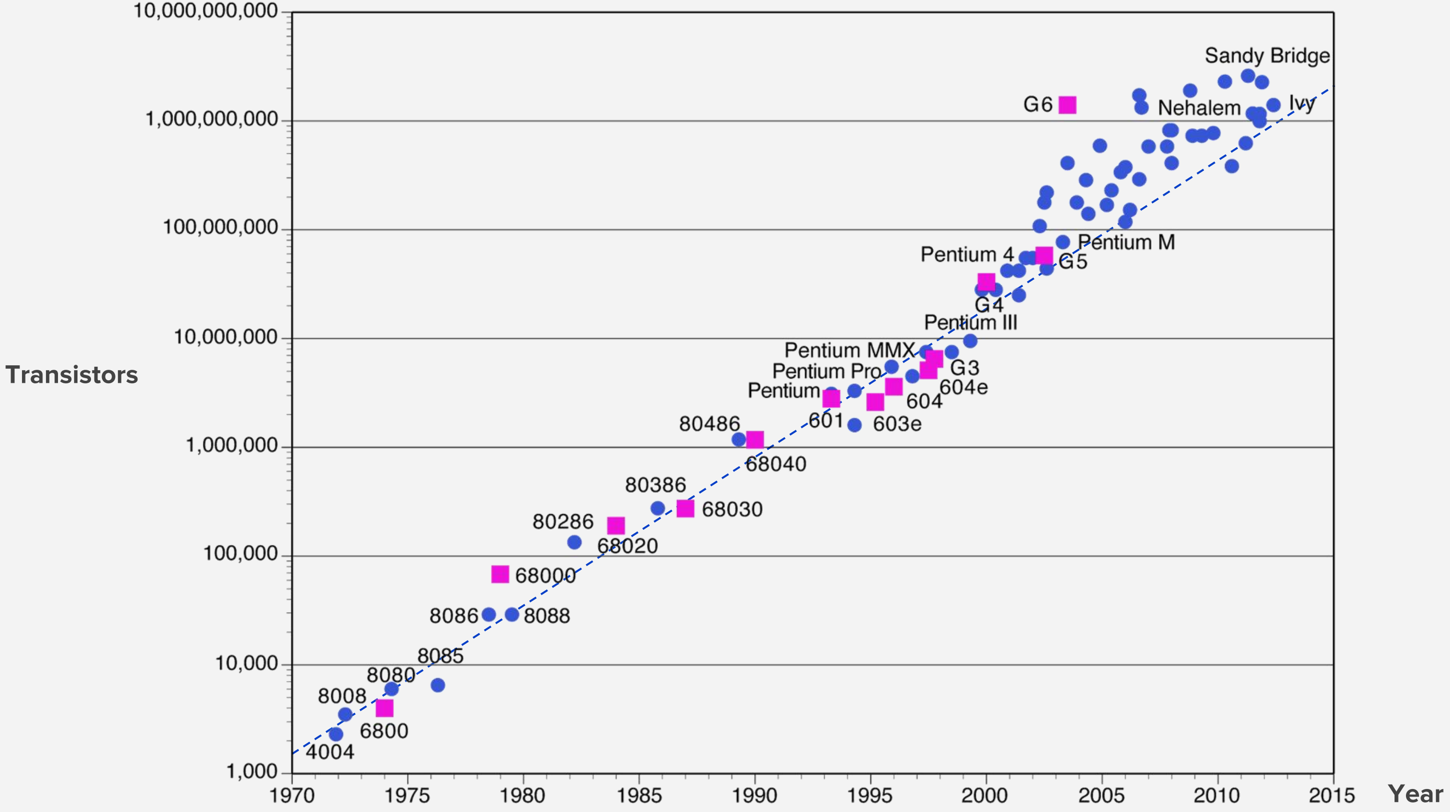
IBM PC & MS-DOS

Operating System

1984

Apple Mac

Moore's law, 1965



Classical computing

NOT

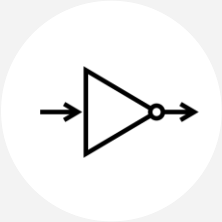
x	F
0	1
1	0

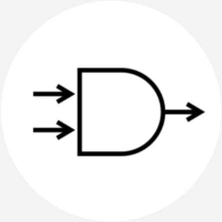
AND

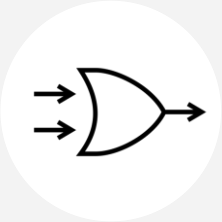
x	y	F
0	0	0
0	1	0
1	0	0
1	1	1

OR

x	y	F
0	0	0
0	1	1
1	0	1
1	1	1







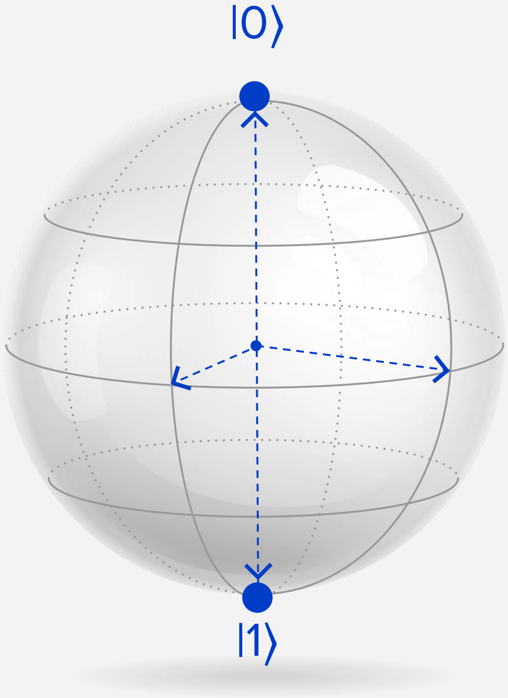
Classical VS Quantum

0

1

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

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



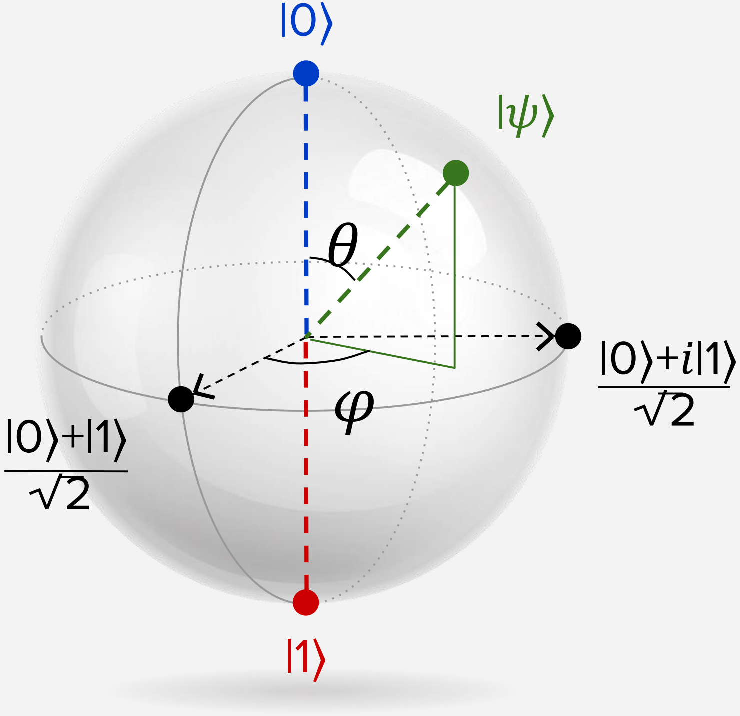
Bit = Scalar

Qubit = Complex Vector

Superposition. Bloch sphere

$$|\psi\rangle = \alpha|0\rangle + \beta|1\rangle$$

$$|\psi\rangle = \cos\frac{\theta}{2}|0\rangle + e^{i\varphi}\sin\frac{\theta}{2}|1\rangle$$



Quantum gates

$$|\phi\rangle = U|\psi\rangle,$$

where

$$U^\dagger U = I$$

Important single qubit gates

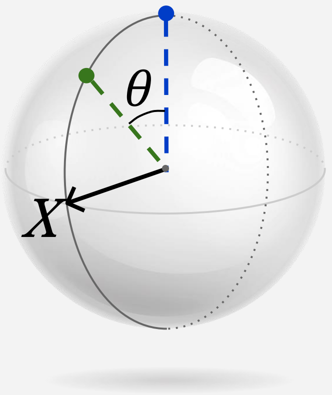
$$X = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \quad Y = \begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix} \quad Z = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$$

$$H = \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix} \quad S = \begin{pmatrix} 1 & 0 \\ 0 & i \end{pmatrix} \quad T = \begin{pmatrix} 1 & 0 \\ 0 & e^{i\pi/4} \end{pmatrix}$$

Rotation gates

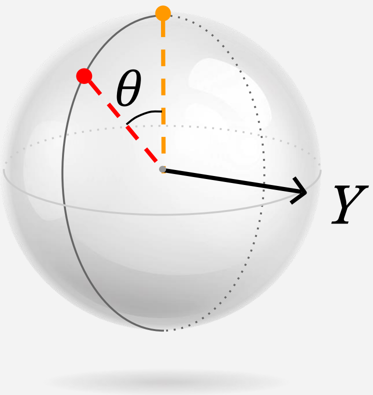
X

$$R_x(\theta) \equiv \cos\frac{\theta}{2} I\text{-}i \sin\frac{\theta}{2}$$



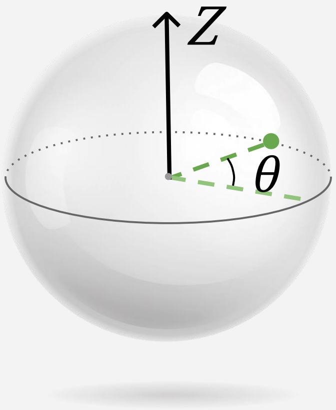
Y

$$R_y(\theta) \equiv \cos\frac{\theta}{2} I\text{-}i \sin\frac{\theta}{2} Y$$



Z

$$R_z(\theta) \equiv \cos\frac{\theta}{2} I\text{-}i \sin\frac{\theta}{2} Z$$



Multiple Qubits

What is “join state”
of two vectors?

$$(v, w) \in C^2 \oplus C^2$$

$$\|(v, w)\|^2 = \|v\|^2 + \|w\|^2 = 2$$

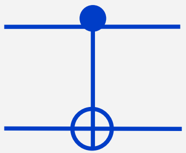
What is alternative?
Tensor product

$$(v, w) \in C^2 \otimes C^2$$

where $v = (v_1, v_2)$ and $w = w\ (w_1, w_2)$

$$(v, w) = (v_1 w_1, v_1 w_2, v_2 w_1, v_2 w_2)$$

Controlled gates

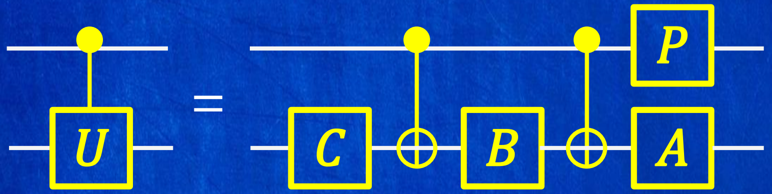


$$CNOT = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{pmatrix}$$

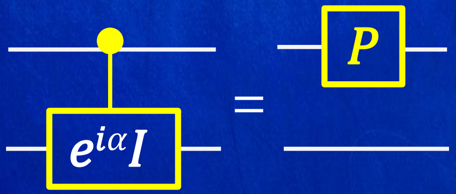
Decomposition

$$U = e^{i\alpha} R_z(\beta) R_y(\gamma) R_z(\delta)$$

Controlled - U gate



Phase shifter



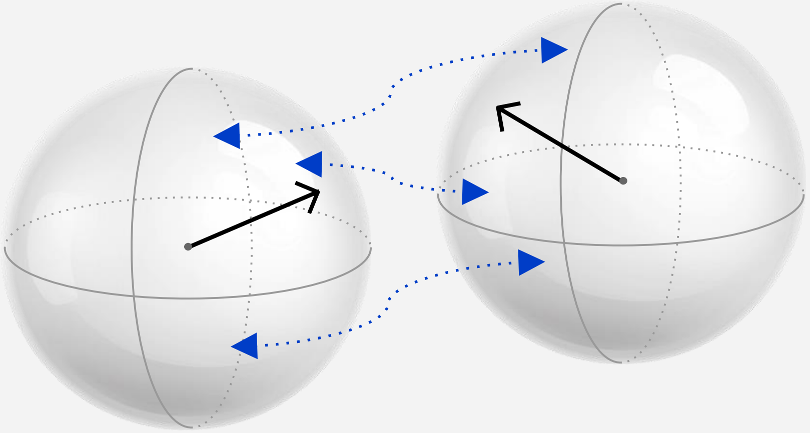
$$P = \begin{pmatrix} 1 & 0 \\ 0 & e^{i\alpha} \end{pmatrix}$$

Quantum entanglement

Examples of two entangled states:

$$\psi_+ = \frac{1}{\sqrt{2}} (|M,N\rangle + |N,M\rangle)$$

$$\psi_- = \frac{1}{\sqrt{2}} (|M,N\rangle - |N,M\rangle)$$



Quantum algorithms

1. Algorithms based on the quantum Fourier transform
   (exponential speedups)
   Deutsch–Jozsa algorithm, Shor's algorithm, Quantum phase estimation algorithm

2. Algorithms based on amplitude amplification
   (quadratic speedups)
   Grover's algorithm, Quantum counting

3. Algorithms based on quantum walks
   (exponential speedups or quadratic)
   Element distinctness problem, Triangle-finding problem

4. Hybrid Quantum/Classical Algorithms

Quantum Computing - IBM

https://www.research.ibm.com/ibm-q/

IBM

Marketplace

IBM Q

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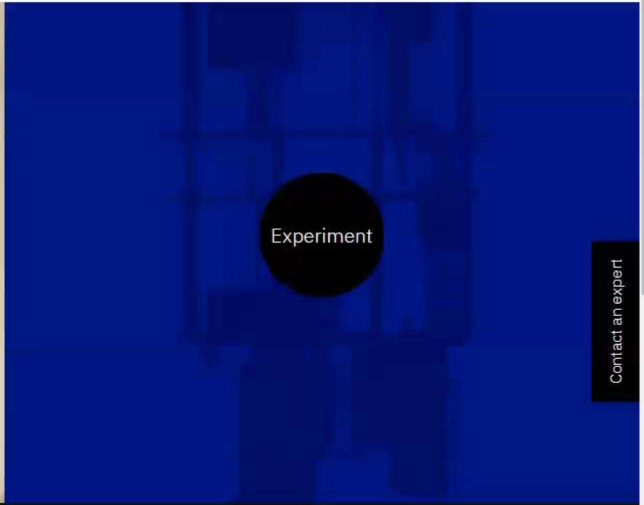
Quantum Computing

Learn



Experiment

Contact an expert

Meet IBM Q

IBM Q is an industry-first initiative to build commercially available universal quantum computers for business and science. While technologies like AI can find patterns buried in vast amounts of existing data, quantum computers will deliver solutions to important problems where patterns cannot be found and the number of possibilities that you need to explore to get to the answer are too enormous ever to be processed by classical computers. We invite you join us in exploring what might be possible with this new and vastly different approach to computing.

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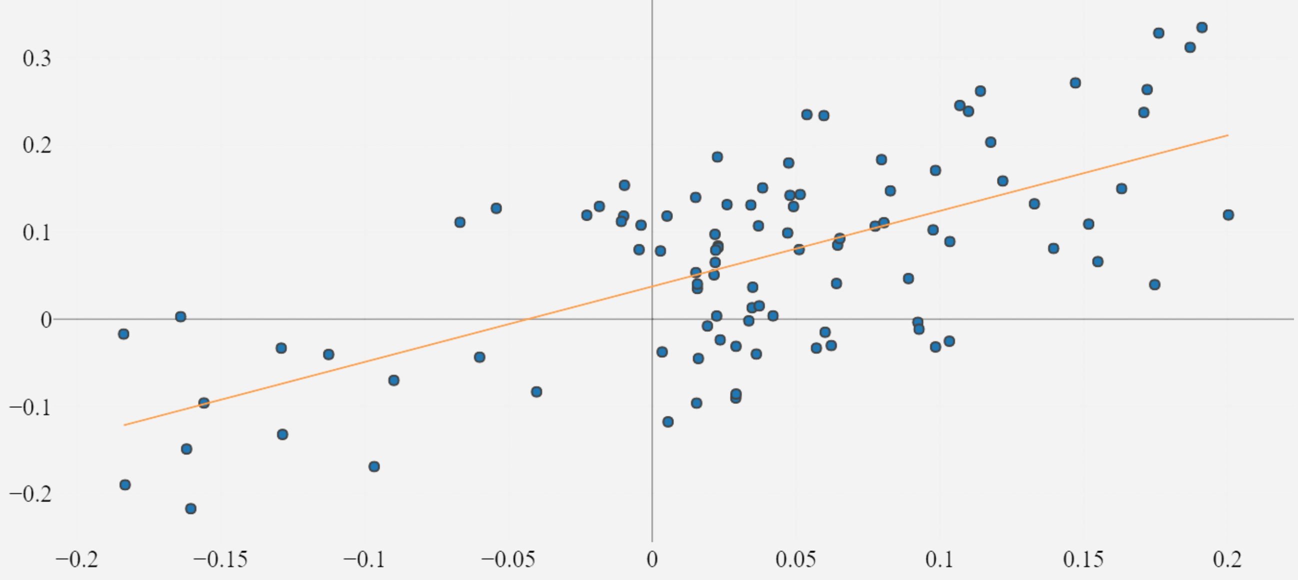
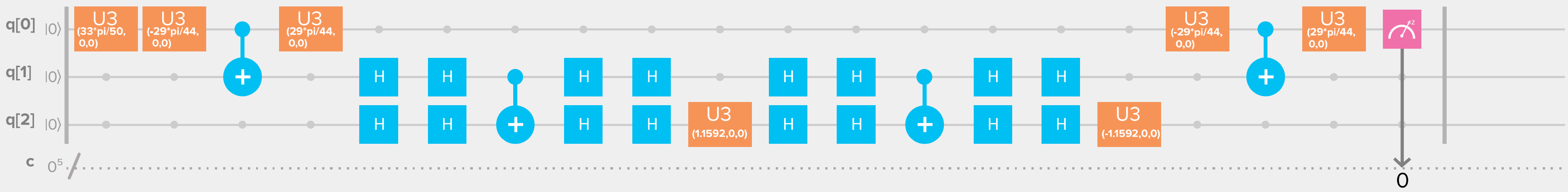
Linear regression

Minimize cost function:

$$J(\theta)=\frac{1}{2m}\Sigma_{i=1}^{m}(y_i - (\theta_0+\theta_1 x_i)^2 \rightarrow min$$

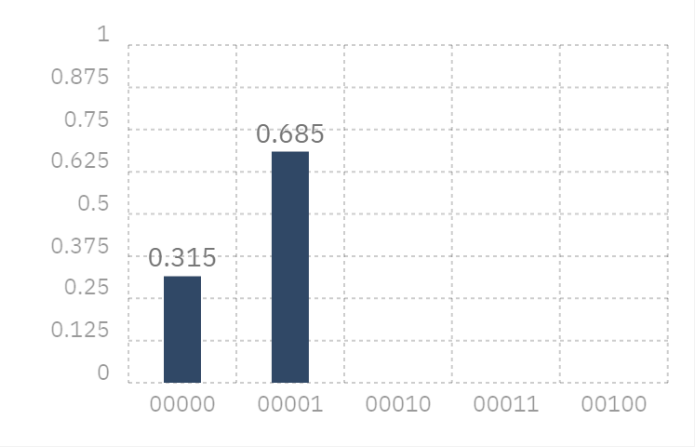


Quantum algorithm. Z - measuring

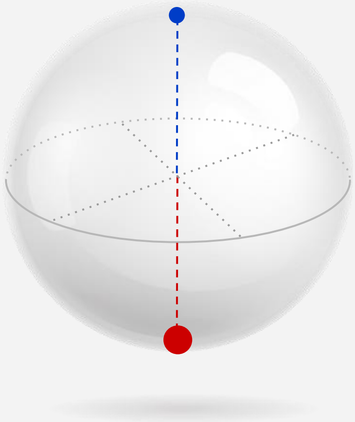


Quantum State:

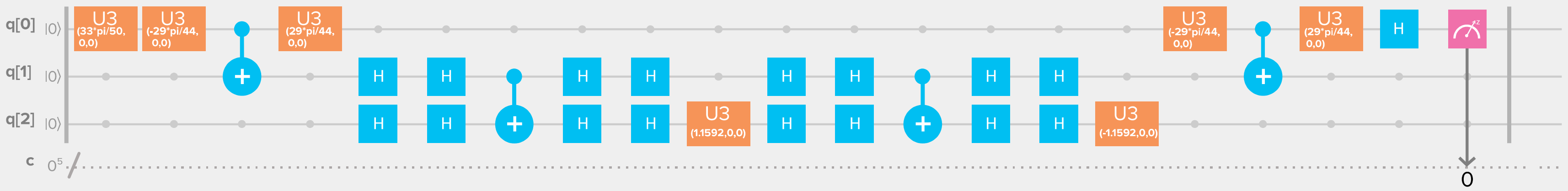
Computation Basis



Quantum Sphere

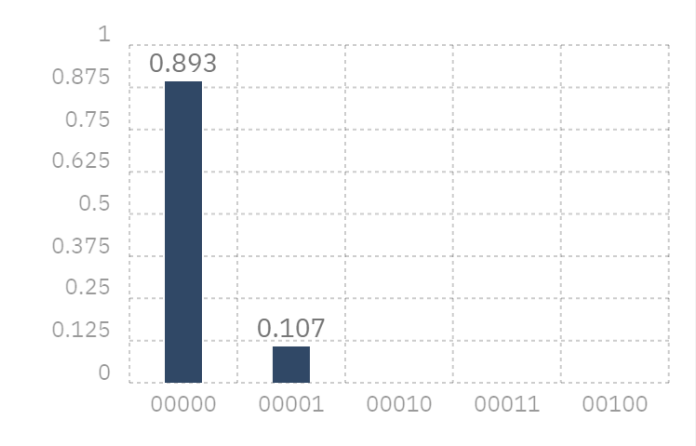


Quantum algorithm. X - measuring

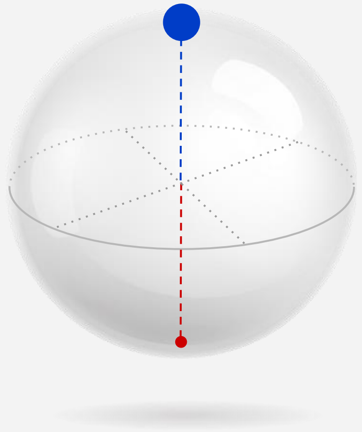


Quantum State:

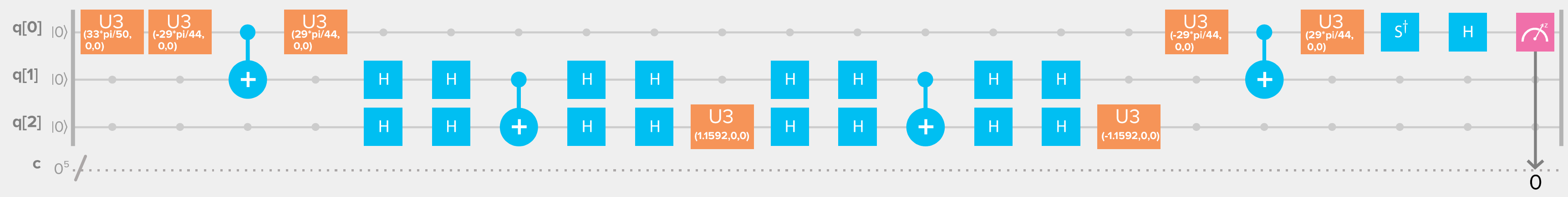
Computation Basis



Quantum Sphere

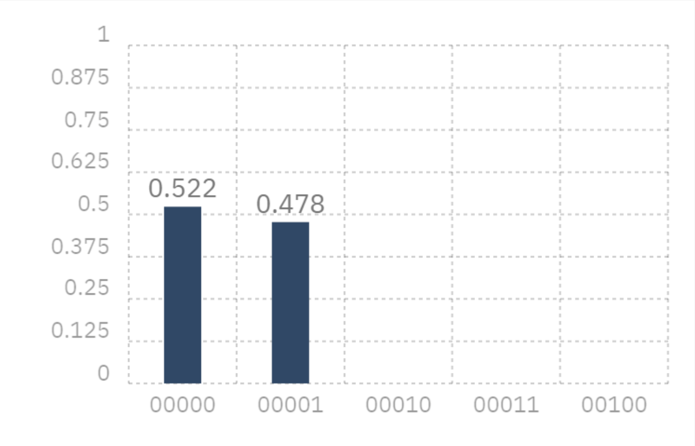


Quantum algorithm. Y - measuring

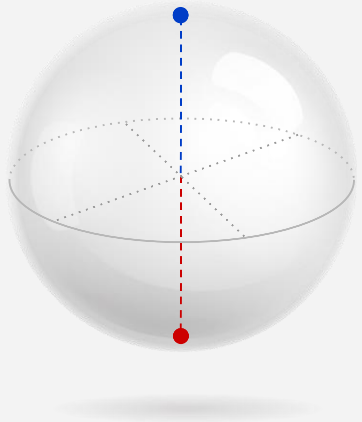


Quantum State:

Computation Basis

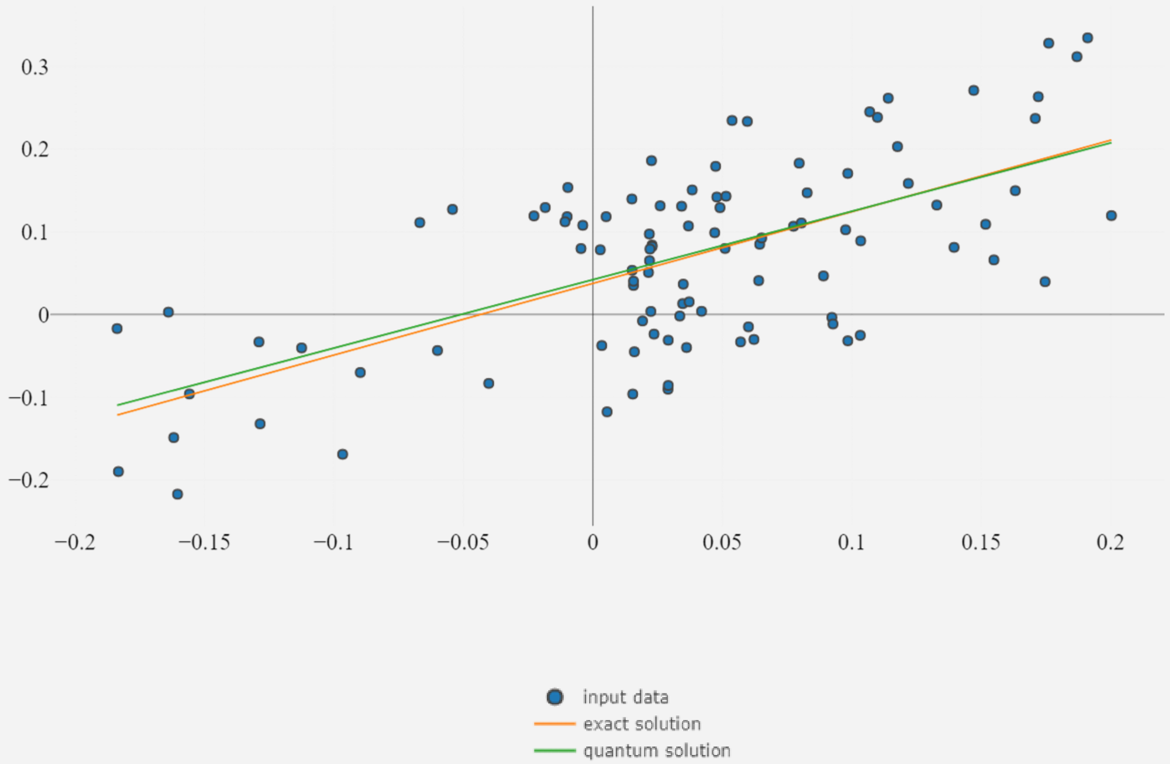


Quantum Sphere



Comparison


0.8
0.6
0.4
0.2
0
−0.2
−0.4
Z
X
Y
Theory
Experiment


0.3
0.2
0.1
0
−0.1
−0.2
−0.2
−0.15
−0.1
−0.05
0
0.05
0.1
0.15
0.2
input data
exact solution
quantum solution

Inspired by Technology.
Driven by Value.

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