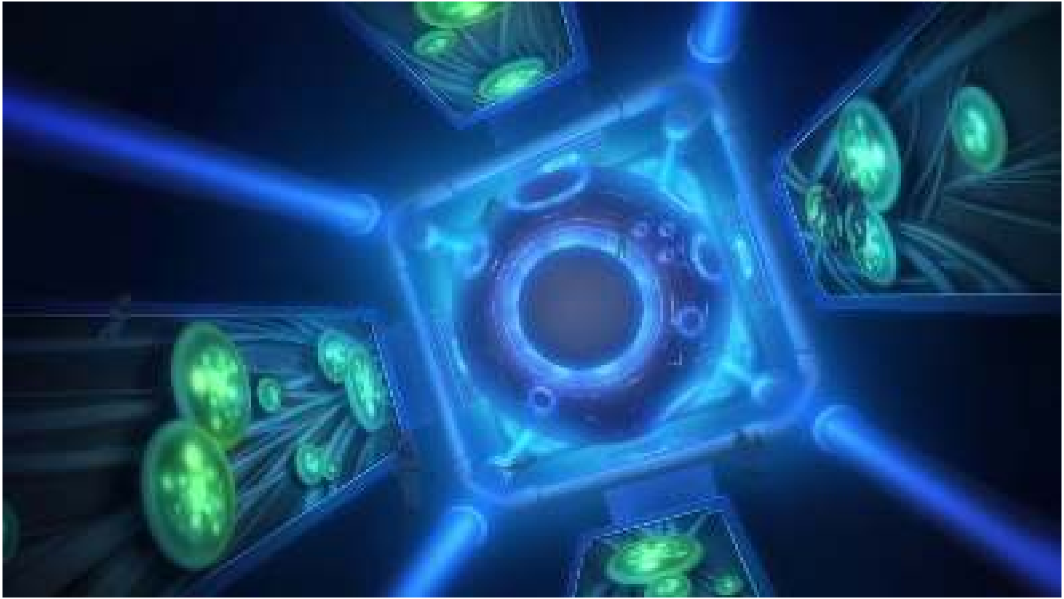
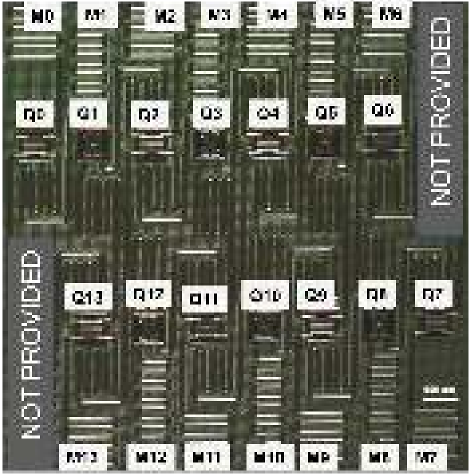
Open Source Quantum Computing

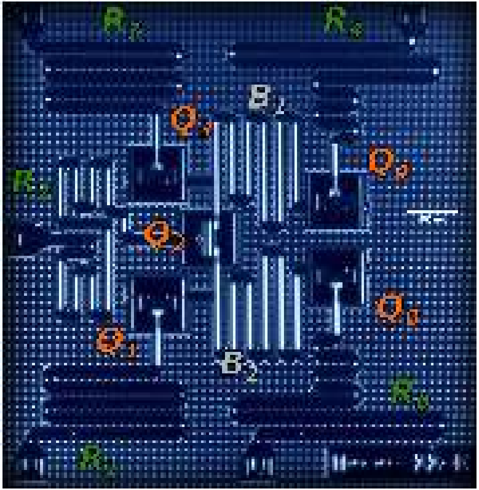
Matthew Treinish
Software Engineer - IBM Research
mtreinish@kortar.org
`mtreinish on Freenode`
https://github.com/mtreinish/open-source-quantum-computing/tree/fossc-2019



Real Quantum Computer

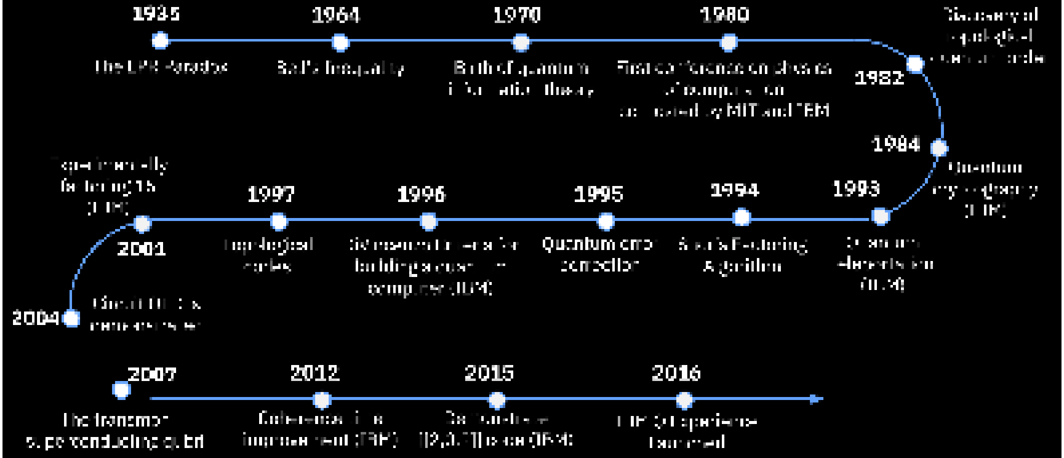
Quantum Chips





https://github.com/Qiskit/ibmq-device-information

History of Quantum Computing



What is Qiskit?

- SDK for working with Noisy Intermediate-Scale Quantum (NISQ) computers
- Apache 2.0 License
- Designed to be backend agnostic
- Includes out-of-the-box local simulators and support for running on IBMQ

Qiskit Elements

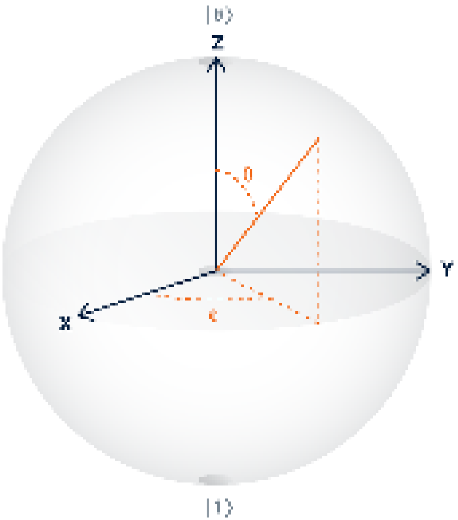
Qiskit Terra

- Is the base layer for applications, provides interface to hardware and simulators
- Provides an SDK for working with quantum circuits
- Compiles circuits to run on different backends
- Written in Python

The Qubit

- The bloch sphere provides a representation of qubit state
- State can be at any point along surface of sphere
- Measuring a qubit occurs along the Z axis. (also called basis states)
- Measuring a qubit is irreversible and will either be 0 or 1

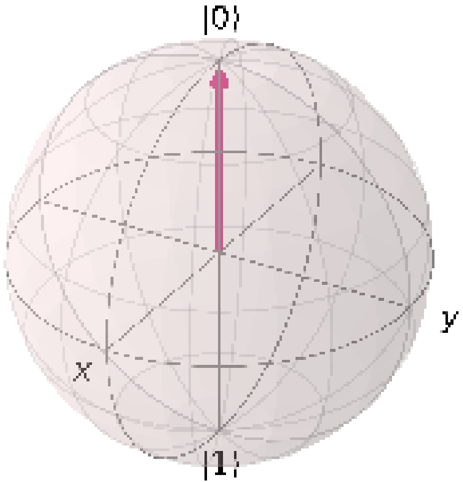
Bloch Sphere:



The Qubit

- The bloch sphere provides a representation of qubit state
- State can be at any point along surface of sphere
- Measuring a qubit occurs along the Z axis. (also called basis states)
- Measuring a qubit is irreversible and will either be 0 or 1

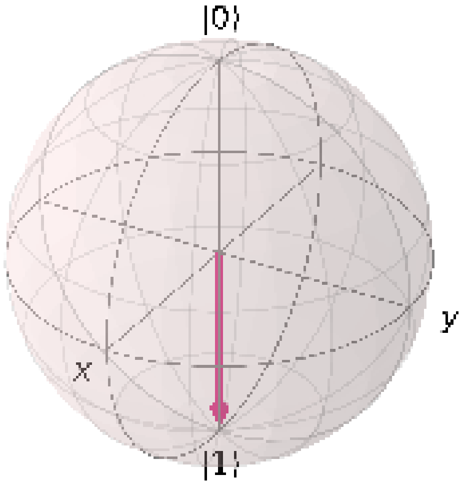
Bloch Sphere:



The Qubit

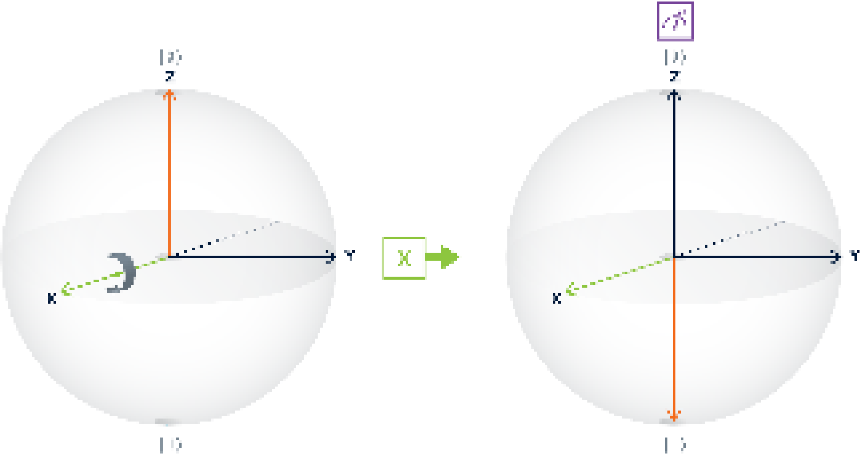
- The bloch sphere provides a representation of qubit state
- State can be at any point along surface of sphere
- Measuring a qubit occurs along the Z axis. (also called basis states)
- Measuring a qubit is irreversible and will either be 0 or 1

Bloch Sphere:



Quantum Gates

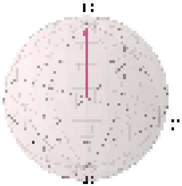
- Quantum Logic Gates are used perform operations on qubits
- Gates are reversible
- Gates can be represented as unitary matrices



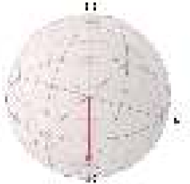
Superposition

- Identically prepared qubits can still behave randomly
- The randomness is inherent in nature

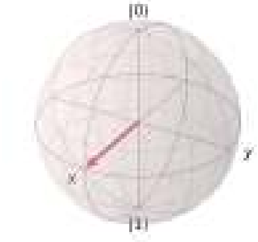
$|0\rangle$



$|1\rangle$



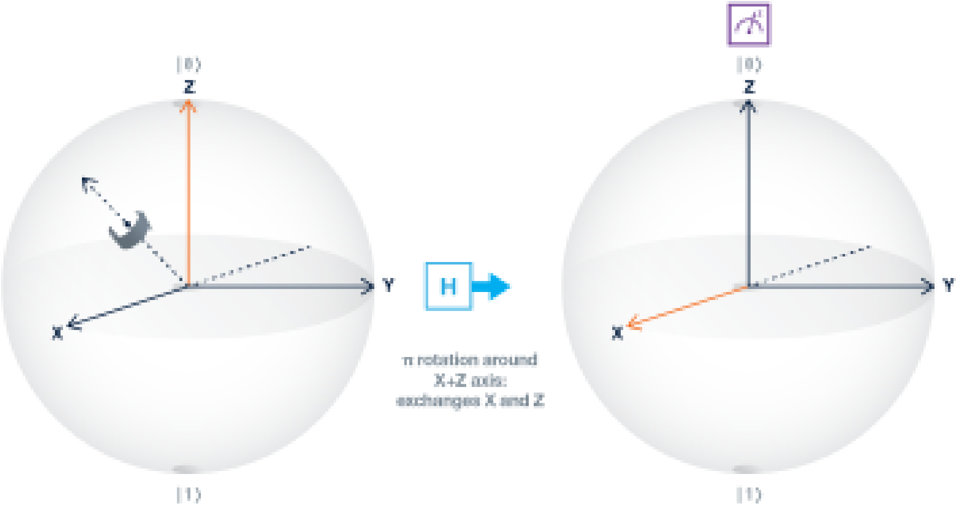
$|0\rangle + |1\rangle$



$\sim$50/50 chance of being

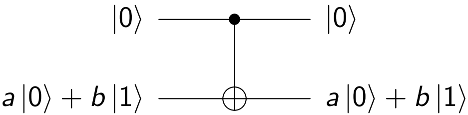
$|0\rangle$ or $|1\rangle$

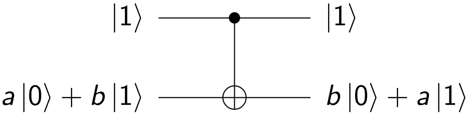
Hadamard Gate



Controlled Not Gate

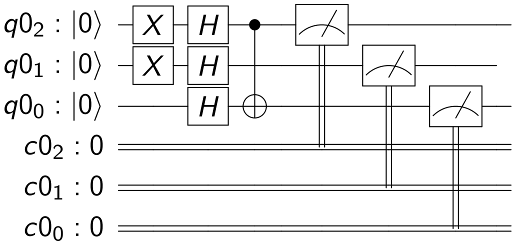
CNOT flips the *target* bit if the *control* bit is 1





Quantum Circuits

Putting it together you build a circuit like:



- Each row represents a bit, either quantum or classical
- The operations are performed each qubit left to right
- Shows dependencies of operations

Bernstein-Vazirani Algorithm[1]

The Oracle

Input (query)

$\Longleftarrow X_{n-1} \cdots X_1 X_0$

Secret Bitstring

$\boxed{S_{n-1} \cdots S_1 S_0}$

Output (result)

$\Longrightarrow X_{n-1} S_{n-1} \oplus \cdots X_1 S_1 \oplus X_0 S_0$

[1]E. Bernstein & U. Vazirani, STOC, 93

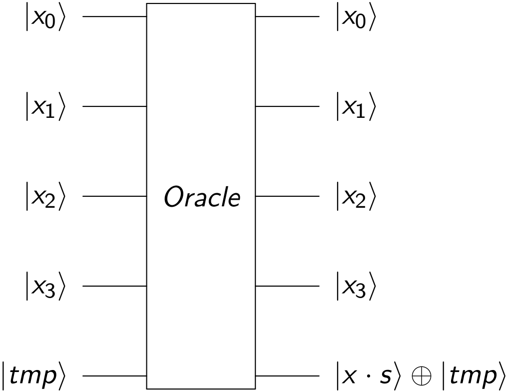
Optimal Classical Oracle

Loop over each bit!

$$\begin{cases} X = 1\,0 \cdots 0\,0 & (2^{n-1}) \\ X = 0\,1 \cdots 0\,0 & (2^{n-2}) \\ \vdots & \\ X = 0\,0 \cdots 1\,0 & (2) \\ X = 0\,0 \cdots 0\,1 & (1) \end{cases}$$

The ideal classical oracle is $\mathcal{O}(n)$

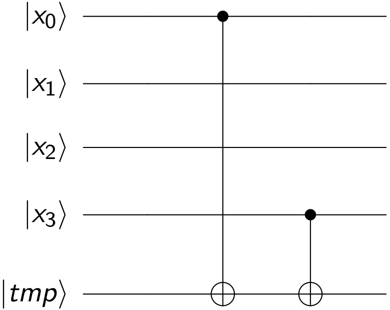
Quantum Oracle



A quantum oracle is $\mathcal{O}(1)$

Quantum Oracle Implementation

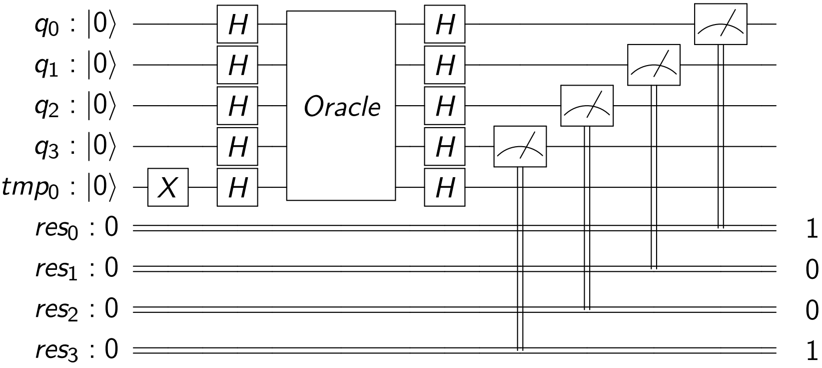
$S = 1001$



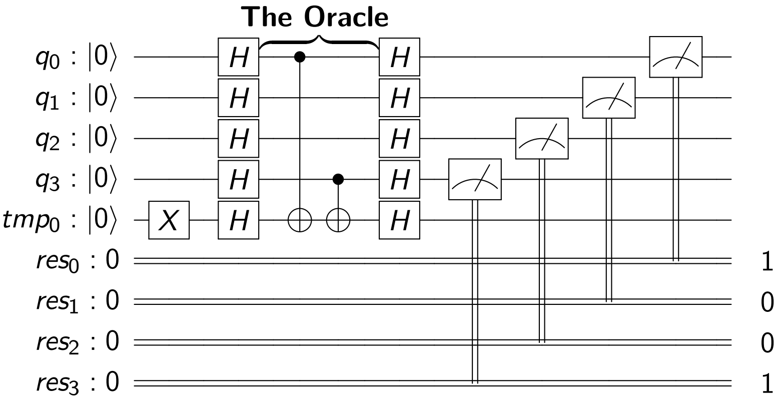
1 0 0 1

$$|x_3 \cdot s_3 \oplus x_2 \cdot s_2 \oplus x_1 \cdot s_1 \oplus x_0 \cdot s_0 \oplus tmp\rangle$$

Full Circuit for a Quantum Oracle



Full Circuit for a Quantum Oracle



Where there is a CNOT phase kickback will set the control qubit to state $|1\rangle$

Live Demo

Open Source in Quantum Computing

- Open source is used to help fosters collaboration
- Also being used as an educational tool to teach quantum concepts
- Learning from the history of development of classical computers
- Many open source quantum computing projects already exist: https://github.com/topics/quantum-computing

Conclusions

- Quantum Computing is about solving problems that we can't with classical computers
- It's still very early for quantum computers
- Not just in labs anymore, quantum computing is accessible by everyone now
- Open source software is playing a key role in the development of quantum computers

Where to get more information

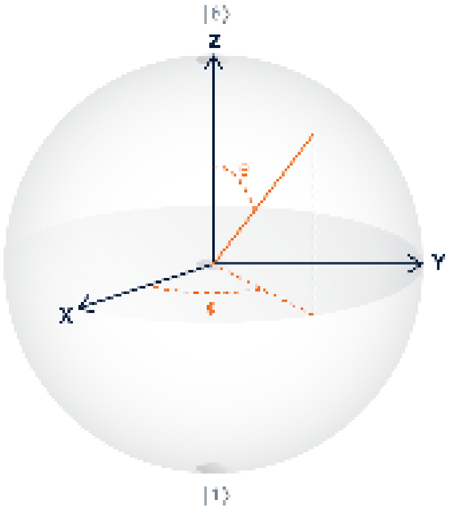
- These Slides: https://github.com/mtreinish/open-source-quantum-computing/tree/fossc-2019
- Qiskit: https://qiskit.org/
- Qiskit Terra on Github: https://github.com/Qiskit/qiskit-terra
- IBM Q Experience: https://quantumexperience.ng.bluemix.net/qx
- Tutorials on Quantum Computing and Qiskit: https://github.com/Qiskit/qiskit-tutorials

BACKUP SLIDES

Qubit Phase

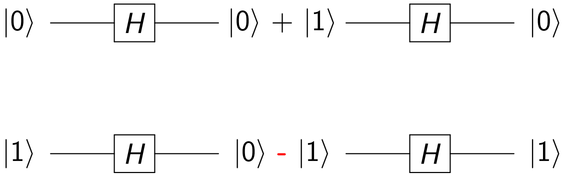
- While qubits are read along the basis vectors you can still use the other dimensions
- The phase can be leveraged to encode more information in the qubit

Phase is ϕ:



Hadamard and Phase

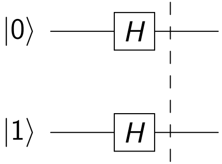
Hadamard gates are self inverses:



Phase

Phase Kickback

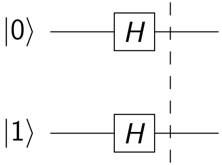
$$(|0\rangle + |1\rangle)(|0\rangle - |1\rangle)$$



Phase Kickback

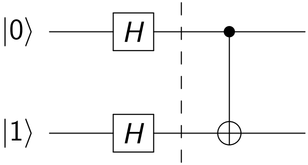
$$(|0\rangle + |1\rangle)(|0\rangle - |1\rangle) = |00\rangle - |01\rangle + |10\rangle - |11\rangle$$

Expand it



Phase Kickback

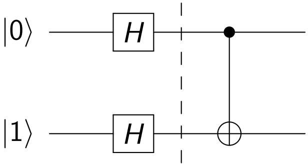
$$(|0\rangle + |1\rangle)(|0\rangle - |1\rangle) = |00\rangle - |01\rangle + |10\rangle - |11\rangle$$



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

Phase Kickback

$$(|0\rangle + |1\rangle)(|0\rangle - |1\rangle) = |00\rangle - |01\rangle + |10\rangle - |11\rangle$$

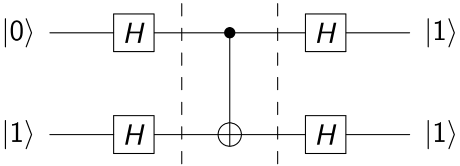


$$|00\rangle - |01\rangle - |10\rangle + |11\rangle = (|0\rangle - |1\rangle)(|0\rangle - |1\rangle)$$

Phase Kickback

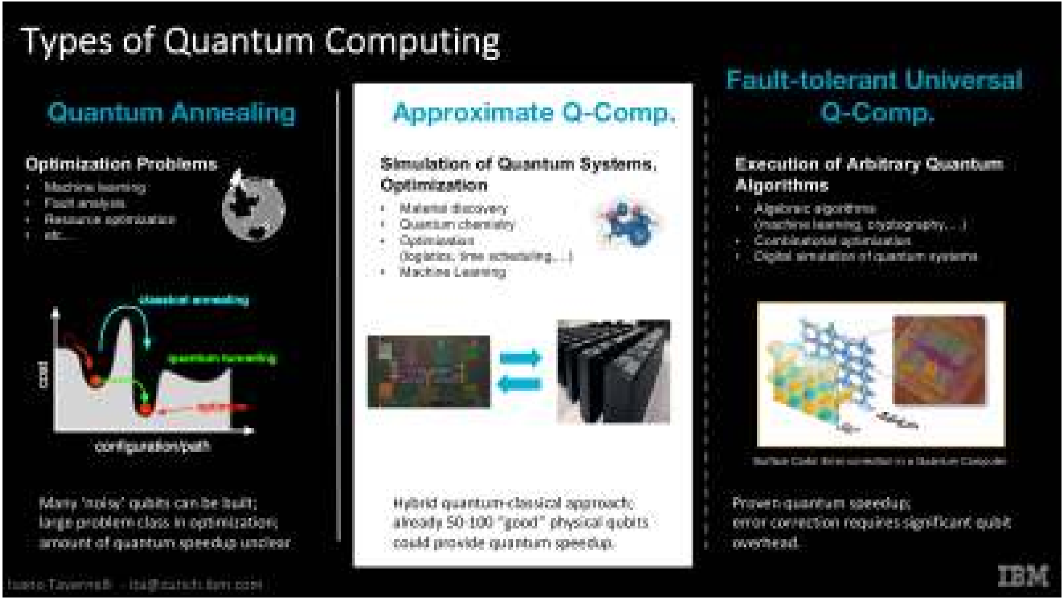
Phase Kickback

$$(|0\rangle + |1\rangle)(|0\rangle - |1\rangle) = |00\rangle - |01\rangle + |10\rangle - |11\rangle$$



$$|00\rangle - |01\rangle - |10\rangle + |11\rangle = (|0\rangle - |1\rangle)(|0\rangle - |1\rangle)$$

Phase Kickback


Types of Quantum Computing
Quantum Annealing
Optimization Problems
classical annealing
quantum tunneling
cost
configuration/path
Many 'noisy' qubits can be built; large problem class in optimization; amount of quantum speedup unclear
Approximate Q-Comp.
Simulation of Quantum Systems, Optimization
Hybrid quantum-classical approach; already 50-100 "good" physical qubits could provide quantum speedup.
Fault-tolerant Universal Q-Comp.
Execution of Arbitrary Quantum Algorithms
Proven quantum speedup; error correction requires significant qubit overhead.
IBM

Entanglement

- 2 qubits too far apart to influence each other can behave in a way that are **individually random** but are **strongly correlated**
- The state of an n-qubit system cannot (in general) be written as the state of its individual components.
- To simulate entanglement you need exponential resources
- CNOT gates are often used to setup entanglements

One Qubit:

$$a|0\rangle + b|1\rangle$$

Two Qubits:

$$a|00\rangle + b|01\rangle + c|11\rangle$$

Three Qubits:

$$a|000\rangle + b|001\rangle + c|010\rangle + d|011\rangle + e|100\rangle + f|101\rangle + g|110\rangle + h|111\rangle$$