Open Source Quantum Computing

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https://github.com/mtreinish/open-source-quantum-computing

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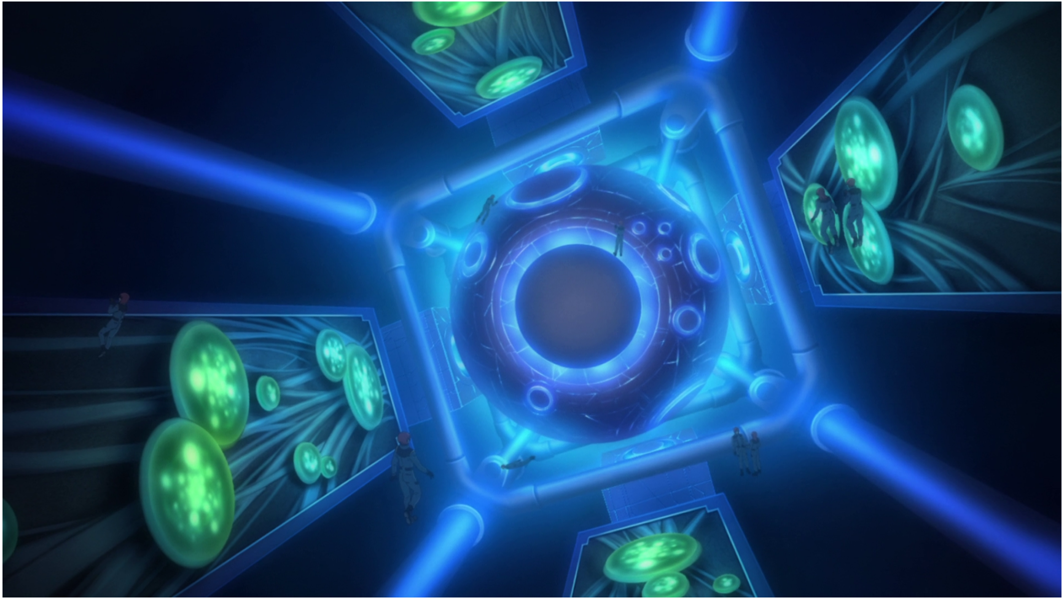
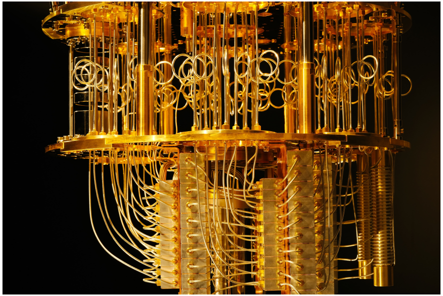
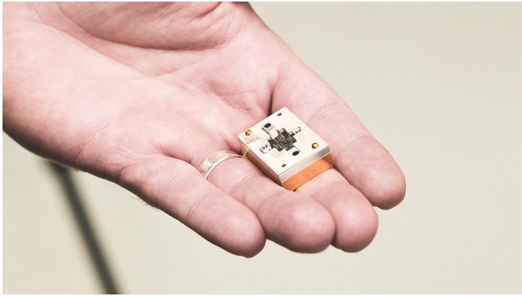
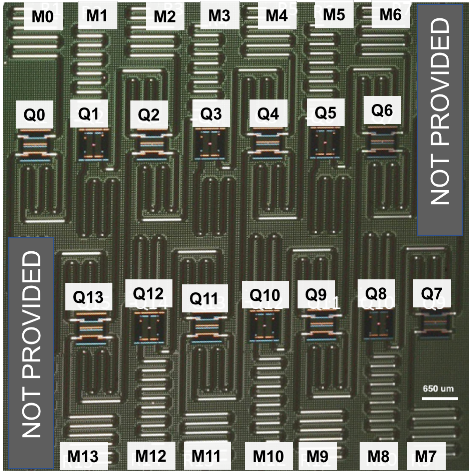


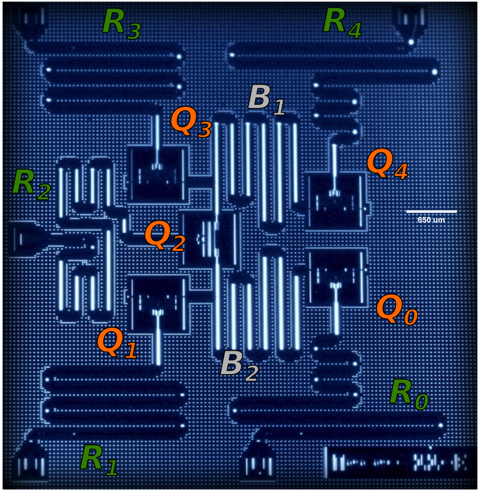
Real Quantum Computer



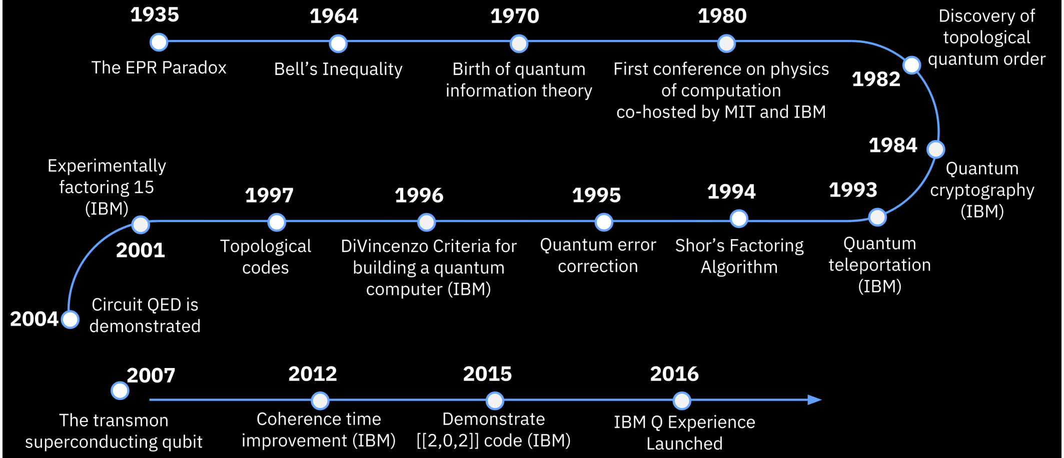


Quantum Chips





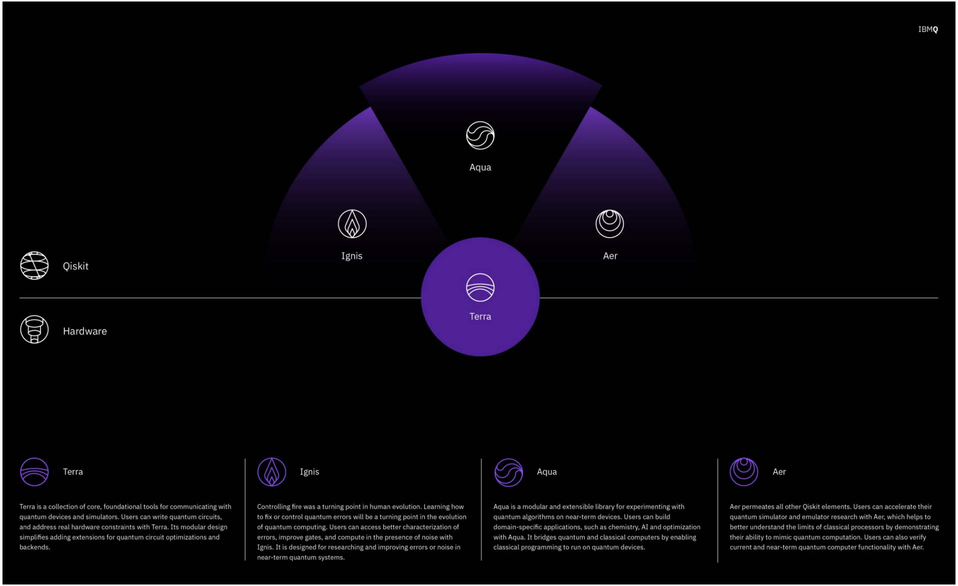
History of Quantum Computing



What is Qiskit?

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

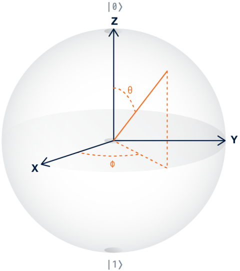
Qiskit Elements



The Qubit

- The bloch sphere provides a represetation 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
- Qubits start at $|0\rangle$

Bloch Sphere:



Quantum Gates

- Quantum Logic Gates are used perform operations on qubits
- Each gate is reversible
-

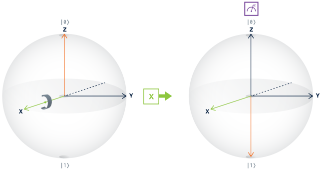
Gate

$|0\rangle \; - \boxed{X} -$

Matrix Form

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

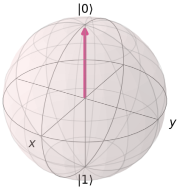
Bloch Sphere



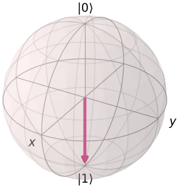
Superposition

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

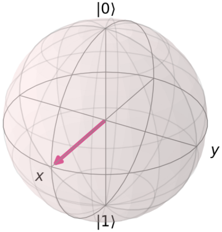
$$|0\rangle$$



$$|1\rangle$$



$$|0\rangle + |1\rangle$$



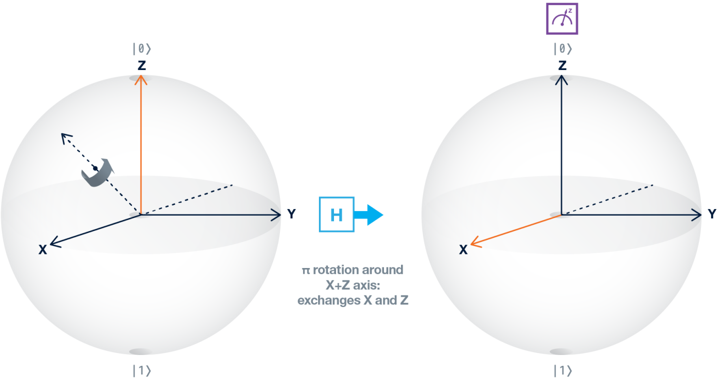
Hadamard Gate

Gate

$$|0\rangle \;—\boxed{H}—$$

Matrix Form

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

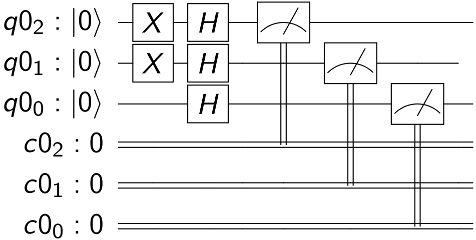


Qubit Phase

- While qubits are read along the basis vectors there is dimension
- The phase can be leveraged to encode more information in the qubit

Quantum Circuits

Putting it together you build a circuit like:



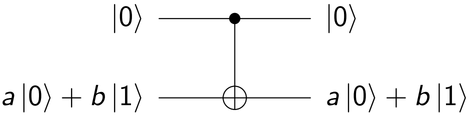
- Each row represents a bit, either quantum or classical
- The operations are performed each qubit left to right

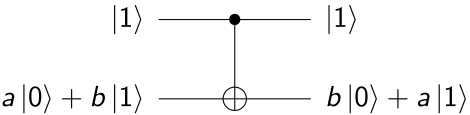
Multiple Qubits

The Complexity and Power of Quantum Information

Controlled Not Gate

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





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

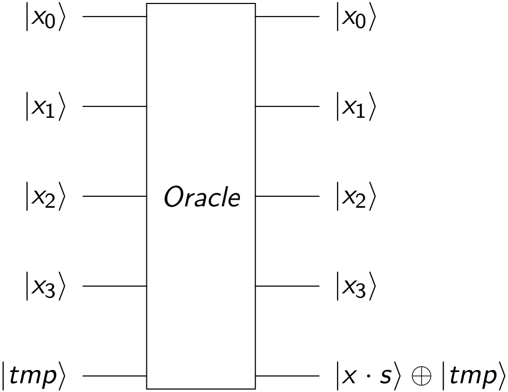
Optimal Classical Oracle

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 $\mathcal{O}(n)$

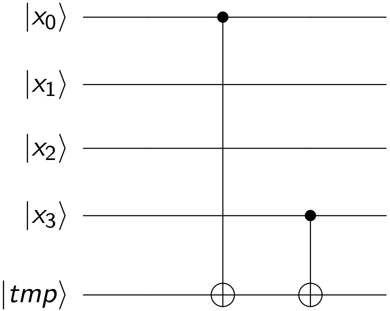
Quantum Oracle



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

Quantum Oracle Implementation

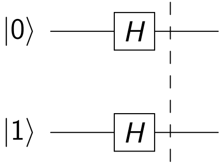
$$S = 0101$$



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

Phase Kickback

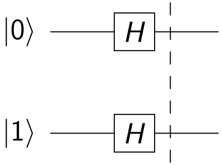
$$(|0\rangle + |1\rangle)(|0\rangle - |1\rangle)$$



Phase Kickback

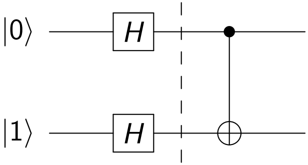
$$(|0\rangle + |1\rangle)(|0\rangle - |1\rangle) = |00\rangle - |01\rangle + |10\rangle - |11\rangle)$$

Expand it



Phase Kickback

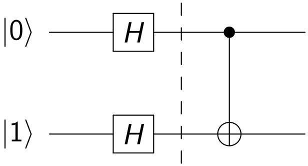
$$(|0\rangle + |1\rangle)(|0\rangle - |1\rangle) = |00\rangle - |01\rangle + |10\rangle - |11\rangle)$$



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

Phase Kickback

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

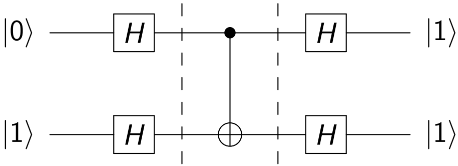


$$|00\rangle - |01\rangle - |10\rangle + |11\rangle = (|0\rangle - |1\rangle)(|0\rangle - |1\rangle)$$

Phase Kickback

Phase Kickback

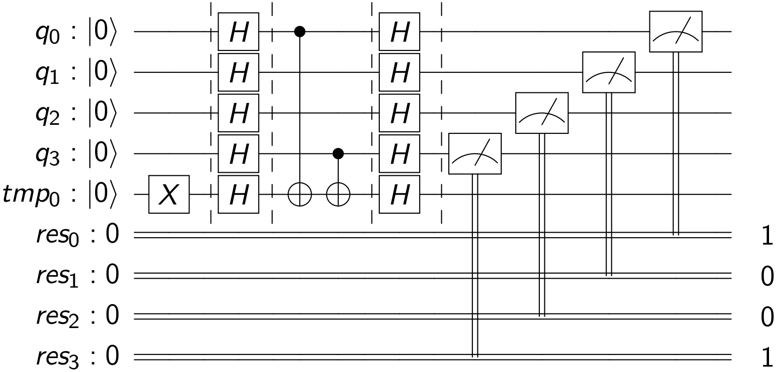
$$(|0\rangle + |1\rangle)(|0\rangle - |1\rangle) = |00\rangle - |01\rangle + |10\rangle - |11\rangle)$$



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

Phase Kickback

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

- The tools for developing quantum programs are almost all open
- Foster collaboaration while the field is just taking off
- Learn and build of history of development of classical computers

Other Open Source Tools

- https://github.com/rigetticomputing/pyquil
- https://github.com/ProjectQ-Framework/ProjectQ
- https://github.com/quantumlib/Cirq
- https://github.com/qutip/qutip
- https://github.com/XanaduAI/strawberryfields

A lot more out there: https://github.com/topics/quantum-computing

Conclusions

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

Where to get more information

- Qiskit: https://qiskit.org/
- IBM Q Experience: https://quantumexperience.ng.bluemix.net/qx
- Tutorials on Quantum Computing and Qiskit: https://github.com/Qiskit/qiskit-tutorials
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