Intro to Quantum Computing

CSC Spring 2022,
Zoë Webb-Mack (CSC Postbacc Fellow, 2021-2022)

Roadmap

- Big picture
  - Why quantum computers?
  - What is a quantum computer?
  - What are they good for? (And what aren't they good for?)
- Nitty gritty
  - How do we make use of quantum logic?
  - How do we "code" on a quantum computer?
- Coding quantum circuits using Qiskit

Big picture

IonQ Stock Is Your Opportunity to Invest In Quantum Computing

OPINION

Quantum computing has a hype problem

Quantum computing startups are all the rage, but it's unclear if they'll be able to produce anything of use in the near future.

By Sankar Das Sarma March 28, 2022

Outgunning The US, China Looks At Gaining Unassailable Lead In Quantum Tech With New Helium Cooling System

By EurAsian Times Desk - April 5, 2022

Quantum Computing Startup Alice&Bob Raises $30M

March 10, 2022

10 DIFFICULT PROBLEMS QUANTUM COMPUTERS CAN SOLVE EASILY

LATEST NEWS QUANTUM COMPUTING

by Apoorva Bellapu / April 3, 2022

New Search Algorithm Could Be Quantum Leap in Detection of Gravitational Waves

TOPICS: Algorithm Astrophysics Gravitational Waves Quantum Computing Quantum Physics University Of Glasgow

By UNIVERSITY OF GLASGOW APRIL 5, 2022

HOW CAN QUANTUM COMPUTING CHANGE THE WORLD?

LATEST NEWS QUANTUM COMPUTING

by Madhurjya Chowdhury / March 24, 2022

Why *quantum* computers?

Quantum computers using quantum logic

Qubits can store more information because of superposition (N qubits ~ 2^N bits)

Can do more complex problems, where probabilistic logic is native, without having to approximate

Could solve classically intractable problems?

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…in theory

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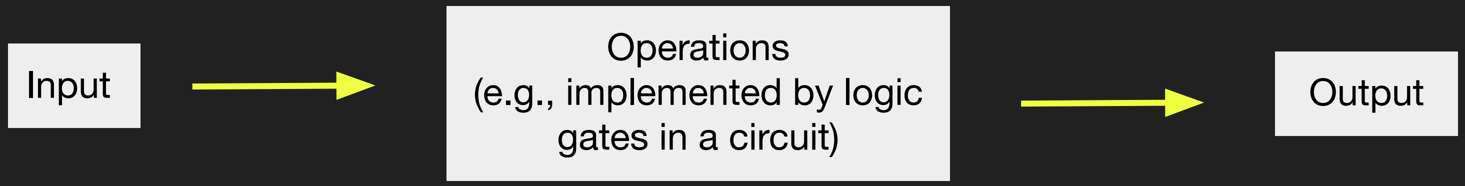
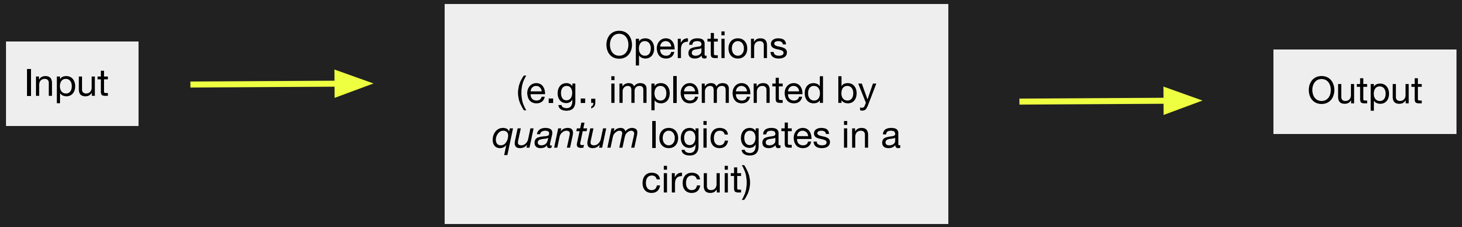


What is a quantum computer?

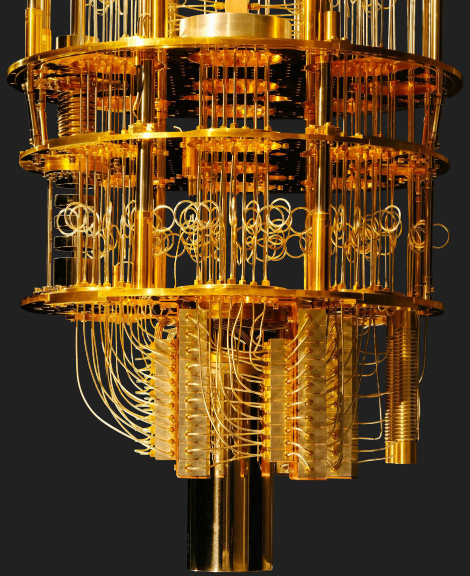
A computer that obeys the rules of quantum physics (as opposed to classical physics).



What is a quantum computer?

Types of hardware (that act like atoms):

- Circuits using superconductors + Josephson Junctions
- Trapped ions
- Defects in crystals
- Single atoms
- Photons



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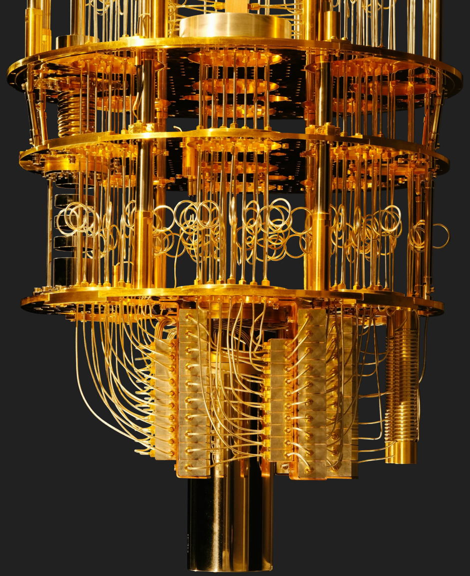

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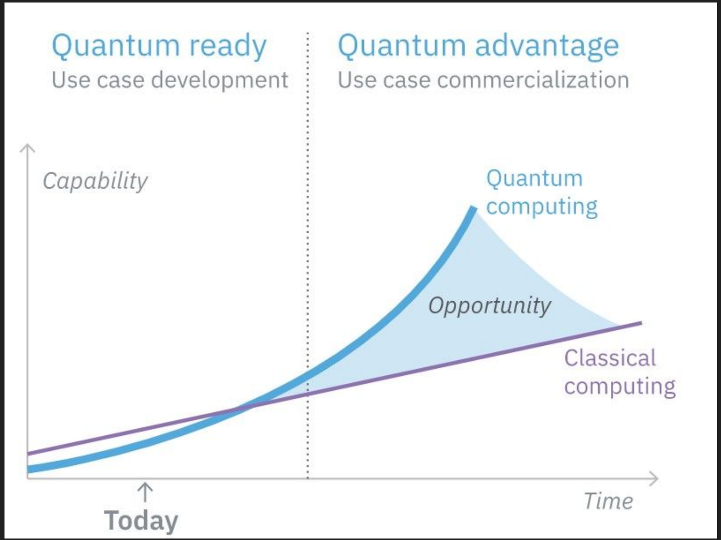
→ an interdisciplinary effort

Some practical challenges

- Quantum computing is in its NISQ (noisy intermediate-scale quantum) era
  - Small and not fault-tolerant
- Challenges with fidelity, coherence time, and processing time
- Also: resource intensive



What *is* a quantum computer good for?

- In the long run: encryption and secure computing, optimization problems, large computations
- In slightly more near-term: simulating naturally quantum systems for uses in biochemistry and physics
  - Simulating nature with nature

Getting down to it…

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Superposition & Entanglement

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Superposition & Entanglement

Multiple states at once

Spooky action at a distance

Superposition

A quantum system (like a qubit, for example) can be in multiple distinct states at the same time. When we make a measurement on the system, superposition "collapses," and we see only one state.

Bits and qubits

Classical bit: 0 or 1

Qubit: superposition of 0 and 1

Superposition

So, we can have a qubit in the following state:

$$|Q\rangle = \frac{1}{\sqrt{2}}|0\rangle + \frac{1}{\sqrt{2}}|1\rangle$$

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$$|Q\rangle = \frac{1}{\sqrt{2}}|0\rangle + \frac{1}{\sqrt{2}}|1\rangle$$

This number squared is the probability that when we measure $|Q\rangle$, we'll get $|0\rangle$

This number squared is the probability that when we measure $|Q\rangle$, we'll get $|1\rangle$

Superposition

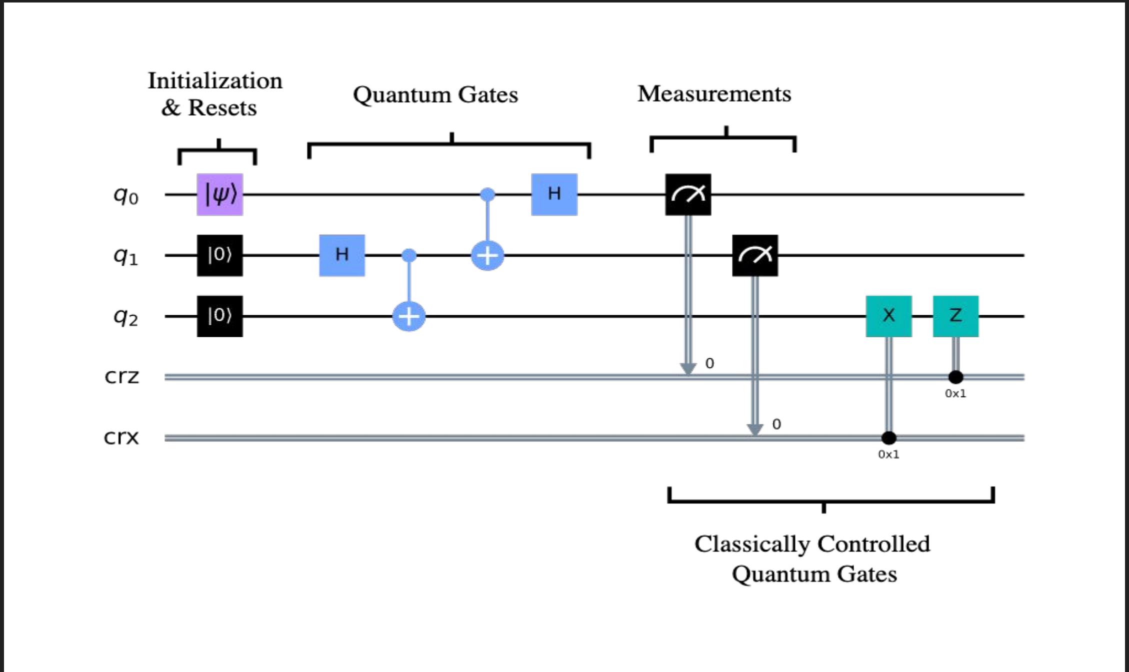
For multiple qubits:

$$|Q1\rangle \otimes |Q2\rangle = [\frac{1}{\sqrt{2}} |0\rangle + \frac{1}{\sqrt{2}} |1\rangle] \otimes |0\rangle$$

$$= \frac{1}{\sqrt{2}} |00\rangle + \frac{1}{\sqrt{2}} |10\rangle$$

$|Q2\rangle$ is always in state $|1\rangle$

Quantum circuits



Logic gates

Hadamard gate: puts qubit in a state of superposition

CX gate (CNOT): if the control qubit is $|1\rangle$, flips the target gate

CCX (CCNOT or "Toffoli"): if both control qubits are $|1\rangle$, flip the target gate

Let's code!