From Qubits to Algorithms

Introduction to Quantum Computing

Lloyd Seo & William Widjaja

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for

From Qubits to Gates: Introduction t...

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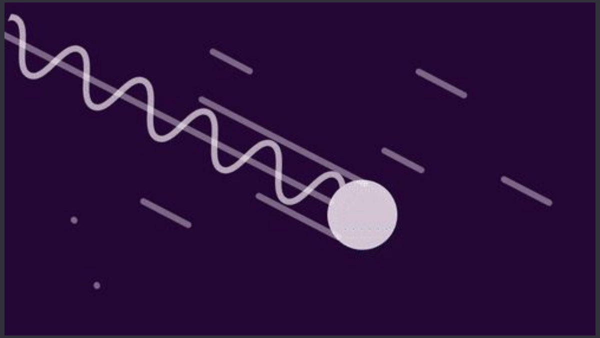
Icebreaker

Introduce yourself to the people around you!

1. Name
2. Pronouns
3. Year
4. College



Q. What do you think quantum computing is?

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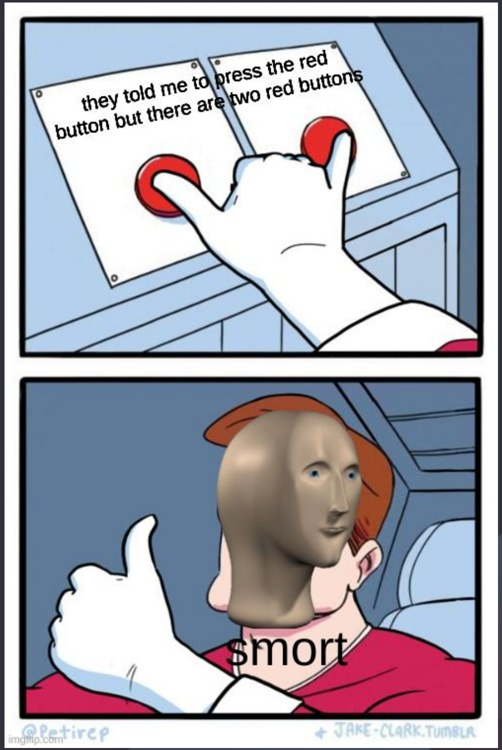
True or False?

Q. Quantum computers can solve and not solve a problem simultaneously

True or False?

Q. Quantum computers can solve and not solve a problem simultaneously

True ✅



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True or False?

Q. Quantum computers need to be kept colder than outer space to work

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True or False?

Q. Quantum computers need to be kept colder than outer space to work

True ✅

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True or False?

Q. We can use a particle on Earth to figure out the state of a particle in the Andromeda Galaxy

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True or False?

Q. We can use a particle on Earth to figure out the state of a particle in the Andromeda Galaxy

True ✅

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True or False?

Q. Quantum computing is real?!

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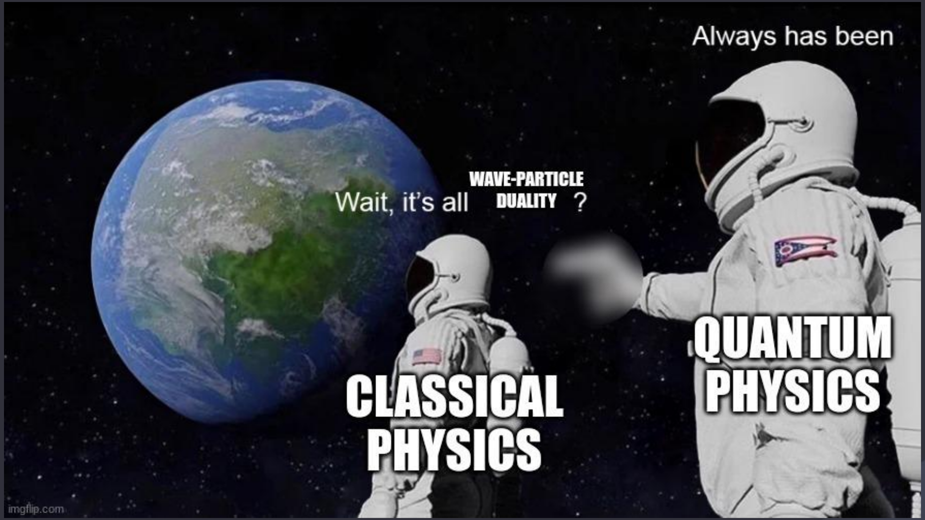
True or False?

Q. Quantum computing is real?!

True ✅



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Agenda

1 **Basics of Quantum Computing**
Quantum vs classical computing

2 **Superposition & Decoherence**
Fundamental quantum mechanics

3 **Entanglement & Interference**
Exploring quantum mechanics

4 **Applications**
Where can we use quantum computing?

5 **The Future**
What's next?

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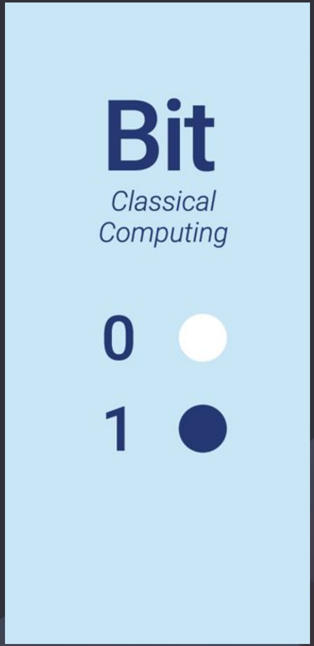
What we’re familiar with: Classical Computing

- Computer chips (ex. CPU)
  - Modules (ex. addition, multiplication)
    - Logic gates (ex. AND, OR, XOR)
      - Transistors
        - Bits



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0000	0001	0010	0011
0100	0101	0110	0111
1000	1001	1010	1011
1100	1101	1110	1111

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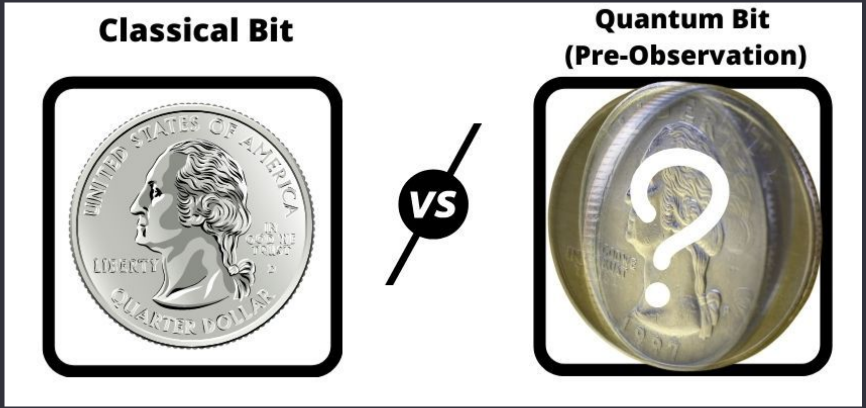
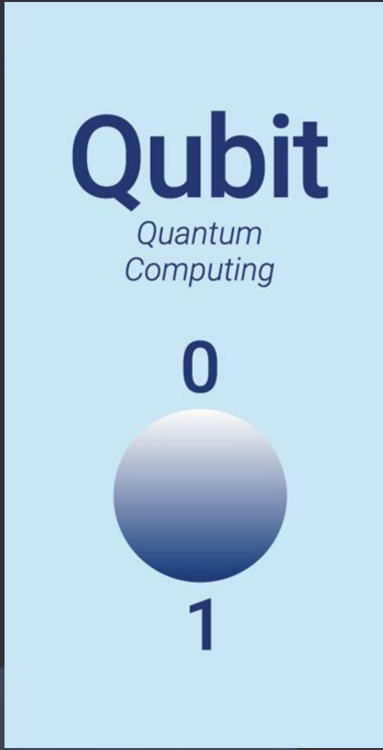
Replacing bits with qubits

Qubit (quantum bit): Can represent 0 and 1 simultaneously





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0000	0001	0010	0011
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Quantum Mechanics

The field of physics that explains the motion and interaction of **subatomic particles**

- "Quantum": Referring to the smallest discrete amount of something

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Quantum Computing

Multidisciplinary field comprising aspects of computer science, physics, and mathematics that utilizes **quantum mechanics** to solve complex problems faster than on classical computers.

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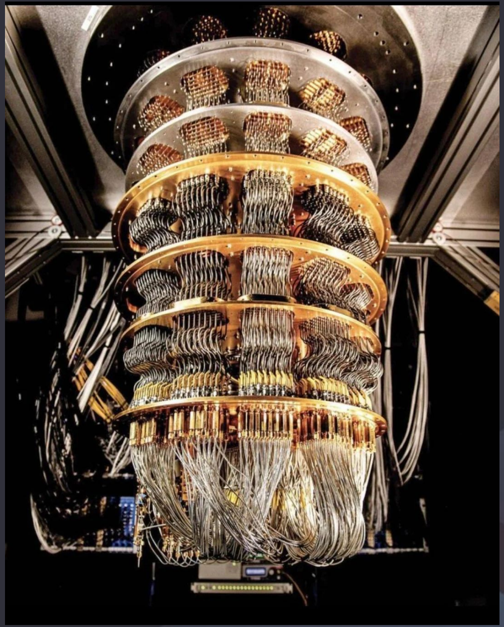
Breakdown of Quantum Computer

- Quantum processor (QPU)
  - Quantum circuits
    - Quantum gates
      - Quantum systems
        - Qubits



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Key Principles of Quantum Mechanics

1. Superposition
2. Entanglement
3. Decoherence
4. Interference

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Superposition

Superposition: State where a qubit represents multiple configurations at once

Chances of Heads (0): 50%

Chances of Tails (1): 50%

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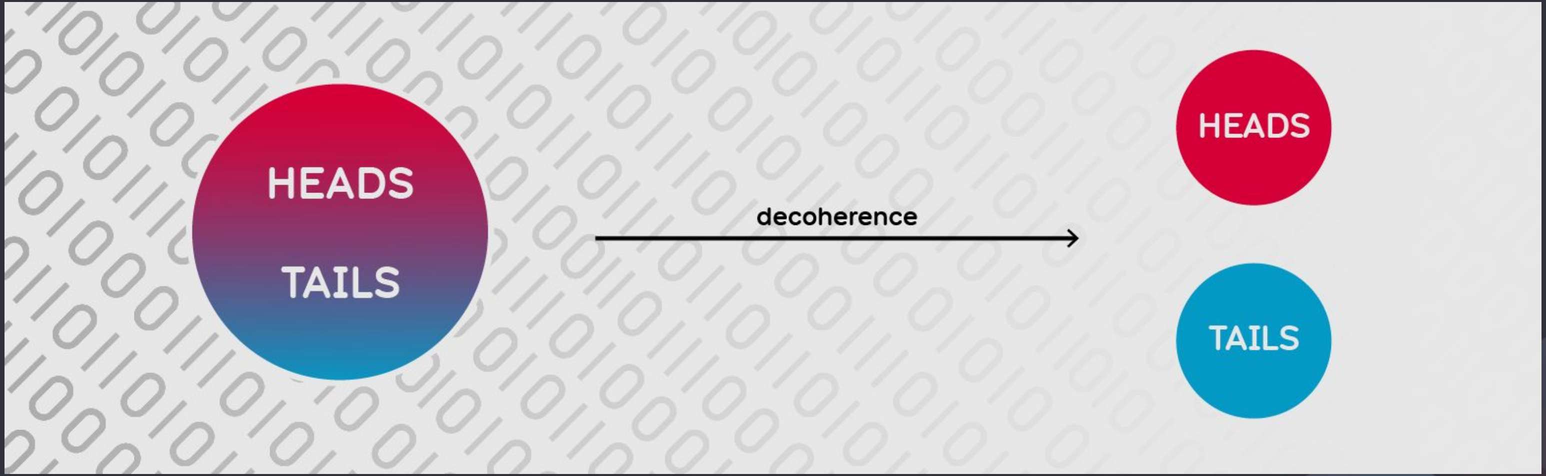
Decoherence



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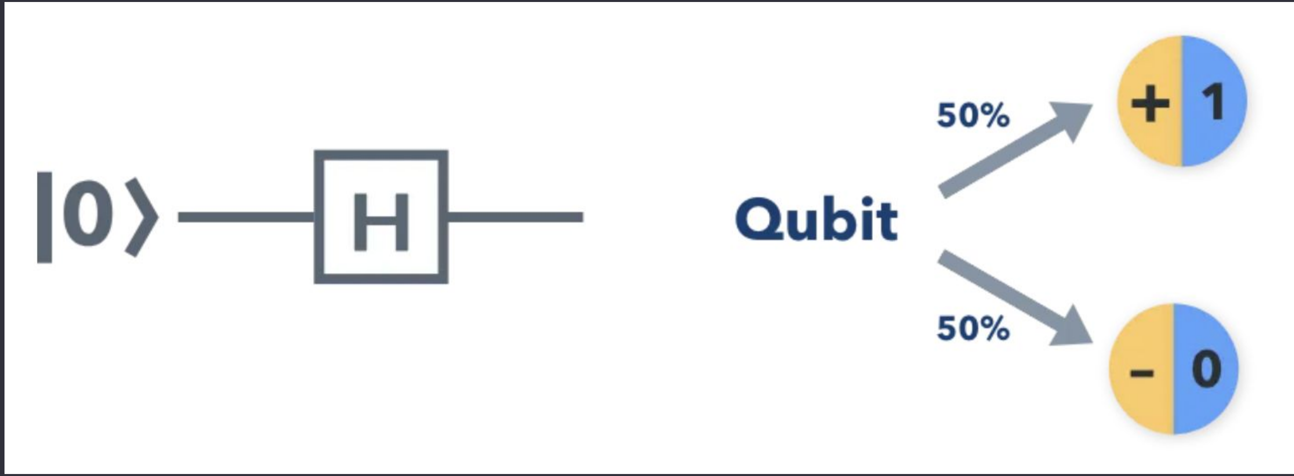
Hadamard Gate



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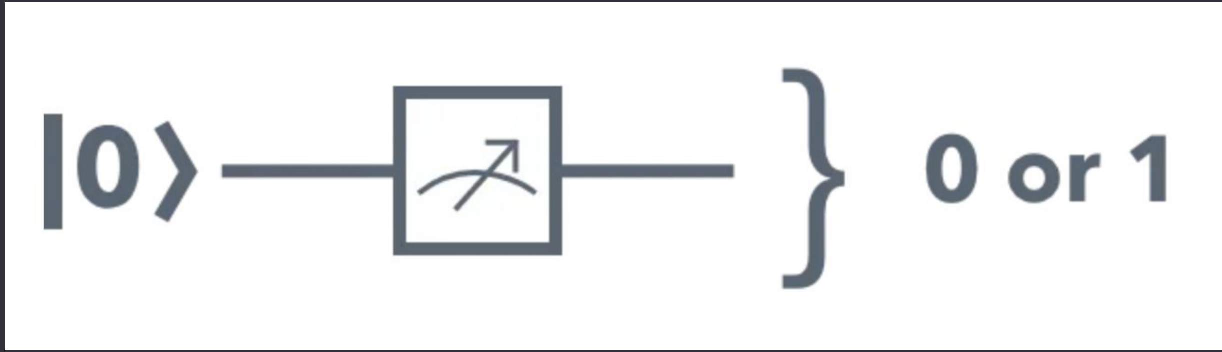
Measurement



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Quantum Circuit–Superposition

acmurl.com/superposition-circuit

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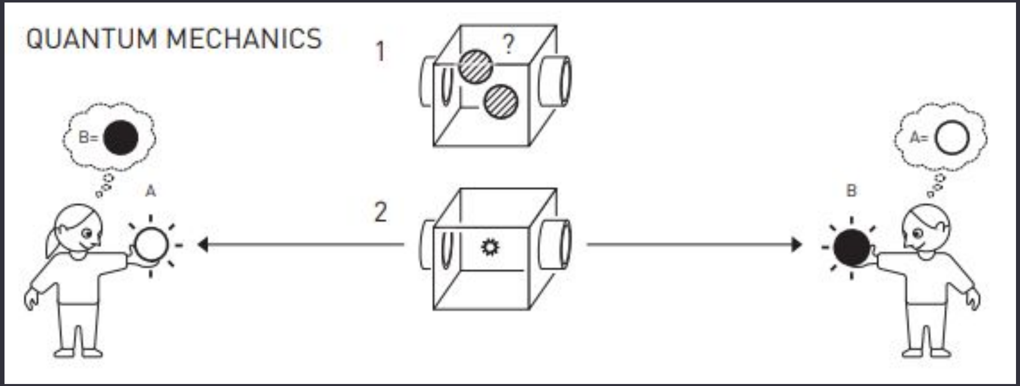
Entanglement



Entanglement: If two qubits are entangled, measuring one qubit collapses the states of both qubits

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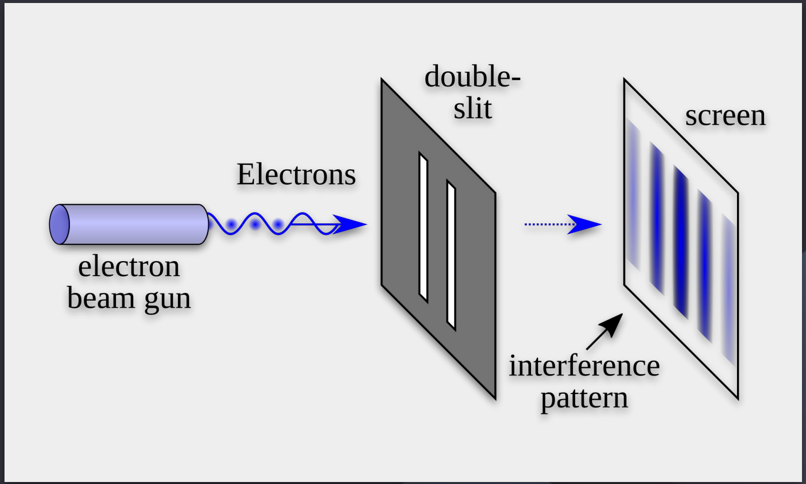
Wave-Particle Duality

Quantum objects, like qubits, do not have a definite state and exhibit both wave-like and particle-like behaviors until they are measured.



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Interference

Interference: Phenomenon where entangled qubits affect the probabilities of outcome for one another

- Constructive interference: Amplifying the correct solution
- Destructive interference: Canceling out wrong solutions

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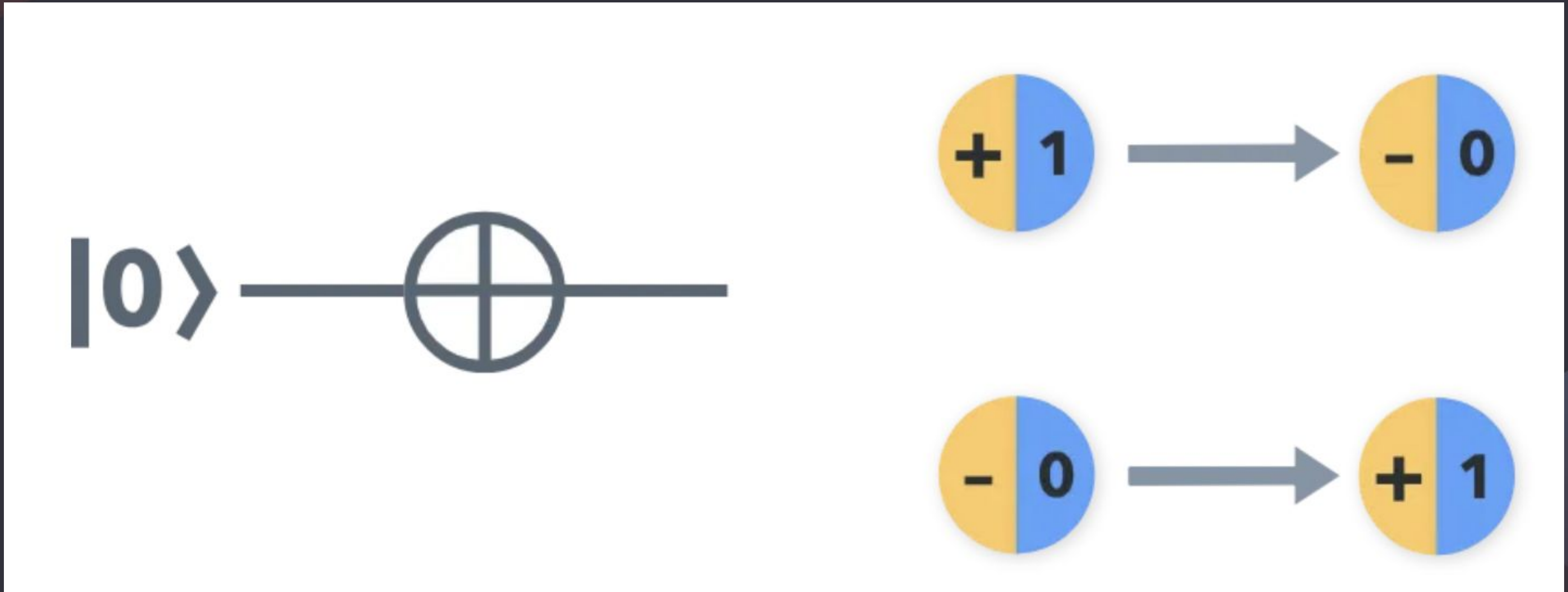
Pauli-X Gate



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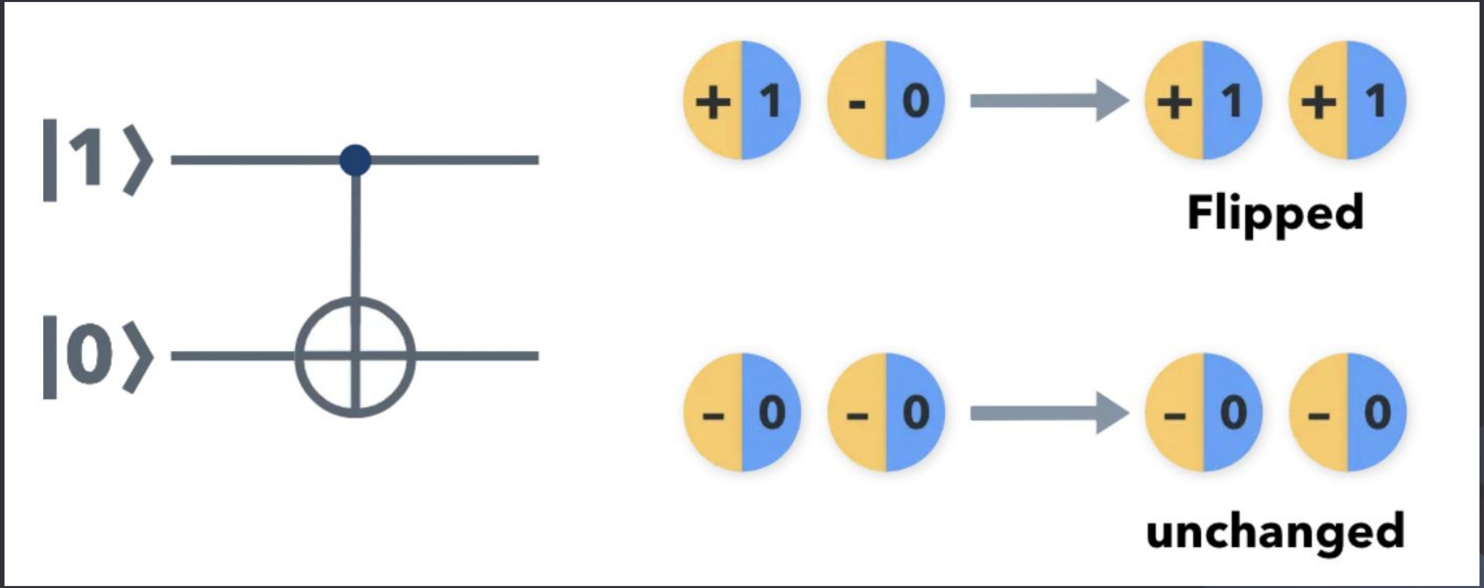
Controlled-NOT (CNOT) Gate



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Quantum Circuit–Entanglement

acmurl.com/entanglement-circuit

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Optimization

- **Grover's algorithm**: Find entry in an unstructured database in **O(√N)**, whereas classical search requires **O(N)** steps
- Used to find optimal path/schedule/allocation in optimization

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Cryptanalysis

- Many encryption algorithms (RSA, Elliptic Curve Cryptography, Diffie-Hellman, etc.) rely on the difficulty of factoring large numbers
- **Shor's algorithm**: Solves encryption problems in $O(n^k)$, whereas classical algorithms take $O(2^n)$

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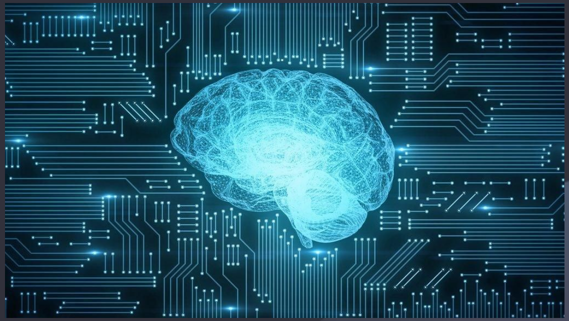
Machine Learning

- Machine learning algorithms often rely on computationally expensive linear algebra operations
- **HHL algorithm**: Solves systems of linear equations (Ax=b) exponentially faster than classical algorithms



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Why is Quantum Computing Not Widely Used?

1. Quantum components are extremely susceptible to environmental factors
2. Difficult to run large quantum programs long enough to solve practical problems
3. Current classical computing hardware is much more advanced than its quantum counterparts

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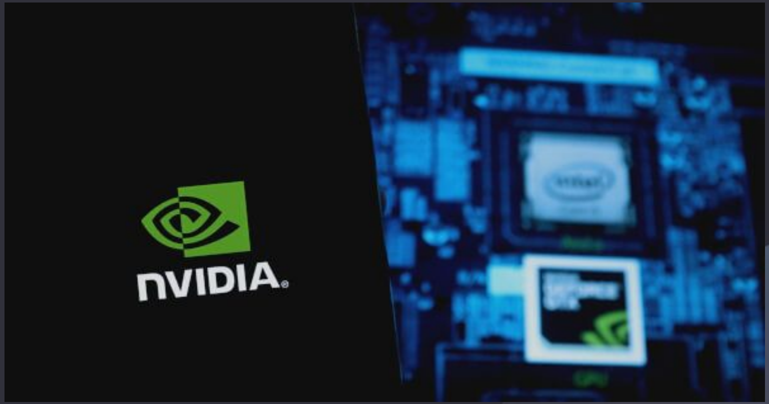
Advancements in Quantum Computing

- Google and NVIDIA are working together to develop quantum processing units using GPU-accelerated quantum simulations



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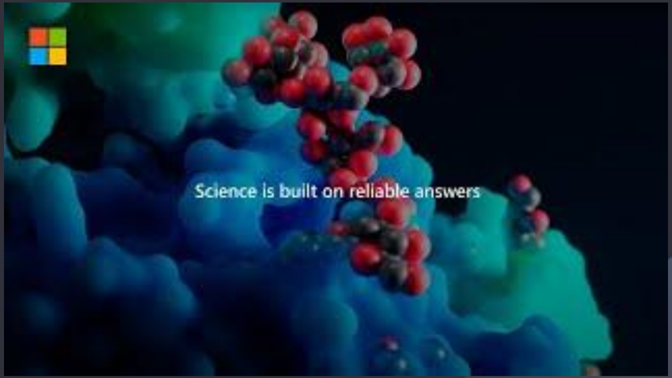
Advancements in Quantum Computing

- Microsoft and Quantinuum created logical qubits with an error rate 800x better than physical qubits



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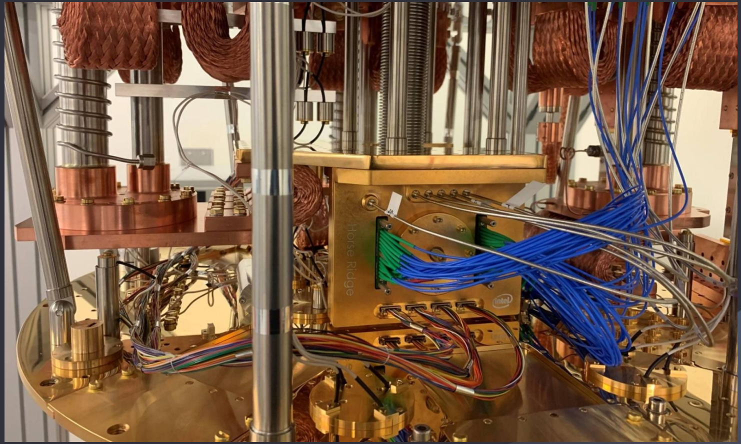
Advancements in Quantum Computing

- Intel developed a cryogenic control chip, Horse Ridge II, which can operate at absolute zero and directly control qubits



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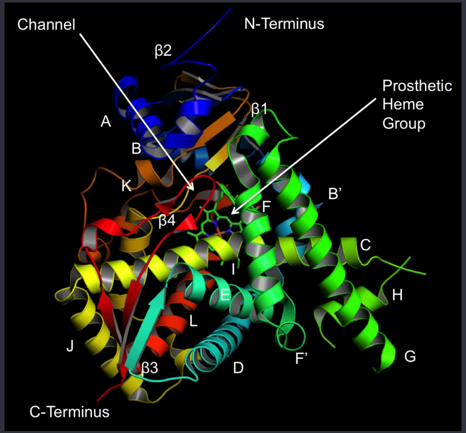
Drug Metabolism

Can allow us to resolve the chemistry of an enzyme called cytochrome P450 responsible for metabolizing ~70% of human drugs



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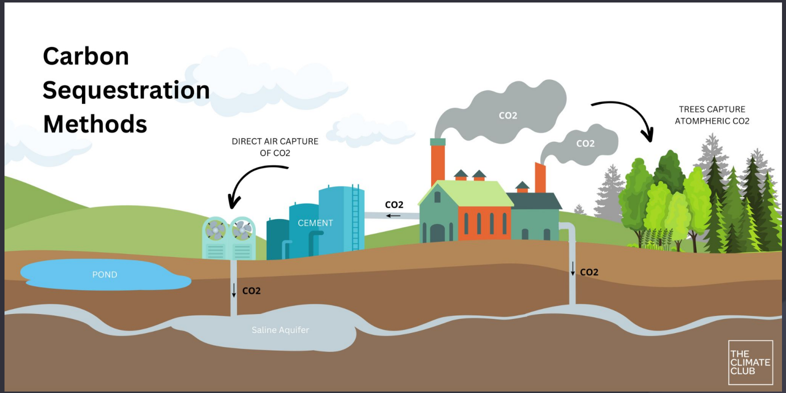
CO_2 Sequestration

studies suggest that quantum computers should be able to model CO_2 reactions with various catalysts more accurately



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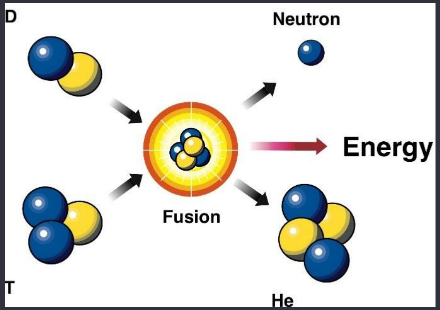
Fusion Reactions

we would be able to simulate one of the first inertial fusion reactions that produces more energy than was put directly into it (more information on the resources slide)



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And More!

QUANTUM FOR REAL-WORLD IMPACT

$5 MILLION

Prize Purse

XPRIZE Quantum Applications is a 3-year, $5M global competition designed to generate quantum computing (QC) algorithms that can be put into practice to help solve real-world challenges.

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Resources for Further Learning

IBM Quantum Composer Tutorial

CSE 190 w/ Daniel Grier

Quantum Hardware:
https://medium.com/swlh/the-physical-side-of-quantum-e69b5c5c30ae

Entanglement and "Spooky Action":
https://www.quantamagazine.org/how-bells-theorem-proved-spooky-action-at-a-distance-is-real-20210720/

Decoherence and Interference:
https://plato.stanford.edu/entries/qm-decoherence/

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