Quantum Computing 101

An Easy Introduction to a Hard Topic

Annie Vella | 9th October 2024

Quantum Computers

- Use the principles of quantum mechanics to process information
- Use qubits instead of bits
- They have to be kept at extremely low temperatures - close to absolute zero (0 Kelvin or -273.15°C) - to enable superconductivity
- This is colder than outer space (average of 2.7 Kelvin)!

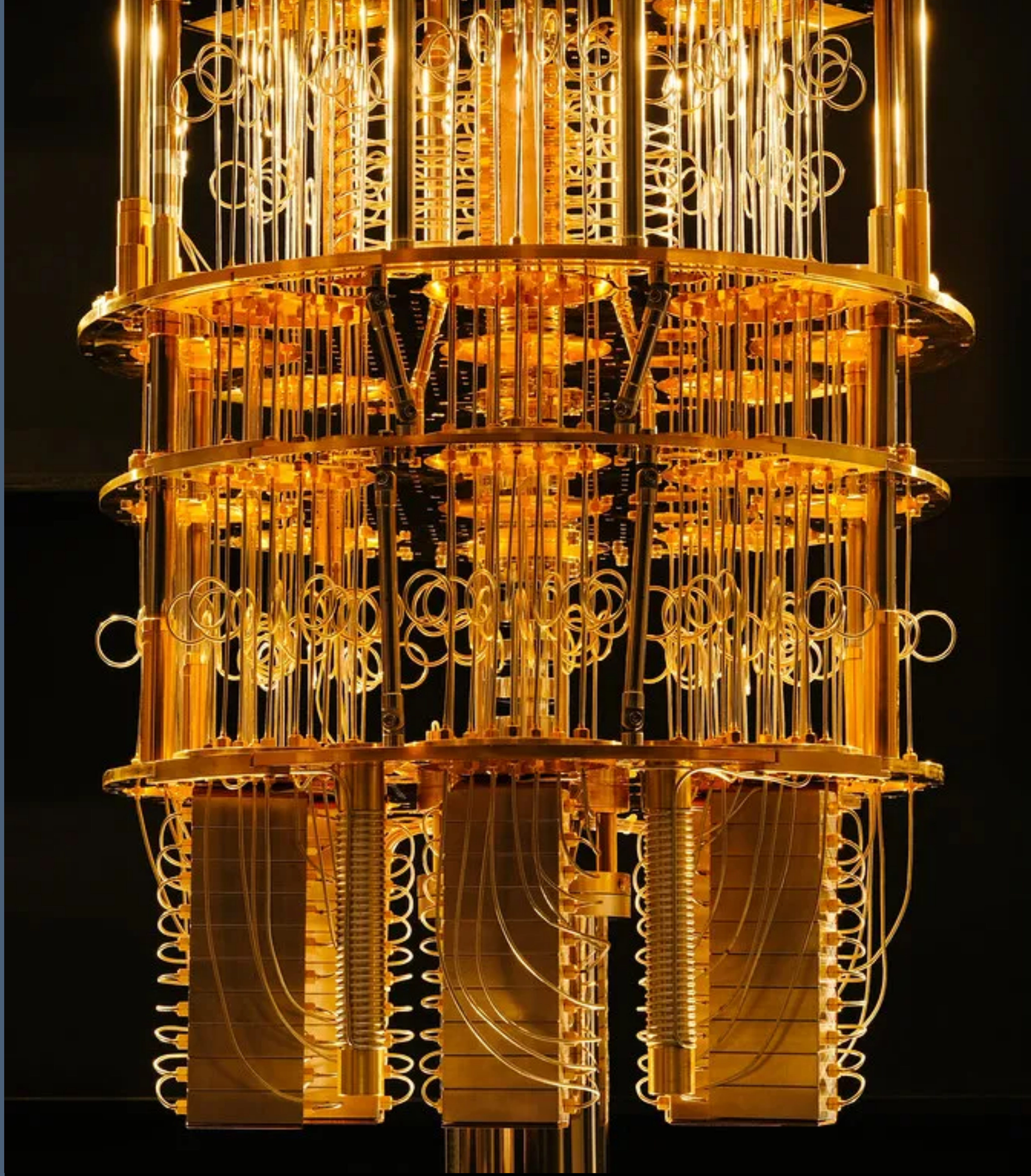
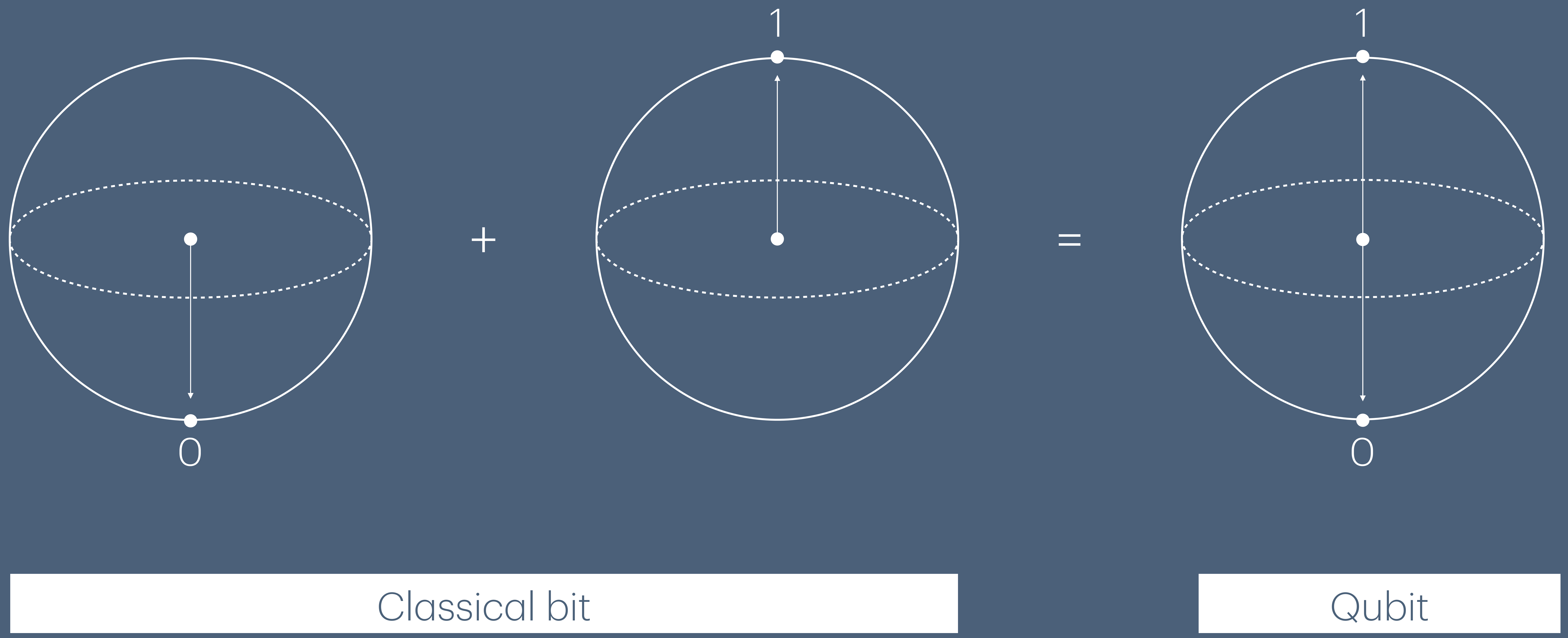


Image credit: https://www.flickr.com/photos/ibm_research_zurich/40786969122

Superposition

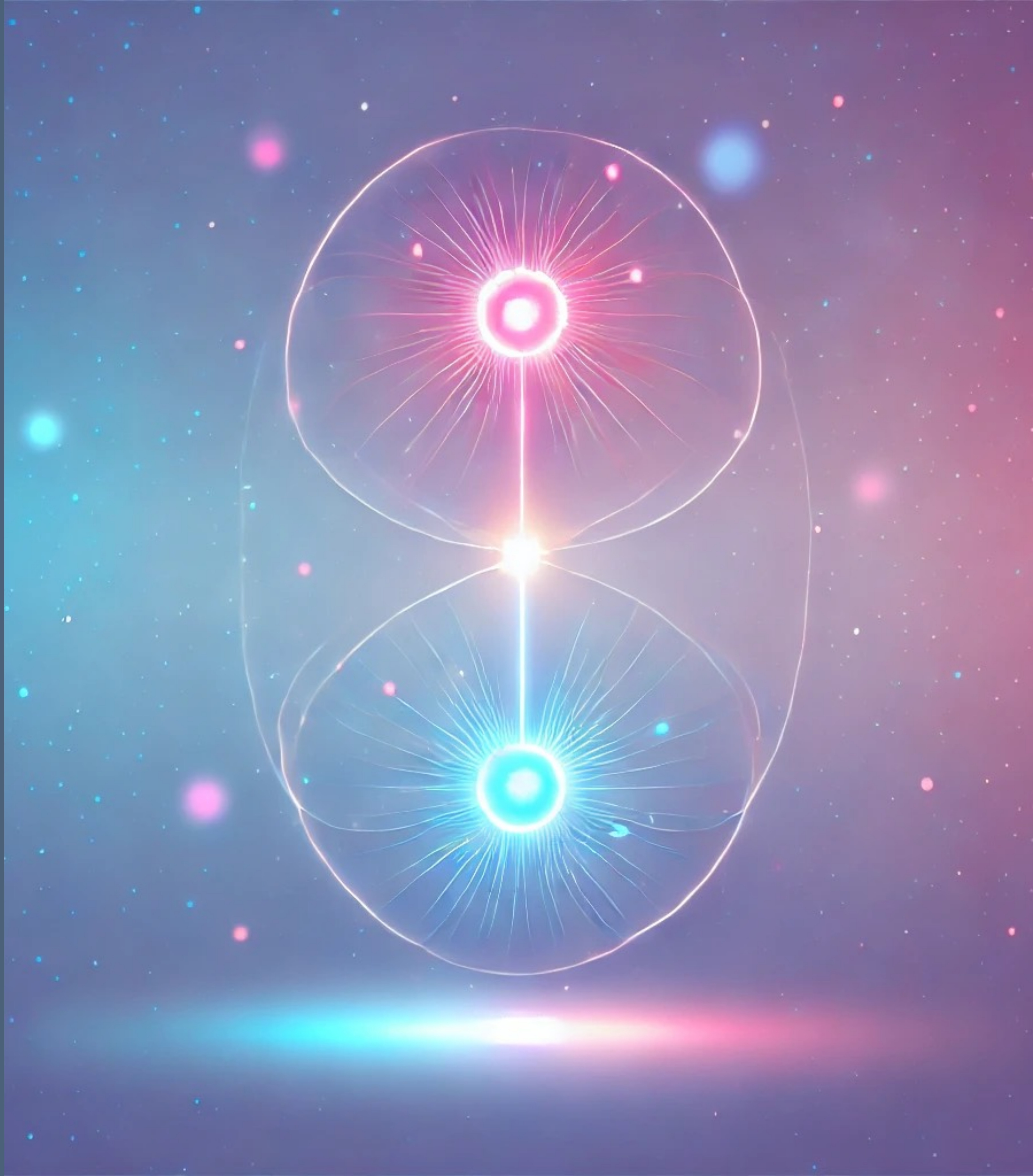
Bits vs qubits



Entanglement

“Spooky action at a distance”

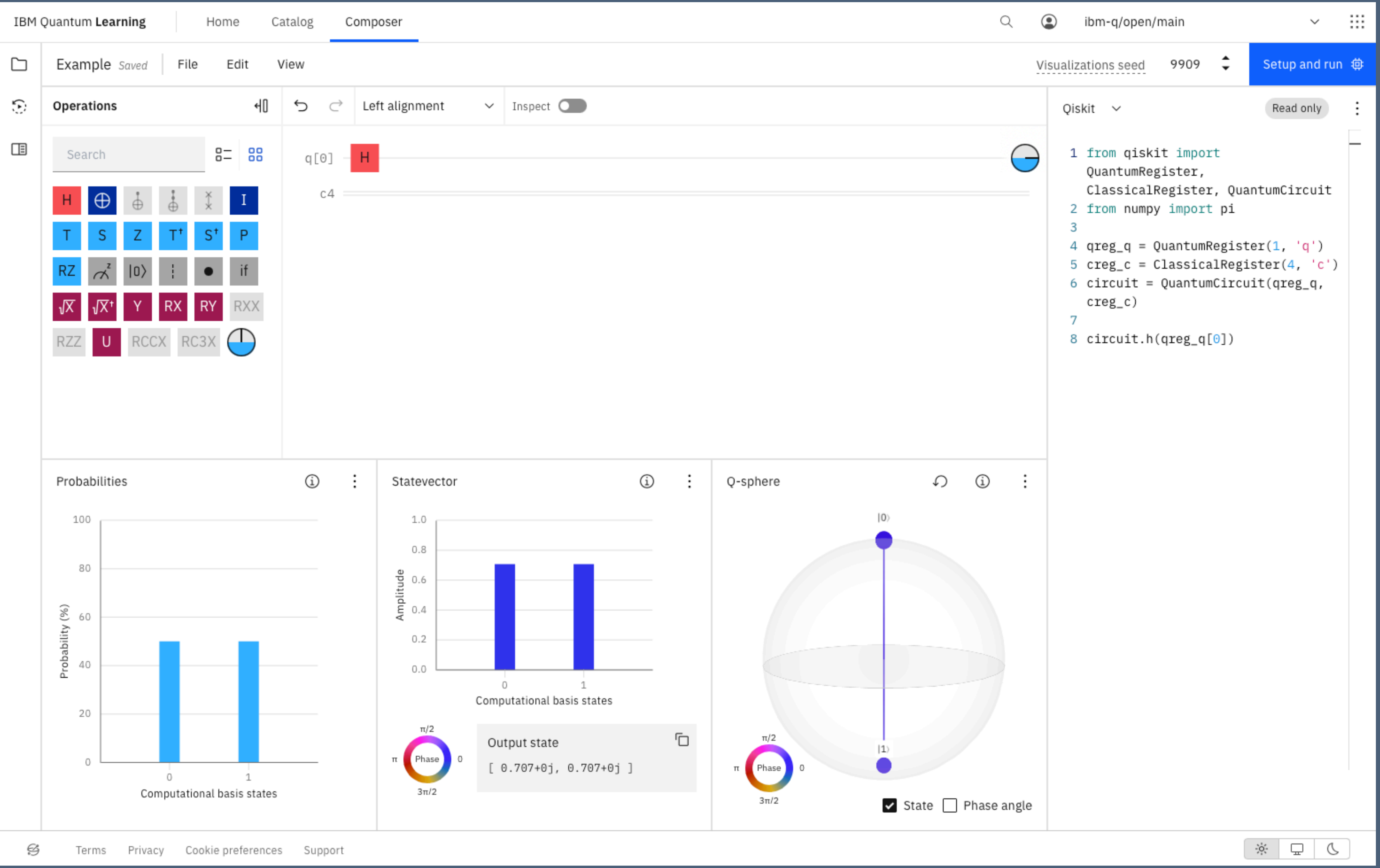
- When two particles become linked in such a way that the state of one immediately influences the state of the other, no matter how far apart they are.
- Einstein called it “spooky action at a distance” as it seems to defy the rule that nothing can travel faster than the speed of light.



Quantum Circuits and Coding

- Quantum computers use quantum gates to manipulate qubits, similar to how classical computers use logical gates for bits
- A quantum circuit is a collection of interconnected quantum gates
- The Hadamard (H) gate turns a state of |0> or |1> into an equal superposition of |0> and |1>
- It can be represented in matrix form as:

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



Key Milestones in Quantum Computing

1980: Paul Benioff describes the first **quantum mechanical model** of a computer

1985: David Deutsch developers the concept of a **universal quantum computer**

1994: Peter Shor develops **Shor's algorithm** for efficient factoring

1996: Lov Grover introduces a **faster quantum search algorithm**

1998: First experimental quantum computations with **qubits**

1999: **D-Wave Systems** is founded to pursue quantum computing

2007: D-Wave claims the first **commercial quantum computer**

2011: D-Wave releases the **D-Wave One**, the first commercial quantum annealer

2016: IBM launches quantum computing on the **cloud**, making it publicly accessible

2019: Google claims **quantum supremacy** with its **Sycamore** processor

2020: China reports quantum supremacy with a **photonic quantum computer**

2021: IBM unveils its **127-qubit Eagle** processor

2022: IBM announces its **433-qubit Osprey** chip

2023: IBM reveals the **1,121-qubit Condor** processor and breakthroughs in qubit arrays

2024: Google demonstrates **quantum error correction**, advancing fault-tolerant quantum computing

Why Quantum Computing Matters

100+ High Value Industry Use Cases

Simulation

- Pharma
- Aerospace
- Chemistry
- Energy
- Finance

~$330 billion

Optimisation

- Finance
- Insurance
- Logistics
- Aerospace

~$220 billion

Machine Learning

- Automotive
- Finance
- Tech

~$250 billion

Cryptography

- Government
- Corporate

~$80 billion

https://www.bcg.com/publications/2024/long-term-forecast-for-quantum-computing-still-looks-bright

Quantum Computing Resources

- Learning:
  - IBM Quantum Learning: https://learning.quantum.ibm.com/
  - Learn quantum programming with PennyLane: https://pennylane.ai/qml/
- Programming:
  - IBM Qiskit: https://www.ibm.com/quantum/qiskit
  - Google Cirq: https://quantumai.google/cirq
  - Microsoft Q#: https://learn.microsoft.com/en-us/azure/quantum/
- YouTube:
  - Quantum Computing for Computer Scientists: https://youtu.be/F_Riqjdh2oM?si=XJWZtpvujF5qlWmD
  - Understanding Quantum Information & Computation: https://youtube.com/playlist?list=PLOFEBzvs-VvqKKMXX4vbi4EB1uaErFMSO&si=uiMvezeeswCaSerF

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