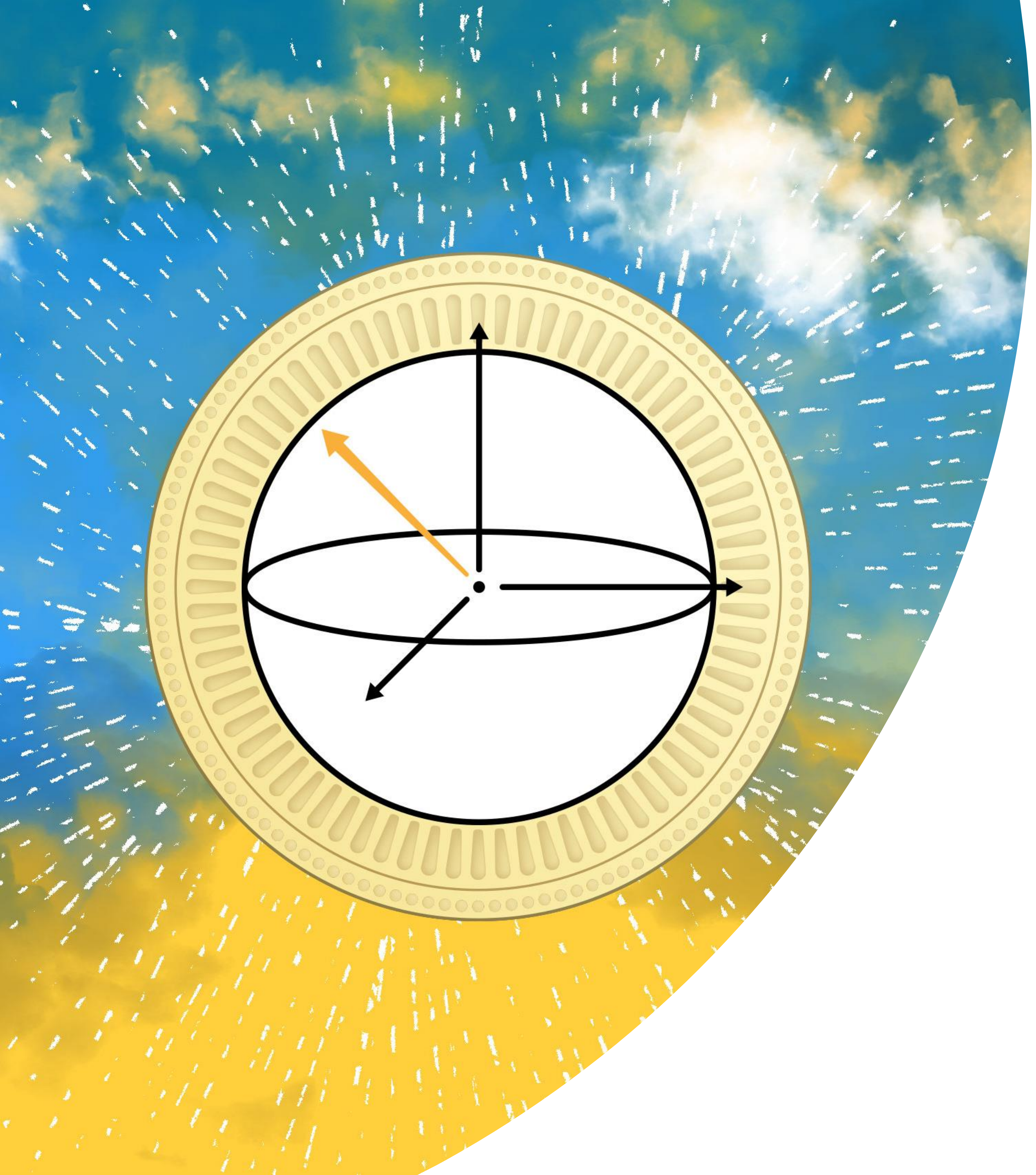


HighTech U

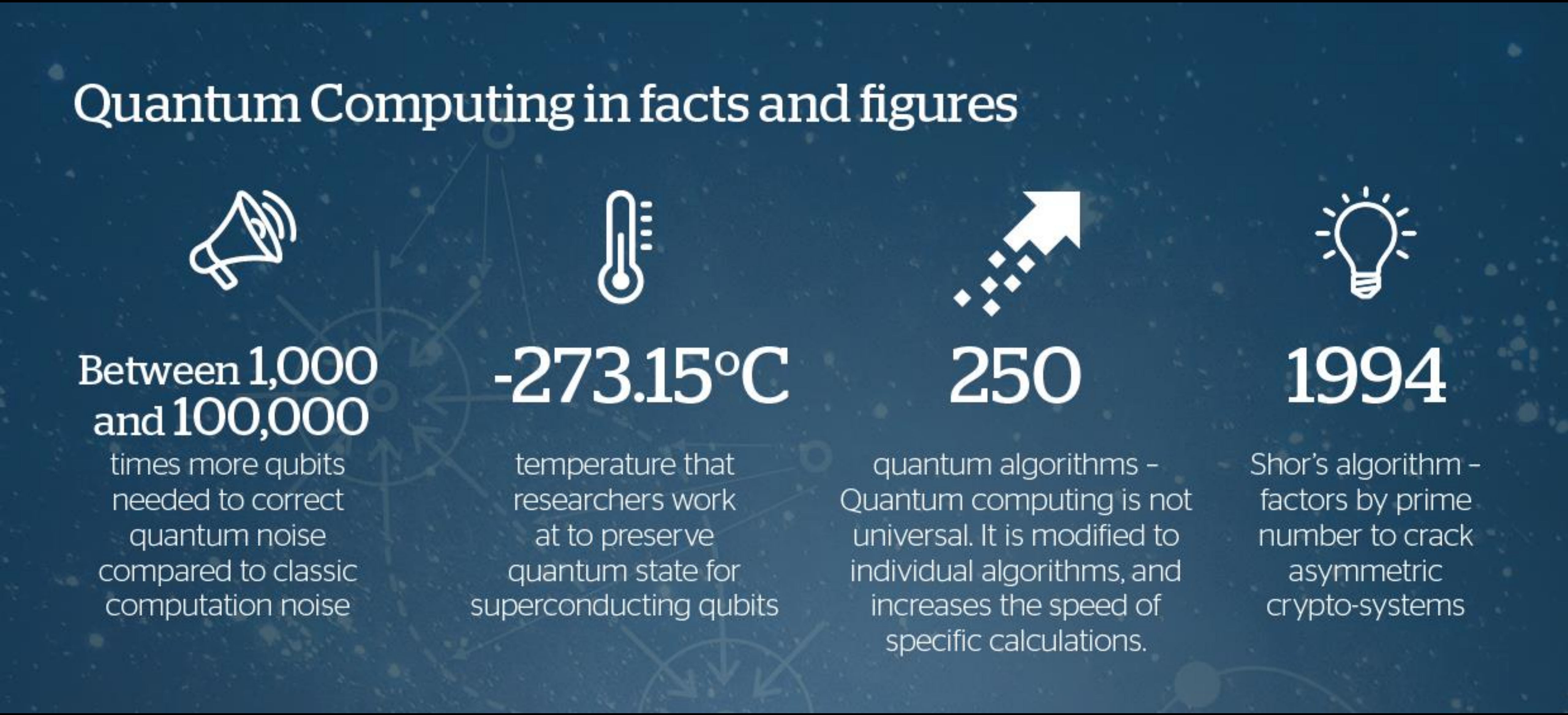
Empowering Future Innovators

What is Quantum Computing?

Priya Angara, Ulrike Stege

Frequently Asked Questions

- Is it real?
- Google just announced Quantum Supremacy. What does that mean?
- Are Qubits in multiple states at once? How can that be possible?
- Is security in our society going to break down?
- How does the cat fit in to quantum computing?



https://atos.net/en/insights-and-innovation/quantum-computing

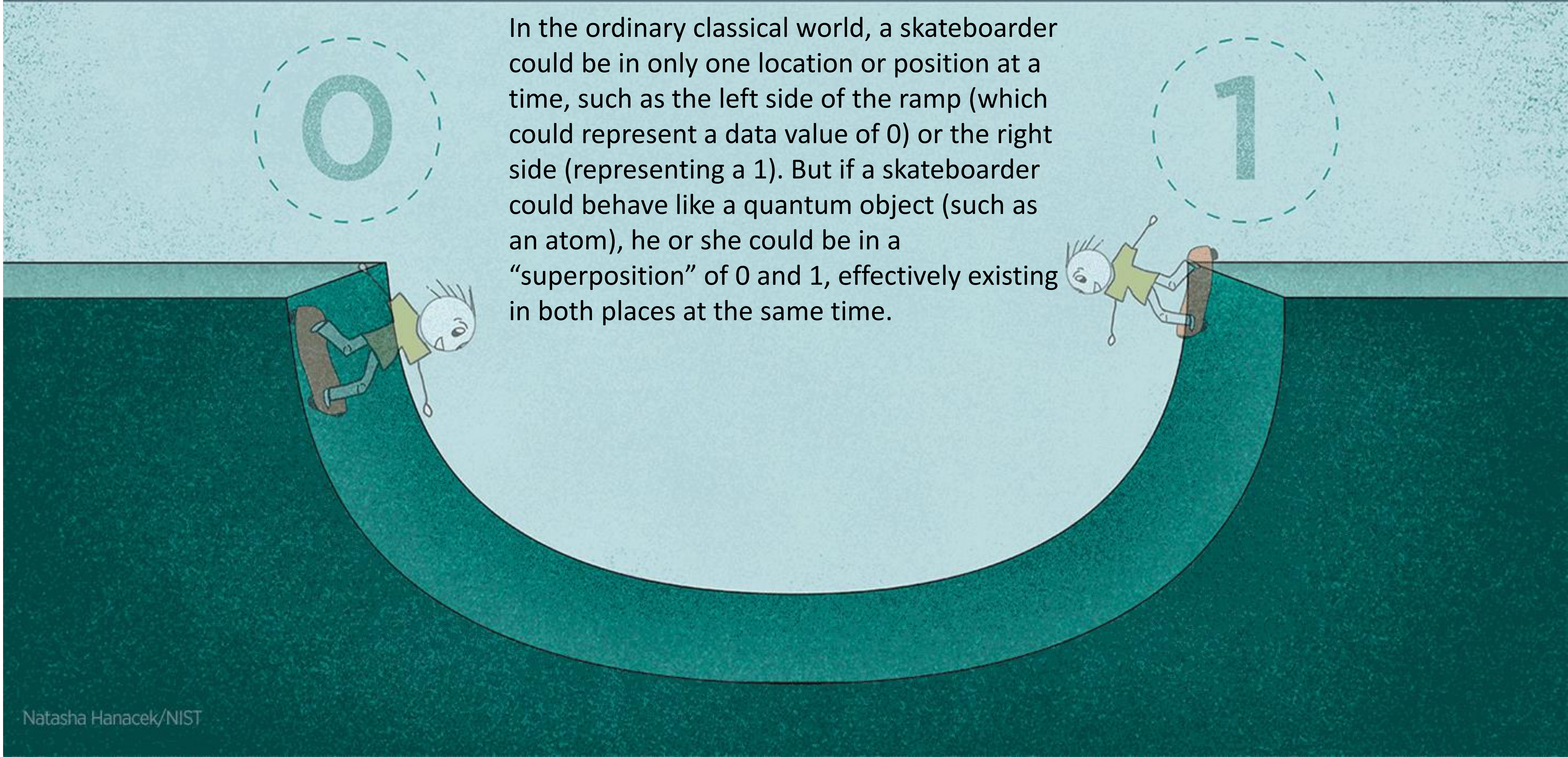
Quantum Physics

10 influential figures in the history of quantum mechanics. Left to right:
Max Planck, Albert Einstein, Niels Bohr, Louis de Broglie, Max Born, Paul Dirac, Werner Heisenberg, Wolfgang Pauli, Erwin Schrödinger, Richard Feynman.

https://en.wikipedia.org/wiki/History_of_quantum_mechanics

SUPERPOSITION

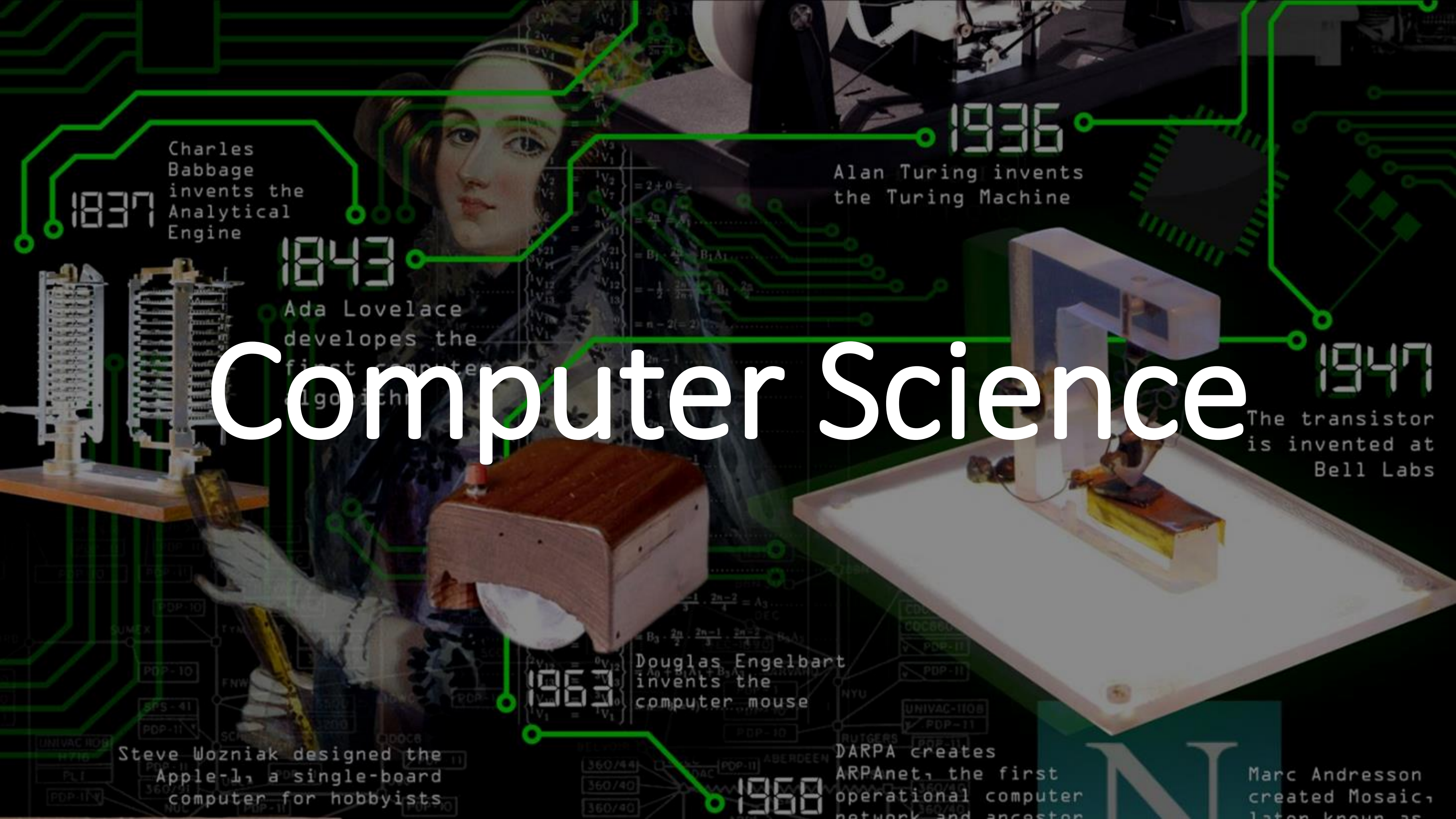
In the ordinary classical world, a skateboarder could be in only one location or position at a time, such as the left side of the ramp (which could represent a data value of 0) or the right side (representing a 1). But if a skateboarder could behave like a quantum object (such as an atom), he or she could be in a "superposition" of 0 and 1, effectively existing in both places at the same time.



Natasha Hanacek/NIST

ENTANGLEMENT

Computer Science



Computer Science

128 64 32 16 8 4 2 1

MuseNet

We've created MuseNet, a deep neural network that can generate 4-minute musical compositions with 10 different instruments, and can combine styles from country to Mozart to the Beatles. MuseNet was not explicitly programmed with our understanding of music, but instead discovered patterns of harmony, rhythm, and style by learning to predict the next token in hundreds of thousands of MIDI files. MuseNet uses the same general-purpose unsupervised technology as GPT-2, a large-scale transformer model trained to predict the next token in a sequence, whether audio or text.

APRIL 25, 2019
6 MINUTE READ, 16 MINUTE LISTEN

https://openai.com/blog/musenet/

Prime Factorization

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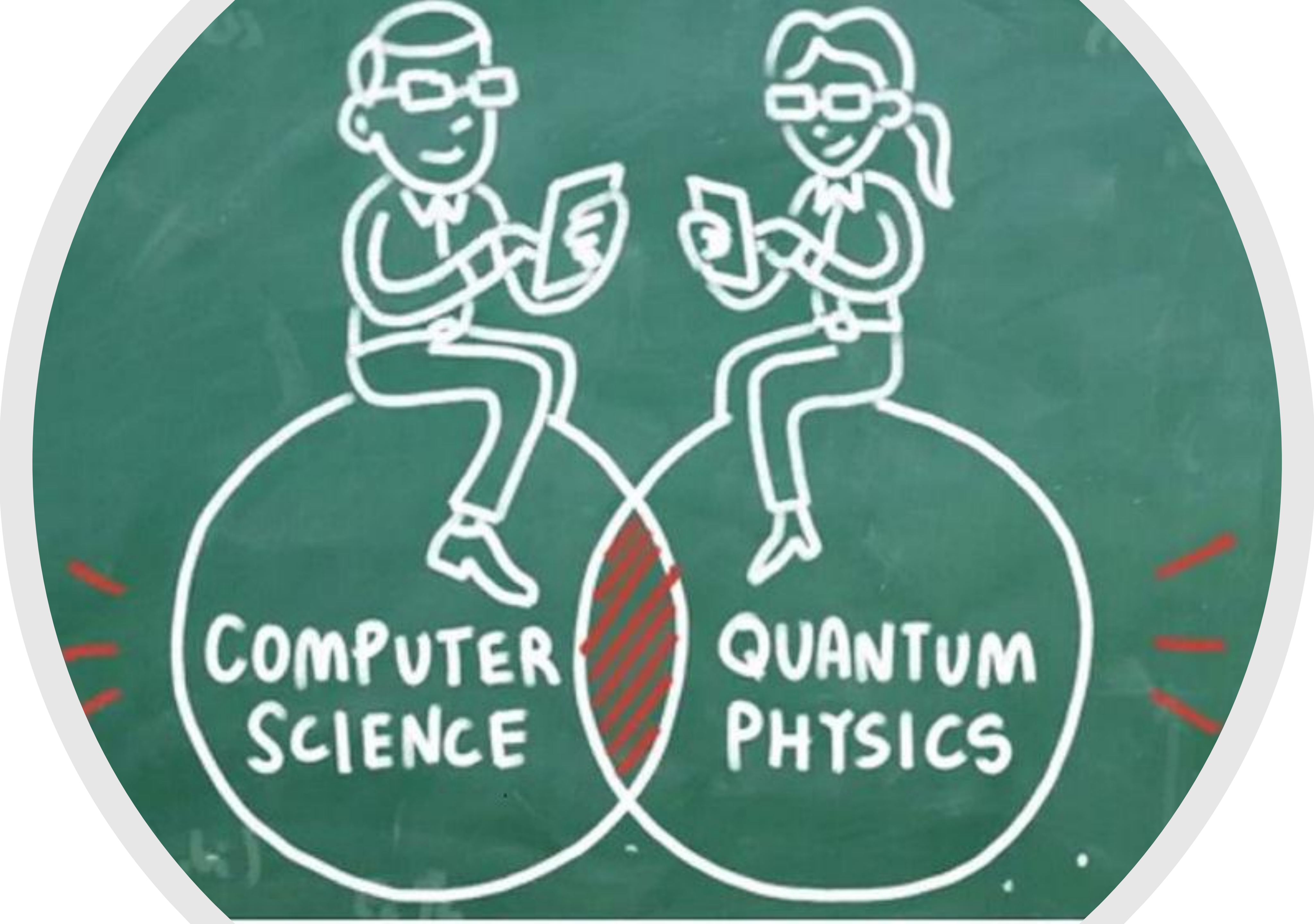
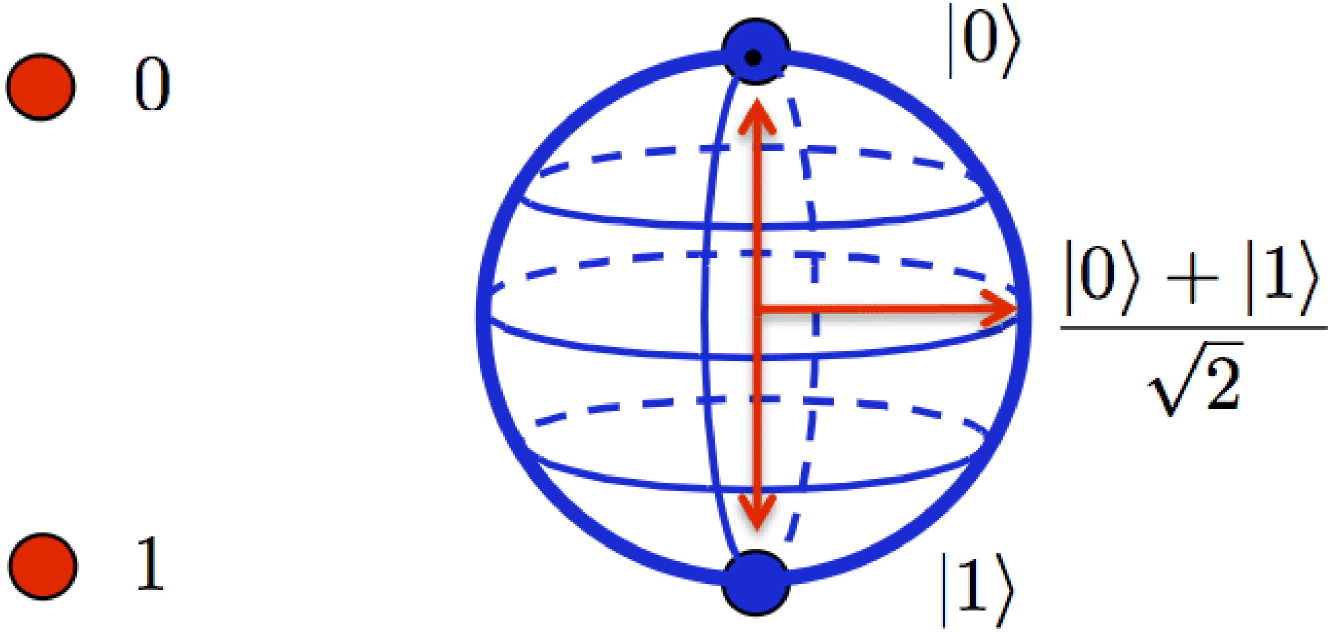
Preview


COMPUTER SCIENCE
QUANTUM PHYSICS

Quantum Computing!

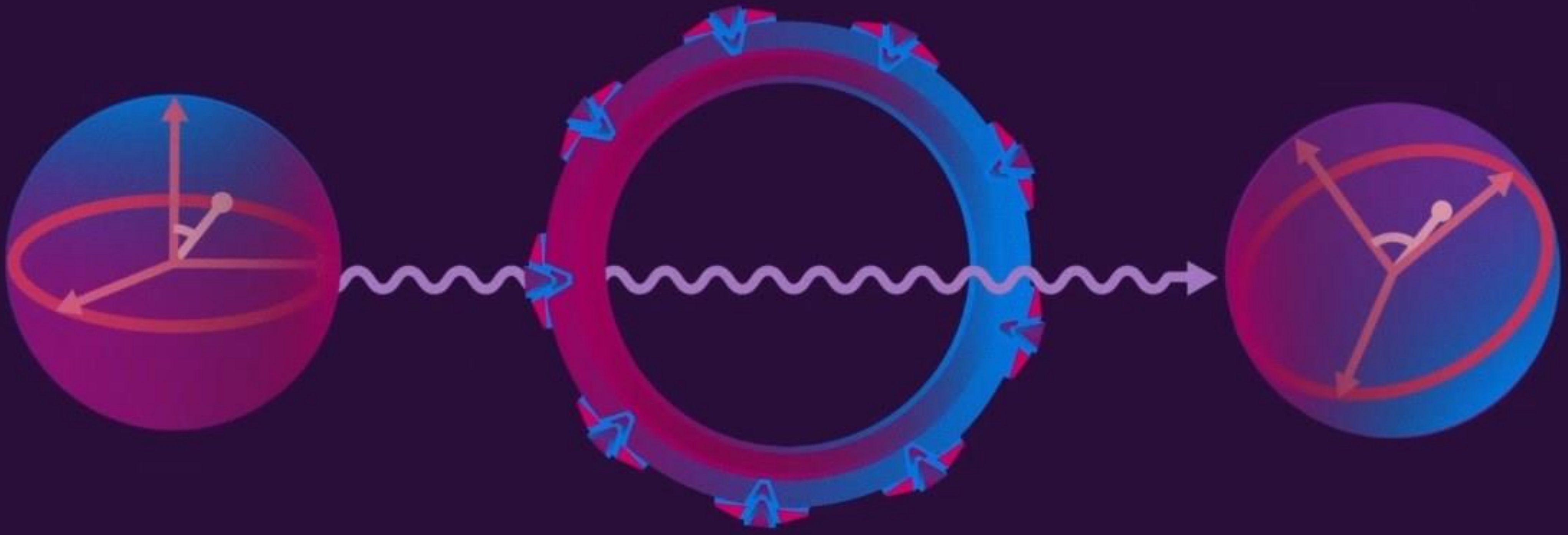
IBM Quantum Computing Scientists Hanhee Paik (left) and Sarah Sheldon (right) examine the hardware inside an open dilution fridge at the IBM Q Lab at IBM’s T. J. Watson Research Center in Yorktown, NY.

Qubits

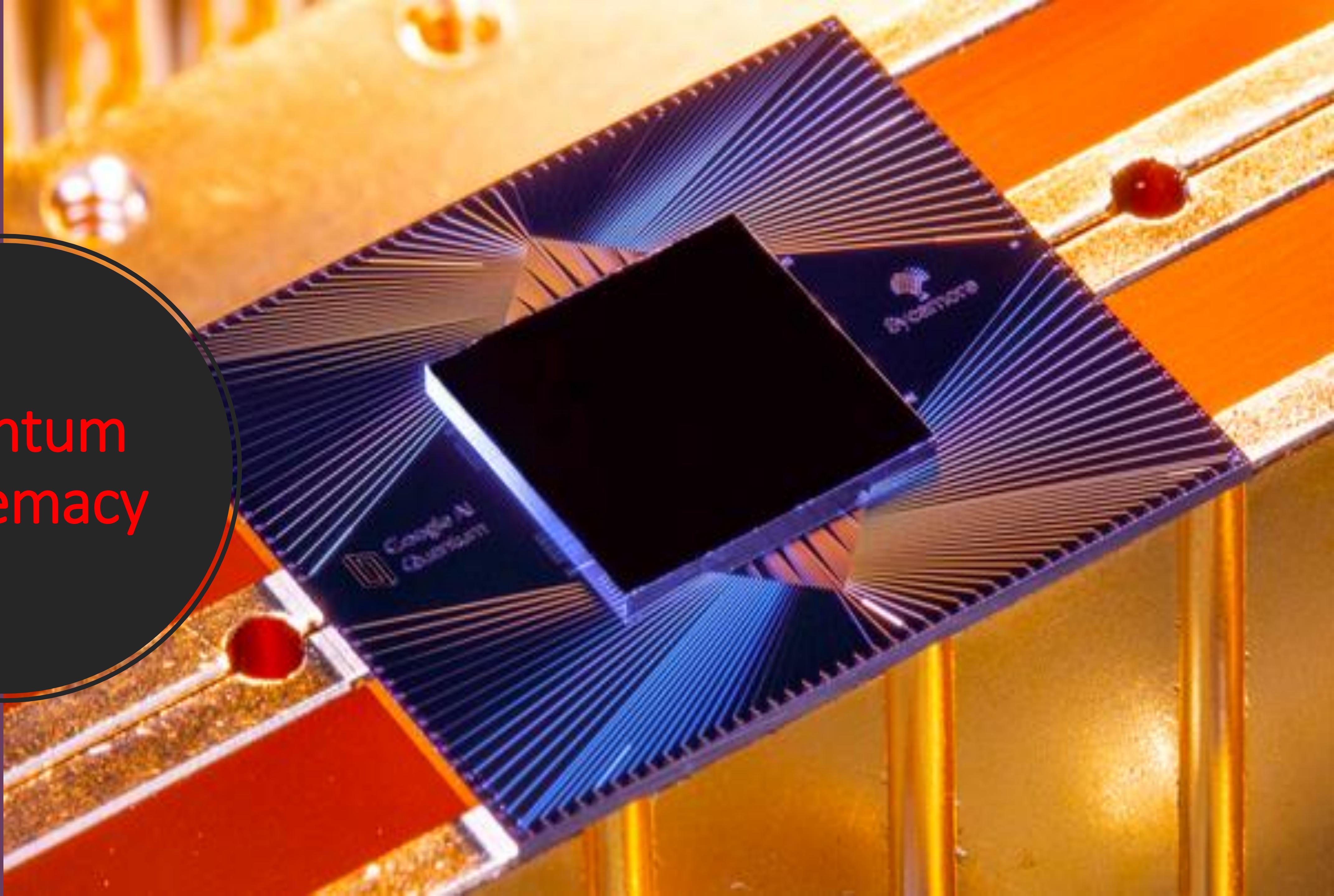


Classical Bit **Qubit**

QUANTUM GATE

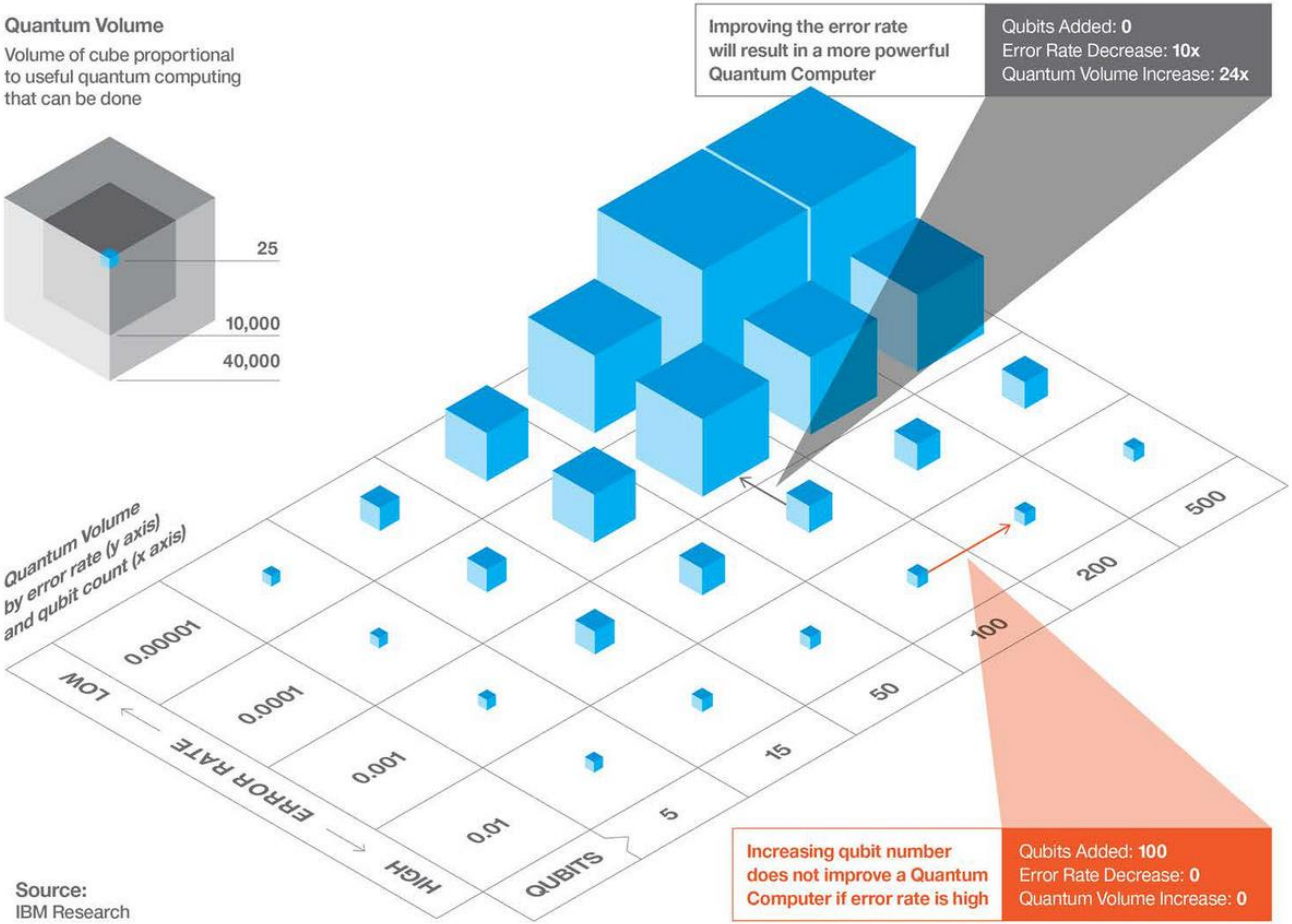


Quantum Supremacy



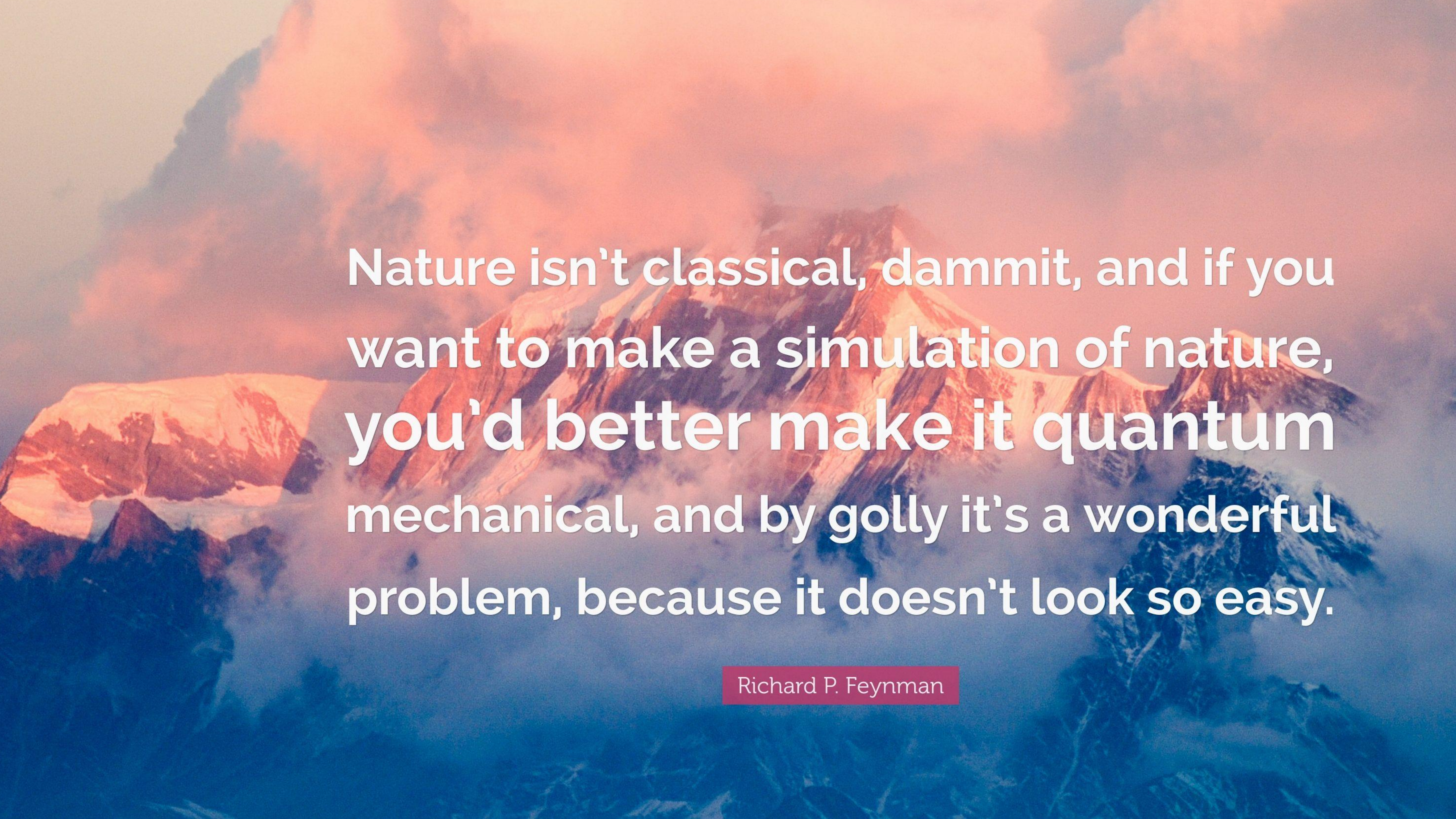
A Quantum Computer's power depends on more than just adding qubits

If we want to use quantum computers to solve real problems, they will need to explore a large space of quantum states. The number of qubits is important, but so is the error rate. In practical devices, the effective error rate depends on the accuracy of each operation, but also on how many operations it takes to solve a particular problem as well as how the processor performs these operations. Here we introduce a quantity called **Quantum Volume** which accounts for all of these things. Think of it as a representation of the problem space these machines can explore.



Source:
IBM Research

Applications


Nature isn't classical, dammit, and if you want to make a simulation of nature, you'd better make it quantum mechanical, and by golly it's a wonderful problem, because it doesn't look so easy.
Richard P. Feynman

Simulating Quantum Phenomena

1. Direct mapping between molecular wave functions and qubits

2. Number of gates scales polynomially with system size

3. Quantum Chemistry applications: simulating molecules

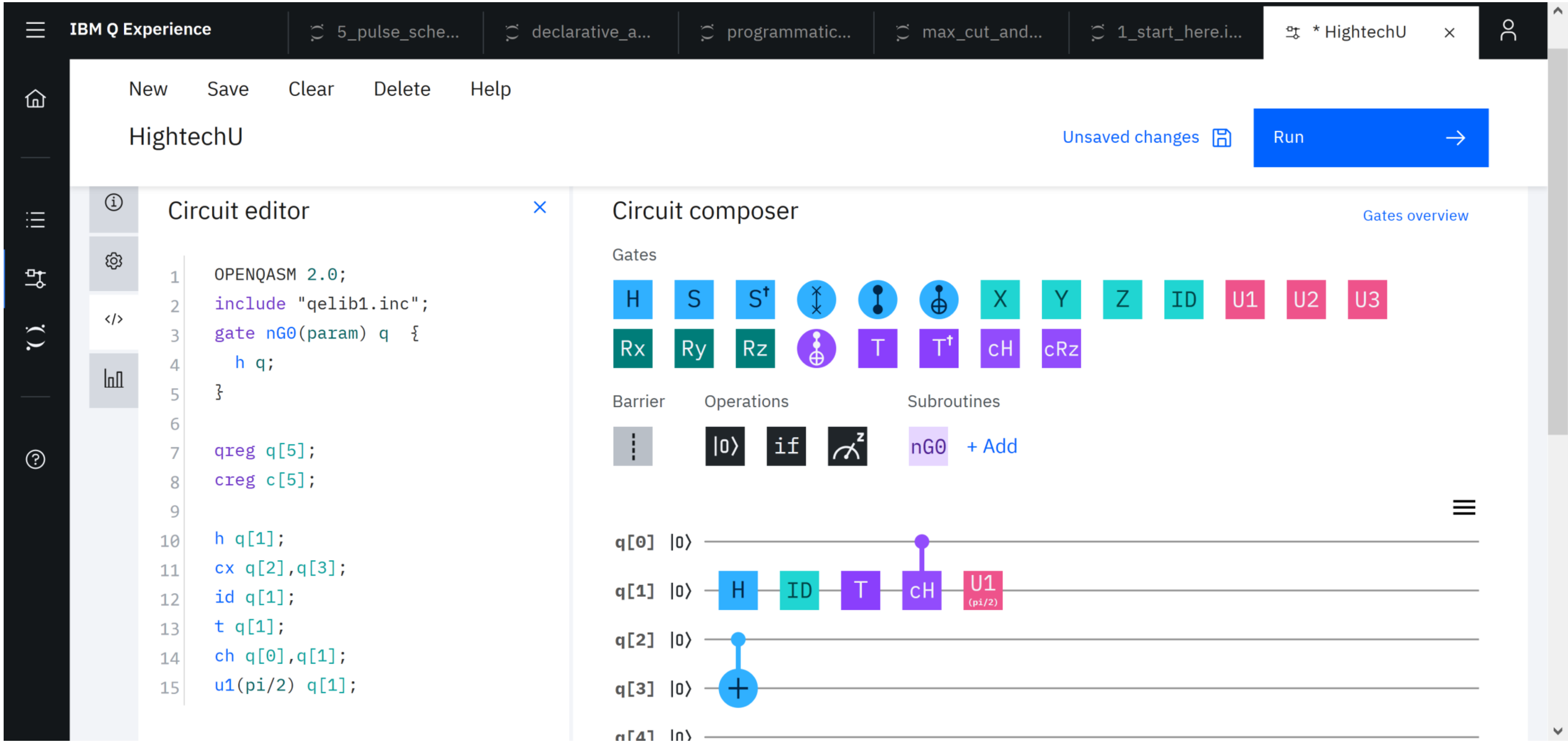
(Post) Quantum Cryptography

1. Perfect quantum computers will break current classical cryptography techniques
2. Research avenues:
   1. PQC: Modify existing protocols so that quantum computers cannot break them
   2. QC: Setup new communications infrastructure which promises security based on quantum physics

Optimization and Machine Learning

1. Hybrid quantum-classical algorithms for optimization
2. No significant exponential speedups yet
3. Developing research area, promising for a few specialized problems

IBM Q Experience

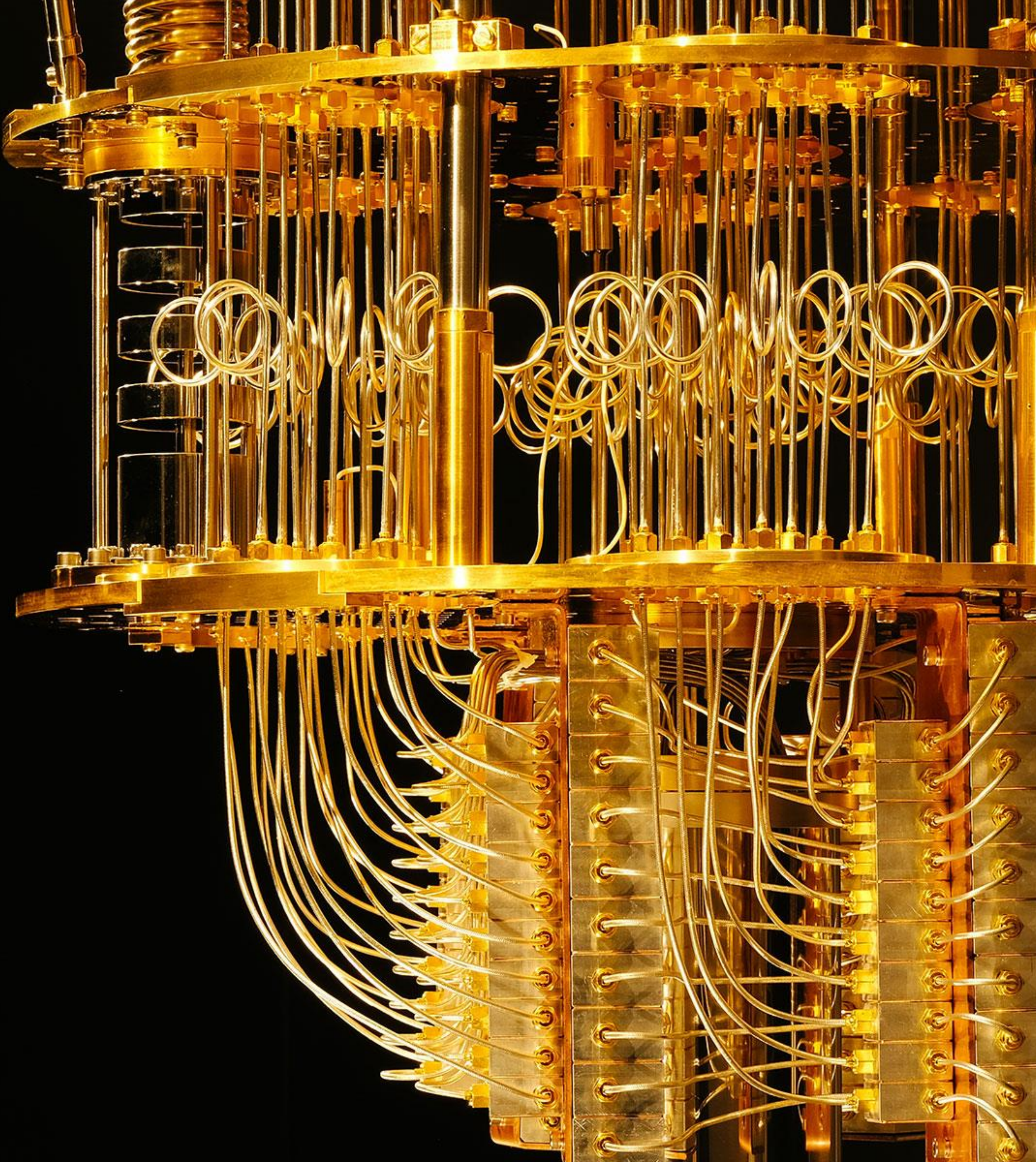


Quantum computing devices
https://quantum-computing.ibm.com/

Circuit Composer
https://quantum-computing.ibm.com/composer

Qiskit
https://qiskit.org/

Shtetl-Optimized
https://www.scottaaronson.com/blog/



Thank You

Backup slides

Timeline


1900
Planck proposes that radiation comes in discrete amounts, or is quantized
1905
Einstein suggests a quantum of light (the photon)
1924
Louis de Broglie proposes that matter has wave properties
1926
Erwin Schroedinger develops wave mechanics
1960
First laser built
1973
GPS launched by US Department of Defense
1981
Richard Feynman invents the concept of a quantum computer
1981
Alain Aspect demonstrates the existence of the entanglement phenomenon
1994
Peter Shor invents the first “useful” quantum algorithm to crack prime number-based cryptographies
2001
First execution of Shor algorithm on a quantum device, Stanford University

The three known types of quantum computing and their applications, generality, and computational power.

A very specialized form of quantum computing with unproven advantages over other specialized forms of conventional computing.

DIFFICULTY LEVEL

Quantum Annealer

The quantum annealer is least powerful and most restrictive form of quantum computers. It is the easiest to build, yet can only perform one specific function. The consensus of the scientific community is that a quantum annealer has no known advantages over conventional computing.

APPLICATION
Optimization Problems

GENERALITY
Restrictive

COMPUTATIONAL POWER
Same as traditional computers

The most likely form of quantum computing that will first show true quantum speedup over conventional computing. This could happen within the next five years.

DIFFICULTY LEVEL

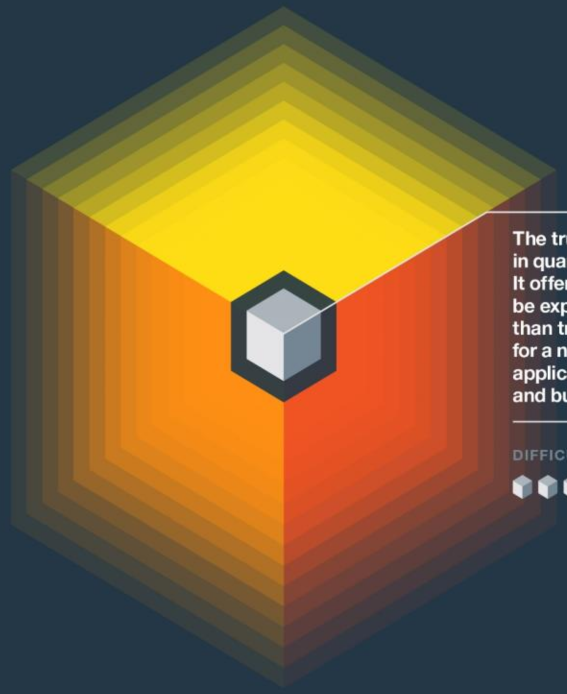
Analog Quantum

The analog quantum computer will be able to simulate complex quantum interactions that are intractable for any known conventional machine, or combinations of these machines. It is conjectured that the analog quantum computer will contain somewhere between 50 to 100 qubits.

APPLICATIONS
Quantum Chemistry
Material Science
Optimization Problems
Sampling
Quantum Dynamics

GENERALITY
Partial

COMPUTATIONAL POWER
High



The true grand challenge in quantum computing. It offers the potential to be exponentially faster than traditional computers for a number of important applications for science and businesses.

DIFFICULTY LEVEL

Universal Quantum

The universal quantum computer is the most powerful, the most general, and the hardest to build, posing a number of difficult technical challenges. Current estimates indicate that this machine will comprise more than 100,000 physical qubits.

APPLICATIONS
Secure computing
Machine Learning
Cryptography
Quantum Chemistry
Material Science
Optimization Problems
Sampling
Quantum Dynamics
Searching

GENERALITY
Complete with known speed up

COMPUTATIONAL POWER
Very High