engineer of the future

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Quantum Computing

“Nature isn’t classical and if you want to make a simulation of nature, you’d better make it quantum”

Richard Feynman - Theoretical Physicist

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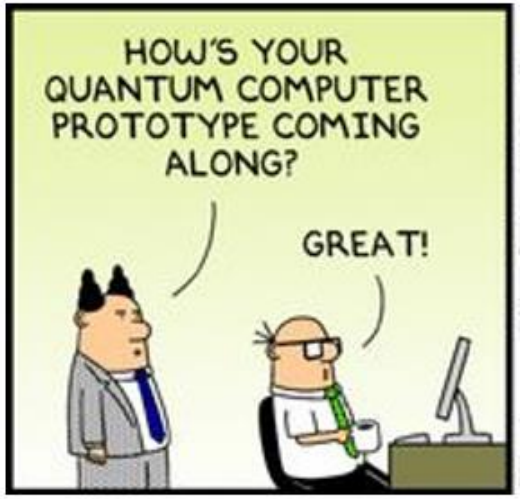
What will I be talking about?



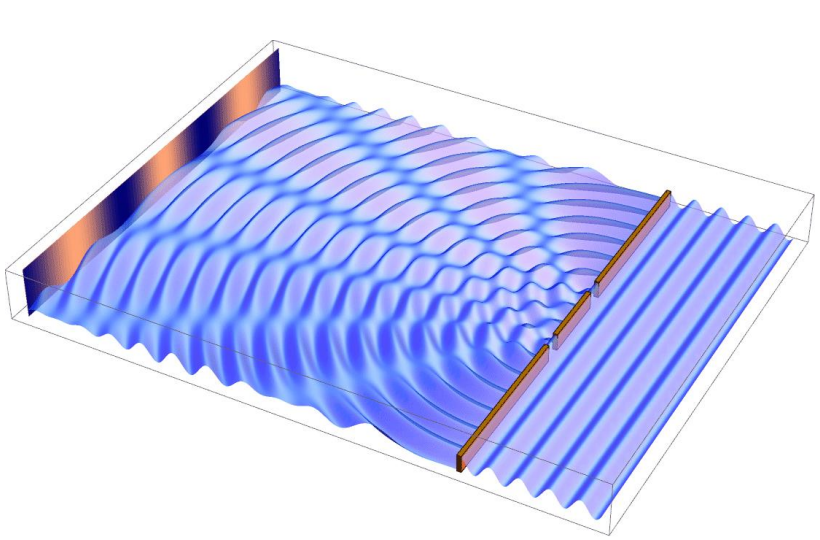
- What is quantum, where is it in nature, what is its history?
- Quantum applicability in major areas of development
- Key principals in quantum mechanics that apply in quantum computers
- Quantum vs Classical computing, quantum supremacy and hybrid solutions
- Quantum race of companies and the current obstacles
- Roadmap of major companies
- Quantum readiness
- Q&A Session

Mentimeter

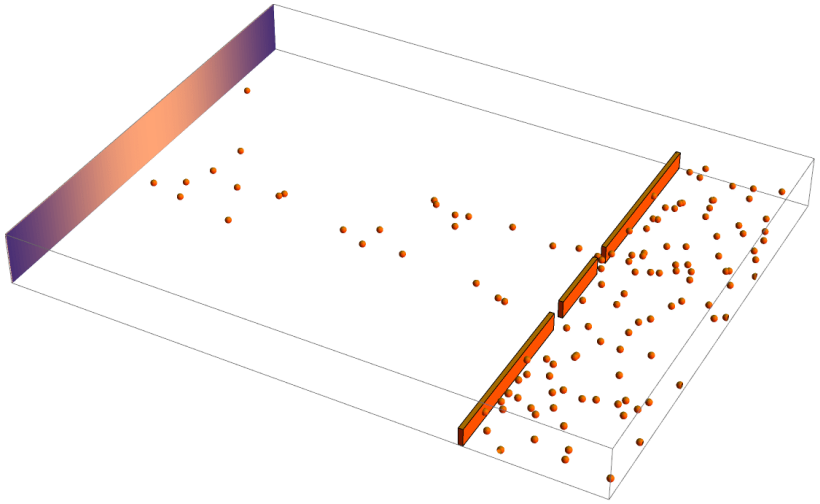
What is Quantum mechanics?

Newton's laws do not apply at subatomic level ☹

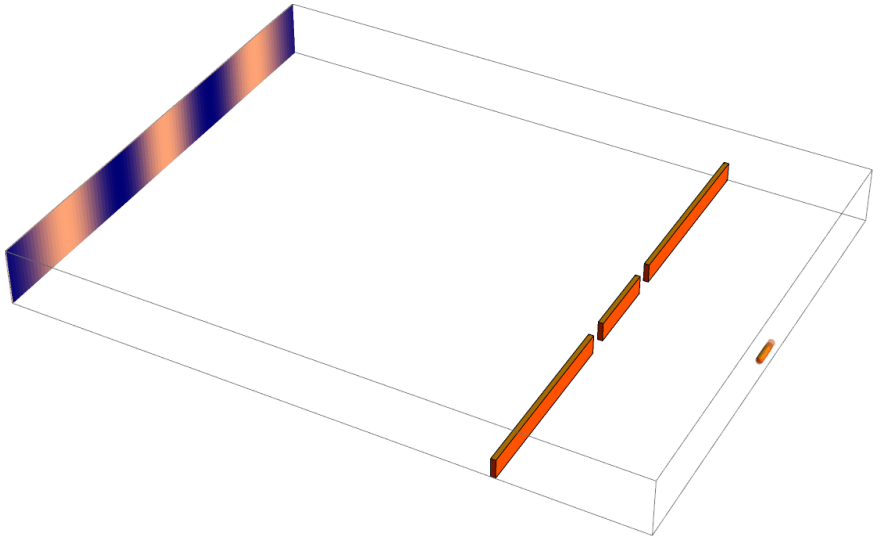
Matter and light can behave both like waves and particles - wave-particle duality



Wave



Particle



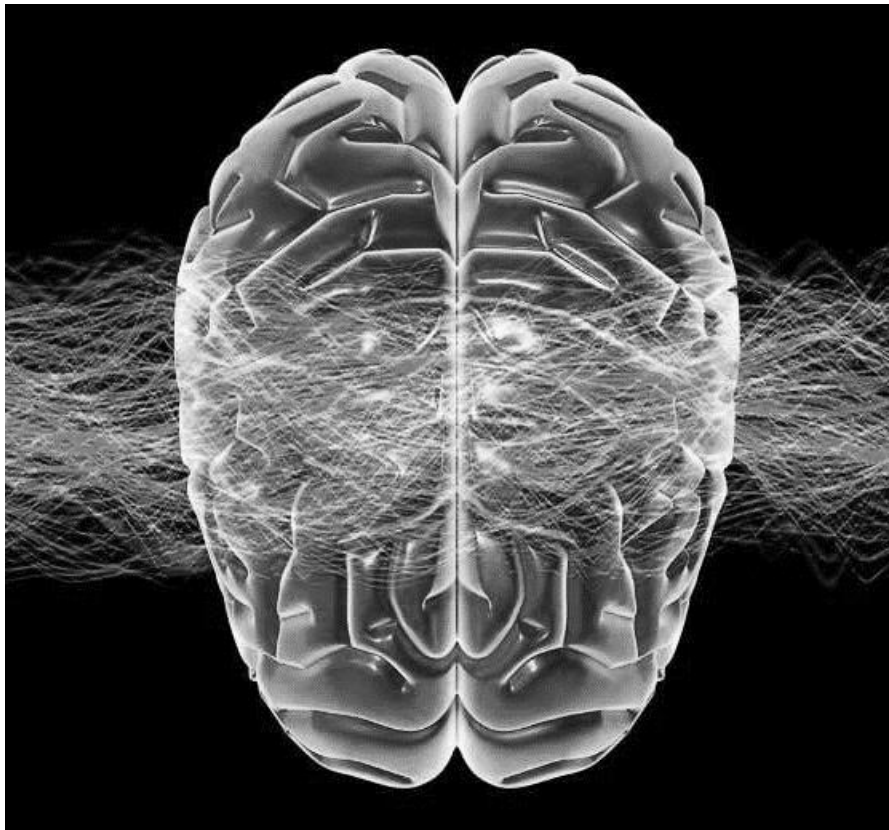
Light particles

The double slit experiment

Where can we find Quantum in nature?

Birds

Navigate sensing the magnetic field : quantum entanglement in cryptochrome in their eyes

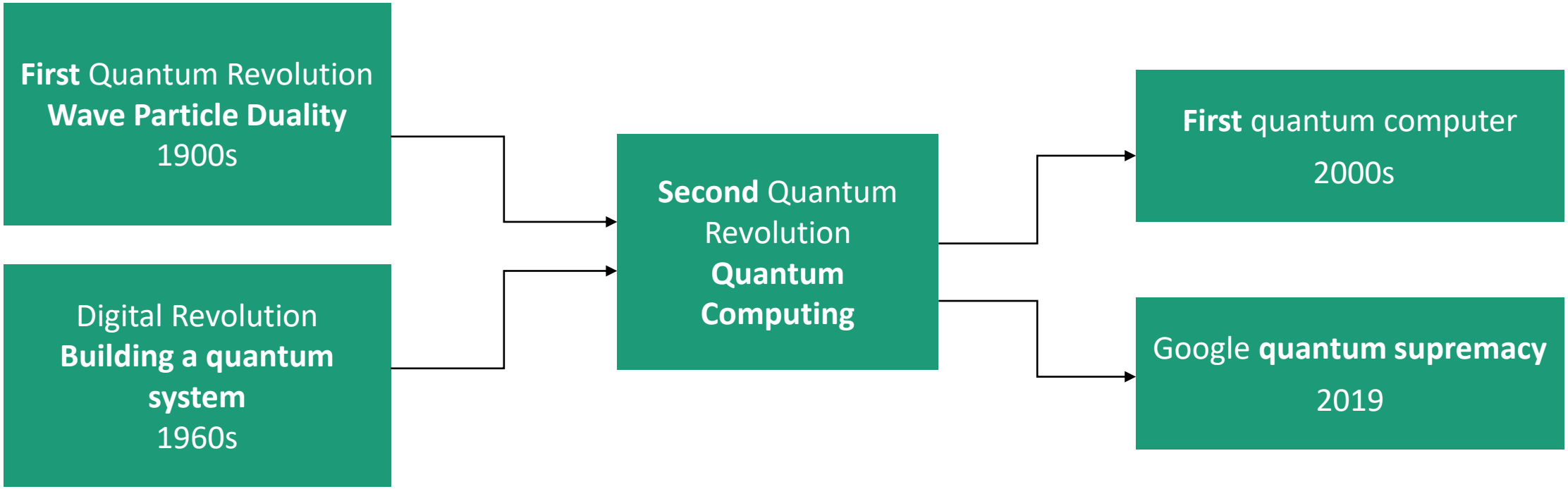


The Brain

The mind has quantum structures in superposition that give rise to consciousness

Sir Roger Penrose theory (Nobel Prize winner)

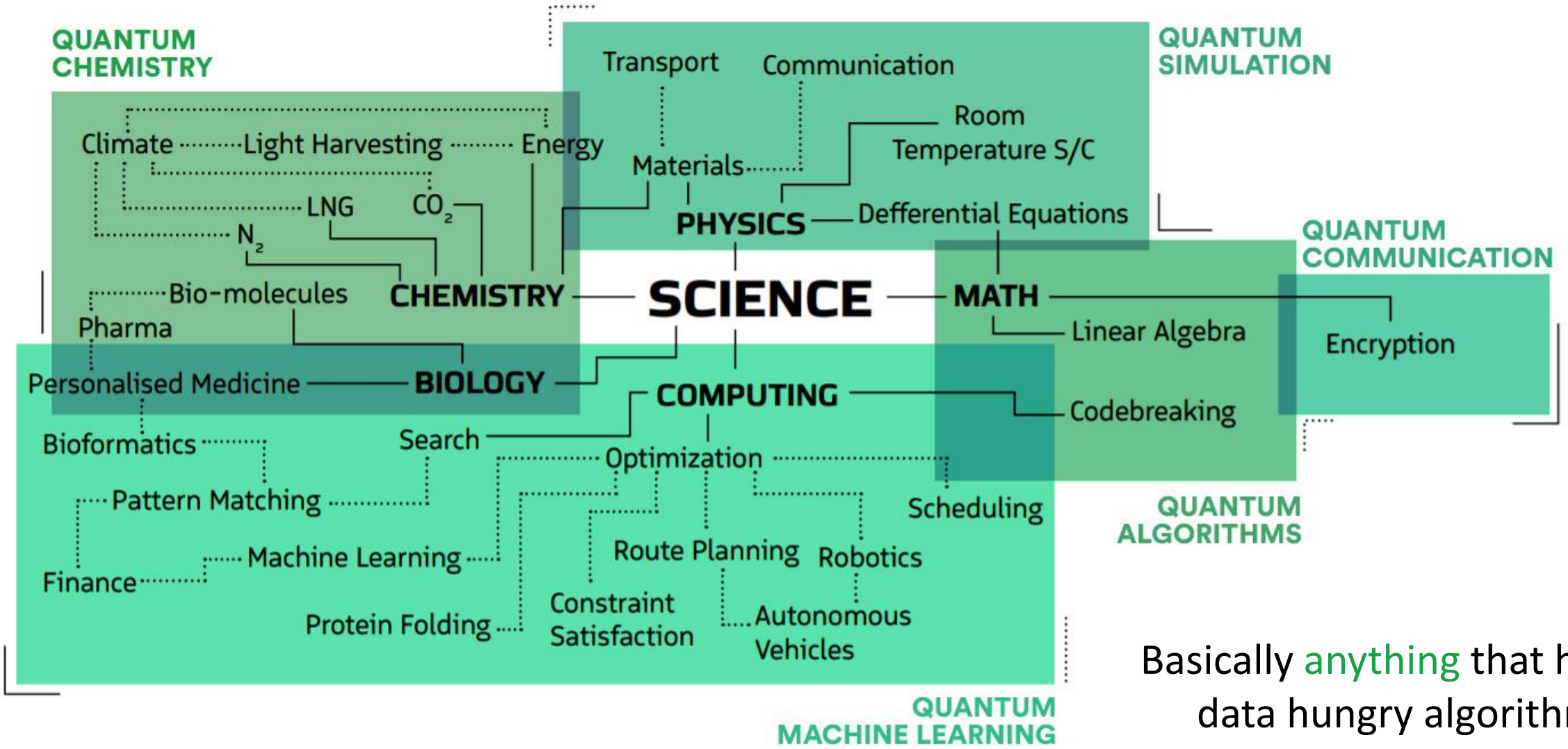
Brief History of The Quantum Realm



Second Revolution is ongoing!

Detailed Timeline of Quantum Evolution

Quantum Computing IMPACT Across Industries



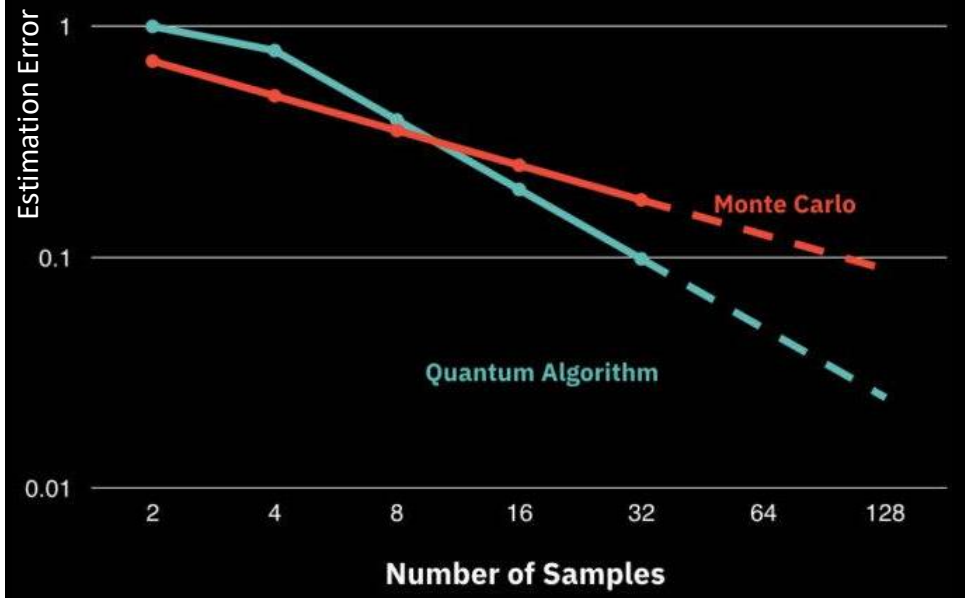
Basically anything that has data hungry algorithms

Quantum in Finance

- Accurate Risk management analysis in quantitative finance
- Dynamic portfolio optimization
- Pricing financial derivatives at quadratic speedup with a quantum Monte Carlo algorithm
- Fast Fourier Transformation speedup with Quantum Fourier Transformation

Quantum Risk Analysis

Quadratic Speedup over Monte Carlo

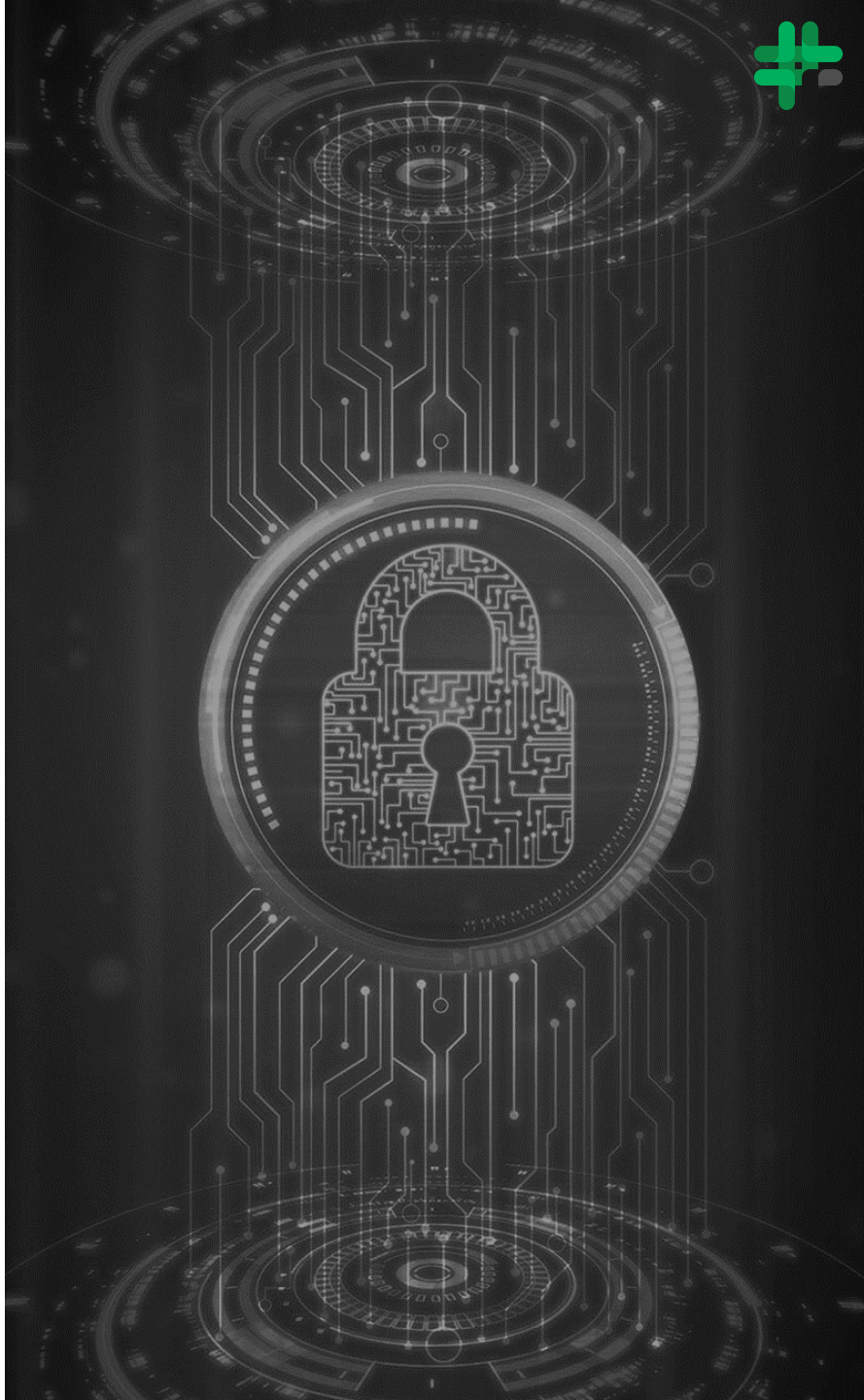


IBM Monte Carlo quantum algorithm

Quantum Communications

Quantum NETWORKING with Quantum key distribution (QKD) that enables 2 parties to produce a unique shared random bit string used as a key to encrypt and decrypt messages.

Avoiding the Quantum SECURITY Threat of breaking private keys – with the Post-quantum cryptography



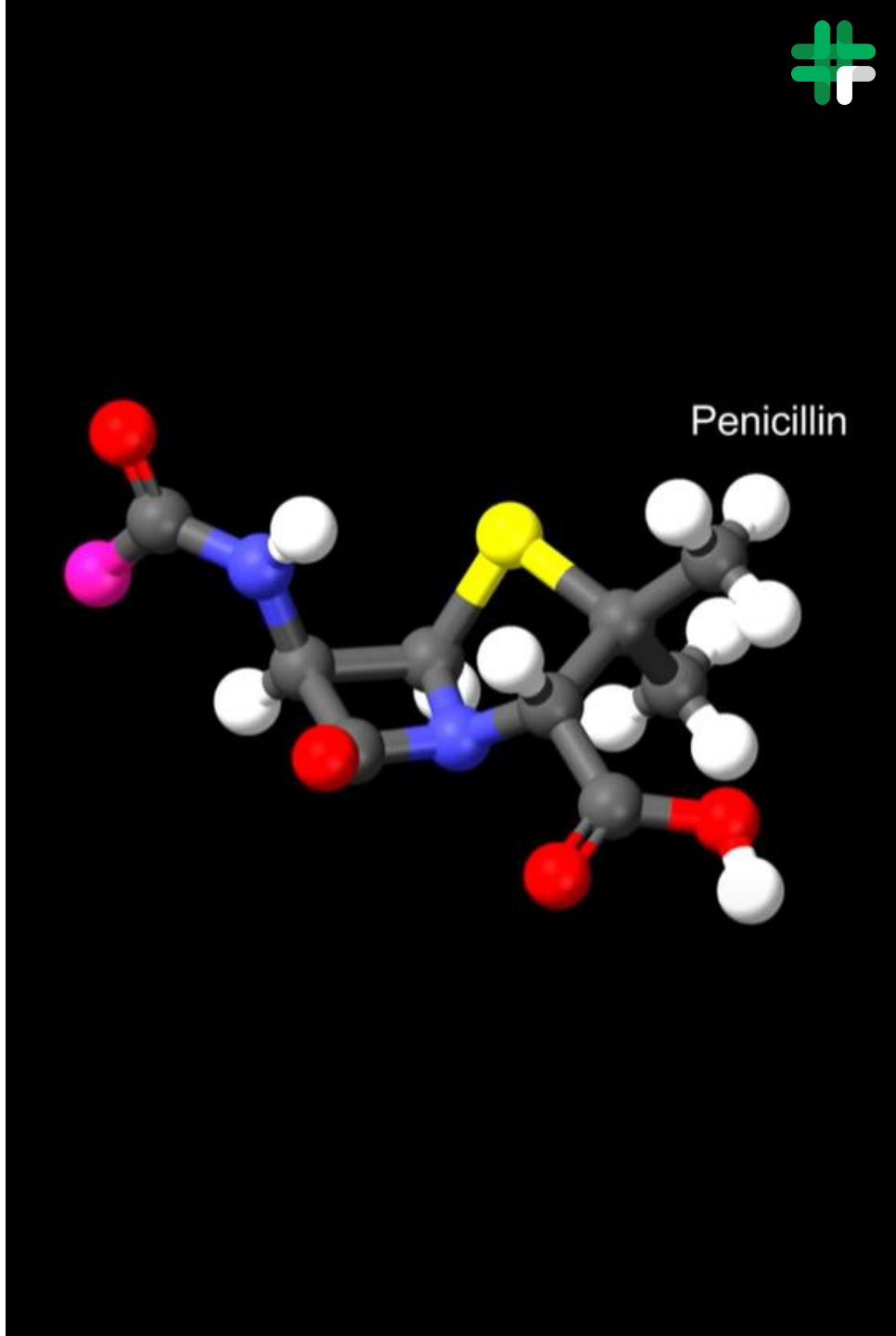
QUANTUM in Chemistry Using ML and Simulations

Highly advanced data modelling: molecular & complex molecular interaction simulations, proteins folds, new drug design

- ProteinQure is already designing drugs
- Discovery of fertilizers and new batteries

Understanding the oceans, climate and weather modelling

Fast and accurate forecasting of natural events such as earthquakes and tsunamis



Quantum in Mobility

Volkswagen uses quantum computers in practice

BMW is also preparing for the Quantum Era

- Quantum ML
  - Solutions for individual road users logistics
  - Control possibilities for urban traffic planning
- Chemistry: Major advances in battery technology

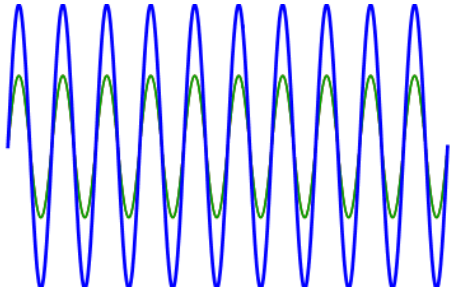
What is Quantum computing about?

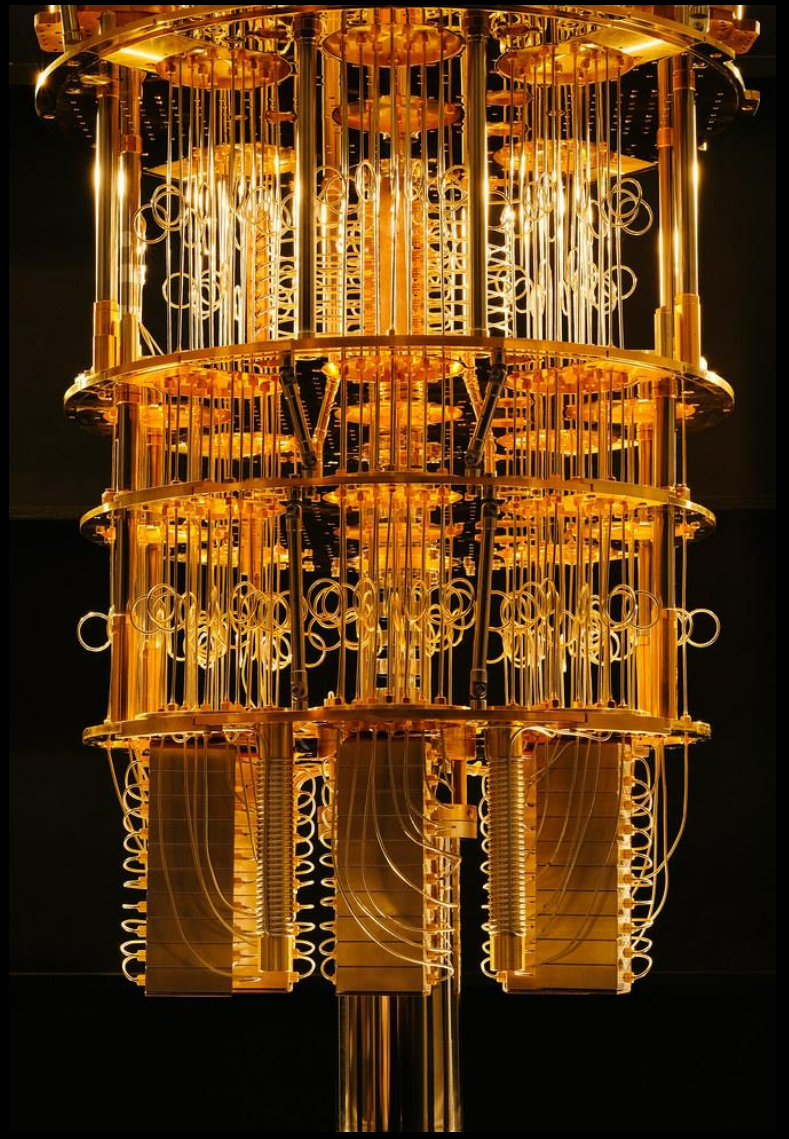
Quantum computers use qubits - electrons, ions or photons

- Isolating the qubits in a controlled quantum state
- Calculate the wave function equation of a quantum object: Schrodinger's equation

Qubits have quantum mechanic properties :

- SUPERPOSITION
- ENTANGLEMENT
- DECOHERENCE



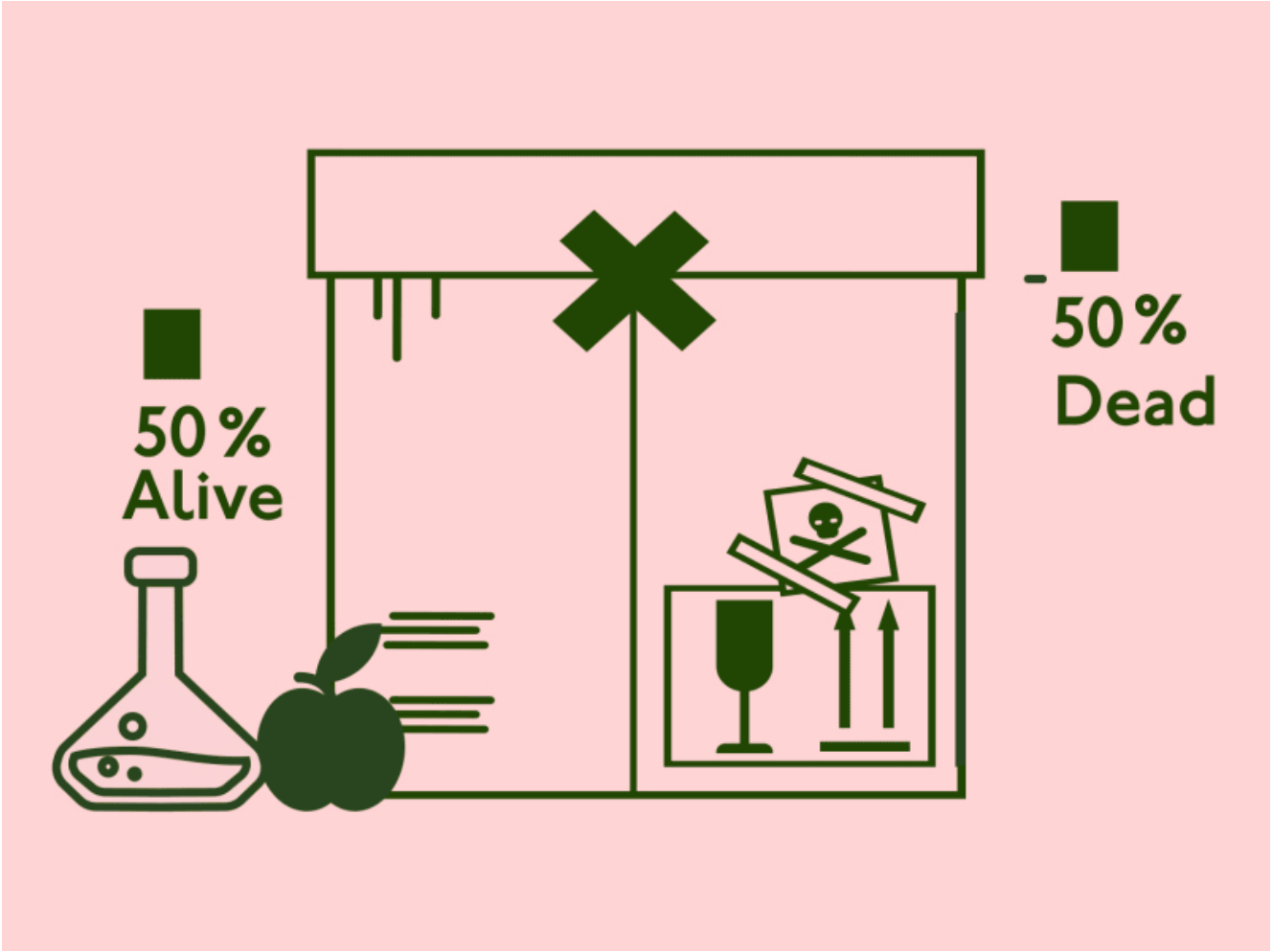


Superposition

The ability of a quantum system to be in multiple states at the same time

A system can be in both 0 and 1 state - until measured

A linear combination of all possible states



Schrodinger's cat can be both **dead** and **alive**

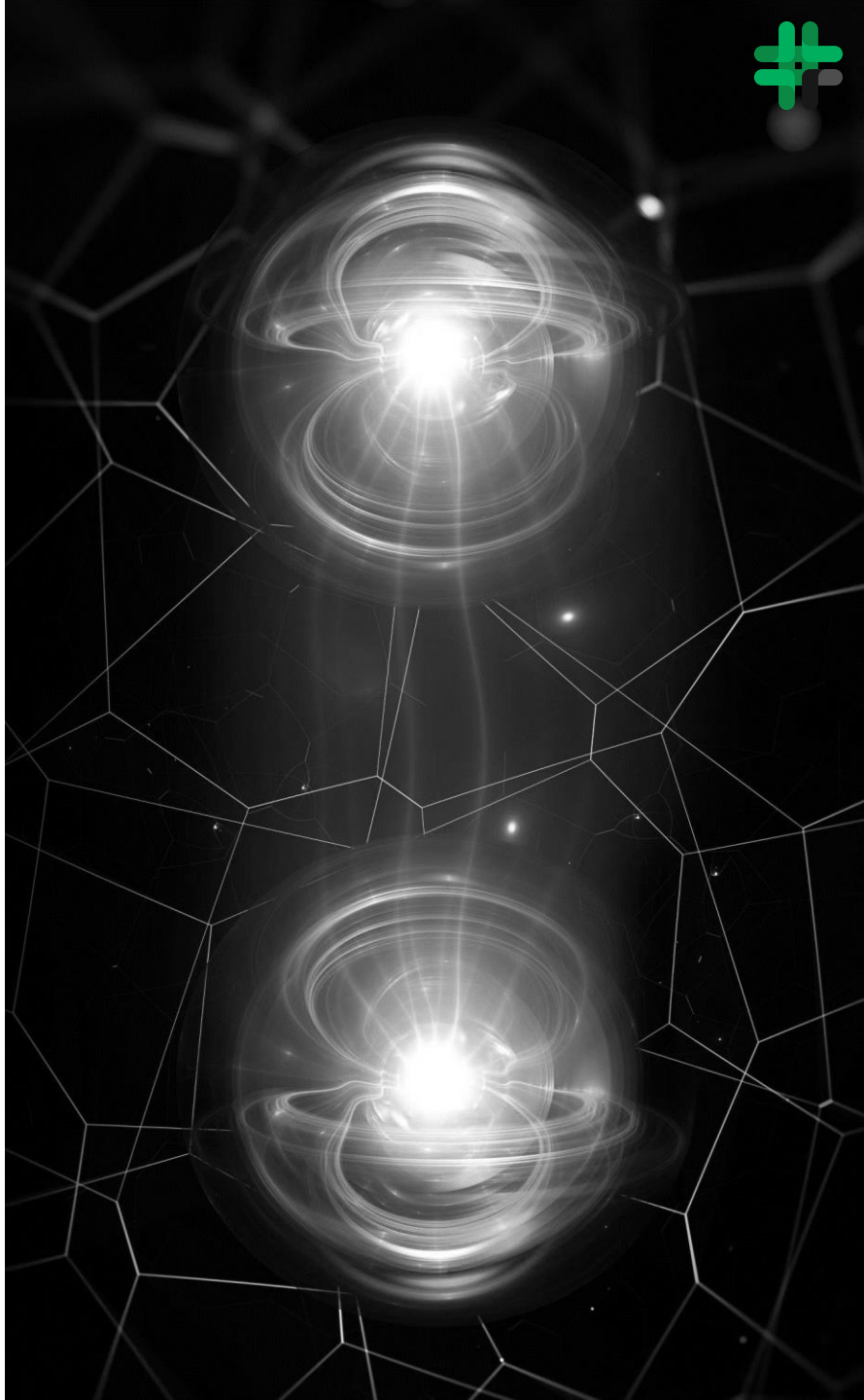
Entanglement

The ability of quantum particles to correlate their measurement results with each other no matter the distance

If we entangled 2 qubits we have a single quantum state:

- Both qubits are in superposition
- One qubit state changes according to the other

“Spooky action at a distance” - Albert Einstein



Decoherence

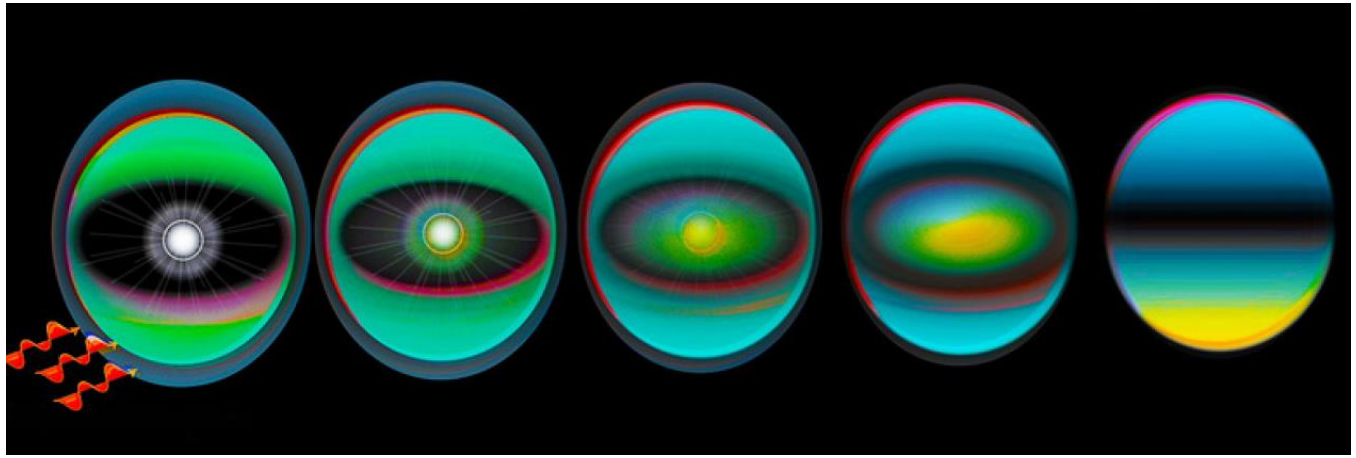
Losing information due to :

- The quantum system being fragile and not being perfectly isolated
- Noise interference even from Cosmic rays
- Coherence time is limited even without noise

Error correction – correcting loss of information by perfecting the hardware

Coherence time:

How long can a quantum state live?

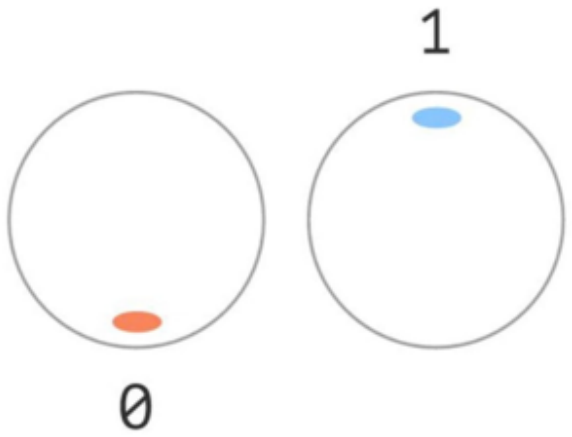


TIME

Environmental
Disruptions
NOISE

Bit vs Qubit

Bit



Qubit

$$|\psi\rangle = \alpha|0\rangle + \beta|1\rangle$$

Quantum Exponential power

1 qubit = 2 bits
2 qubits = 2^2 = 4 bits
…
n qubits = 2^n bits

Quantum Parallelism

Exponential Computational Power
Quantum Supremacy

There are $10^{90} \sim 2^{300}$ known particles in the universe :

- As many numbers to describe the state of 300 qubits

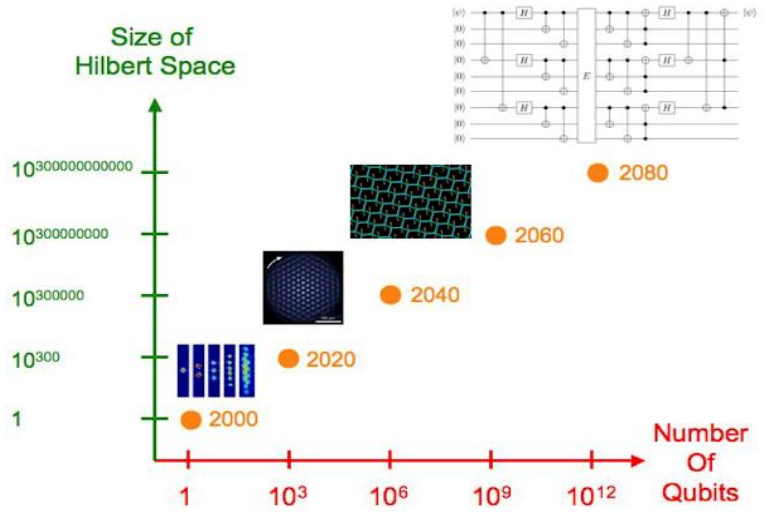
- If all 300 states are exploited at the same time you can perform a computation that is impossible on classical computers

Quantum vs Classical Computers

The smallest transistors are only **2nm wide** (6 – 10 atoms) and is not feasible to create smaller ones

Moore's law for classical computers is replaced by Neven's law for quantum computers

Classical computers will not be replaced, there are many problems that can be solved better on classical computers



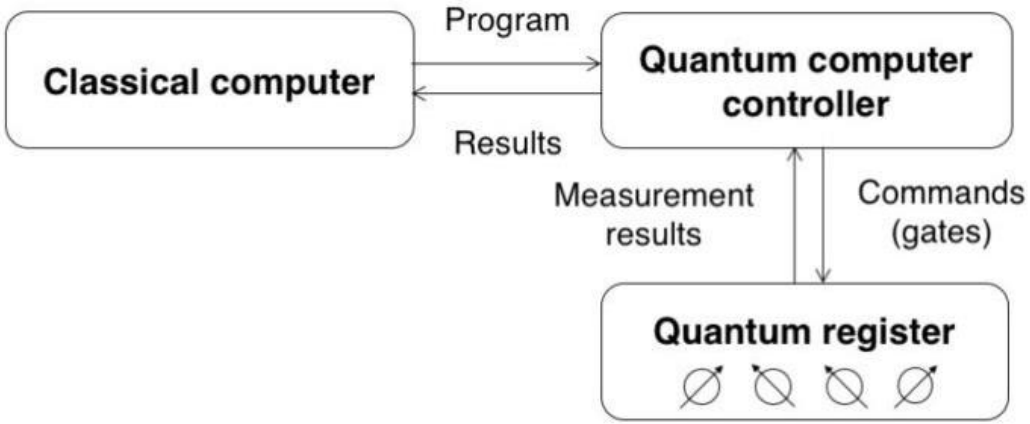
Neven's Law

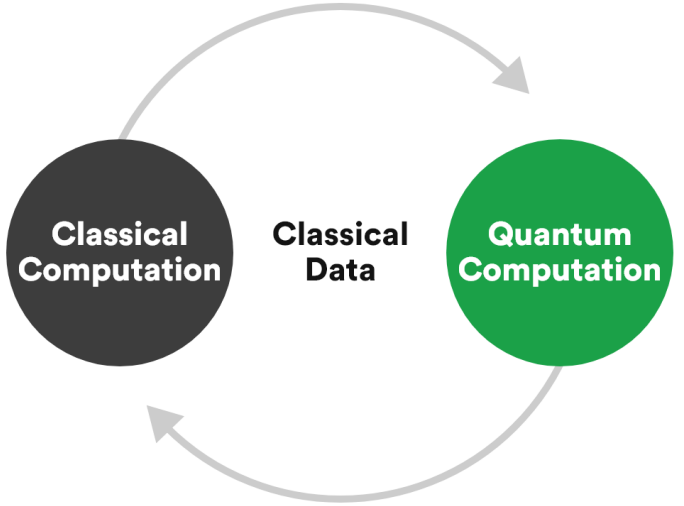
Moore's Law

Hybrid Quantum - Classical Computing

The QPU (Quantum Processor Unit) is dependent on the CPU for reading the data – coprocessor - same as GPU to CPU

Utilizing both classical and quantum hardware, sharing classical data between them, to try to exploit the best of both worlds for each computing model.

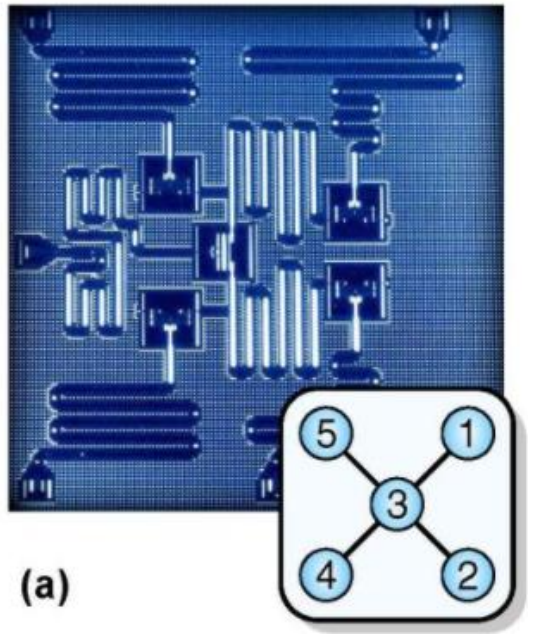




The Quantum RACE

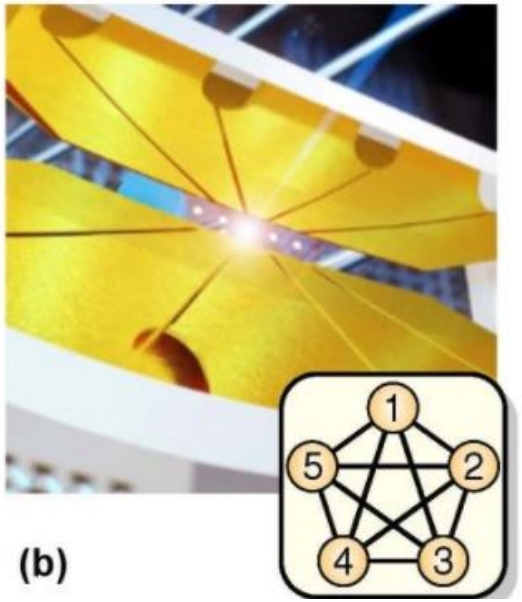
A qubit is built using quantum mechanics principles by combining different materials and architectures:

- Superconducting **(a)** - IBM, Google and Rigetti
  - Quantum annealers – different computation/specialized – D-wave
- Trapped ions **(b)** - IonQ and Honeywell (Oxford)
- Photonics - Photon qubits : Psi Quantum , Xanadu, NU Quantum
- Neutral (Cold) atoms - ColdQuanta (UK), Pasqal
- Topological qubits - Microsoft



(a)

Why different?

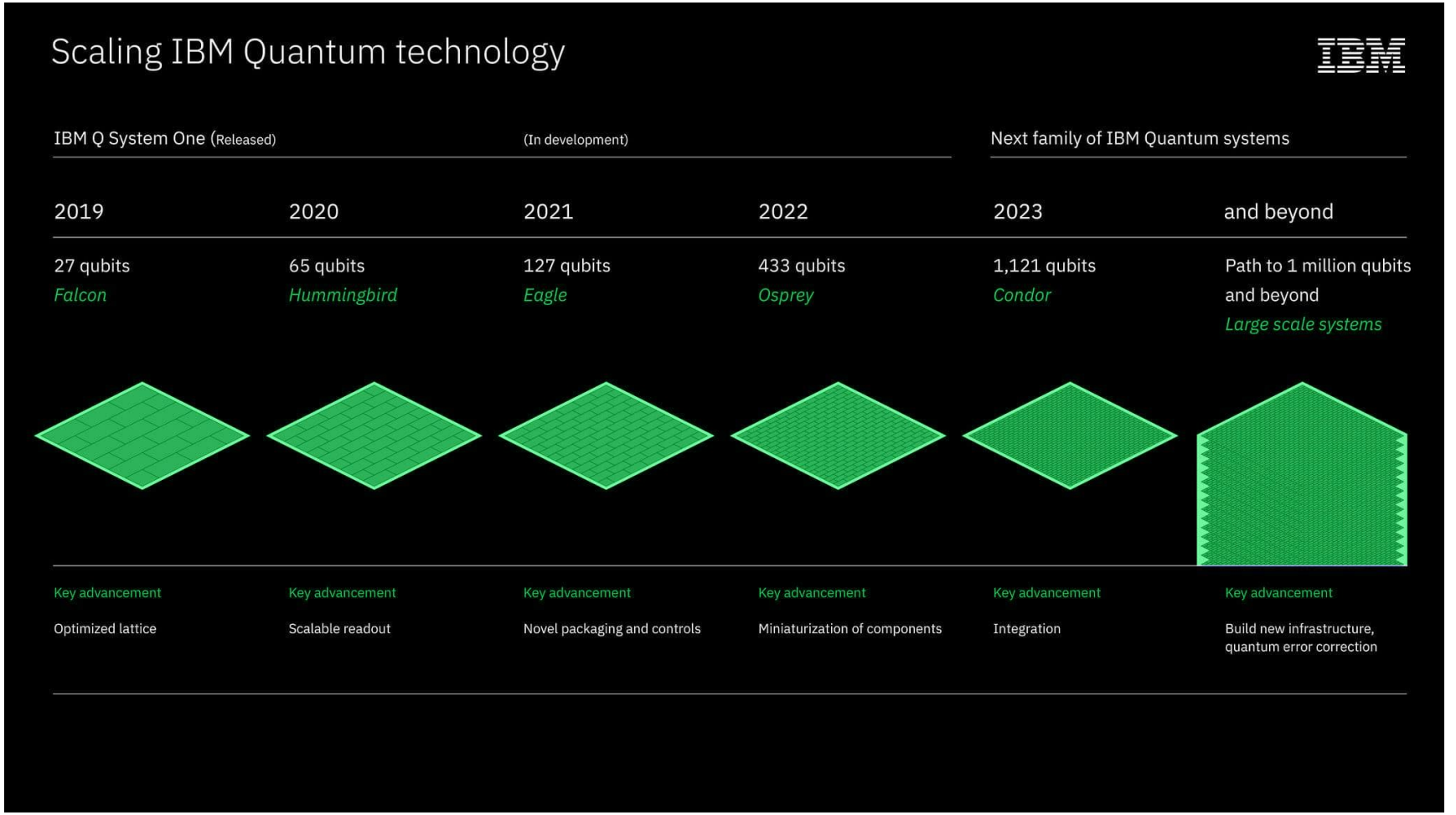


(b)

LIST of all companies involved - Comparison between architectures

RoadMap for Quantum computers

IBM



IONQ

Honeywell

Where is Quantum now?

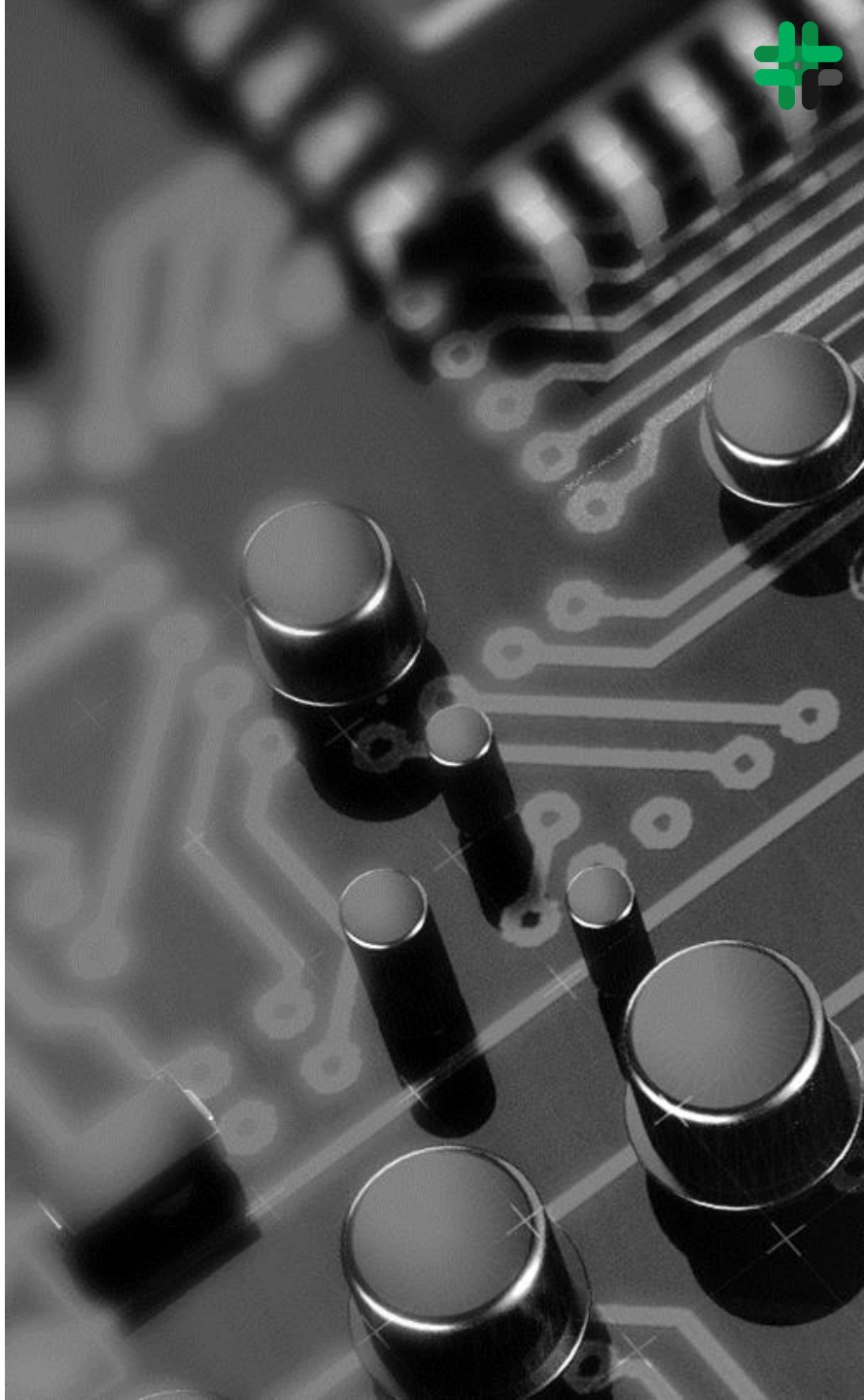
Current state is **NISQ** - Noisy-Intermediate Scale Quantum

All architectures are affected by **decoherance**:

- Noise interference that needs error correction
- Complicated cooling the systems to 0.01-0.05K colder than interstellar space (2.7K)

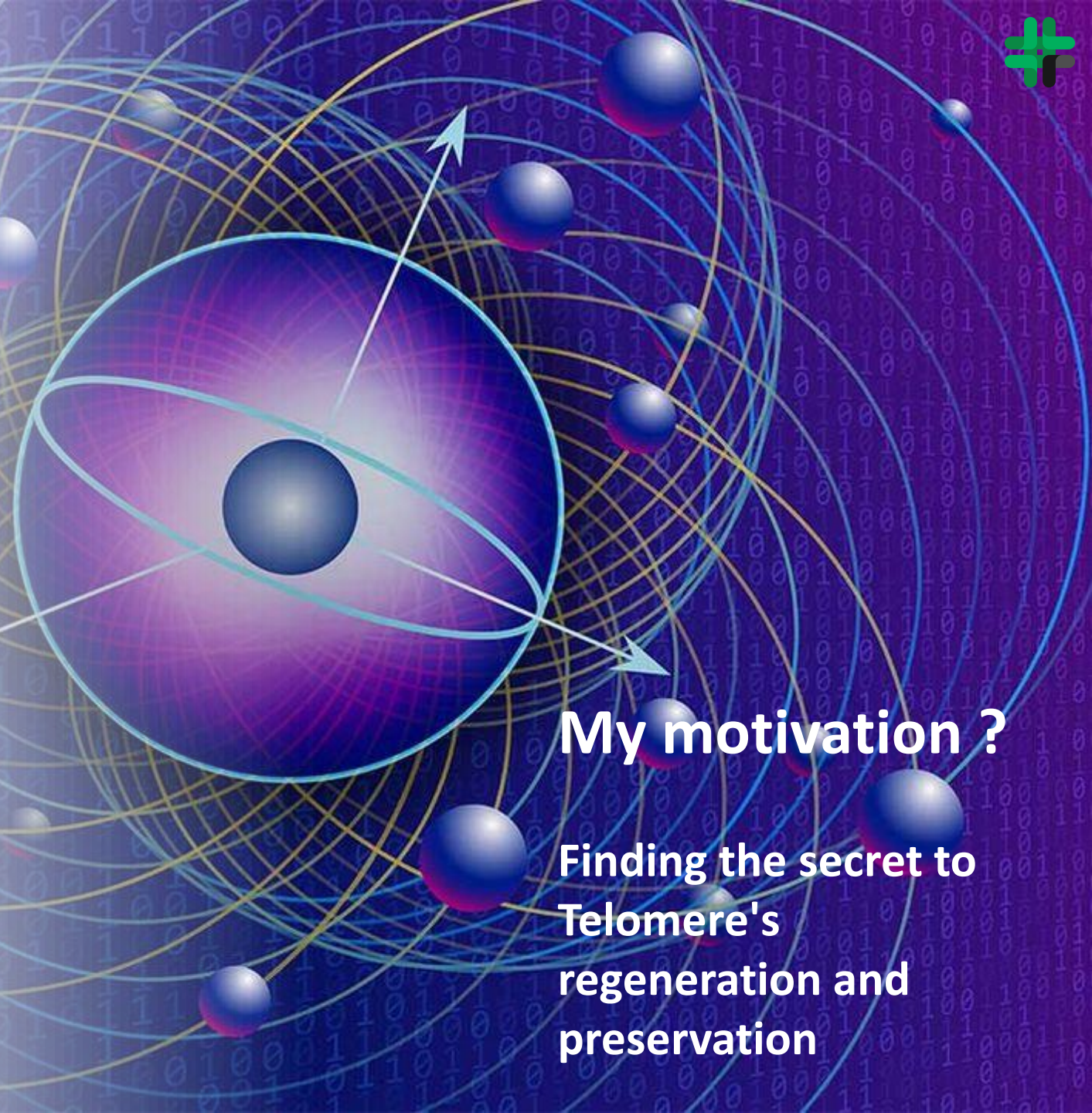
→ Large scaling is very challenging

Future state will be **QEC** – Quantum Error Correction that enables building large scale computers in spite of noise



Preparing for the Quantum Era – Quantum READY

- Building partnerships
- Education, training and communities
- Creating teams of specialists
- Following the innovation and doing **R&D** : Quantum use cases and algorithms
- Skills required for Quantum coding - <u>Quantum Developers</u>
  - Quantum mechanics
  - Math's
  - Programming



My motivation ?

Finding the secret to Telomere's regeneration and preservation

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Q & A

Mentimeter :

Where are we now?
Current Innovation **2021**

CHALLENGES	BREAKTHROUGHS
Decoherence – Error detecting and correction	Detect and Correct Quantum Errors in Real Time Time Crystals Silicone 3 spin entaglement Emergent quantum mechanics (EmQM)
Cooling systems	Cold Atom Quantum Technology
Increasing number of qubits (scalability)	1000 QPU - 2021 -> 1 million QPU by2029
Quantum simulators	256 qubit simulation
Creating quantum algorithms	Implemented quantum algorithms