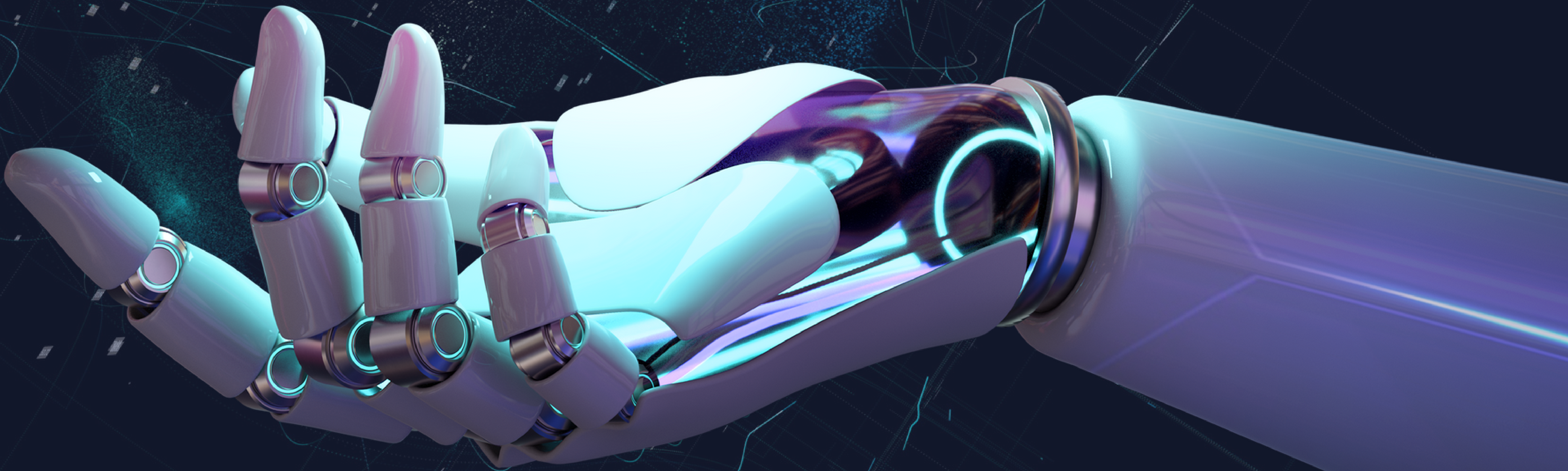
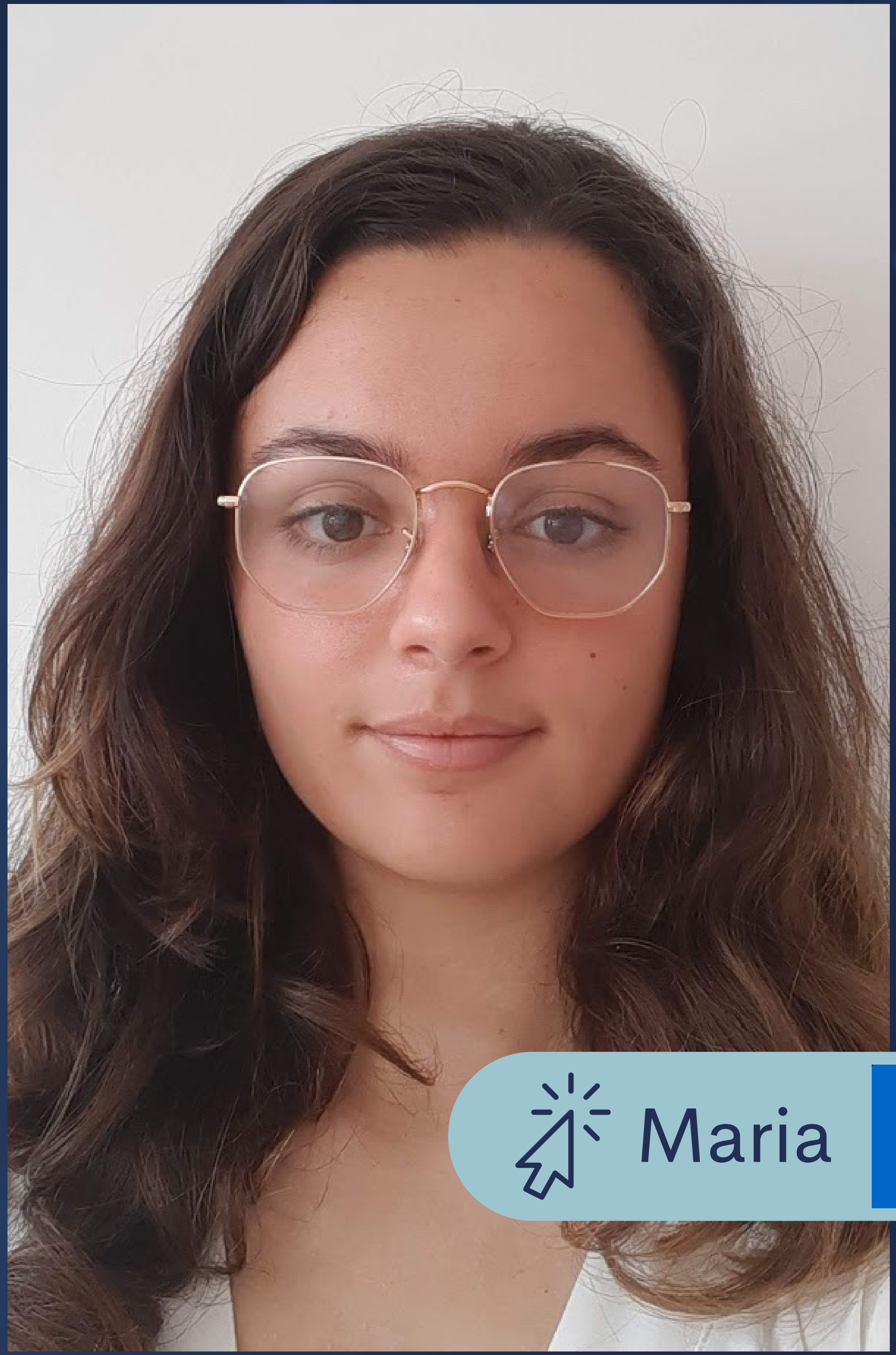
Quantum Optimization

MARIA GRAGERA GARCES



A little bit about me

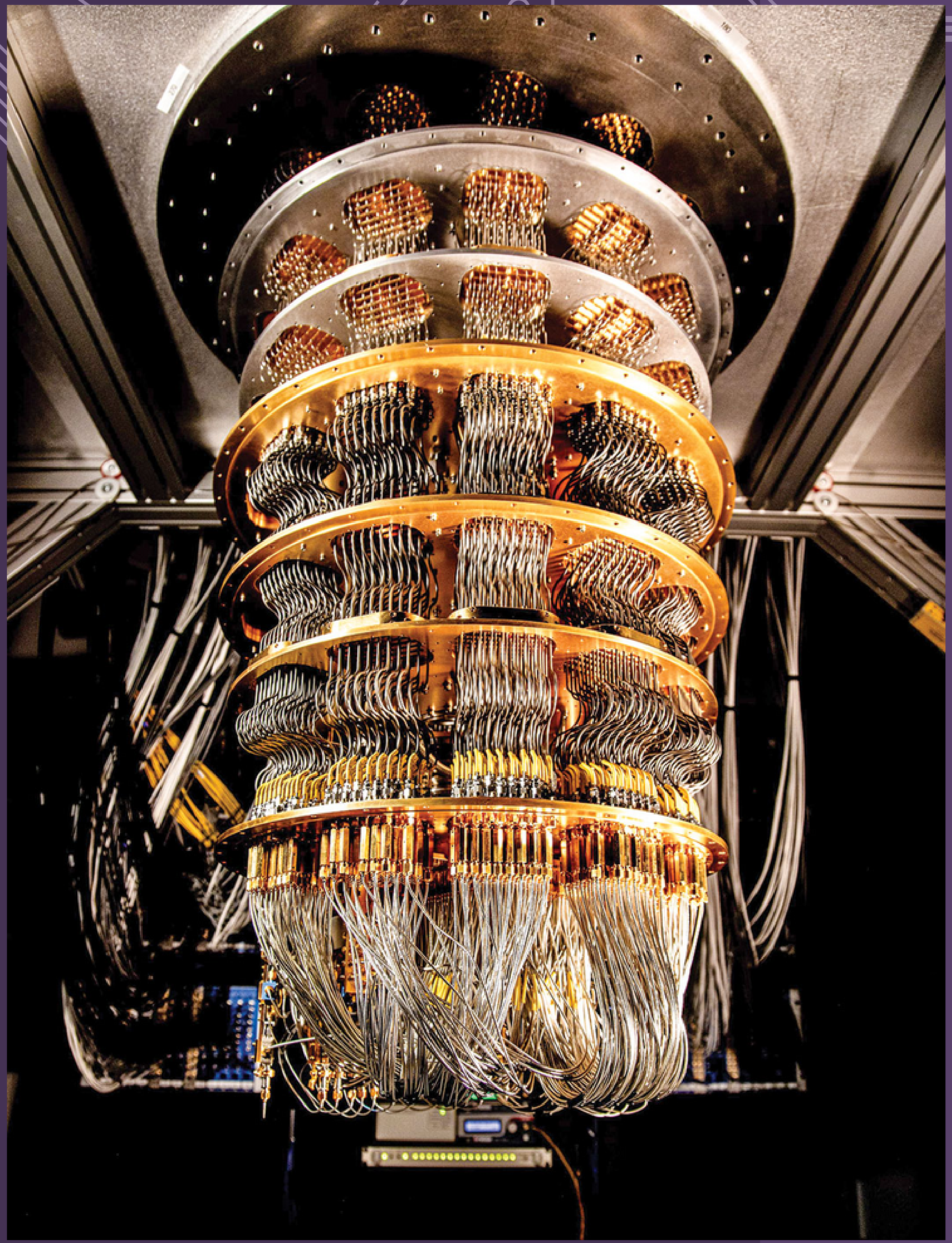


Maria

- Originally from Spain, Madrid
- Physics Undergraduate @ the University of Bath, UK
- Been in the Quantum Industry since 2021
- Worked and consulted for a multitude of companies:
  - Multinationals: Cisco, IBM
  - Startups and midsized companies: EllieTrac.AI, Quantum Foundry, The Quantum Insider, QuAIL Technologies, Ingenii
- Researched Quantum tech in academia:
  - 2022 Google of Summer in Code: Implementation of a quantum error correction code library for Julia's Clifford gate simulator
  - Researched the topological advantages of quantum networks over classical networks at the University of Bath
- Active member of the quantum open source ecosystem

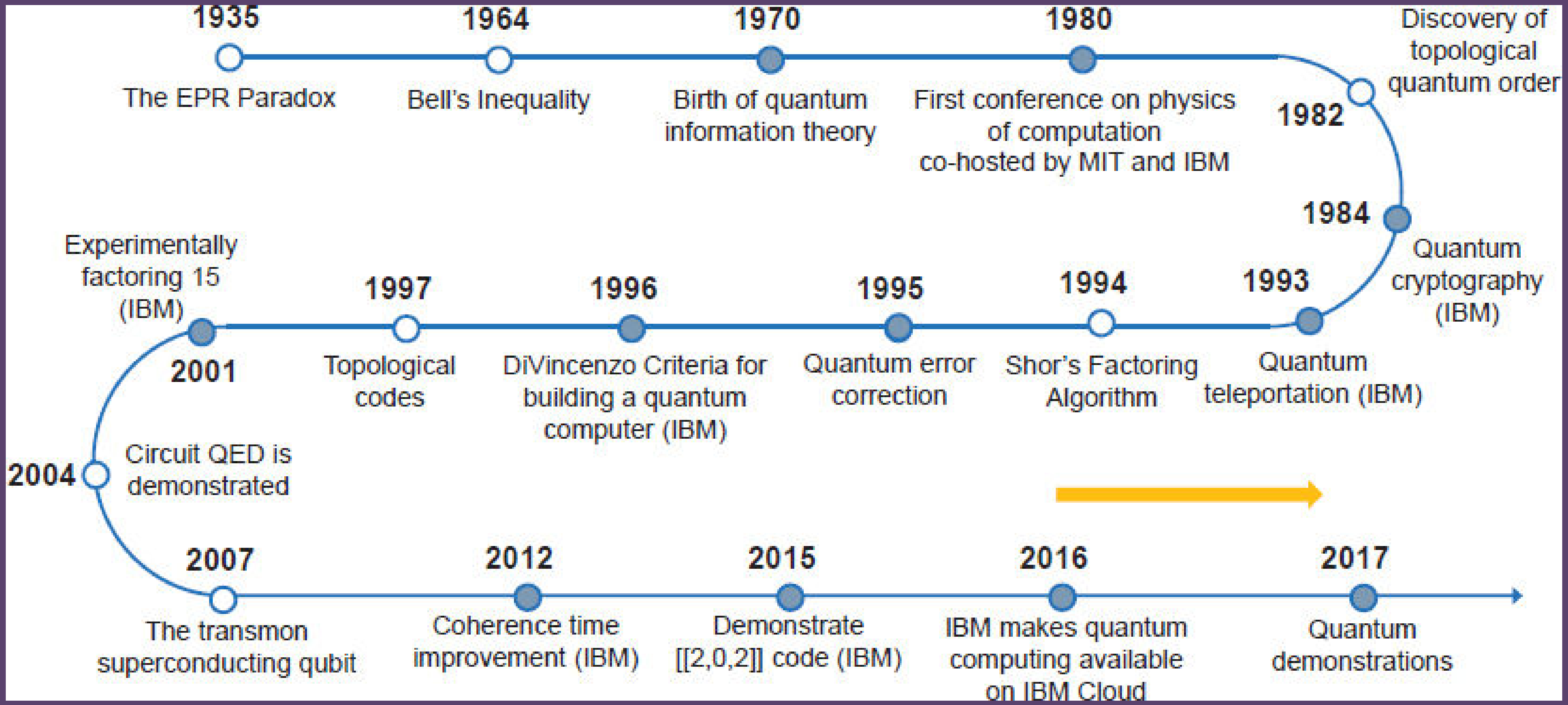
About today's topic

During the next 45 minutes we will discuss 3 major topics and hopefully give you a good overview of the past, present and future of Quantum, as well as it's offered advantage. We will delve into these topics as beginners, and by the end I will give you the tools and resources to continue your quantum journey. Let's get started!

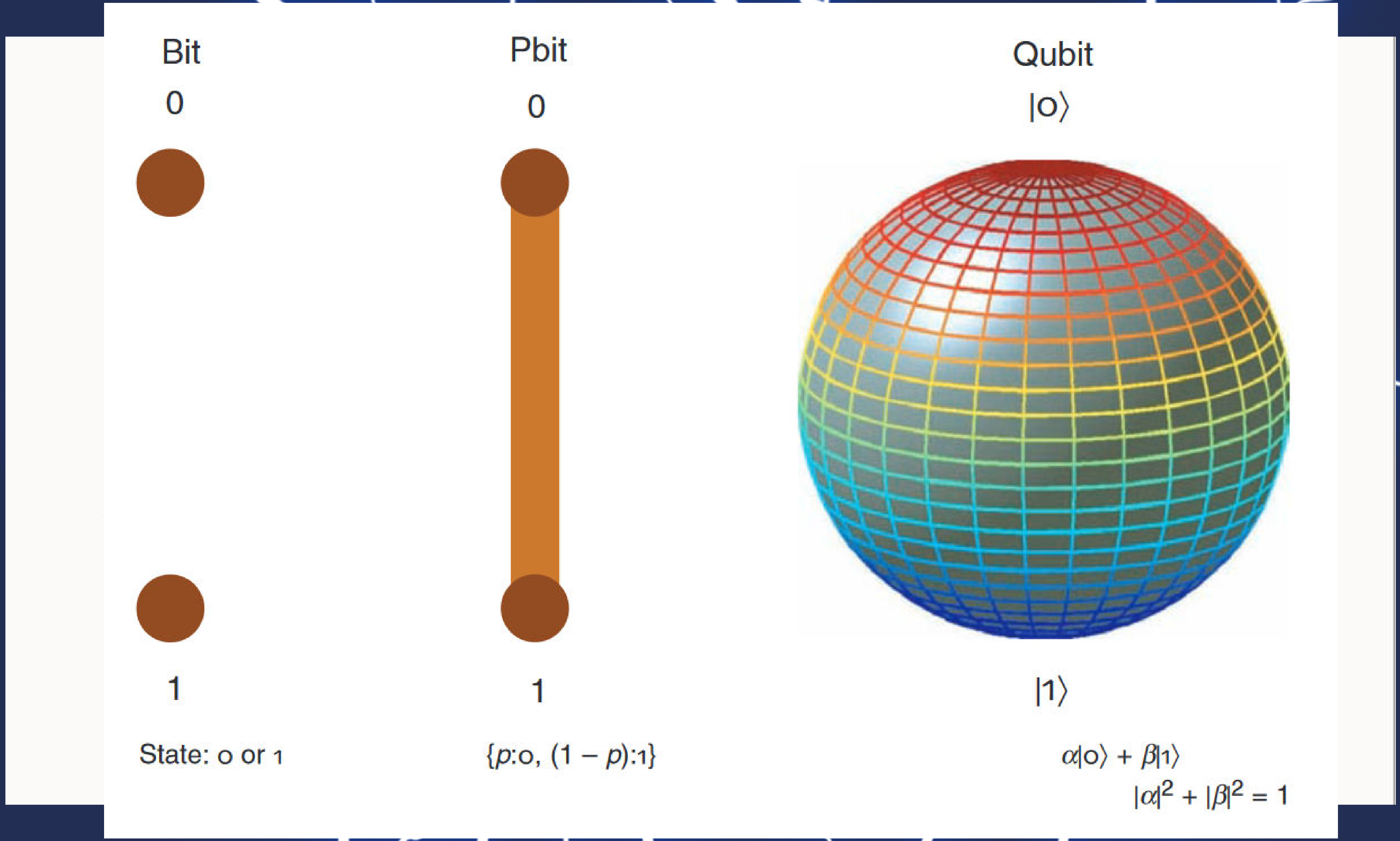


A historic perspective

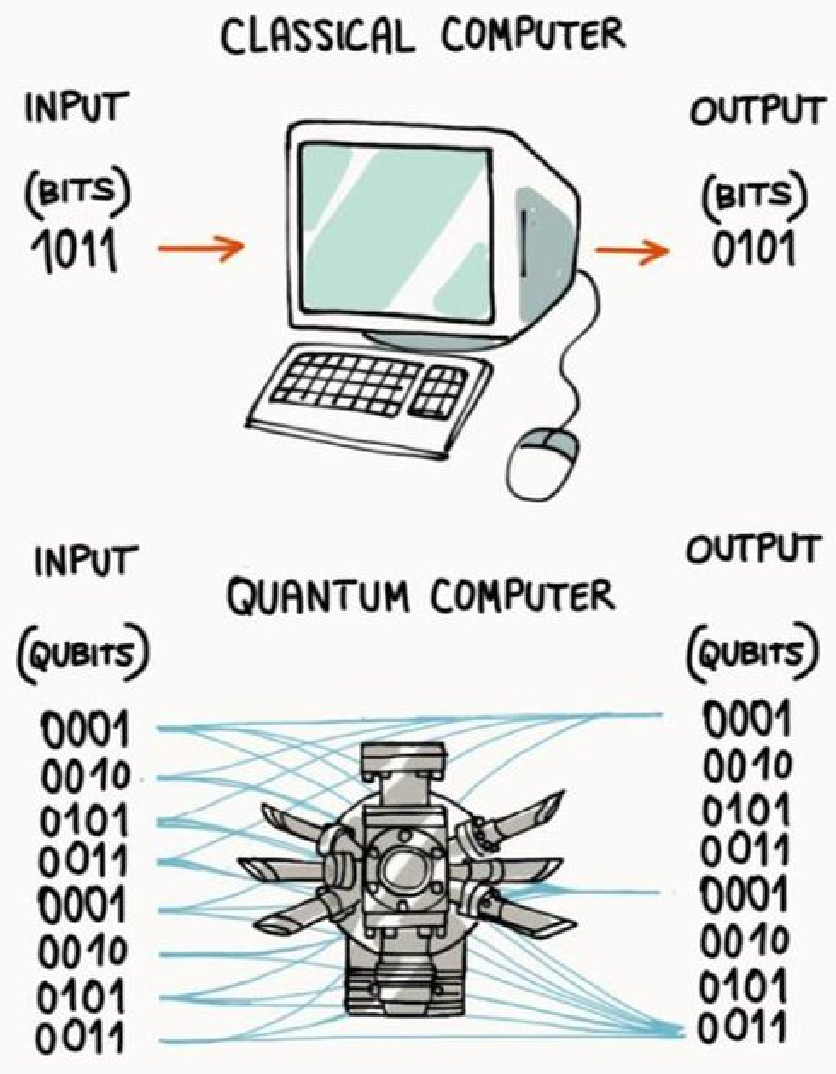
Quantum computing originated in the early 1980s when physicist Richard Feynman proposed the idea of simulating quantum systems using quantum mechanical phenomena. In 1985, David Deutsch formulated the first universal quantum computer model, laying the theoretical foundation for quantum computation. Significant progress was made in the 1990s, with Peter Shor's discovery of a quantum algorithm capable of efficiently factoring large numbers and Lov Grover's algorithm for fast searching, sparking widespread interest and research in the field.



VS



Bit
0
1
State: 0 or 1
Pbit
0
1
$\{p{:}0, (1-p){:}1\}$
Qubit
$|0\rangle$
$|1\rangle$
$\alpha|0\rangle + \beta|1\rangle$
$|\alpha|^2 + |\beta|^2 = 1$

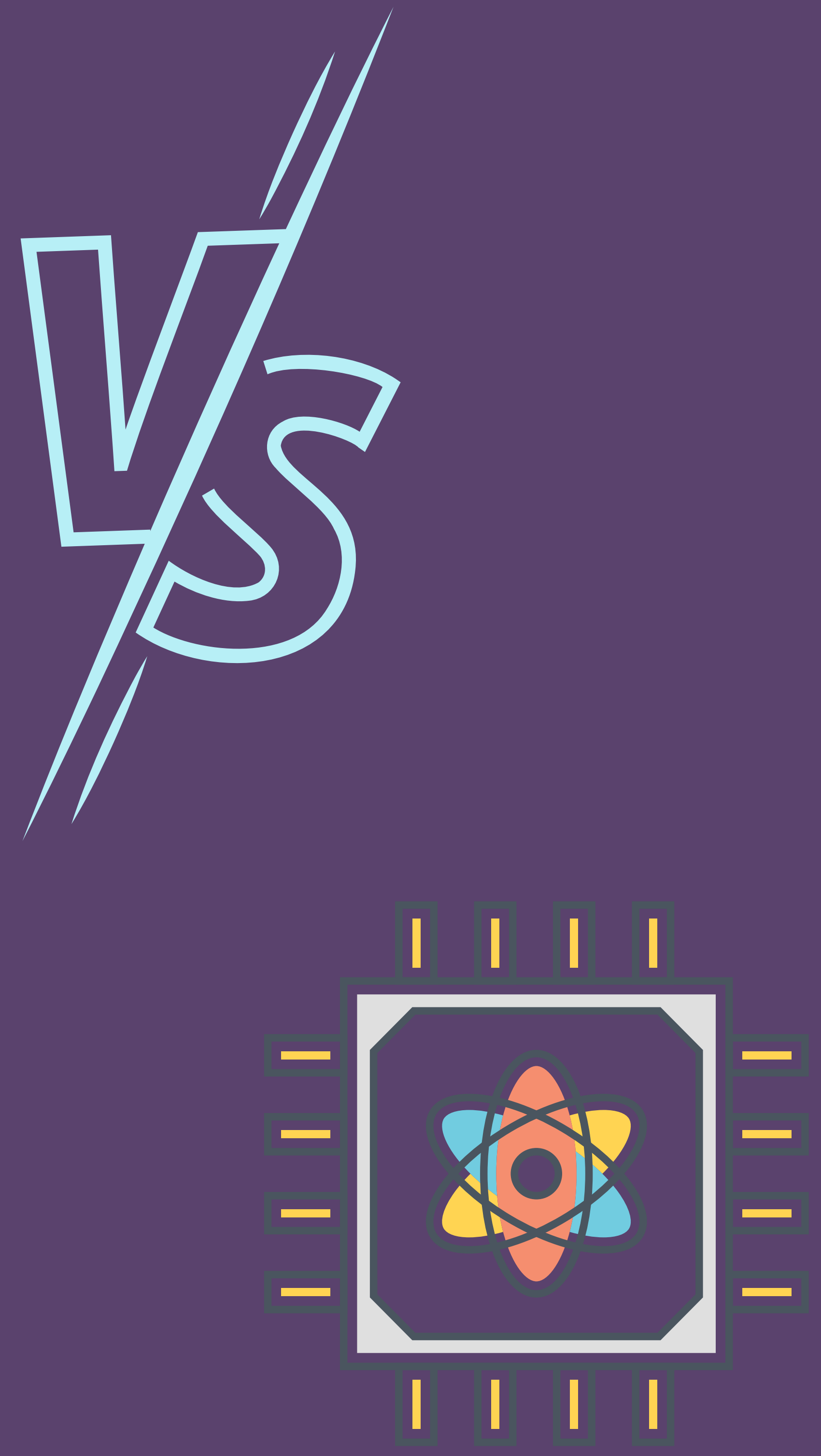


- A QUANTUM SYSTEM REPLACES CLASSICAL BITS WITH QUANTUM QUBITS

- QUBITS FOLLOW THE SUPERPOSITION PRINCIPLE AND CAN EXIST AS "0" AND "1" AT THE SAME TIME

- USING QUBITS INSTEAD OF BITS, WITH A SINGLE IMPUT ONE COULD PROCESS ALL THE POSSIBLE COMBINATIONS OF "0" AND "1"'S IN A STRING AT THE SAME TIME

- QUANTUM ALGORITMS USING THIS ABILITY COULD SOLVE CERTAIN TYPES OF PROBLEMS MUCH, MUCH FASTER THAN ANY CLASSICAL COMPUTER



Quantum Computing Vs. Classical Computing

Quantum Computing	Classical Computing
Calculates with qubits, which can represent 0 and 1 at the same time	Calculates with transistors, which can represent either 0 or 1
Power increases exponentially in proportion to the number of qubits	Power increases in a 1:1 relationship with the number of transistors
Quantum computers have high error rates and need to be kept ultracold	Classical computers have low error rates and can operate at room temp
Well suited for tasks like optimization problems, data analysis, and simulations	Most everyday processing is best handled by classical computers

CBINSIGHTS

Myths vs Facts

MYTH BUSTING

The Telegraph

Google quantum computer instantly makes calculations that take rivals 47 years

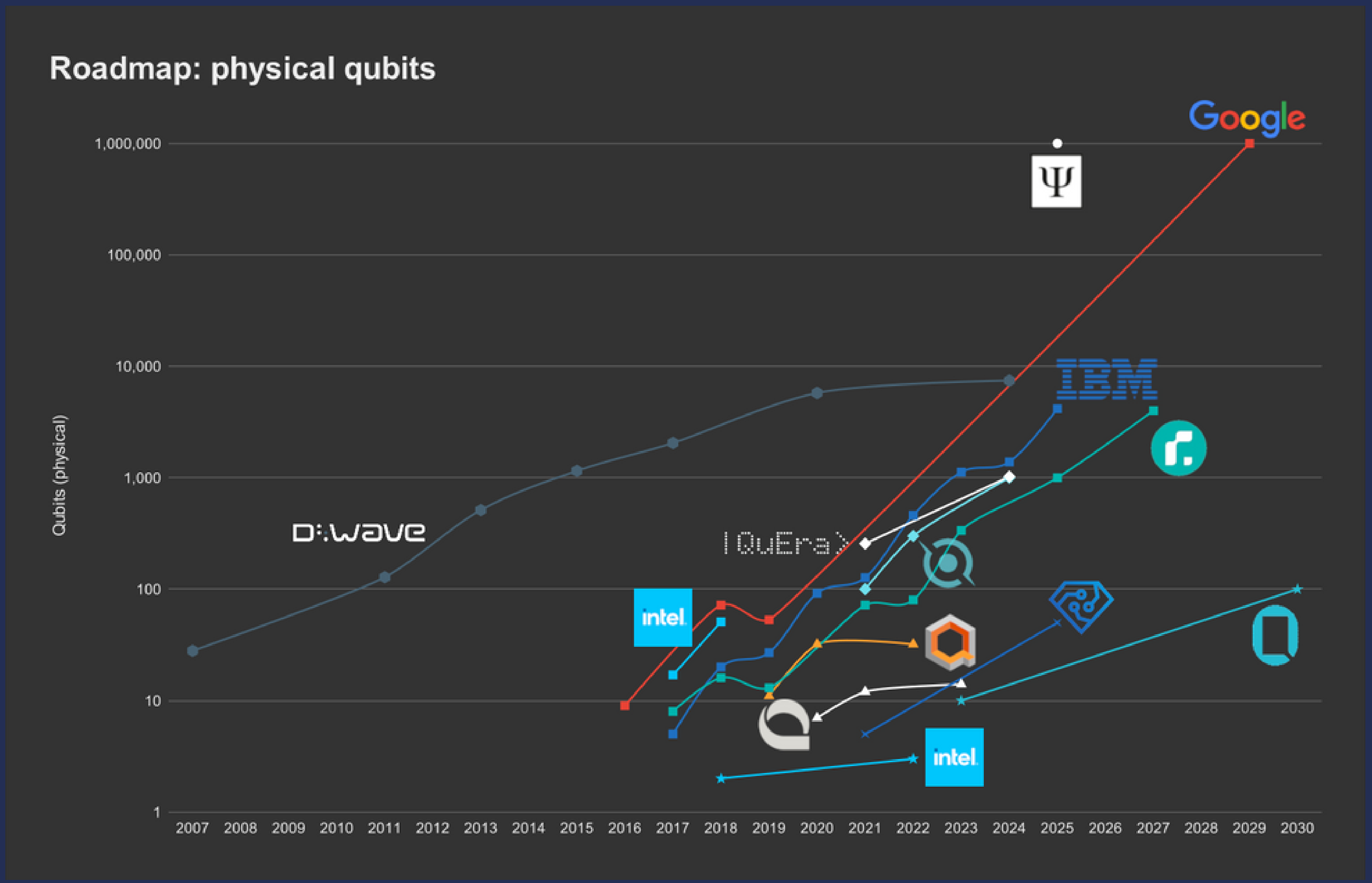
Google has developed a quantum computer that instantly makes calculations that would take the best existing supercomputers 47 years,...

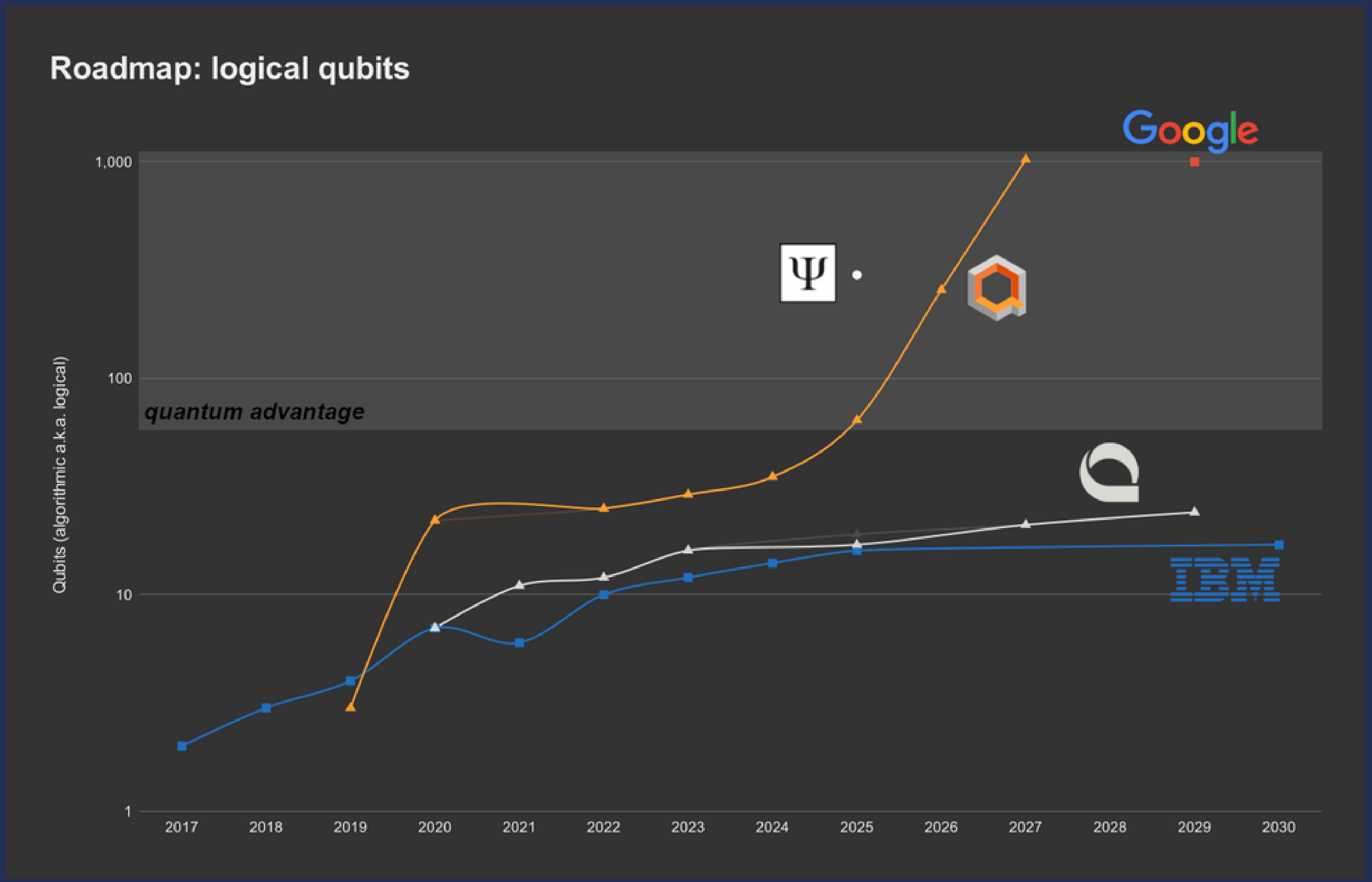
Firstpost

Googles new supercomputer is ahead of others by... 47 years!

Google's new supercomputer is actually a quantum computer and is the fastest in the world. It can carry out super complex calculations...

Advantage VS Supremacy





Current shortfalls

1. Hardware and Operating Conditions

Building and maintaining quantum computers requires sophisticated and expensive equipment, such as cryogenic cooling systems to keep qubits at extremely low temperatures. These technical requirements make quantum computers costly, large, and challenging to operate outside specialized laboratory settings.

2. Error Rates and Scalability

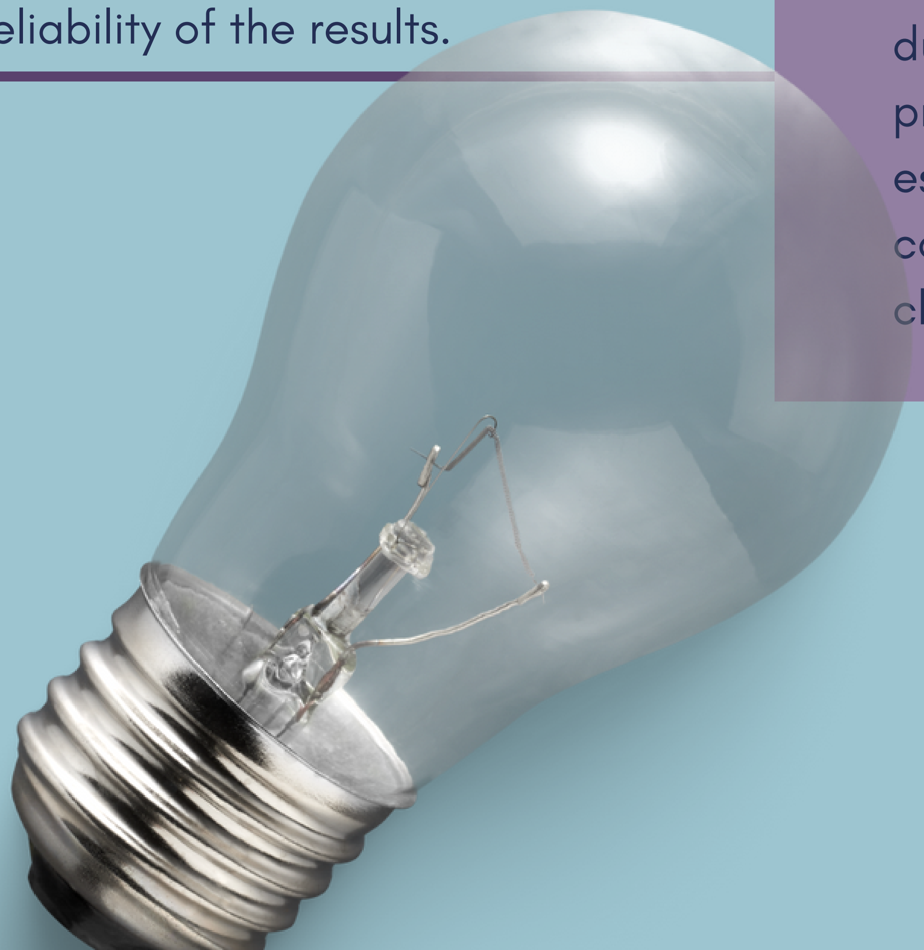
Quantum computations are susceptible to errors due to various factors, including noise and imprecise gates. As quantum computers scale up with more qubits, the probability of errors also increases exponentially, making it difficult to maintain the accuracy and reliability required for complex computations.

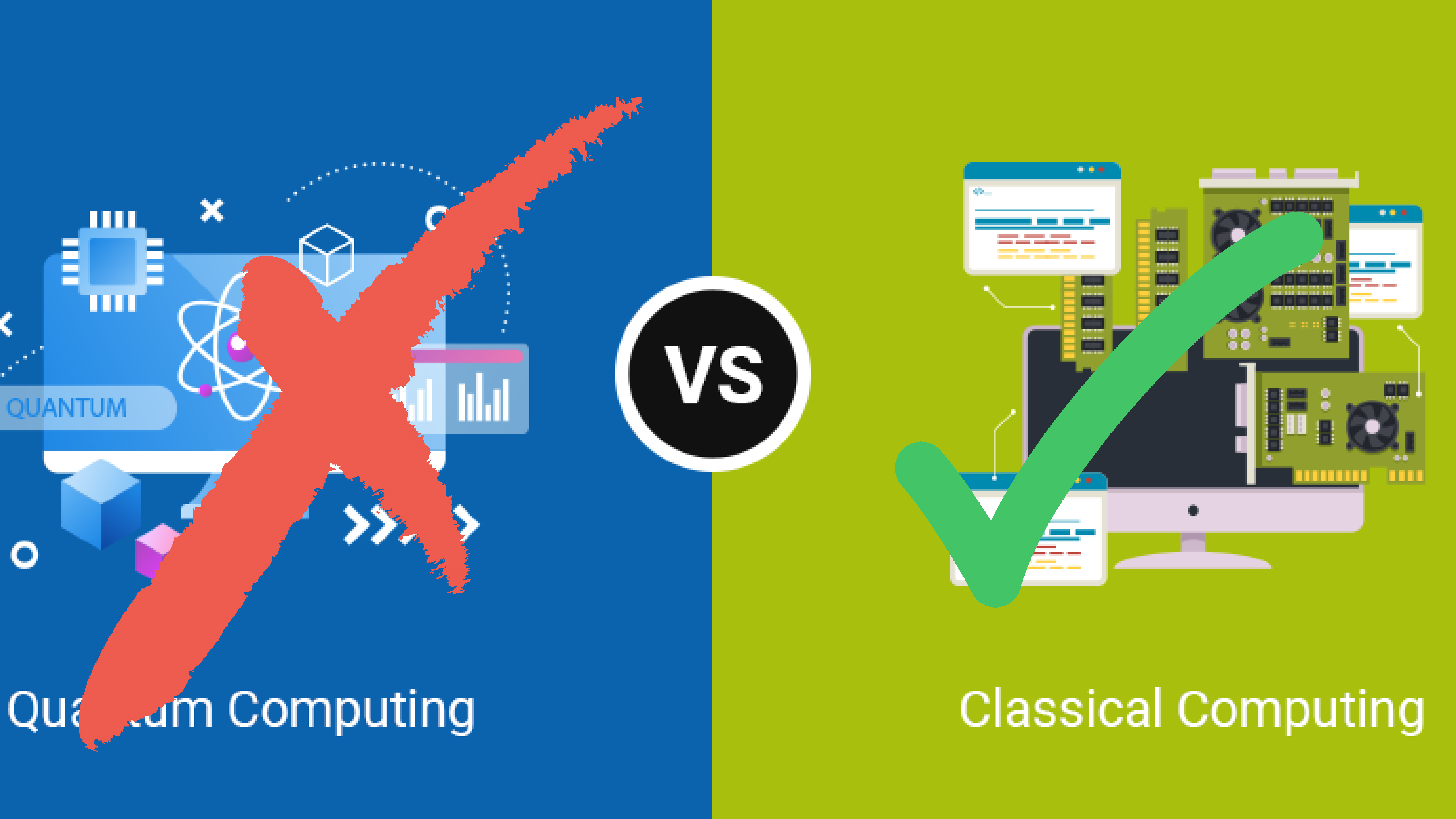
3. Decoherence

Quantum computers rely on qubits, which are highly sensitive and prone to interference from the surrounding environment. This interference causes a phenomenon known as decoherence, leading to errors in computations and reducing the reliability of the results.

4. Information Loss

Quantum information is extremely delicate and can be lost or corrupted during processing. Ensuring the preservation of quantum information, especially over extended computations, is a significant challenge in current quantum systems.

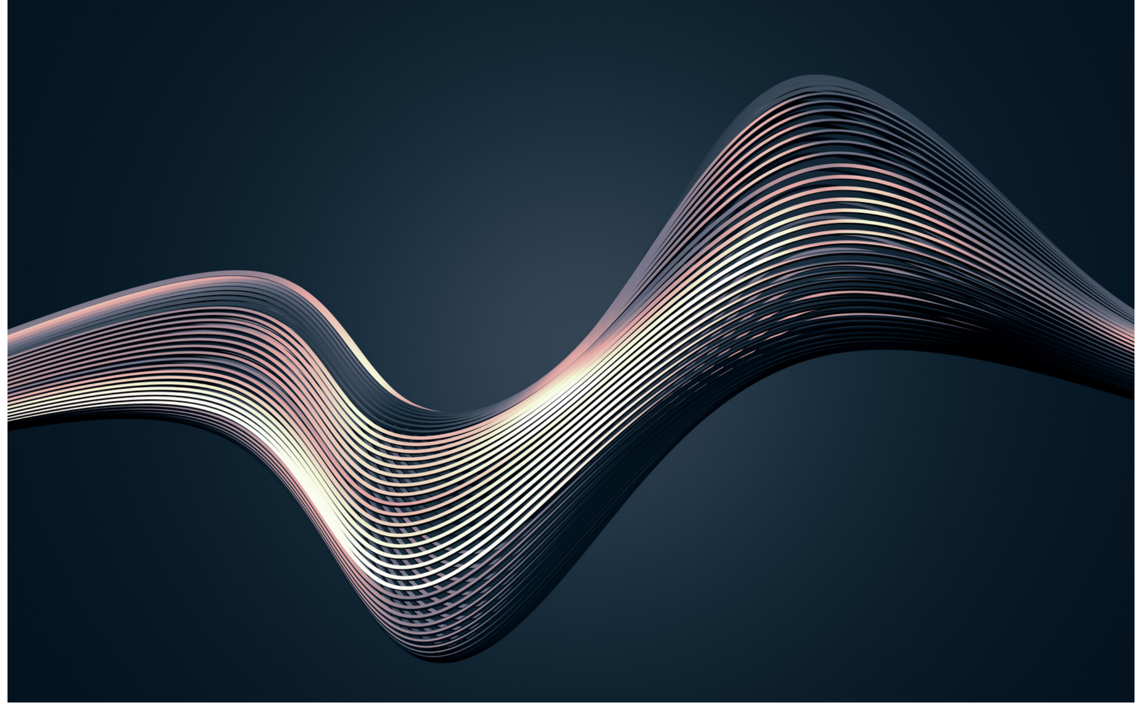


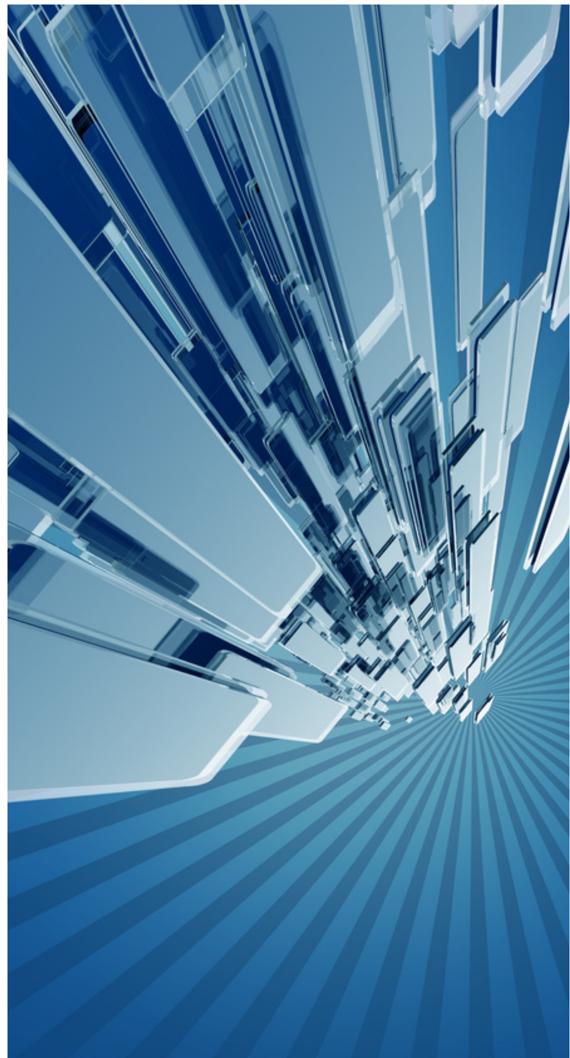

QUANTUM
VS
Qua tum Computing
Classical Computing

How do we overcome these issues?

Overcoming the significant challenges of modern quantum computers requires a multi-faceted approach that involves advancements in both hardware and software technologies.

- **Novel qubit technologies**





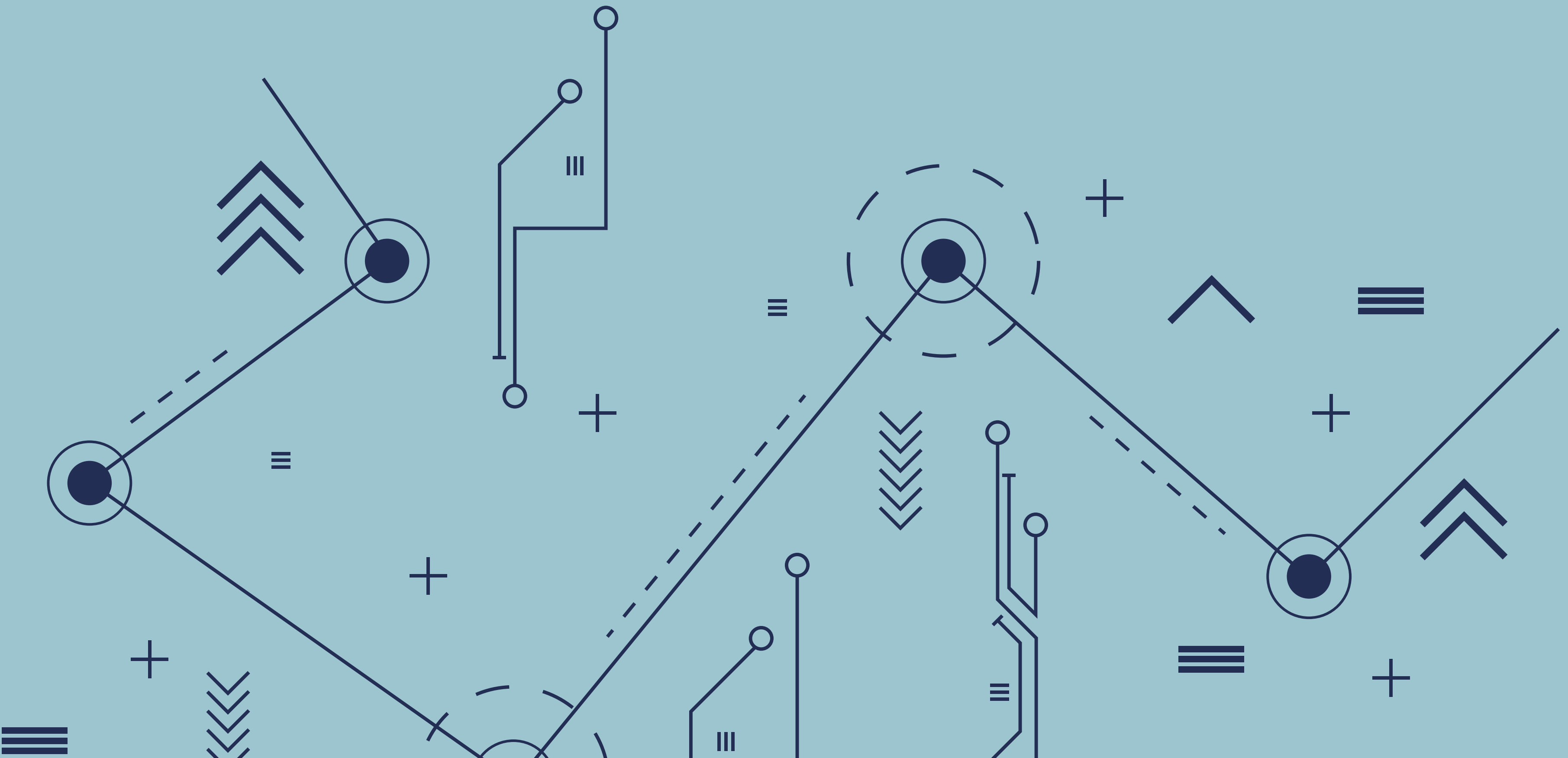
	Atoms		Electrons				Photons
Most of the illustrations are taken from: "From Science News Feature, 'Scientists are close to building a quantum computer that can beat a conventional one", Gabriel Popkin, 2016. Illustration by Chris Bickel/Science							
Qubit technology	**Trapped Ions**	**Cold Atoms**	**Superconductors**	**Silicon (+quantum dot)**	**Diamant impurity (NV center)**	**Majorana Fermion (topological)**	**Photons**
Application domain	metrology, computing, communication (repeaters, photon coupling)	metrology, computing, communication (photon coupling)	metrology, computing	metrology, computing	metrology, communication, computing	computing	metrology, communication, computing
Qubits Nature	ions trapped electromagnitically	atoms trapped by laser tweezers	superconducting loop/circuit	electrons trapped in a semiconductor	electron trapped in the cavity of a diamond cristal near a Nitrogen atom	quasi-particules, pairs of anyons, in superconducting nanowires	photons circulating in waveguides
Qubit quantum State	energy level of trapped-ion	energy level of atoms	3 types: phase qubits, charge qubits a.k.a transmon and flux qubit	electron spin	energy level of the NV center electrons	direction of anyon	one property of photon (polarity…)
Maturity (TRL) & scalability potential	**5 Scalability : relatively difficult**	**4 Scalability : hard**	**5 Scalability : relatively easy**	**3 Scalability : not easy today but could be good**	**3 Scalability : relatively difficicult**	**1 Scalability : too early to tell**	**3 Scalability : hard**

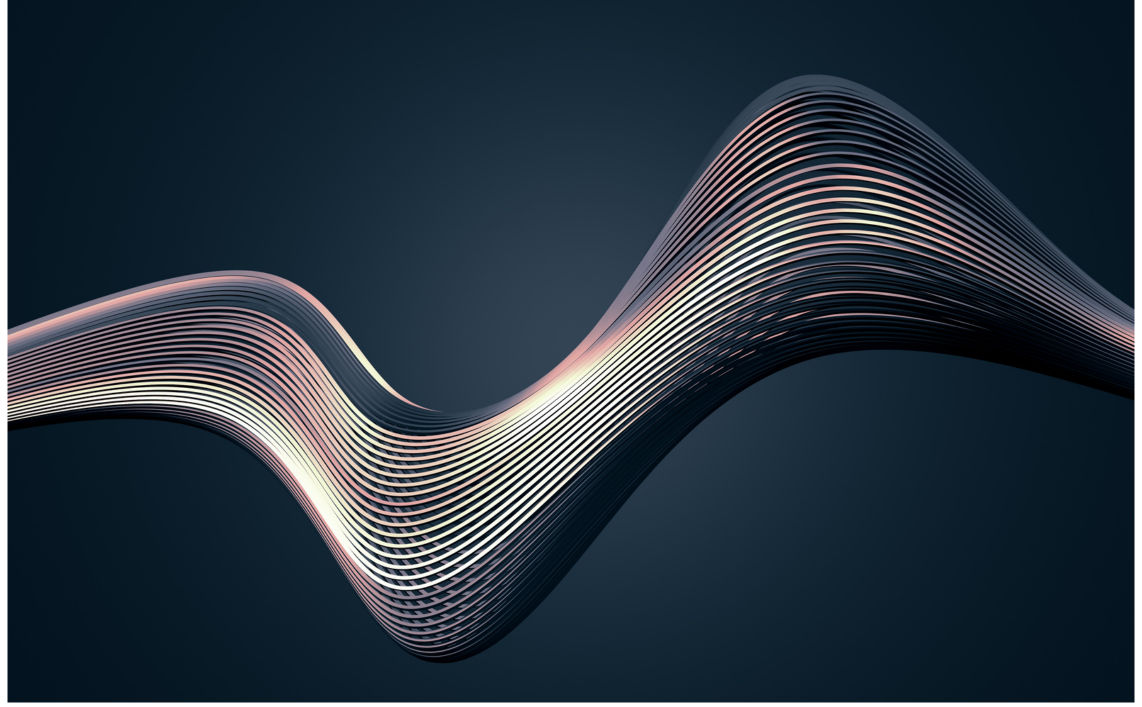
AQT, Universal Quantum, IONQ, oxford ionics | QuEra Computing Inc., PASQAL, ColdQuanta, atom computing | Google, rigetti, QuTech, qci Quantum Circuits, Inc, IBM Q, 本源量子 Origin Quantum | intel, diraq, Quantum Motion, Silicon Quantum Computing | Quantum Brilliance | XANADU, ORCA Computing, PsiQuantum, QuiX Quantum

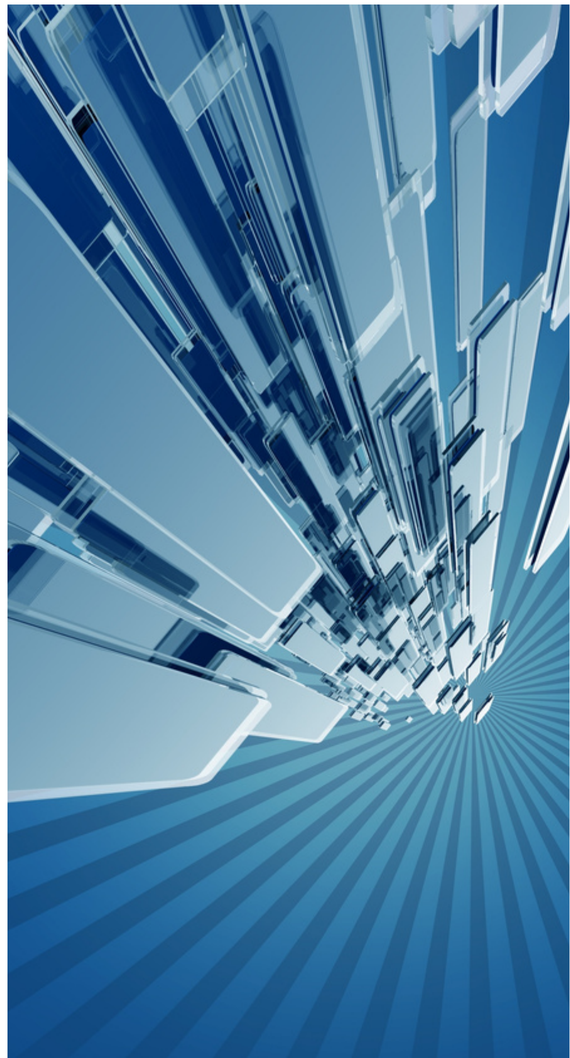
How do we overcome these issues?

Overcoming the significant challenges of modern quantum computers requires a multi-faceted approach that involves advancements in both hardware and software technologies.

- Novel qubit technologies
- **Simplification of control systems**







Article | Open Access | Published: 14 November 2022

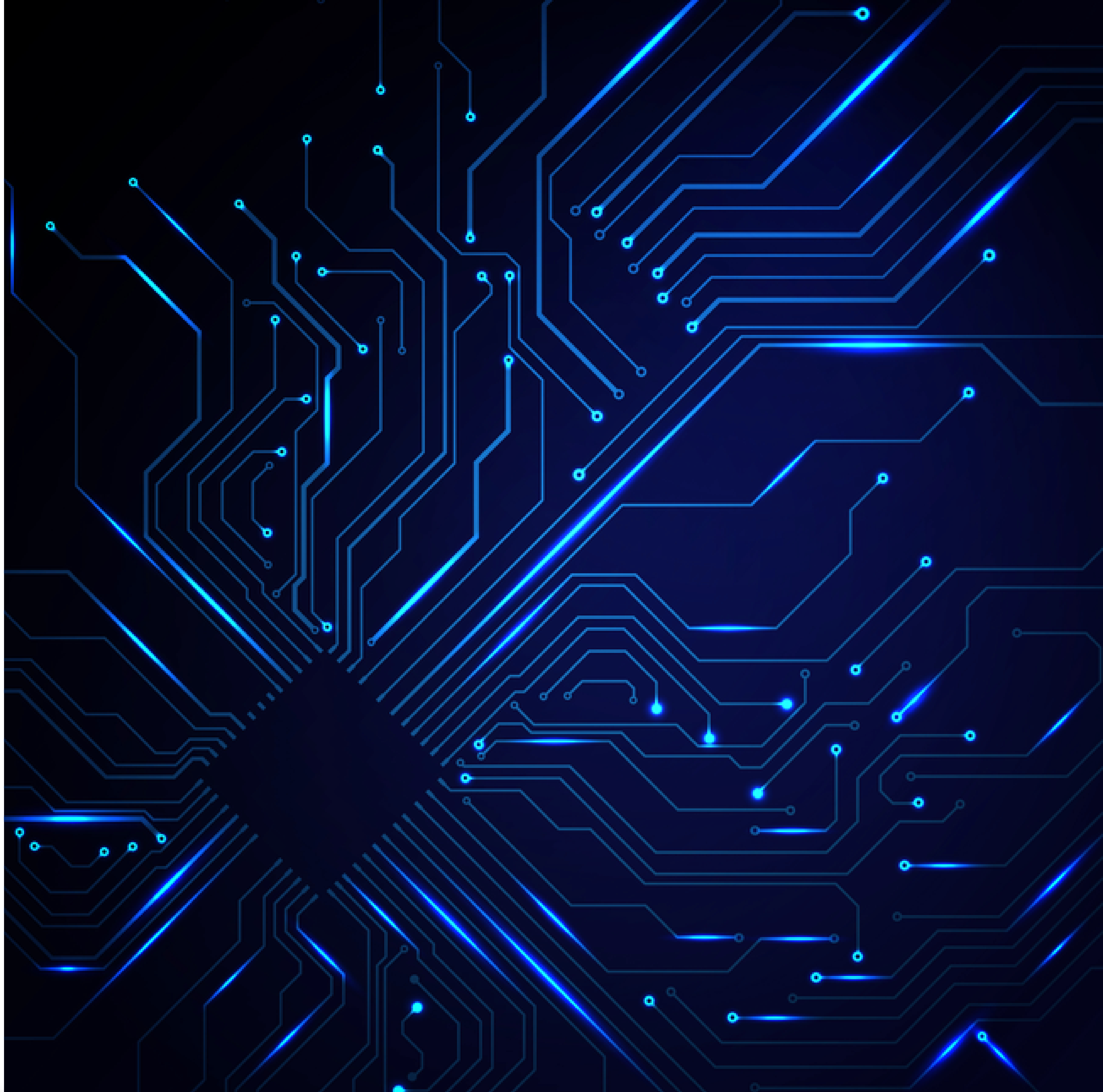
Scalable algorithm simplification using quantum AND logic

Ji Chu, Xiaoyu He, Yuxuan Zhou, Jiahao Yuan, Libo Zhang, Qihao Guo, Yongju Hai, Zhikun Han, Chang-Kang Hu, Wenhui Huang, Hao Jia, Dawei Jiao, Sai Li, Yang Liu, Zhongchu Ni, Lifu Nie, Xianchuang Pan, Jiawei Qiu, Weiwei Wei, Wuerkaixi Nuerbolati, Zusheng Yang, Jiajian Zhang, Zhida Zhang, Wanjing Zou, ... Dapeng Yu + Show authors

Nature Physics **19**, 126–131 (2023) | Cite this article

Abstract

Implementing quantum algorithms on realistic devices requires translating high-level global operations into sequences of hardware-native logic gates, a process known as quantum compiling. Physical limitations, such as constraints in connectivity and gate alphabets, often result in unacceptable implementation costs. To enable successful near-term applications, it is crucial to optimize compilation by exploiting the capabilities of existing hardware. Here we implement a resource-efficient construction for a quantum version of AND logic that can reduce the compilation overhead, enabling the execution of key quantum circuits. On a high-scalability superconducting quantum processor, we demonstrate low-depth synthesis of high-fidelity generalized Toffoli gates with up to 8 qubits and Grover's search algorithm in a search space of up to 64 entries. Our experimental demonstration illustrates a scalable and widely applicable approach to implementing quantum algorithms, bringing

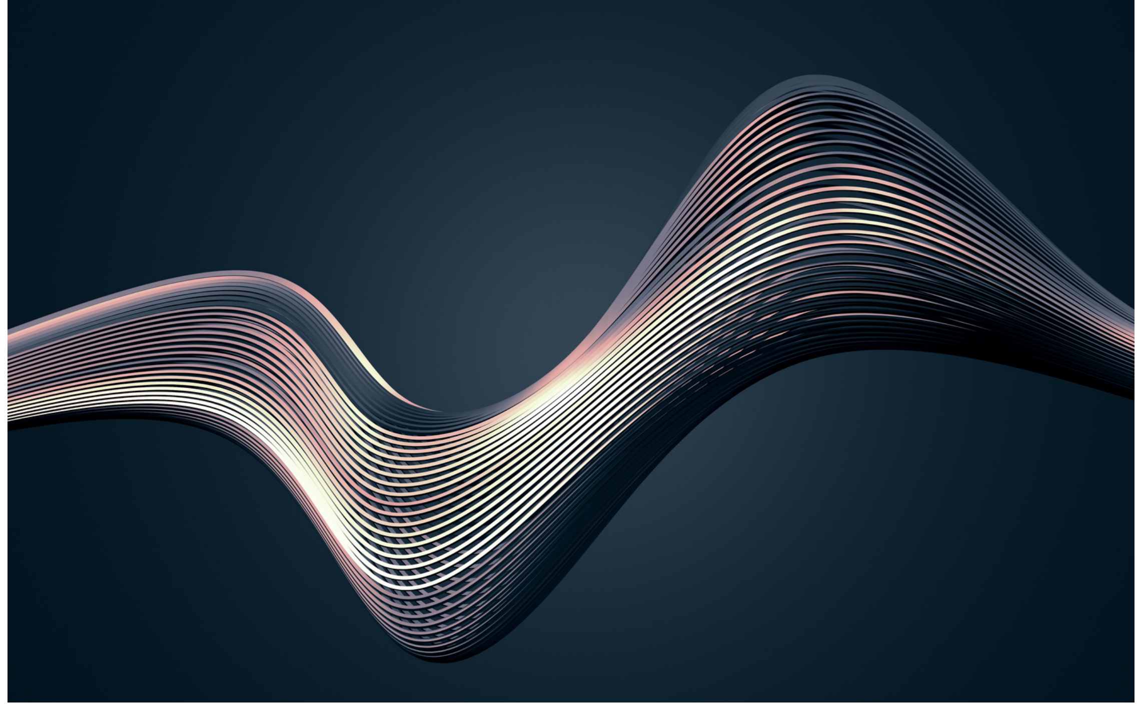


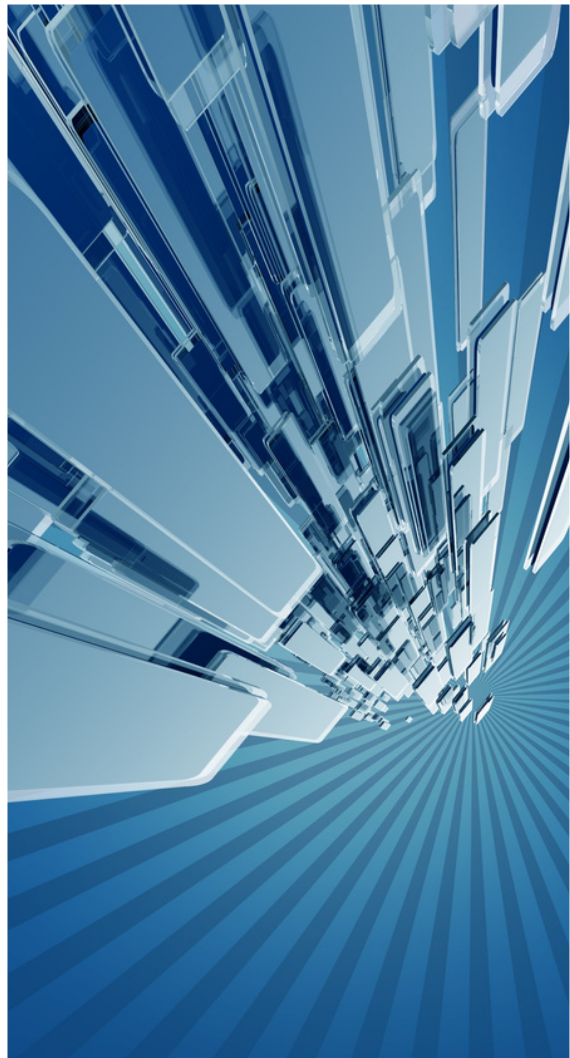
- **Quantum Parallelism:** Quantum algorithms leverage the principle of superposition to explore multiple possibilities simultaneously, enabling exponential speedup over classical algorithms for certain tasks.
- **Grover's Search Algorithm:** Provides a quadratic speedup in searching an unsorted database compared to classical algorithms, valuable for solving problems with large search spaces.
- **Quantum Fourier Transform (QFT):** Essential in many quantum algorithms, QFT enables the efficient transformation between position and momentum space, significantly impacting quantum simulations and factoring algorithms.
- **Variational Quantum Algorithms:** Algorithms that combine classical and quantum computing resources, allowing optimization of parameters to solve optimization problems efficiently.
- **Quantum Approximate Optimization Algorithm (QAOA):** A variational quantum algorithm designed to solve combinatorial optimization problems.
- **Quantum Machine Learning Algorithms:** Quantum algorithms designed to accelerate machine learning tasks, including quantum support vector machines and quantum neural networks.

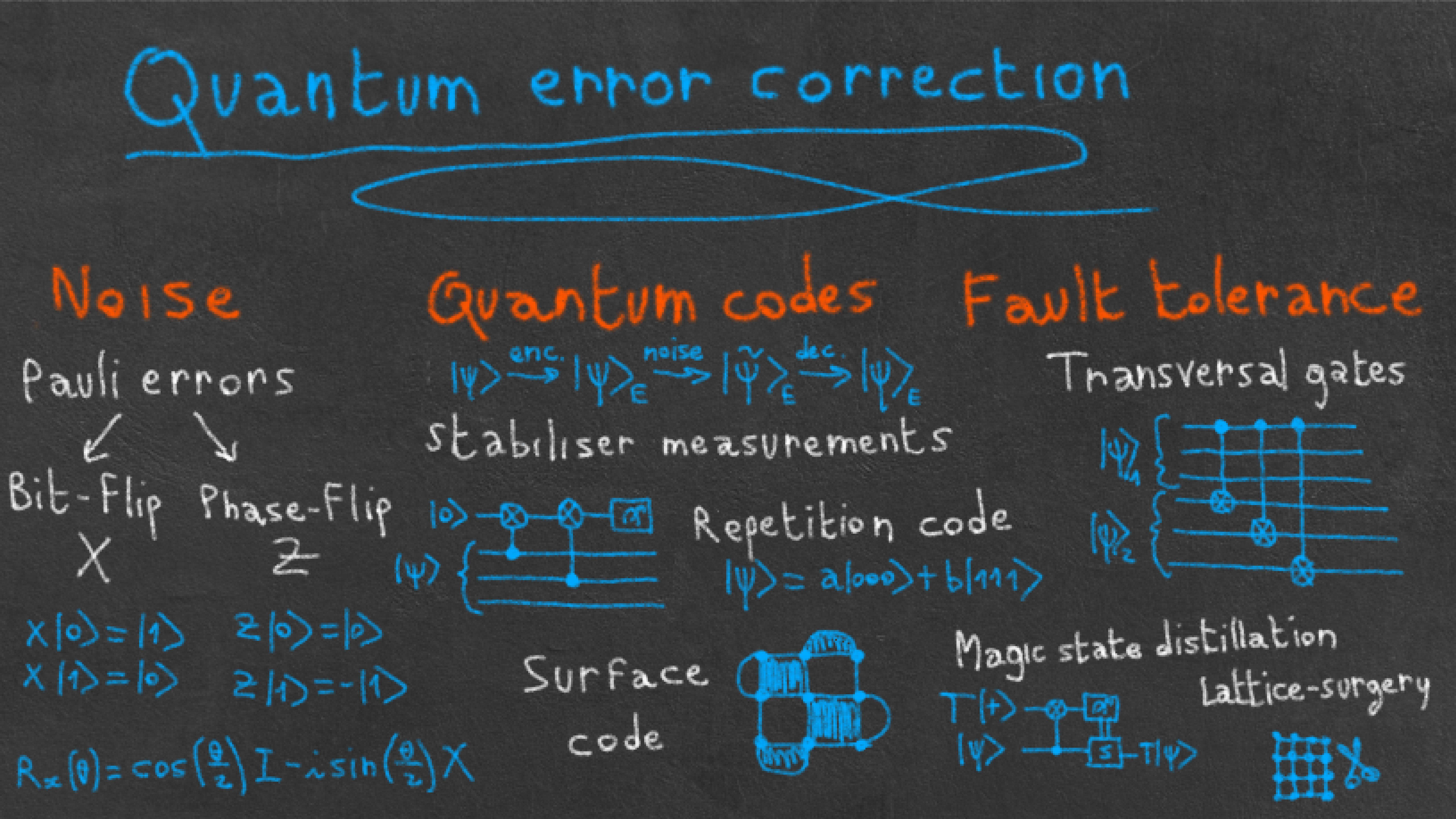
How do we overcome these issues?

Overcoming the significant challenges of modern quantum computers requires a multi-faceted approach that involves advancements in both hardware and software technologies.

- Novel qubit technologies
- Simplification of control systems
- **Quantum error-correction**
- **Quantum error-mitigation**



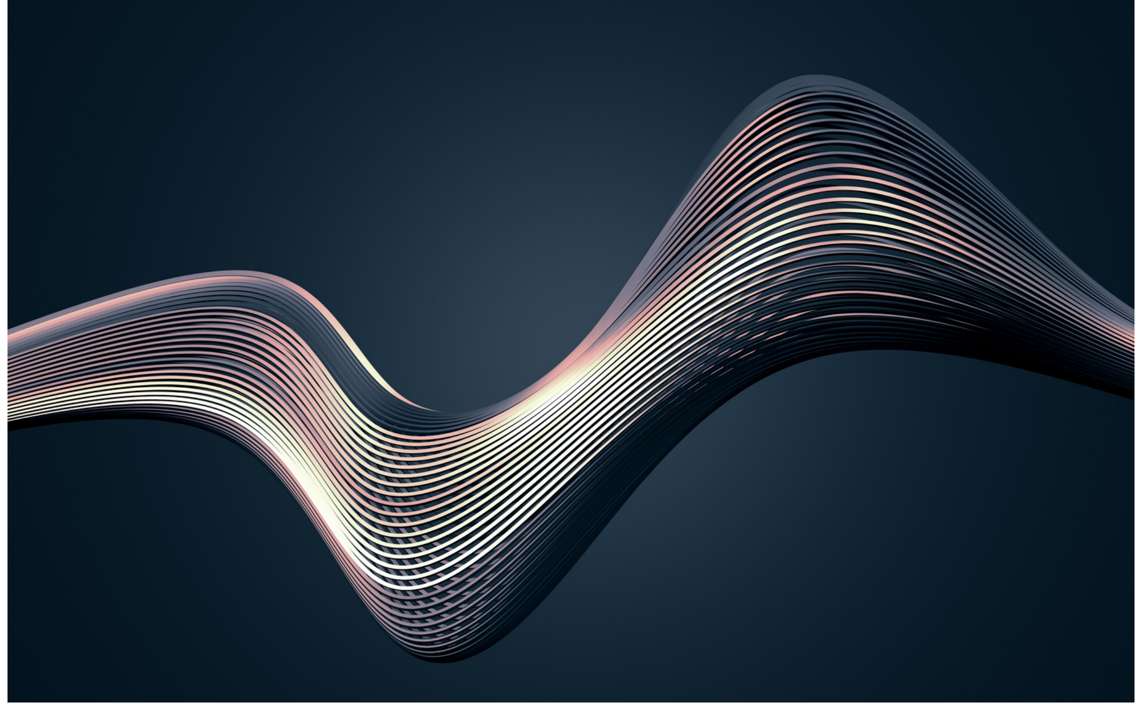


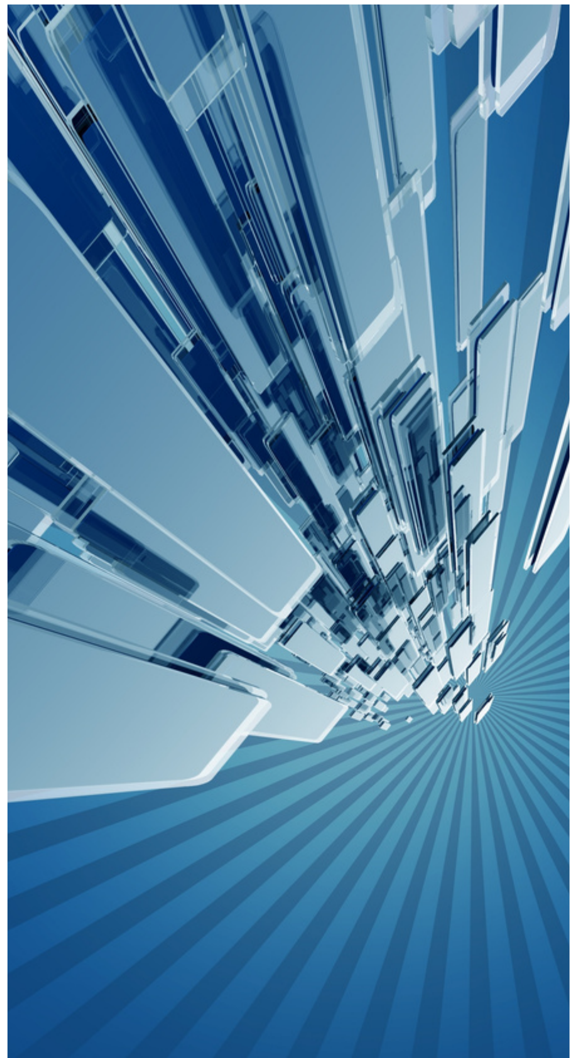

Quantum error correction
Noise
Pauli errors
Bit-Flip
X
Phase-Flip
Z
X|0⟩=|1⟩
X|1⟩=|0⟩
Z|0⟩=|0⟩
Z|1⟩=-|1⟩
Rx(θ)=cos(θ/2) I - i sin(θ/2) X
Quantum codes
|ψ⟩ enc. → |ψ⟩E noise → |ψ̃⟩E dec. → |ψ⟩E
stabiliser measurements
|0⟩
|ψ⟩
Repetition code
|ψ⟩ = a|000⟩ + b|111⟩
Surface code
Fault tolerance
Transversal gates
|ψ⟩1
|ψ⟩2
Magic state distillation
T|+⟩
|ψ⟩
S
T|ψ⟩
Lattice-surgery

How do we overcome these issues?

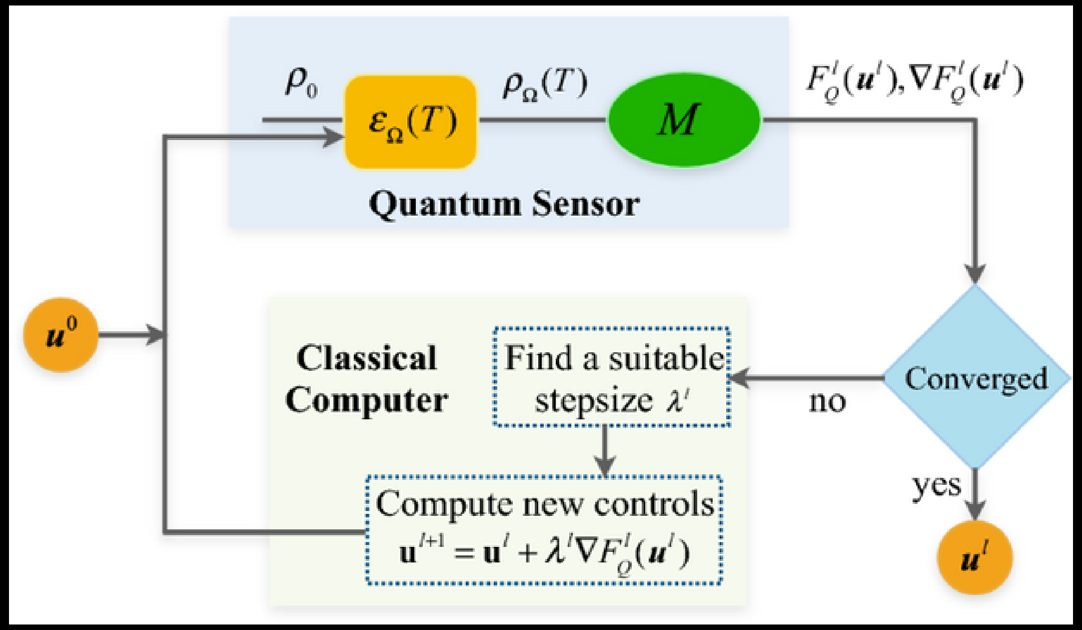
Overcoming the significant challenges of modern quantum computers requires a multi-faceted approach that involves advancements in both hardware and software technologies.

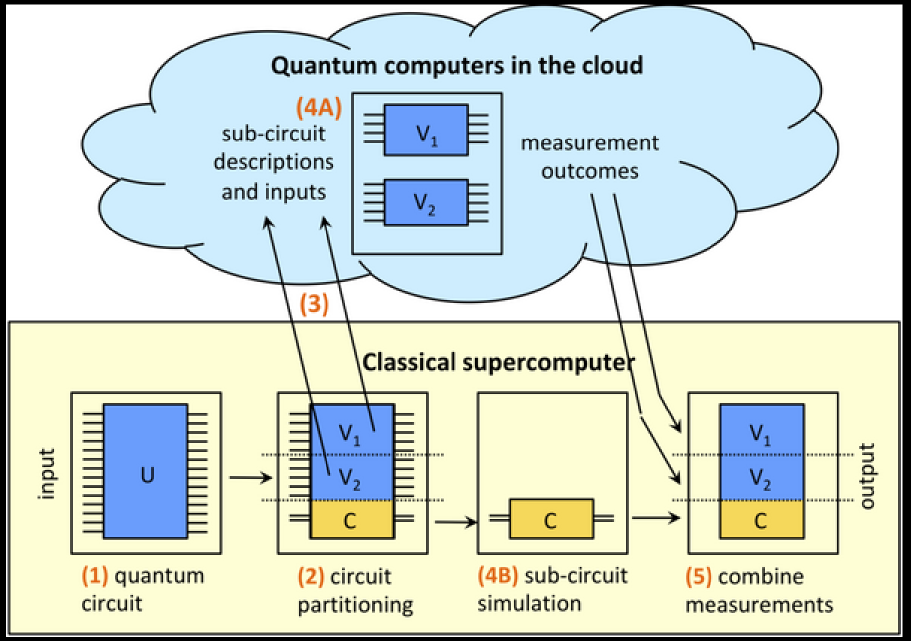
- Novel qubit technologies
- Simplification of control systems
- Quantum error-correction
- Quantum error-mitigation
- **Hybrid solutions**

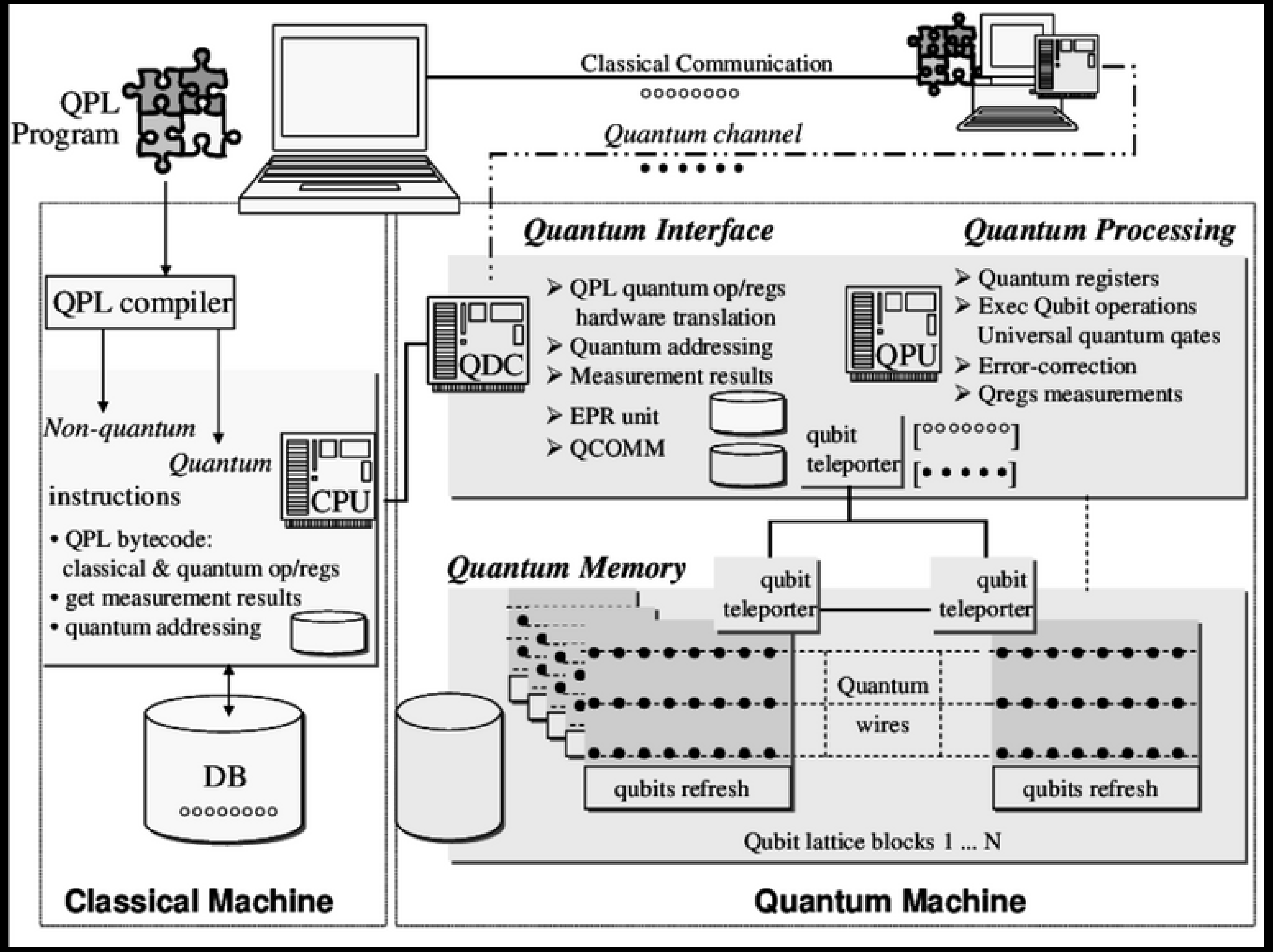


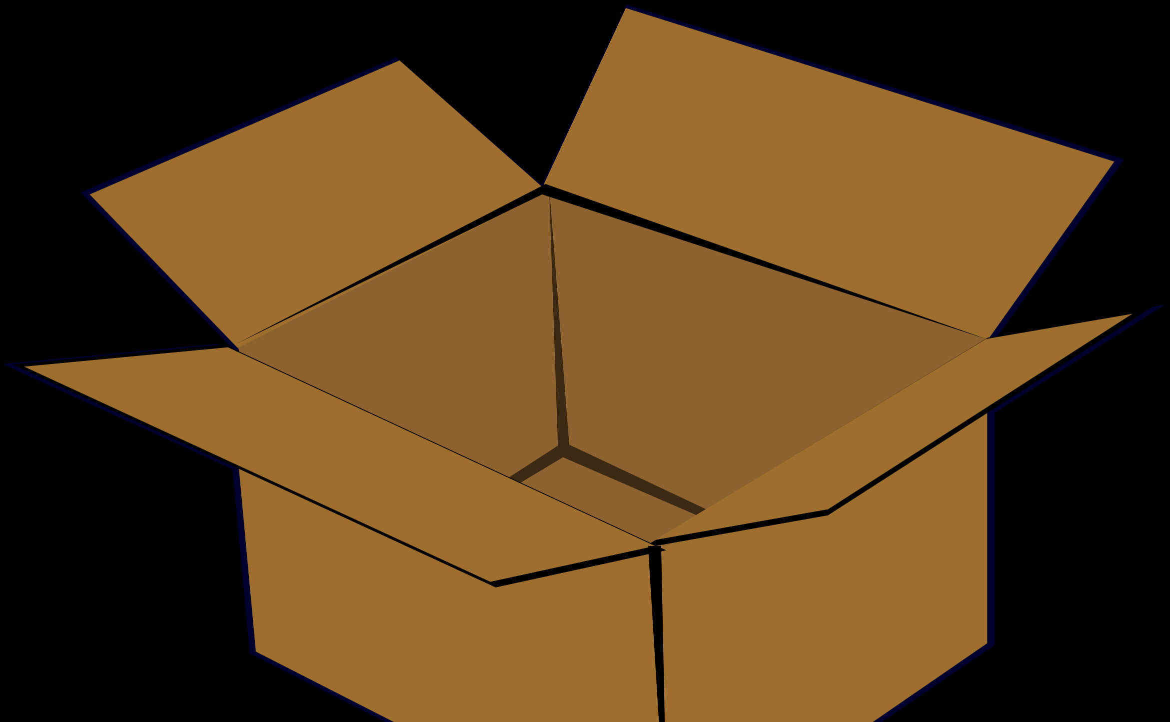


Hybrid solutions



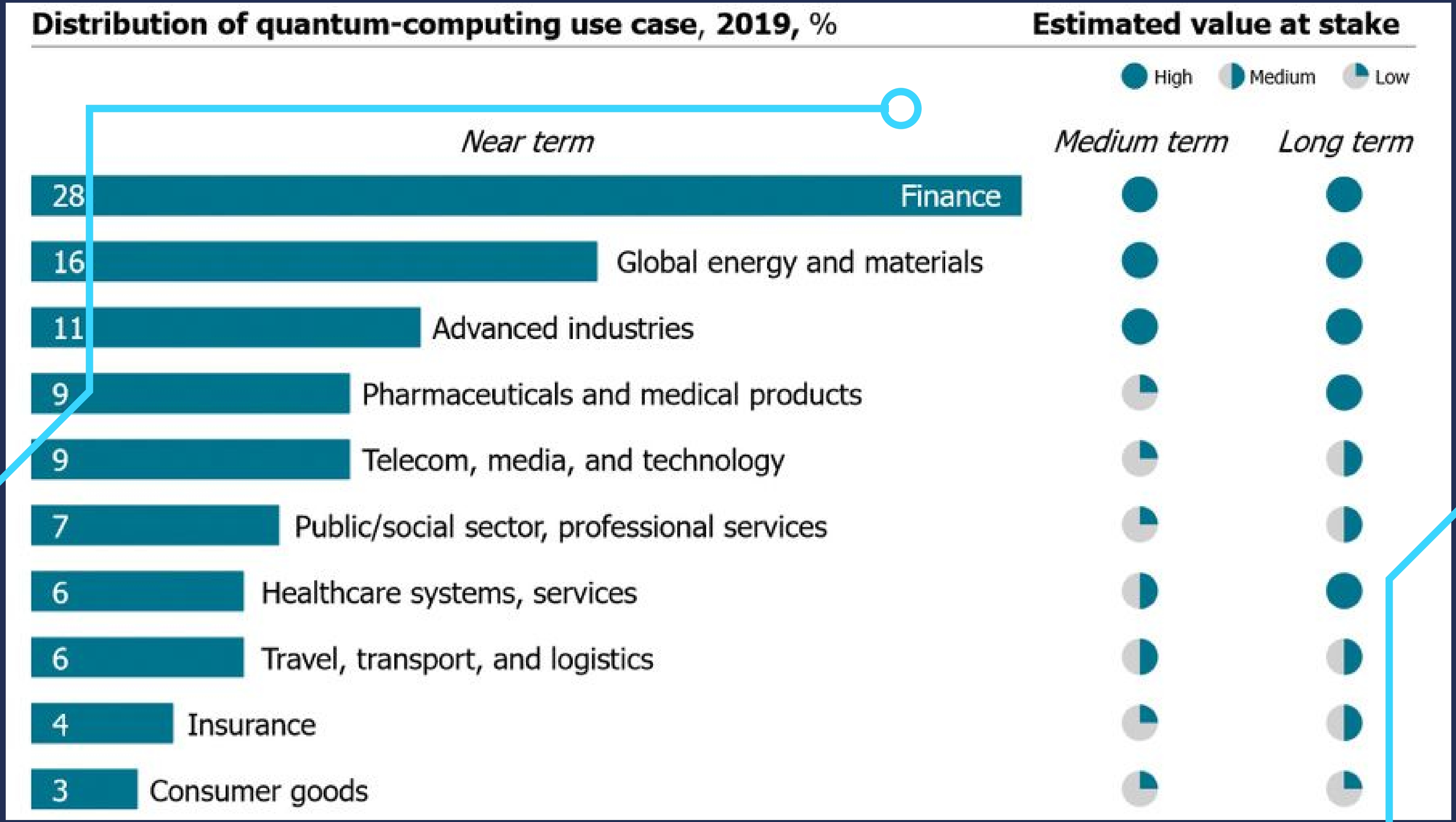







WHY
WHAT?
WHO!
WHEN
WHY
WHAT?
WHO!
WHEN
WHY
WHAT?
!?

Use cases


Distribution of quantum-computing use case, 2019, %
Estimated value at stake
High
Medium
Low
Near term
Medium term
Long term
28
Finance
16
Global energy and materials
11
Advanced industries
9
Pharmaceuticals and medical products
9
Telecom, media, and technology
7
Public/social sector, professional services
6
Healthcare systems, services
6
Travel, transport, and logistics
4
Insurance
3
Consumer goods

Hardware

AQT
Universal Quantum
IONQ
oxford ionics
|QuEra⟩ COMPUTING INC.
PASQAL
ColdQuanta
atom computing
Google
rigetti
QuTech
qci Quantum Circuits, Inc
IBM Q
本源量子 Origin Quantum
intel
diraq
QUANTUM MOTION
Silicon Quantum Computing
QUANTUM BRILLIANCE
XANADU
ORCA Computing
Ψ PsiQuantum
QUIX QUANTUM

Software

rigetti

STRANGE WORKS

river lane

QUANTINUUM

ZAPATA

XANADU

D:wave

HUAWEI

CQC
CAMBRIDGE QUANTUM COMPUTING

Honeywell

ingenii

A Quantum Challenge: Building a Skilled Workforce

20 ago 2021 — The challenge is that finding **skilled** people for the **quantum** computing space is not the same as finding data scientists or cybersecurity experts ...

aps.org
https://www.aps.org › apsnews › q...

The Newest Quantum Frontier: Building a Skilled Workforce

The Newest **Quantum** Frontier: Building a **Skilled Workforce**. Education in **quantum** mechanics has lagged for years. Experts are trying to change this.

mckinsey.com
https://www.mckinsey.com › five-...

Closing the quantum workforce gap: Lessons from AI - McKinsey

1 dic 2022 — Our research finds that there is only one **qualified quantum** candidate available for every three **quantum** job openings (Exhibit 1).

ibm.com
https://newsroom.ibm.com › quan...

Building a Quantum Workforce Requires Interdisciplinary ...

The primary goal of such educational efforts is, of course, to eventually create a **skilled quantum** computing **workforce**. Such a **workforce** will include many ...

insidequantumtechnology.com
https://www.insidequantumtechnology.com › ...

Five Ways to Combat the Quantum Skills Shortage

20 oct 2021 — Almost 95% of survey respondents said they would like to be **trained** in **quantum**, and more than 95% said they believed high schools and ...

ANYONE CAN DO QUANTUM

Why is there a shortage?

"From the supply side [those providing the talent], "the supply is lagging behind because if we think of this revolution as starting in, say, 2017, there was a really low demand," he said. The rising demand "caught the universities by surprise. No one expected this and this means a boom in quantum information science is required to fill all this demand." – Yehuda Naveh – Quantum physicist and computer scientist, Classiq

SO HOW DO WE START

How will you contribute to the Quantum revolution?

Research and Learn

Start contributing

Apply for the right opportunities

Show enthusiasm

FIRST STEP IDEAS

University club

Reading group

Join a discord server

Follow Quantum people on LinkedIn

Start a free online course

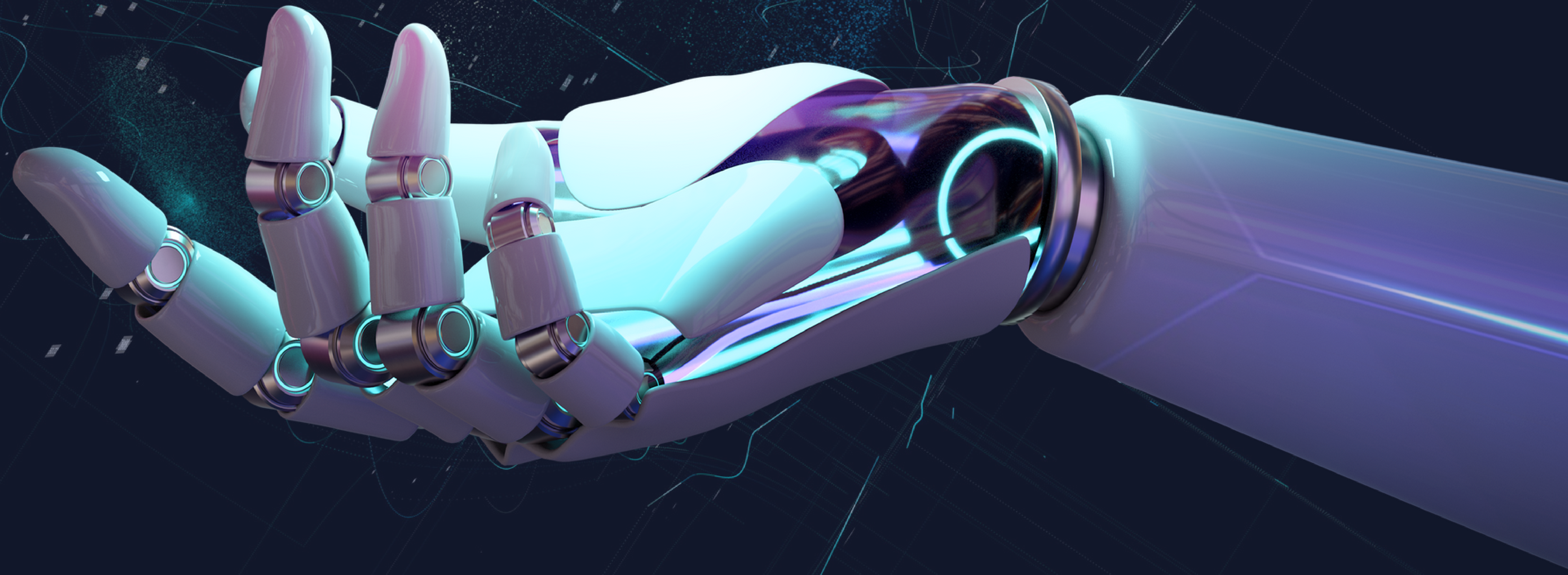
Read a book on Quantum information

Investigate the Qiskit textbook

Learn Python (or try out existing quantum software if you are already familiar with coding)

Q and A

ASK AWAY!



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