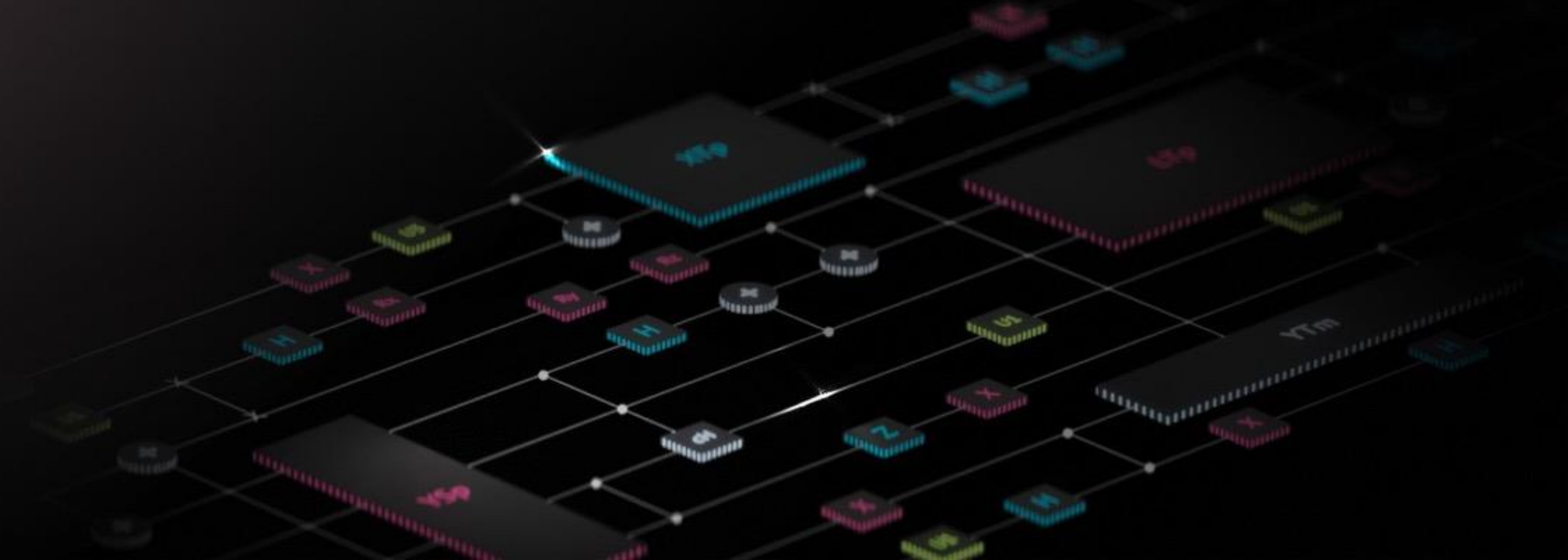
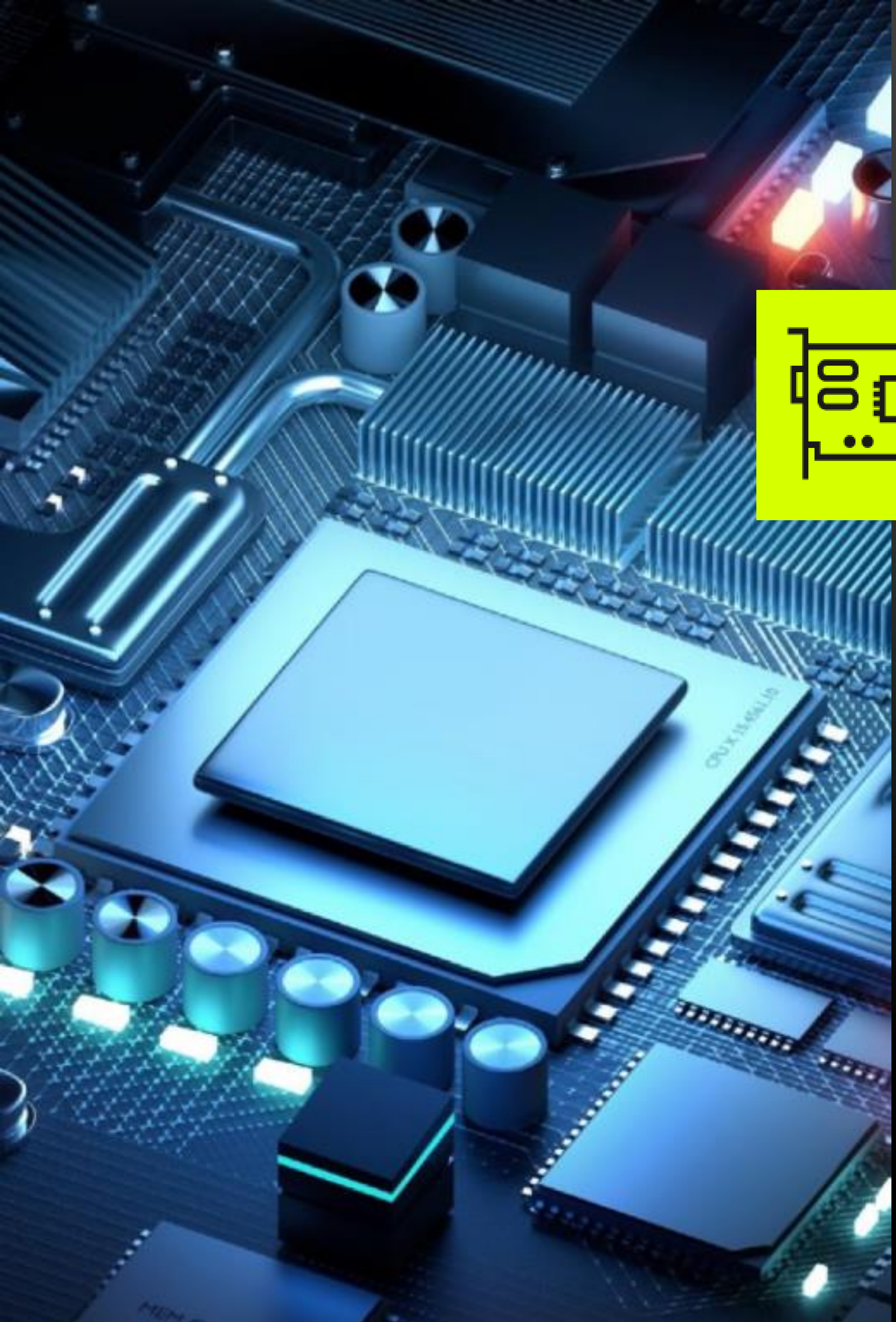
QUANTUM TECHNOLOGY
WHAT IT IS AND ITS IMPACT ON THE WORLD OF FINANCE





WHY NOT BIGGER CLASSICAL COMPUTERS?

Hitting The Limits

Transistor Size

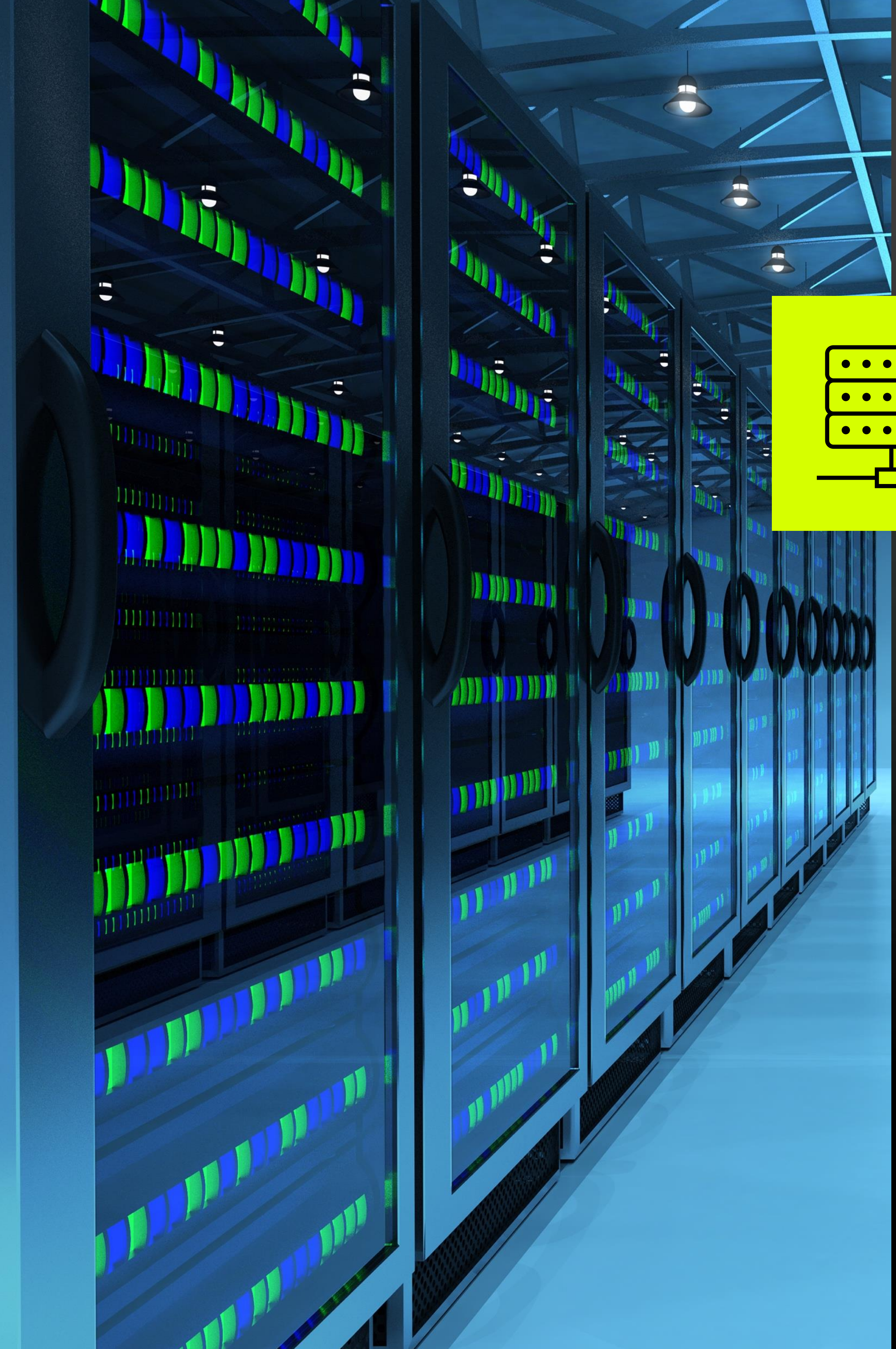
Shrinking transistor sizes approach physical limits where quantum effects increase leakage currents, challenging the distinction between on and off states.

Power Consumption

Reduced transistor sizes lead to higher leakage currents, elevating static power consumption and reducing efficiency,

Heat Dissipation

Higher power density in smaller chips complicates heat removal, risking thermal damage and impacting performance.



THE END GOAL FOR QUANTUM

Part of the HPC Stack

Central

CPU: Adept at a wide range of tasks from running applications to processing complex algorithms in a sequential manner.

Graphics

GPU: Excellent for graphics rendering and tasks requiring massive parallel processing, enhancing performance in gaming, simulations, and certain areas of research.

Tensor

TPU: Optimized for deep learning, offering accelerated computation for neural networks and machine learning models, significantly reducing training and inference times.

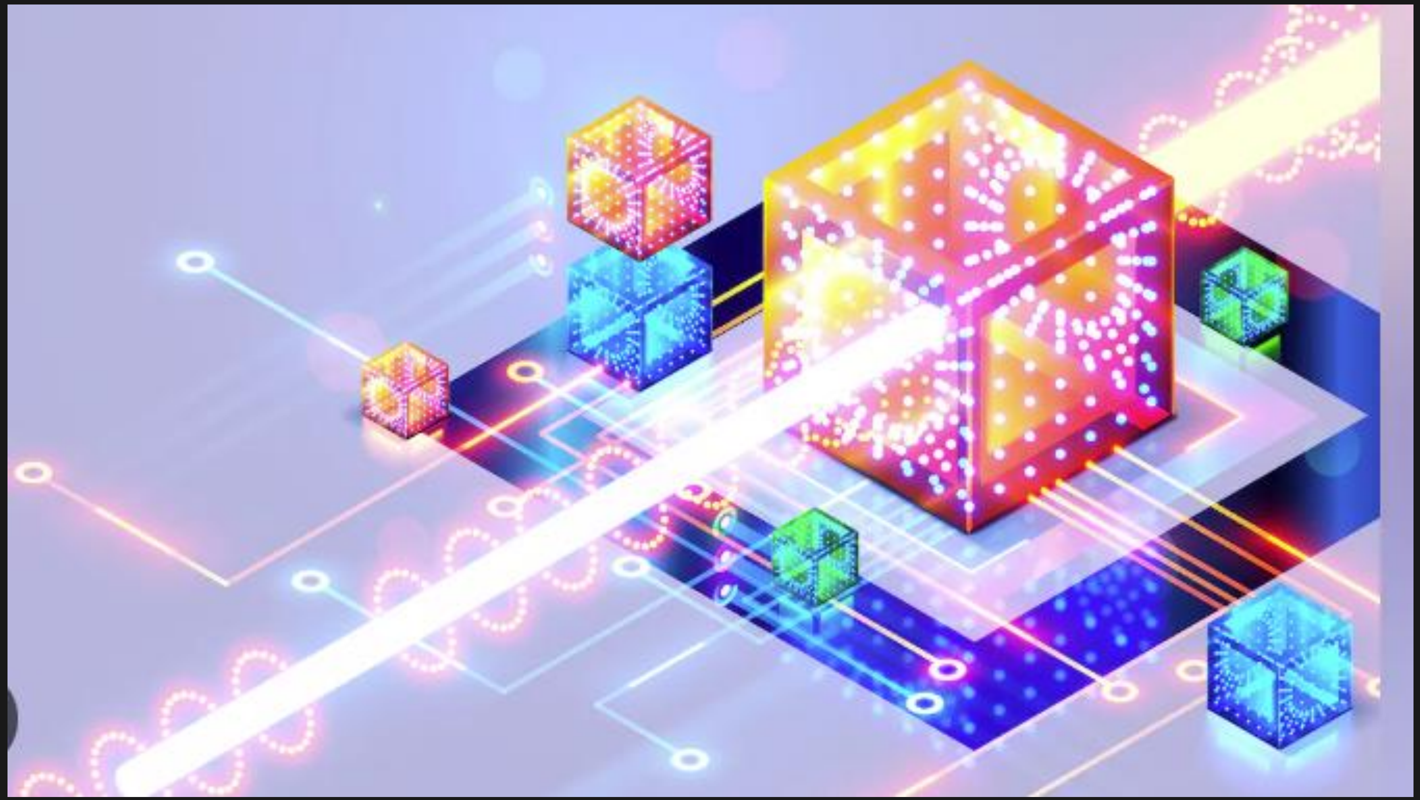
Quantum

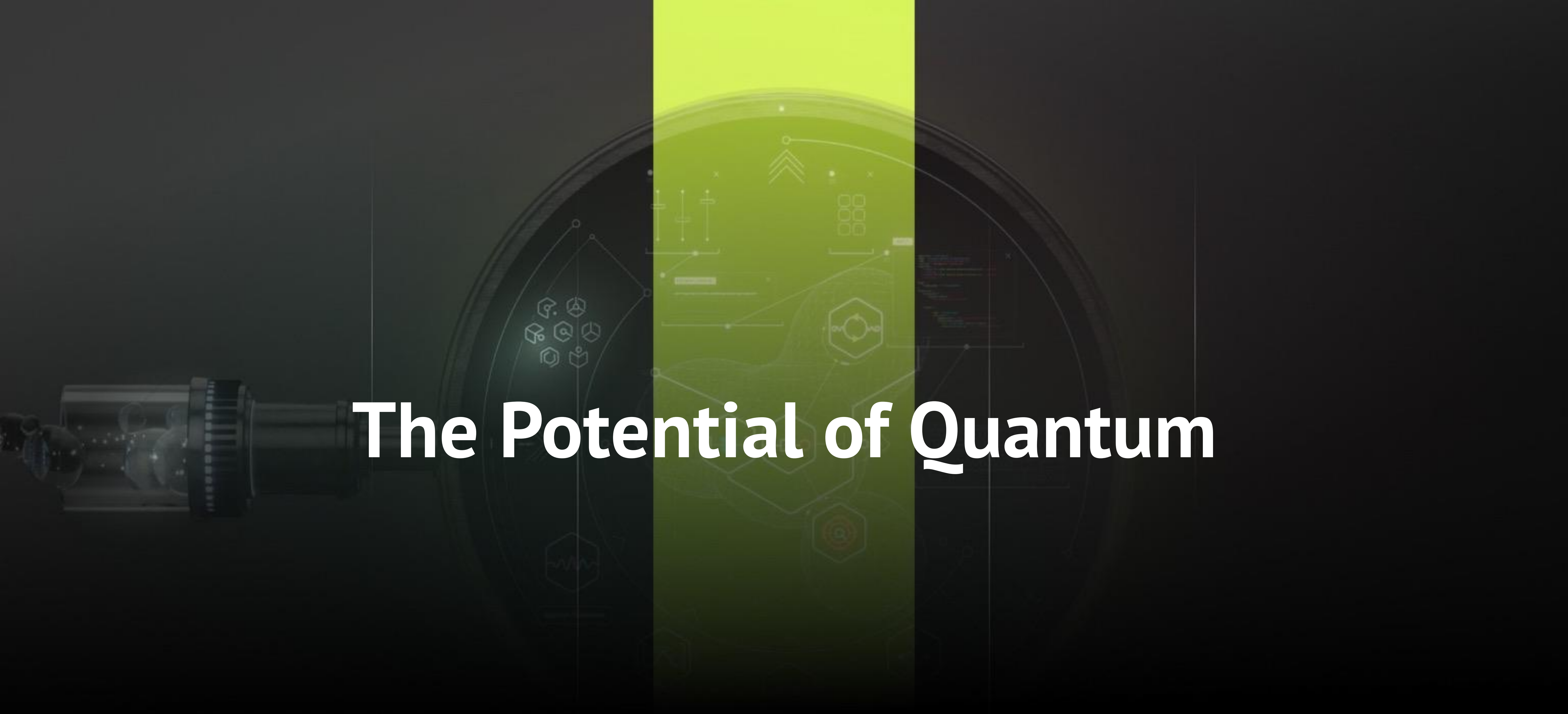
QPU: Used to solve problems intractable for classical computers, with potential breakthroughs in cryptography, optimization, and simulation.

QUANTUM COMMUNICATION

QUANTUM COMMUNICATIONS

- Post Quantum Cryptography (PQC)
- Quantum Key Distribution (QKD).
  - QKD utilizes quantum entanglement, where qubits become interdependent regardless of the distance between them. Practically impossible to intercept without disturbing the entanglement.

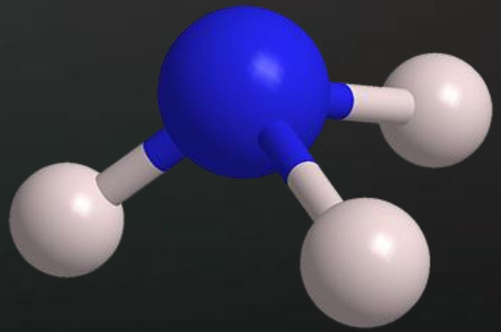


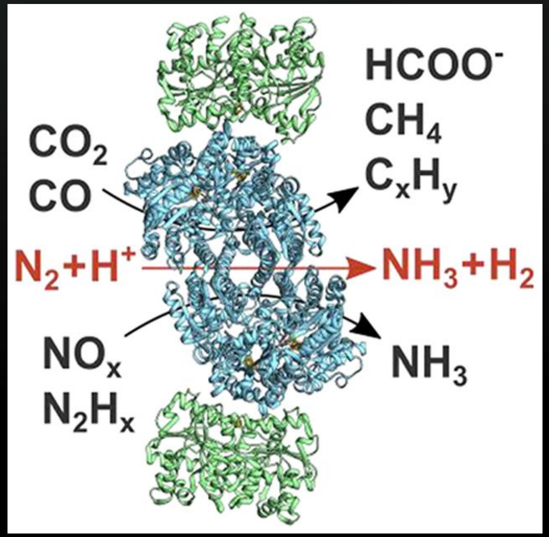


The Potential of Quantum

Motivation

Natural process, room temperature



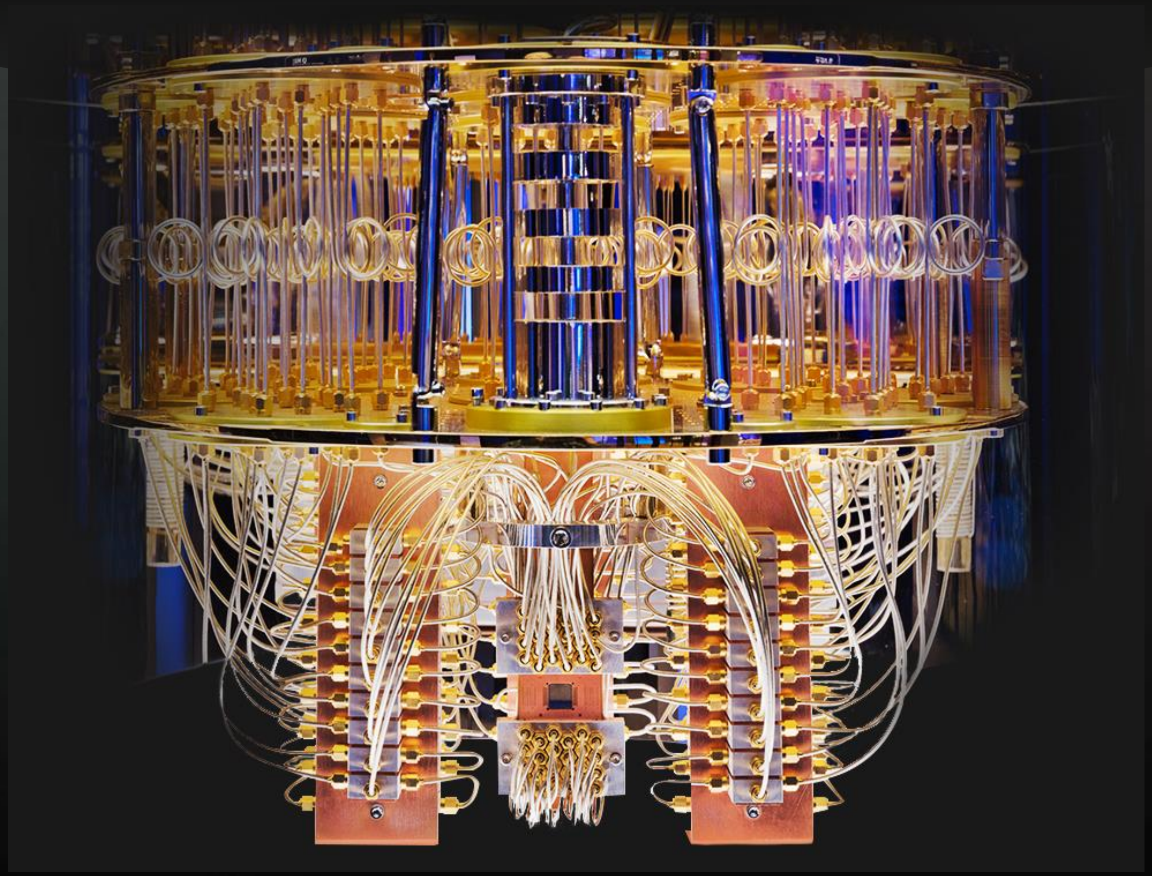


2% of the world's energy consumption

A supercomputer

1,000,000 years of calculation

A Quantum Computer – Several Hours of Calculation



Quantum algorithms like:

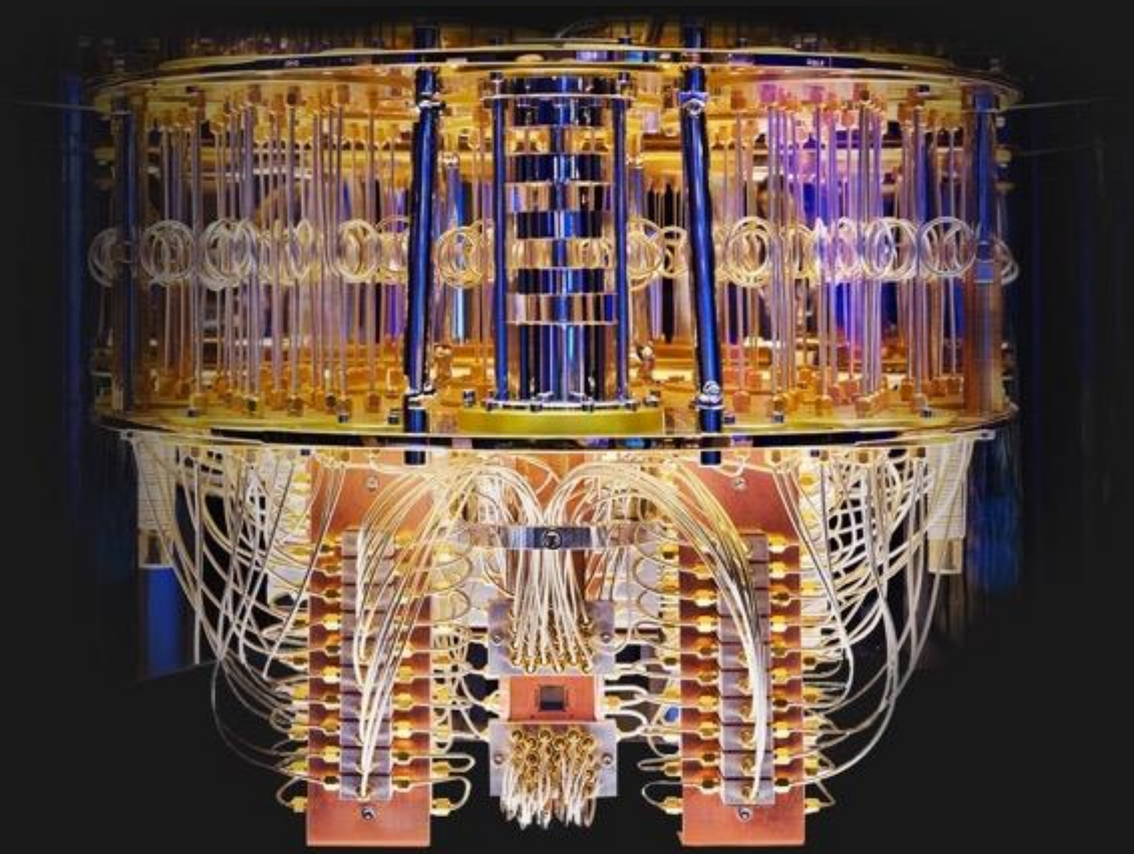
Variational Quantum Eigensolver (VQE) and **Quantum Phase Estimation (QPE)**

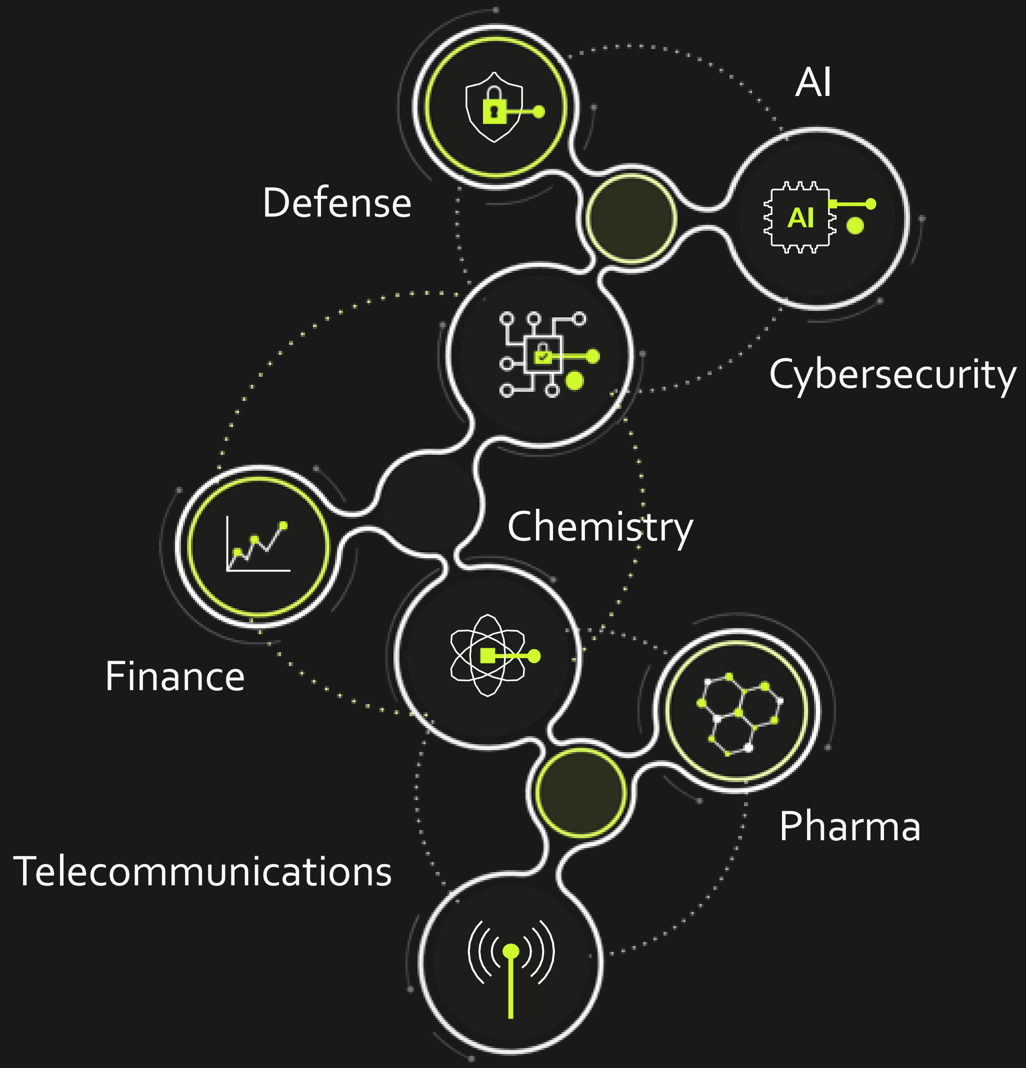
Near Term Adoption

ENTERPRISE ADOPTION

Goldman Sachs
BBVA
J.P.Morgan
RBC Royal Bank
Bank of America
citi
Deutsche Bank
HSBC
Santander
SOCIETE GENERALE
BASF We create chemistry
ExxonMobil
INTESA SANPAOLO
mastercard
covestro
Air Liquide
NOVARTIS
Roche
AstraZeneca
AXA
BAYER
bp
Alphabet
Anthem.
Alibaba Group 阿里巴巴集团
novo nordisk
أرامكو aramco
Boehringer Ingelheim
Mercedes-Benz
Ford
BMW
ROLLS ROYCE
DENSO
HUAWEI
Deutsche Telekom
TotalEnergies
LOCKHEED MARTIN
BOEING
Tencent
e.on
DELL
NTT
SIEMENS
LEONARDO
AIRBUS
KDDI
vodafone
cisco
FUJITSU
LG
THALES
GENERAL ATOMICS AERONAUTICAL
Swiss Re Institute
pwc
Deloitte.
accenture
equinor

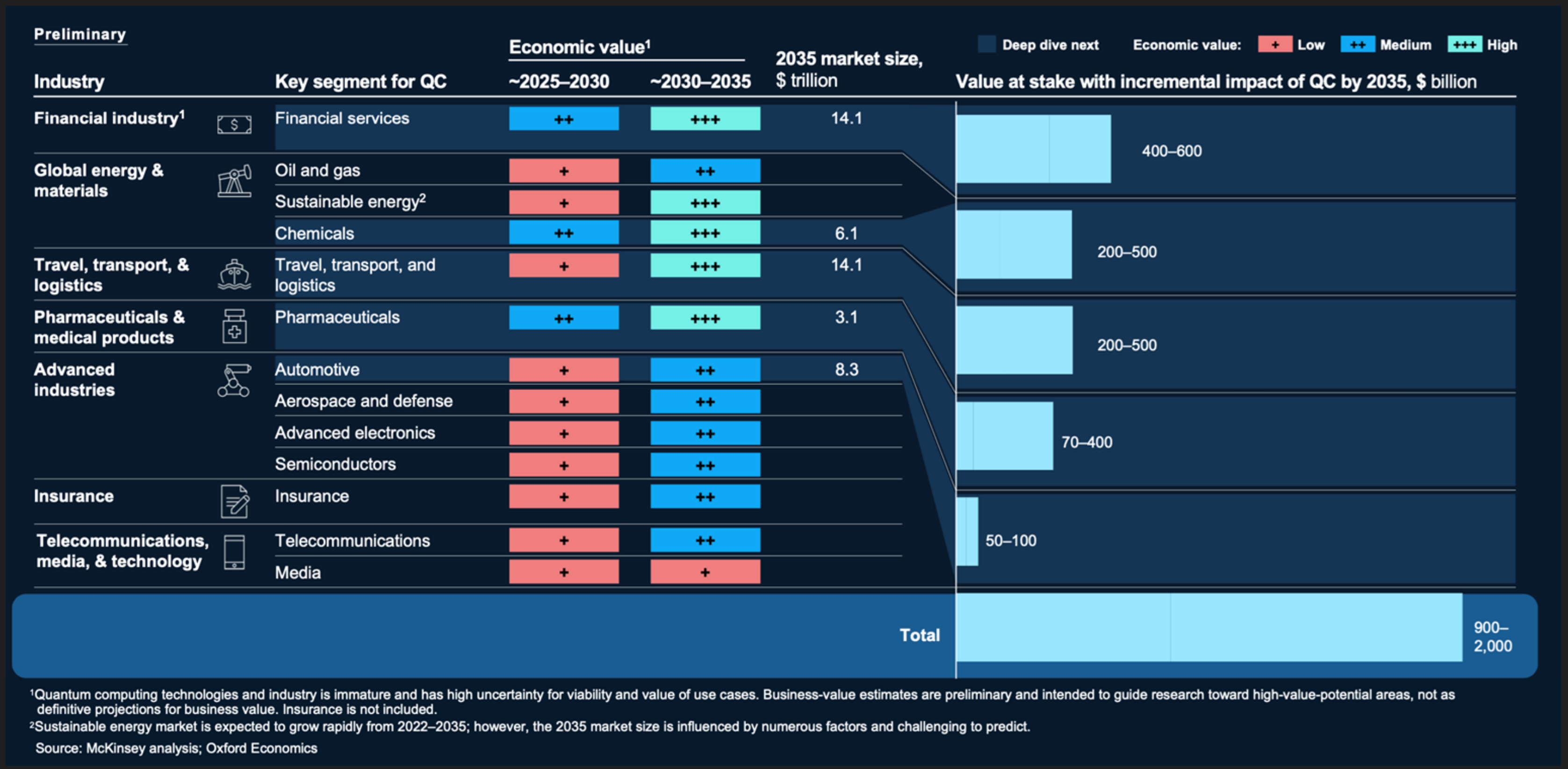
A NEW ERA IN COMPUTING





Quantum Processing's Near-Term Impact

Industry Analysts Agree



Industry	Key segment for QC	Economic value[1] ~2025–2030	Economic value[1] ~2030–2035	2035 market size, $ trillion
Financial industry[1]	Financial services	++	+++	14.1
Global energy & materials	Oil and gas	+	++	
	Sustainable energy[2]	+	+++	
	Chemicals	++	+++	6.1
Travel, transport, & logistics	Travel, transport, and logistics	+	+++	14.1
Pharmaceuticals & medical products	Pharmaceuticals	++	+++	3.1
Advanced industries	Automotive	+	++	8.3
	Aerospace and defense	+	++	
	Advanced electronics	+	++	
	Semiconductors	+	++	
Insurance	Insurance	+	++	
Telecommunications, media, & technology	Telecommunications	+	++	
	Media	+	+	

[1]Quantum computing technologies and industry is immature and has high uncertainty for viability and value of use cases. Business-value estimates are preliminary and intended to guide research toward high-value-potential areas, not as definitive projections for business value. Insurance is not included.
[2]Sustainable energy market is expected to grow rapidly from 2022–2035; however, the 2035 market size is influenced by numerous factors and challenging to predict.
Source: McKinsey analysis; Oxford Economics

The industries likeliest to see the earliest economic impact from quantum processing:

- Finance
- Travel, Transportation, & Logistics
- Chemicals
- Pharmaceuticals
- Automotive

These industries stand to gain between $0.9-$2 trillion in value by 2035.

- McKinsey: Quantum Technology Monitor, April 2024

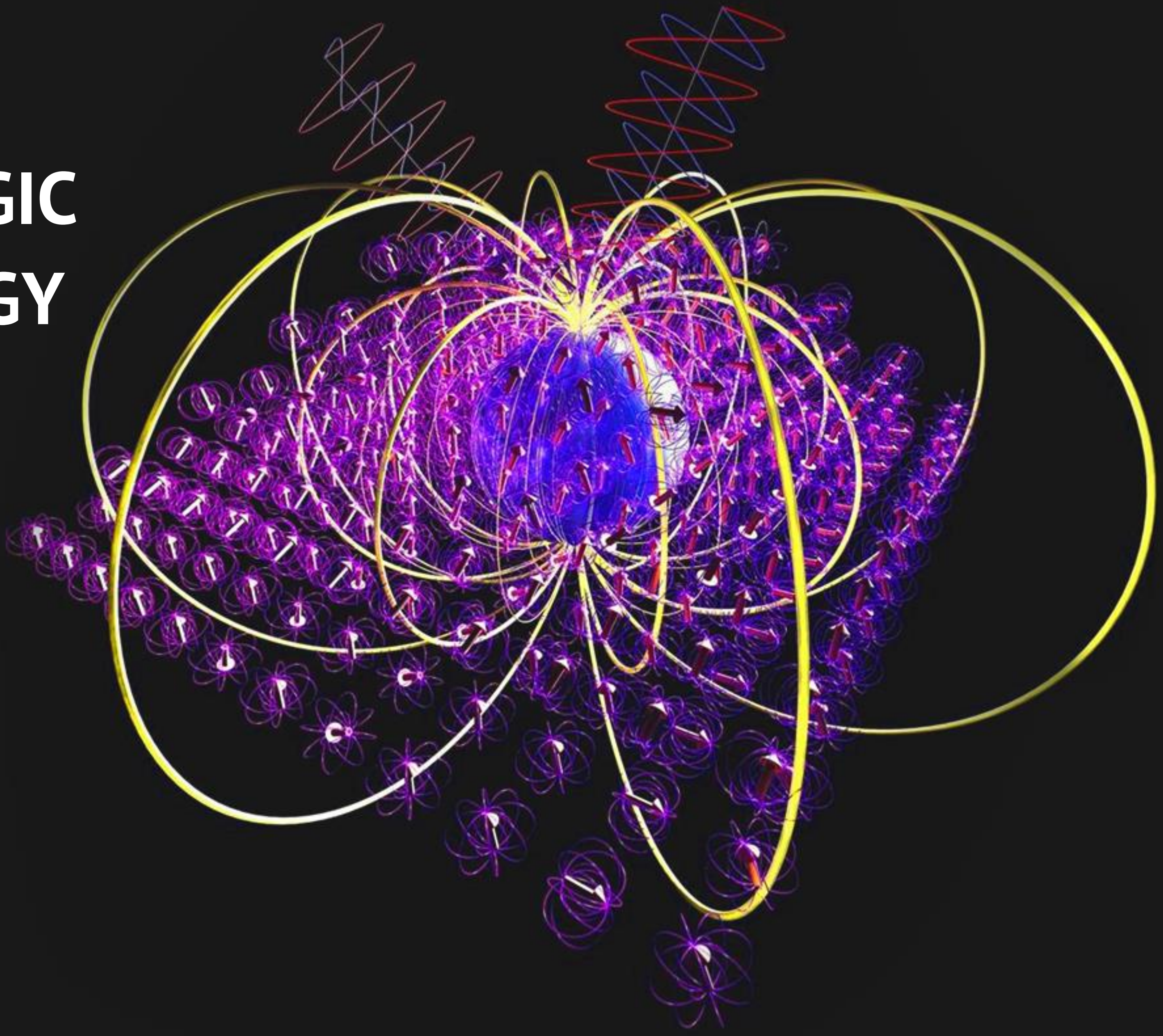
MANY ALGORITHMS, MANY SOLUTIONS

	Manufacturing	Chemistry	Pharma	Finance	Other
QAOA	Job shop scheduling	Logistics optimization	Drug component selection	Portfolio optimization	General optimization problems
HHL	Machine optimization	Combustion control	Drug manufacturing optimization	Portfolio optimization	CFD simulation
QML	Anomaly detection	Molecule ground state calculation	Characterizing new drugs	Fraud detection	Image classification
Grover	SAT Problems	Molecular Distance	Structure finding	Database search	Cryptography

QUANTUM AS STRATEGIC NATIONAL TECHNOLOGY

$42 billions

Announced governmental funding



THE END USER AT THE FRONT

Quantum computing ambition: Japan aims for 10m users by 2030

asia.nikkei.com

WHAT & WHY OF QUANTUM PROCESSING?

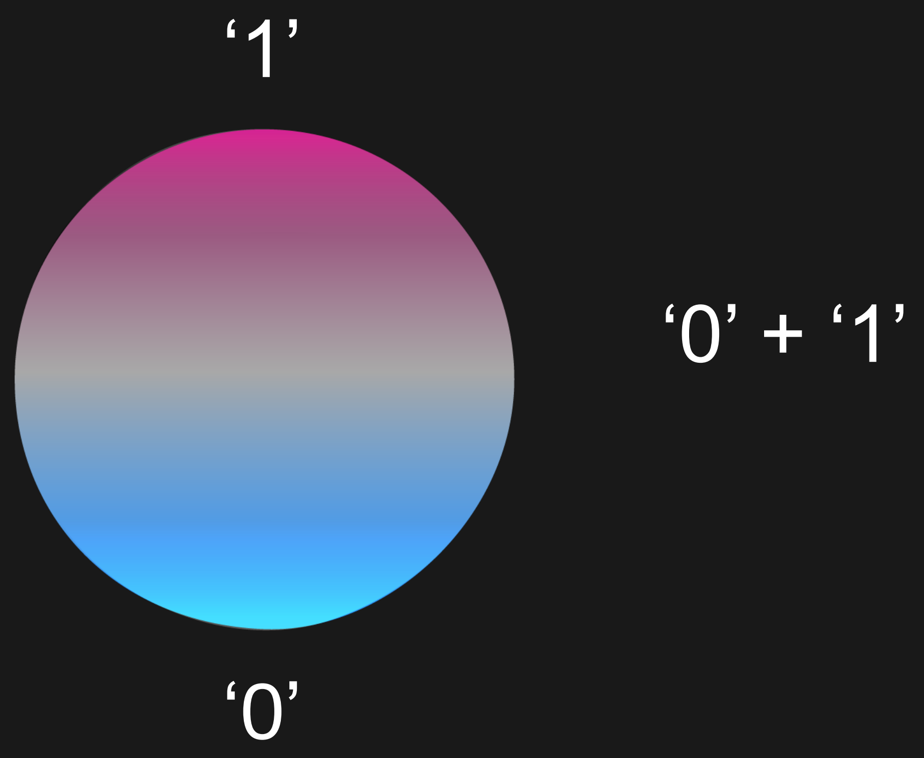
A SUPERCOMPUTER

Bits

1

0

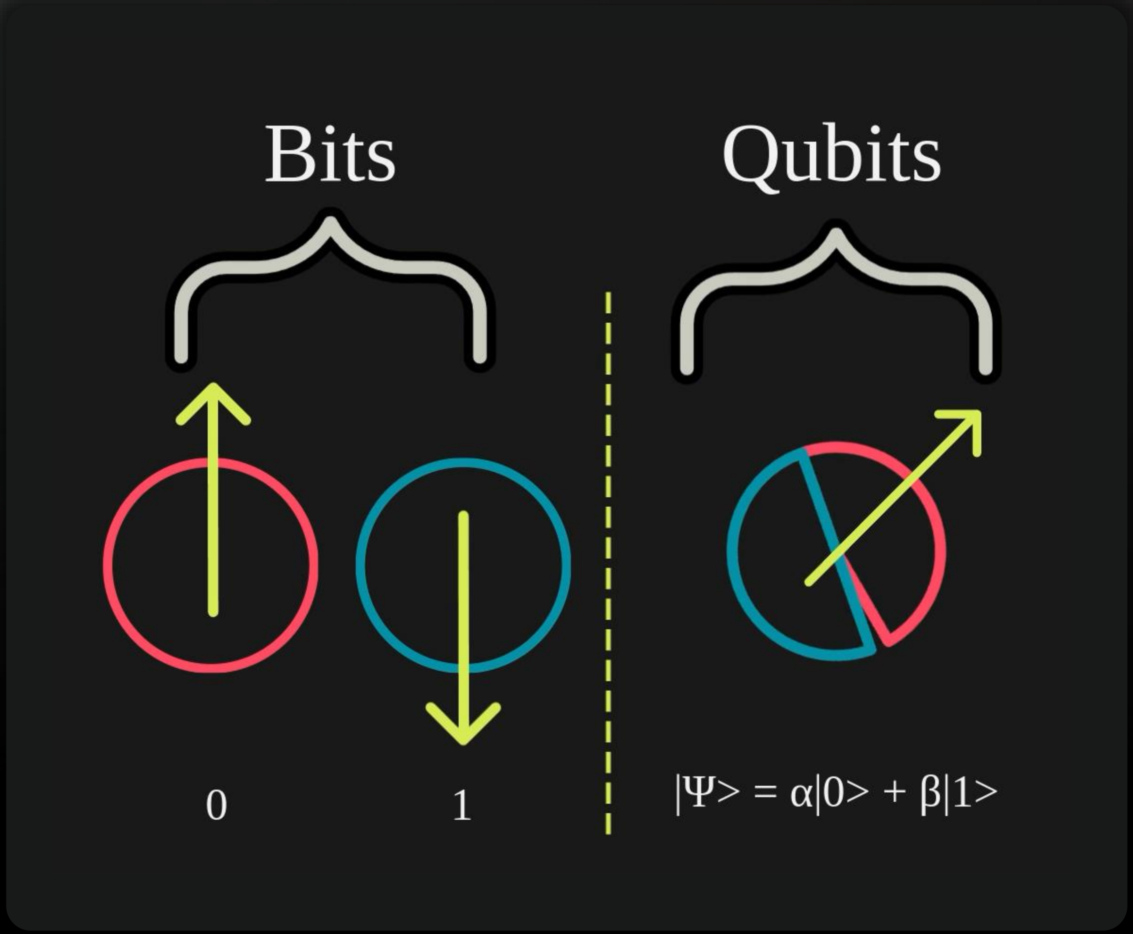
QUBITS



Entanglement

WHY QUANTUM PROCESSING?

A New Compute Resource



Qubits

1 qubit

$$\begin{array}{cc} \begin{pmatrix} a_1 \\ a_2 \end{pmatrix} & \begin{array}{c} 0 \\ 1 \end{array} \end{array}$$

$$|a_1|^2 + |a_2|^2 = 1$$

2 qubits

$$\begin{array}{cc} \begin{pmatrix} b_1 \\ b_2 \\ b_3 \\ b_4 \end{pmatrix} & \begin{array}{c} 00 \\ 01 \\ 10 \\ 11 \end{array} \end{array}$$

$$|b_1|^2 + |b_2|^2 + |b_3|^2 + |b_4|^2 = 1$$

n qubits

$$\begin{array}{cc} \begin{pmatrix} c_1 \\ c_2 \\ . \\ . \\ . \\ c_{2^n - 1} \\ c_{2^n} \end{pmatrix} & \begin{array}{c} 00 \dots 0 \\ 00 \dots 1 \\ \vdots \\ 11 \dots 0 \\ 11 \dots 1 \end{array} \end{array}$$

$$\sum_i |c_i|^2 = 1$$

Quantum States Grow Exponentially

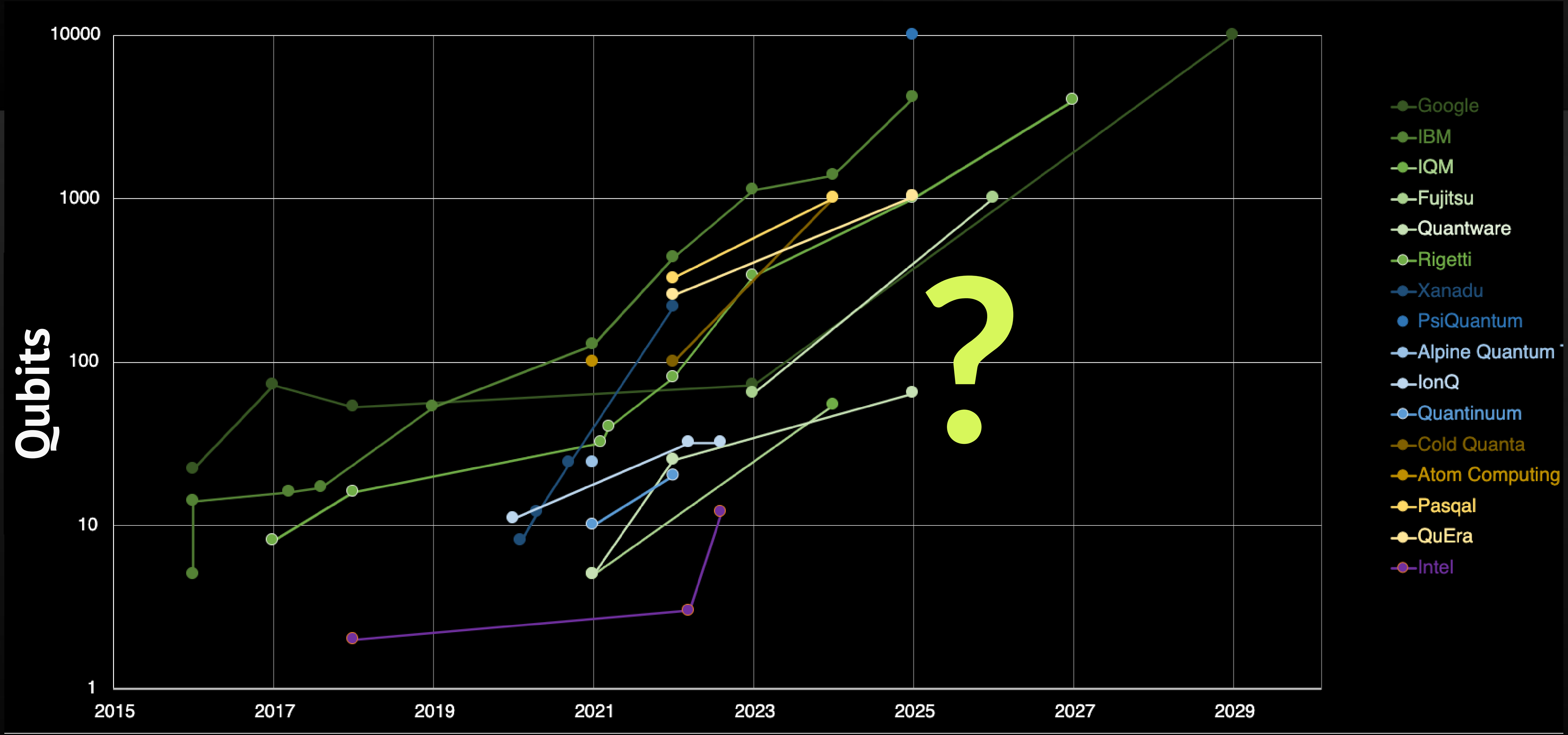
IBM's quantum computing roadmap targets a 4000-qubit device this year

Qubits	Number of parallel states
1	2
2	4
3	8
10	1024
16	65,536
20	1,048,576
30	~1 Billion
35	~34 Billion
100	> Number of atoms on the planet
280	> Number of atoms in universe

QUANTUM HARDWARE DEVELOPMENT

Google	Microsoft	IBM	intel	Oak Ridge National Laboratory	Los Alamos National Laboratory EST. 1943	DLR
aws	rigetti	ALICE & BOB	seeqc	EQUS Australian Research Council Centre of Excellence for Engineered Quantum Systems	FLEET ARC Centre of Excellence in Future Low-Energy Electronics Technologies	QUANTUM FLAGSHIP
IQM	PASQAL	|QuEra⟩ Computing Inc.	QUANTINUUM	Quantum Art	⟨quantum|gov⟩	FUJITSU
atom computing	Infleqtion	XANADU	IONQ	University of Michigan	WACQT Wallenberg Centre for Quantum Technology	RIKEN
OQC	D-Wave The Quantum Computing Company	PsiQuantum	AQT	慶應義塾大学 Keio University Tokyo, Japan	Fraunhofer	מכון ויצמן למדע WEIZMANN INSTITUTE OF SCIENCE
Alibaba.com	oxford ionics	ORCA Computing	QCi	TUM	MIT	HARVARD UNIVERSITY

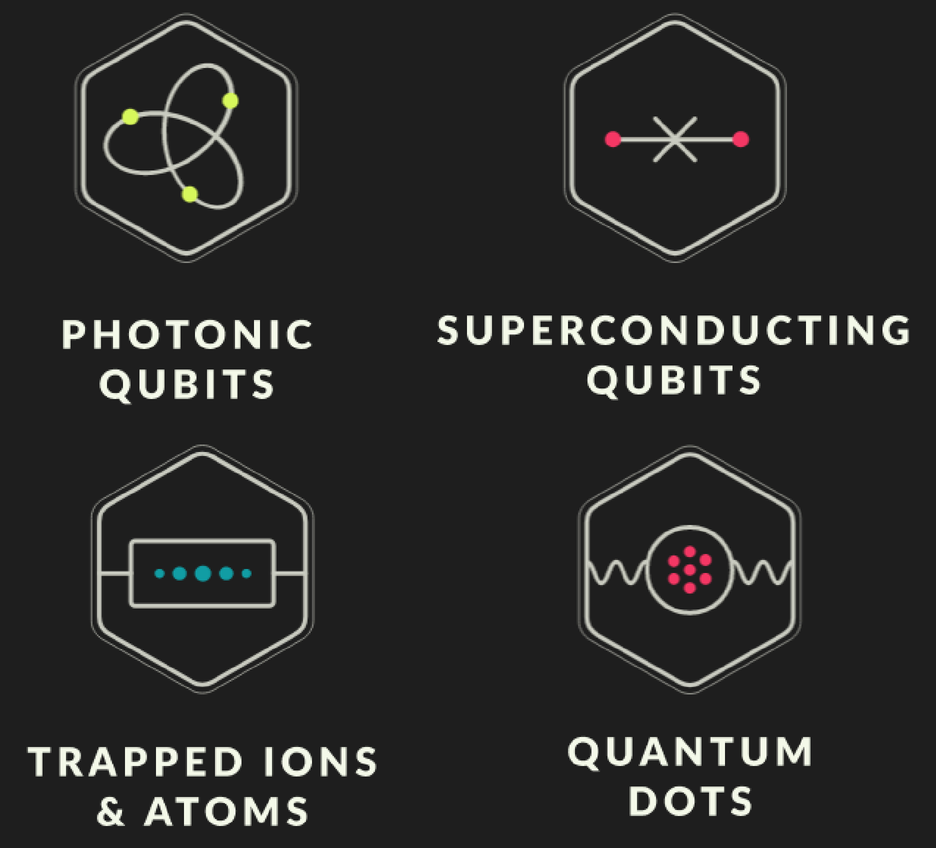
BUT THERE'S 'MOORE': STEADY GROWTH IN QUBIT COUNTS

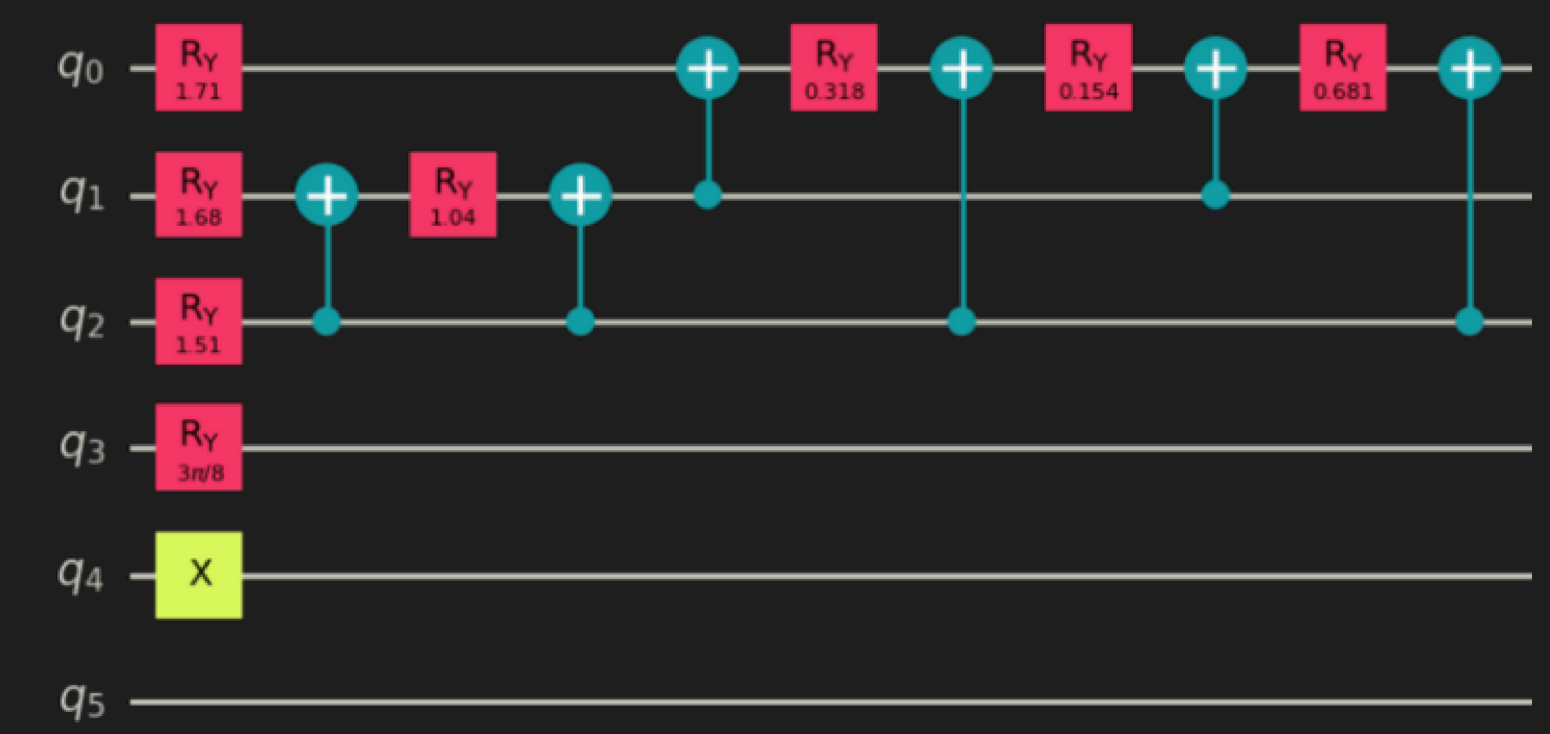


CLASSIQ

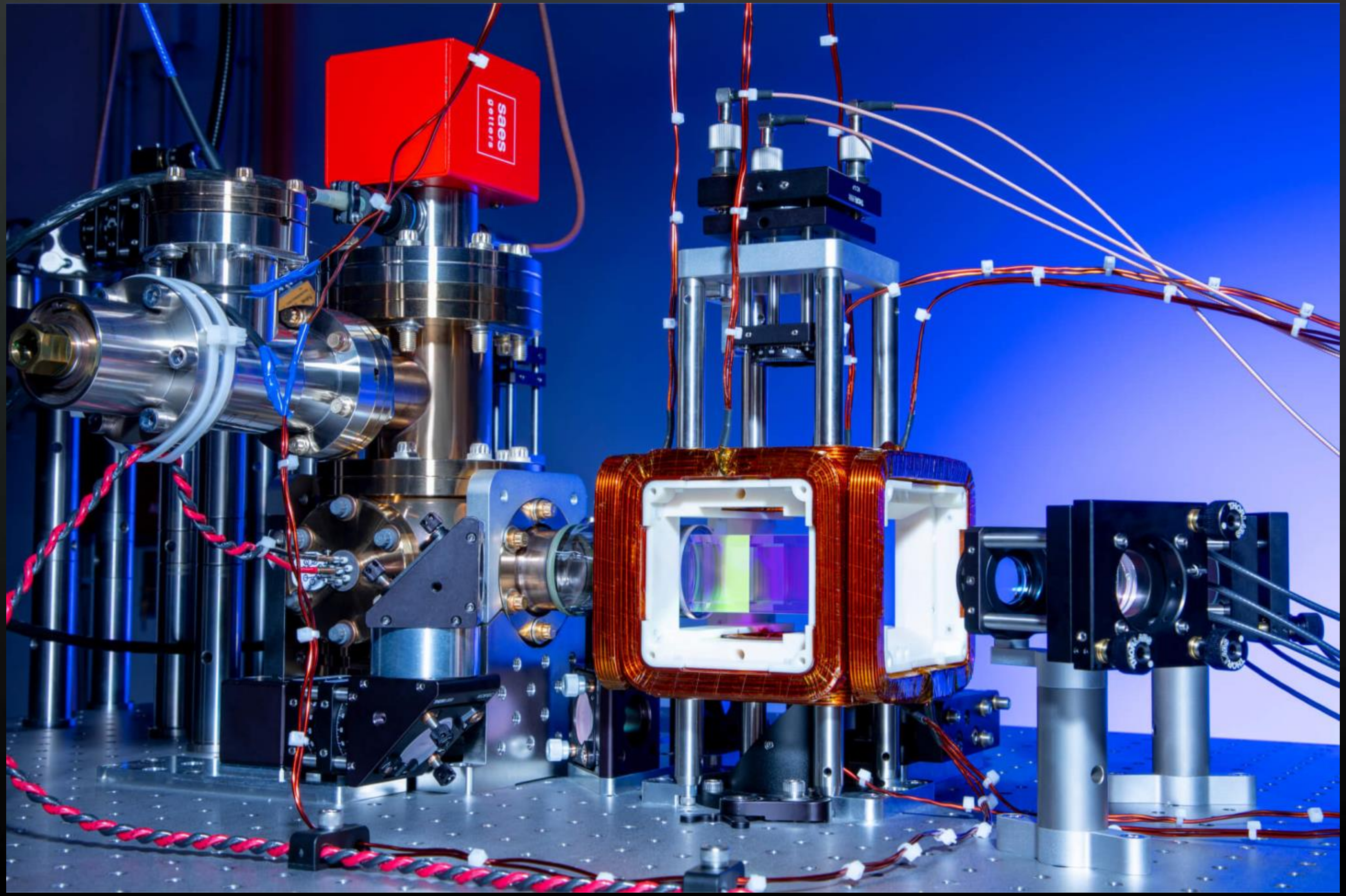
THE NISQ ERA

Noisy Intermediate-Scale Quantum (NISQ)





The Future



Classical Interface

n-bit classical input: 0011000101110110101101

n-bit classical output: 1010101111011000100

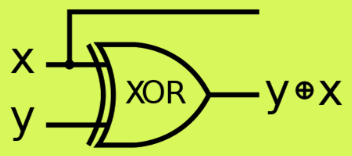
State Preparation

Measurement

2^n internal, inaccessible computation paths

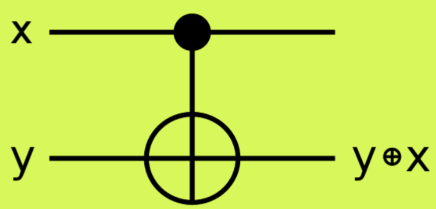
HOW DO YOU PROGRAM A QUANTUM COMPUTER?

Electronic circuit design



input x	input y	output
0	0	0
0	1	1
1	0	1
1	1	0

Quantum circuit design

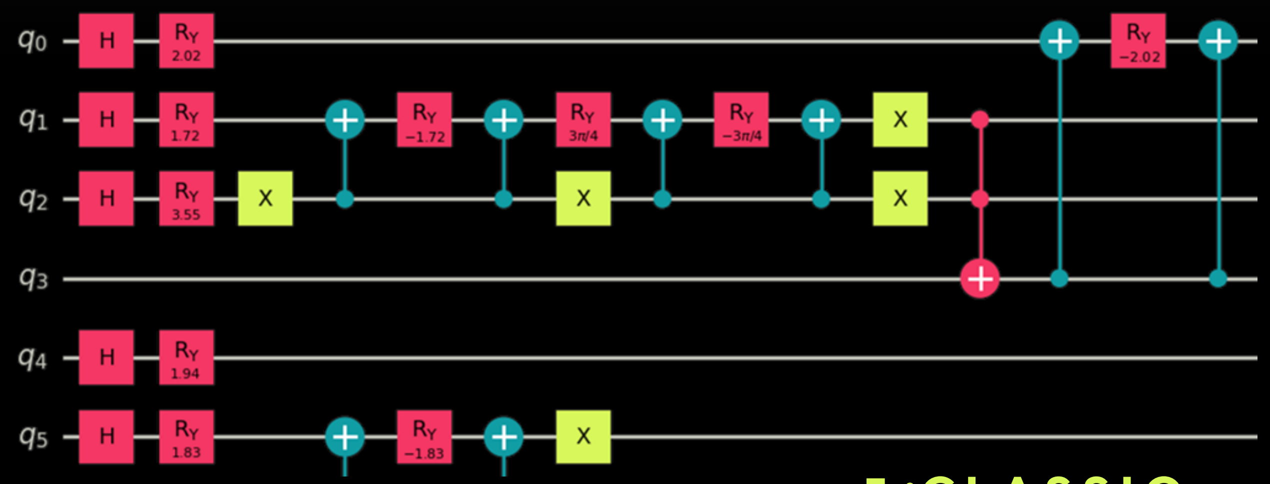


input x	input y	output
$\vert 0\rangle$	$\vert 0\rangle$	$\vert 0\rangle$
$\vert 0\rangle$	$\vert 1\rangle$	$\vert 1\rangle$
$\vert 1\rangle$	$\vert 0\rangle$	$\vert 1\rangle$
$\vert 1\rangle$	$\vert 1\rangle$	$\vert 0\rangle$

Writing software for quantum computers is a little bit like electronic design and a little bit like assembly language

To create a quantum program, one specifies which qubits (wires) connect to which gates (square blocks)

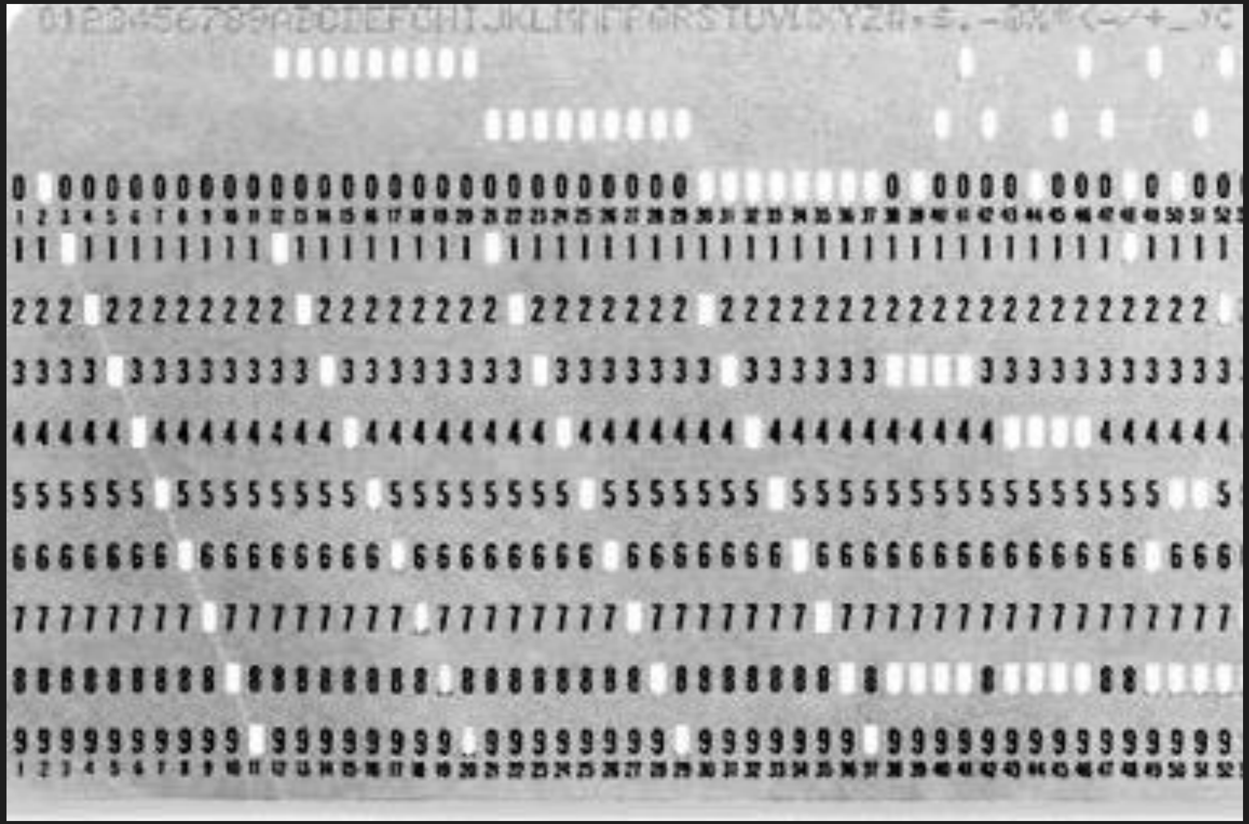
This is quantum assembly language



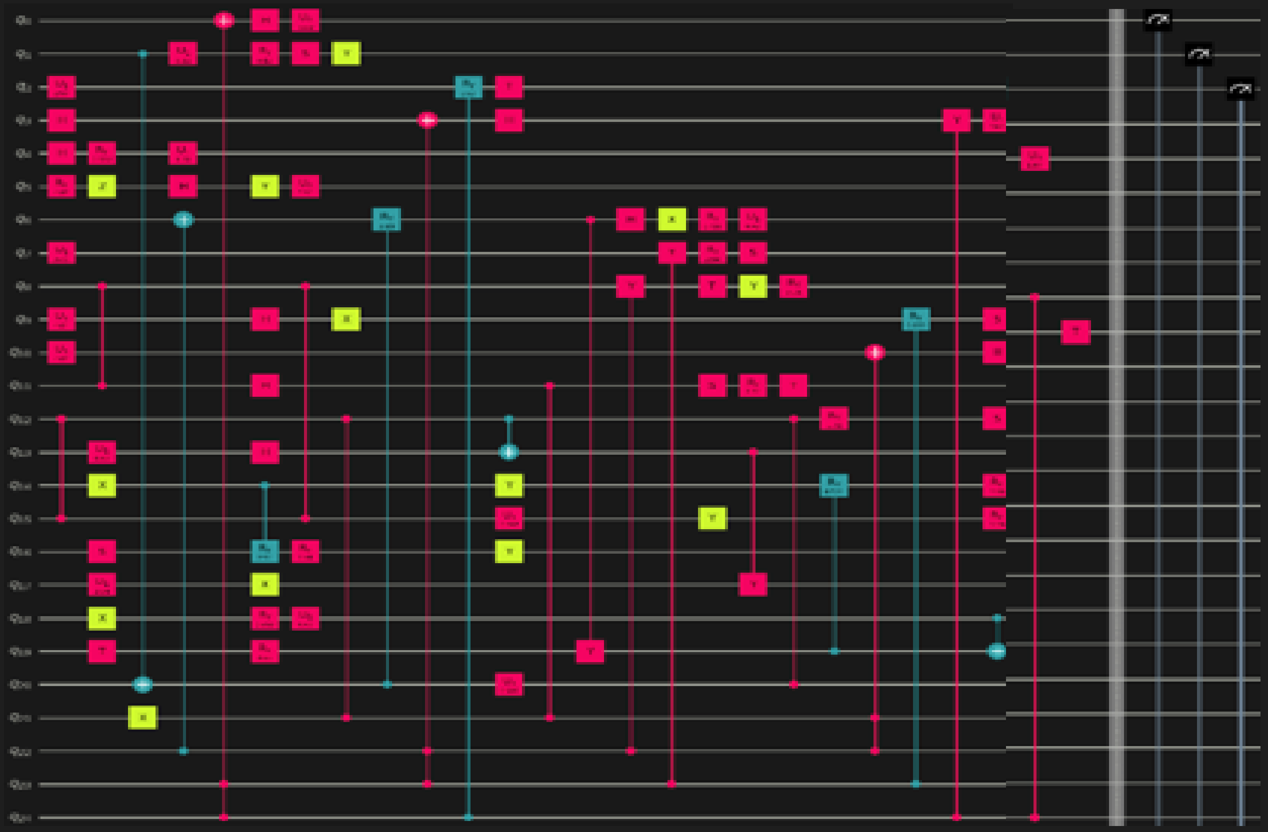
CLASSIQ

THE SOFTWARE CHALLENGE

Punch Card, 1965



Quantum Software, 2020

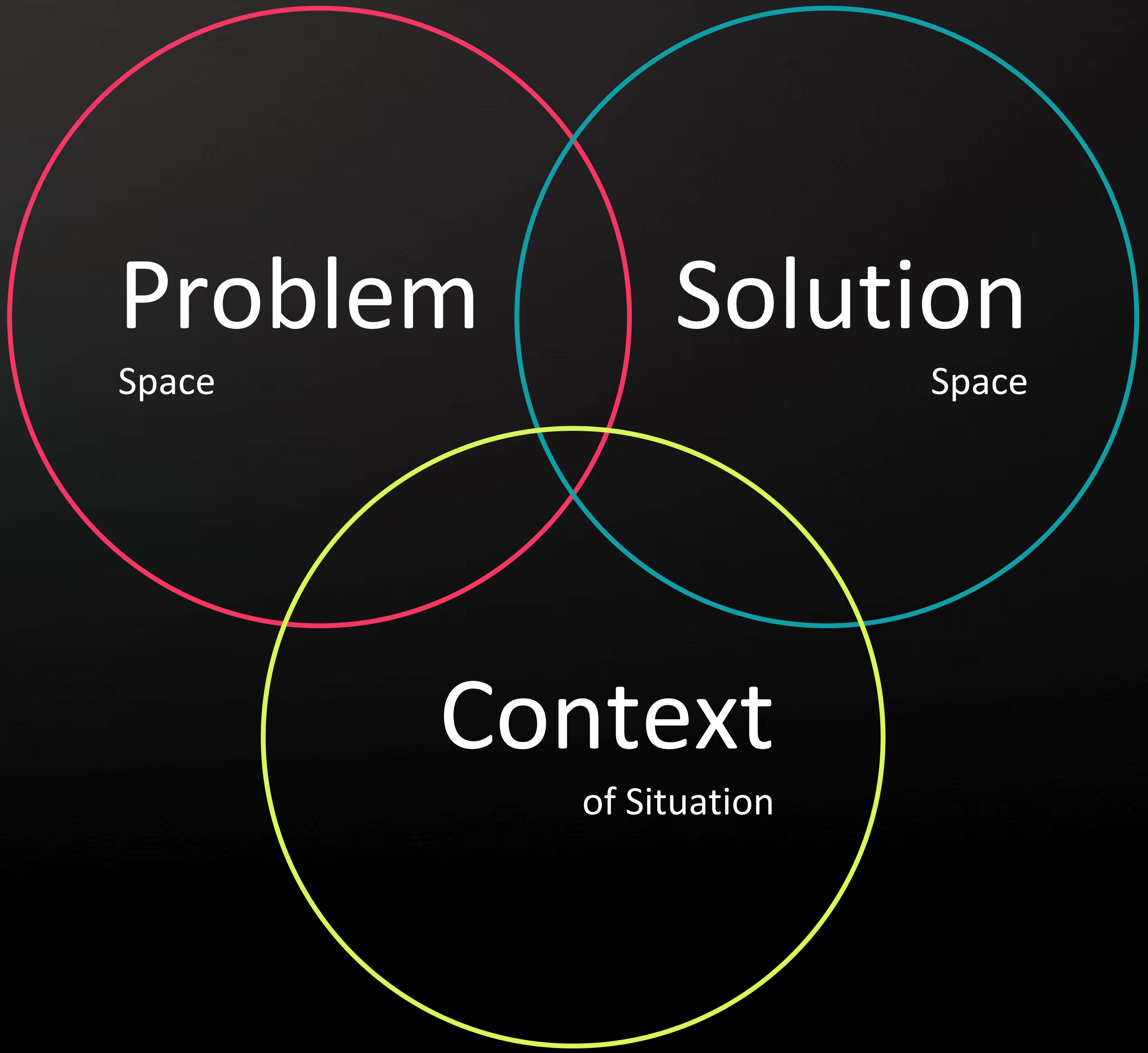


REQUIRES A WHOLISTIC APPROACH

Quantum coding requires many considerations:

Possible Quantum Implementations
- What quantum algorithms can address the problem?
- What hardware is available to run this algorithm?
- Could the algorithm run more efficiently on different hardware?
- Do I know how to code in the language of the targeted hardware (Qiskit, Q#, Cirq, etc.)?

Operational Context
- What are the tradeoffs between algorithmic efficiency and solution accuracy?
- How do hardware characteristics affect possible algorithmic implementations and overall resource use?
- What algorithms should I use and how do I modify my code to run on near-term quantum computers?



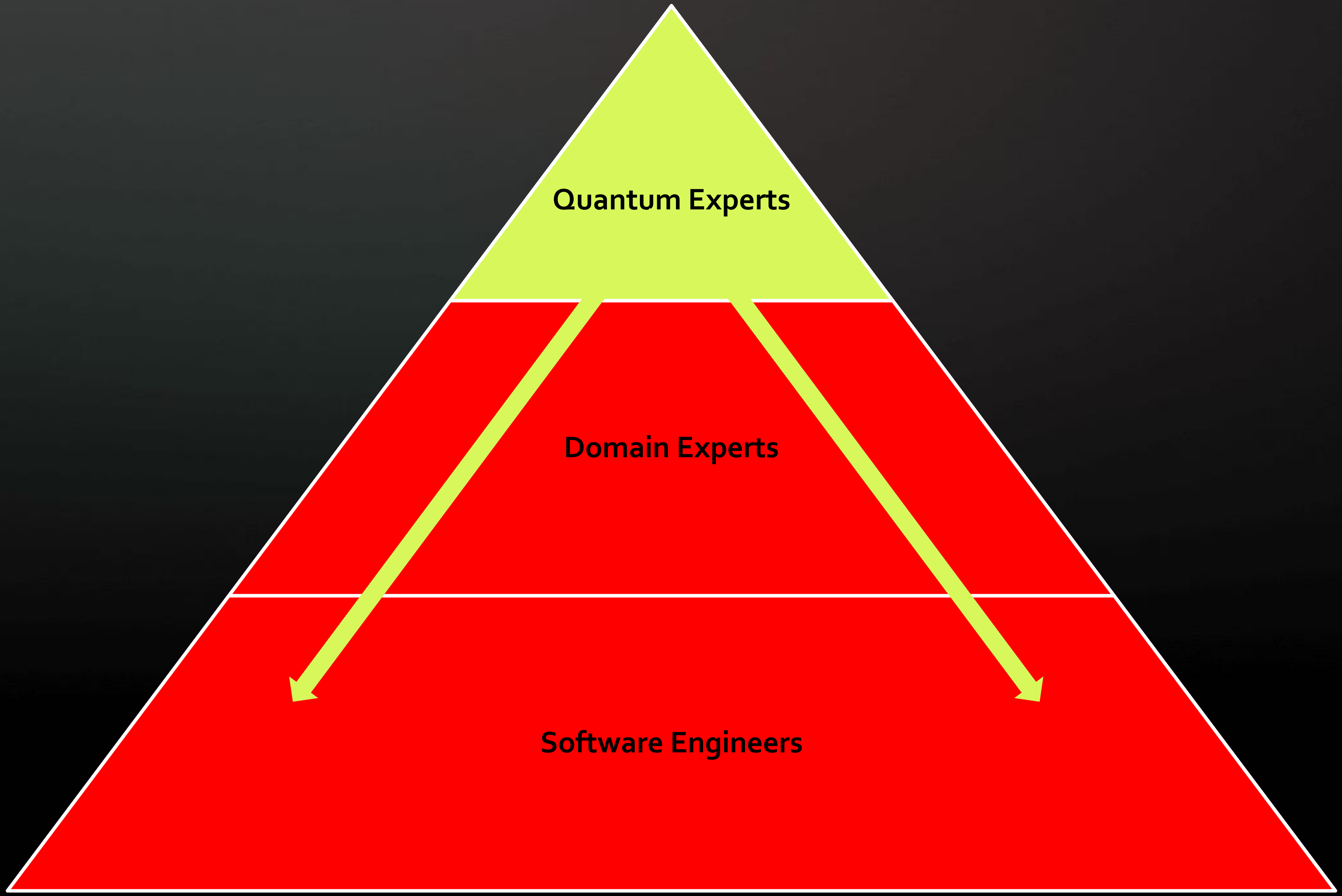
PROGRAMING WITH OTHER PLATFORMS

Define desired functionality → Use pre-existing scheme/algorithm → Modify and adapt for specific use-case → Optimize the circuit → Compile/Transpile

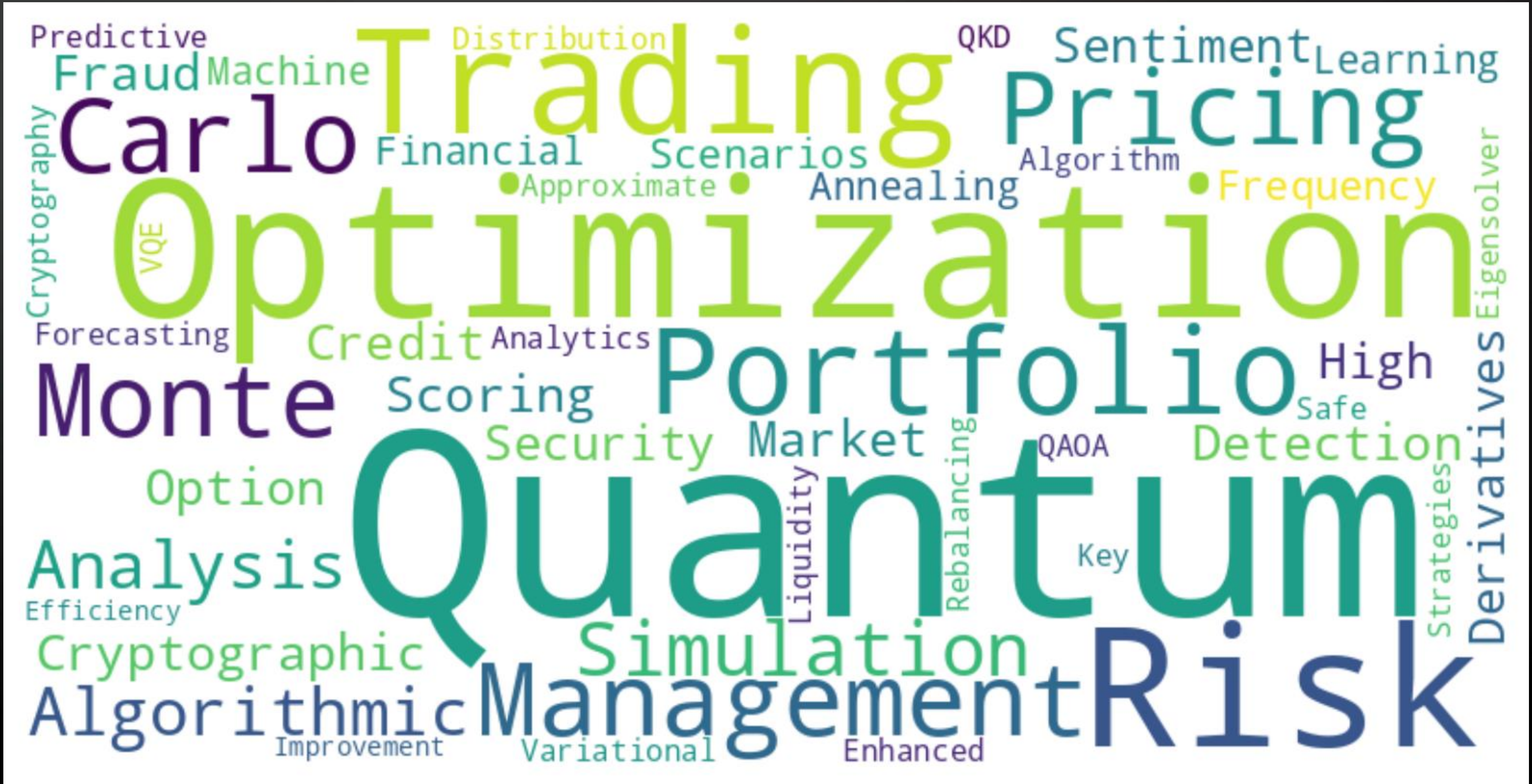
Manual

Automatic

WHO WILL PROGRAM QUANTUM COMPUTERS?



FINANCIAL SERVICES IMPLEMENTATIONS


Optimization
Quantum
Trading
Pricing
Carlo
Monte
Portfolio
Risk
Management
Simulation
Algorithmic
Analysis
Cryptographic
Option
Security
Market
Scoring
Credit
Detection
Derivatives
High
Annealing
Scenarios
Financial
Fraud
Machine
Predictive
Distribution
QKD
Sentiment
Learning
Algorithm
Approximate
Frequency
Eigensolver
Cryptography
VQE
Forecasting
Analytics
Safe
QAOA
Key
Liquidity
Rebalancing
Strategies
Efficiency
Improvement
Variational
Enhanced

CLASSIQ

QUANTUM COMPUTING SOFTWARE

APPENDIX

HELPFUL LINKS

Technical Documents

Quantum computing for finance JP Morgan https://arxiv.org/abs/2307.11230

Science Direct https://www.sciencedirect.com/science/article/pii/S2405428318300571

General Interest Quantum Computing & Regulatory Impact

Deloitte https://www2.deloitte.com/us/en/insights/industry/financial-services/financial-services-industry-predictions/2023/quantum-computing-in-finance.html

McKinsey https://www.mckinsey.com/capabilities/mckinsey-digital/our-insights/tech-forward/quantum-technology-use-cases-as-fuel-for-value-in-finance

WEF & FCA on quantum security https://www.regulationtomorrow.com/eu/world-economic-forum-and-fca-joint-white-paper-on-quantum-security-for-the-financial-sector/

FINRA https://www.finra.org/rules-guidance/key-topics/fintech/report/quantum-computing/regulatory-considerations

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Citi https://www.classiq.io/insights/citi-and-classiq-advance-quantum-solutions-for-portfolio-optimization-using-amazon-braket

Intesa Sanpaolo https://arxiv.org/pdf/2402.05574

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