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Institute of Digital Technology

Quantum Computing

From Theory to Practical

Gen 10 SE Y4 2026-2027

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Course Outline

Chapter 1: Introduction to Quantum Computing

Chapter 2: Basic of Quantum Mechanics

Chapter 3: Quantum Algorithms

Chapter 4: Quantum Fourier Transform

Chapter 5: Quantum Errors & Noises

Chapter 6: Quantum Machine Learning

Chapter 7: Quantum Chemistry

Chapter 8: Quantum Cryptography

Final Presentation

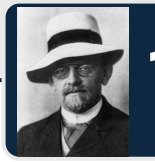
Chapter 1: Introduction to Quantum Computing

- What is Quantum Computing?
- Classical vs Quantum
- Advantages of Quantum Computing
- Challenges of Quantum Computing
- Near-Term Quantum Devices (NISQ Era)
- The Bigger Picture: Quantum Advantage
- Quantum Computing Technology Types
- Quantum Computing Applications
- Practical Tools

What is quantum computing?

History of Quantum Computer

- German Mathematician, **David Hilbert**

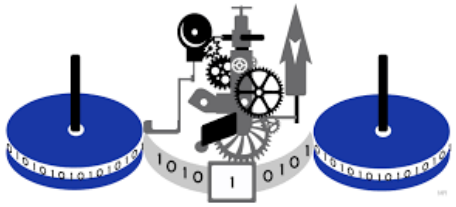


1928



1936

- English mathematician, **Alan Turing**



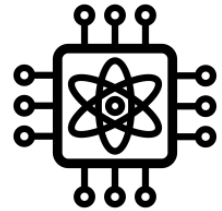
Turing Machine

- English Physicist, **David Deutsch**



1985

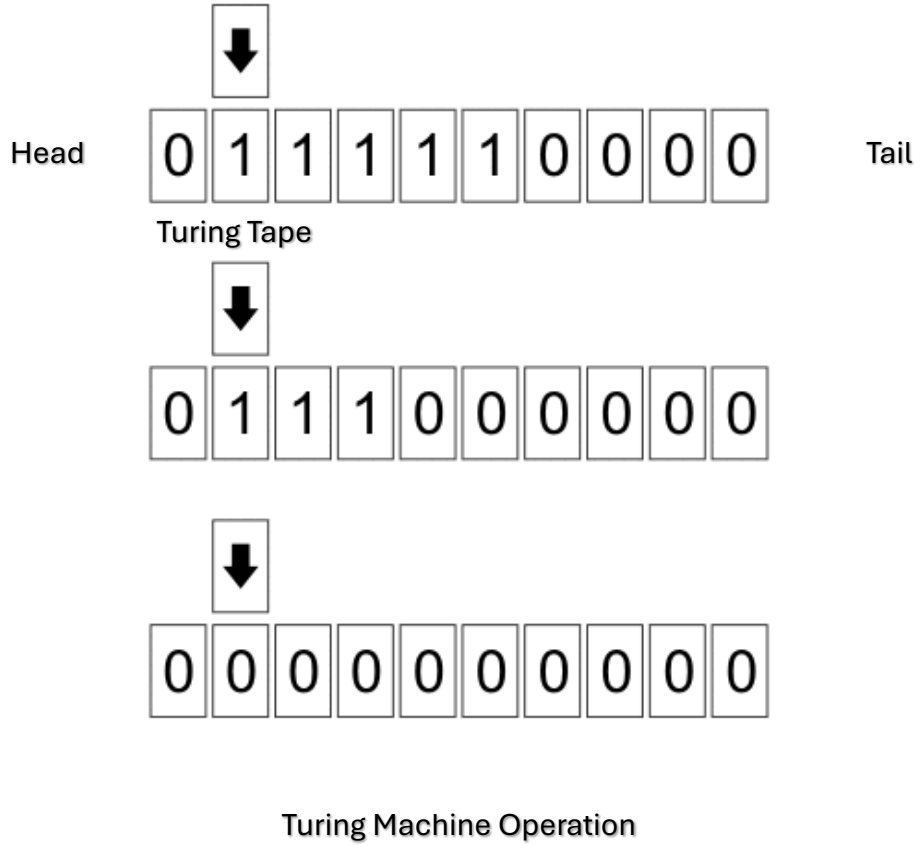
Quantum Theory



Quantum Computer

What is quantum computing?

History of Quantum Computer

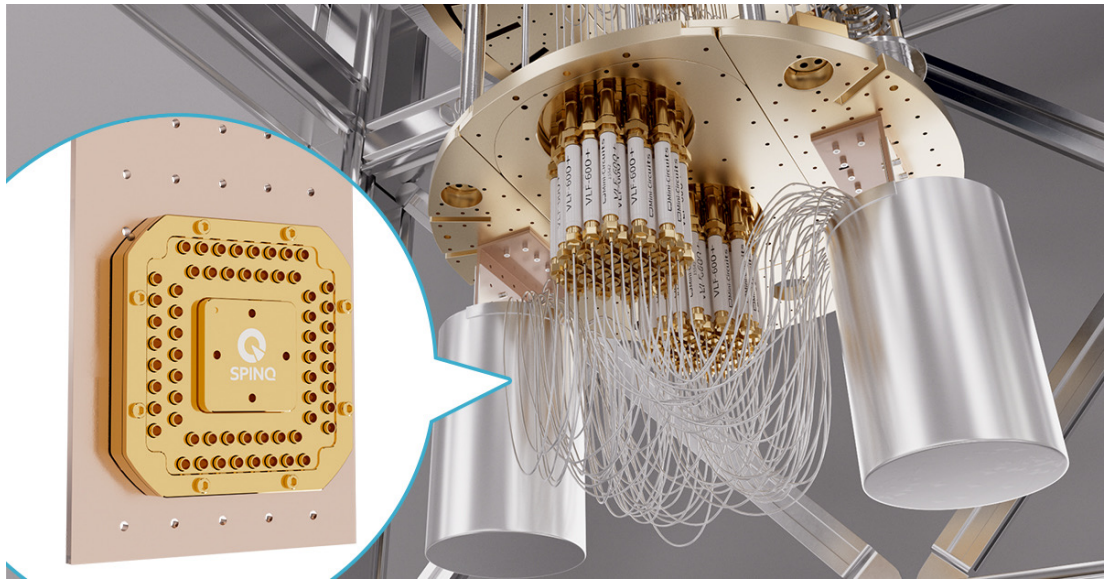


Turing Machine Operation

What is quantum computing?

What Quantum Computing?

- Quantum Computing is a new model of computing that uses the rules of quantum physics to process information in ways classical computers can't, enabling speedups on specific problem types.
- Eventually, there is **no standalone quantum computers**. Yet we have
  - **QPU** is something like CPU, GPU, TPU, or FPGA

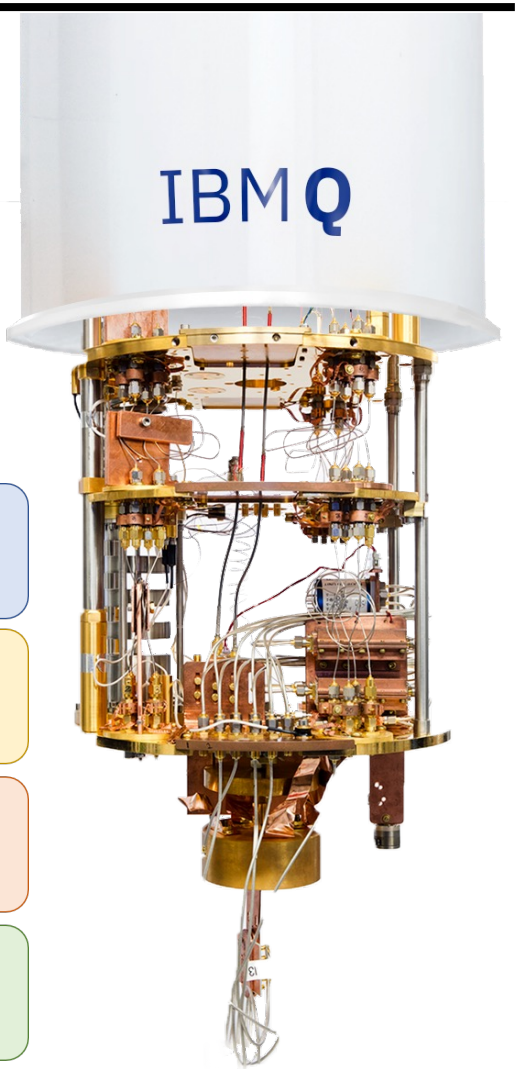


CPU
- Small models
- Small datasets
- Useful for design space exploration

GPU
- Medium-to-large models, datasets
- Image, video processing
- Application on CUDA or OpenCL

TPU
- Matrix computations
- Dense vector processing
- No custom TensorFlow operations

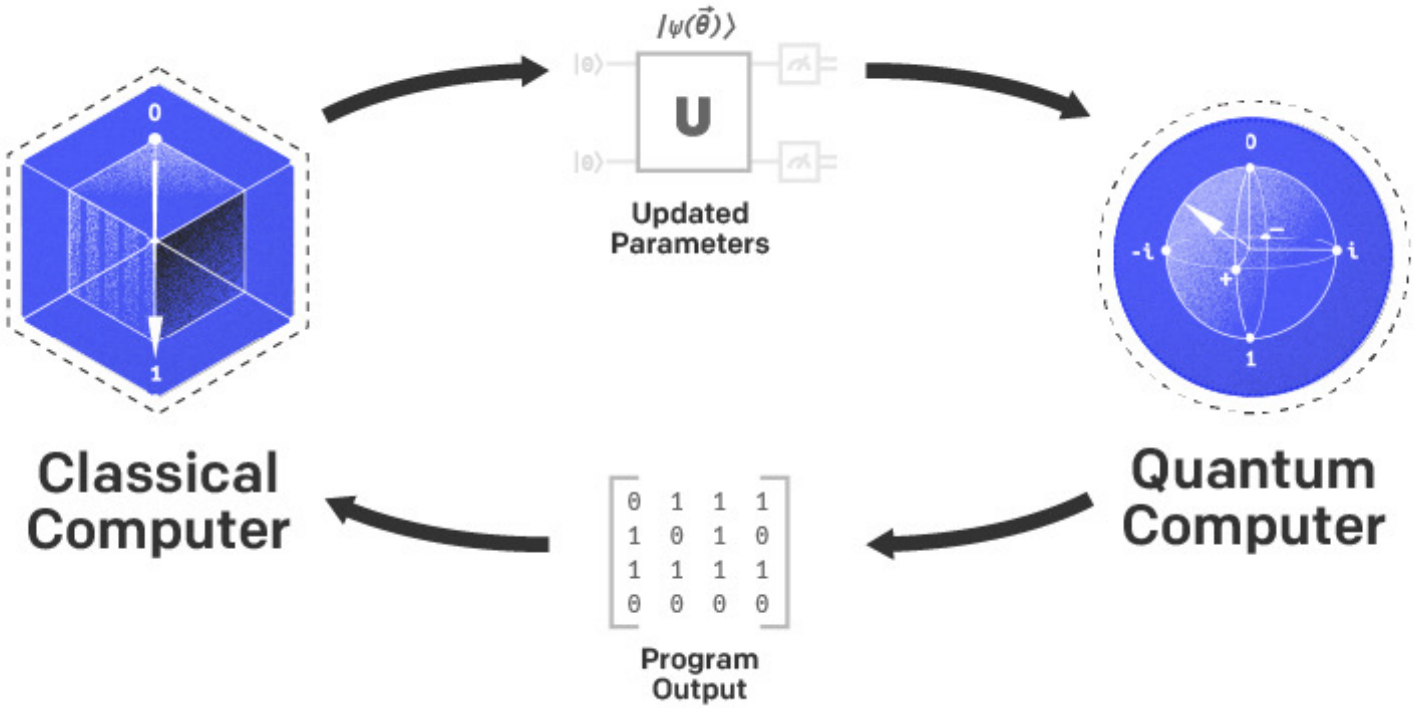
FPGA
- Large datasets, models
- Compute intensive applications
- High performance, high perf./cost ratio



What is quantum computing?

Why Quantum Computing?

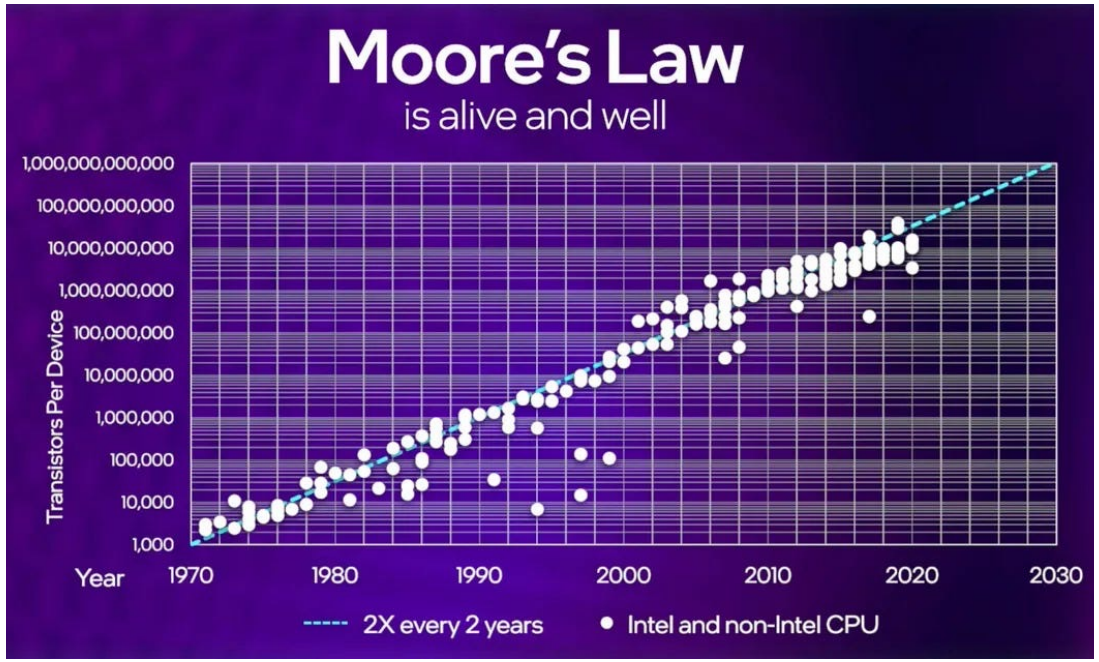
- **Limits of classical computing**: Moore's Law slowing, intractable NP-hard problems.
- **Quantum advantage**: unique ability to solve problems beyond classical reach.
- **Applications emerging in:**
  - Finance & optimization
  - Chemistry & biomedicine
  - Cryptography & security
  - Artificial Intelligence
  - Logistic

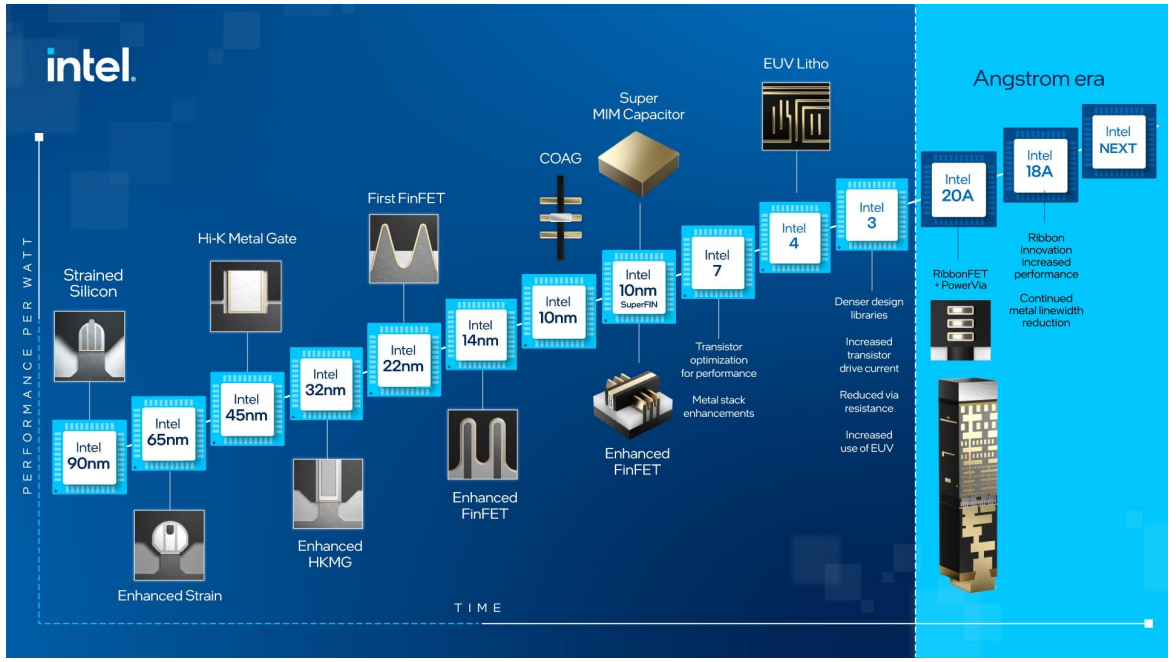


What is quantum computing?

Why Quantum Computing?

- Moore's Law slowing on Chip Production

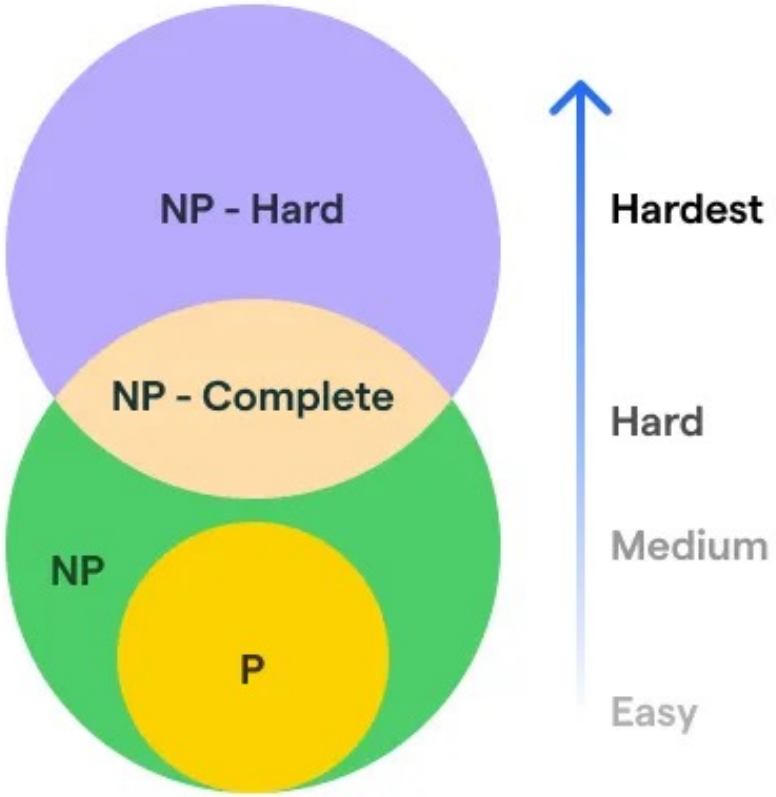


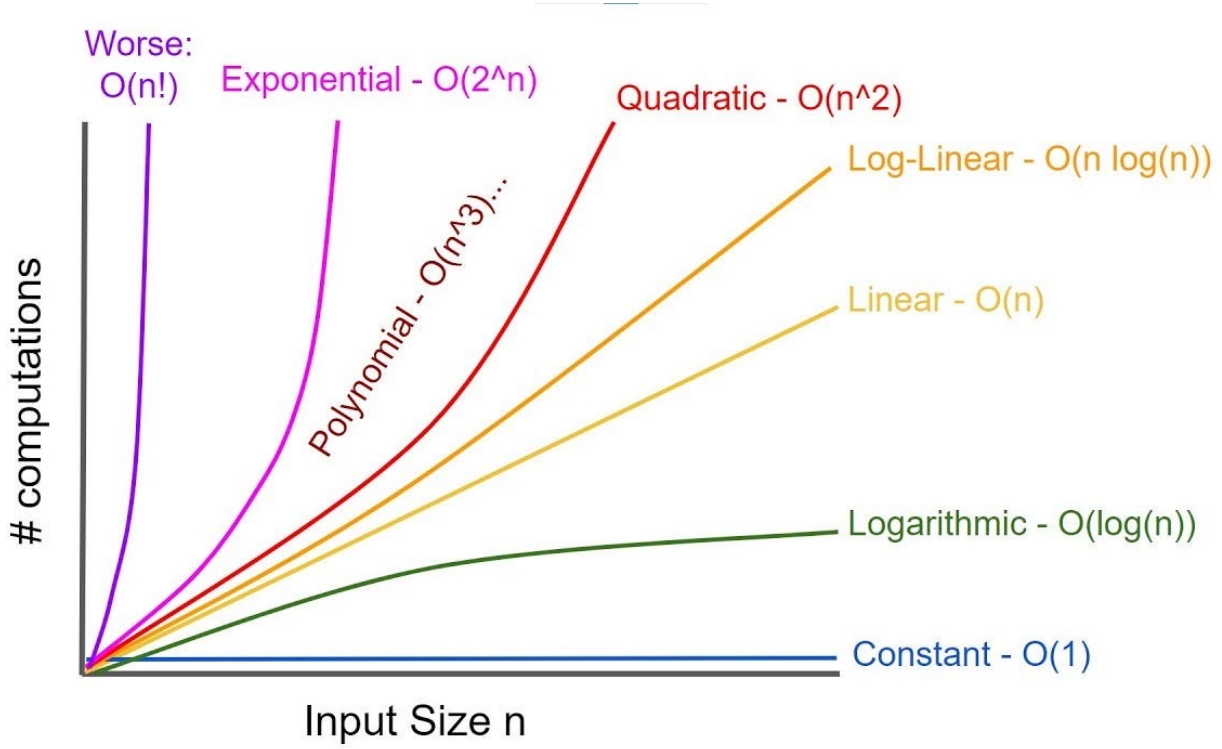


What is quantum computing?

Why Quantum Computing?

- Problem and Computational Complexity Theory

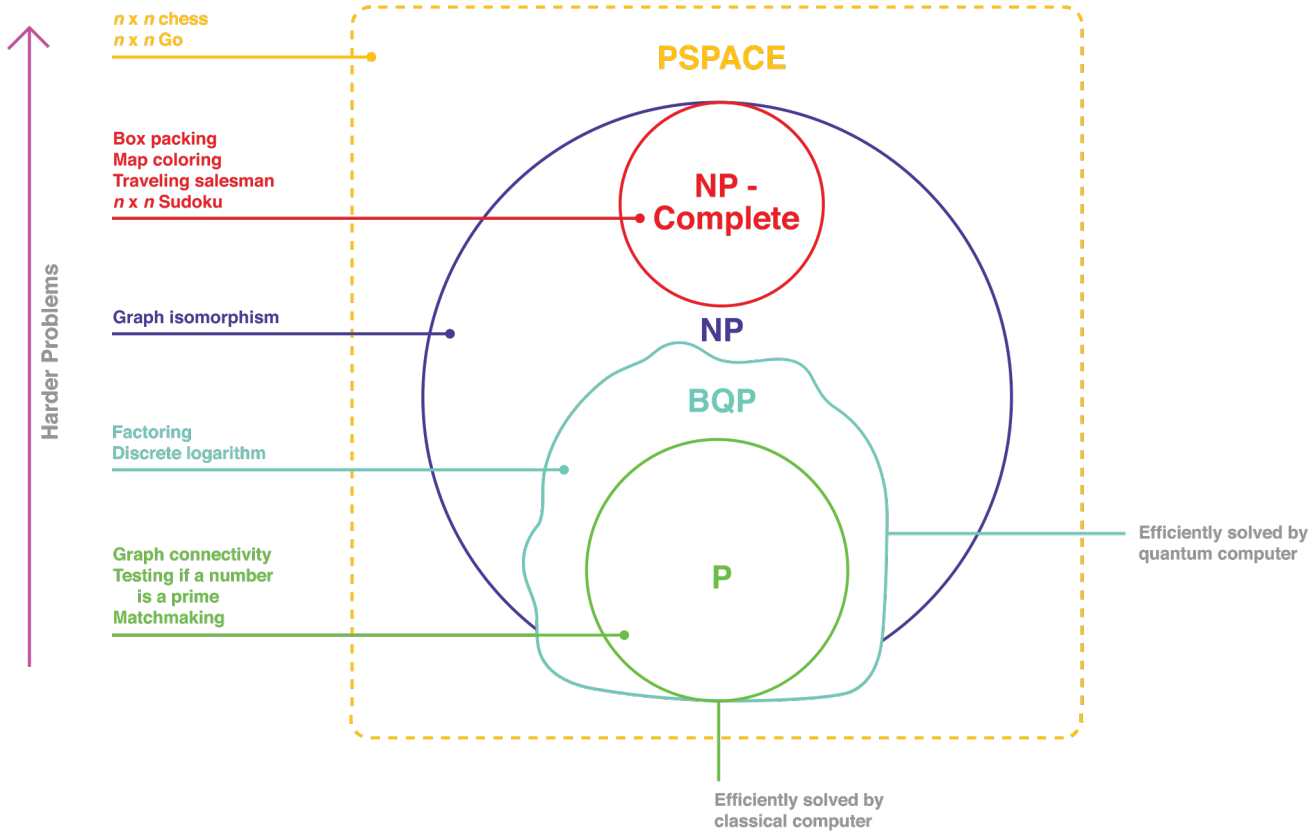


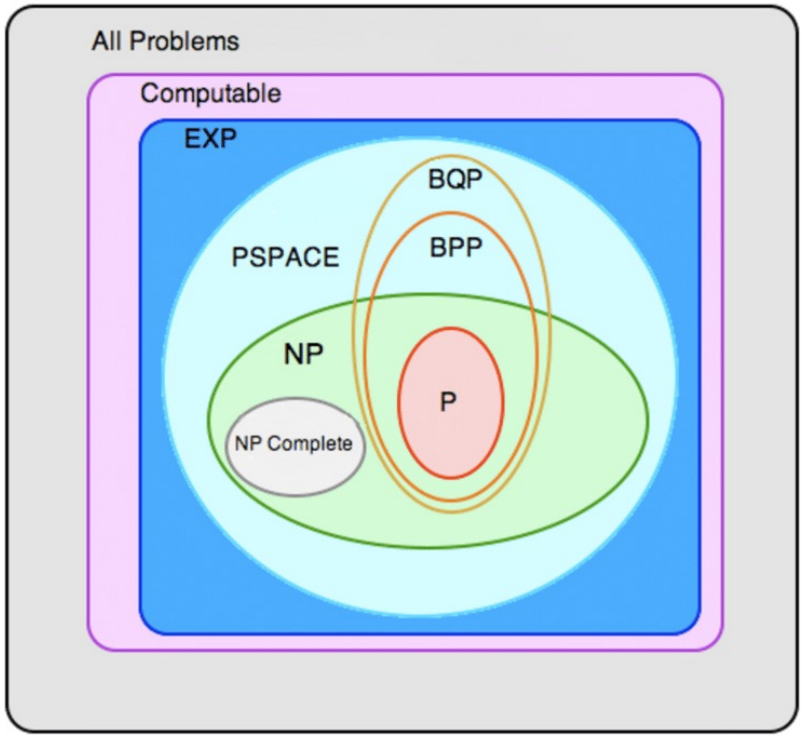


What is quantum computing?

Why Quantum Computing?

- Problem and Computational Complexity Theory



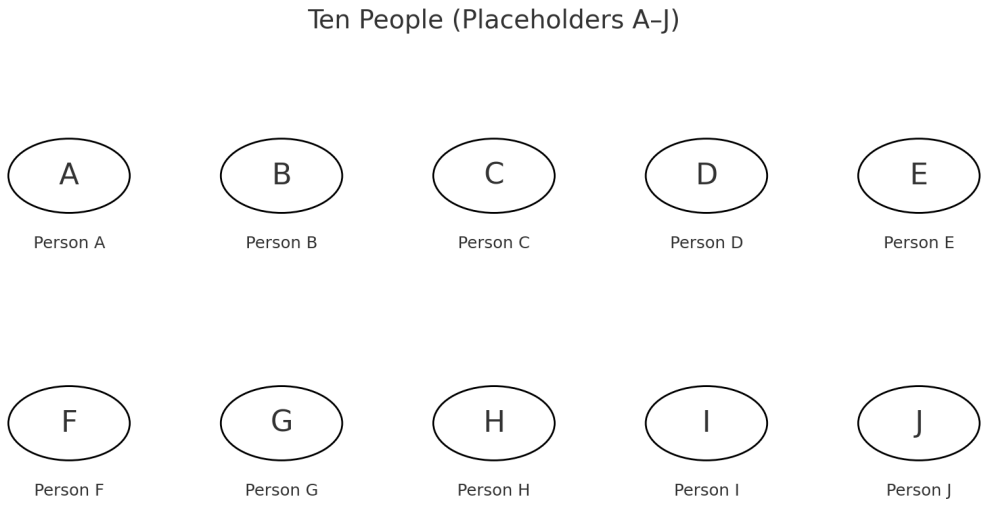


P	solution can be found in time polynomial in the size (number of bits)
NP	solution can be checked in polynomial time
NP COMPLETE	any NP problem can be reduced to one of these
BPP	solution in polynomial time at probability $p>1/2$
BQP	solution in polynomial time at probability $p>1/2$ on quantum computer
PSPACE	solution requires a polynomial amount of memory
EXP	solution can be found in exponential time
COMPUTABLE	solution can be found eventually

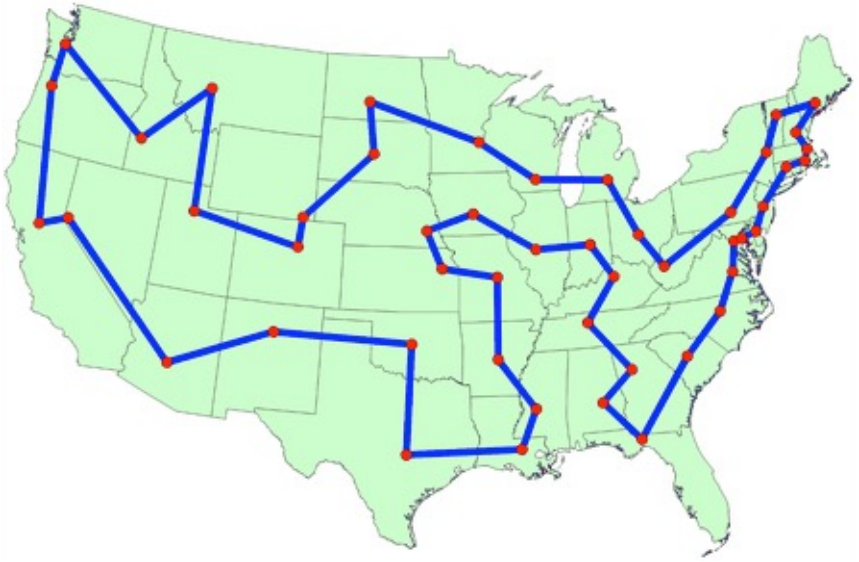
What is quantum computing?

Why Quantum Computing?

- Intractable NP-hard problems example:



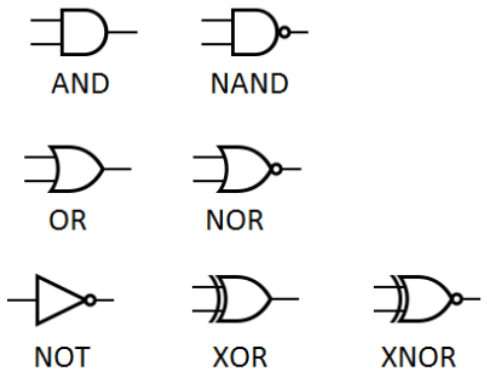
Combinational of 10 people in one round-table seatings = **9! = 362,880**



Travelling Salesman Problem of 20 spots and find the shorted path so the search space = **(20−1)! / 2 = 60,822,550,204,416,000 ≈ 6.08×10^16**.

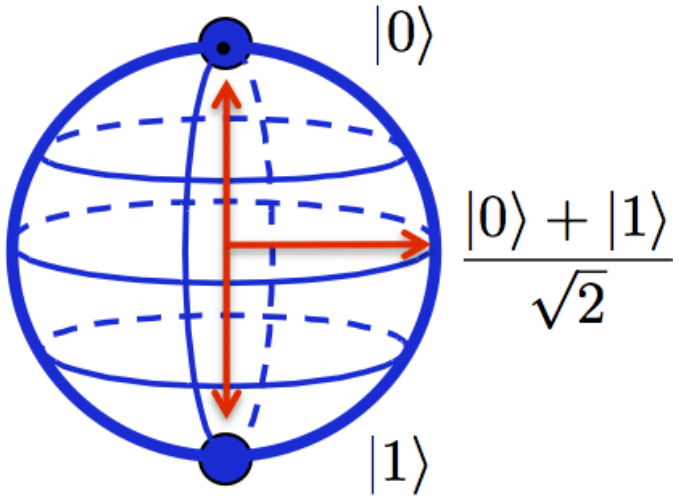
Classical vs Quantum

- **Classical Computing**
  - Bits: 0 or 1
  - Deterministic logic gates
  - Sequential operations
- **Quantum Computing**
  - Qubits: superposition & entanglement
  - Quantum gates: unitary operations
  - Probabilistic, parallel computation

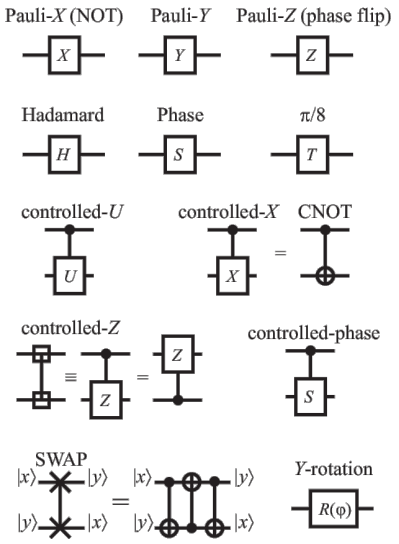




Classical Bit



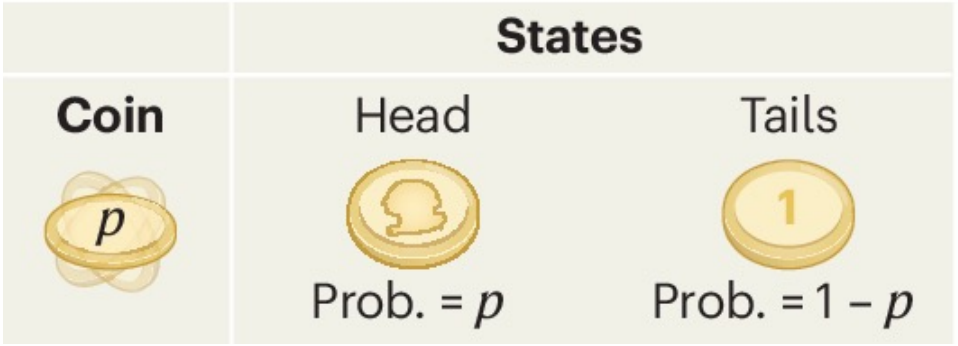
Qubit



Classical vs Quantum

Why Quantum Computing?

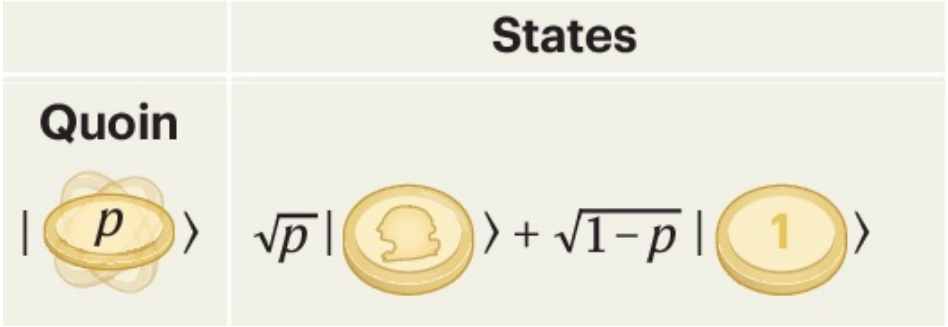
- **Classical Coin** vs Quantum Coin (Randomness)
- Sample space: **{H, T}**
- Randomness from chaos (initial spin, air, surface)
- Can be biased (weighted coin, flipping style)



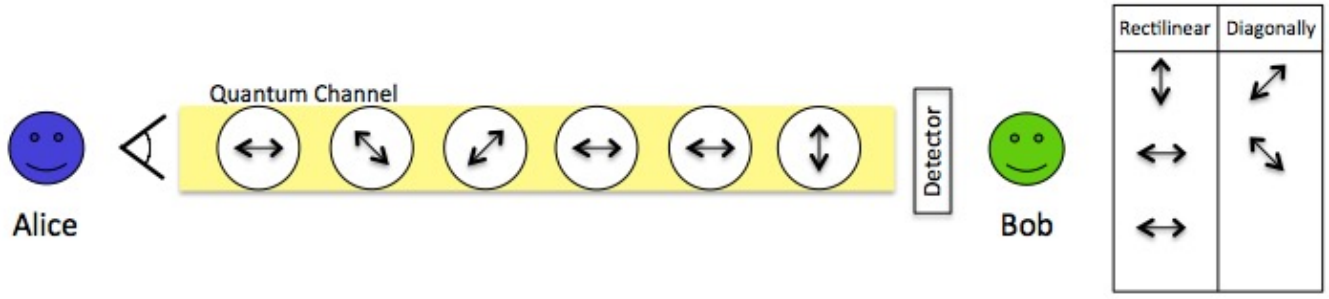
- **Pseudo Random Number Generators (PRNGs)**: is an algorithm that generates a sequence of numbers that appear random, but are actually produced deterministically from an initial value called a **seed**. Unlike true randomness (from physical processes), PRNGs are predictable if the seed and algorithm are known — but they are **fast**, **reproducible**, and widely used in computing.
- Physical noise (thermal, avalanche diode, radioactive decay) needed for true randomness

Classical vs Quantum

Why Quantum Computing?



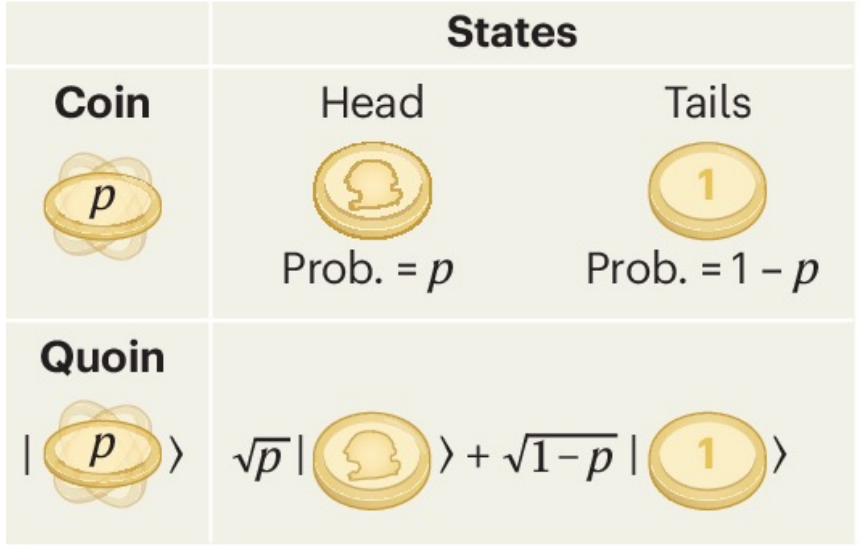
- Classical Coin vs **Quantum Coin** (Randomness)
- A qubit in superposition:
  $|+\rangle = \frac{1}{\sqrt{2}}(|0\rangle+|1\rangle)$
- Measure in Z basis → 0 or 1 with **50/50 probability**
- Randomness is **intrinsic** (not due to ignorance)
- Can **tune bias**: $|\psi\rangle = \cos\ \theta|0\rangle + \sin\ \theta|1\rangle \rightarrow P(0) = \cos^2\theta$, $P(1) = \sin^2\theta$
- **Certifiable randomness:** Bell tests, device-independent QRNG (produces randomness by exploiting **intrinsic quantum uncertainty**.)



Classical vs Quantum

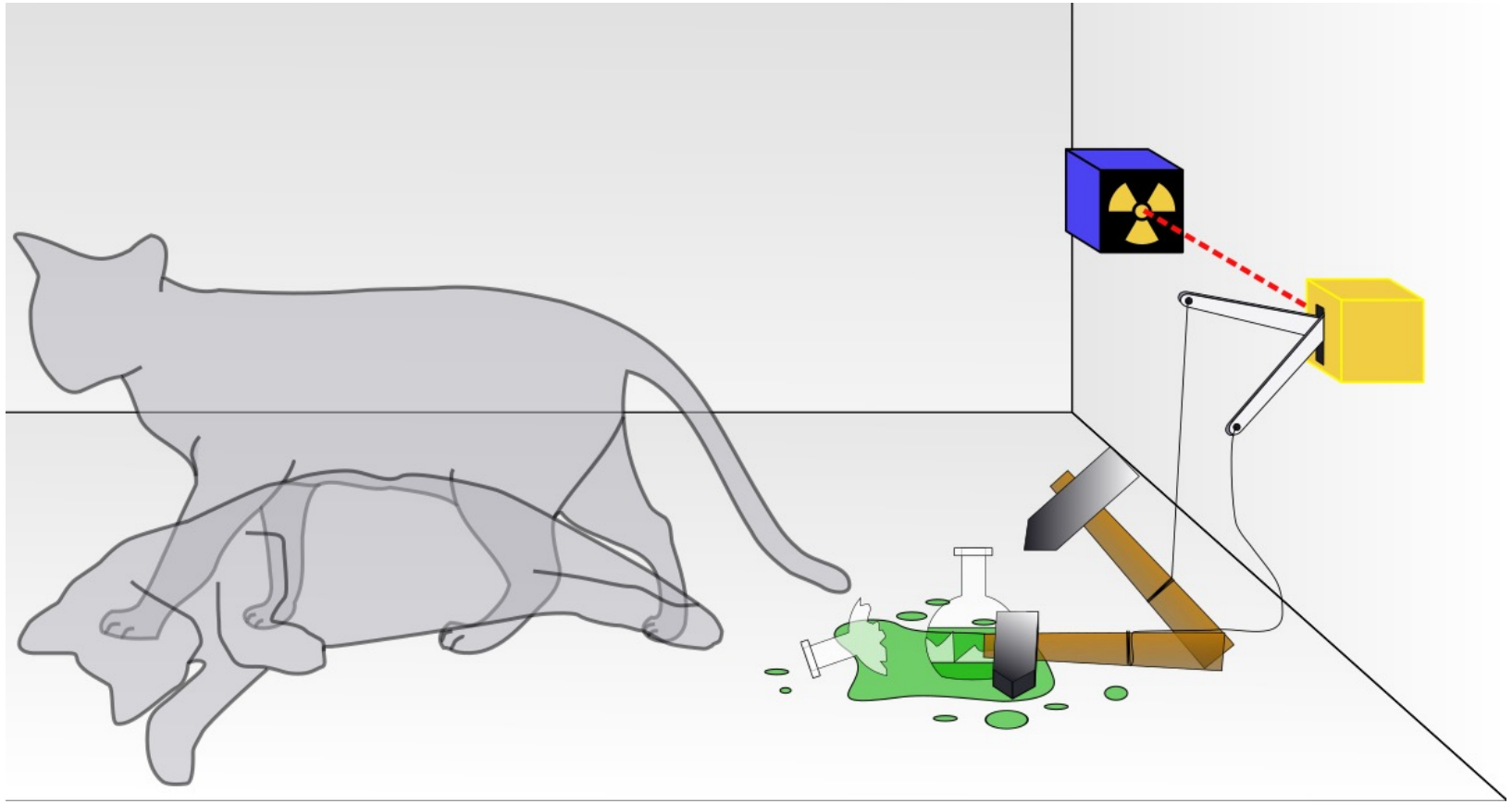
Why Quantum Computing?

- **Classical Coin vs Quantum Coin** (Randomness)
- Classical fair coin: **P(H) = P(T) = 0.5P**
- Quantum fair coin: Hadamard on **|0⟩ → measure → P(0) = P(1) = 0.5P**
- Biased quantum coin: **θ = 30∘ → P(0) = 0.75, P(1) = 0.25**



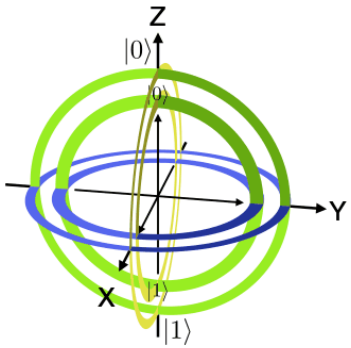
Classical vs Quantum

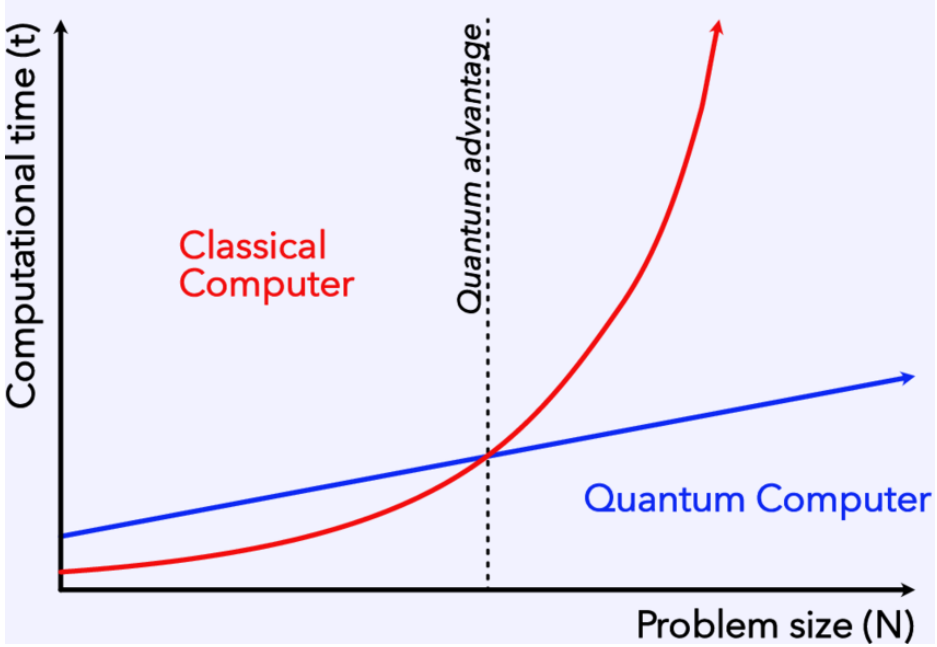
- **Classical Computing**
- **Quantum Computing: Schrodinger's Cat**

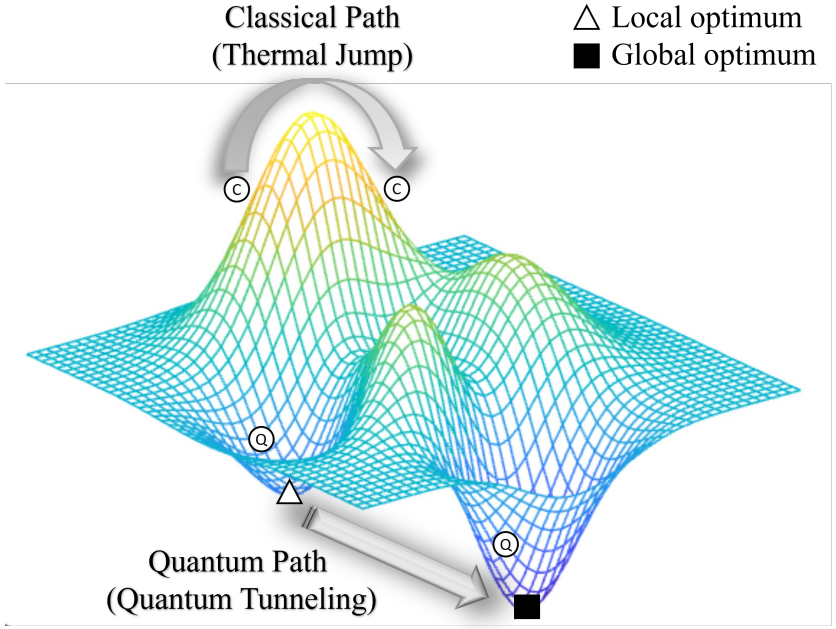


Advantages of Quantum Computing

- **Parallelism:** explore many states simultaneously.
- **Exponential speed-ups** for certain problems (Shor, Grover).
- **Natural simulation** of quantum systems (chemistry, materials).
- **Potential breakthroughs** in AI, finance, optimization.

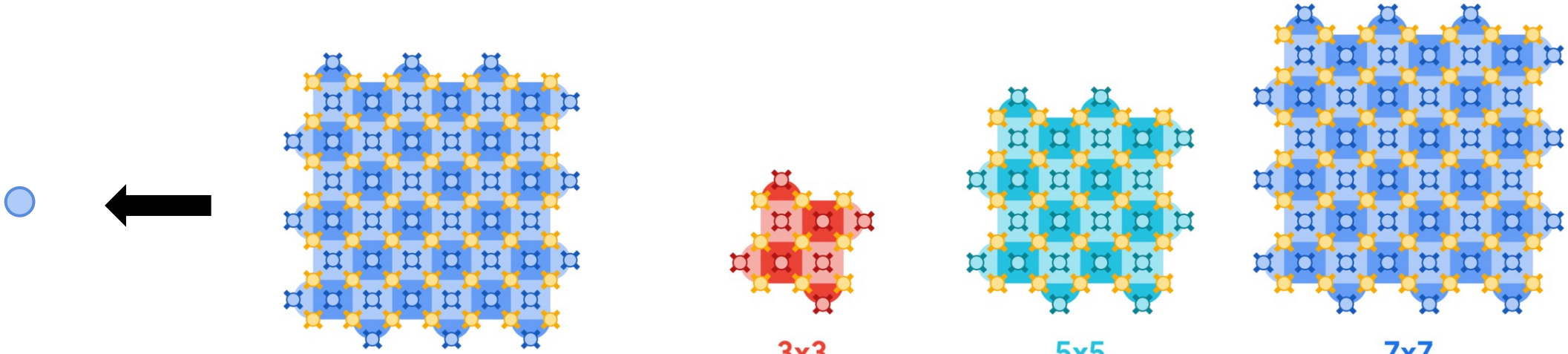






Challenges of Quantum Computing

- **Fragile qubits** → decoherence & noise.
- **Error correction** requires many extra qubits.



1 logical qubit need ~1,000 physical qubits

Quantum Error Correction (QEC)

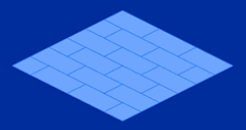
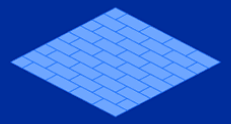
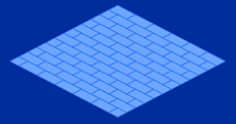
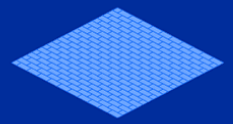
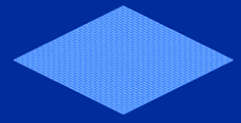
Challenges of Quantum Computing

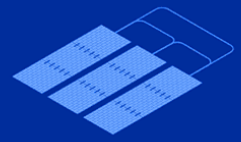
- **Scalability:** current devices = small (tens–hundreds of qubits).
- **Algorithm maturity:** only few proven quantum speedups.

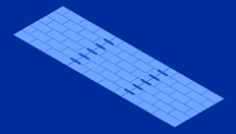
Development Roadmap | Executed by IBM ✓ On target ↻

IBM **Quantum**

	2019 ✓	2020 ✓	2021 ✓	2022	2023	2024	2025	Beyond 2026
	Run quantum circuits on the IBM cloud	Demonstrate and prototype quantum algorithms and applications	Run quantum programs 100x faster with Qiskit Runtime	Bring dynamic circuits to Qiskit Runtime to unlock more computations	Enhancing applications with elastic computing and parallelization of Qiskit Runtime	Improve accuracy of Qiskit Runtime with scalable error mitigation	Scale quantum applications with circuit knitting toolbox controlling Qiskit Runtime	Increase accuracy and speed of quantum workflows with integration of error correction into Qiskit Runtime
Model Developers					Prototype quantum software applications →		Quantum software applications	
							Machine learning | Natural science | Optimization	
Algorithm Developers		Quantum algorithm and application modules ✓			Quantum Serverless			
		Machine learning | Natural science | Optimization				Intelligent orchestration	Circuit Knitting Toolbox	Circuit libraries
Kernel Developers	Circuits ✓		Qiskit Runtime ✓					
				Dynamic circuits ↻	Threaded primitives	Error suppression and mitigation		Error correction
System Modularity	Falcon ✓ 27 qubits	Hummingbird ✓ 65 qubits	Eagle ✓ 127 qubits	Osprey ↻ 433 qubits	Condor 1,121 qubits	Flamingo 1,386+ qubits	Kookaburra 4,158+ qubits	Scaling to 10K-100K qubits with classical and quantum communication
					Heron 133 qubits x p	Crossbill 408 qubits		





IBM Quantum Roadmap, May 2022

Updated IBM Quantum Roadmap, August 2024

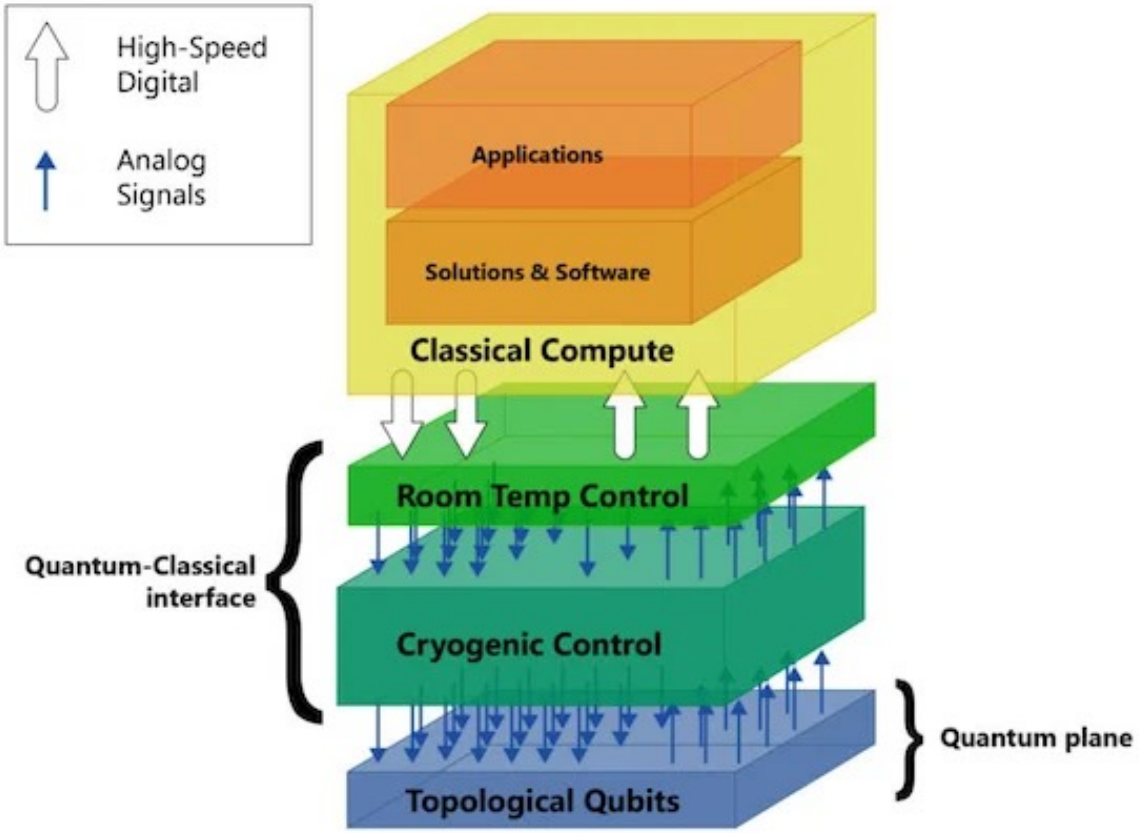
	2016–2019 ✓	2020 ✓	2021 ✓	2022 ✓	2023 ✓	2024	2025	2026	2027	2028	2029	2033+
	Ran quantum circuits on the IBM Quantum Platform	Released multi-dimensional roadmap publicly with initial aim focused on scaling	Enhanced quantum execution speed by 100x with Qiskit Runtime	Brought dynamic circuits to unlock more computations	Enhanced quantum execution speed by 5x with Quantum Serverless and execution modes	Improve quantum circuit quality and speed to allow 5K gates with parametric circuits	Enhance quantum execution speed and parallelization with partitioning and quantum modularity	Improve quantum circuit quality to allow 7.5K gates	Improve quantum circuit quality to allow 10K gates	Improve quantum circuit quality to allow 15K gates	Improve quantum circuit quality to allow 100M gates	Beyond 2033, quantum-centric supercomputers will include 1000's of logical qubits unlocking the full power of quantum computing
Data scientists						Platform						
						Code assistant	Functions	Mapping collections	Specific libraries			General purpose QC libraries
Researchers					Middleware							
					Quantum Serverless ✓	Transpiler service	Resource management	Circuit knitting x p	Intelligent orchestration			Circuit libraries
Quantum physicists			Qiskit Runtime									
	IBM Quantum Experience ✓		QASM 3 ✓	Dynamic circuits ✓	Execution modes ✓	Heron (5K)	Flamingo (5K)	Flamingo (7.5K)	Flamingo (10K)	Flamingo (15K)	Starling (100M)	Blue Jay (1B)
	Early ✓ Canary 5 qubits Albatross 16 qubits Penguin 20 qubits Prototype 53 qubits	**Falcon** ✓ Benchmarking 27 qubits	**Eagle** ✓ Benchmarking 127 qubits			Error mitigation 5k gates 133 qubits Classical modular Up to 133x3 = 399 qubits	Error mitigation 5k gates 156 qubits Quantum modular Up to 156x7 = 1092 qubits	Error mitigation 7.5k gates 156 qubits Quantum modular Up to 156x7 = 1092 qubits	Error mitigation 10k gates 156 qubits Quantum modular Up to 156x7 = 1092 qubits	Error mitigation 15k gates 156 qubits Quantum modular Up to 156x7 = 1092 qubits	Error correction 100M gates 200 qubits Error corrected modularity	Error correction 1B gates 2000 qubits Error corrected modularity

✓ Executed by IBM

On target

Challenges of Quantum Computing

- **Cost & technology limits:** cryogenics, stability, hardware complexity





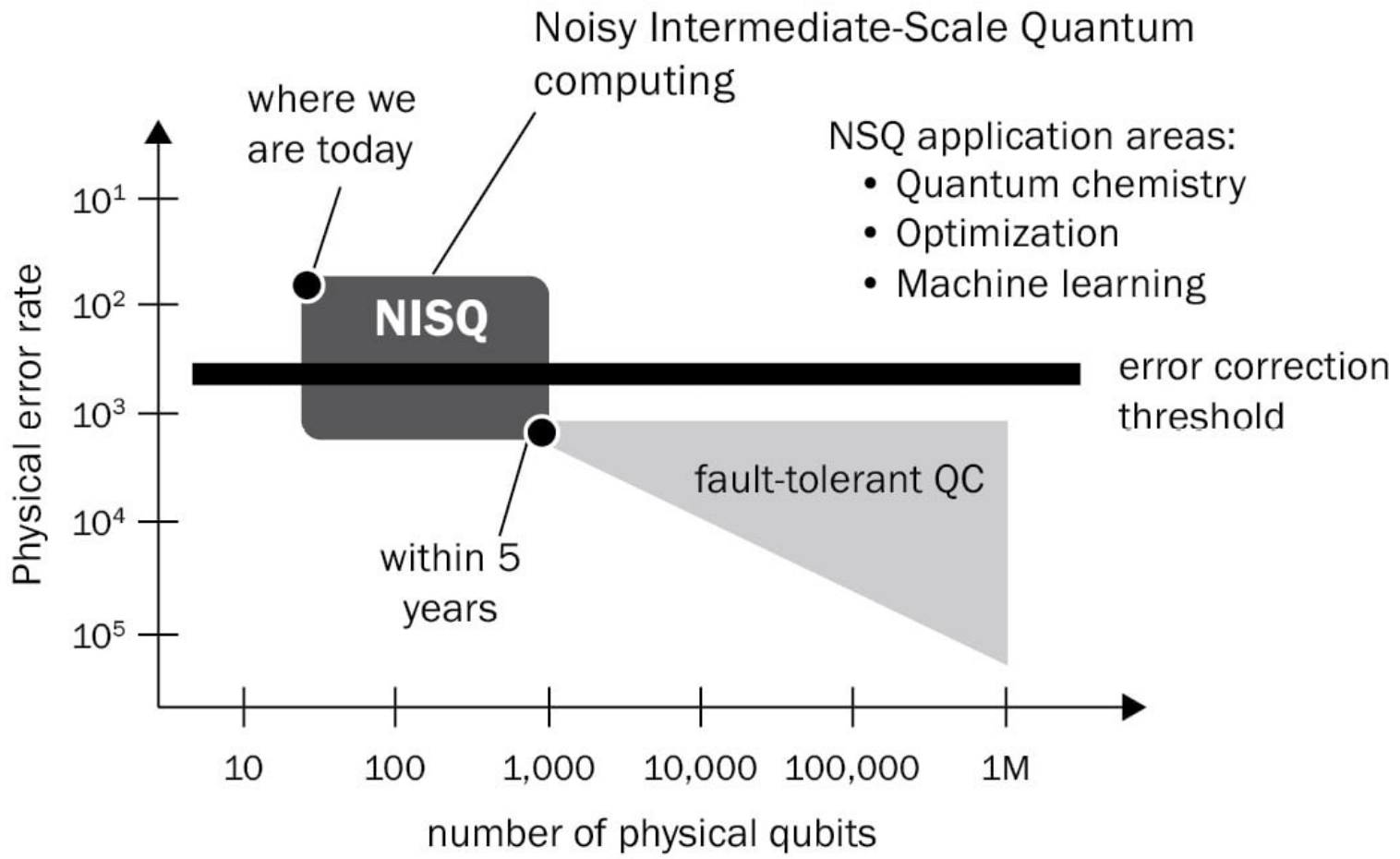
Quantum cryogenics systems operate at extremely low temperatures, above absolute zero around 20-100 millikelvin (mK) range.

Near-Term Quantum Devices (NISQ Era)

- **NISQ** = Noisy Intermediate-Scale Quantum
- Devices with **50–1,000 qubits,** not error-corrected
- Useful for:
  - Quantum simulation (chemistry, physics)
  - Hybrid quantum–classical algorithms (VQE, QAOA)
  - Research & proof-of-concept applications
- Limitation: *not yet full-scale universal quantum computing*.

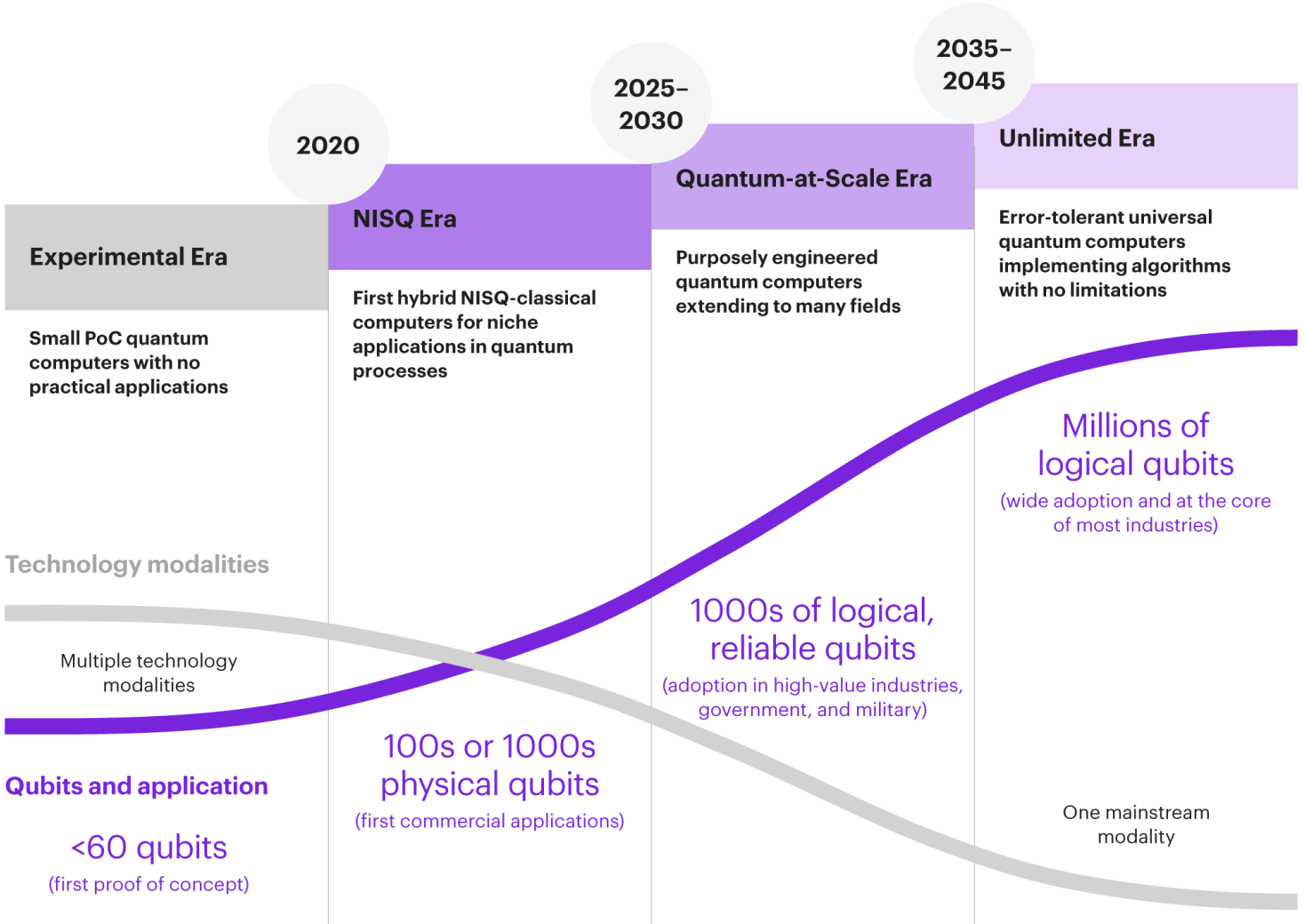
Near-Term Quantum Devices (NISQ Era)

- **NISQ** = Noisy Intermediate-Scale Quantum



Near-Term Quantum Devices (NISQ Era)

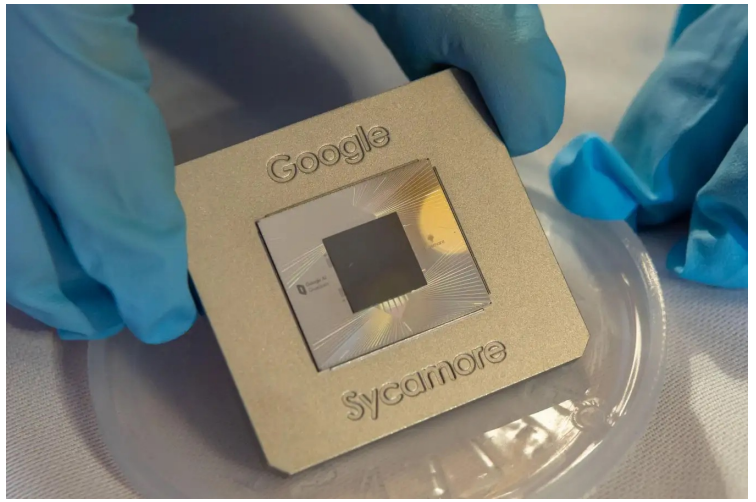
- We are at the **dawn of NISQ**



Notes: PoC is proof of concept. NISQ is noosy intermediate scale quantum. HPC is high-performacne computing. ICT is information communication technology.
Source: Kearney analysis

The Bigger Picture: Quantum Advantage

- **FTQC - Fault-Tolerant Quantum Computing**
- **Quantum Supremacy**: first demonstration that a quantum device solves a task no classical computer can (e.g., Google Sycamore, 2019).
- **Quantum Advantage**: *practical* benefit over classical methods in real applications.
- Current progress: moving from "**supremacy**" → "**advantage**."
- Key areas to watch: cryptography, optimization, drug discovery, climate modeling.



Quantum Computing Technology Types

Vendor	Quantum technology type	Connectivity / topology used	# qubits (or modes)	Real device
Quantinuum	Gate-based Ion Trap Processors	Linear trapped-ion chain, **all-to-all connectivity**	~20	**Quantinuum H1-1**
IBM (Google, Rigetti)	Gate-based Superconducting Processors	**Heavy-hex** lattice	133 & 156	**Heron r1** & **Heron r2**
Xanadu (PsiQuantum)	Photonic Processors	Time-multiplexed Gaussian boson sampling (**modes**)	216 **squeezed modes**/GBS	**Xanadu Borealis**
Atom Computing	Neutral Atom Processors (alkaline-earth)	2D optical lattice (nuclear-spin qubits)	~1,200	**AC1000** platform as whitepaper
QuEra	Rydberg Atom Processors (neutral atoms)	2D programmable Rydberg array	256	**QuEra Aquila** as whitepaper
D-Wave	Quantum Annealers	**Pegasus** (Advantage), sparse Chimera-style minor-embedding	**5,000+**	**Advantage**
IonQ (Honeywell)	Trapped Ion Quantum Computers	Linear chain, effectively **all-to-all**	**#AQ 25** (algorithmics. qubits)	**IonQ Aria**
Google	Superconducting Quantum Computing	2D grid of transmons	**53**	**Sycamore**

Quantum Technology Market Map – Quantum Computers

NON-EXHAUSTIVE, NO ORDER, EXCLUDES LABS

Neural Atoms

atom computing
QuEra Computing Inc.
PASQAL
Infleqtion
AQUARK TECHNOLOGIES
planqc

Cavity QED

NanoQT

Carbon

C12

Silicon

diraq
equal1
intel
photonic
QUANTUM MOTION
quobly
SemiQon
Silicon Quantum Computing
HITACHI Inspire the Next

NV Diamond

QUANTUM BRILLIANCE
SaxonQ
XEED

Topological Qubits

QUOHERENT
Microsoft

Electrons on Helium

EeroQ

Quantum Annealers

D-Wave
KILIMANJARO
NEC
Tokyo Quantum Computing

Superconducting

IQM
ALICE & BOB
IBM
Google Quantum AI
FUJITSU
OQC
QUANTWARE
本源量子 ORIGIN QUANTUM
Anyon Technologies
D-Wave The Quantum Computing Company
RIKEN
ATLANTIC QUANTUM
aws
rigetti
SPINQ 量旋科技
qci

Trapped Ion

CRYSTAL QUANTUM COMPUTING
QUANTINUUM
Universal Quantum
AQT
oxford ionics
eleQtron
ROSATOM
Quantum Art
QUDOOR 启科量子
FOXCONN
IONQ

Photonics

PsiQuantum
Rotonium
Quantum Source
QCi
XANADU
ORCA COMPUTING
QUANDELA
Lighton
TURING
QC82

Source: The Quantum Insider Intelligence Platform

QUANTUM COMPUTING ECOSYSTEM



CORE QC SYSTEMS, PLATFORMS, AND TECHNOLOGIES

Quantum Computing Systems

Super Conducting Quantum Computers

rigetti, Google, IBM, IQM, RIKEN QUANTUM COMPUTING

Trapped Ion Quantum Computers

atom computing, IONQ, QUANTINUUM

Spin-based Quantum Computers

RIKEN QUANTUM COMPUTING, intel., Zurich Instruments

Other Quantum Computers

RIKEN QUANTUM COMPUTING, Microsoft, NQCG, ColdQuanta, QUANTUM

Quantum Computing Platforms and Technologies

Quantum Software Development Kits (QSDKs)

Microsoft Azure, Google, rigetti, IONQ, IBM

Quantum Error Correcting Software

QUANTINUUM, Q-CTRL

Quantum Computational Platforms

rigetti, FUJITSU, IBM, Alibaba.com

CORE QC SERVICES

Quantum Computing Platforms and Technologies

Quantum Computing IaaS

rigetti, FUJITSU, Google, IONQ, IBM, D-Wave

Quantum Computing PaaS

Google, Microsoft Azure

Quantum Computing SaaS

1QBit, ZAPATA, QCWARE, Q-CTRL

Quantum Computing Platforms and Technologies

Development Services

D-Wave, rigetti, IONQ, Microsoft Azure

ADJACENT QC SYSTEMS, PLATFORMS, AND TECHNOLOGIES

Quantum–Inspired Computing Systems

Quantum Simulators (Emulators)

IBM, intel., Google, rigetti, QUANTINUUM

Hybrid Quantum Classical Computers

NVIDIA, rigetti, QUANTUM BRILLIANCE

Quantum Annealers

D-Wave, FUJITSU, Atos

Quantum re-active Systems, Platforms, and Technologies

Quantum–Safe Cryptography (Post–Quantum Cryptography)

ARQIT, QUANTINUUM, IDQ, QuSecure

Quantum–Inspired Platforms, and Technologies

Quantum Optics and Imaging

QUSPIN, ZABRE

Quantum Sensing

Q-CTRL, NuCrypt, IDQ, Raytheon Technologies

Quantum Communication and Cryptography

QuSecure, IDQ, Qrypt, FUJITSU, TOSHIBA, MagiQ, KETS

Other Quantum-inspired Technologies and Platforms

accenture, PASQAL, QCWARE, Qu&Co, 1QBit

ADJACENT QC SERVICES

Quantum–inspired Provisioned Services

Quantum–inspired PaaS

Microsoft Azure, Google

Quantum–inspired SaaS

IBM, KANADU, QUANTINUUM

Other Quantum–inspired Provisioned Services

NVIDIA

Quantum–inspired Professional Services

Modernization Services

QCWARE, IBM, D-Wave

Consulting Services

Qu&Co, Atos, accenture

Indian Quantum Ecosystem

NON-EXHAUSTIVE, NO ORDER, EXCLUDES LABS

Quantum Computing

Start-Ups

Q→NU, QRDLab, Bilodo Feller, SheQ, QUTICO, BosonQ Psi, QKRISHI, qbit labs, bloq, Automatski, Aqrl, Qπ AI, Quantica Computacao

Government Entities

Department of Science & Technology, Ministry of Electronics and Information Technology, I-HUB Quantum Technology Foundation, National Quantum Mission (NQM), इसरो ISRO

Enterprise Users

TCS, Infosys, LTIMindtree, wipro, HCLTech, ZenSar Technologies, Bank of Baroda, SBI, TECH mahindra, Mphasis, Reliance Industries Limited

Universities

tifr, IISER PUNE, cmi Chennai Mathematical Institute

Investors

HEM Angels, BLUME, Bharat Innovation Fund, 3to Capita, SEQUOIA, YourNest, Franklin Templeton

Quantum Communication and Security

Start-Ups

Q→NU, Qπ AI, Pramatra, QuantumShift, Crypta Labs, TAQBIT, Scytale Alpha

Government Entities

Ministry of Defence, इसरो ISRO, DOT India Telecom, Department of Science & Technology

Enterprise Users

TECH mahindra, TATA COMMUNICATIONS, Reliance Industries Limited

Universities

RRI, IISER PUNE

Investors

सी-डॉट C-DOT

Quantum Sensing and Meteorology

Start-Ups

Qπ AI, SciAM

Government Entities

NPL, National Quantum Mission (NQM), Department of Science & Technology

Enterprise Users

TCS

Universities

Investors

Quantum Materials & Devices

Start-Ups

Qπ AI, BRAHMASENS, AJ Technologies, BosonQ Psi, PRENISHQ

Government Entities

NPL, IISER

Enterprise Users

intel

Universities

tifr, International Institute of Information Technology

Investors

Quantum Technology Market Map - Quantum Communication and Security

NON-EXHAUSTIVE, NO ORDER, EXCLUDES LABS

THE QUANTUM INSIDER

Multiple Security Solutions

Adtran, NORMA, Chelpis, HUB, QUANTUMXCHANGE, Quintessence Labs, QCNs, orange, 中创为量子, TAQBIT LABS, QUANTUM RESISTANT CRYPTOGRAPHY, qtlabs, QSIM+, AxionTech, SANDBOXAQ, DENCRYPT, elecnor, infotecs, TQ|, Q→NU, dacoso, NXM, ISARA, PATERO, SECURE-IC, QUANTUM IMPENETRABLE, Aliro QUANTUM, ThalesAlenia Space, QuantiCor, purevpn, QINETIQ, PQSHIELD, PQSecure, SMARTS, DREAM SECURITY, asky, SENETAS, IDQ, CRYPTO QUANTIQUE

Post Quantum Cryptography

01 COMMUNIQUÉ, TAU QUANTUM, ZY4, BTQ, quantropi, cyph, ABELIAN, IRONCAP, AGILEPQ, CYPHERTOP, CEW Systems Canada, QApp, QUANTUM BLOCKCHAINS, QRL, PHYSEC, NomiDio, NORMA, ARQIT, Qualcomm, QuSecure, CRYPTO EXPERTS, utimaco, XSOC, cyberhive, SQE.io, WISeKey, SSH, RESQUANT, CRYPTONEXT SECURITY, ravel, HYPERSPHERE, KMS, wedge networks, CROWN STERLING, Veridify Security, QWERX, CASTLE SHIELD, QAISEC

Quantum Communication and Security Hardware

Crypta Labs, CAMBRIDGE SPACE TECHNOLOGIES, bridgecomm, QUANTUM NUMBERS CORP, alternatio, Optalysys, QUANTUM DICE, ICARUS, RHEA GROUP, RANDAEMON, QUANTUM CORRIDOR, ComScire, KI3 PHOTONICS, m6, QTEC 九州量子, SECQAI, CORNAMI, Quside, Amphenol, kpn, iQrypto, quantumotion, RANDOM POWER, TTI, CRYPTO4A, COWEAVER

Quantum Internet

TTI, QTI, Qubit Reject, Quantum Bridge, LQUOM, memQ, Q.LABS, Q'bird, ThalesAlenia Space, nu, Qunnect, BOHR QUANTUM

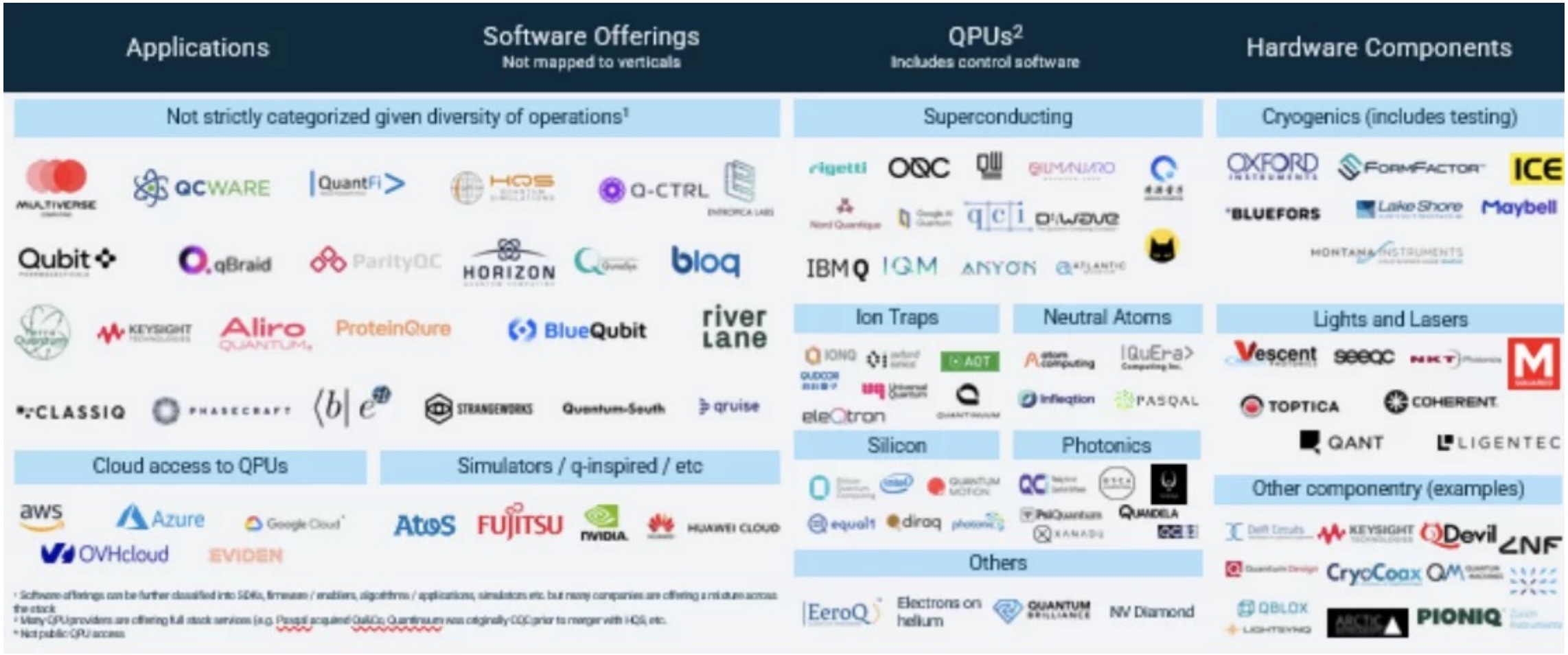
Quantum Encryption

QUANTUM INDUSTRIES, KETS, CROWN STERLING, SPEQTRAL, MATRICS², Aegis Quantum, MagiQ TECHNOLOGIES, TOSHIBA, HEQA SECURITY, qssys Quantum Space Systems, Q.TI, QTI, KEEQUANT, nutshell, QuBalt, VeriQloud, LUXQUANTA, Qrypt, ZTE, FlipsCloud, QRATE, QEYnet

*Strict distinction between these companies is challenging, so it's defined as best as possible

Source: The Quantum Insider Intelligence Platform

Quantum Computing Technology Types



Source: Quantum Insider

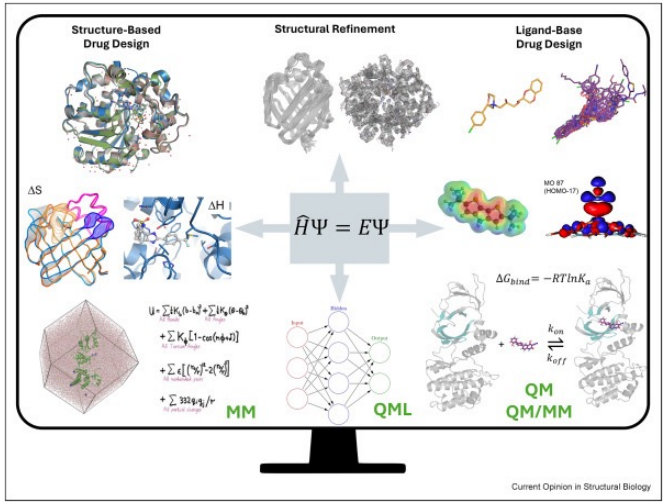
Quantum Computing Applications

- **Finance**
  - **Portfolio optimization** with QAOA/Ising models for risk-return trade-offs
  - **Credit-risk scoring** & **Stress Testing** via quantum kernels/boosting
  - **Derivatives Pricing** using Quantum Monte Carlo Amplitude Estimation
  - **Fraud/Anomaly Detection** with Variational Quantum Classifiers
  - **Liquidity/Market-Impact Simulation** using quantum walks
  - **Quantum Money**



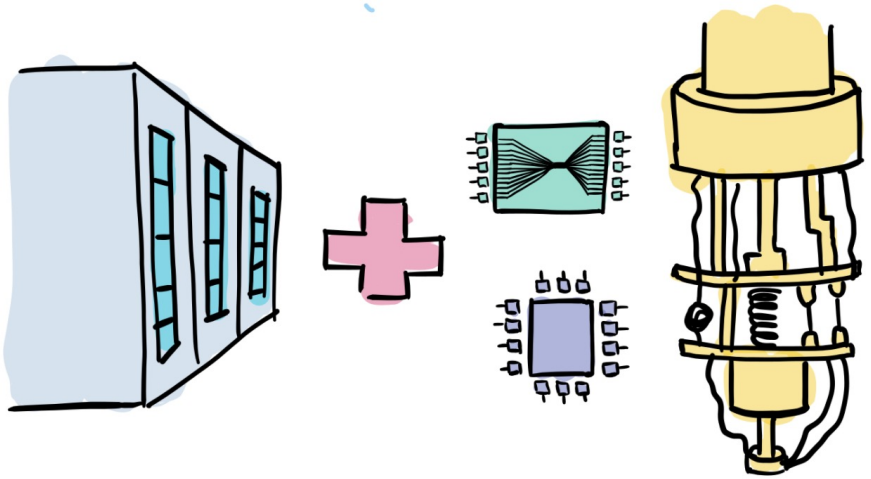
Quantum Computing Applications

- **Chemistry/Biomedicine/Healthcare**
  - **Ground-State Energy Estimation** (VQE) for catalytic design
  - **Protein–Ligand Docking/Search** with QAOA/QUBO encodings
  - **Peptide/Protein Design** via quantum generative models
  - **Multi-Omics Feature Selection/Clustering** with quantum kernels
  - **Imaging Reconstruction** (MRI/CT) with quantum-inspired solvers
  - **Patient-Fow & OR Scheduling (nurse/bed/slot)** via QUBO
  - **Personalized Treatment Policy Learni**ng with quantum RL
  - **Molecule Simulation**
  - **Drug Discovery**
  - **Protein Folding/Prediction**



Quantum Computing Applications

- **AI / ML**
  - **Quantum Kernels** for small-data classification
  - **Variational Quantum Classifiers/Regressors** (**VQC/VQR**)
  - **Quantum-Enhanced Generative** models (**QGANs/VAEs**)
  - Feature Selection & Sparse Coding via **Ising/QUBO**
  - Combinatorial Hyperparameter Search with **QAOA**
  - Speed-up in model training such as **QNN**, **QSVM**, **QLSTM**, **QRL**, **QAOA**, **VQE**



Quantum Computing Applications

- **Cybersecurity**
  - **Quantum Key Distribution (QKD)** for tamper-evident links
  - **Quantum Random Number Generation (QRNG)** for crypto keys
  - **Post-Quantum Cryptography** readiness testing with Shor/Grover simulators
  - **Quantum-Secure Federated Learning Protocols**
  - Graph-based intrusion pattern search via QAOA: Implementation of **PQC algorithms** is classical, but **quantum simulators** help demonstrate threats.
  - **Quantum Channel**
  - **Quantum Safe**
  - **Quantum Communication**



Quantum Computing Applications

- **Logistics & Supply Chain**
  - Vehicle routing with time windows (VRPTW) via QUBO
  - Warehouse picking & bin-packing optimization
  - Crew/roster scheduling under constraints
  - Production planning & lot sizing
  - Multi-echelon inventory optimization
  - Cargo loading and scheduling
  - Fleet maintenance
  - Demand forecasting.



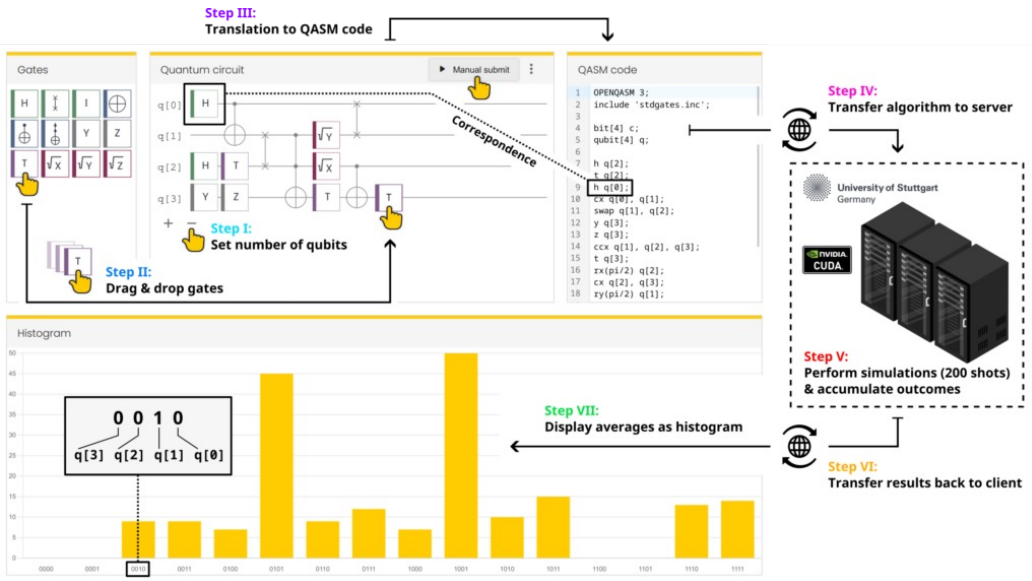
Quantum Computing Applications

- **Game / Interactive Media**
  - Quantum Go
  - Quantum Chess
  - Quantum Tic-Tac-Toe
  - Quantum game AI using quantum RL primitives
  - Quantum puzzles/education titles (quantum rules as mechanics)



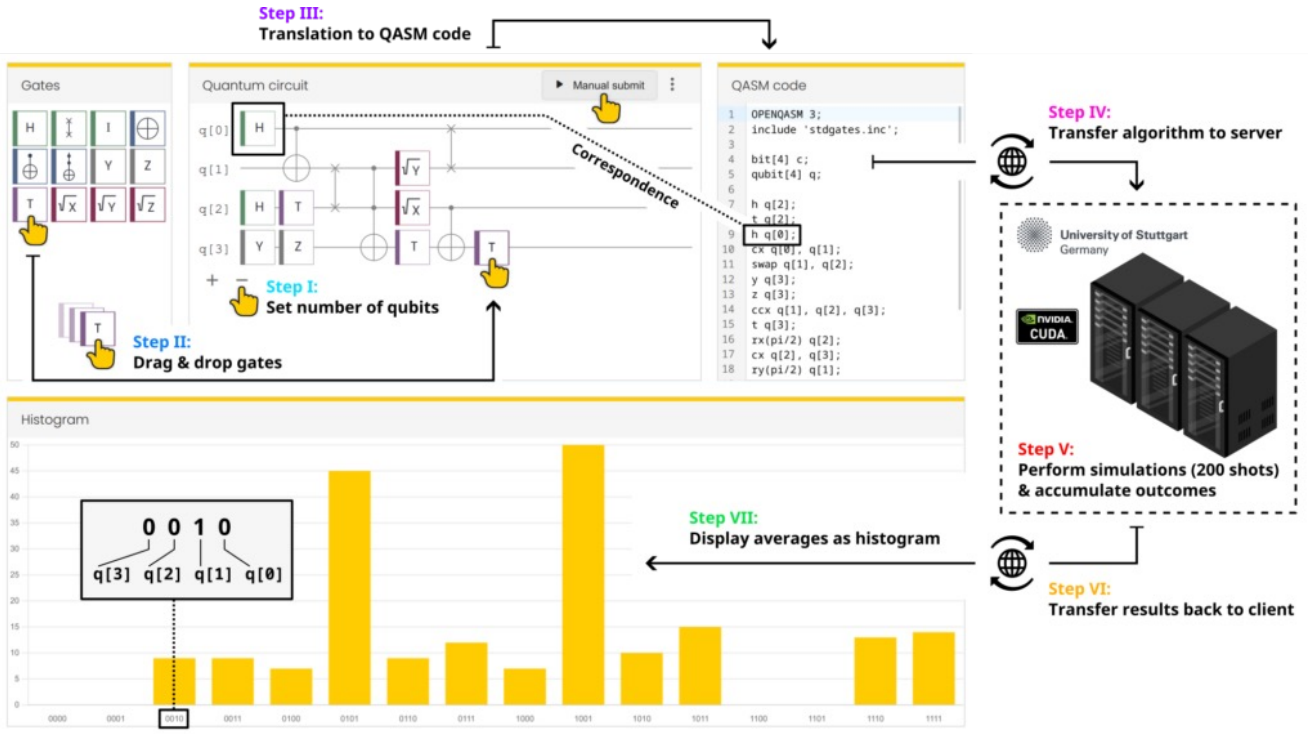
Quantum Computing Applications

- **Education**
  - Virtual labs with real QPU backends & simulators
  - Interactive circuit sandboxes for curricula
  - Quantum-enhanced grading of small graph/comb problems
  - Course modules on Q-algorithms for STEM/CS
  - Quantum Teachable Machine (Like Google Teachable Machine)
    - QAOA for scheduling
    - VQE for chemistry



Practical Tools

- **Real Quantum Computer:** IBM, Google, Rigetti, Fujitsu
- **Fake Device :** IBM Quantum, AWS Braket, Azure Quantum
- **Simulators:** THE QUANTUM LÄND, Qiskit, Cirq.




Thank you!