Beyond the Hype:
Quantum Computing’s Real Impact on Higher Education and Industry

November 6, 2025

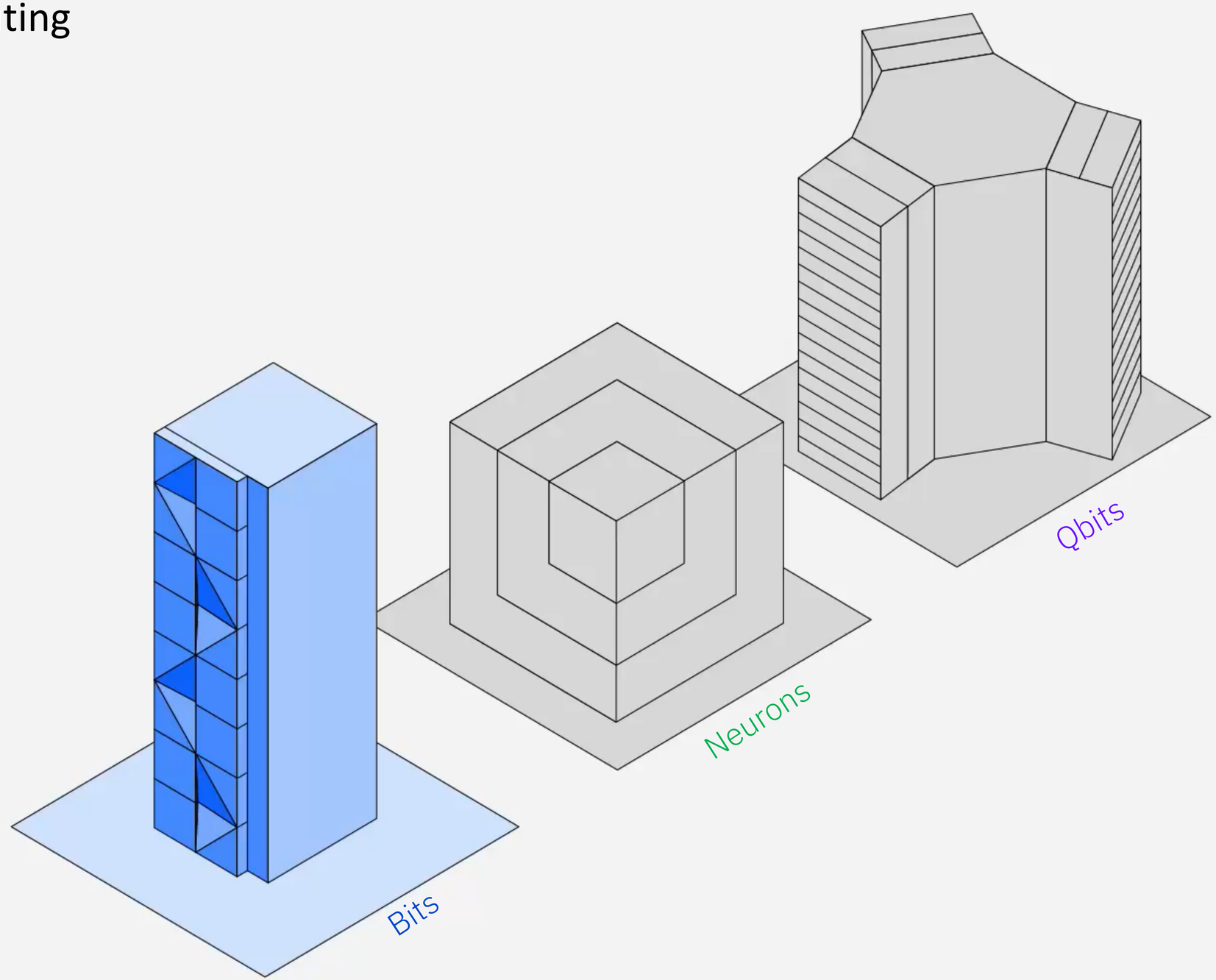
Ray Harishankar
IBM Fellow & Vice President
IBM Quantum

Let us start with the basics

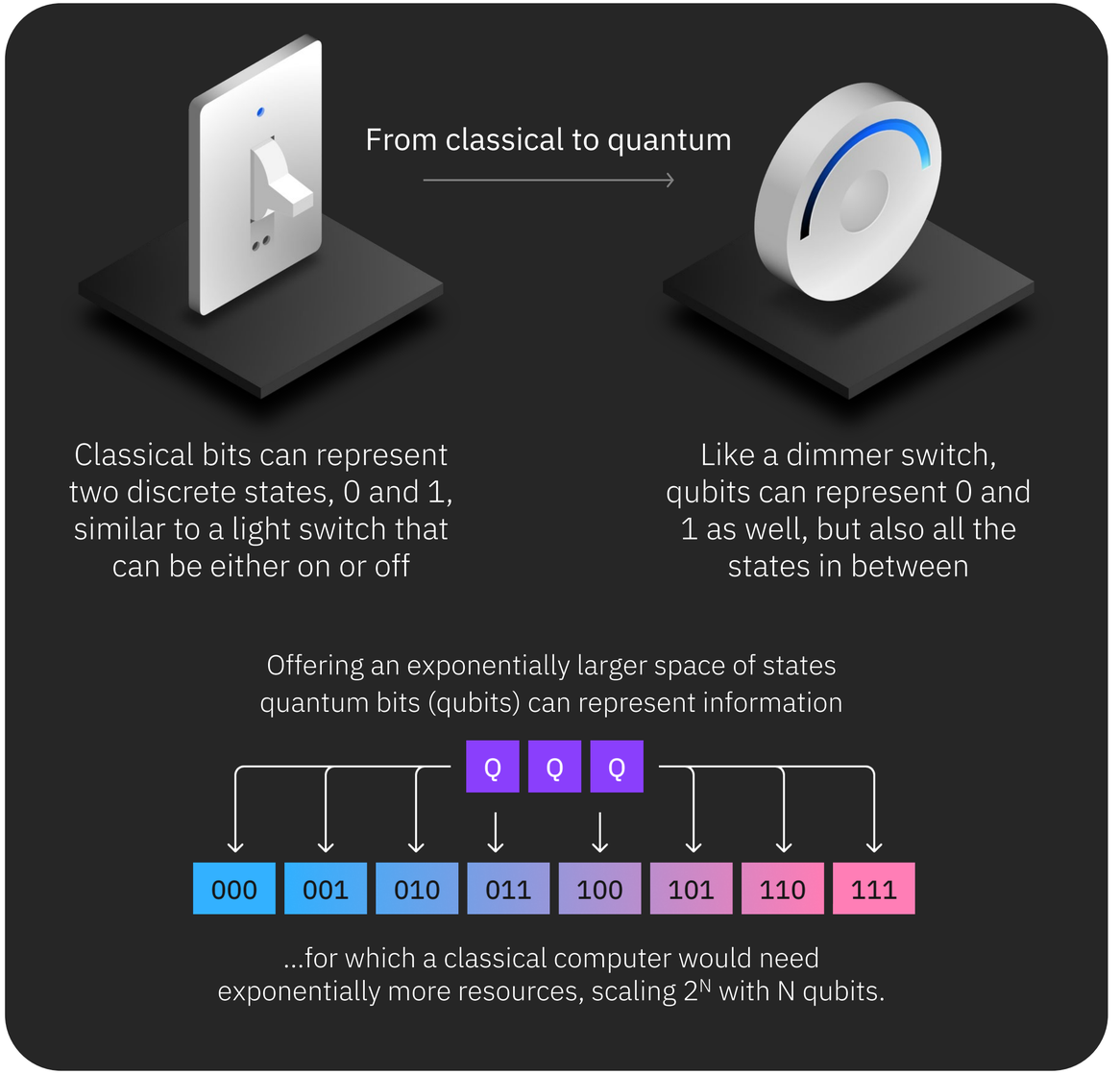
→ Bring useful quantum computing to the world

→ Make the world quantum safe

Future of computing

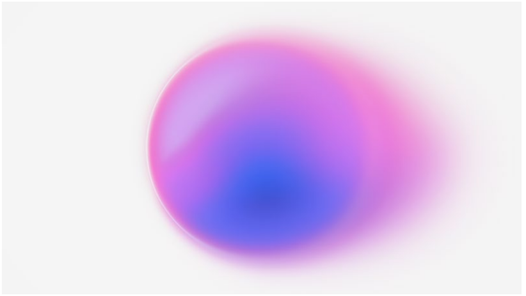


Quantum computing
is transforming the way
we represent and process information

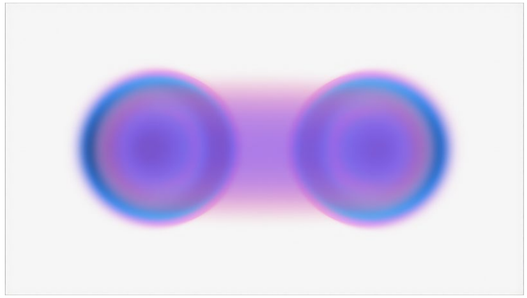


Uniquely quantum

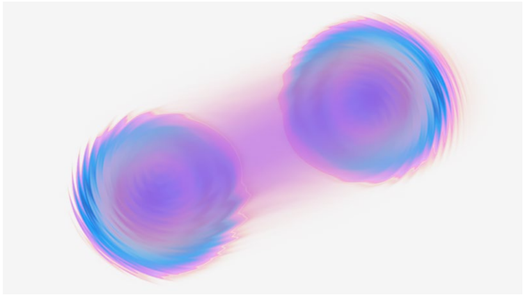
Fundamental properties that are at the core of quantum computers



Superposition
A quantum system existing in a complex linear combination of two states until it is measured

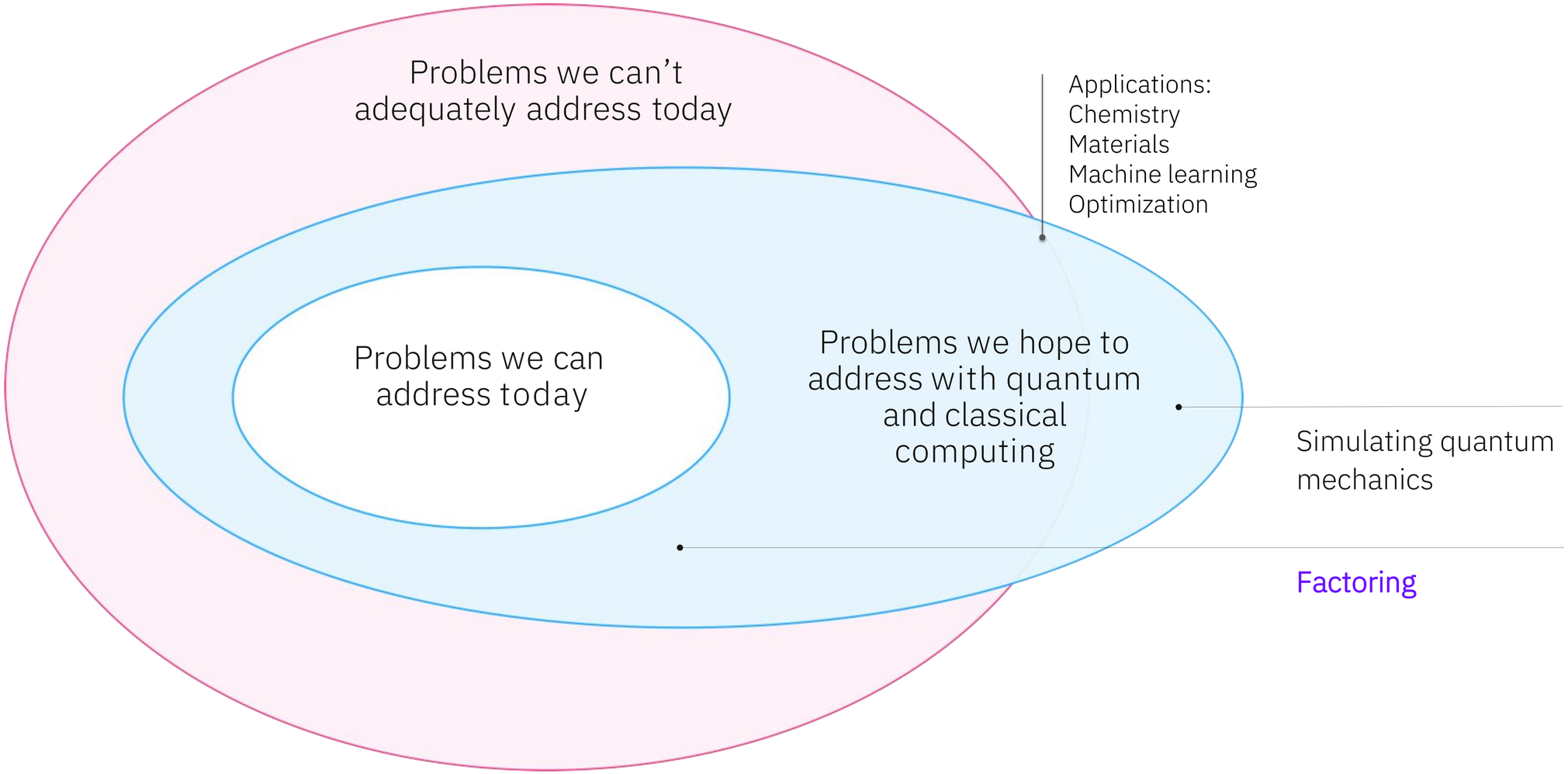


Entanglement
Information shared jointly between entangled pairs or groups



Interference
Interaction that affects likelihood of solutions

Quantum computers are good at solving certain types of problems



Quantum computing will have impact across industries

Algorithms

Nearer Term

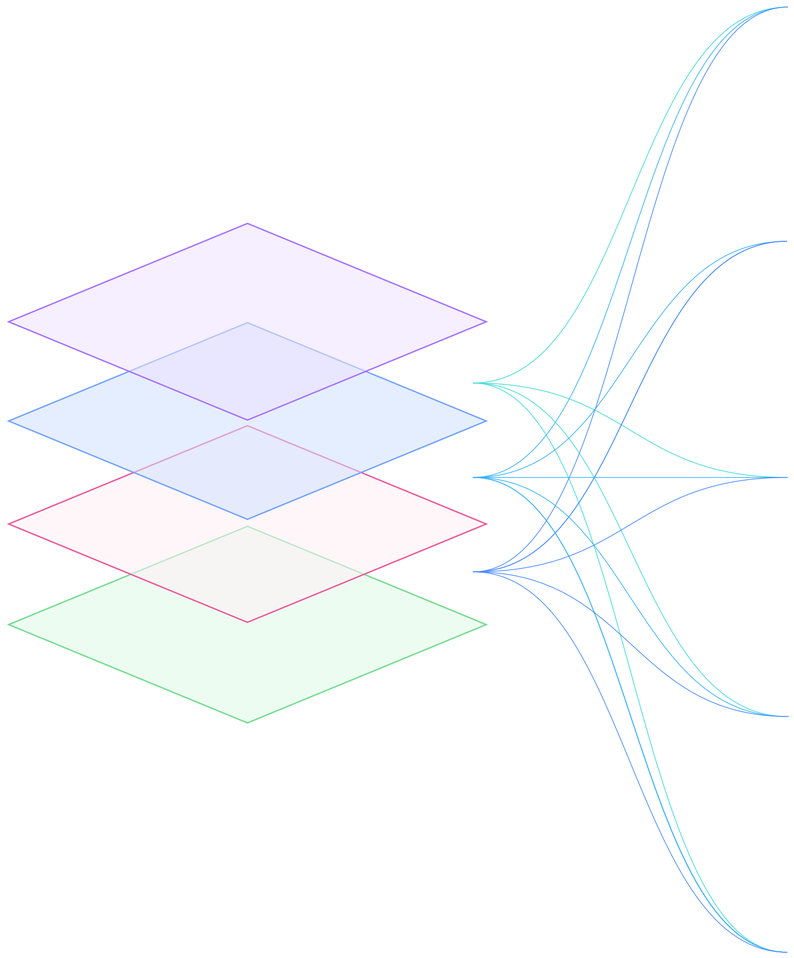
Longer Term

Hamiltonian simulation

Optimization

Machine Learning

Partial differential equations (PDEs)



Applications

Aerospace
- High strength-to-weight materials development
- Wing ply-composite design optimization
- Aircraft computational fluid dynamics

Automotive
- Advanced batteries
- Multi-objective vehicle routing optimization
- Auto design and simulation

Chemicals
- Lower energy fertilizer manufacturing
- Efficient Catalysts
- Accelerated product development

Electronics & semiconductors
- Placement and routing optimization
- Deposition/etch process modeling
- Multi-domain simulation

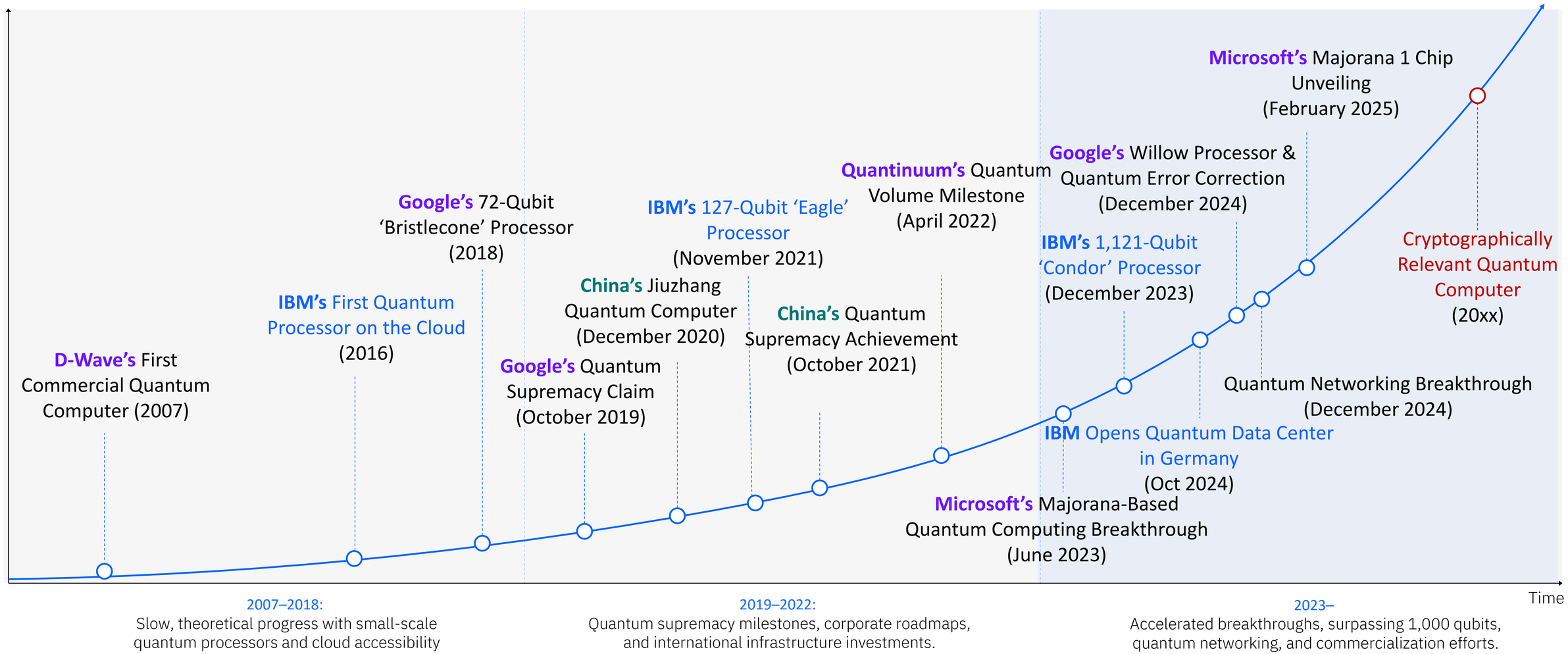
Energy
- Grid management
- Grid optimization with EV's
- Carbon Sequestration

Financial Services
- Portfolio optimization
- Derivatives/options pricing
- Antti-Money laundering

Health Care & Life Sciences
- Drug discovery and drug design optimization
- mRNA & protein structure predictions
- Disease target & biomarker discovery

Recent advancements in quantum computing

Quantum Computing - Progress over the years



IBM has been a leader in quantum research for over 40 years.

2016

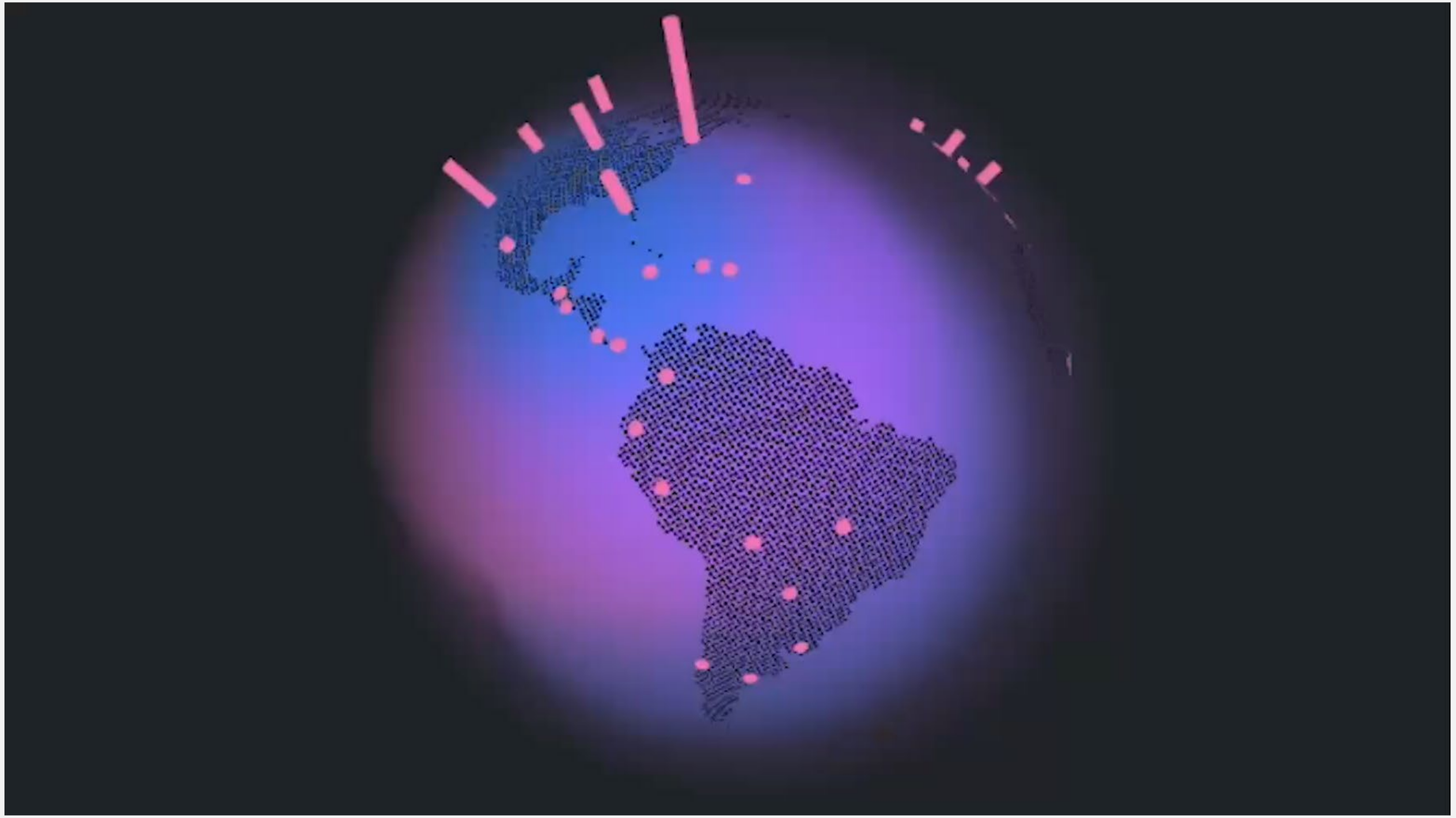
→ IBM Quantum Experience

The first quantum computer in the cloud.

2017

→ IBM Quantum Network

The first network dedicated to quantum discovery.



The field is moving even *faster* →

2010

2011

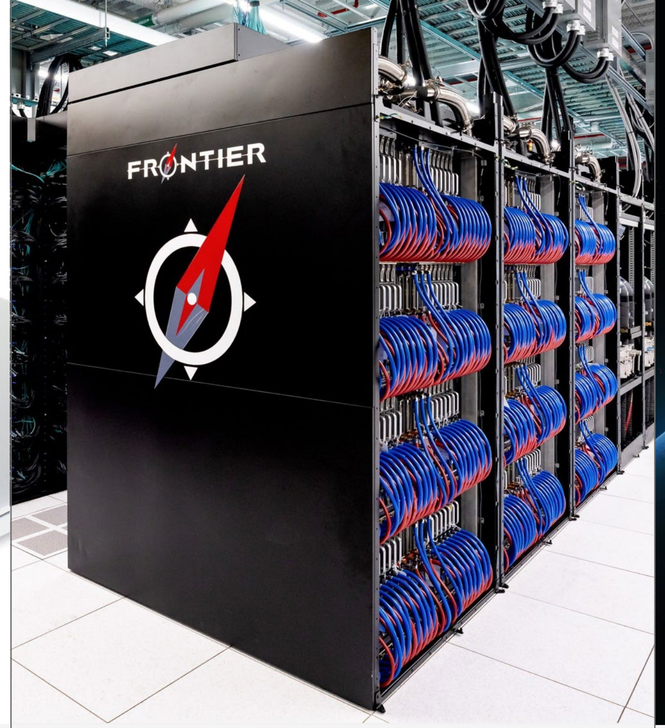
2012

2022

→ First to break the 100-qubit barrier

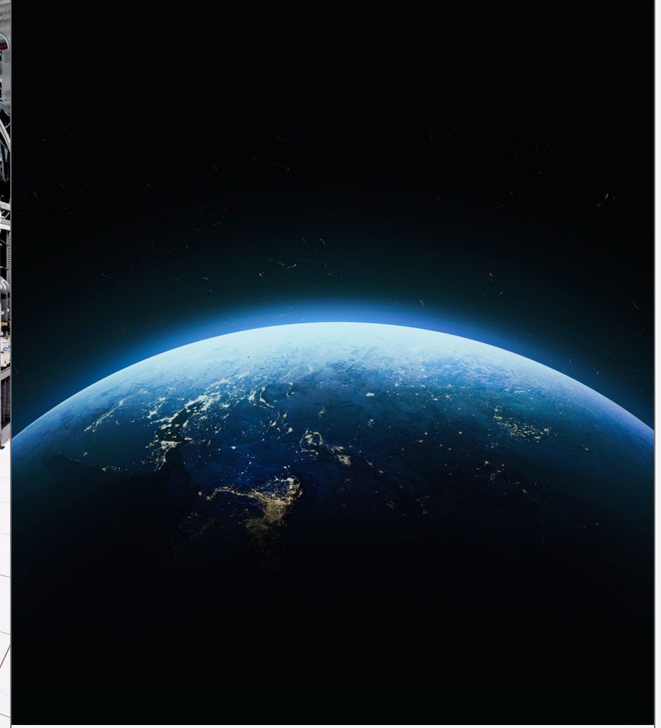
Modern laptop

30 qubits



Frontier Supercomputer

49 qubits



All classical computers on earth connected

100 qubits

IBM Quantum Heron

156 qubits

2024 ↴
Quantum-centric supercomputing

IBM has built the largest global quantum community

→ 80

Quantum computers deployed since 2016

600K+

User community & ecosystem

300+

IBM Quantum Network members

10M+

Learners on IBM Quantum Learning

Ecosystem

IBM Quantum Platform hosts the strongest ecosystem advancing quantum computing

The IBM Quantum Network has 300+ members

Industry members	50+
Commercial partners and startups	65+
Academic and research institutions	170+

Commercial quantum applications
&
Workforce development to support it

Quantum computing will have impact across industries

Algorithms

Nearer Term

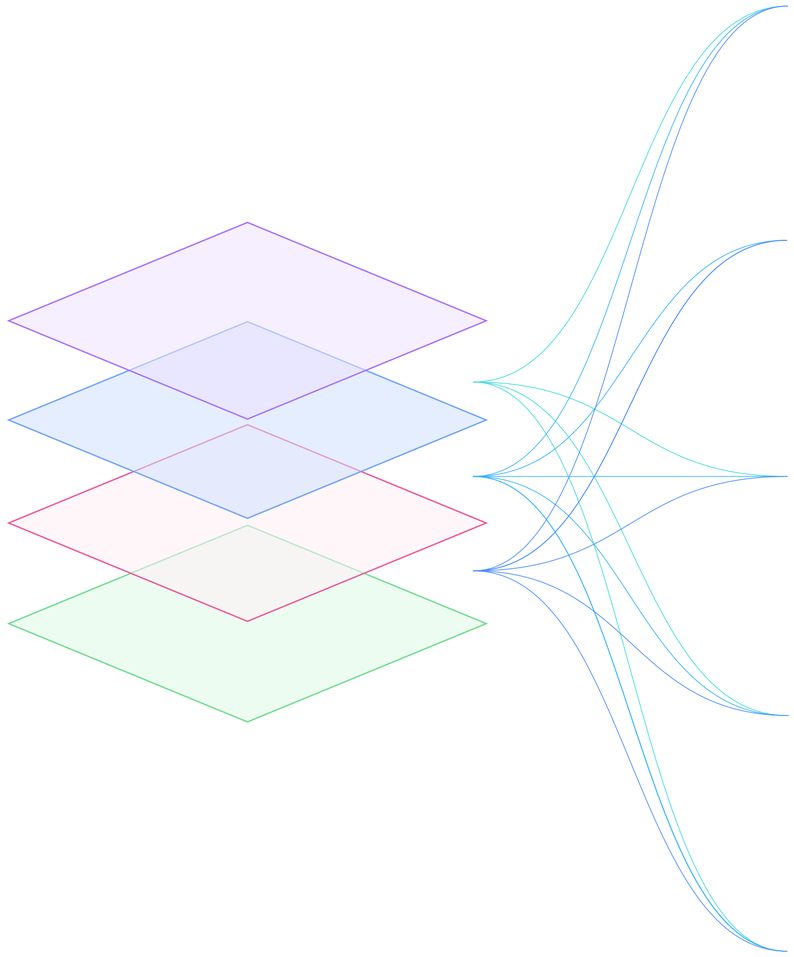
Longer Term

Hamiltonian simulation

Optimization

Machine Learning

Partial differential equations (PDEs)



Applications

Aerospace
- High strength-to-weight materials development
- Wing ply-composite design optimization
- Aircraft computational fluid dynamics

Automotive
- Advanced batteries
- Multi-objective vehicle routing optimization
- Auto design and simulation

Chemicals
- Lower energy fertilizer manufacturing
- Efficient Catalysts
- Accelerated product development

Electronics & semiconductors
- Placement and routing optimization
- Deposition/etch process modeling
- Multi-domain simulation

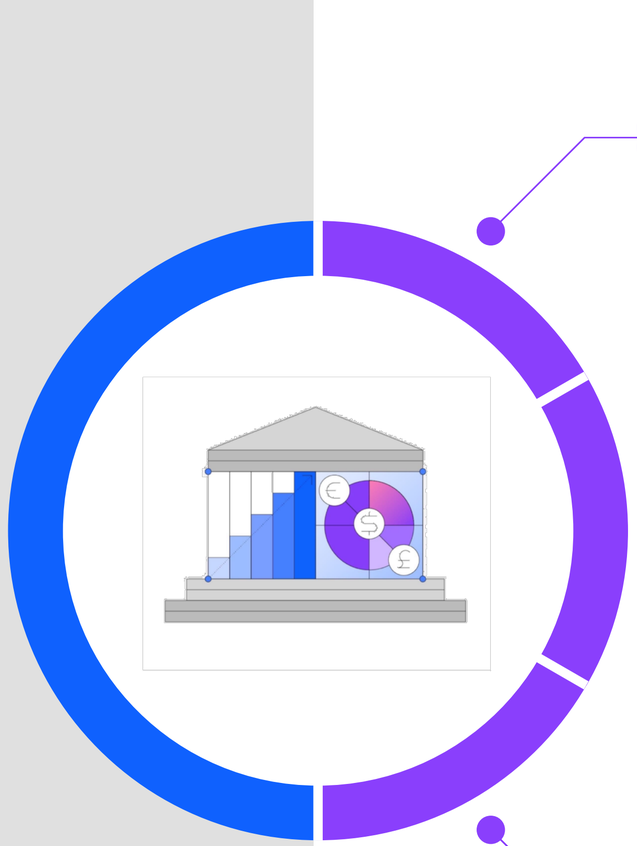
Energy
- Grid management
- Grid optimization with EV's
- Carbon Sequestration

Financial Services
- Portfolio optimization
- Derivatives/options pricing
- Antti-Money laundering

Health Care & Life Sciences
- Drug discovery and drug design optimization
- mRNA & protein structure predictions
- Disease target & biomarker discovery

Financial Services – Recent news

Clients are partnering with IBM to explore quantum computing applications



HSBC

Optimizing trade execution strategies with up to ~34% improvement in trade fill predictor estimates

Vanguard

Portfolio optimization for fixed income assets, with a quantum-classical workflow consistently outperforming a purely classical local search approach, especially as problem size increases

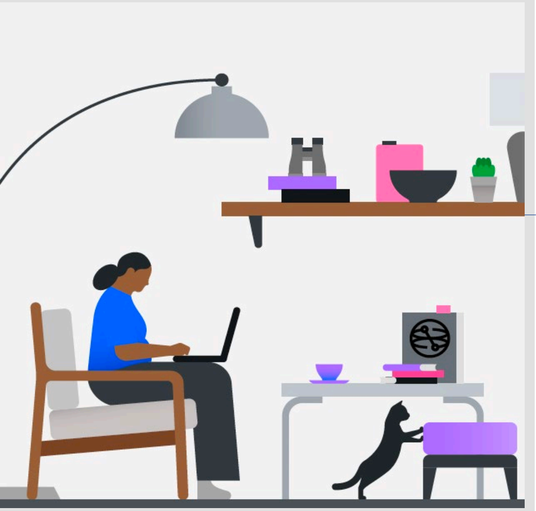
WELLS FARGO

Modeling financial time series and sequences, with quantum models parsimonious in resources compared to classical methods and efficiently learnable

Impact on Industry and Higher Education

Organizations need professionals with a unique blend of technical, domain-specific, and interdisciplinary skills.

Valued expertise is at the intersection of quantum science, advanced software engineering, mathematics, and industry knowledge.



Foundational Quantum Knowledge

- **Quantum mechanics fundamentals:** Superposition, entanglement, and measurement theory *(Basic level).*
- **Quantum information theory:** Concepts like qubits, gates, decoherence, and error correction.
- **Quantum algorithms:** Familiarity with key algorithms; Grover's, Shor's, QAOA, & VQE; how they map to optimization, ML, and simulation problems.

Hybrid & Interdisciplinary Skills

- **Applied mathematics and data science:** Strong grounding in linear algebra, probability, and optimization theory.
- **Classical ML/AI expertise:** Design hybrid quantum–AI models that leverage both classical and quantum.
- **Systems integration:** Knowledge of how to plug quantum solutions into enterprise data pipelines, APIs, and regulatory-compliant environments.

Industry and Business Quantum use-case identification:

Ability to assess where quantum offers a *real* advantage over classical methods.

- **Cross-functional communication:** Translating between tech. & business
- **Ethical, legal, & regulatory understanding:** Critical in healthcare (HIPAA, FDA frameworks) and finance (SEC, Basel standards).

Quantum Prog. & Systems Engineering

- **Quantum software development:** Platforms like Qiskit, Cirq, Braket, or PennyLane for hybrid quantum–classical workflows.
- **Algorithm-to-hardware mapping:** Understanding how algorithms behave on noisy intermediate-scale quantum (NISQ) devices versus error-corrected systems.
- **Cloud-based quantum access:** Skill in managing workflows that integrate quantum backends with classical HPC systems.

Security & Quantum-Safe Expertise

- **Post-quantum cryptography (PQC):** Understanding of transitioning from classical to PQC
- **Quantum network security:** Familiarity with quantum key distribution (QKD) and emerging quantum internet standards.

Domain-Specific Modeling Skills

<u>Financial services:</u>

- Quantum optimization for portfolio management, risk analysis, & fraud detection.
- Quantum-enhanced Monte Carlo simulations and pricing models.

<u>Healthcare & life sciences:</u>

- Quantum chemistry & drug discovery simulations.
- Quantum ML for biomarker discovery and medical imaging.
- Genomics modeling and patient outcome predictions using hybrid quantum AI.

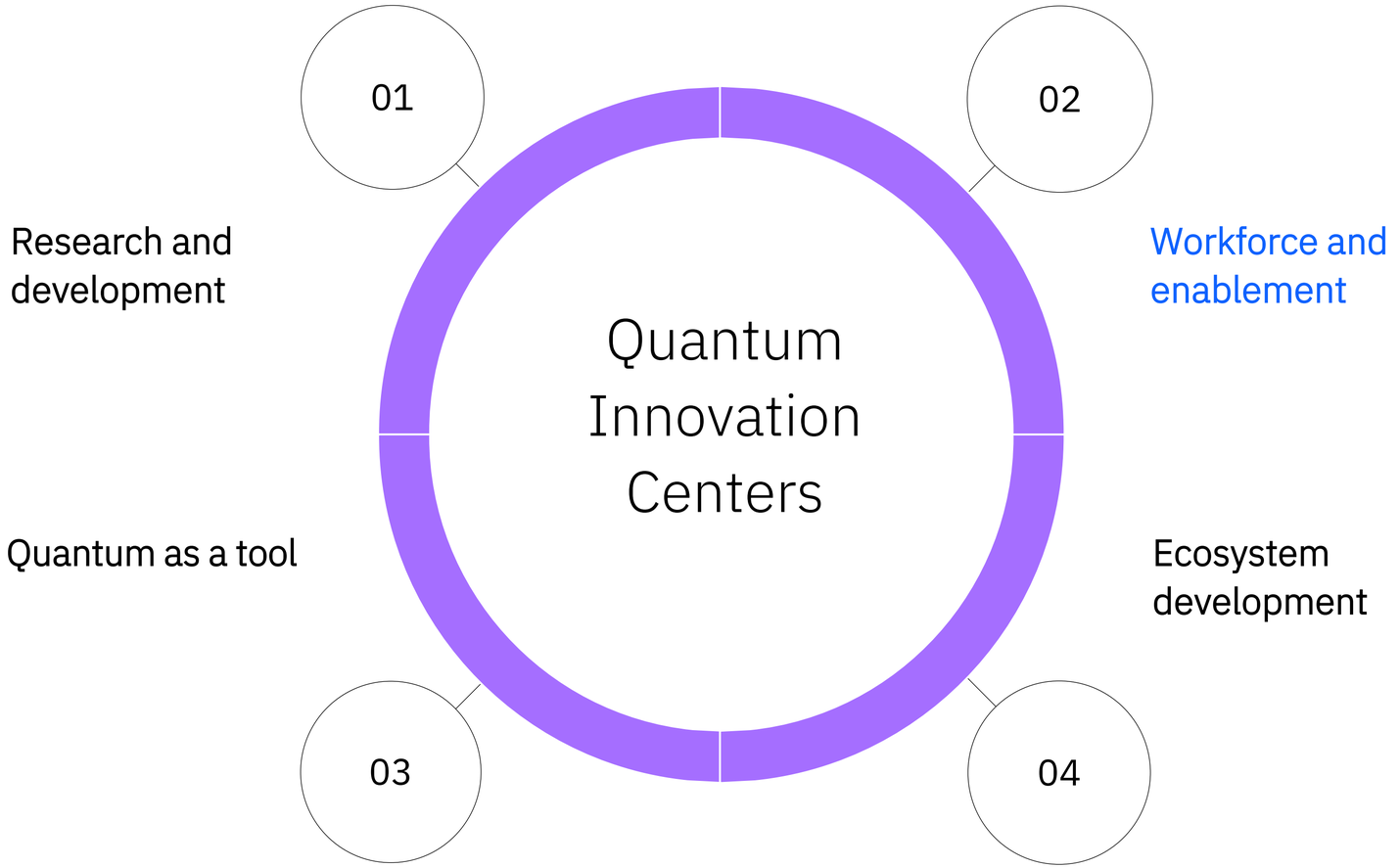
Quantum Innovation Centers

Strategic partners developing regional and national leadership in quantum computing by leveraging IBM Quantum capabilities and expertise

---

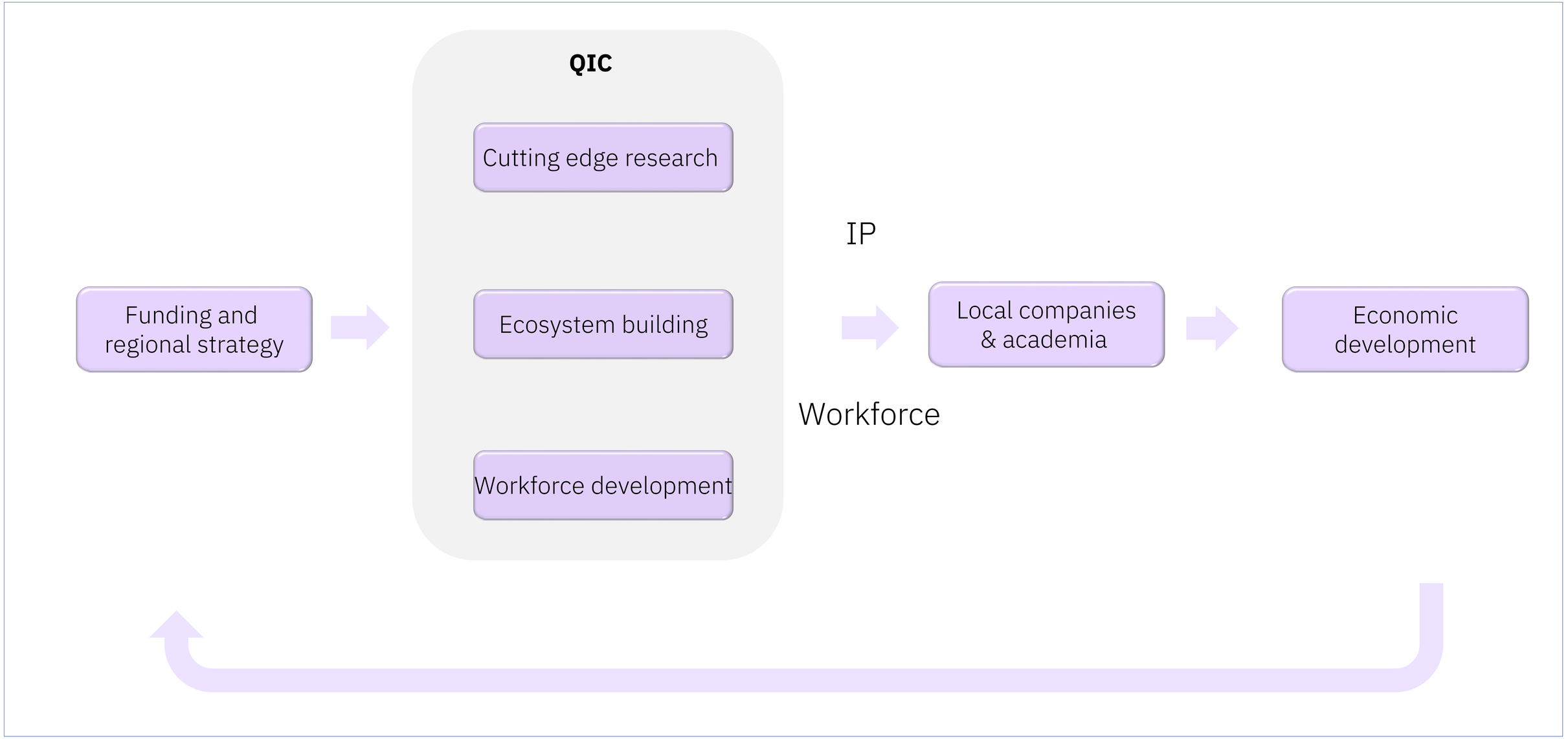
Join the 39+ other institutes with QICs, including...

BasQ (Ikerbasque)
Cleveland Clinic Foundation
Oak Ridge National Lab
PINQ^2
QuantumBasel
Rensselaer Polytechnic University
RIKEN
University of Missouri
University of Southern California
University of Tokyo
Yonsei University

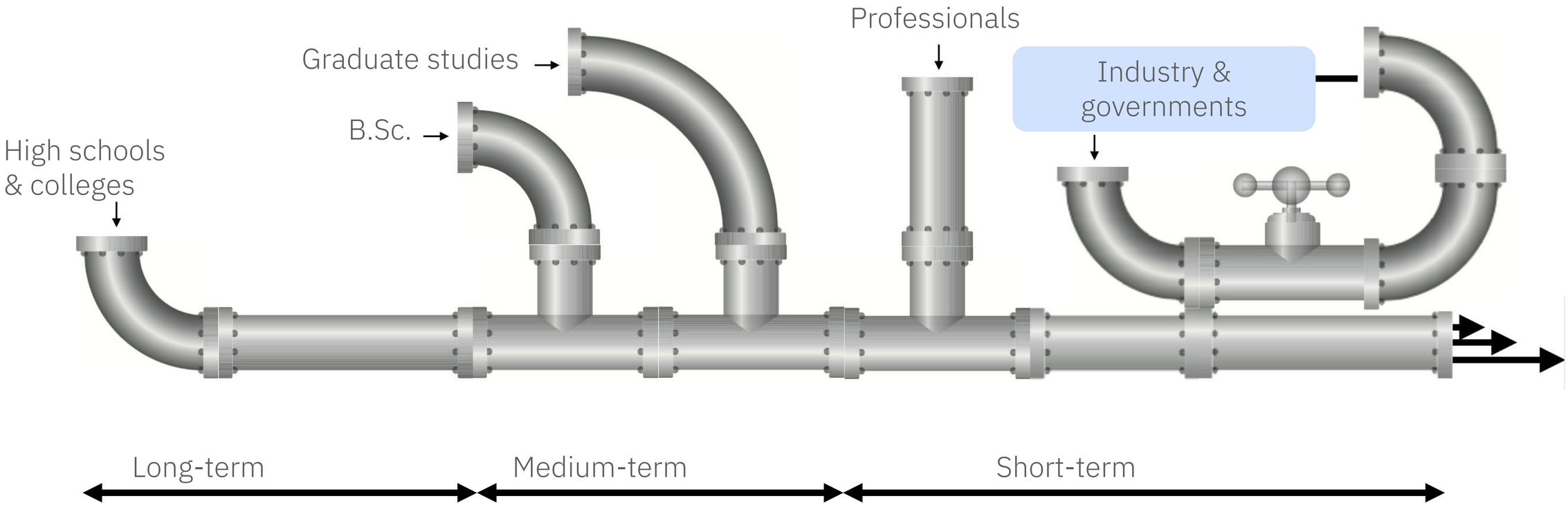


Successful Quantum Innovation Center

Ecosystem multiplier to fuel economic development in the region



A scalable model for collaboration among Public, Private and Academia



Cleveland Clinic QIC

From 0 to leading quantum experts

Mission

Cleveland Clinic (CCF) leverages quantum computing to advance biomedical research and address pressing human health challenges. The Quantum Innovation Center is part of the CCF/IBM Discovery Accelerator which focuses on education, research, and ecosystem development.

2021-22

Partnership signing (Dec 2021)

Identifying workstreams and governance

Upskilling personnel - customized education journeys

First projects defined and funded (DARPA)

2023-24

Quantum System One installation and ribbon cutting (Apr 2023)

Leadership in the HCLS working group and sharing expertise

3 prestigious Wellcome Leap **grants won** – Quantum Computing for Bio

New top PI hire – Kennie Merz

Annual partner event kick-off: Cleveland Forum

2025

Full system adoption

Focus on sustainable research pipeline: 23 projects, 10 publications

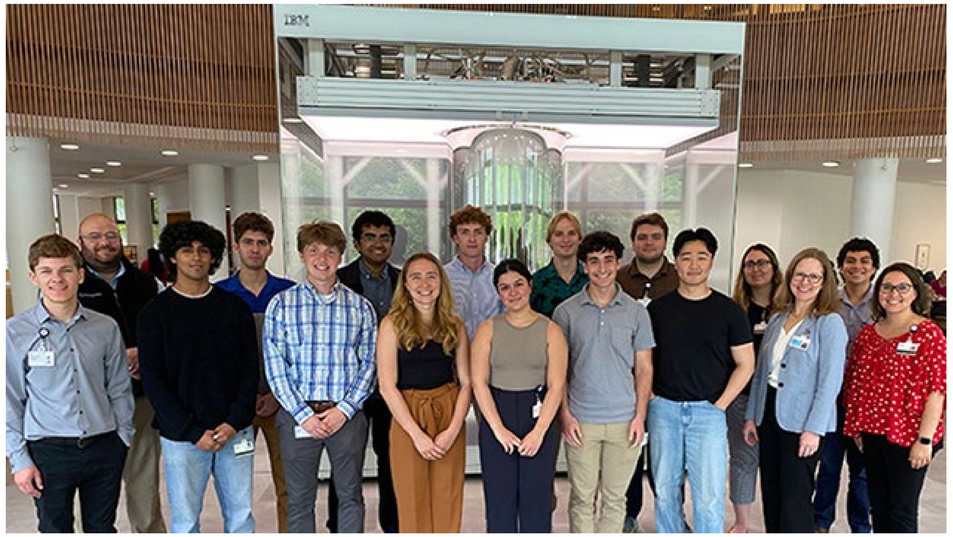
Technical enablement for 6 projects contributing to 3 publications

Ranked #2 in Quantum Innovation Index (Life Sciences)

Launching 2nd **Startup Program**

Cleveland Clinic and Miami University – Quantum Computing Collaboration

MIAMI UNIVERSITY



- Advances education, workforce development, and research in quantum computing with focus on healthcare.
- Ohio's first Specialized BS, MS and PhD degree programs in quantum computing, aimed at biomedical innovation.
- Internship & hands-on research opportunities for students at Cleveland Clinic using IBM Quantum System One.
- $7 million awarded to create the Ohio Institute for Quantum Computing Research.
- Joint efforts address workforce needs, entrepreneurship, and integration with Cleveland Innovation District.
- Combines Cleveland Clinic's biomedical expertise with Miami University's academic strengths to prepare graduates for quantum healthcare innovation.

IBM & University of Illinois build national quantum algorithm center in Chicago

Key Components of the Collaboration

- 10 year “**Discovery Accelerator Institute**” partnership with UIUC, covering cloud, AI, quantum computing, materials discovery and sustainability.
- The **National Quantum Algorithm Center** (NQAC) in the Illinois Quantum and Microelectronics Park (IQMP) in Chicago, anchored by IBM’s next-generation quantum hardware (IBM Quantum System Two) and involving UIUC through the Illinois/Chicago ecosystem
- Through the wider Illinois quantum ecosystem (which includes UIUC as a member of the Chicago Quantum Exchange (CQE)), IBM became an **Academic Partner** of the IBM Q Network and CQE.
- Enabled UIUC faculty and post-docs to **access IBM quantum systems**, funding and research collaborations.

Focus Areas & Goals

- **Research & algorithm development:** UIUC (via CQE) and IBM collaborate on quantum algorithms, software, and hardware workflows (e.g., optimized software stacks for IBM’s superconducting quantum systems) to move toward “practical-scale quantum computing.”
- **Workforce development & education:** UIUC benefits from the partnership by gaining access to hardware, research opportunities, and bridging academia/industry to train students and post-docs in quantum information science and engineering (QISE).
- **Ecosystem and innovation hub creation:** Through the Discovery Accelerator, NQAC, IQMP and other efforts, IBM + UIUC are helping build a quantum-innovation ecosystem in Illinois (academia + industry + hardware + software) to accelerate deployment of quantum-centric supercomputing.

Academic workforce initiatives – (selected subset)

IBM-HBCU Quantum Center

- Partnership between IBM and a consortium of HBCUs aimed at building a more **diverse quantum workforce.**
- Community building, undergraduate & graduate research funding, faculty engagement, speaker series, hackathons.
- Focus on equity/diversity + concrete access to QISE research for under-represented students.

Chicago Quantum Exchange (CQE) Education & Training Activities

- Community building, undergraduate & graduate research funding, faculty engagement, speaker series, hackathons.
- **Comprehensive workforce development portfolio** from K-12 to professionals, undergrad/grad, and postdocs.
- Provide internships, professional retraining, curriculum initiatives (e.g., "TeachQuantum"), and resources for educators.
- Broad ecosystem approach — not just a single course/program but spanning roles, levels, and career transitions.

Rochester Institute of Technology (RIT) Quantum Education & Workforce Program

- Studying how to prepare students for quantum careers: tracking what courses exist, what employers want, and how to make entry paths smoother.
- Interdisciplinary quantum information science & technology minor (from 2022) and are researching barriers to access, awareness, etc.
- A data-driven approach to curriculum design + broadening access.

University of Missouri

- Became a QIC in Fall 2024
- Provides cloud access to quantum computers & Qiskit
- Developing a QC certificate program, with longer term goals of a QC degree offered
- Emphasis on quantum education, training and internships
- Aims to build a "quantum ready" workforce and innovation ecosystem in Missouri.

Virginia Tech Quantum Experiential Learning & Diversity Effort

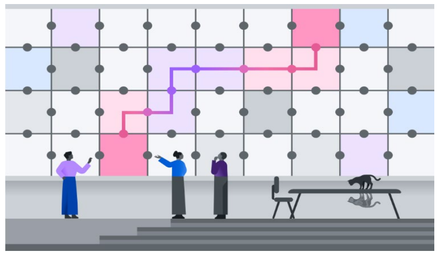
- Deploying a "quantum experiential learning lab" and working with HBCUs to replicate it, with the aim of **diversifying the quantum workforce.**
- Providing faculty development and equipment acquisition at partner institutions.
- Emphasis on hands-on infrastructure + partnership with minority-serving institutions to broaden the pipeline.

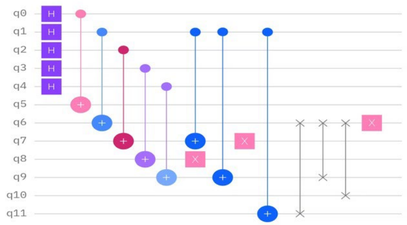
Curriculum Frameworks and Standards

- European Competence Framework for Quantum Technologies
- "Extending the European Competence Framework for Quantum Technologies" (2024) proposes **proficiency levels & qualification profiles for jobs** in quantum technology.
- Provides a structured "taxonomy" of what skills/knowledge quantum-industry roles require — useful for academics designing programs.

Robust set of courses available through IBM

Taking the guesswork out of your upskilling journey





Learn the basics of quantum computing and how to solve real-world problems with IBM Quantum services and systems

1. 20+ quantum courses
2. 30+ hands-on tutorials
3. 10+ curated learning paths

Quantum for Universities

Quantum Mechanics
1. Bell's inequalities
2. Quantum superposition
3. Stern-Gerlach experiment

Computer Science
1. Quantum teleportation
2. Quantum key distribution
3. Grover's algorithm

Chemistry
1. VQE and variational principle

and more ...

Earn badges and certifications

And more educational resources by leading quantum experts

Quantum courses for upskilling

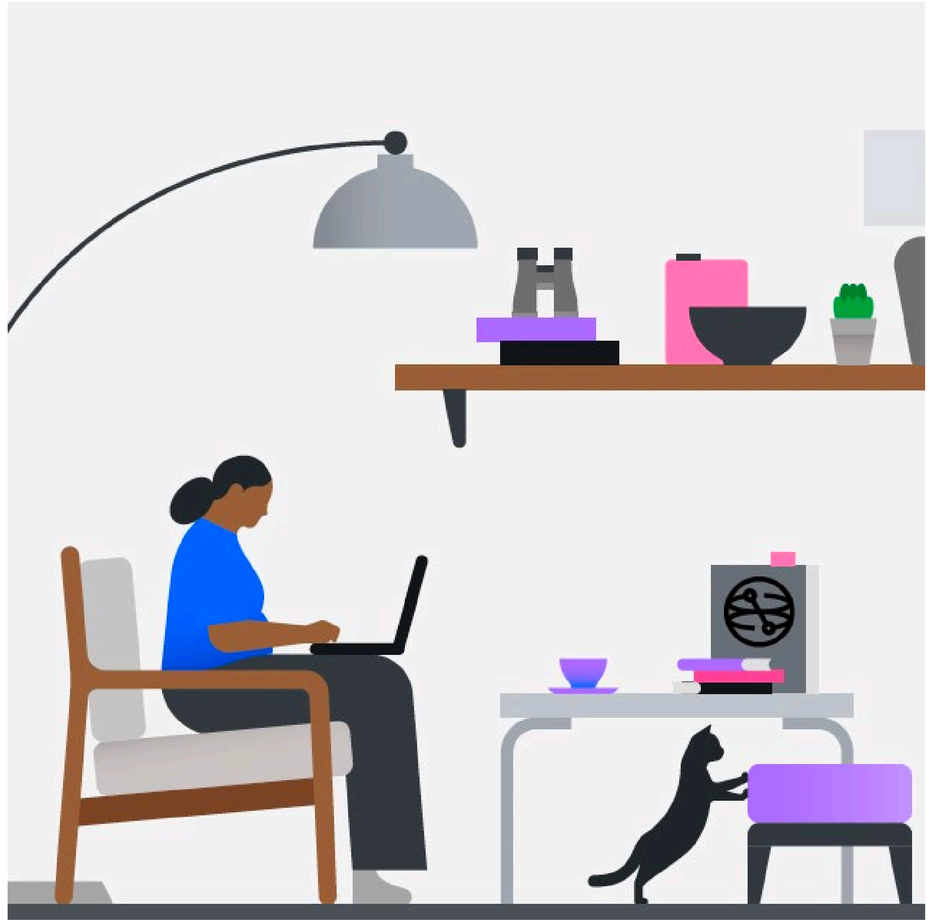
Learning paths for awareness (~40hrs)
1. Quantum business foundations and applications
2. Getting started with Qiskit
3. Understanding quantum information & computation

Learning paths for advantage (~34hrs)
1. Quantum business foundations and applications
2. Getting started with Qiskit
3. Understanding quantum information & computation

Understanding Quantum Information & Computation
1. Basics of quantum information
2. Fundamentals of quantum algorithms
3. General formulation of quantum information
4. Foundations of quantum error correction

Quantum computing in practice
1. Utility-scale quantum computing
2. Running quantum circuits with Qiskit
3. Which problems are quantum computers good for?
4. Quantum workflows on real use cases

Key takeaways for higher education and workforce development



- **Multiple education levels:**
  Efforts span K-12, undergraduate, graduate, professional training, and even retraining for existing engineers.
- **Hands-on / experiential learning:**
  Programs like Virginia Tech's lab and RIT's research on courses emphasize interactive, project-based learning.
- **Curriculum aligned with industry/roles:**
  Look at what employers need (skills, tasks, roles) and design programs accordingly.
- **Access & diversity:**
  Several programs explicitly include underrepresented groups, minority-serving institutions, and aim to expand the pipeline beyond traditional elite STEM routes.
- **Ecosystem & partnerships:**
  Collaborating with industry, national labs, consortia, and government agencies to build infrastructure, define standards, and create pathways.
- **Frameworks & credentials:**
  There's a need for defined qualifications/proficiency profiles (see the European framework) so that education maps to job roles.

When will quantum computing become a mainstream reality?

2025 ↴
Quantum Safe

Much of today's cryptography

~~relies on hard mathematical problems~~

can be broken with a cryptographically relevant quantum computer (CRQC)

~~Public key encryption~~	~~RSA~~
~~Digital signatures~~	~~DSA~~
~~Key exchange algorithms~~	~~ECC~~
	~~ECDSA~~
	~~DH~~

Factorization

Challenge:
Find prime factors

= p x q

Difficulty

The most powerful computer today
would take millions of years to find the solution

Shor's quantum algorithm is anticipated to possibly break RSA in **hours** using hardware available soon.

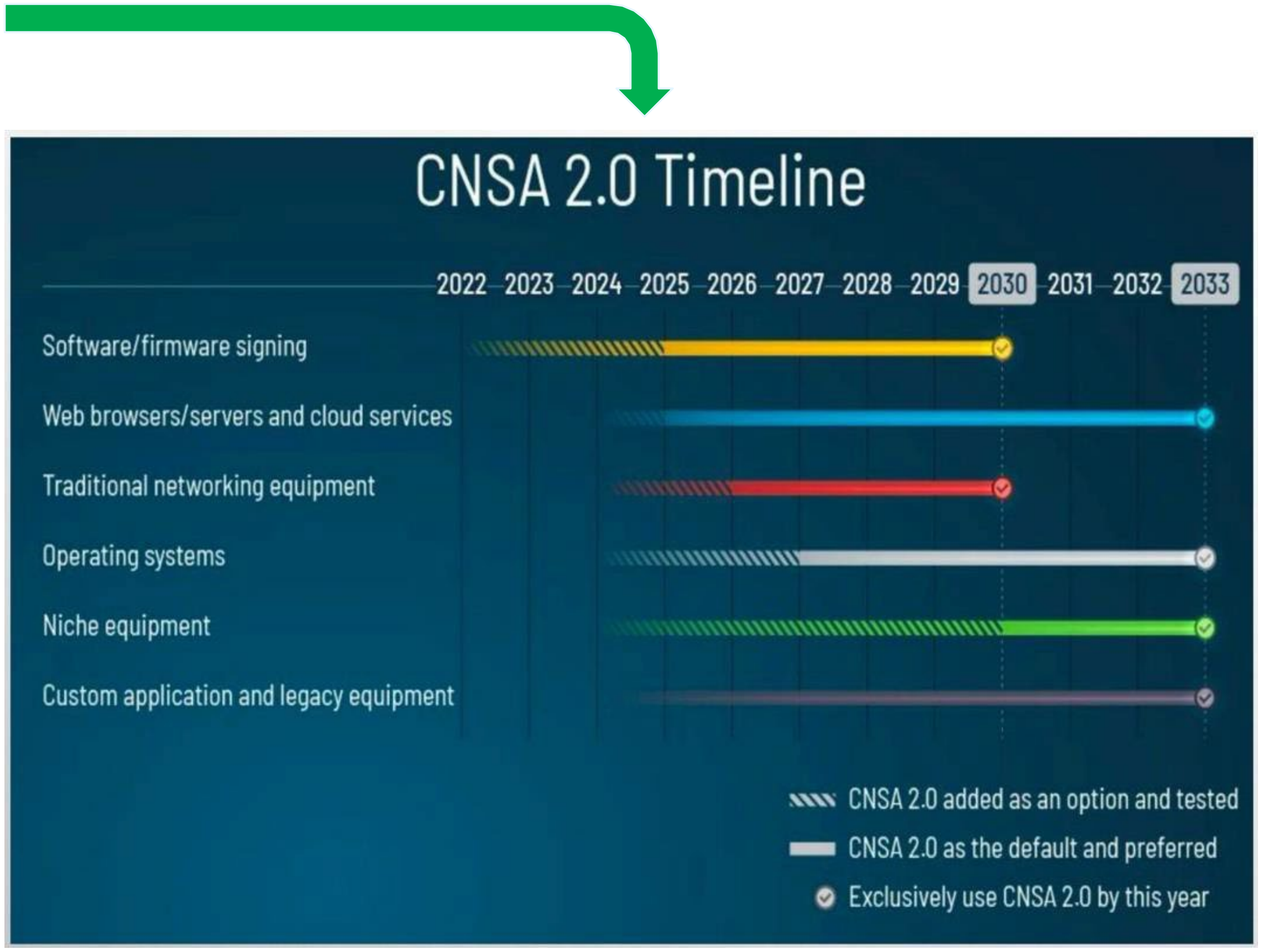
So what?

- In the future, when a cryptographically relevant quantum computer (CRQC) becomes available, cybercriminals can decrypt confidential data, perform fraudulent authentication, forge digital signatures, etc.
- **Harvest Now and Decrypt Later** is a challenge that exists today

What is the solution?

- NIST published PQC standard on August 13, 2024.
- All 3 algorithms codeveloped by current IBM Research scientists.
- Additional algorithms are under evaluation.

US Government Mandates Quantum Safe for Federal Agencies



CNSA 2.0: Quantum-safe standards are preferred for national security systems by the mid-2020s and required by the early 2030s to defend against threats.

Advantage ↴ 2026

2025 Development Roadmap: Hardware

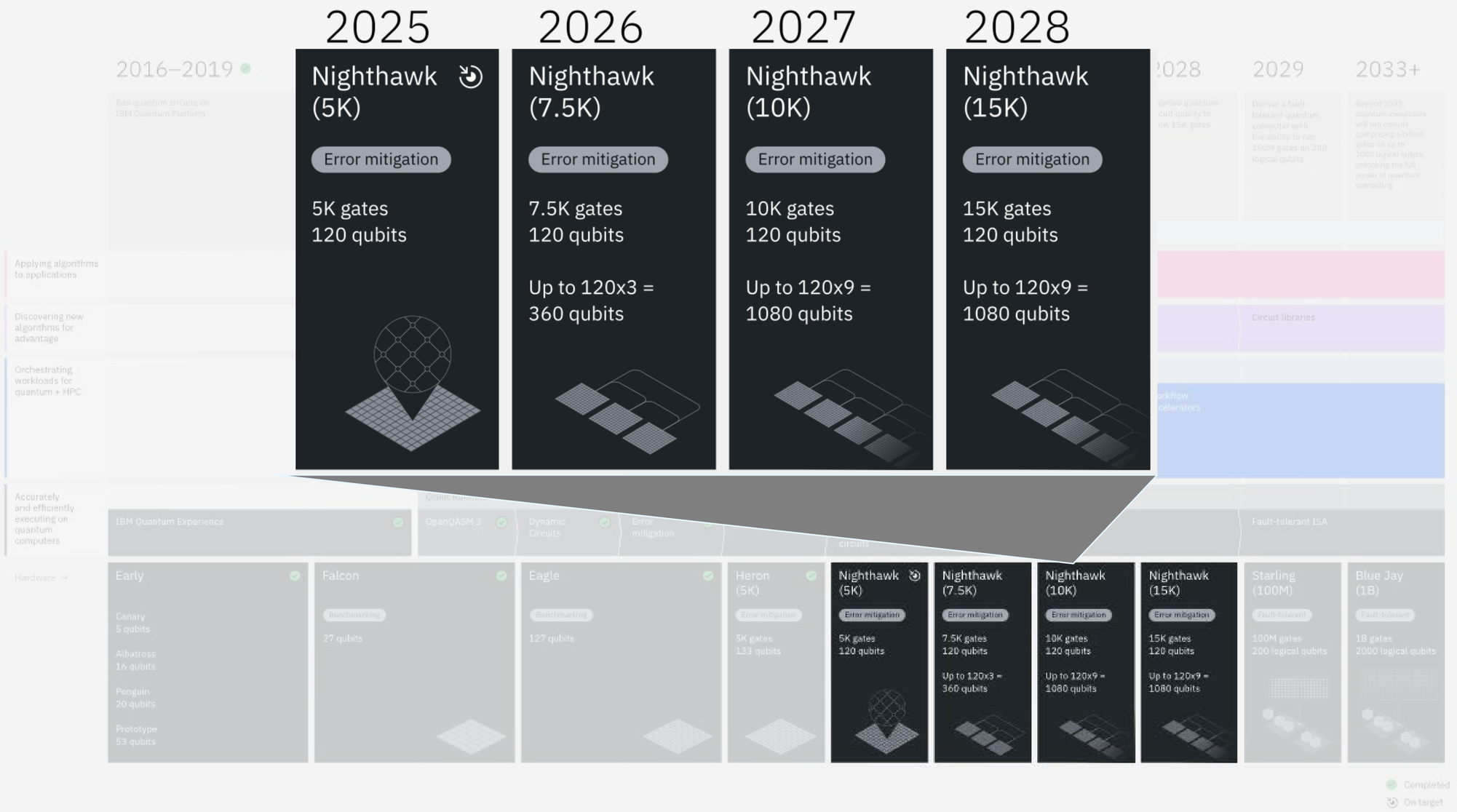
IBM Quantum Nighthawk is our platform for exploring and scaling quantum advantage ahead of large-scale fault-tolerant quantum computing.

Previously, our quantum processors used a “heavy-hex” lattice, with each qubit connected to up to three neighbors. Nighthawk moves us to a square lattice, connecting each qubit to up to four neighbors.

This square lattice supports more efficient circuits, with fewer gates required for information routing. As a result, users can run more complex algorithms at the same gate scale.

Paired with techniques that reduce errors, Nighthawk is expected to run circuits with 5,000 gates in 2025, 7,500 gates in 2026, 10,000 gates in 2027, and 15,000 gates in 2028.

As we improve and scale Nighthawk, we expect our team and partners to make major progress toward quantum advantage.



Fault tolerance ↴
2029

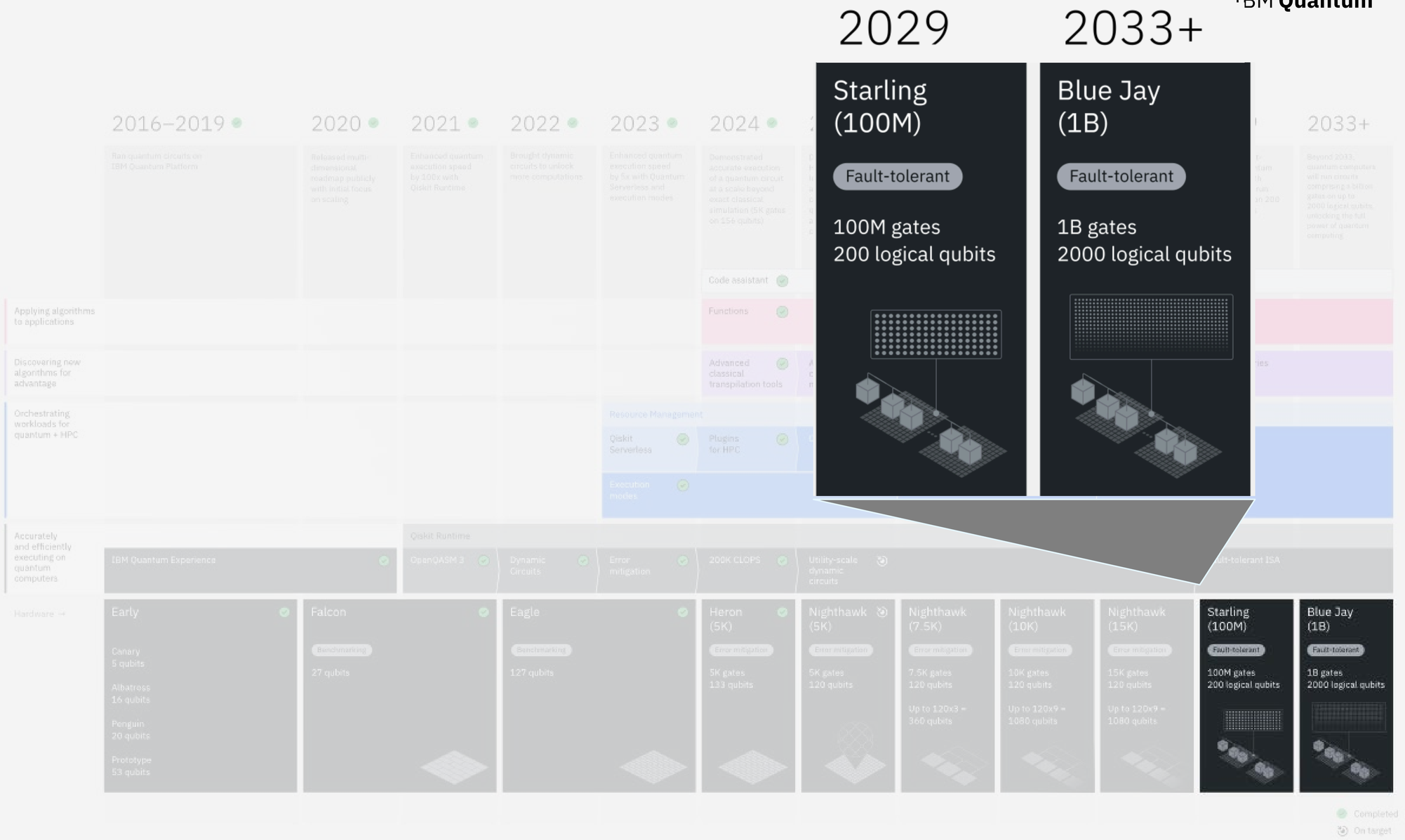
2025 Development Roadmap: Hardware

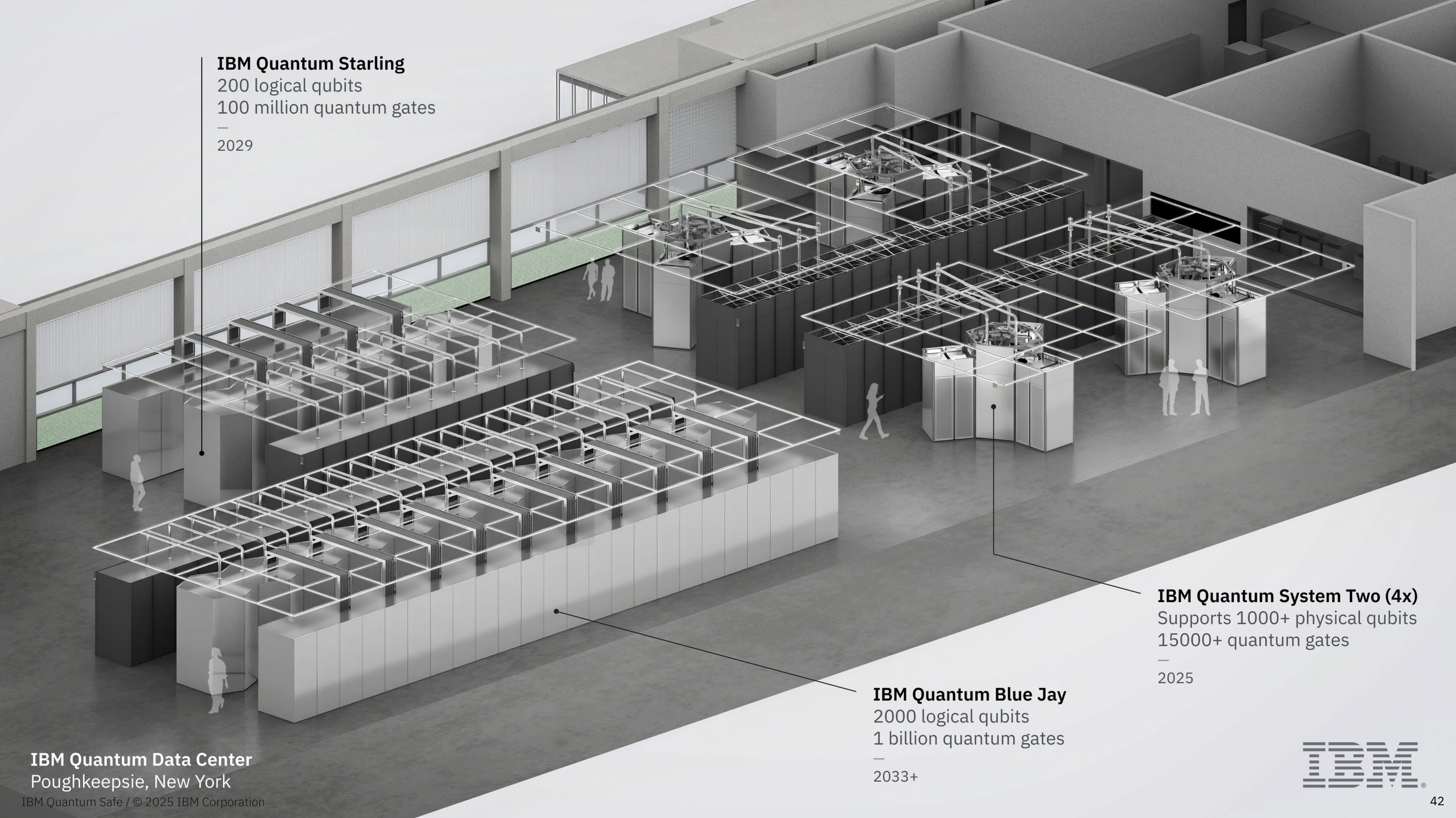
IBM Quantum

At the same time, we are driving toward **IBM Quantum Starling**—a system capable of running circuits with 100 million gates on 200 logical qubits—and aim to debut it by 2029.

In 2033, we will debut **IBM Quantum Blue Jay**, a system capable of running circuits with a billion gates on 2,000 logical qubits. These large-scale fault-tolerant quantum computers will unlock a new era of algorithmic complexity and application discovery.

Developers will not need to change how they write quantum programs in this era. They will simply notice that they can run longer workloads.





BACKUP

Rensselaer Polytechnic Institute

Multiplier to the New York region

Mission

- Lead globally in education and workforce development for Quantum Computing
- Development of new quantum use cases and applications, particularly in STEM fields
- Be the growth engine for technology between NYC and Capital region

2024

Installation and ribbon cutting of the first IBM Quantum System One installed at a university campus

Establishment of RPI Quantum Enablement and Development Team (QED)

Joint IBM/RPI kick-off of research and **education workstreams**

2025

Research focus and designing quantum curriculum roadmap

Build out of HPC and Quantum integration architecture, HPC and Quantum demonstrations

Inaugural **RPI Quantum Forum** at RPI for Global IBM Quantum Computation Centers

Creation of quantum software development course for RPI Computer Science department

2026

HPC upgrade supporting quantum centric supercomputing (QCSC) vision

Focus on **developing Troy/NY ecosystem** anchored by IBM Quantum System

Launch **Quantum Accelerator for Hudson Valley Startups**