Quantum Computing State-Of-The-Art

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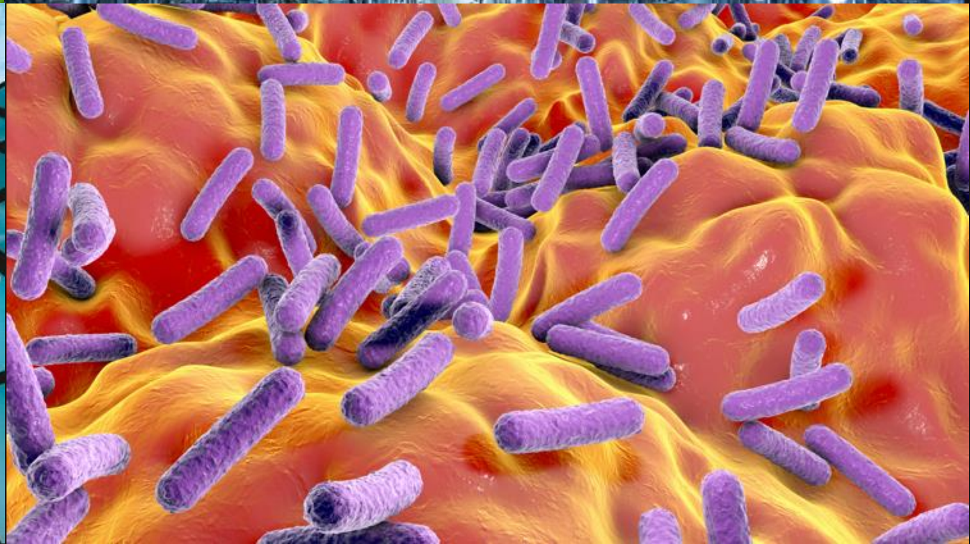
Qiskit Advocate

5-Dec-2023


C-2301



Mission 1

Bring useful quantum computing to the world

Make the world quantum safe

Mission 2

Bring useful quantum computing to the world

Make the world quantum safe

One of the world's most powerful supercomputers

IBM **Quantum**

Oak Ridge National Laboratory
US Department of Energy

Summit supercomputer specs

200 quadrillion calculations per second

9216 IBM Power 9 processors

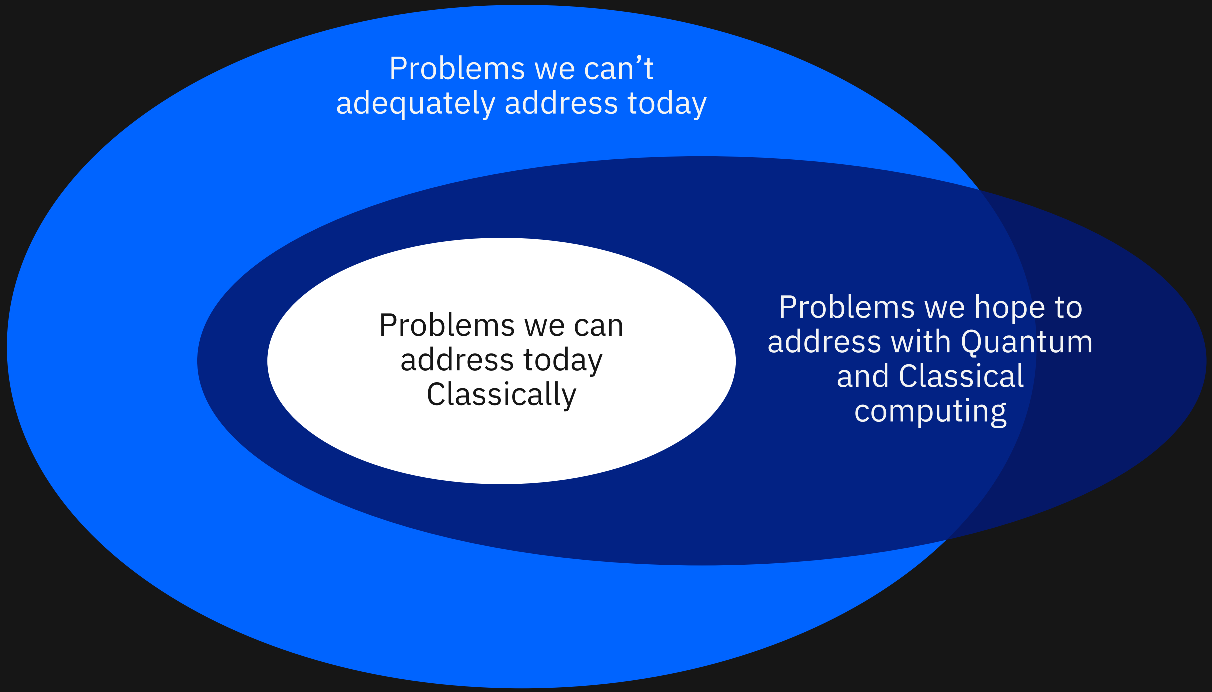
27,648 NVIDIA GPUs

250 PB File System

IBM Red Hat Enterprise Linux (RHEL) v 7.4 Operating System

https://www.ibm.com/thought-leadership/summit-supercomputer/

Why Quantum?



Despite how sophisticated digital “classical ” computing has become, there are many scientific and business problems for which we’ve barely scratched the surface.

The limit of bits

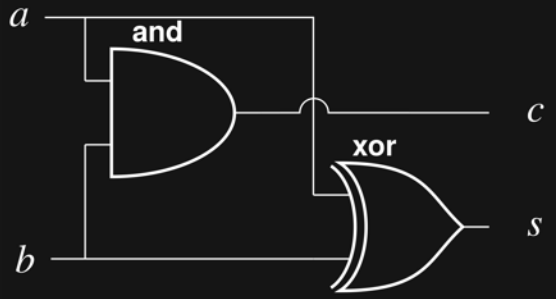
For decades we’ve been simplifying nature into **1**s and **0**s because that was the only way we could manage to create a useful and scalable system of computation.

```
001001101110010010001001001001100100111
001011100111110010100100011100010001001
010001001001010101001010101110010011011
100100100010010010011001001110010111001
111100101001000111000100010010100010010
010101010010101011101110011100101011110
```

But the future isn’t just **1**s and **0**s.

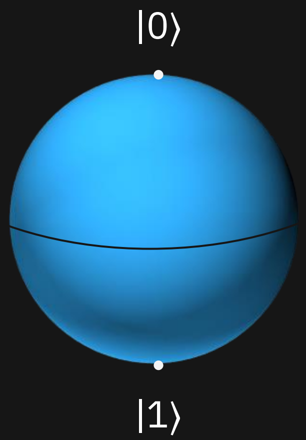
Bits and classical logic circuits

A bit is a controllable classical object that is the unit of information

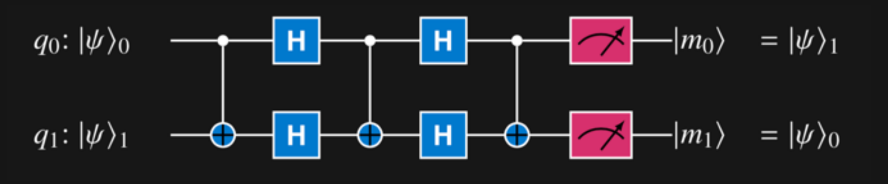


A classical logic circuit is a set of gate operations on bits and is the unit of computation

Quantum bits (Qubits) and quantum circuits

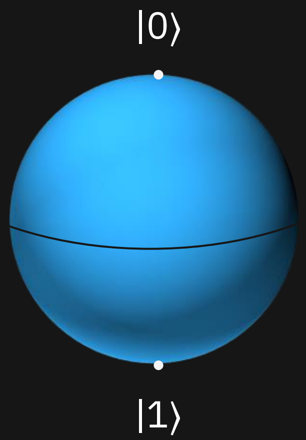


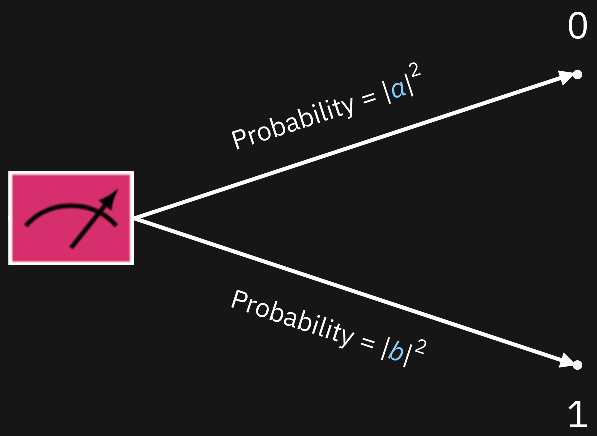
A quantum bit or qubit is a controllable quantum object that is the unit of information



A quantum circuit is a set of quantum gate operations on qubits and is the unit of computation

Bits and Qubits





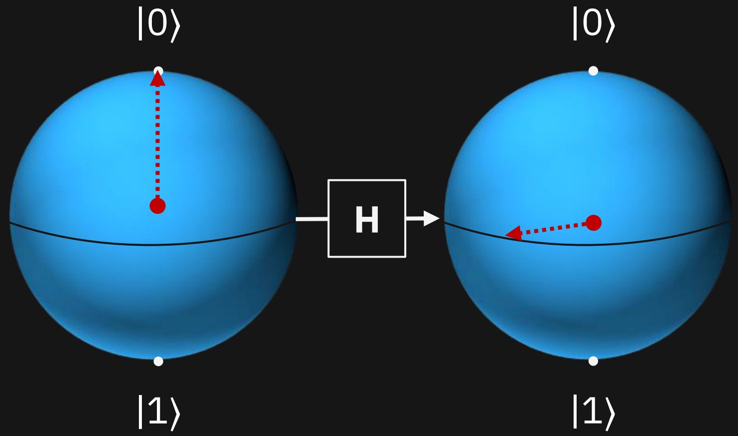
A qubit's state is a combination of |0⟩ and |1⟩:

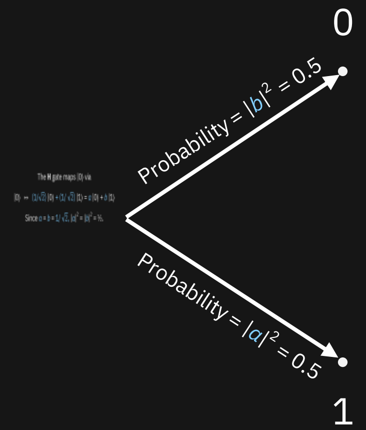
$$a\,|0\rangle + b\,|1\rangle$$

This means that a single qubit contains two pieces of information.

When we measure a qubit, it becomes **0** or **1** based on probability.

Bits and qubits: the effect of the **H** gate on $|0\rangle$





The **H** gate maps $|0\rangle$ via

$$|0\rangle \;\mapsto\; (1/\sqrt{2})\,|0\rangle + (1/\sqrt{2})\,|1\rangle = a\,|0\rangle + b\,|1\rangle$$

Since $a = b = 1/\sqrt{2}$, $|a|^2 = |b|^2 = ½$.

When measured, the probability of getting **0** or **1** is the same, 0.5.
Quantum randomness!

Quantum computing uses essential ideas from quantum mechanics

Superposition

$|0\rangle$ and $|1\rangle$ are vectors in the two-dimensional complex vector space $\mathbb{C}^2$:

$$|0\rangle = \begin{bmatrix} 1 \\ 0 \end{bmatrix} \quad \text{and} \quad |1\rangle = \begin{bmatrix} 0 \\ 1 \end{bmatrix}$$

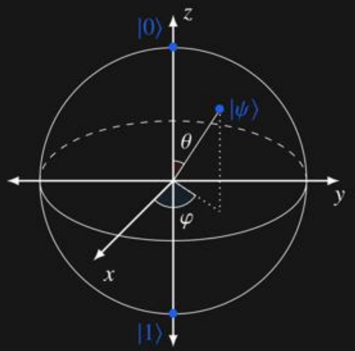
So we can write any vector in $\mathbb{C}^2$ as

$$a\,|0\rangle + b\,|1\rangle$$

We pronounce $|0\rangle$ and $|1\rangle$ as “ket zero” and “ket one.” These are called the *computational basis*.

Quantum computing uses essential ideas from quantum mechanics

Superposition



Superposition is creating a quantum state that is a combination of $|0\rangle$ and $|1\rangle$

$$a\,|0\rangle + b\,|1\rangle$$

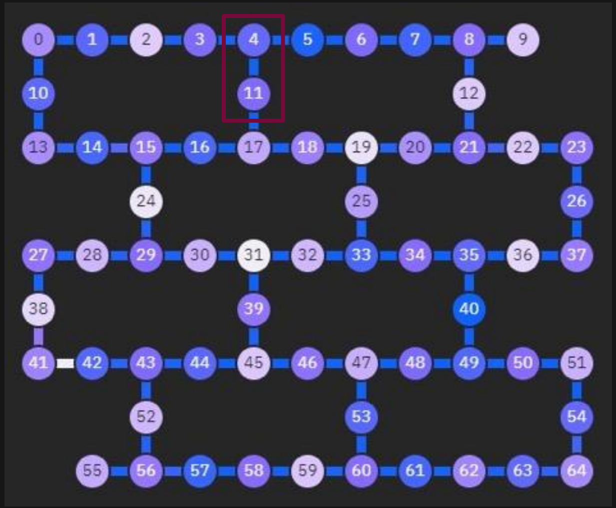
These conditions allow us to map the qubit onto the *Bloch Sphere*.

Note that if a and b are non-zero, then the qubit's state contains both $|0\rangle$ and $|1\rangle$.

This is what people mean when they say that a qubit can be "0 and 1 at the same time."

Quantum computing uses essential ideas from quantum mechanics

Entanglement



We can write

$$\frac{\sqrt{2}}{2}\,|00\rangle + \frac{\sqrt{2}}{2}|01\rangle$$

as

$$|0\rangle\,(\frac{\sqrt{2}}{2}\,|0\rangle + \frac{\sqrt{2}}{2}|1\rangle)$$

but we cannot write

$$\frac{\sqrt{2}}{2}\,|00\rangle + \frac{\sqrt{2}}{2}|11\rangle$$

as the “product” of two single qubit states.

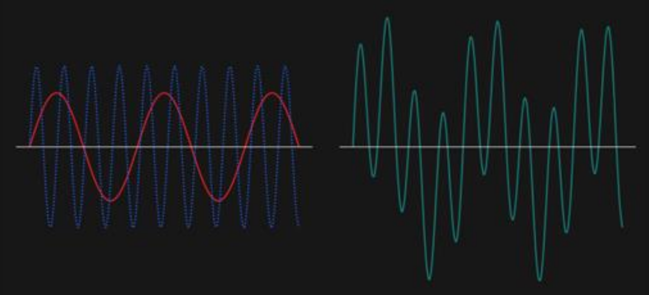
They are entangled!

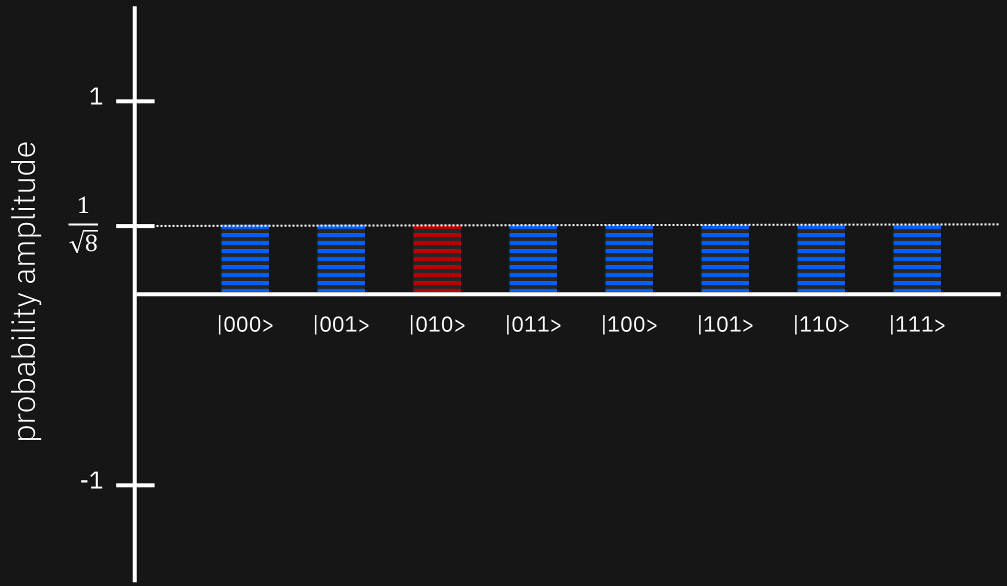
Once you measure the first qubit, the second is uniquely determined.

Quantum computing uses essential ideas from quantum mechanics

Interference allows us to increase the probability of getting the right answer and decrease the chance of getting the wrong one.

Interference





Quantum computing uses essential ideas from quantum mechanics

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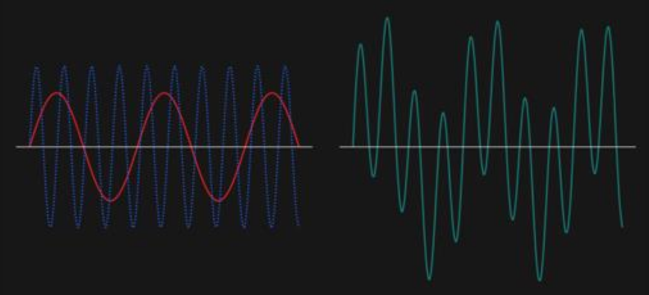
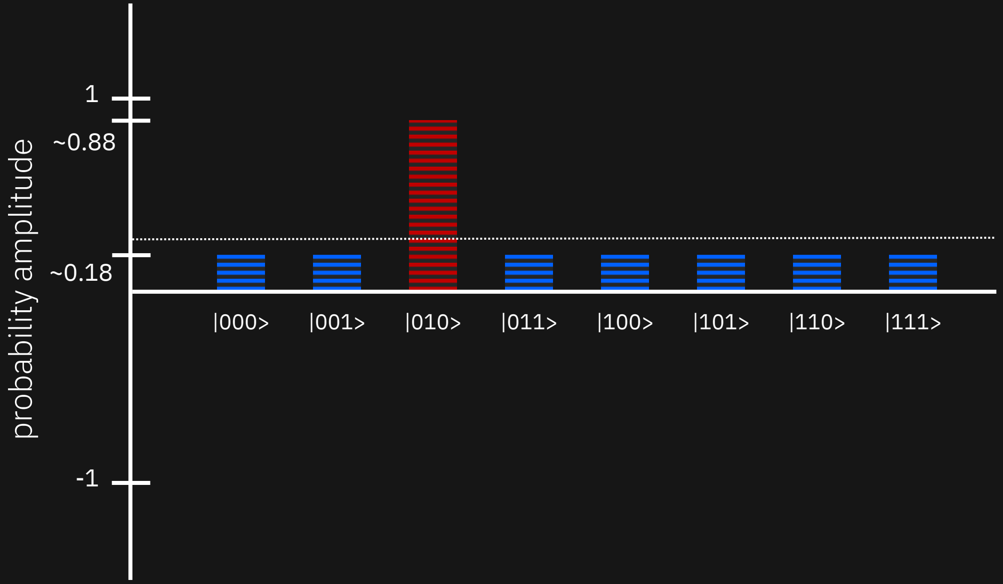
Interference





Exponential growth

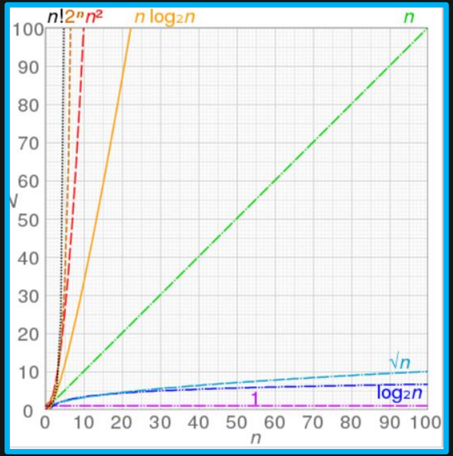
2^1

2^2

2^3

...

2^n



1 qubit – 2 quantum state dimensions

$$a\,|0\rangle + b\,|1\rangle$$

where *a* and *b* are complex numbers.

2 qubits – 4 quantum state dimensions

$$a\,|00\rangle + b\,|01\rangle + c\,|10\rangle + d\,|11\rangle$$

where *a, b, c,* and *d* are complex numbers.

3 qubits – 8 quantum state dimensions

$$a\,|000\rangle + b\,|001\rangle + c\,|010\rangle + d\,|011\rangle + e\,|100\rangle + f\,|101\rangle + g\,|110\rangle + h\,|111\rangle$$

where *a, b, ... , g,* and *h* are complex numbers.

2^{10} = 1,024

2^{20} = 1,048,576

2^{50} = 1,125,899,906,842,624

2^{65} = 36,893,488,147,419,103,232

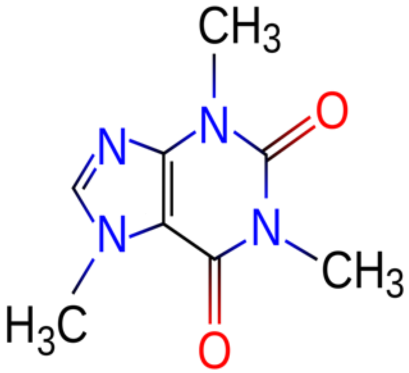
2^{127} = 170,141,183,460,469,231,731,
687,303,715,884,105,728

Computing with caffeine

If our best classical computers are so powerful, shouldn't we be able to perfectly simulate molecules and chemical reactions?

This would allow us to accelerate discovery of new compounds and processes for healthcare, materials, alloys, and sustainable energy creation.

Let's consider caffeine ...



Computing with caffeine

We would need approximately 10^{48} bits to represent the energy configuration of a single caffeine molecule at a single instant in a classical computer.

This is 1 to 10% of the total number of atoms in the Earth.

10^{48} = 1,000,000,000,000,000,
000,000,000,000,000,000,
000,000,000,000,000

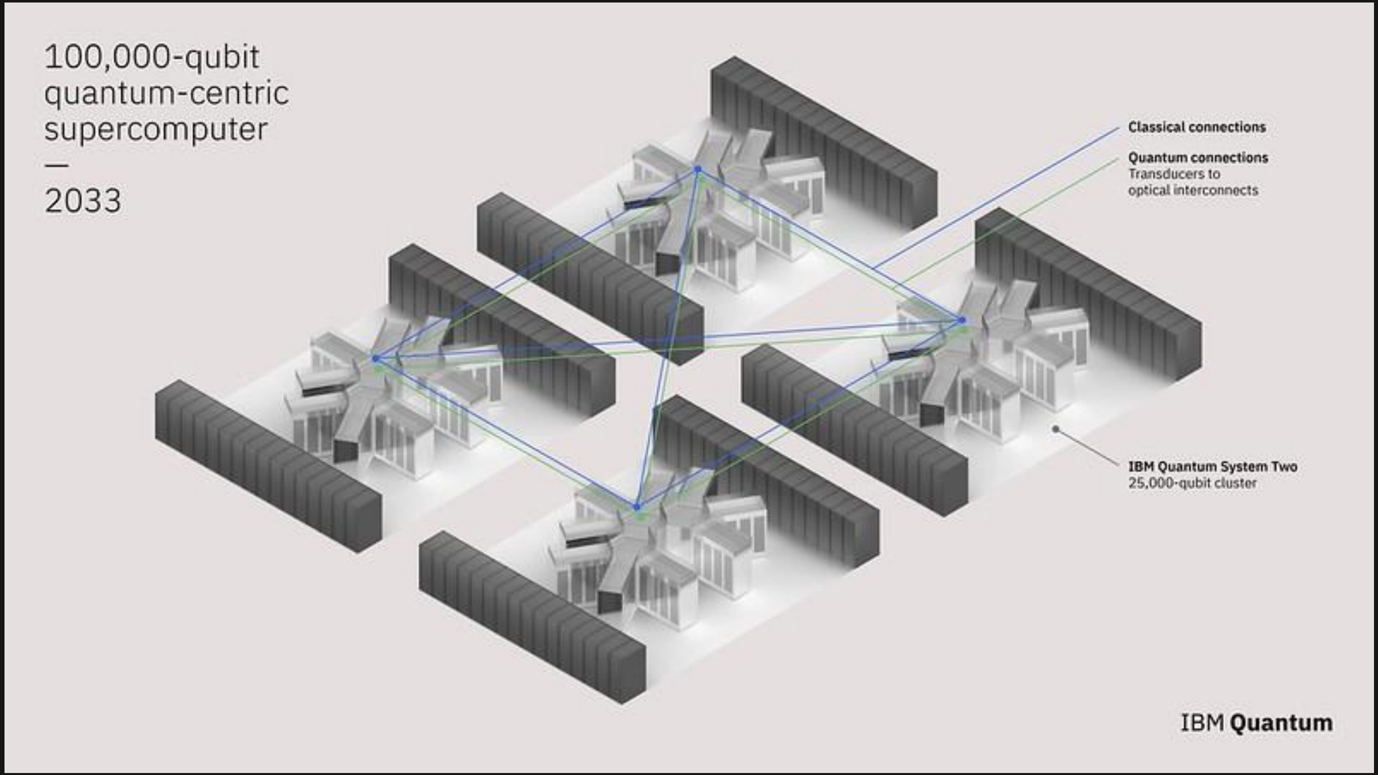
Computing with caffeine

Although it’s impossible to completely represent the molecular configuration of caffeine on today’s most powerful super computers, we could represent it using 160 logical qubits.

IBM launches partnership with the University of Chicago and the University of Tokyo to develop a 100,000-qubit Quantum-Centric Supercomputer

The 10-year, $100 million initiative is a global collaboration and an activation of talent and resources across industries and research institutions is being initiated.

By partnering with the University of Chicago, the University of Tokyo, and IBM's broader global ecosystem, IBM will work over the next decade to advance the underlying technologies for this system, as well as to design and build the necessary components at scale [1].

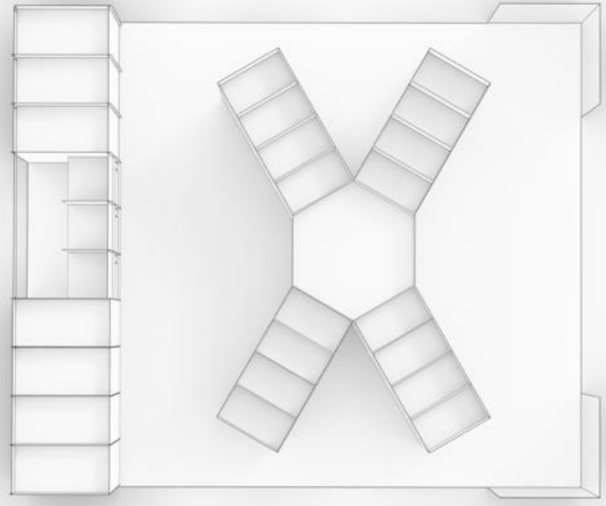


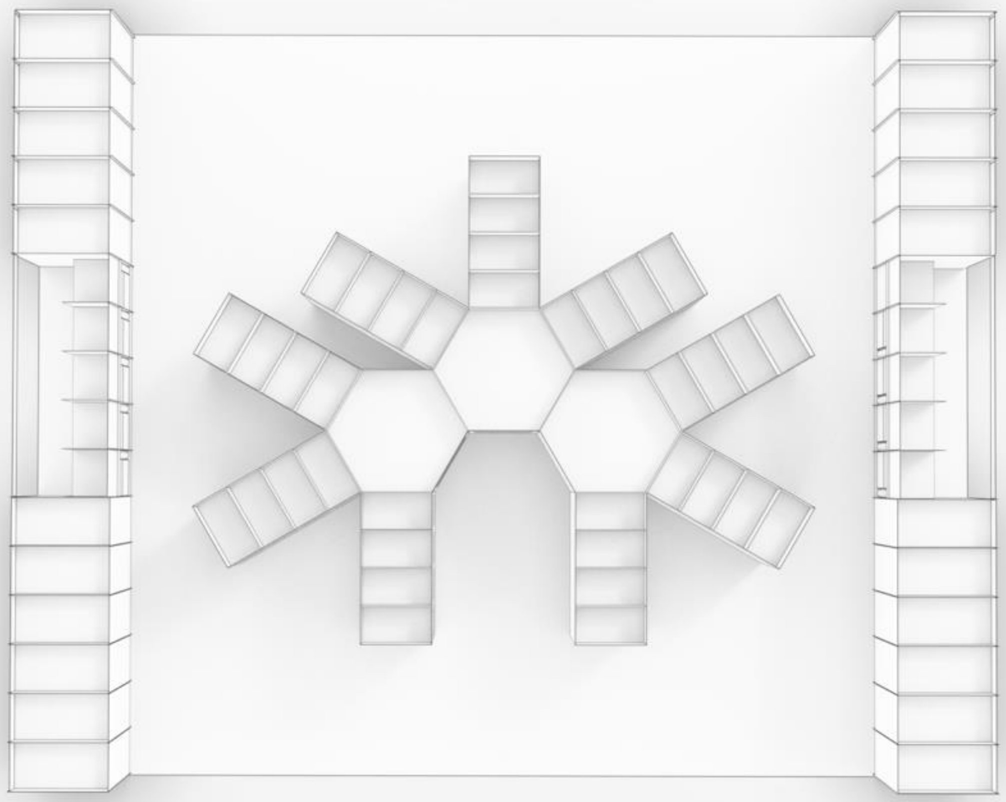
Cryogenic Platform KIDE

Rethink user access

Multiple and dedicated cooling units

Expandable into clusters





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

	2019	2020	2021	2022	2023	2024	2025	Beyond 2026
Model Developers					Prototype quantum software applications →		Quantum software applications: Machine learning | Natural science | Optimization	
Algorithm Developers		Quantum algorithm and application modules ✓ (Machine learning | Natural science | Optimization)			Quantum Serverless	Intelligent orchestration	Circuit Knitting Toolbox	Circuit libraries
Kernel Developers	Circuits ✓		Qiskit Runtime ✓	Dynamic circuits ✓	Threaded primitives (on target)	Error suppression and mitigation		Error correction
System Modularity	Falcon 27 qubits ✓	Hummingbird 65 qubits ✓	Eagle 127 qubits ✓	Osprey 433 qubits ✓	Condor 1,121 qubits (on target)	Flamingo 1,386+ qubits (on target)	Kookaburra 4,158+ qubits	Scaling to 10K-100K qubits with classical and quantum communication
					Heron 133 qubits x p (on target)	Crossbill 408 qubits (on target)		

A path towards Quantum Advantage

"The point of view and goal is a computational Quantum Advantage, where a computational task of business or scientific relevance can be performed more ***efficiently****, cost-effectively, or accurately using a quantum computer than with classical computations alone."*

IBM **Quantum**

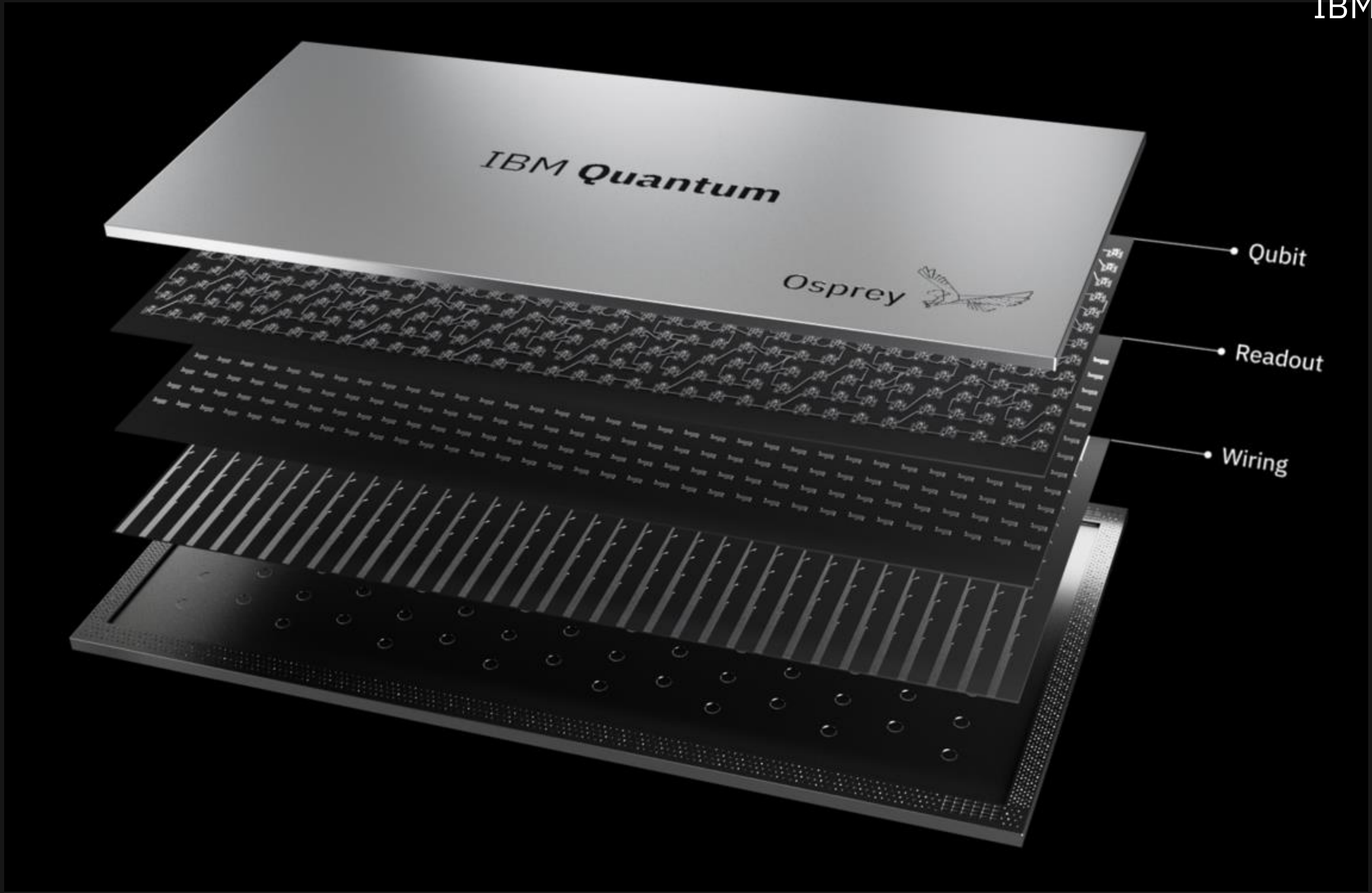
Performance =

Scale — Number of qubits

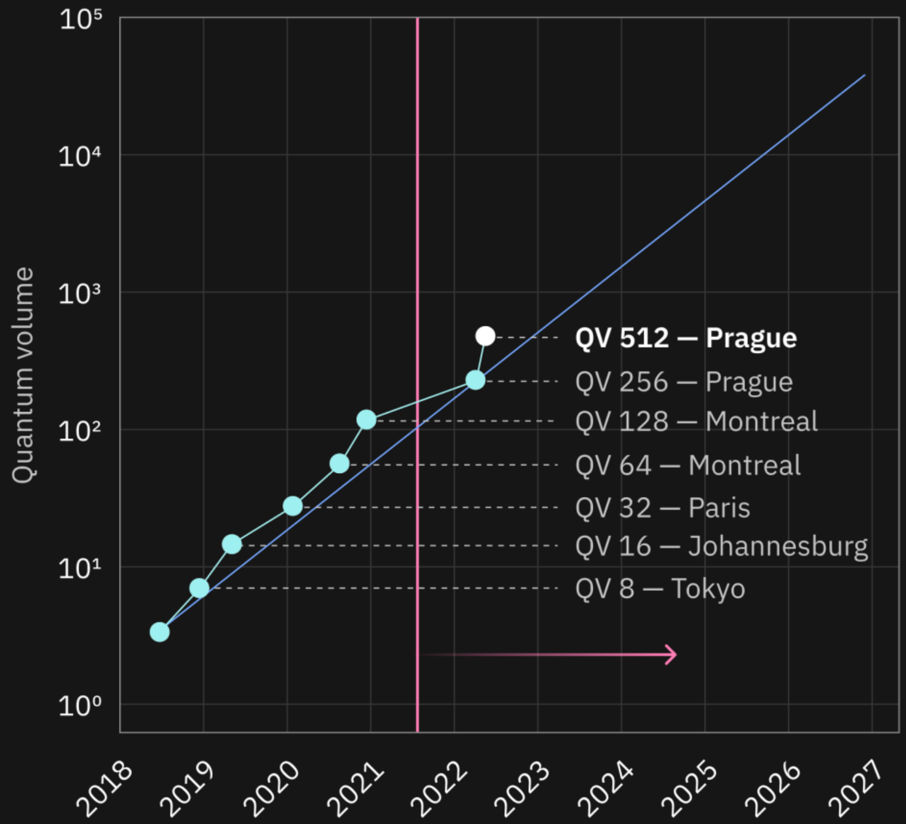
\+ Quality — Circuit fidelity

\+ Speed — Circuit execution speed

IBM **Quantum**



Quantum volume

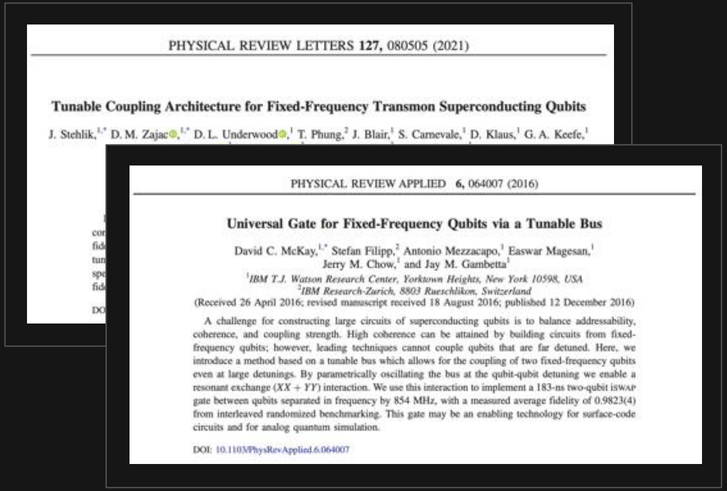


Quality

Coherence

Improved control

New architectures



PHYSICAL REVIEW LETTERS **127,** 080505 (2021)

Tunable Coupling Architecture for Fixed-Frequency Transmon Superconducting Qubits

J. Stehlik,[1,*] D. M. Zajac,[1,*] D. L. Underwood,[1] T. Phung,[2] J. Blair,[1] S. Carnevale,[1] D. Klaus,[1] G. A. Keefe,[1]

PHYSICAL REVIEW APPLIED **6,** 064007 (2016)

Universal Gate for Fixed-Frequency Qubits via a Tunable Bus

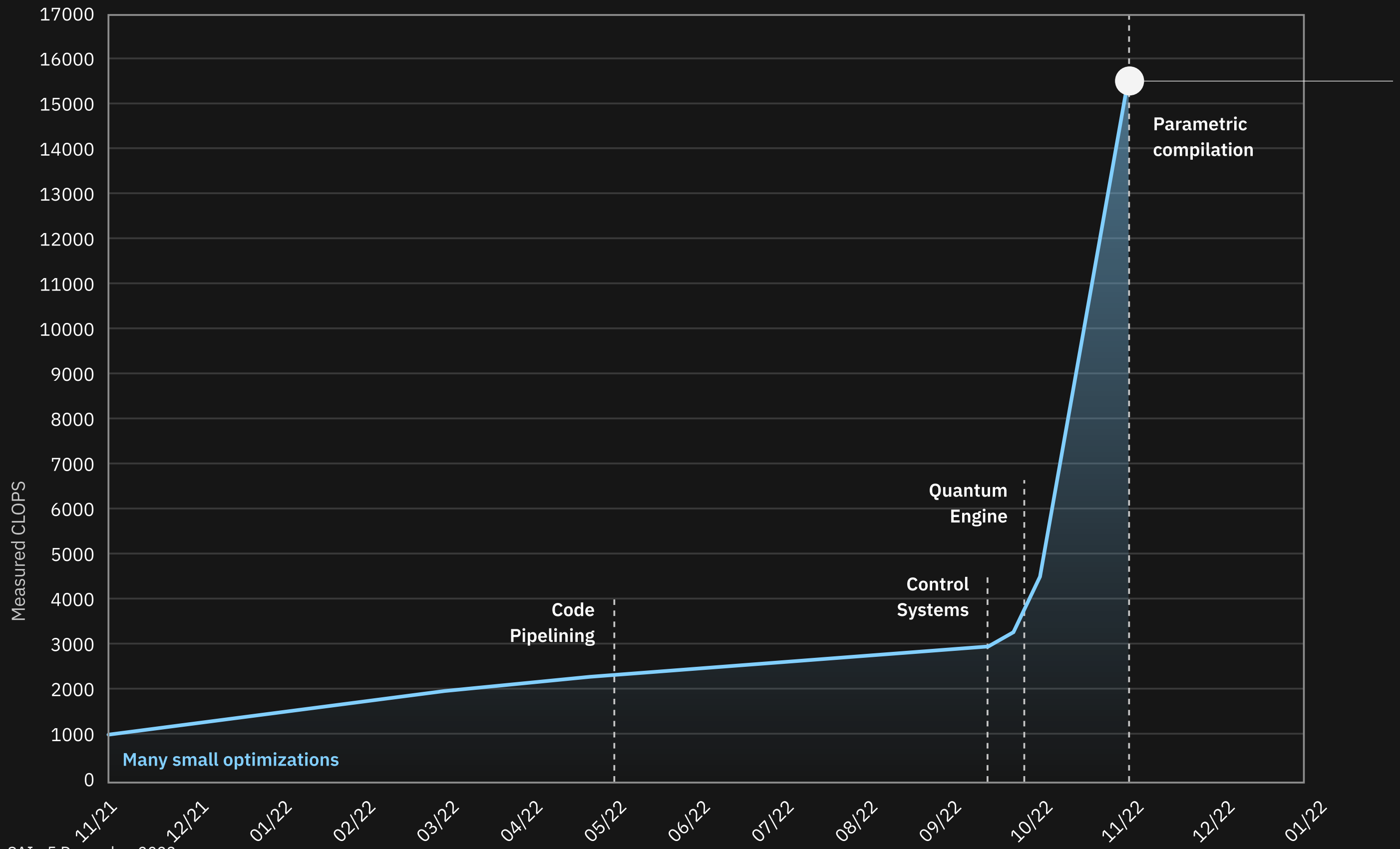
David C. McKay,[1,*] Stefan Filipp,[2] Antonio Mezzacapo,[1] Easwar Magesan,[1]
Jerry M. Chow,[1] and Jay M. Gambetta[1]
[1]*IBM T.J. Watson Research Center, Yorktown Heights, New York 10598, USA*
[2]*IBM Research-Zurich, 8803 Rueschlikon, Switzerland*
(Received 26 April 2016; revised manuscript received 18 August 2016; published 12 December 2016)

A challenge for constructing large circuits of superconducting qubits is to balance addressability, coherence, and coupling strength. High coherence can be attained by building circuits from fixed-frequency qubits; however, leading techniques cannot couple qubits that are far detuned. Here, we introduce a method based on a tunable bus which allows for the coupling of two fixed-frequency qubits even at large detunings. By parametrically oscillating the bus at the qubit-qubit detuning we enable a resonant exchange ($XX + YY$) interaction. We use this interaction to implement a 183-ns two-qubit iSWAP gate between qubits separated in frequency by 854 MHz, with a measured average fidelity of 0.9823(4) from interleaved randomized benchmarking. This gate may be an enabling technology for surface-code circuits and for analog quantum simulation.

DOI: 10.1103/PhysRevApplied.6.064007

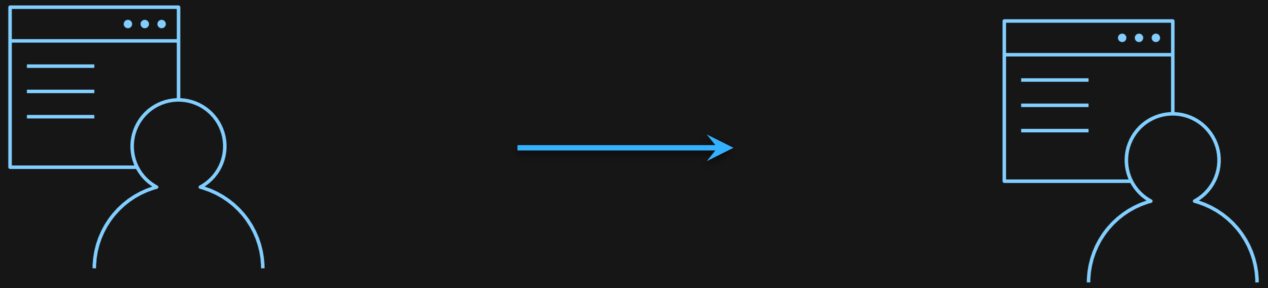
Critical elements for speed

IBM **Quantum**



15,700
CLOPS

Frictionless development for quantum computing



Developer using classical

Developer using quantum

Same tools
Same languages
Same code

Developer ecosystem

Model developers

Makes circuits and algorithms accessible to non-experts by allowing developers to describe their problem rather than the solution methodology.

Algorithm developers

Uses higher level building blocks like state prep, operators and oracles to help them construct algorithms.

Kernel developers

Creates high performance circuits using pulse level and timing controls

Quantum applications span three general areas

Simulating Quantum Systems	Artificial Intelligence	Optimization / Monte Carlo
Quantum chemistry Material science High energy physics	Better model training Pattern recognition Fraud detection	Portfolio optimization Risk analysis Loans & credit scoring Monte Carlo-like applications

Quantum applications span three general areas

Simulating Quantum Systems	Artificial Intelligence	Optimization / Monte Carlo

- Improved battery materials
- Manufacturing defect identification
- Semiconductor materials
- Chemical property prediction
- Drug Discovery
- Protein Structure Predictions
- Disease Risk Predictions

- Accelerated Diagnosis
- Genomic Analysis
- Chemical product design
- Catalyst discovery
- Chemical process optimization
- High energy physics classification
- Transaction classification
- Product recommendation

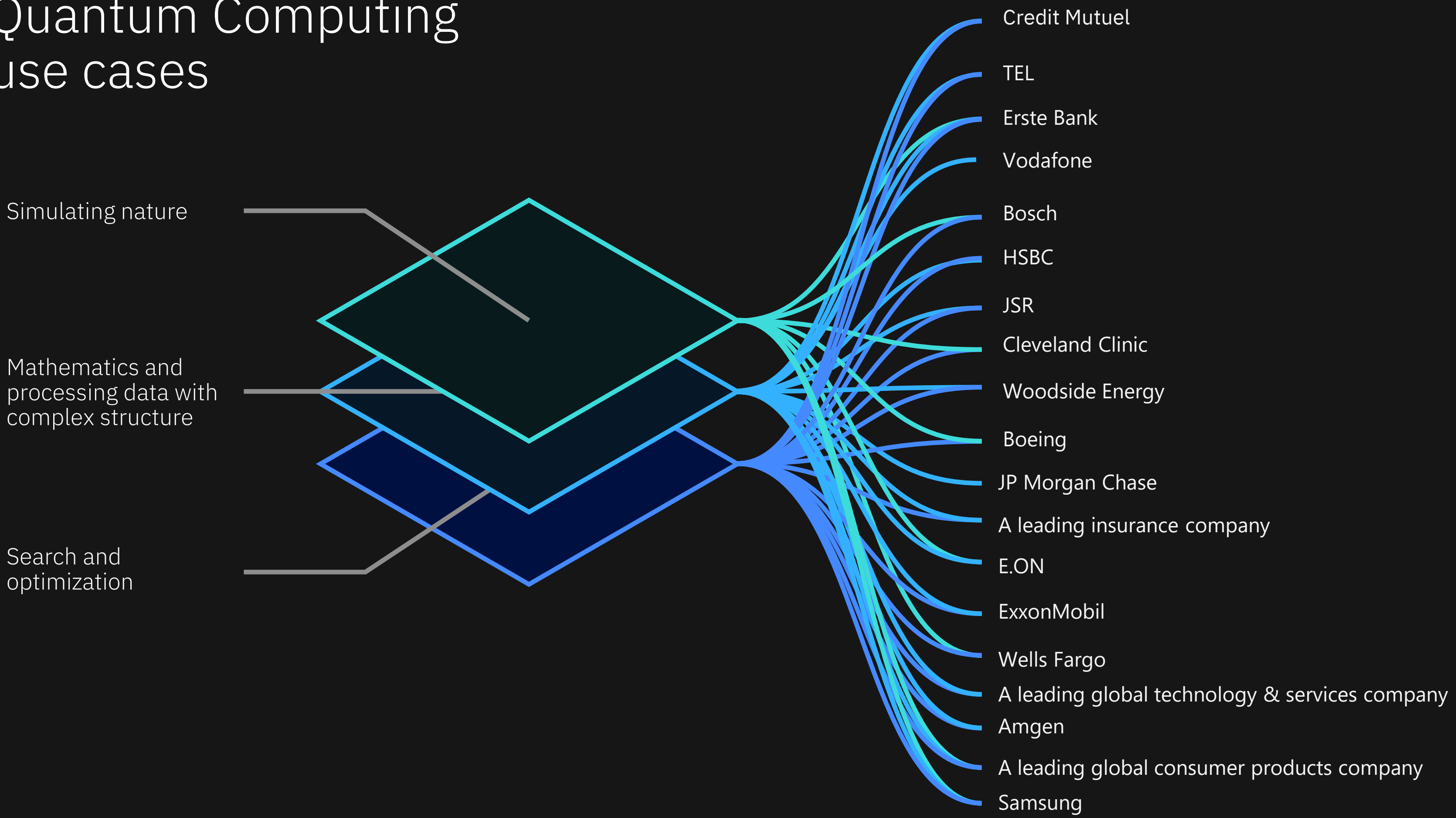
- Fraud detection
- Risk analysis
- Options pricing
- Derivatives Pricing
- Investment Risk Analysis
- Portfolio Management
- Transaction Settlement
- Finance Offer Recommender
- Credit/Asset Scoring
- Airline Scheduling

- Irregular Operations
- Network Optimization
- Product Portfolio Optimization Process Planning
- Quality Control
- Vehicle Routing
- Raw materials shipping
- Refining Processes
- Seismic imaging
- Disruption Management

- Freight Forecasting
- Irregular Operations
- Fabrication Optimization
- Manufacturing Supply Chain
- Fluid Dynamics

and many more ...

Connecting industry clients with Quantum Computing use cases



Mercedes-Benz

IBM **Quantum**

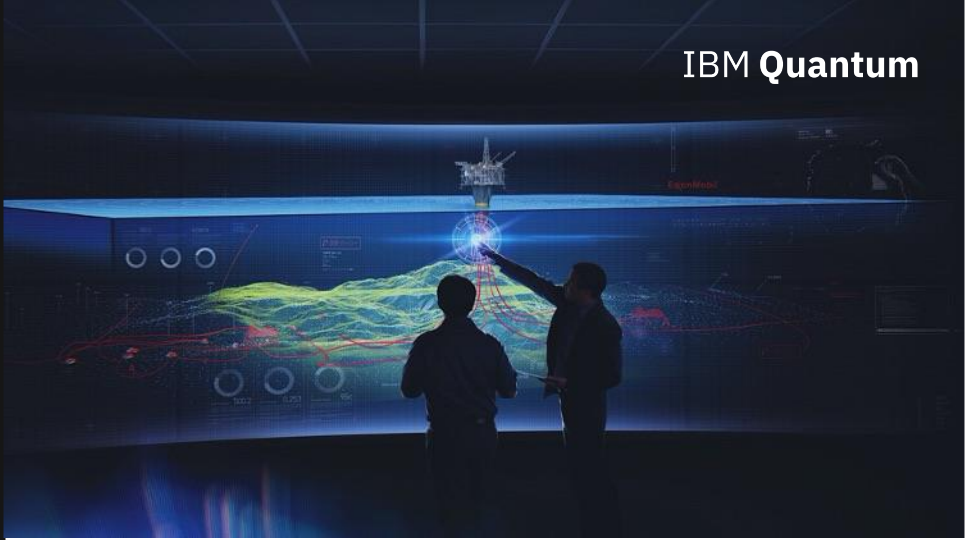
Quantum Computing for Materials Discovery and Manufacturing Optimization

Mercedes-Benz and IBM have recently published a series of papers demonstrating progress toward using quantum computers to model material systems including Lithium-sulfur that are relevant to advancing the performance of batteries. The teams have also demonstrated applications in manufacturing defect analysis and product recommendation.

"Developing and perfecting these hypothetical batteries could unlock a billion-dollar opportunity."

Benjamin Boeser
[Former] Director of Innovation Management, Silicon Valley at Mercedes-Benz R&D North America

ExxonMobil



Quantum Computing as a Tool for Chemistry and Engineering

Working together, ExxonMobil and IBM recently demonstrated advancements in using quantum computers to accurately calculate thermodynamic observables, demonstrating how quantum can be the next generation tool for chemists and chemical engineers developing advanced energy solutions.

"We know in our bones that there are huge global challenges that we will tackle in the foreseeable future. When quantum computing scales to become utterly disruptive, we'll be ready."

Dr. Vijay Swarup
ExxonMobil Vice President of Research and Development

ExxonMobil

IBM Quantum

Maritime Routing's Mind-Boggling Math

In 2021 more than 500 LNG (liquified natural gas) ships are used to transport critical fuel supplies across the oceans. Together, they make thousands of journeys per year to destination ports where the LNG is deployed to power critical infrastructure.

Finding optimal routes for a fleet of such ships can be a mind-bendingly complex optimization problem.

Quantum computers take a new approach to addressing this sort of complexity, with the potential to find solutions that classical supercomputer alone cannot handle. Industry leaders like Exxon are getting involved now to explore how blending classical and quantum computing techniques might solve big, complex, pressing global challenges.

JP Morgan Chase

Quantum Computing for the Financial Services Industry

Recently, JPMC and IBM used Quantum Amplitude Estimation, a Monte Carlo-like sampling algorithm, to compute European option pricing, pricing path depend options, showing a quadratic speed-up versus a classical Monte Carlo approach.

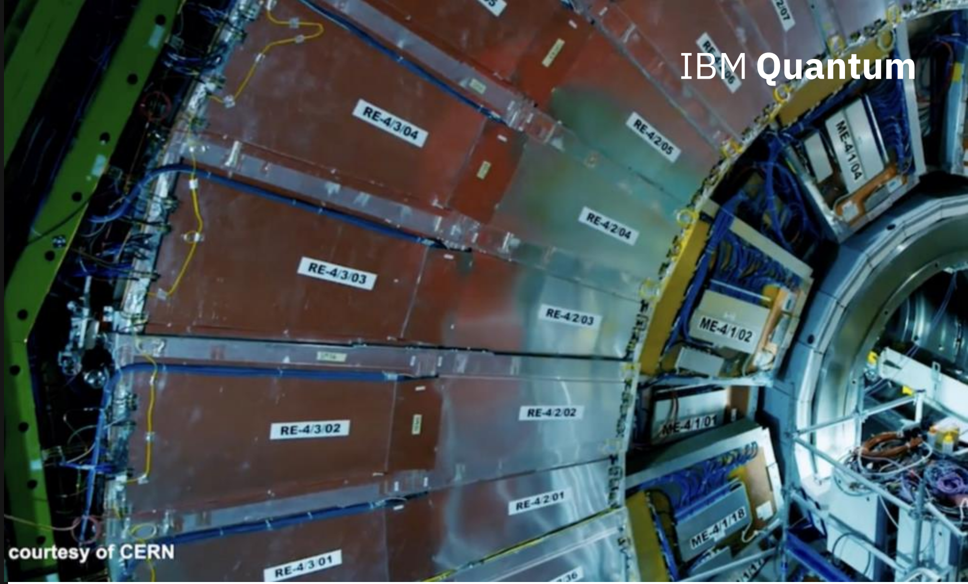
European derivative pricing on a Quantum computer implements the Black-Scholes model using a Quantum Machine Learning Algorithm, namely a quantum Generative Adversarial Network (qGAN). The qGAN utility loads the log-normal probability distribution and models the spot price of an asset underlying a European call option.

The resulting model can then be integrated into a Quantum Amplitude Estimation based algorithm to evaluate the expected payoff.

CERN

Quantum Machine Learning to understand what sews the universe together

CERN’s partnership with IBM Quantum seeks new ways of finding patterns in data of the Large Hadron Collider. A recent collaboration with IBM scientists involves the detection and analysis of the Higgs boson, a recently discovered particle that helps explain the origin of mass. Sifting through raw data to find occurrences of Higgs behavior is a knotty problem that stretches classical computers to their limit.



courtesy of CERN

“Quantum computing may play a significant role in (...) exploring the many open questions related to issues such as dark matter, dark energy, (...) and more.”

Alberto Di Meglio
Head of CERN openlab

IBM **Quantum**

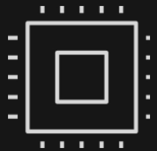
Mitsubishi Chemical, JSR and Keio University

Exploring new forms of light with Quantum Computing

A Japanese research partnership comprising corporate teams from industrial chemists Mitsubishi Chemical and JSR Corporation, and academics from Keio University, have joined the IBM Quantum Network. Their mission is to collaborate with IBM scientists to create a new breed of disruptively efficient OLED materials — flexible, scalable and able to produce more (and more visually appealing) light with far less energy.

Optimizations through the Qiskit Runtime Primitives

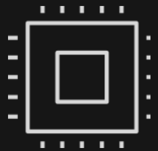
Sampler



Circuit → $\tilde{p}(\hat{x})$

Quasi-probability distribution

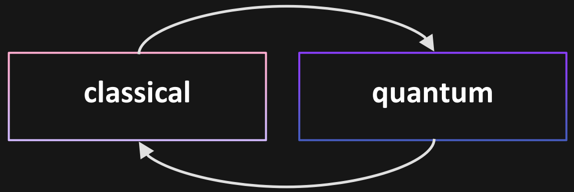
Estimator



Circuit + Observable $\tilde{o}$ → $\langle \tilde{O} \rangle$

Expectation value

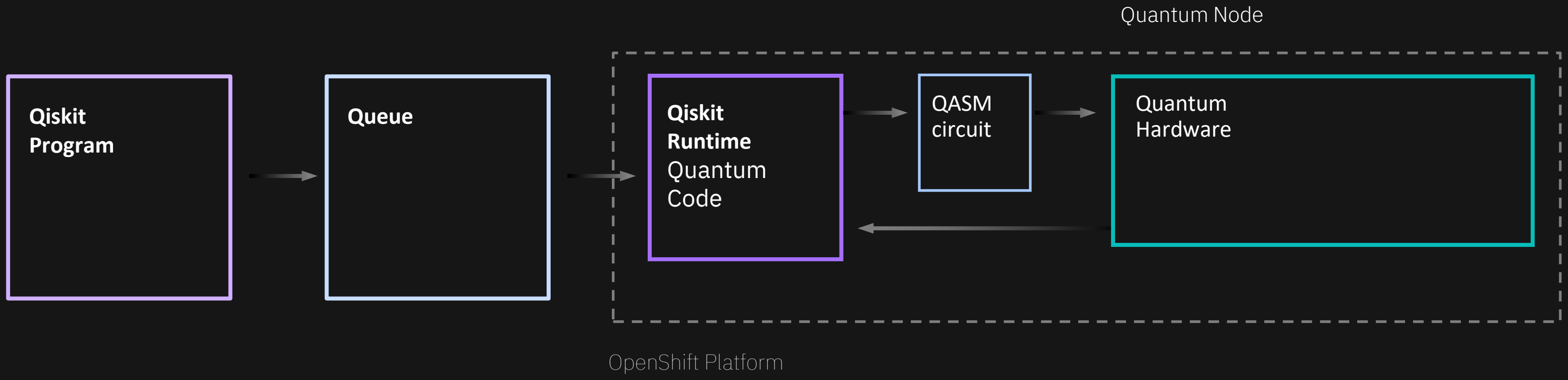
Structure of a typical workload



Real workloads are not purely quantum, but rather require interaction between quantum and classical compute resources.

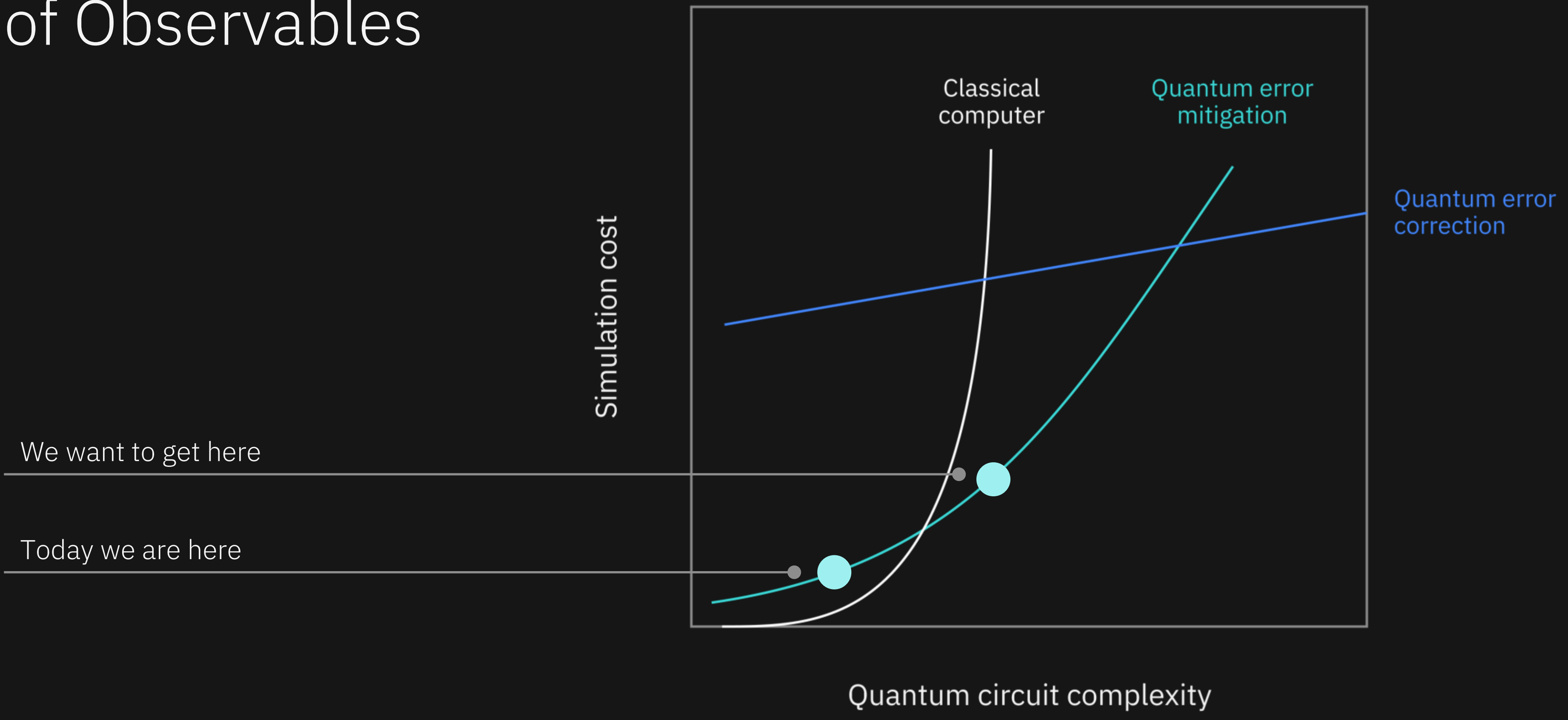
IBM Quantum © 2023 IBM Corporation

Near-time classical: Qiskit Runtime



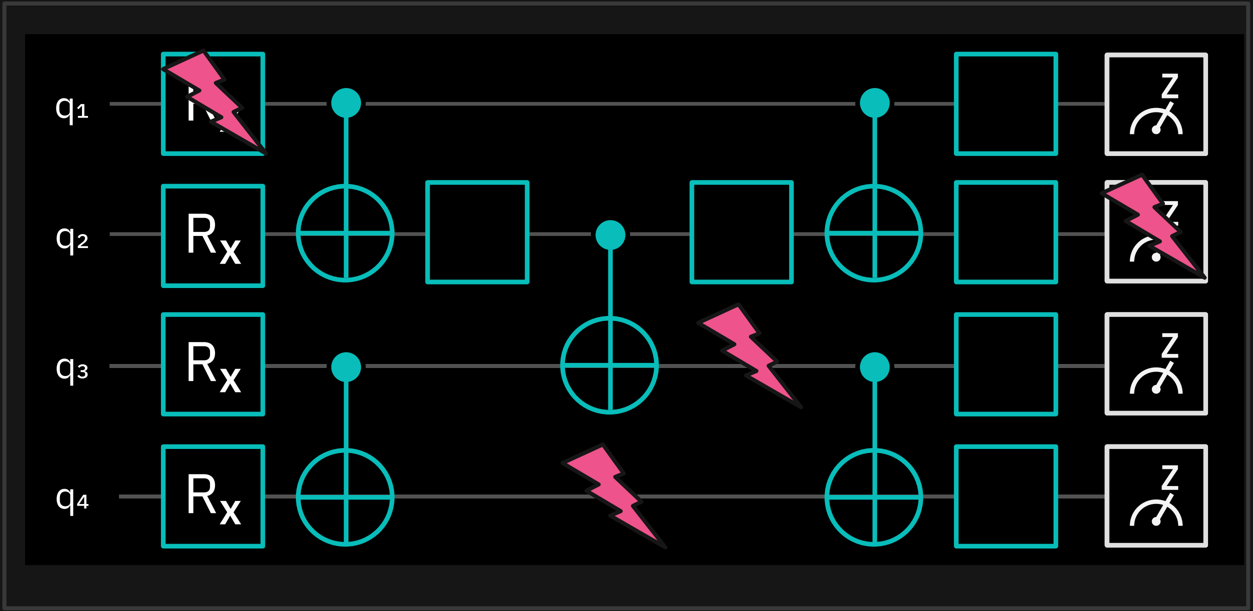
A high-performance system also requires low-latency interaction to generic classical compute.

Noise-free Estimates of Observables



Error Suppression and Mitigation

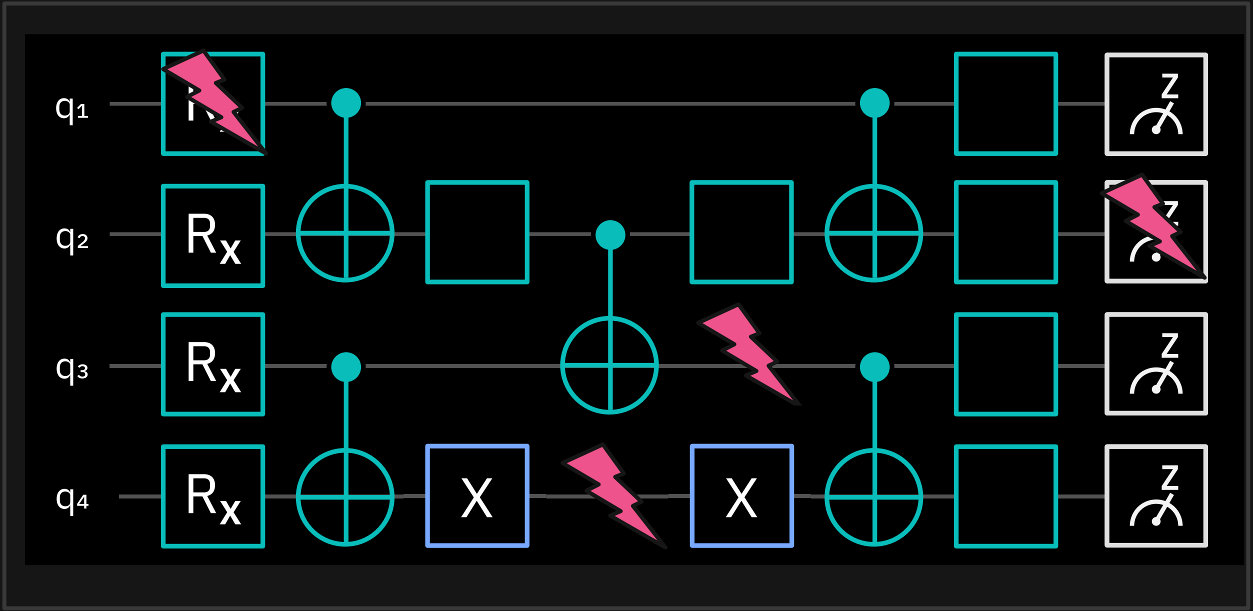
In quantum computation,
we must deal with errors.



Error Suppression and Mitigation

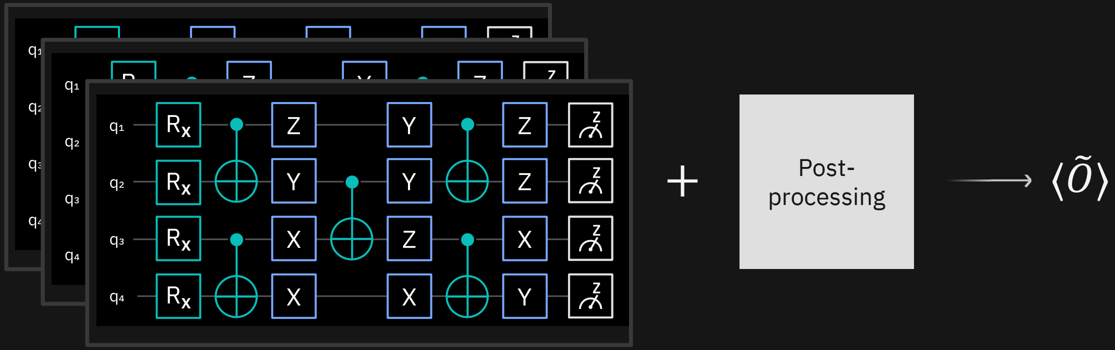
In quantum computation, we must deal with errors.

Error suppression reduces errors by modifying the circuit.



Error Suppression and Mitigation

Error mitigation uses outputs from ensembles of circuits to increase accuracy in expectation values.



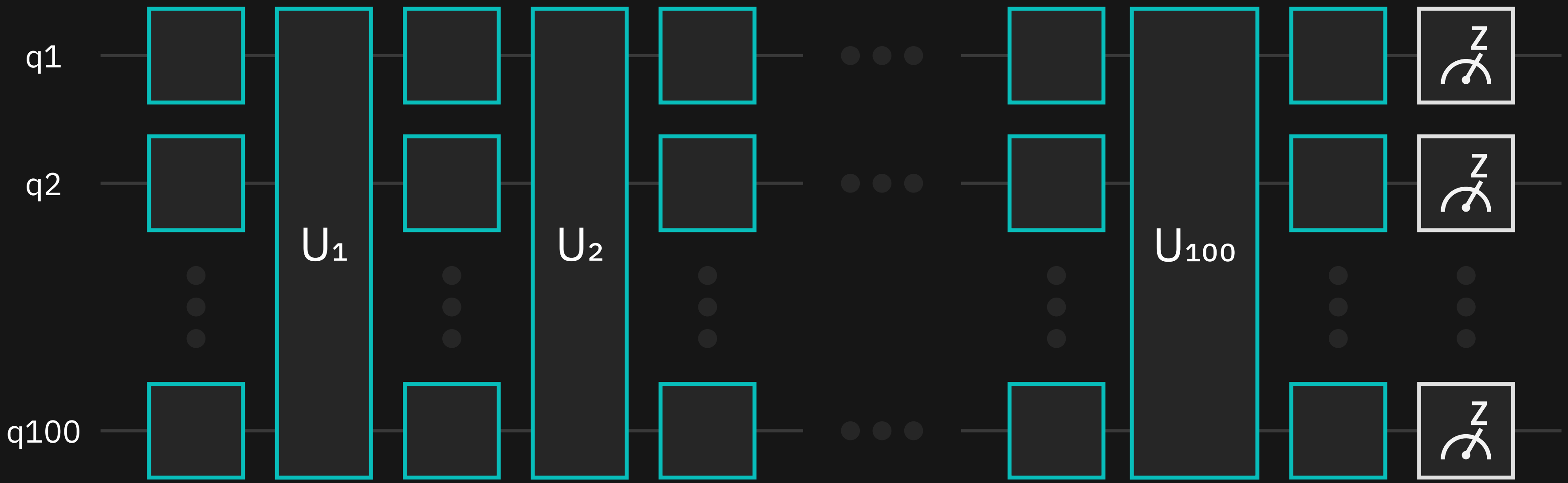
100 x 100 *challenge*

100x100 challenge

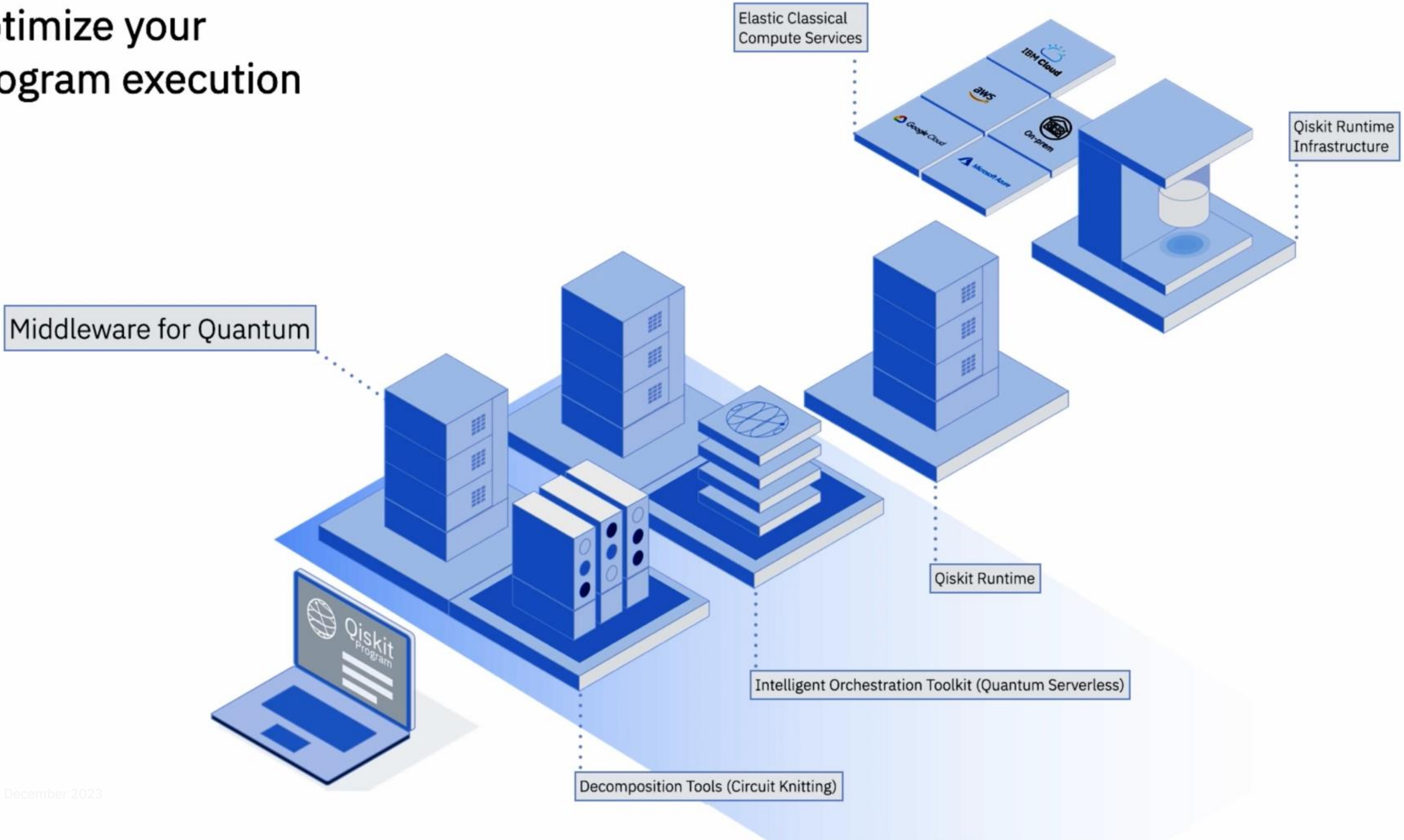
We want to build a tool, which beginning in 2024, is capable of estimating noise-free observables of circuits consisting of 100 qubits and depth 100 within a day.

100 qubits running at depth 100... but noise-free!

IBM **Quantum**



How to use services to optimize your program execution



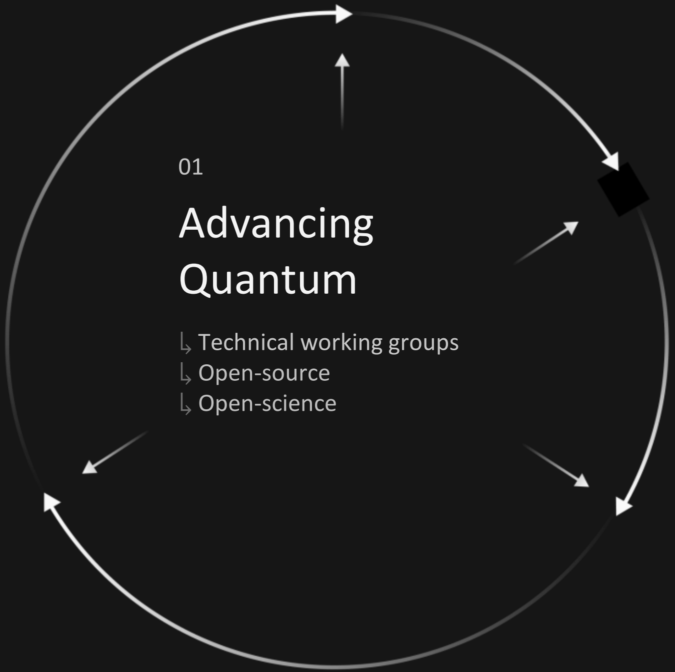
Building a Quantum Computing *Industry*

IBM **Quantum**

03

Industry Adoption

↳ Direct client interactions
↳ Scaling solutions with partner engagements



01

Advancing Quantum

↳ Technical working groups
↳ Open-source
↳ Open-science

04

Application Services

↳ Access compute resellers
↳ Software providers
↳ Application integration

02

Quantum Innovation Centers

↳ Access to leading-edge quantum compute services
↳ Research and development
↳ Education and workforce development
↳ Economic development

05

Quantum Safe

↳ Direct client interactions
  ↳ Prepare & Discover
  ↳ Assess & Plan Transformation
  ↳ Transform & Ongoing Observability

IBM Quantum Network members 250+ worldwide

1Qbit Systems
AIQTECH Inc
Adam Mickiewicz University
Agnostiq Inc
Alabama A&M University
Alabama State University
Albany State University
Algorithmiq Oy
Aliro Quantum
Amgen
Anaqor
AngelQ
Ansys Inc
Applied Quantum Computing
Argonne National Lab
Arizona State University
Assured Information Security
BP
Banco Bradesco
Baobab AiBIO
Beit
Boeing
Bosch
BosonQ Psi
Boston University
Bowie State University
Brookhaven National Lab
Bundeswehr University Munich
CERN
CMC Microsystems
Cambridge Quantum Computing
Capgemini SE
Carelon
Carnegie Mellon Software Engineering Institute
Center for Theoretical Physics Polish Academy of Sciences
Centrum Wiskunde & Informatica
Chalmers University of Technology
Chicago Quantum Exchange
Clark Atlanta University
Cleveland Clinic Foundation
Cognizant
ColdQuanta
ColibriTD
Consiglio Nazionale delle Ricerche - Istituto di calcolo e reti ad alte prestazioni
Coppin State University
Cornell University
Credit Mutuel
DIC Corporation
DNeuro.ai
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Dell Technologies
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Deutsches Elektronen Synchrotron
Dillard University
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ETH Zurich
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ExxonMobil
Fermi National Accelerator Laboratory
First Quantum
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Georgia Institute of Technology
Global Data Quantum
HQS Quantum Simulations
HSBC
Hampton University
Hanyang University
Hartree Center
Harvard University
Hitachi Ltd
Horizon Quantum Computing
Howard University
Hyundai Motor Company
IBM-HBCU Quantum Center - Howard University
IBM-Illinois Discovery Accelerator Institute - University of Illinois Urbana Champaign
III Taiwan
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Industrial Technology Research Institute
Infosys
Institute of Theoretical and Applied Informatics Polish Academy of Sciences
Iowa State University of Science and Technology
Israel Aerospace Industries
Istituto Italiano di Tecnologia
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JSR Corporation
Jij Inc.
JoS Quantum
Johns Hopkins University
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Lawrence Livermore National Laboratory
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Mitsubishi UFJ Financial Group
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Moderna
Mondragon Unibertsitatea
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Morgan State University
Multiverse Computing
National Energy Technology Laboratory
National Institute for Nuclear Physics
National Taiwan University
National University of Singapore
Naval Air Warfare Center Aircraft Division
Naval Air Warfare Center Weapons Div.
Naval Information Warfare Center Atlantic Command
Naval Information Warfare Center Pacific Command
Naval Surface Warfare Center
Netherlands Organization for Applied Scientific Research
Netherlands eScience Center
New Mexico State University
New York University
Norfolk State University
North Carolina AT State University
North Carolina Central University
North Carolina State University
Northeastern University
Northwestern University
OESIA
Oak Ridge National Lab
Pacific Northwest National Lab
Pfizer
Phasecraft
Plateforme d'Innovation Numerique et Quantique
Poznan Supercomputing and Networking Center
Prairie View AM University
Purdue University
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QC Ware
QCENTROID
QEDMA Quantum Computing
Qruise GmbH
Quantagonia
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Quantum South
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QuantumNET
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qBraid Co

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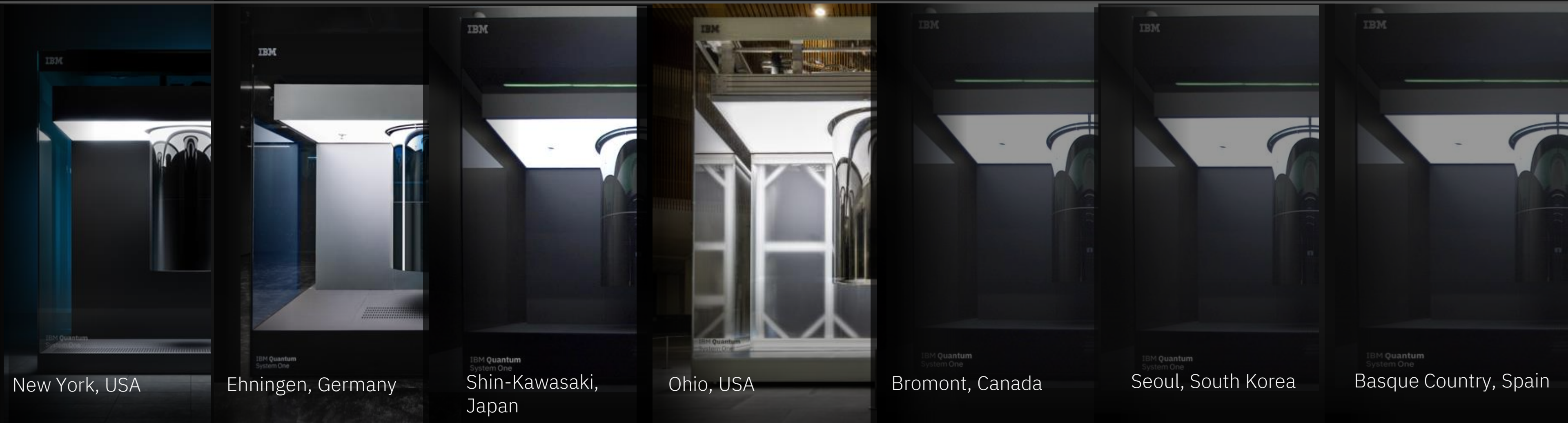
SAI - 5 December 2023

IBM Quantum Computation Centers (QCC)

Centers with dedicated Quantum Systems committed to advancing industry-specific initiatives or regional quantum ecosystems

- IBM Quantum datacenter in NY
- Fraunhofer – Dec 2020
- University of Tokyo – Jun 2021
- Cleveland Clinic – Mar 2023
- PINQ^2 – Sept 2023
- Yonsei – Projected 2023
- BasQ – Projected 2025

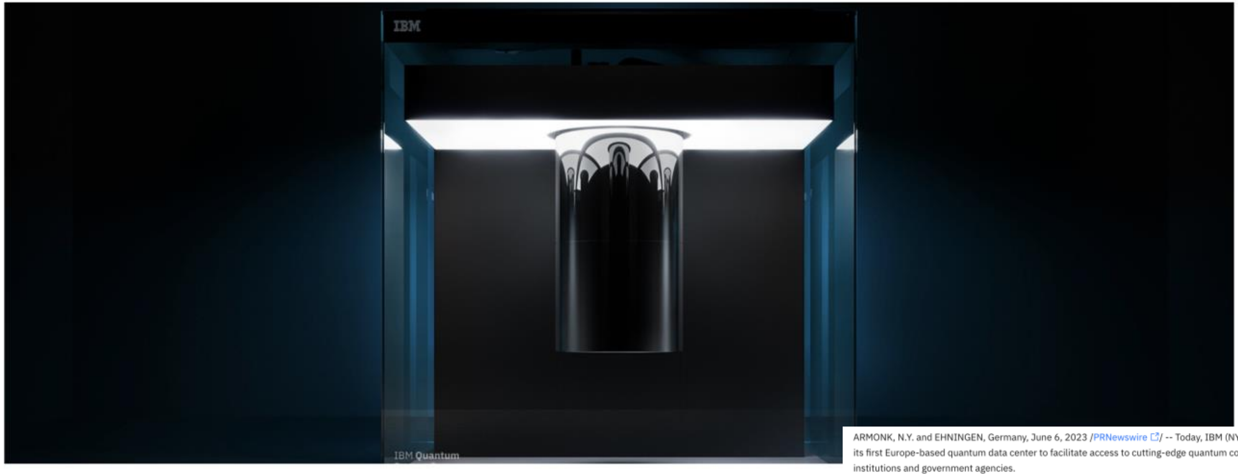


IBM to Build its First European Quantum Data Center to Serve Expanding Ecosystem

The IBM facility in Ehningen, Germany, expected to open in 2024

IBM Quantum to allow European cloud region users to provision quantum systems and process data within the EU

Jun 6, 2023



ARMONK, N.Y. and EHNINGEN, Germany, June 6, 2023 /PRNewswire/ -- Today, IBM (NYSE: IBM) announced plans to open its first Europe-based quantum data center to facilitate access to cutting-edge quantum computing for companies, research institutions and government agencies.

The data center is expected to be operational in 2024, with multiple IBM quantum computing systems, each with utility scale quantum processors, i.e., those of more than 100 qubits.

The data center will be located at IBM's facility in Ehningen, Germany, and will serve as IBM Quantum's European cloud region. Users in Europe and elsewhere in the world will be able to provision services at the data center for their cloud-based quantum computing research and exploratory activity. The data center is being designed to help clients continue to manage their European data regulation requirements, including processing all job data within EU borders. The facility will be IBM's second quantum data

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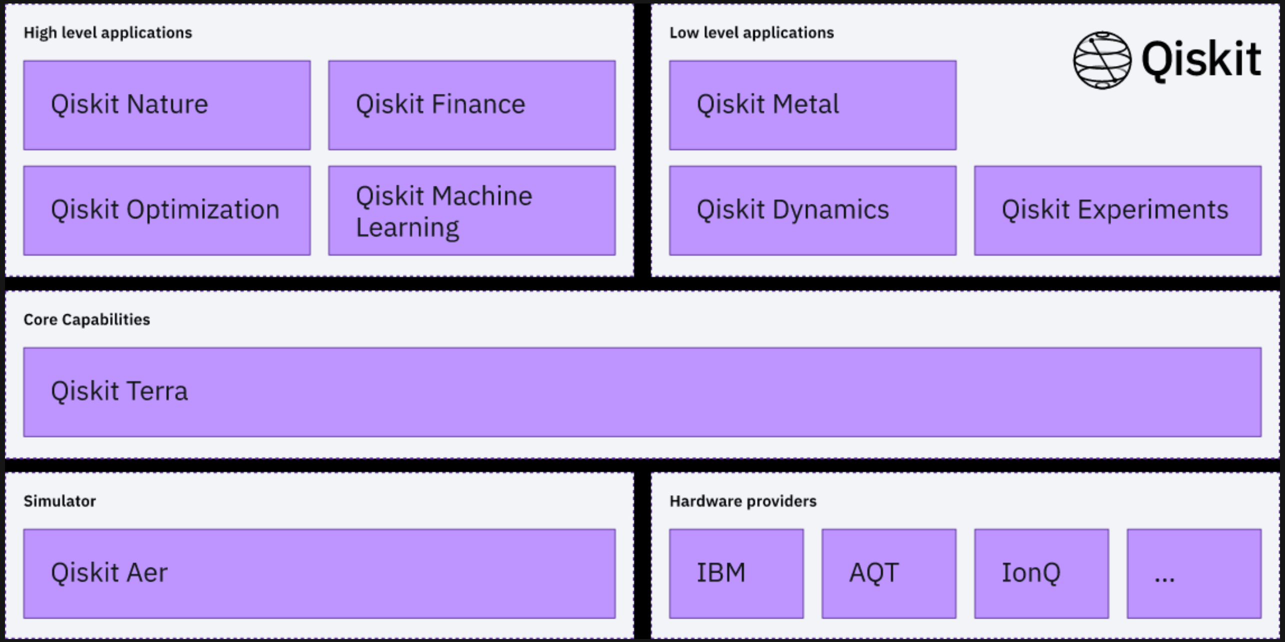
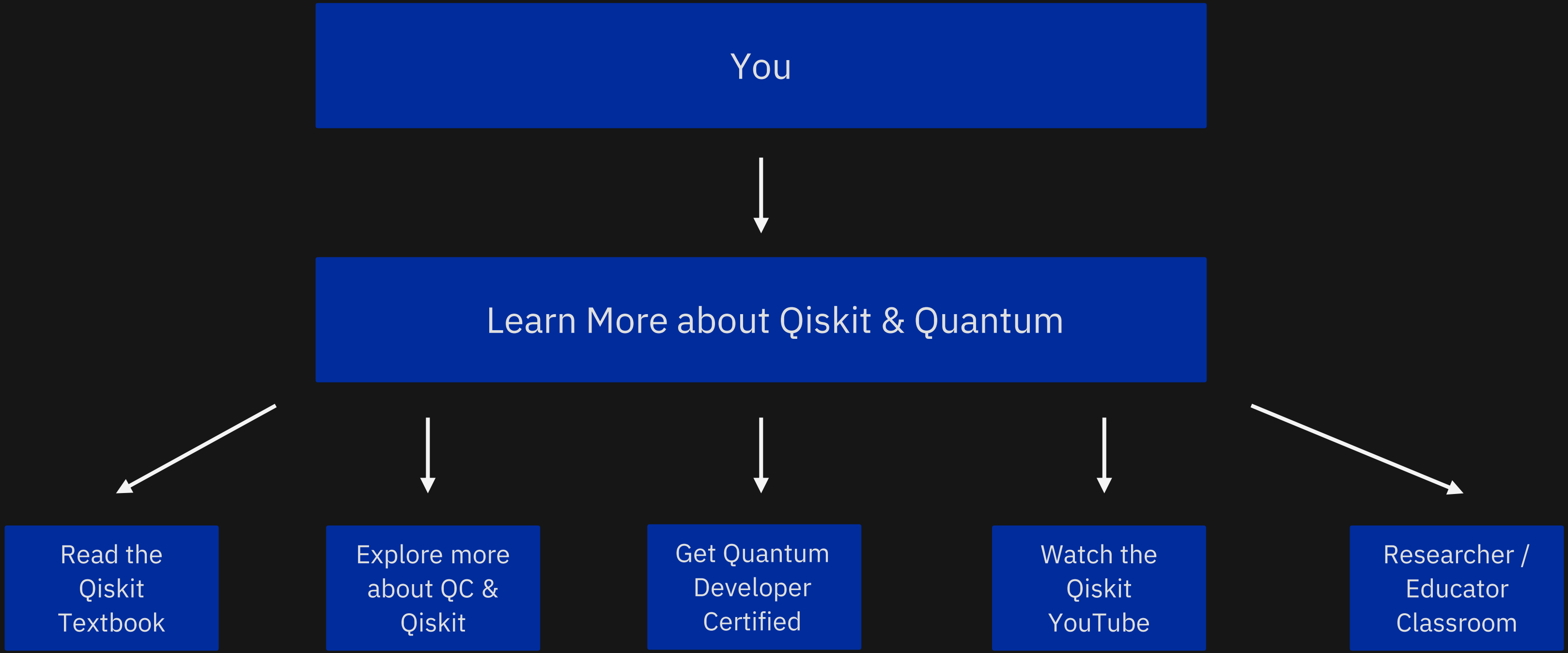
center and quantum cloud region, after Poughkeepsie, New York.

"Europe has some of the world's most advanced users of quantum computers, and interest is only accelerating with the era of utility scale quantum processors," said Jay Gambetta, IBM Fellow and Vice President of IBM Quantum. "The planned quantum data center and associated cloud region will give European users a new option as they seek to tap the power of quantum computing in an effort to solve some of the world's most challenging problems."

"Our quantum data center in Europe is an integral piece of our global endeavor," said Ana Paula Assis, IBM General Manager for EMEA. "It will provide new opportunities for our clients to collaborate side-by-side with our scientists in Europe, as well as their own clients, as they explore how best to apply quantum in their industry."

Qiskit – Open-Source SDK

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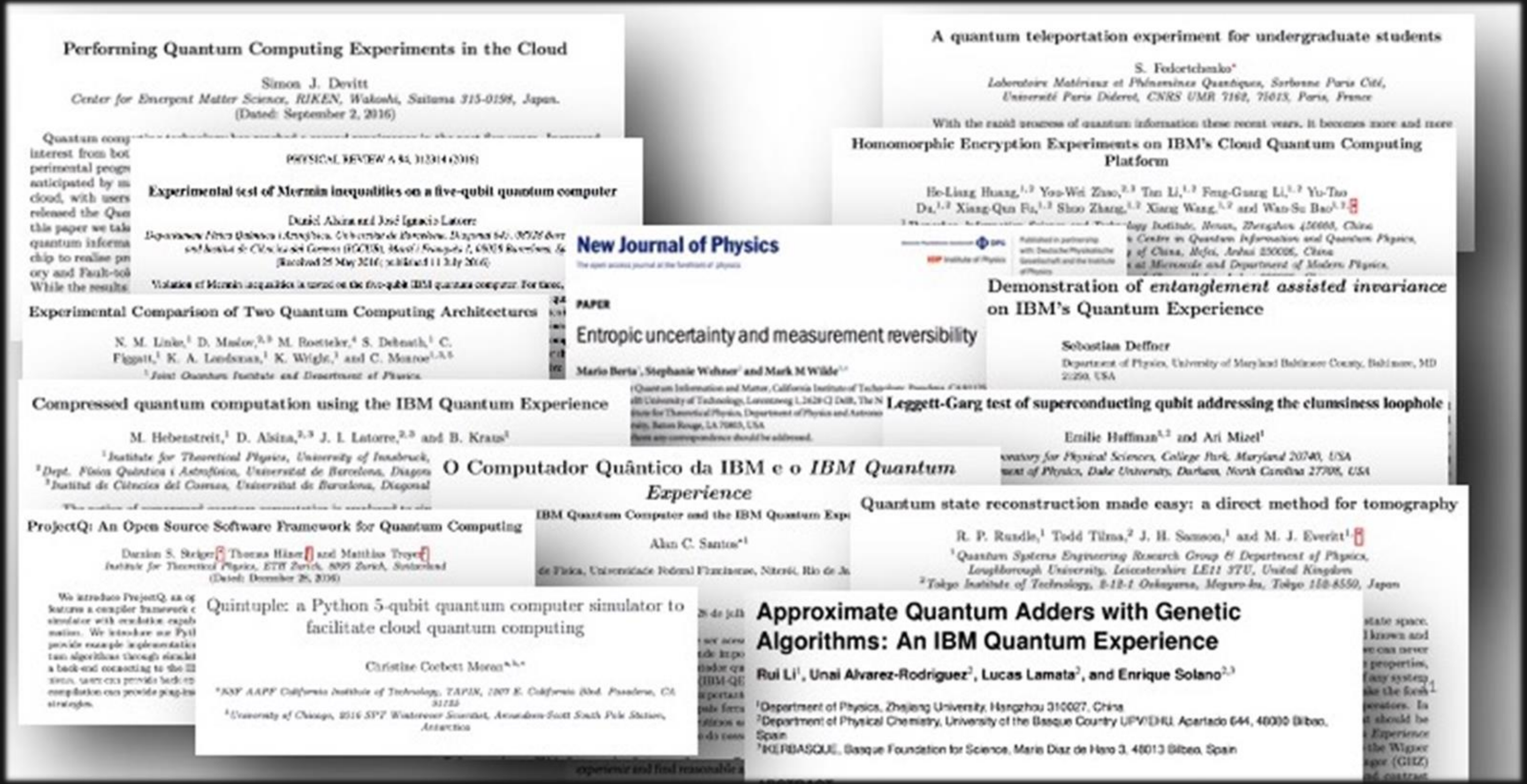


Our modern digital world depends on public key *cryptography*

This is now a problem

Journey to Quantum Safe

U.S. National Institute of Standards and Technology announced the first quantum-safe cryptography protocol standards for cybersecurity (July 2022), three of which were created by IBM in collaboration with industry and academic partners.

Purpose	Algorithm
Public-key Encryption and Key establishment Algorithms	CRYSTALS-Kyber
Digital Signature Algorithms	CRYSTALS-DILITHIUM
DSA (alternate)	Falcon
DSA (alternate)	SPHINCS+
NIST Selected Algorithms, July 5th 2022. NIST recommended two primary algorithms to be implemented for most use cases: CRYSTALS-KYBER (key-establishment) and CRYSTALS-Dilithium (digital signatures).	NIST National Institute of Standards and Technology U.S. Department of Commerce

US Government

establishes timeline for transition to CNSA 2.0-compliant algorithms

z16

First Quantum-safe platform

GSMA Telco Consortium

Support industry transition to quantum-safe cryptography

vodafone

GSMA Taps IBM, Vodafone for Post-Quantum Taskforce

IBM Quantum Safe

Support client transition to quantum-safe cryptography

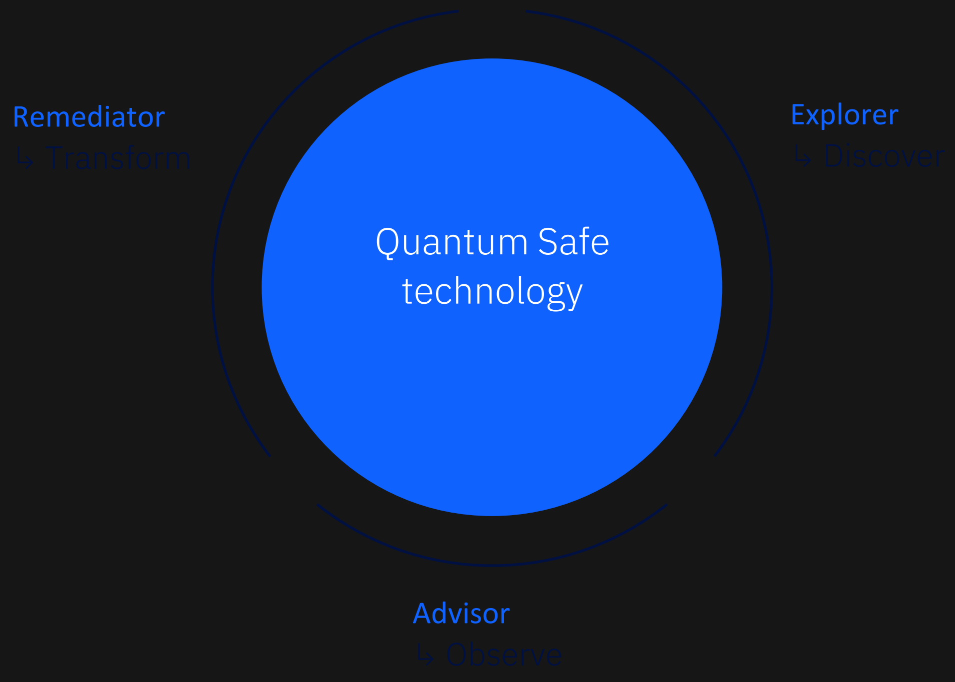
IBM technology helping clients throughout their journey to quantum safe

Technology with expertise powering client engagements

Quantum Safe Explorer
↳ discover your cryptography
Scan source code and object code for cryptography usage and generate cryptography bill of materials (CBOM)

Quantum Safe Advisor
↳ observe your cryptography
Analyze cryptography posture of compliance and vulnerabilities, prioritize remediation actions

Quantum Safe Remediator
↳ transform your cryptography
Apply remediation patterns for implementation of crypto-agility



Quantum Computing

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ibm.com/quantum

Tools

Access IBM **Quantum** Systems via

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- Quantum Lab

quantum-computing.ibm.com

Quantum Safe

Securing the world's digital infrastructure for the era of quantum computing

ibm.com/quantum/quantum-safe

Report:

Security in the quantum computing era

(IBM Institute for Business Value)

Qiskit

Open Source Quantum Development

Qiskit textbook

- Online learning
- Qiskit Community

qiskit.org

Qiskit YouTube Channel

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Contact IBM **Quantum**

Send an e-mail so an IBM Quantum representative may follow up with you.

$$\langle 10 - Q \rangle$$

for your attention !