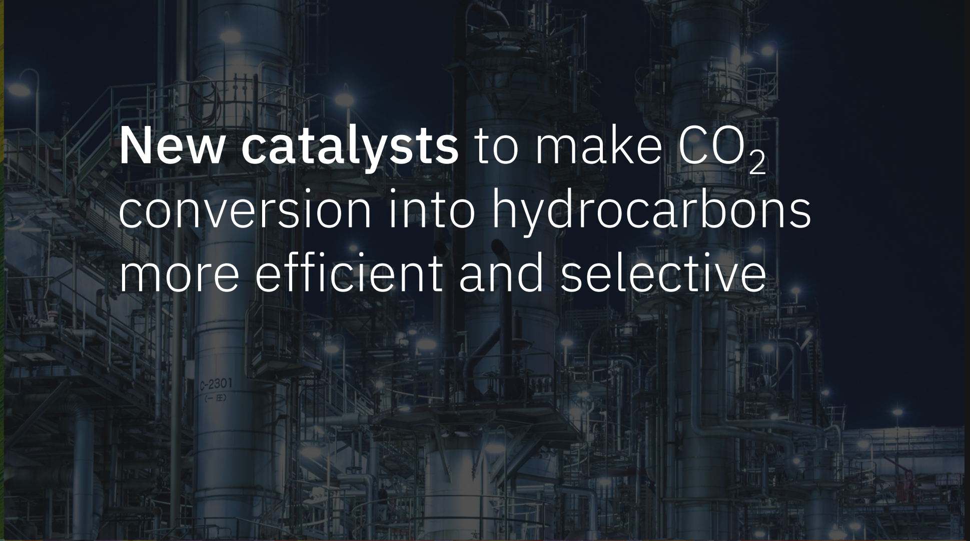
IBM Quantum:
An Introduction

https://ibm.com/quantum-computing

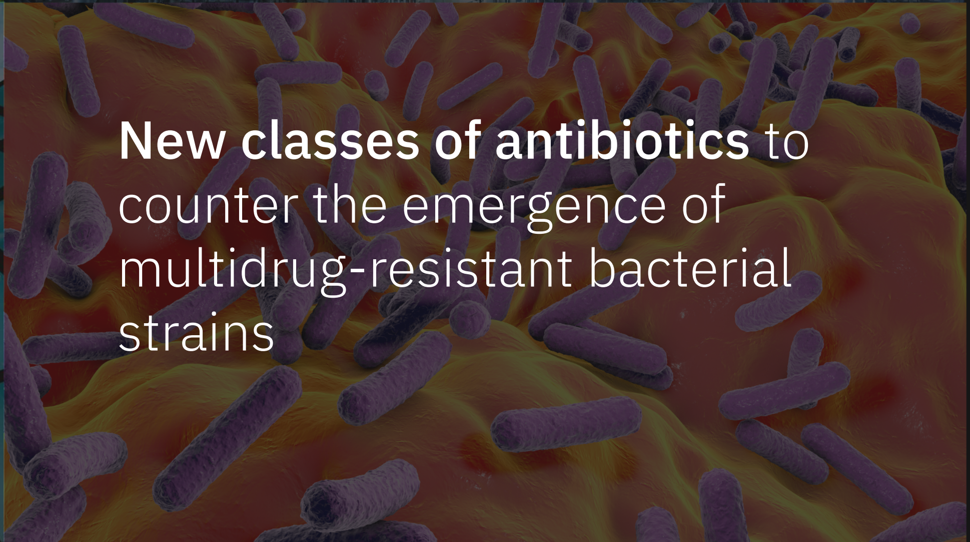
https://qiskit.org

IBM **Quantum**

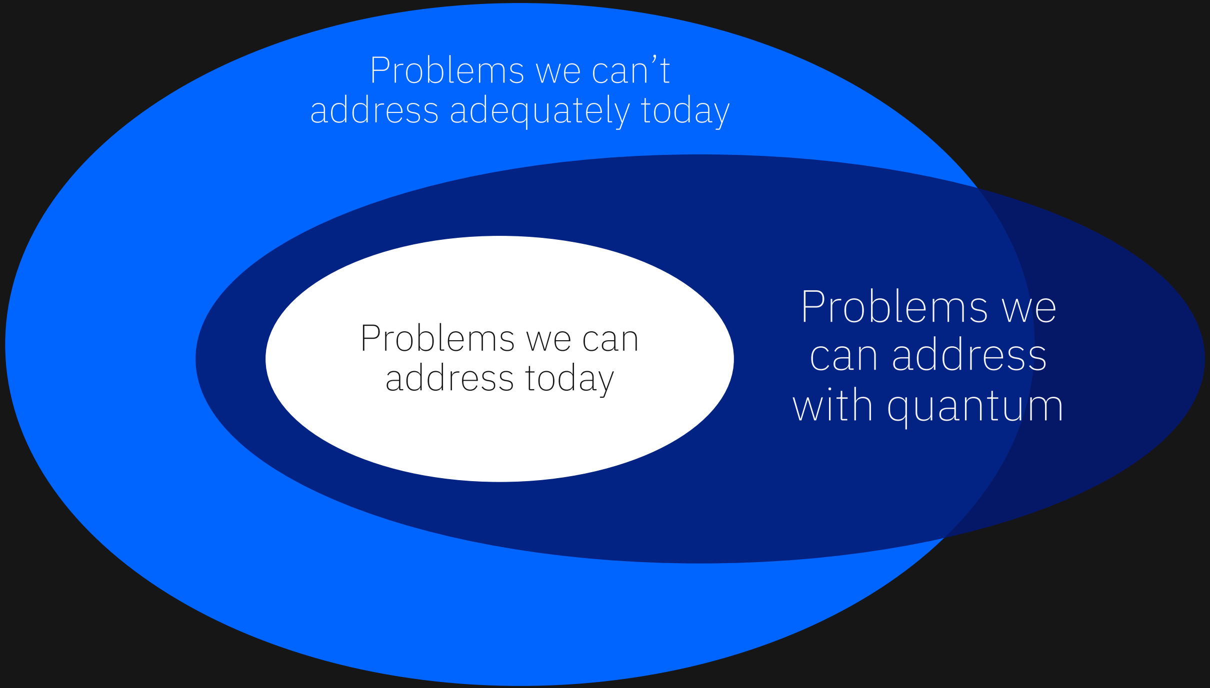

Improved nitrogen-fixation process for creating ammonia-based fertilizer


New catalysts to make CO_2 conversion into hydrocarbons more efficient and selective


Better financial models to improve stability, predictability and growth of world economies


New classes of antibiotics to counter the emergence of multidrug-resistant bacterial strains

Why quantum?



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

Quantum applications span three general areas

Simulating Quantum Systems

- Quantum chemistry
- Material science
- High energy physics

Artificial Intelligence

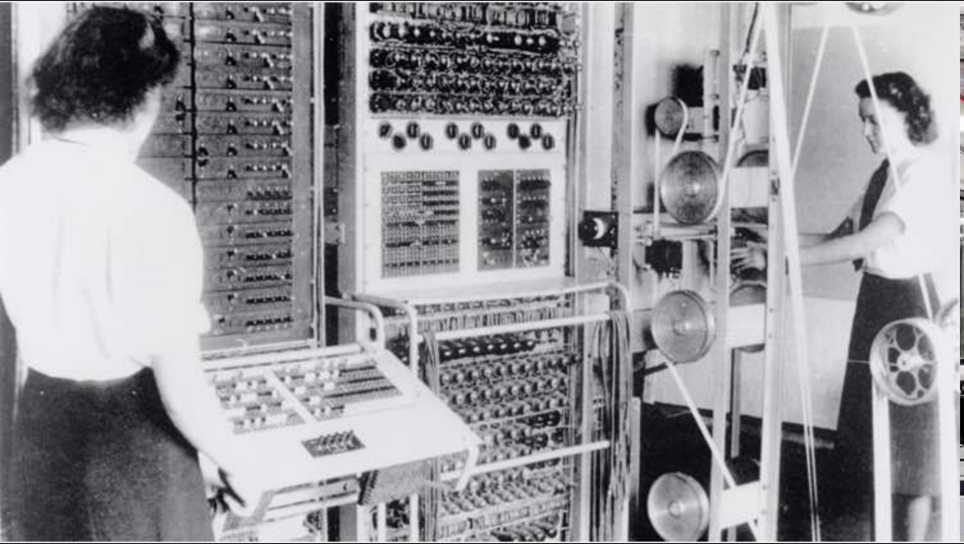
- Better model training
- Pattern recognition
- Fraud detection

Optimization / Monte Carlo

- Portfolio optimization
- Risk analysis
- Loans & credit scoring
- Monte Carlo-like applications

We are in the early stages of a rapidly advancing new computing technology

IBM **Quantum**



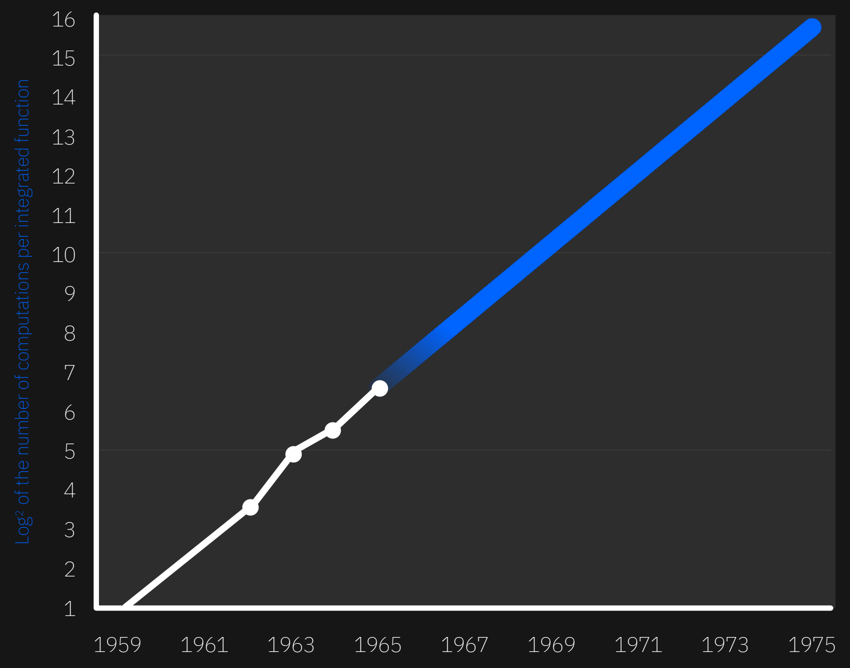
Computer: 1944

Quantum Computer: 2019

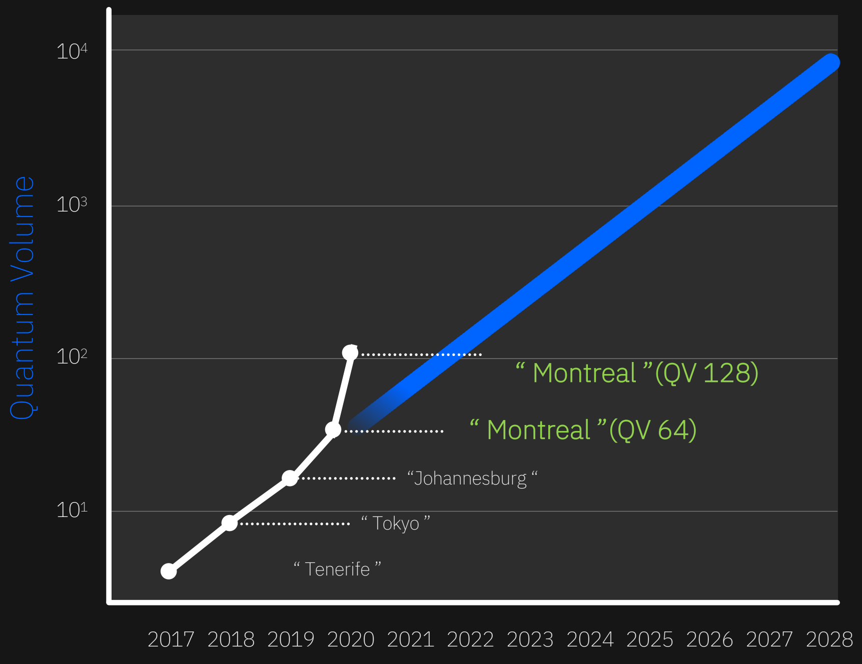
We are in the early stages of a rapidly advancing new computing technology

IBM **Quantum**

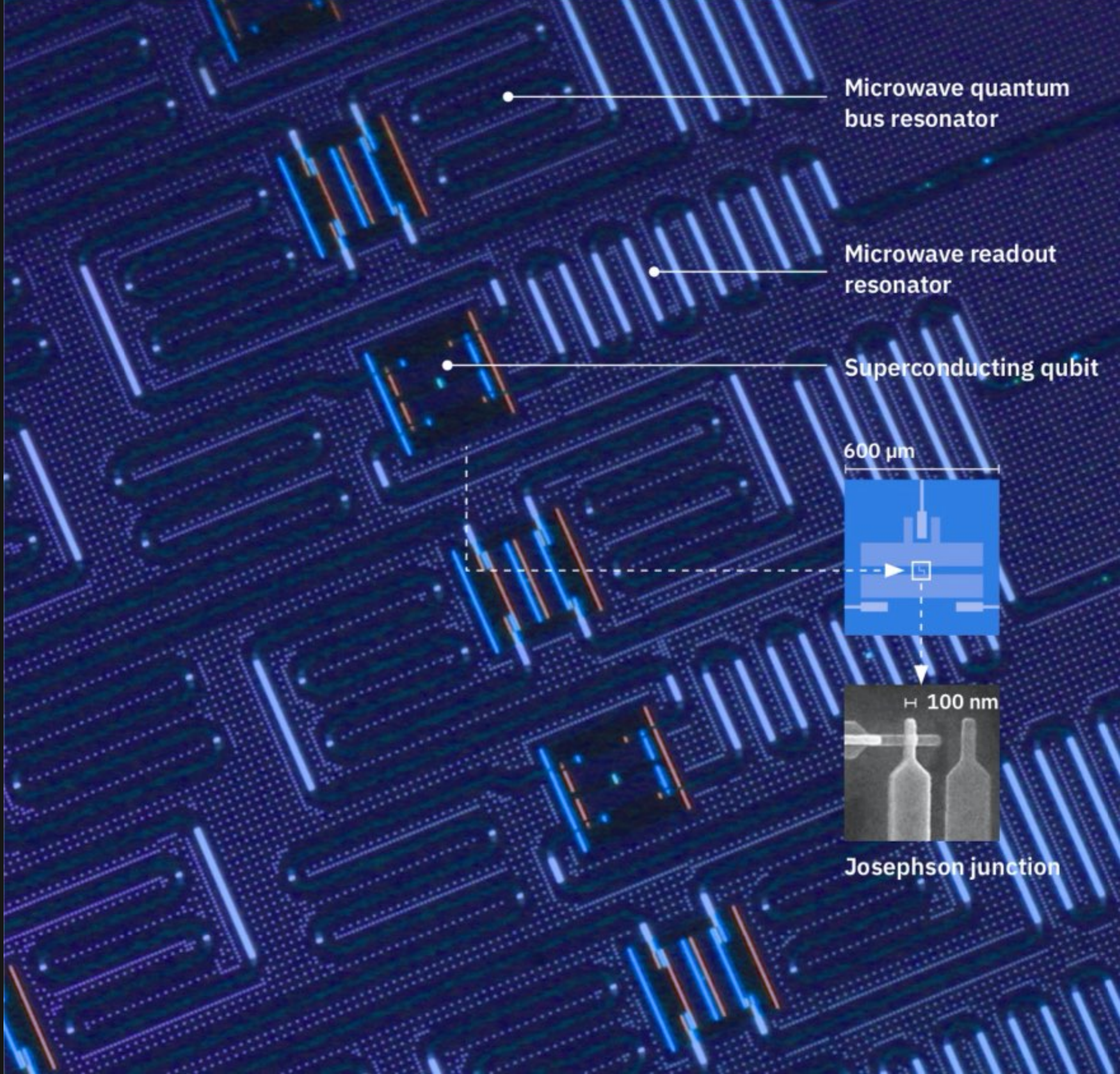
Moore's law



Quantum Volume: The New Moore's Law

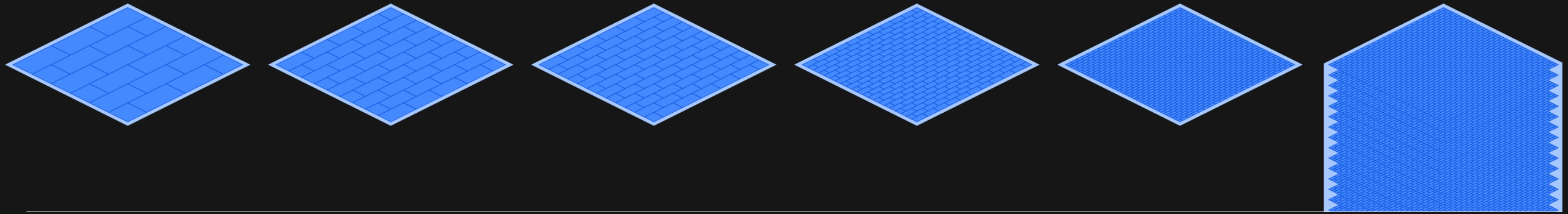


Inside an IBM Quantum Chip



Scaling IBM Quantum technology

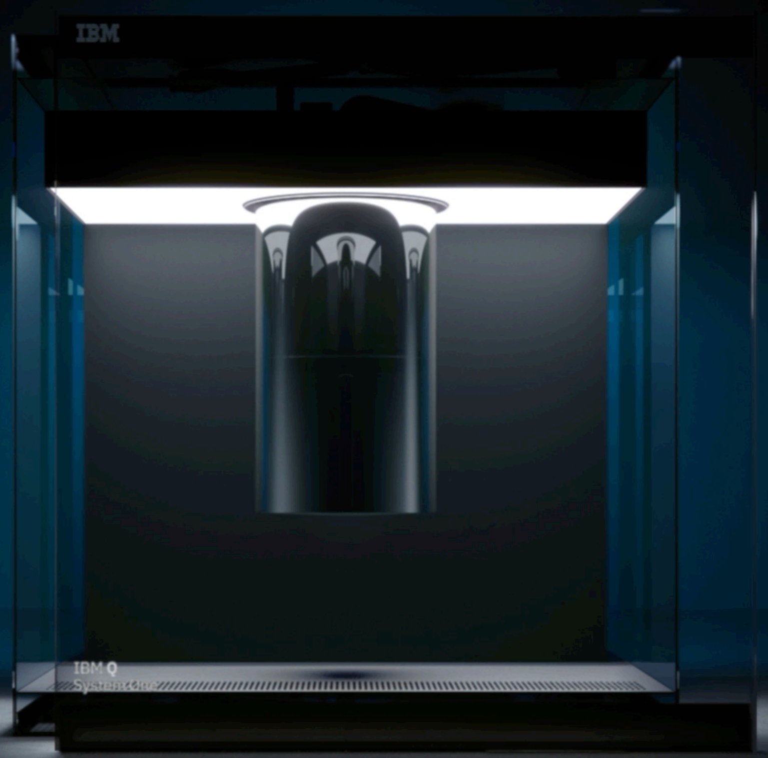
IBM Quantum System One (Released)		(In development)		Next family of IBM Quantum systems	
2019	2020	2021	2022	2023	and beyond
27 qubits *Falcon*	65 qubits *Hummingbird*	127 qubits *Eagle*	433 qubits *Osprey*	1,121 qubits *Condor*	Path to 1 million qubits and beyond *Large scale systems*



Key advancement	Key advancement	Key advancement	Key advancement	Key advancement	Key advancement
Optimized lattice	Scalable readout	Novel packaging and controls	Miniaturization of components	Integration	Build new infrastructure, quantum error correction

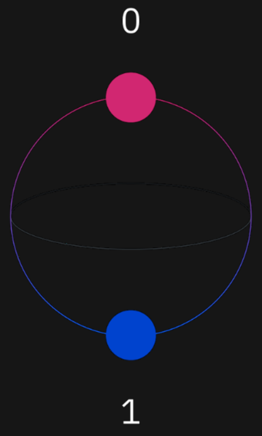
IBM Quantum System One

IBM Research prototype in Yorktown, NY.

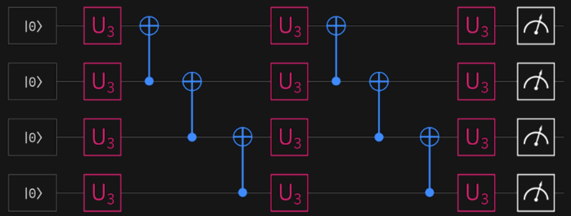


Quantum bits and quantum circuits

IBM **Quantum**



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

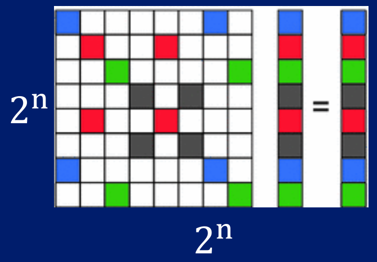
Quantum Circuits for Applications

IBM **Quantum**

Quantum Simulations

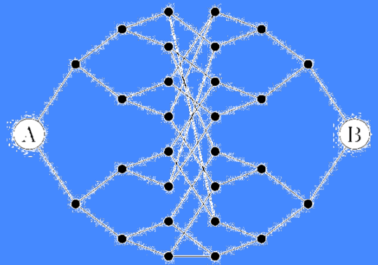
- Physics
- Chemistry
- Materials discovery

Linear Systems ($\mathbf{Ax} = \mathbf{b}$)



- Network analysis
- Differential equations
- Option pricing, heat transfer
- Classification (Machine Learning)

Quantum Walks



- Graph properties (network flows, electrical resistance)
- Search
- Collision finding

What will it take to make quantum computing a practical part of an industry-relevant workflow?

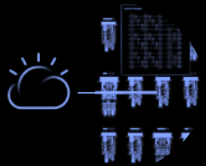
IBM **Quantum**

Quality

How well are circuits implemented in quantum systems?

Low operation errors mean large Quantum Volume for larger circuits to run effectively

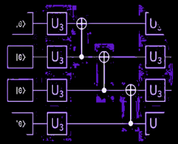
Capacity



How many circuits can run on quantum systems?

Seamless synchronization of quantum and classical circuits increase the rate at which circuits can run

Variety



What kind of circuits can be implemented in quantum systems?

Dynamical integration of quantum and classical operations reduce the computational overhead for quantum advantage.

Development Roadmap

IBM **Quantum**

2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026+

Enterprise Clients

2019–2022:
Use case exploration
Problem mapping
Skills building

2023–2026+:
Workflow integration
Application development
Skills building

Model developers

Quantum model services (2023–2026+): Natural Sciences, Finance, Optimization, Machine Learning

Algorithm developers

Qiskit application modules (2020–2022): Natural Sciences, Finance, Optimization, Machine Learning

Prebuilt quantum runtimes (2023–2024)

Prebuilt quantum + HPC runtimes (2025–2026+)

Kernel developers

Circuits (2019–2020)

Qiskit Runtime (2021)

Dynamic circuits (2022)

Circuit libraries (2023–2024)

Advanced control systems (2025–2026+)

Quantum systems

Falcon 27 qubits (2019)

Hummingbird 65 qubits (2020)

Eagle 127 qubits (2021)

Osprey 433 qubits (2022)

Condor 1121 qubits (2023)

Beyond 1K - 1M+ qubits (2024–2026+)

IBM Cloud

Circuits (2019–2020)

Programs (2021–2022)

Models (2023–2026+)

Key take-aways

To take full advantage of IBM Quantum's increasingly powerful hardware, we are announcing a detailed **Development Roadmap** through 2025.

We are implementing this industry-defining roadmap through:

- **The Qiskit Runtime** to run quantum applications 100x faster on the IBM Cloud,
- **Dynamic circuits** to bring real-time classical computing to quantum circuits, improving accuracy and reducing required resources, and
- **Qiskit application modules** to lay the foundation for quantum model services and frictionless quantum workflows.

The Limits of Bits

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

But the future isn't just 1s and 0s.

IBM Quantum Network

A collaborative community of discovery

Educate and Train

Accelerate Research

Develop Applications

IBM Quantum Network: A Snapshot

Over 300,000 users have...

Run over 700 Billion quantum circuits

1.4 Billion quantum circuits per day

using total 34 quantum computers deployed up top date

More than 140 Clients and Partners

Collaborating on 30+ applications

Over 300 contributors to Qiskit

Over 400 scientific papers so far

IBM Quantum

Advancing technology platform and enabling our partners.

Our Partners

Advancing applications and enabling technology and guiding IBM.

Our Model

Advance the technology and practical implementation of applications and algorithms.

Build a cloud platform for application development and deployment in industry.

Algorithm Families

Quantum Simulation

Linear Systems

Quantum Walks

User Types

Application Developers

Algorithm Developers

Kernel Developers

New battery materials
Manufacturing optimization
Benchmarking
Electronic materials
Transaction classification
Compilers and transpilers
Product recommendation
Fraud detection
Random Number Generation
Chemical observable prediction
Logistics and routing optimization
Financial transaction settlement
Portfolio optimization
Variational optimization/factoring
Classical control hardware
Risk analysis and options pricing
Material degradation

A Snapshot of Global Collaboration in the IBM Quantum Network

IBM Quantum

Publishes algorithm paper on Amplitude Estimation.

Zurich, Switzerland

Keio University

Advance method, publishes with Mizuho and MUFG.

Tokyo, Japan

JPMorgan Chase

Applies the method to options pricing and publishes.

New York, USA

Qiskit

Contributed code into open source Qiskit for all to use.

Global

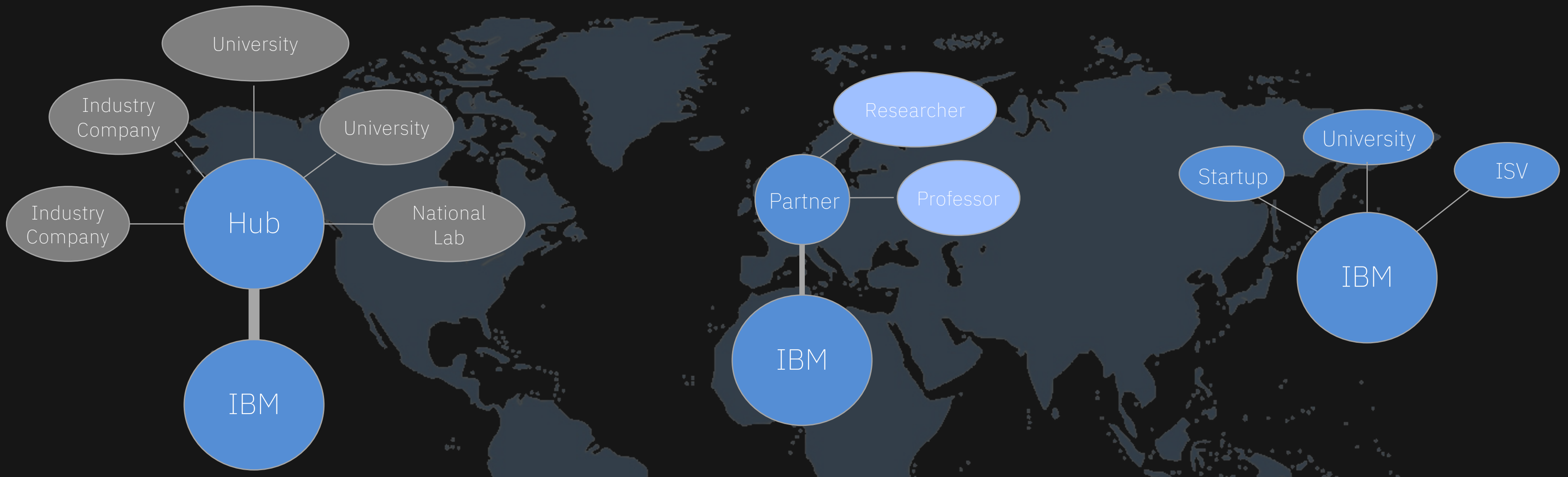
IBM Quantum Network Today

Total: 140 members worldwide

1QBit
A*Quantum
Aalto University
Accenture
Agnostiq
AIQTech
AIS
Aliro
Amgen
Anthem
Apply Science
Archer
Argonne Lab
Barclays
BEIT
Berkeley Lab
Boeing
Boston University
Boxcat
BP
Brookhaven Lab
CERN
Chalmers University
CMC
CMU-SEI
Cornell
CQC
CSIC Spain
CU Boulder
Daimler
Delta
Deloitte
DIC
Duke
EDX.org
Entropica
EPFL
Equal1
ETH Zurich
ExxonMobil
Fermilab
Flight Profiler
Florida State
Fraunhofer
GE Research
General Atomics
Georgia Tech
Goldman Sachs
Grid
Harvard
Hitachi
Iberian Nanotech Lab
III Taiwan
ITRI
Johns Hopkins
JoS Quantum
JP Morgan Chase & Co.
JSR Corp
KAIST
Keio University
Keysight
Lockheed Martin
Los Alamos National Laboratory
MaxKelsen
MDR
Miraex
MIT
Mitsubishi Chemical
Mizuho
Molecular Forecaster
MUFG
Multiverse
Munich Hub at U. Bundeswehr
National Taiwan University
National U. Singapore
NC State University
Netramark
New Mexico State University
Nordic Quantum
Northwestern
Notre Dame
NYU
Oak Ridge National Lab
Opacity
Pacific Northwest Labs
Paypal
Phasecraft
Princeton
ProteinQure
Purdue
Q-CTRL
QC Ware
Qu&Co
QuantFi
Quantum Benchmark
Quantum Machines
Quemix
Qunasys
Rahko
Saarland University
Samsung
Sandia National Lab
SoftwareQ
SolidStateAI
Sony
Stanford
Strangeworks
SuMiTB
Super.tech
SVA
Toshiba
Toyota
Tradeteq
U. Automata Madrid
U. Basque Country
U. Chicago
U. Georgia
U. Illinois
U. Innsbruck
U. Melbourne
U. Minho
U. Montpellier
U. New Mexico
U. Oxford
U. Sherbrooke
U. Stony Brook
U. Tennessee
U. Turku
U. Waterloo
University of Tokyo
US Air Force Research Lab
US Naval Research Lab
Virginia Tech
Wells Fargo
Wits
Woodside Energy
Xanadu
Yokogawa
Zapata
Zurich Instruments

IBM Quantum Network Partnership Structures

IBM **Quantum**



Hubs

Regional centers of quantum R&D and education centered on leading research institutions.

Industry

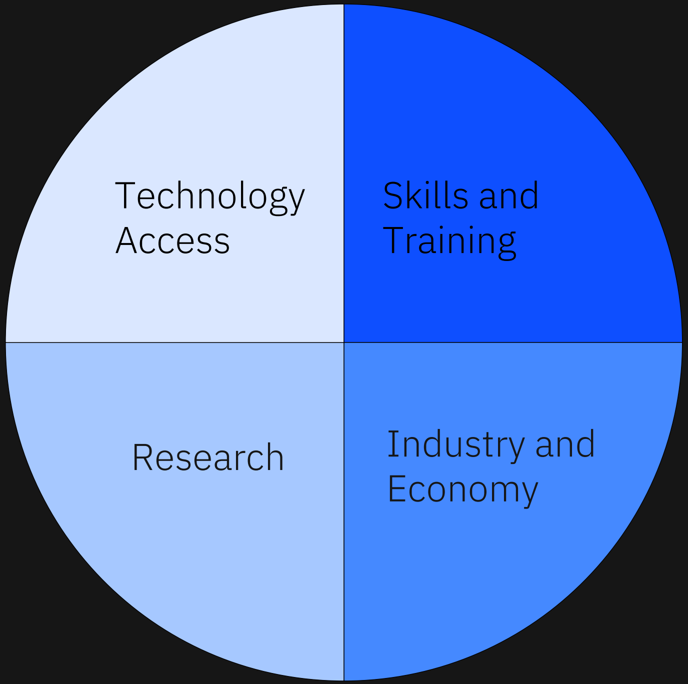
Deep collaborative research on applications utilizing IBM Quantum systems and collaboration.

Ecosystem

Enabling organizations to learn and leverage IBM Quantum for their development and products.

Building a Quantum Industry and Ecosystem

IBM and organizations worldwide are partnering to advance quantum computing with broad-scale, jointly-run programs to advance quantum across all four essential areas.



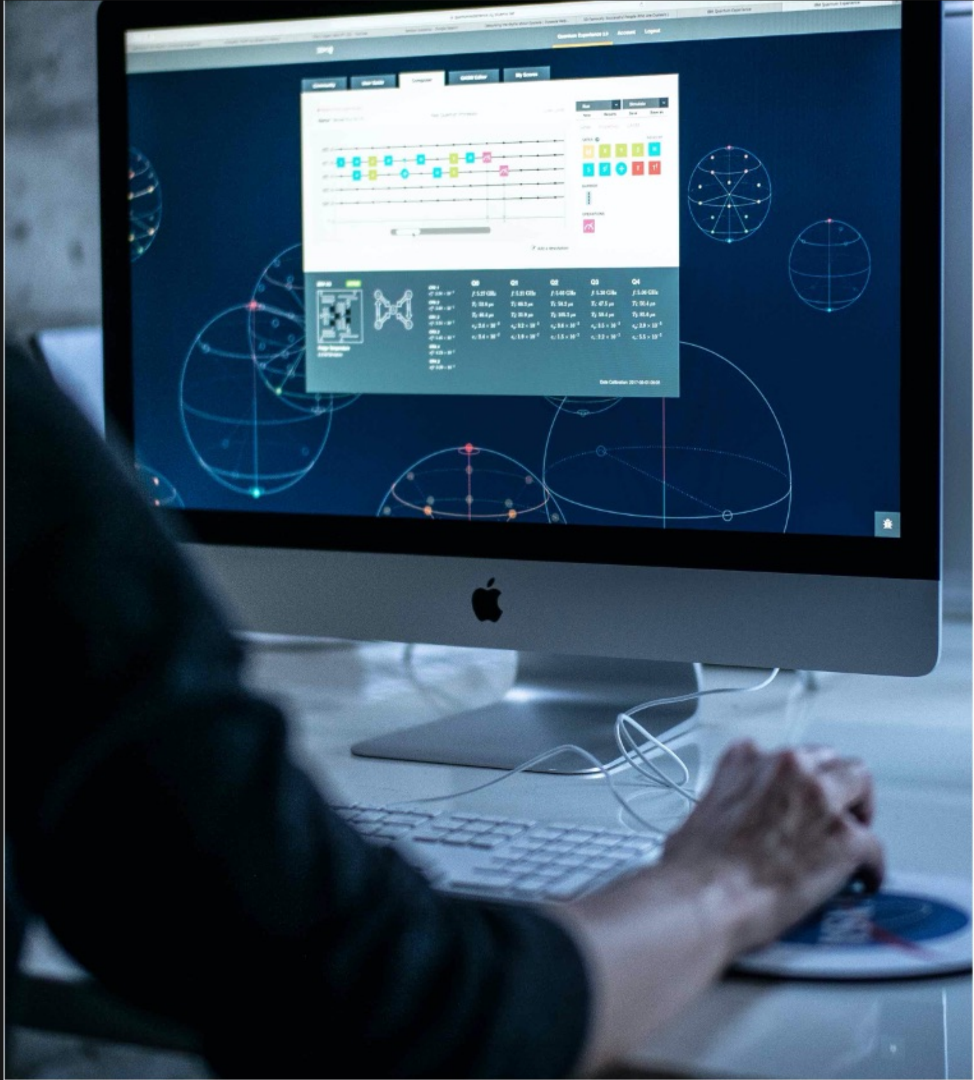
Technology Access

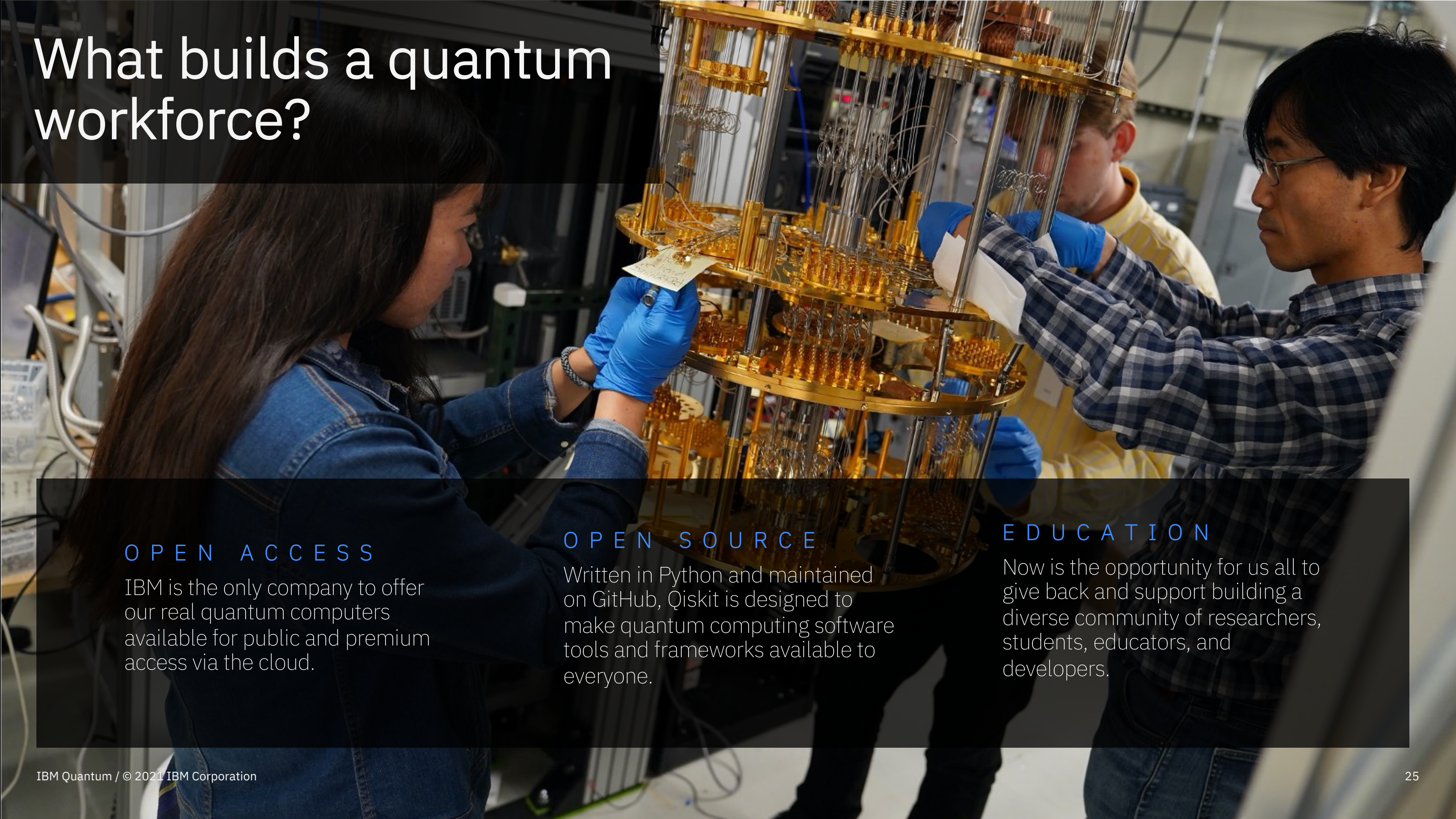
IBM Quantum Computation Center

34 quantum computers to date have deployed on the IBM Cloud.

Spanning 5 to 65 qubits

> 95% system availability to users





What builds a quantum workforce?

OPEN ACCESS

IBM is the only company to offer our real quantum computers available for public and premium access via the cloud.

OPEN SOURCE

Written in Python and maintained on GitHub, Qiskit is designed to make quantum computing software tools and frameworks available to everyone.

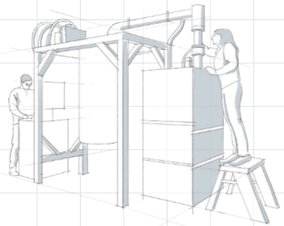
EDUCATION

Now is the opportunity for us all to give back and support building a diverse community of researchers, students, educators, and developers.

Open Source Textbook

https://qiskit.org/textbook/

Learn Quantum Computation using Qiskit



Greetings from the Qiskit Community team! This textbook is a university quantum algorithms/computation course supplement based on Qiskit to help learn:

1. The mathematics behind quantum algorithms
2. Details about today's non-fault-tolerant quantum devices
3. Writing code in Qiskit to implement quantum algorithms on IBM's cloud quantum systems

Read the textbook →

Traditional Quantum Computation Course

Linear Algebra
Quantum Mechanics → Quantum Algorithms → Quantum Hardware

Learn Quantum Computation using Qiskit Textbook

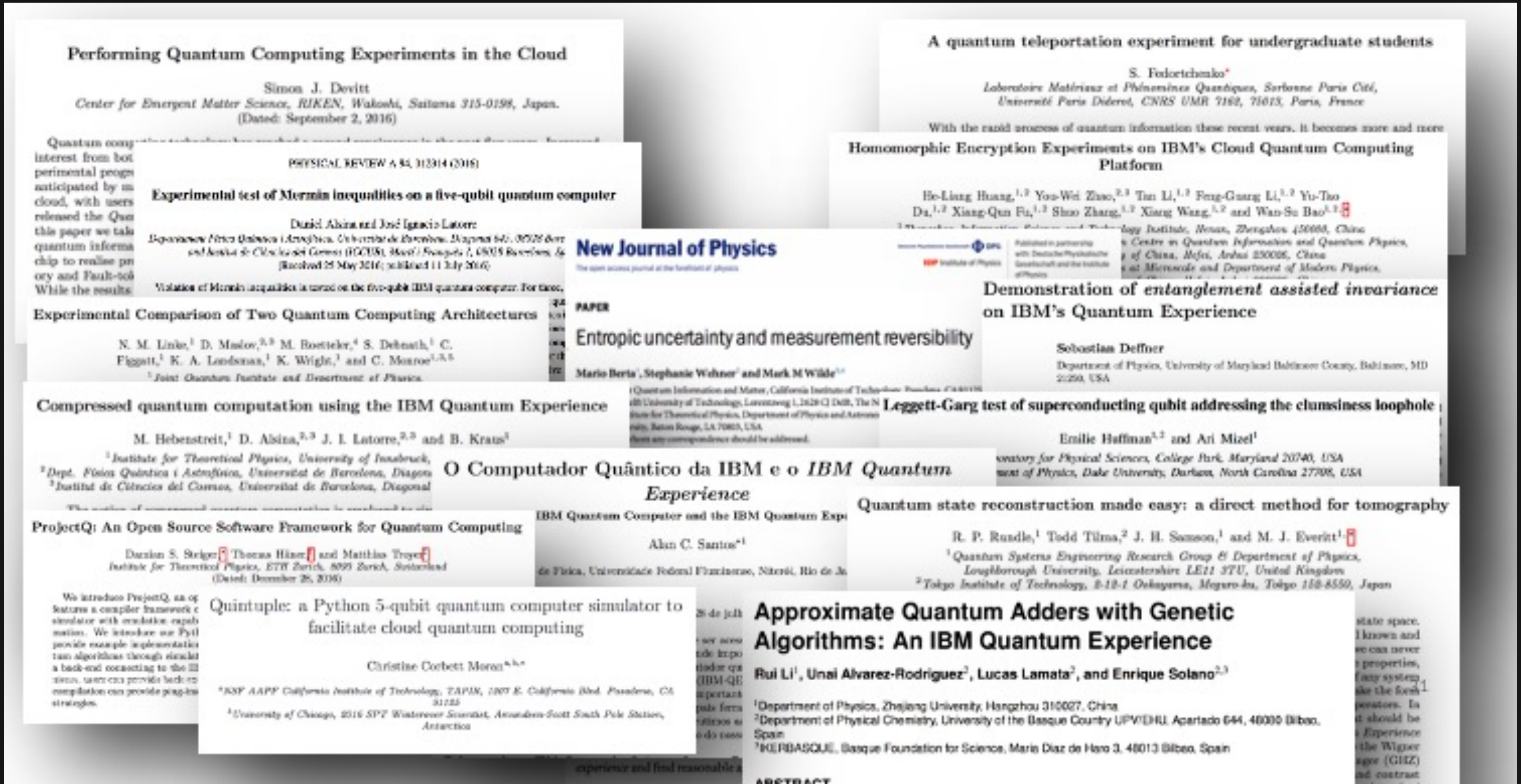
Python
Qiskit → Quantum Programming → Quantum Algorithms on Today's Hardware

Chapters:

0. Prerequisites
1. Quantum States and Qubits
2. Single Qubits and Multi-Qubit Gates
3. Quantum Algorithms
4. Quantum Algorithms for Applications
5. Investigating Quantum Hardware Using Qiskit
6. Implementations of Recent Quantum Algorithms

Enabling Research: 400+ Papers and Counting...

IBM **Quantum**



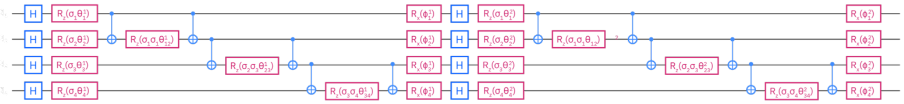
Engaging Industry

Daimler

Quantum Computing for Materials Discovery and Manufacturing Optimization

Daimler 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.

Energy of binary crystalline materials circuit.

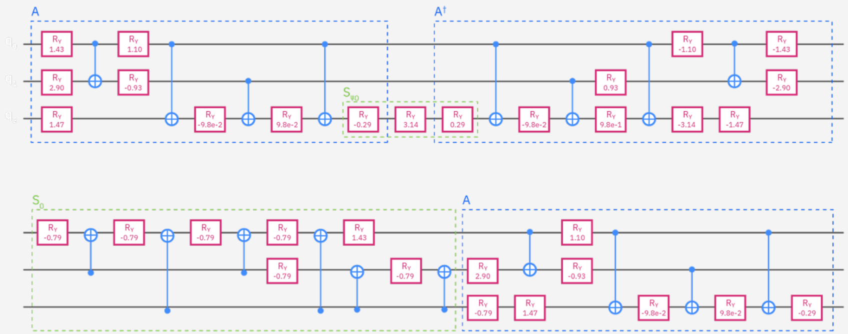


JP Morgan Chase

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 circuit

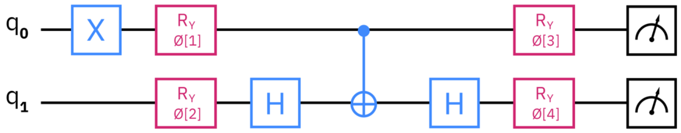


ExxonMobil

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.

Accurate thermodynamic observables calculation circuit



IBM Quantum Resource links

IBM Quantum

IBM Quantum
http://ibm.com/quantum-computing

IBM Quantum Experience
https://quantum-computing.ibm.com/

Qiskit
https://qiskit.org

Development Roadmap:
https://www.ibm.com/blogs/research/2021/02/quantum-development-roadmap/

IBM Quantum Network research paper publications:
https://ibm.biz/q-network-arxiv

Qiskit textbook, video series and other learning
https://qiskit.org/learn

Open Pulse Development
https://arxiv.org/pdf/1809.03452.pdf

IBM **Quantum**

https://quantum-computing.ibm.com