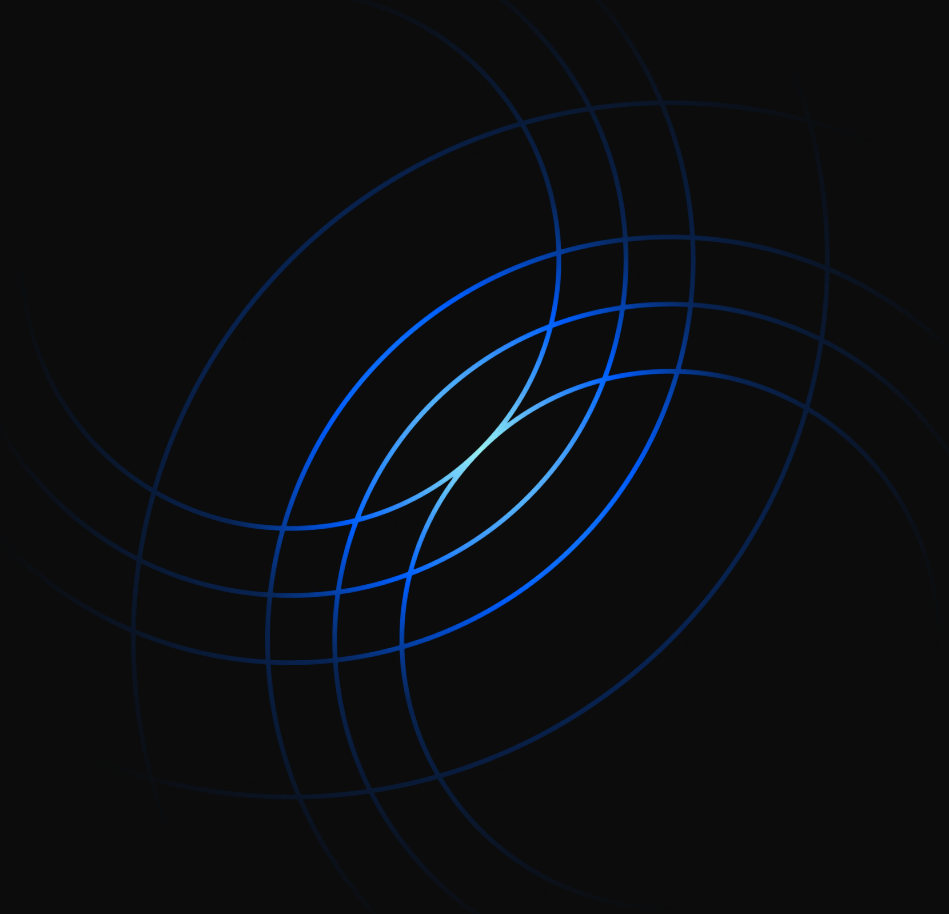
Introduction to Quantum Computing and IBM Quantum

Radha Pyari Sandhir
India Community Manager, IBM Quantum

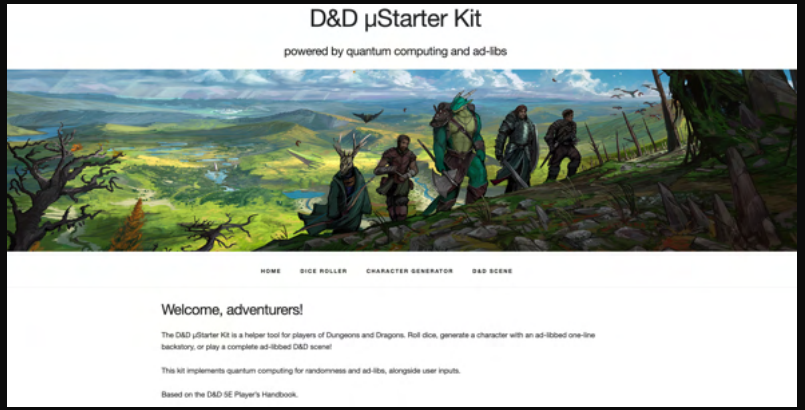


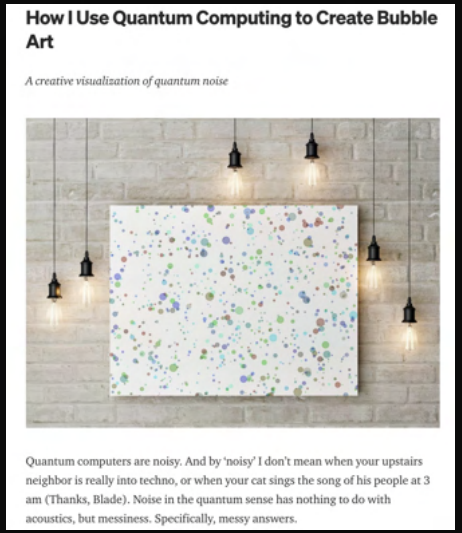
IBM **Quantum**

Radha Pyari Sandhir, PhD

- India Community Lead and Qiskit Advocate at IBM Quantum
- Interested in:
  - outreach, education, community growth
  - quantum + creative: quantum art, quantum games, etc.
- Conceptualized & authored educational game

  [The Photonic Trail: A Quantum Optics Treasure Hunt]
- Co-created apps:
  - [D&D µStarter Kit]
  - [Quantum Bubble Art Generator]





Today's Agenda

Start	End	Duration	Subject
15:00	15:05	0:05	Opening and Overview
15:05	15:30	0:25	Introduction to Quantum Computing and IBM Quantum
15:30	16:10	0:40	Hands-on session: • IBM Quantum tools • Qiskit demo
16:10	16:20	0:10	Break
16:20	16:50	0:30	Introduction to Quantum Finance
16:50	17:50	1:00	Hands-on session: • Portfolio optimization • Option pricing
17:50	18:00	0:10	Q & A

Tip: If you haven't done so already, create an account on quantum-computing.ibm.com if you want to follow along hands-on later!

Let’s talk about books!

Suppose we have an optimization problem involving book arrangement on a bookshelf

- Objective: to find a single (optimal) arrangement of books on a shelf
  - 3 books = 3! = 6 possible combinations
  - 5 books = 5! = 120
  - 10 books = 10! = 3,628,800
- Overall issue: classical computers aren’t good at handling **exponential growth** for tasks like optimization problems

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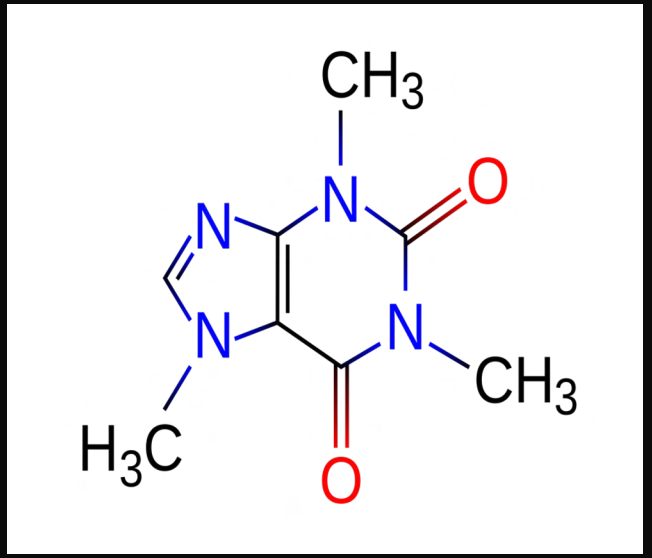
And now, coffee!



This is the caffeine molecule.

A perfect simulation of it is not possible.

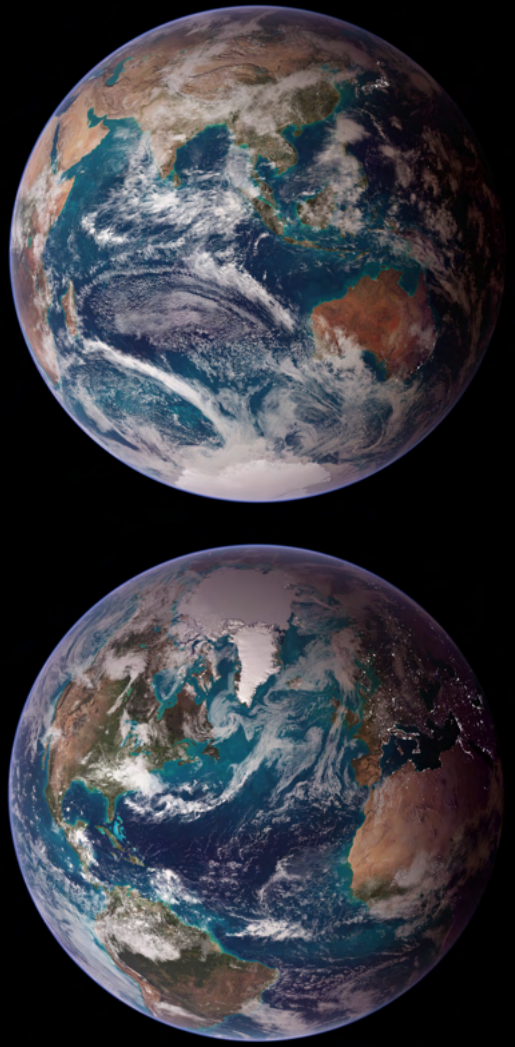
Modeling the Caffeine Molecule

Perfect simulations of complex molecules and chemical reactions are not possible even on today's most powerful supercomputers.

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 on Earth.

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



But we can successfully simulate it with 160 perfect qubits!

Qubits can handle exponential growth

$$2^n$$

n qubits – 2^n quantum state dimensions.

$2^{10} = 1{,}024$

$2^{20} = 1{,}048{,}576$

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

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

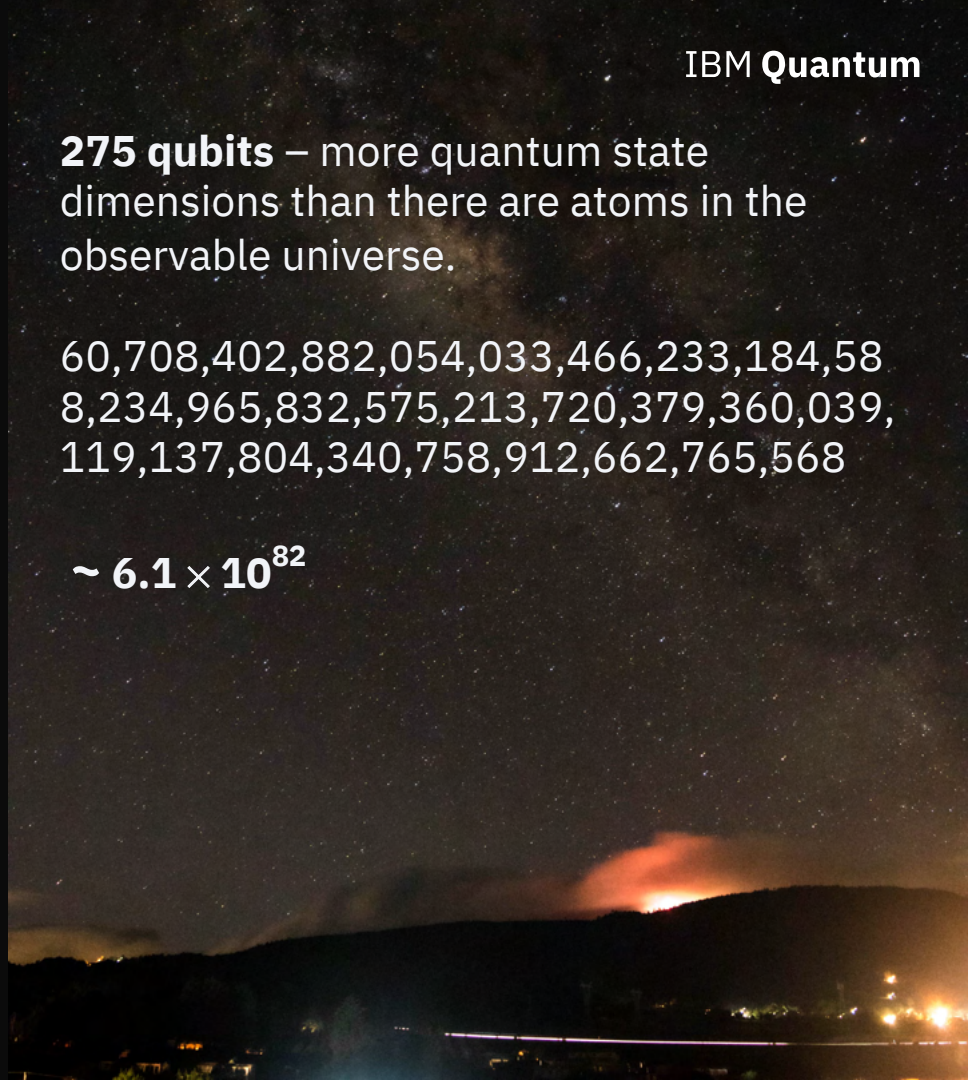
$2^{127} = 170{,}141{,}183{,}460{,}469{,}231{,}731{,}687{,}303{,}715{,}884{,}105{,}728$

2^{275}

275 qubits – more quantum state dimensions than there are atoms in the observable universe.

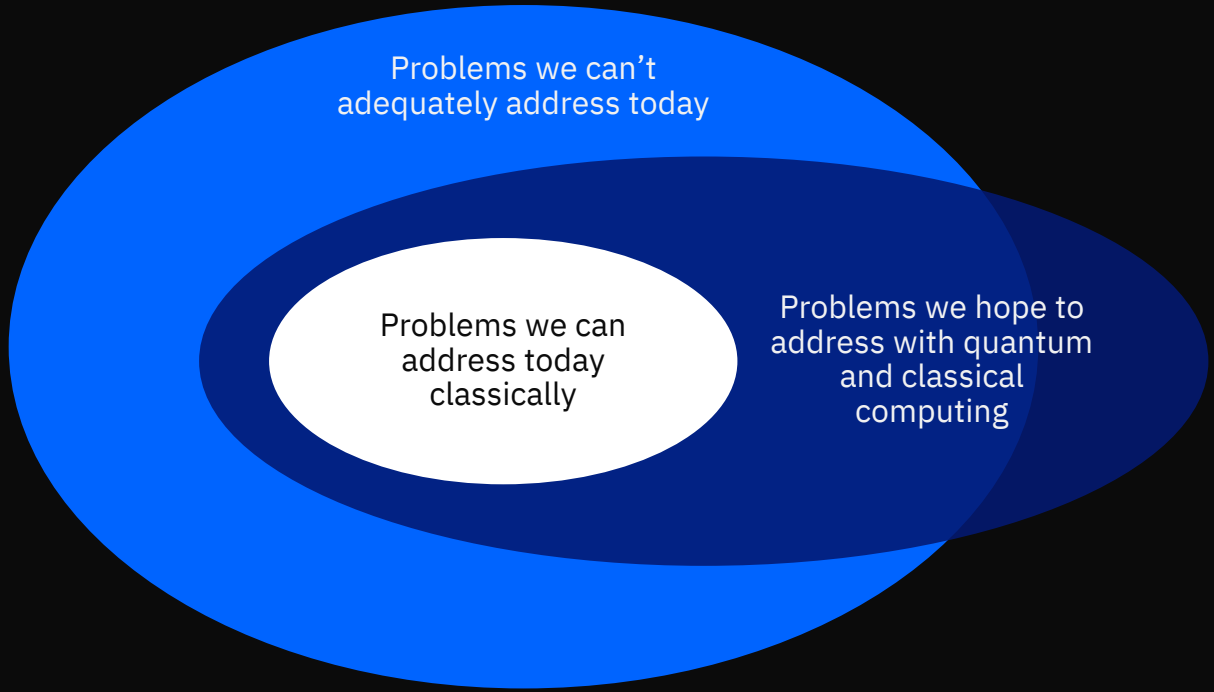
60,708,402,882,054,033,466,233,184,588,234,965,832,575,213,720,379,360,039,119,137,804,340,758,912,662,765,568

~ 6.1×10^{82}



There *are* still intractable problems, but quantum will come in handy.

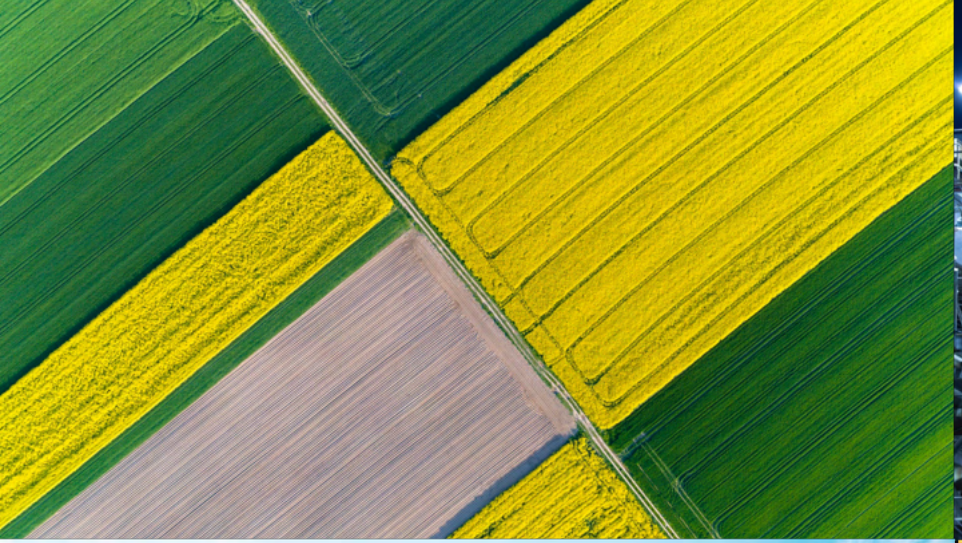
Why quantum?

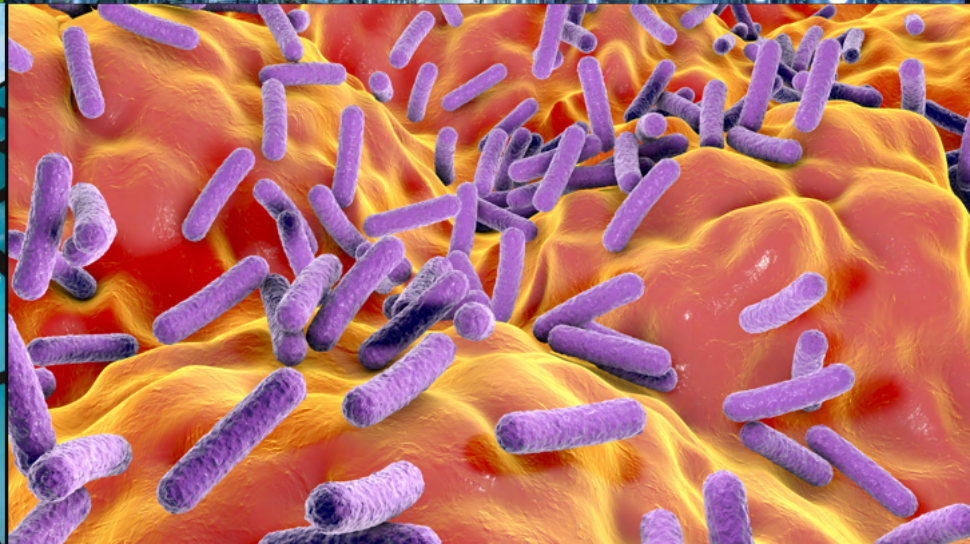


Despite how sophisticated digital "classical " computing has become, there are many scientific and business problems for which we've barely scratched the surface.

Enormous Potential

- Quantum computers will not replace classical computers but extend the realm of possibilities
  - Co-exist with conventional computing environments
- Possibilities, relative to conventional computer:
  - Hundreds of thousands times faster
  - Requires smaller fraction of memory
  - Makes ‘impossible’ possible
- Potential to reinvent industries as a nascent disruptive technology
  - Change the worlds of business, science, education, and government

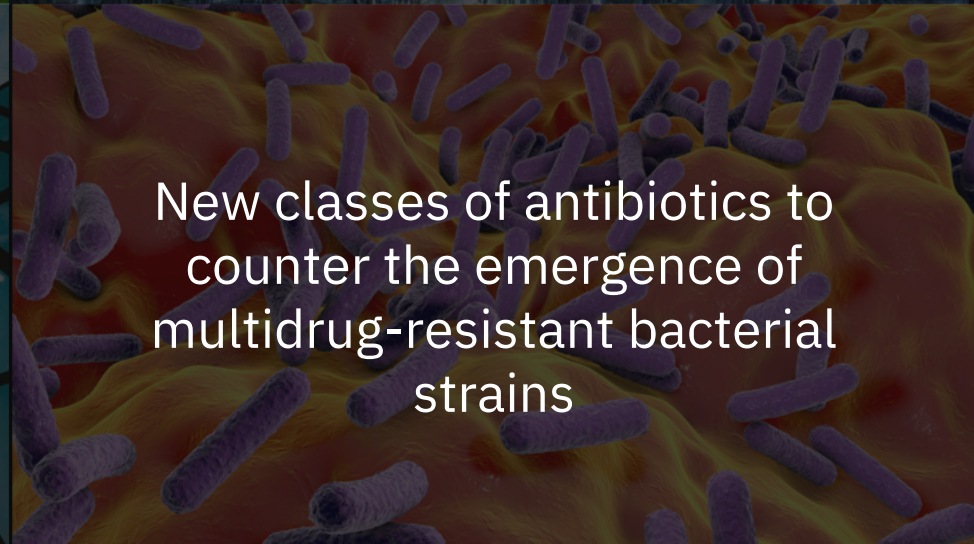




Improved nitrogen-fixation process for creating ammonia-based fertilizer

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

There’s a but...

- Near-term quantum computers are not perfect, they’re noisy
  - ‘Noisy’ != acoustic noise, but messy results
- Quantum computers rely on a different set of physical laws than classical computers
  - Quantum systems are sensitive
  - Difficult to build stable real devices with hundreds of qubits

Why it’s important to start now

- Access to real quantum computers now important to build realistic algorithms with near-term applications
- Build solid, evolving skill-set as hardware scales up
  - ask and solve complex questions we may not yet fathom
- IBM Quantum in 2016: first company to launch cloud computing services with public access to real quantum computers!

IBM Quantum – On the cloud since May 2016

Over 380,000 registered users

Over 1.4 TRILLION hardware quantum circuits run in total

Users run over 3.25 BILLION hardware quantum circuits on a typical day

24 quantum computing systems on the IBM Cloud

Over 1400 scientific and research papers

IBM Quantum System One – Strategic partnerships

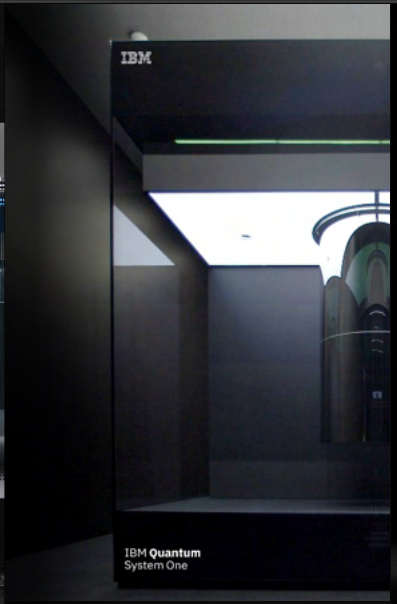
IBM Quantum datacenter with 20+ systems deployed

New York, USA

IBM Quantum | Fraunhofer

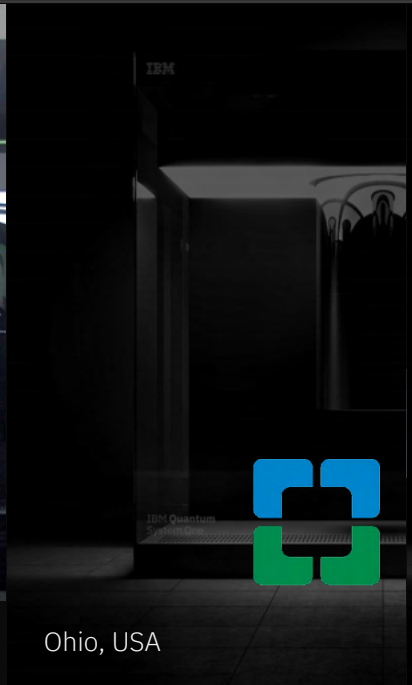
Ehningen, Germany

IBM Quantum | University of Tokyo



Shin-Kawasaki, Japan

IBM Quantum | Cleveland Clinic



Ohio, USA

IBM Quantum | Yonsei University

Seoul, South Korea

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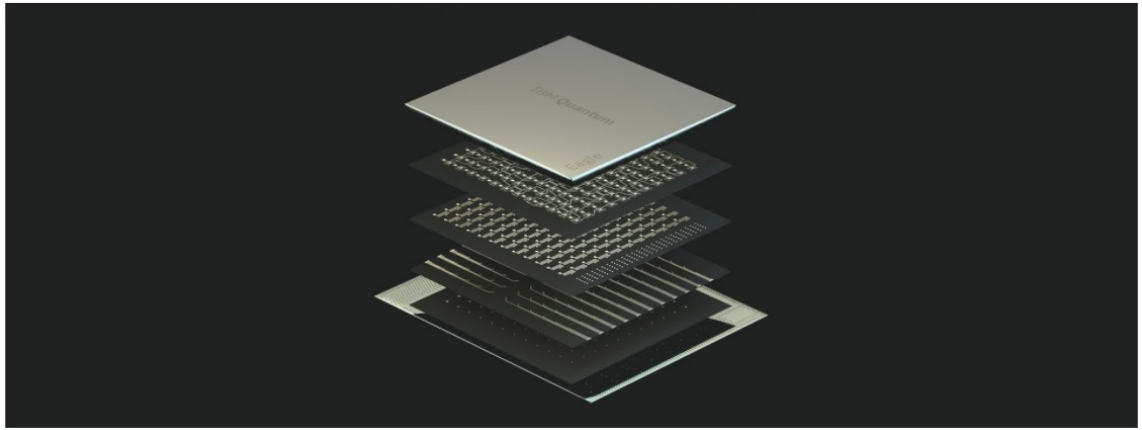
IBM Unveils Breakthrough 127-Qubit Quantum Processor

- Delivers 127 qubits on a single IBM quantum processor for the first time with breakthrough packaging technology

- New processor furthers IBM's industry-leading roadmaps for advancing the performance of its quantum systems

- Previews design for IBM Quantum System Two, a next generation quantum system to house future quantum processors

Nov 16, 2021



https://newsroom.ibm.com/2021-11-16-IBM-Unveils-Breakthrough-127-Qubit-Quantum-Processor

Development Roadmap

IBM **Quantum**

Executed by IBM | On target

2019	2020	2021	2022	2023	2024	2025	2026+
Run quantum circuits on the IBM cloud	Demonstrate and prototype quantum applications	Run quantum applications 100x faster on the IBM Cloud	Dynamic circuits for increased circuit variety, algorithmic complexity	Frictionless development with quantum workflows built in the cloud	Call 1K+ qubit services from Cloud API and investigate error correction	Enhance quantum workflows through HPC and quantum resources	

Model developers

Quantum application services

Optimization | Natural Science | Finance | Machine Learning ....

Algorithm developers

Quantum application modules

Optimization | Natural Science | Finance | Machine Learning ....

Prebuilt Qiskit Runtime and Classical integration

Error mitigation | Circuit knitting | Circuit Embedding | .... Error correction

Kernel developers

Circuits

Qiskit Runtime

Dynamic circuits

Circuit libraries

Circuits for sampling | Circuits for time evolution | Circuits for ...

Quantum systems

Falcon 27 qubits

Hummingbird 65 qubits

Eagle 127 qubits

Osprey 433 qubits

Condor 1121 qubits

Beyond 1K - 1M+ qubits

IBM Cloud

Circuits

Programs

Applications

IBM Quantum Network Today

175 total

12 industry partners

20 hubs

51 members

41 startups

51 academic members and partners

Partners

BP
Boeing
Capgemini SE
Daimler
E.ON
ExxonMobil
Goldman Sachs
JP Morgan Chase
JSR Corporation
LG Corporation
Samsung Advanced Institute of Technology
Woodside Energy Ltd

Hubs

Brookhaven National Lab
Bundeswehr University Munich
CERN Openlab
CSIC Spanish National Research Council
Cleveland Clinic Foundation
Fraunhofer
Iberian Nanotechnology Laboratory
KEIO University
Lantik SA
Los Alamos National Laboratory
National Taiwan University
North Carolina State University
Oak Ridge National Lab
Pacific Northwest National Lab
Science and Technology Facilities Council Daresbury
Sungkyunkwan University
United States Air Force Research Lab
University of Melbourne
University of Sherbrooke
University of Tokyo

Members

A*QUANTUM
Anthem
Archer Materials Limited
Argonne National Lab
Assured Information Security
CMC Microsystems
Carnegie Mellon Software Engineering Institute
DIC Corporation
Deloitte
Delta Airlines
Fermi National Accelerator Laboratory
Fidelity Investments
Flightprofiler
Fraunhofer members
GE Global Research
GRID Inc
General Atomics
Hitachi Ltd
III Taiwan
Industrial Technology Research Institute
Istituto di Calcolo e Reti ad Alte Prestazioni
Lawrence Berkeley National Laboratory
Lockheed Martin
Mitsubishi Chemical Corporation
Mitsubishi UFJ Financial Group
Mizuho Bank
Molecular Forecaster Inc
Sandia National Labs
Sony
Sumitomo Mitsui Trust Bank Limited
System Vertrieb Alexander GmbH
Toshiba
Toyota
TradeTeq Marketplace
United States Naval Research Laboratory
Wells Fargo
Yokogawa Electric Corporation
Zahnrad Friedrichshafen AG

Startups

1Qbit Systems
AIQTECH Inc
Agnostiq Inc
Aliro Quantum
Apply Science
Beit
Blueqat
Boxcat Inc
Cambridge Quantum Computing
Classiq
ColdQuanta
Entropica Labs
Equal1
Horizon Quantum Computing
JoS Quantum
Keysight
Max Kelsen
Menten AI
Miraex
Multiverse Computing
NetraMark Corp
Nordic Quantum Computing Group
Opacity
Phasecraft
ProteinQure
Q-Ctrl
QC Ware
Qedma Quantum Computing
Qu & Co
Quantfi
Quantum Machines
Qunasys
Rahko
SoftwareQ
Solid State AI
SpinUp AI
Strangeworks
Super Tech Labs
Xanadu
Zapata Computing Inc
Zurich Instruments

Academic

Aalto University
Boston University
Chalmers University of Technology
Cornell University
Duke University
EPFL
ETH Zurich
Florida State University
Georgetown University
Georgia Institute of Technology
Hanyang University
Harvard
Johns Hopkins University
Korea Advanced Institute of Science and Technology
Korea University
Massachusetts Institute of Technology
National University of Singapore
New Mexico State University
New York University
Northeastern University
Northwestern University
Pohang University of Science and Technology
Princeton University
Purdue University
Saarland University
Seoul National University
Stanford University
Stony Brook University
Turku University
Ulsan National Institute of Science and Technology
United States Naval Postgraduate Military University
University of Basque Country
University of Chicago
University of Colorado Boulder
University of Georgia
University of Illinois at Urbana Champaign
University of Innsbruck
University of Madrid
University of Minho
University of Montpellier
University of New Mexico
University of Notre Dame
University of Oxford
University of Southern California
University of Stuttgart
University of Tennessee
University of Washington
University of Waterloo
University of Witwatersrand Johannesburg
Virginia Tech
Yonsei University

Current as of 2022-01-25 09:34:52

IBM Quantum Network
Industry: Banking & Financial Services

175 total

12 industry partners

20 hubs

51 members

41 startups

51 academic members and partners

Fidelity Investments

Goldman Sachs

JP Morgan Chase

Mitsubishi UFJ Financial Group

Mizuho Bank

Sumitomo Mitsui Trust Bank Limited

Wells Fargo

Current as of 2022-01-25 09:34:52

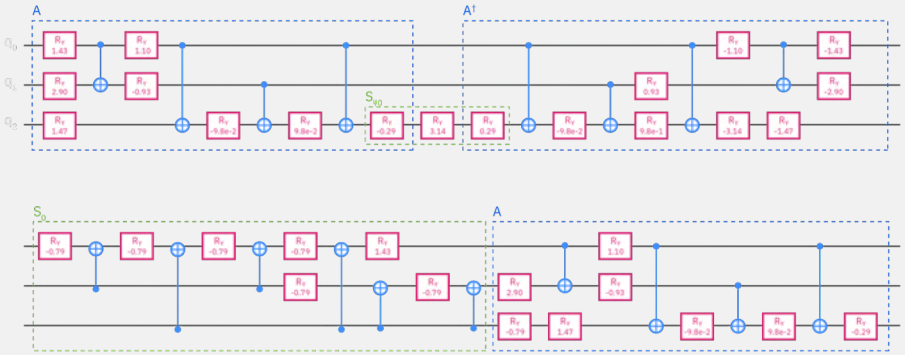
Some IBM Quantum Network members belong to more than one industry

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



You can program and access real quantum computers too!

Resources: Self-learning

IBM Quantum Tools

Cloud applications for programming real quantum hardware and quantum circuit simulators

- IBM Quantum for Developers
- IBM Quantum Composer
- IBM Quantum Lab

Qiskit.org

Open-source quantum computing software development

- Documentation, Tutorials, Events, Education
- Qiskit Metal – quantum device design
- OpenQASM 3.0

Learn Quantum Computation using Qiskit

Interactive online advanced text on quantum algorithms and computation based on Qiskit

Qiskit YouTube Channel

- Qiskit Foundations – Coding with Qiskit Season 1
- Qiskit Algorithms – Coding with Qiskit Season 2
- Qiskit Live – livestream of public lecture series
- SuperPosition series – explores how individuals became Qiskit developers
- 1 Minute Qiskit – Qiskit tips and tricks

Resources: Social media and blogs

- IBM Quantum Blog
- Qiskit on Medium
- IBM Quantum Hardware Roadmap
- IBM Quantum Development Roadmap
- Qiskit on Slack
- Qiskit on Twitter
- Jay Gambetta on Twitter
- IBM Research on Twitter
- Qiskit on GitHub
- Quantum computing on Stack Exchange

IBM **Quantum**