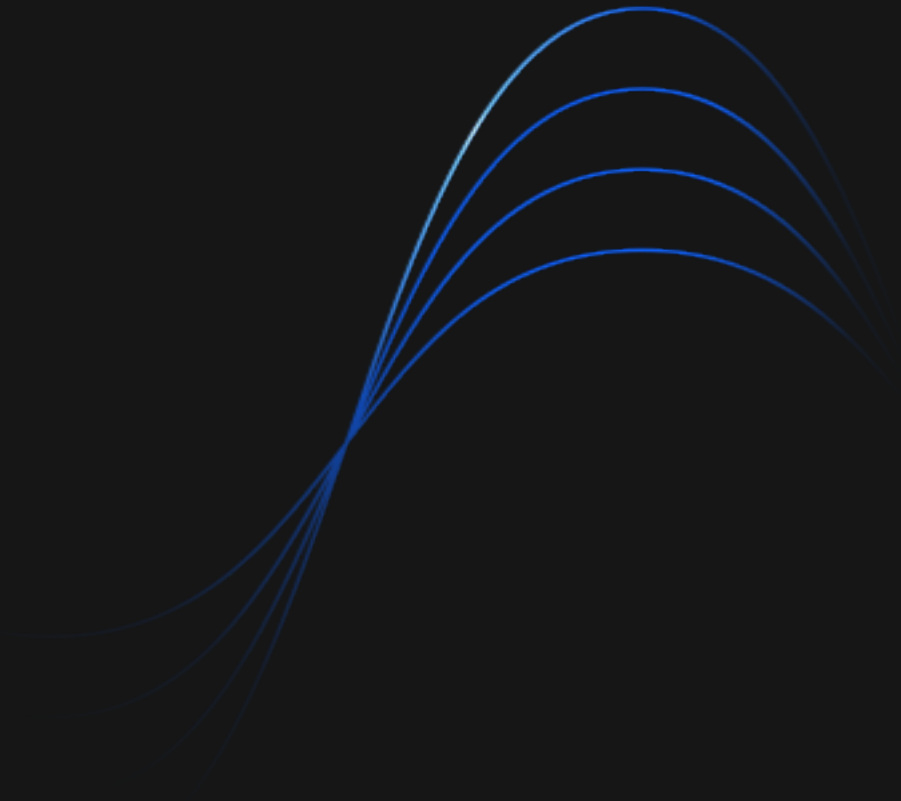
Introduction to Quantum Computing @ SUTD

Huang Junye
Quantum Developer Advocate

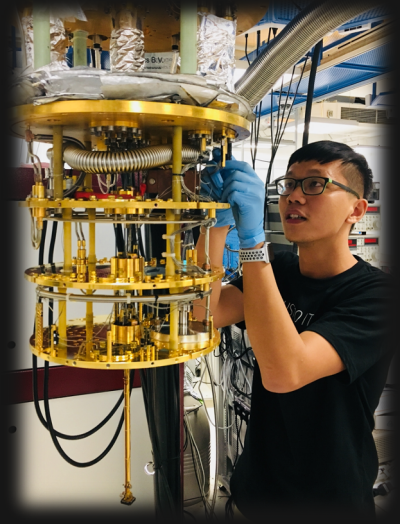


IBM **Quantum**

Huang Junye

IBM **Quantum**

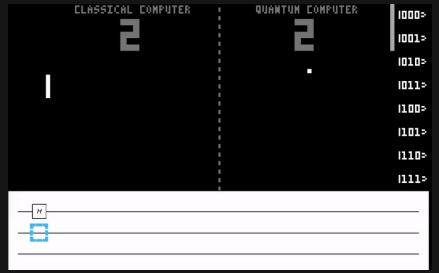
- Quantum developer advocate focusing on quantum education
- Leads Qiskit advocate program, supporting most active members of the Qiskit community through events, networking and mentorship.
- Led a team of 40+ for IBM Quantum Challenge 2021 for celebration of 5th anniversary of IBM Quantum and 40 years of quantum computing.
- Outstanding Accomplishment (highest level of recognition) from IBM Research for supporting Qiskit Global Summer School 2020.
- Co-creator of quantum games: QPong, QPong Arcade, QiskitBlocks, ...
- Graduate research in topological quantum computation at NUS



Connect with the *advocates* from within the Qiskit community

IBM Quantum Challenge generates better solutions than challenge creators thought possible

From May 20 to 26, 1,431 people from 76 countries participated in the IBM Quantum Challenge 2021, a celebration for 5-year anniversary of IBM Quantum and 40 years of quantum computing. Not only was the event a blast, but participants devised a more-efficient solution to one quantum computing problem than the problem's authors even thought possible.



Agenda

Date	Start	End	Subject
26 Aug	15:00	17:00	Quantum Lab
27 Aug	9:30	14:00	Quantum Algorithms

Quantum Lab

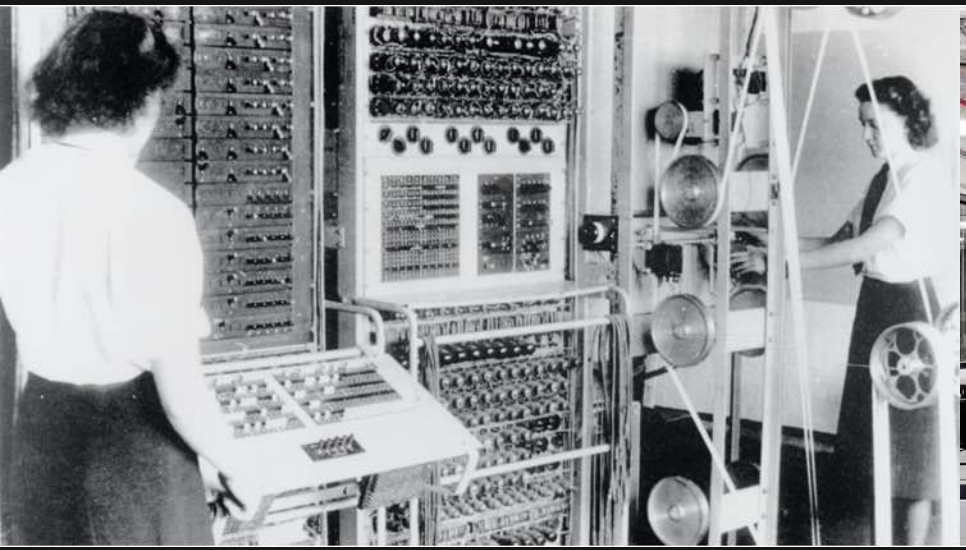
Start	End	Duration	Subject
15:00	15:05	0:05	Opening and Overview
15:05	15:15	0:10	IBM Quantum Hardware
15:15	16:00	0:45	IBM Quantum Platform • Quantum Composer • Quantum Lab • Quantum Services • Documentations
16:00	16:10	0:10	Break
16:10	17:00	0:50	Hands-on Session: Implement Simple Quantum Circuits • Classical logic gates • Bell state circuit • GHZ state circuit • Qiskit logo circuit

Quantum Algorithms (Day 2)

Start	End	Duration	Subject
9:30	9:40	0:10	Recap and Overview
9:40	10:20	0:40	Deutsch-Jozsa algorithm + hands-on implementations
10:20	10:30	0:10	Break
10:30	11:10	0:40	Grover's algorithm + + hands-on implementations
11:10	12:30	1:20	Shor's algorithm + hands-on implementations
12:30	13:30	1:00	Lunch Break
13:30	14:00	0:30	Near-term algorithms and applications

IBM Quantum Hardware

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

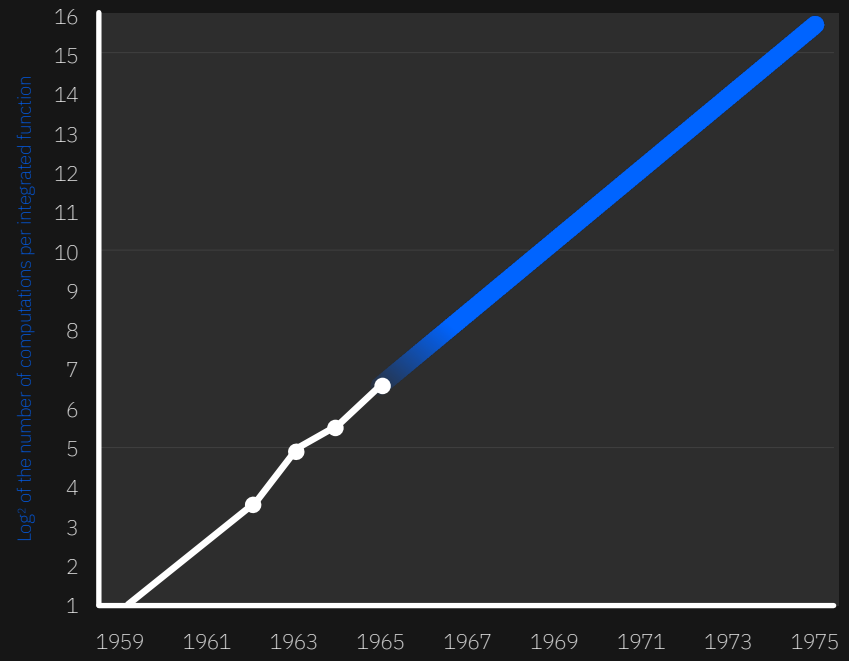


Computer: 1944

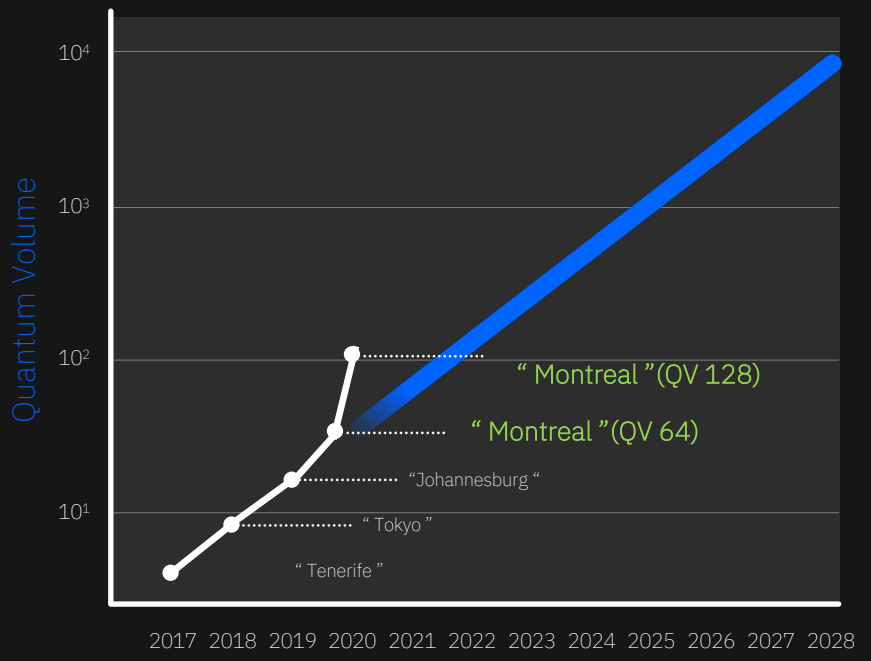
Quantum Computer: 2019

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

Moore's law



Quantum Volume: The New Moore's Law



IBM Quantum History

1970s IBM Fellow Charles Bennett first write down the term “quantum information theory”.

1981 MIT and IBM jointly organize Physics of Computation conference where Feynman delivered the famous lecture *Simulating Physics with Computers*.

1984 Bennett and Brassard propose BB84 quantum encryption protocol.

1993 Bennett and Brassard propose quantum teleportation algorithm.

1996 DiVincenzo proposes a list of minimal requirements for physical implementation of quantum computers.

2001 IBM demonstrate Shor’s algorithm experimentally for the first time.

2007 IBM Fellow Jay Gambetta and collaborators invented transmon qubits in Yale University.

2011 IBM invented 2-qubit cross-resonance gate, which is the backbone of IBM Quantum Systems

2016 IBM puts the first quantum computer on the cloud (IBM Quantum Experience).

2017 IBM simulates ground state energy of molecules using variational quantum eigensolver (VQE).

2019 IBM unveils Quantum System One, the first circuit-based commercial quantum computer.

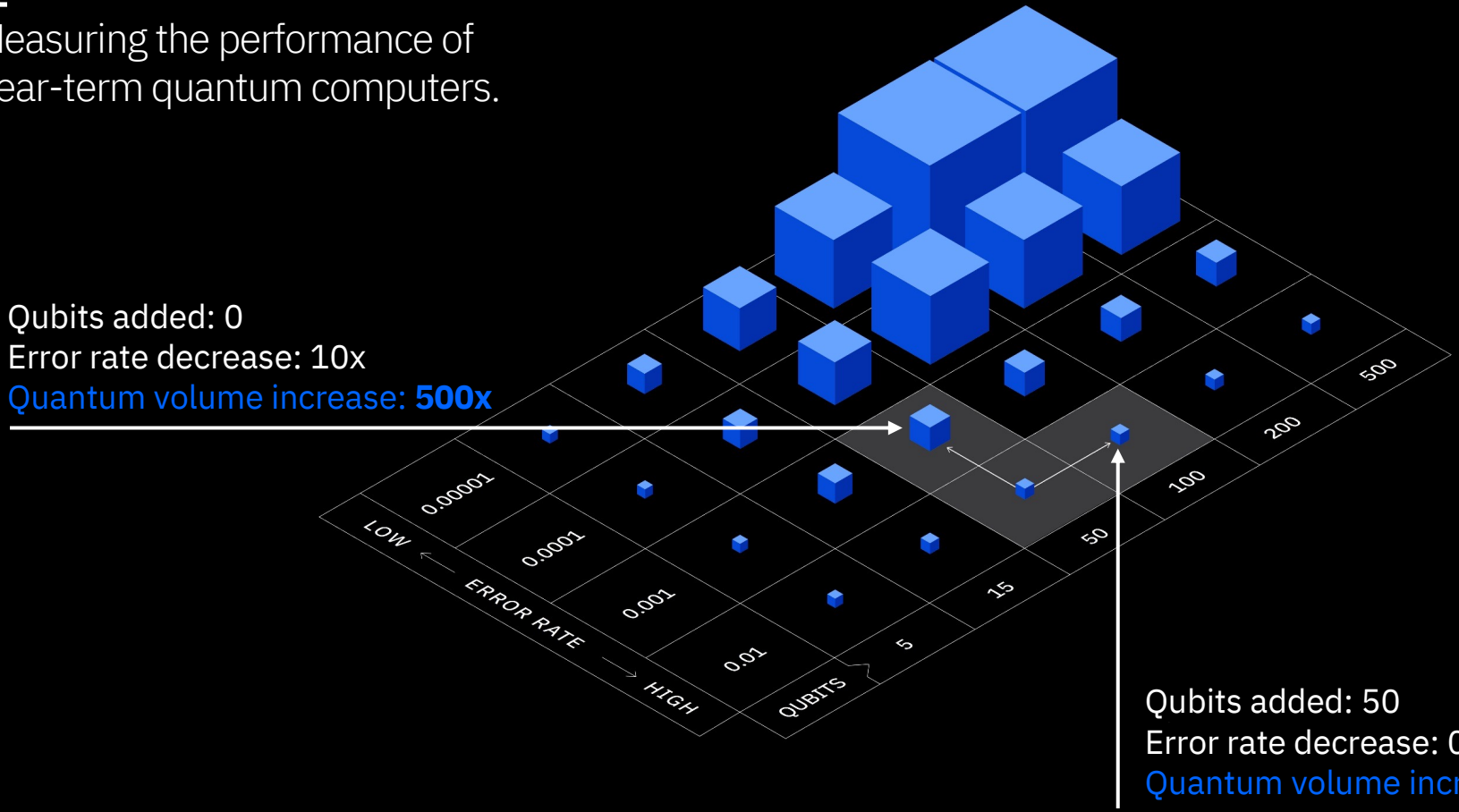
In May of 1981, IBM and MIT hosted the *Physics of Computation Conference*

Qubit technology: quick comments

- D-wave quantum annealing vs gate model
- Superconducting qubits vs trapped ions
  - Trapped ions have lower error rates but hard to scale up (no clear path to >100 qubits)
  - Superconducting qubits have higher error rates but it is easier to scale up (clear path to at least 1000 qubits)

Quantum Volume

Measuring the performance of near-term quantum computers.



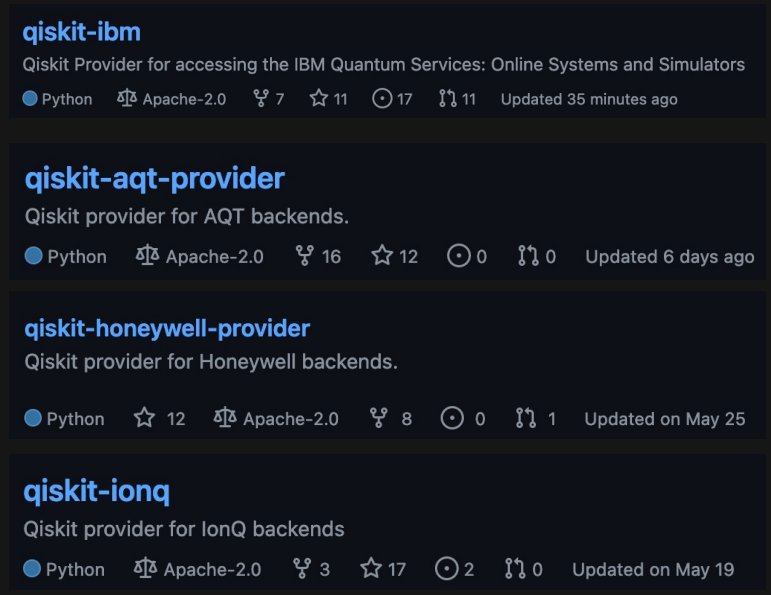
Qiskit

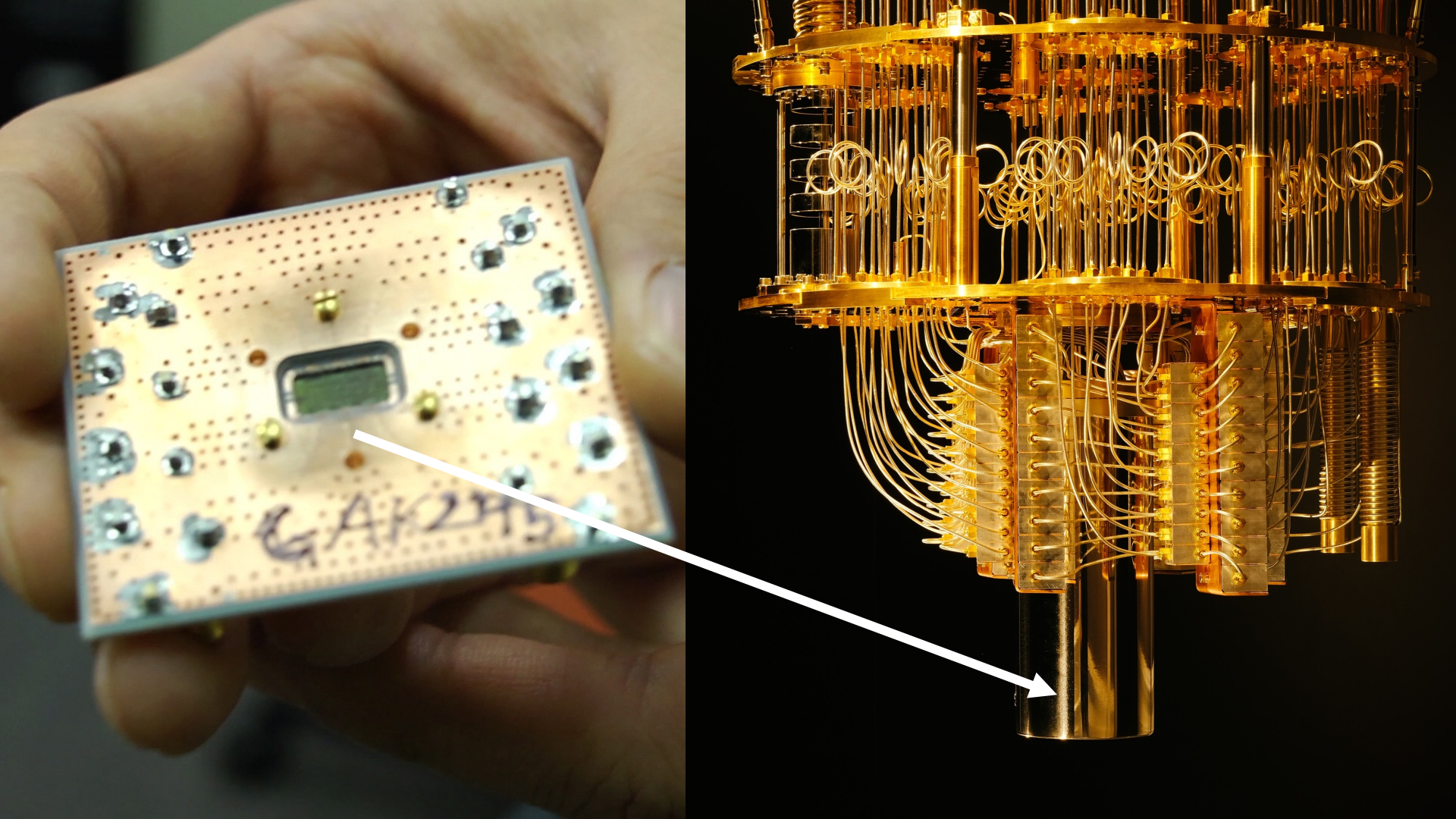
IBM Quantum is full stack

- Hardware: IBM Quantum Services / Systems
- Software: Qiskit

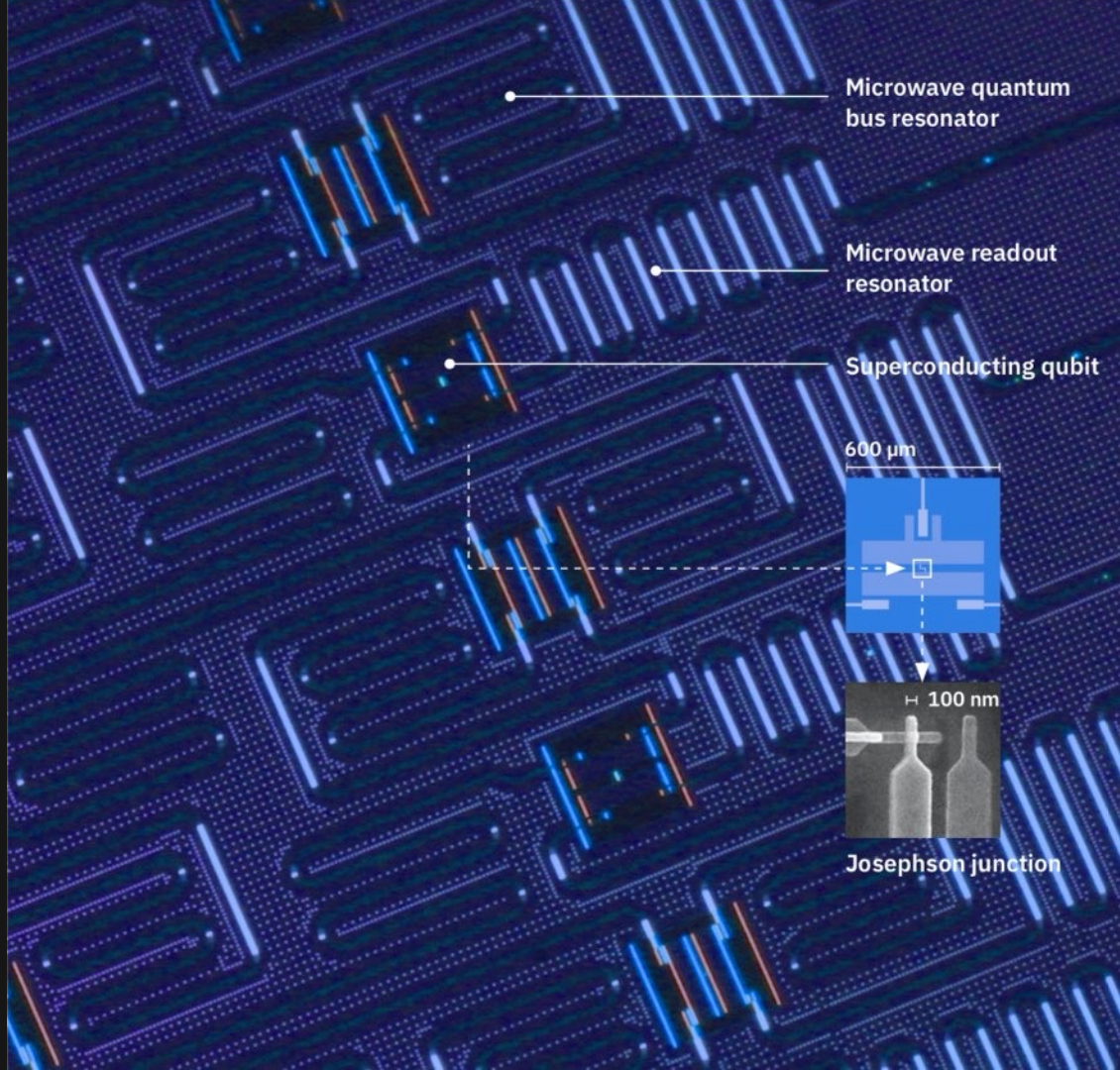
Qiskit

- Open source
- Supports multiple qubit technologies
  - superconducting qubits
  - trapped ions





Inside an IBM Quantum Chip



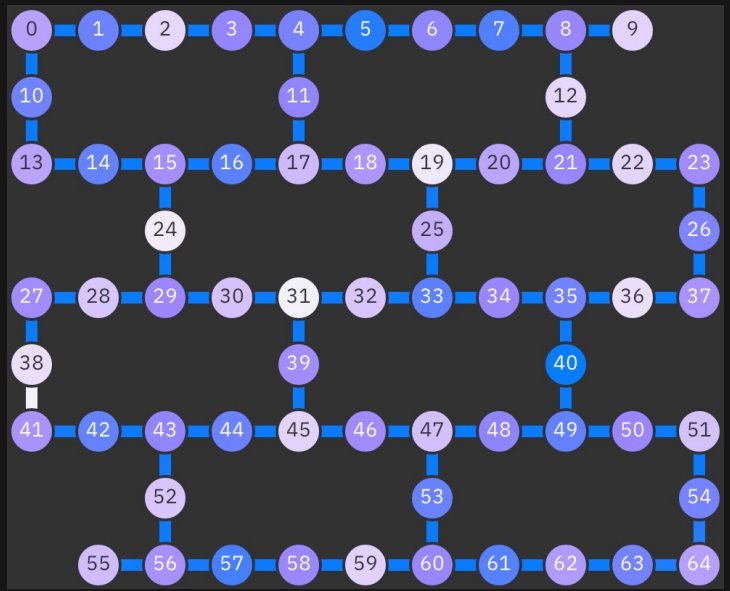
IBM Quantum Systems

Up to 65 qubits

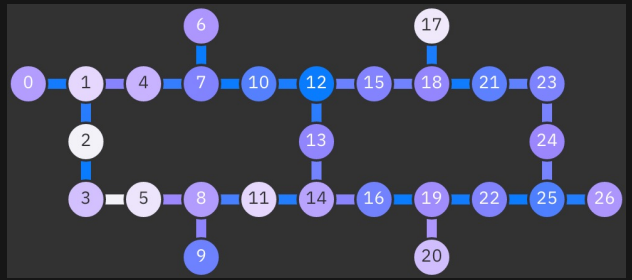
> 20 systems online

> 30 deployed to date

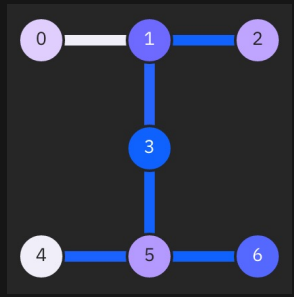
65 qubits



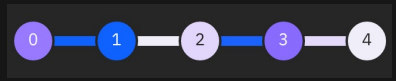
27 qubits



7 qubits



5 qubits

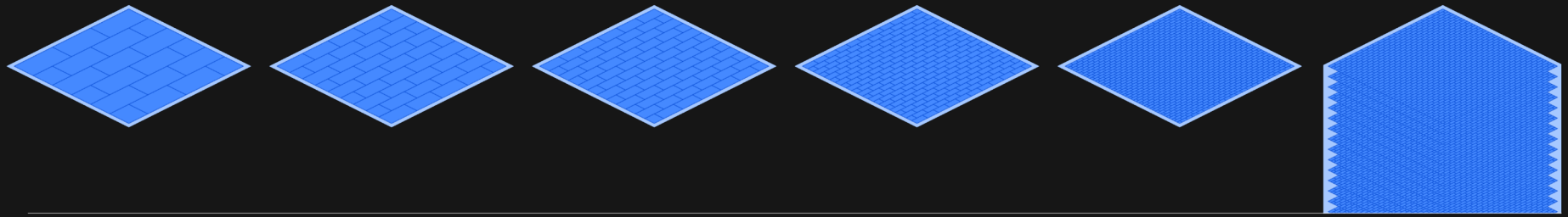


Scaling IBM Quantum technology

IBM **Quantum**

IBM Quantum System One (Released) | (In development) | Next family of IBM Quantum systems

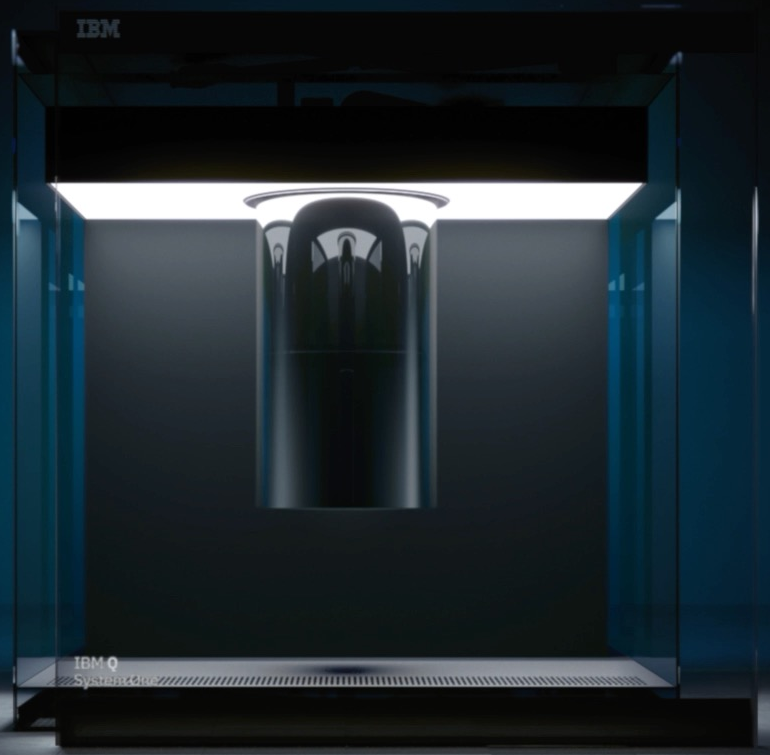
2019	2020	2021	2022	2023	and beyond
27 qubits *Falcon*	65 qubits *Hummingbird*	127 qubits *Eagle*	433 qubits *Osprey*	1,121 qubits *Condor*	Path to 1 million qubits and beyond *Large scale systems*



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.



IBM Quantum National Scale Partnership

IBM, Fraunhofer partner on German-backed quantum computing research push

Douglas Busvine

3 MIN READ

FRANKFURT (Reuters) - IBM is joining forces with a German research institute to explore the potential of quantum computing, backed by a government plan to invest 650 million euros ($717 million) over two years in wider research in the field.

Germany

IBM Quantum National Scale Partnership

IBM **Quantum**

IBM News Room

IBM and the University of Tokyo Unveil the Quantum Innovation Initiative Consortium to Accelerate Japan's Quantum Research and Development Leadership

Keio University, Toshiba, Hitachi, Mizuho, MUFG, JSR, DIC, Toyota, Mitsubishi Chemicals and IBM to expand the country-wide quantum computing research, development and education ecosystem

Japan

Superfridge - first of its kind dilution refrigerator 10 x the cooling power at 100 mK and 8 x the cooling planned at 4K

IBM Quantum Platform

The road to Quantum Advantage

Quantum Science

Create the fundamental theoretical and physical building blocks of quantum computing.

Quantum Ready

Engage the world to prepare for the quantum computing era.

IBM puts quantum computers on the cloud

Launch IBM Quantum Network

Quantum Advantage

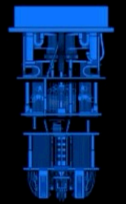
Commercial advantage to solving real world problems with quantum computing systems.

1900s | 2016 | ~2020s | 2050+

Quantum developer

IBM Cloud

IBM Quantum Systems



IBM Quantum Network: A Snapshot

Over 300,000 users have...

Run over 700 Billion quantum circuits

1.4 Billion quantum circuits per day

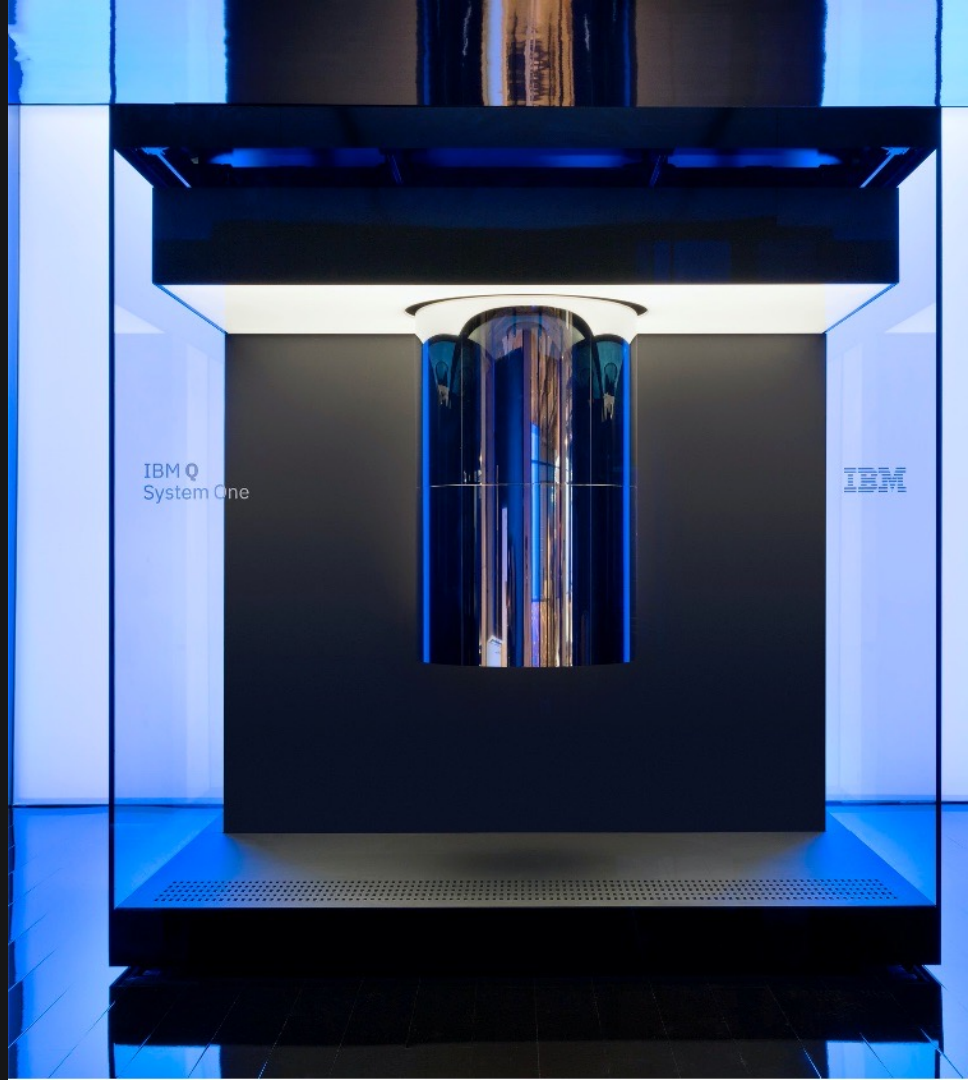
using total 34 quantum computers deployed up to date

More than 140 clients and partners (NUS)

Collaborating on 30+ applications

Over 300 contributors to Qiskit

Over 400 scientific papers so far



Welcome, Junye Huang

Graphically build circuits with
IBM Quantum Composer

Launch Composer

Develop quantum experiments in
IBM Quantum Lab

Launch Lab

Jump back in:

- Grover 3-qubit |010> 2 iterati...
- Deutsch-Jozsa Algorithm (Bal...
- runtime/07_leveraging_qiskit...
- DJ N=3 Example

API token

****

View account details

Run on circuits & algorithms via
IBM Quantum services

View all

4	19	5	30
Your programs	Your systems	Your simulators	Total quantum services

Recent jobs View all

0	6
Pending	Completed

No pending jobs

Reservations

0

Your reservations

Recent notifications

View all

- Product Update
  Pulse Gates available to all users on Open Systems
  13 days ago | Learn more
- Quantum News
  Qiskit Textbook Beta is now Open!
  15 days ago | Learn more
- Quantum News
  Why IBM is moving to heavy hex lattices only
  21 days ago | Learn more
- Product Update
  Updates to the IBM Quantum Privacy Page
  2 months ago | Learn more
- Service Alert
  Upcoming System Retirement: Melbourne, IBMQX2
  2 months ago | Learn more
- Service Alert
  ibmq_jakarta now available for Advanced and Premium users!
  2 months ago | Learn more

IBM **Quantum Composer**

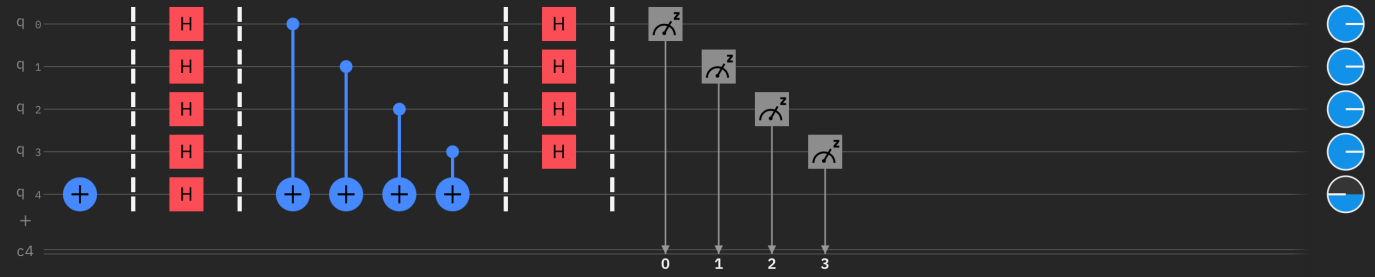
File Edit Inspect View Share

Setup and run

Deutsch-Jozsa Algorithm (Balanced) *Saved*

Visualizations seed 6148

H ⊕ ● ● ✕ I T S Z T† S† P RZ ● |0⟩ if ⋮ √X √X† Y RX RY U RXX RZZ + Add

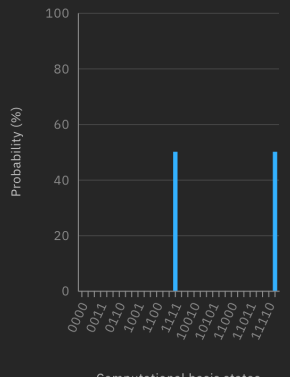


OpenQASM 2.0

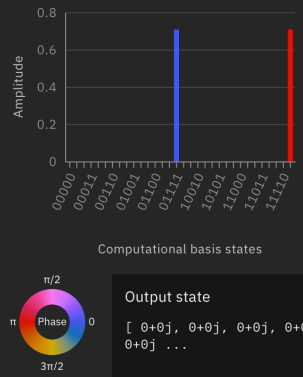
Open in Quantum Lab

```
OPENQASM 2.0;
include "qelib1.inc";

qreg q[5];
creg c[4];

x q[4];
barrier q;
h q[0];
h q[1];
h q[2];
h q[3];
h q[4];
barrier q[0],q[1],q[2],q[3],q[4];
cx q[0],q[4];
cx q[1],q[4];
cx q[2],q[4];
cx q[3],q[4];
barrier q[0],q[1],q[2],q[3],q[4];
h q[0];
h q[1];
h q[2];
h q[3];
barrier q[0],q[1],q[2],q[3],q[4];
measure q[0] -> c[0];
measure q[1] -> c[1];
measure q[2] -> c[2];
measure q[3] -> c[3];
```

Probabilities



Statevector

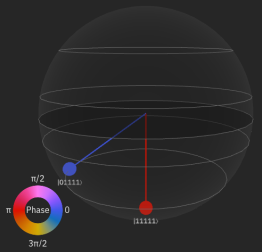


Output state

```
[ 0+0j, 0+0j, 0+0j, 0+0j, 0+0j,
0+0j ...
```

Show more

Q-sphere



State Phase angle

Getting Started with Qiskit

Here, we provide an overview of working with Qiskit. The fundamental package of Qiskit is Terra that provides the basic building blocks necessary to program quantum computers. The fundamental unit of Qiskit is the quantum circuit. A basic workflow using Qiskit consists of two stages: **Build** and **Execute**. **Build** allows you to make different quantum circuits that represent the problem you are solving, and **Execute** that allows you to run them on different backends. After the jobs have been run, the data is collected and postprocessed depending on the desired output.

In [1]:

```
import numpy as np
from qiskit import *
%matplotlib inline
```

Circuit Basics

Building the circuit

The basic element needed for your first program is the QuantumCircuit. We begin by creating a `QuantumCircuit` comprised of three qubits.

In [2]:

```
# Create a Quantum Circuit acting on a quantum register of three qubits
circ = QuantumCircuit(3)
```

After you create the circuit with its registers, you can add gates ("operations") to manipulate the registers. As you proceed through the tutorials you will find more gates and circuits; below is an example of a quantum circuit that makes a three-qubit GHZ state

$$|\psi\rangle = (|000\rangle + |111\rangle)/\sqrt{2}.$$

To create such a state, we start with a three-qubit quantum register. By default, each qubit in the register is initialized to $|0\rangle$. To make the GHZ state, we apply the following gates:

- A Hadamard gate H on qubit 0, which puts it into the superposition state $(|0\rangle + |1\rangle)/\sqrt{2}$.

Services

View the availability and details of IBM Quantum programs, systems, and simulators.

Programs | **Systems** | Simulators

IBM Quantum systems combine world-leading quantum processors with cryogenic components, control electronics, and classical computing technology. Learn more →

Card | Table

Search by system name

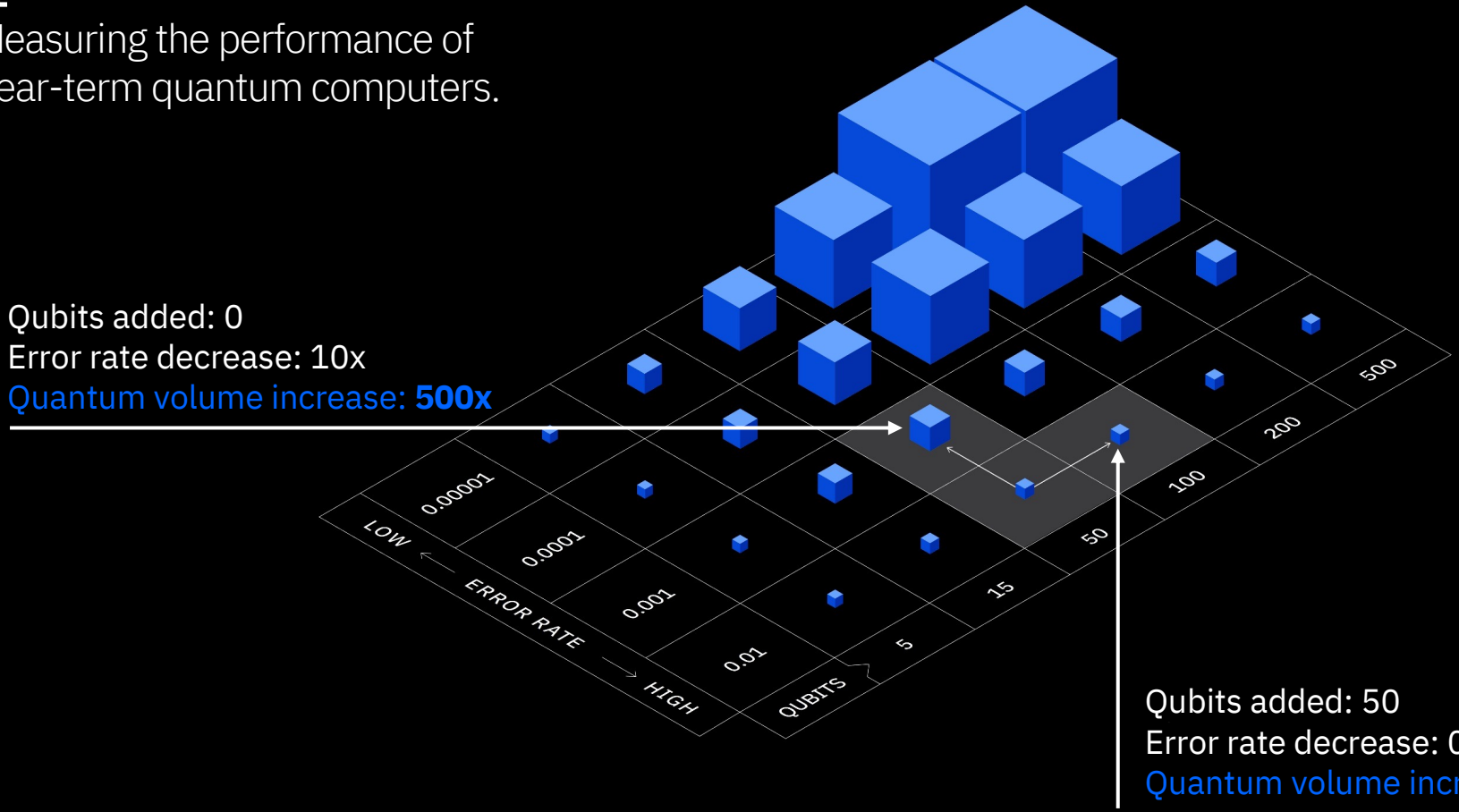
All systems (21)

	System status	Processor type	Qubits	Quantum volume
ibmq_**mumbai**	Online - Dedicated	Falcon r5.1	27	128
ibmq_**montreal**	Online	Falcon r4	27	128
ibmq_**kolkata**	Online	Falcon r5.11	27	128
ibmq_**dublin**	Online	Falcon r4	27	64
ibmq_**manhattan**	Online	Hummingbird r2	65	32
ibmq_**brooklyn**	Online	Hummingbird r2	65	32
ibmq_**toronto**	Online - Dedicated	Falcon r4	27	32
ibmq_**sydney**	Online - Dedicated	Falcon r4	27	32
ibmq_**guadalupe**	Online	Falcon r4P	16	32
ibm_**nairobi**	Online	Falcon r5.11H	7	32
ibmq_**casablanca**	Online	Falcon r4H	7	32
ibm_**lagos**	Online	Falcon r5.11H	7	32
ibmq_**santiago**				
ibmq_**manila**				
ibmq_**bogota**				
ibmq_**jakarta**				

Explore our aviary of quantum processors Learn more →

Quantum Volume

Measuring the performance of near-term quantum computers.



Docs directory

Returning User? Go straight to the tool-specific documentation:
Quantum Composer | Quantum Lab | Quantum services | Administration

New here? Select a path to get started:

New to quantum

Learn the basics of circuit creation with IBM Quantum Composer, a drag-and-drop interface for building and running circuits

Build your first circuit with Quantum Composer →

Developers

Learn to build quantum models & applications with **IBM Quantum Lab**, a Qiskit-optimized Jupyter interface

Code your first circuit in Quantum Lab →

Educators

Teach topics with example circuits built in Quantum Composer

Explore learning in the Field Guide →

Researchers

Build & test algorithms in Quantum Lab

Try out Qiskit tutorials in Quantum Lab →

Explore Qiskit Runtime to speed up your quantum experiments on our devices in the cloud

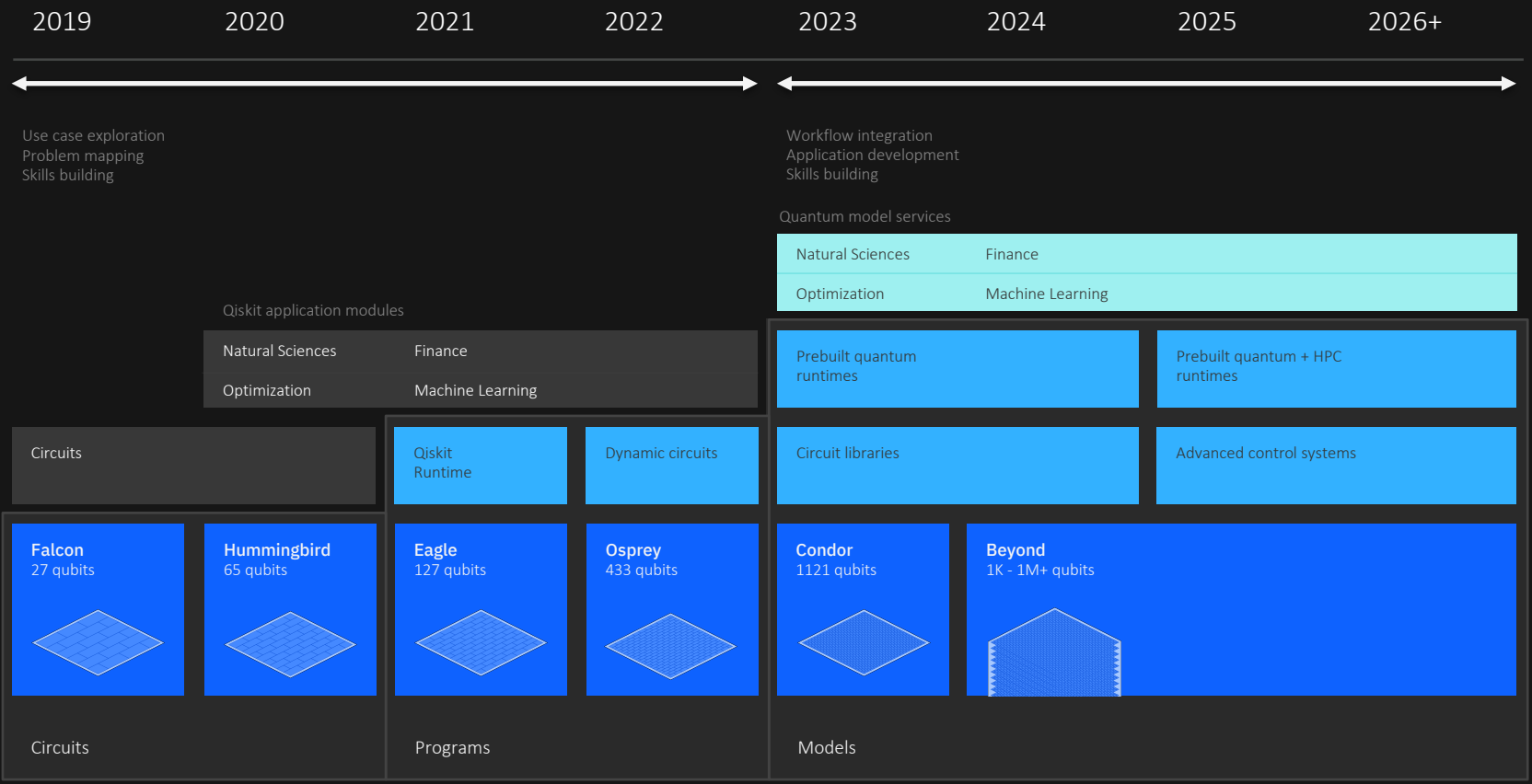
Qiskit Runtime is currently in private beta for some members of the IBM Quantum Network... but check back, as we'll be releasing it publicly soon!

Overview
Experiment with Qiskit Runtime
Qiskit Runtime program architecture

Guides to IBM Quantum tools in the cloud

Development Roadmap

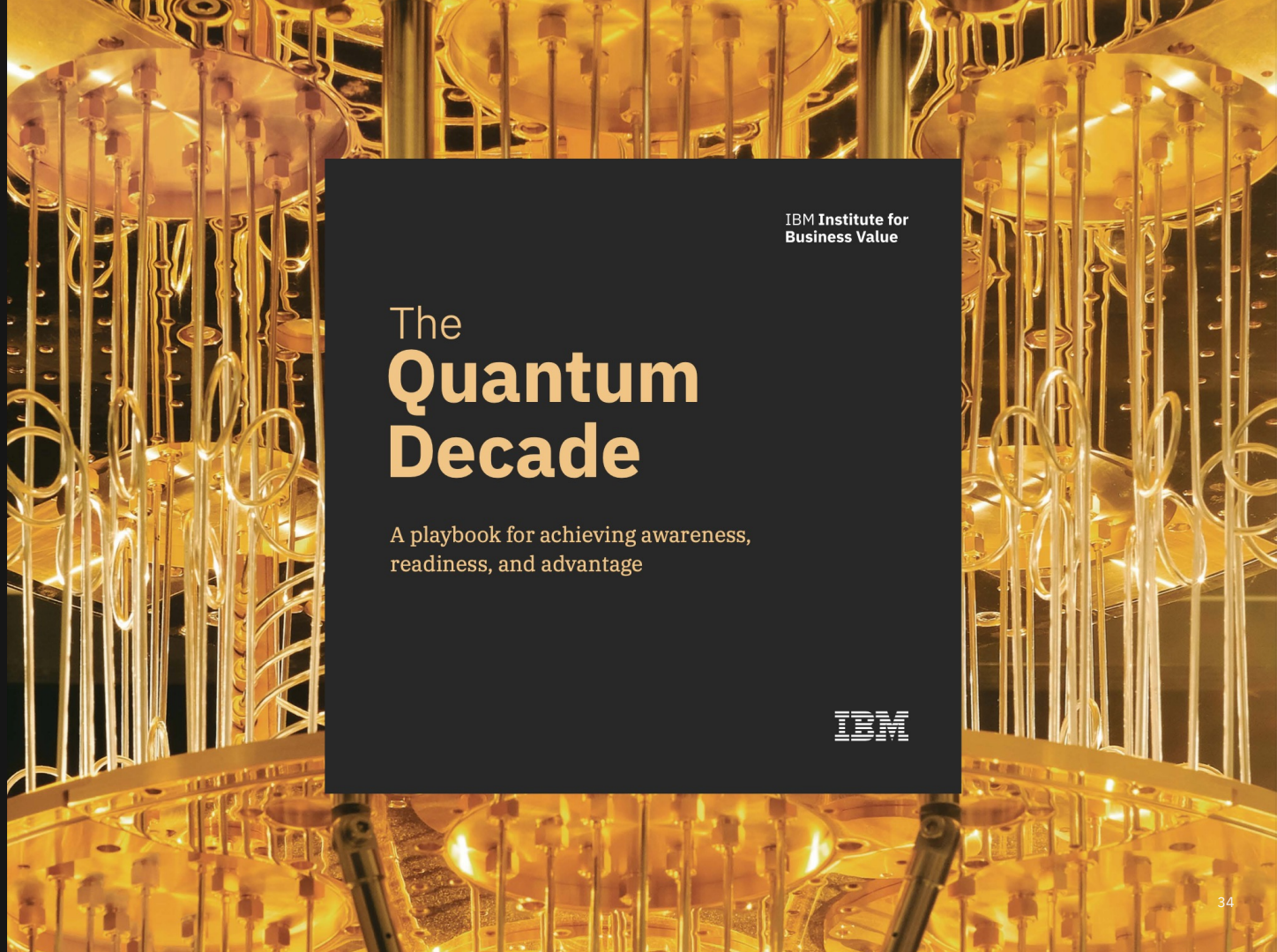
IBM **Quantum**



The Quantum Decade is Here

Find out how you can be quantum-ready—and how this bleeding-edge technology can help you and your business thrive the moment quantum computers come of age. Because that moment is closer than you think.

Download the playbook here

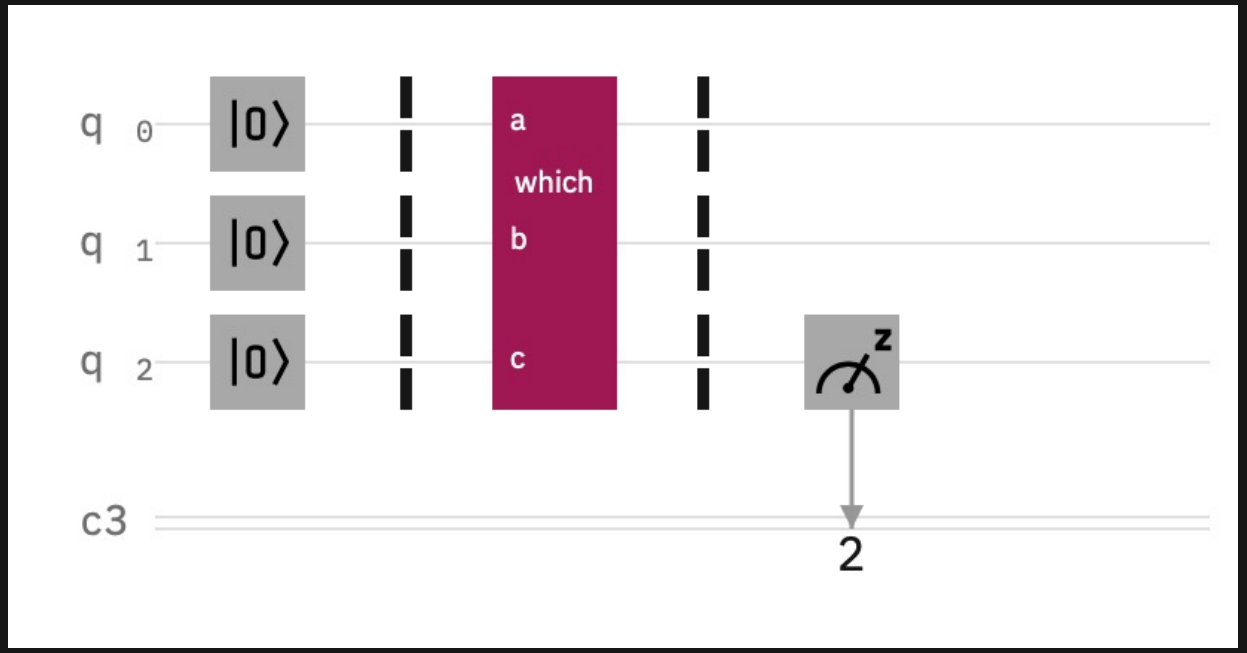


Hands-on Session

NOT gate

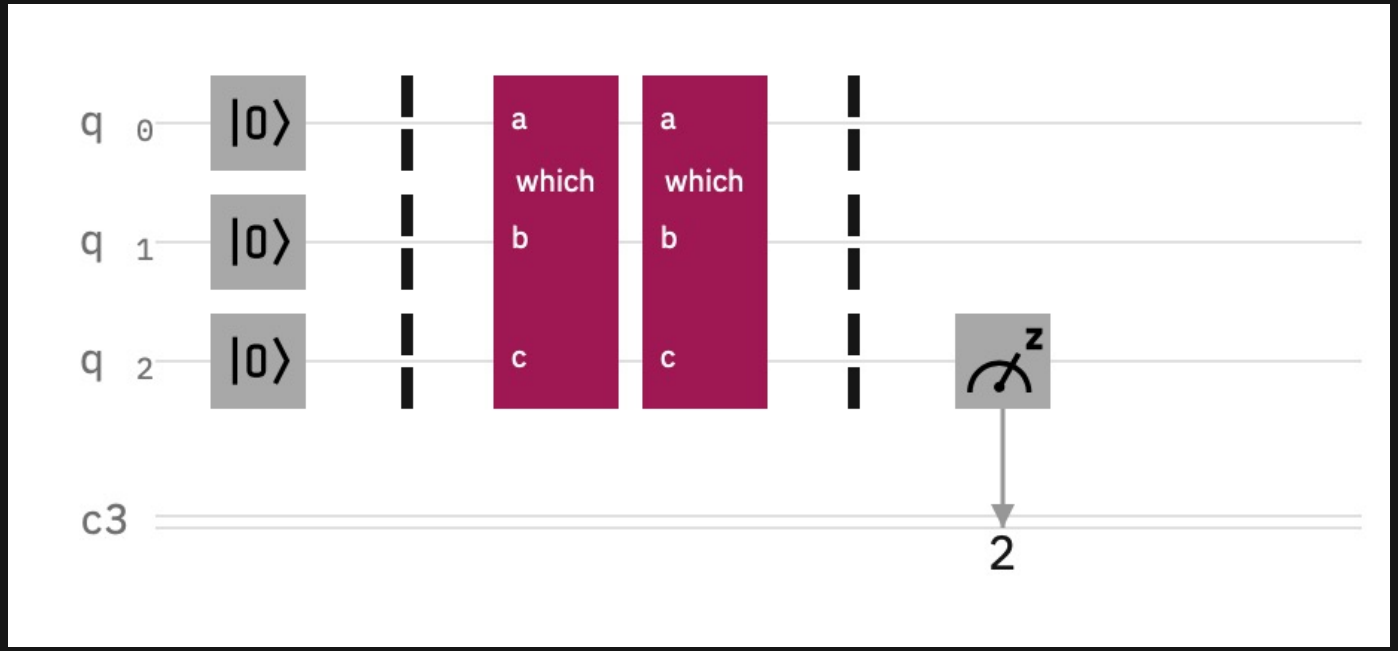
In	Out
0	1
1	0

AND gate



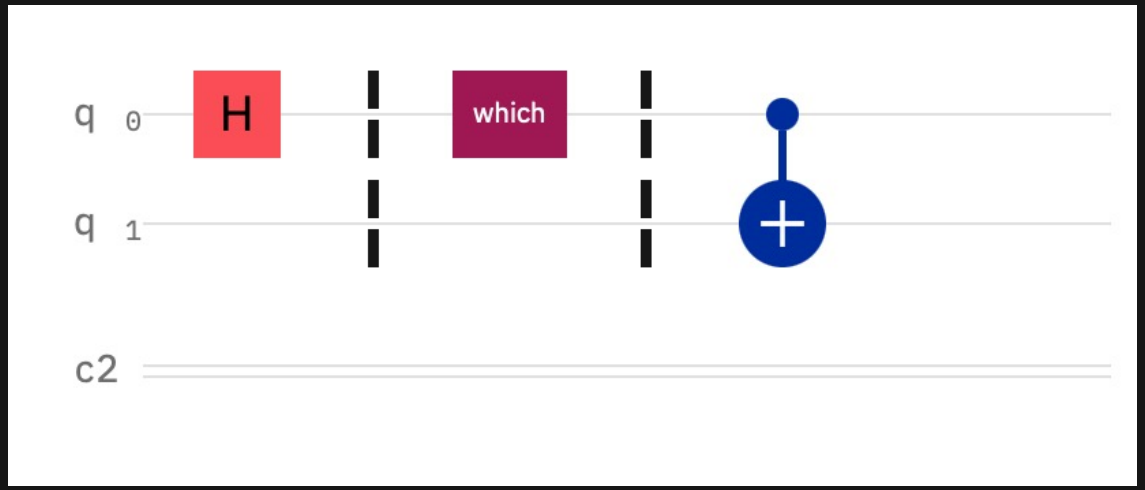
A	B	Out
0	0	0
0	1	0
1	0	0
1	1	1

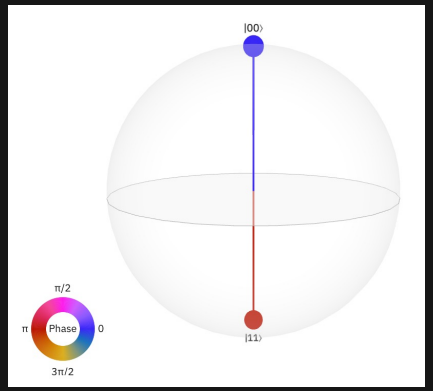
XOR gate

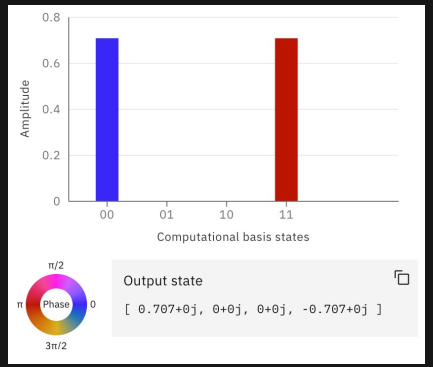


A	B	Out
0	0	0
0	1	1
1	0	1
1	1	0

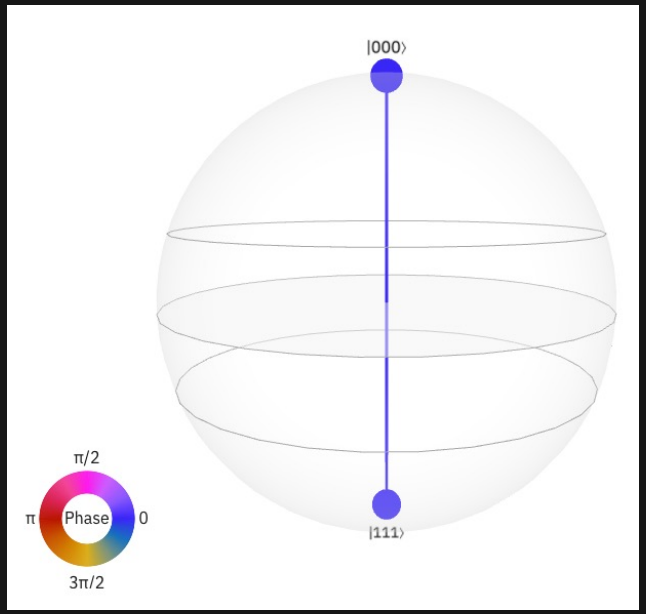
Φ^- Bell state circuit

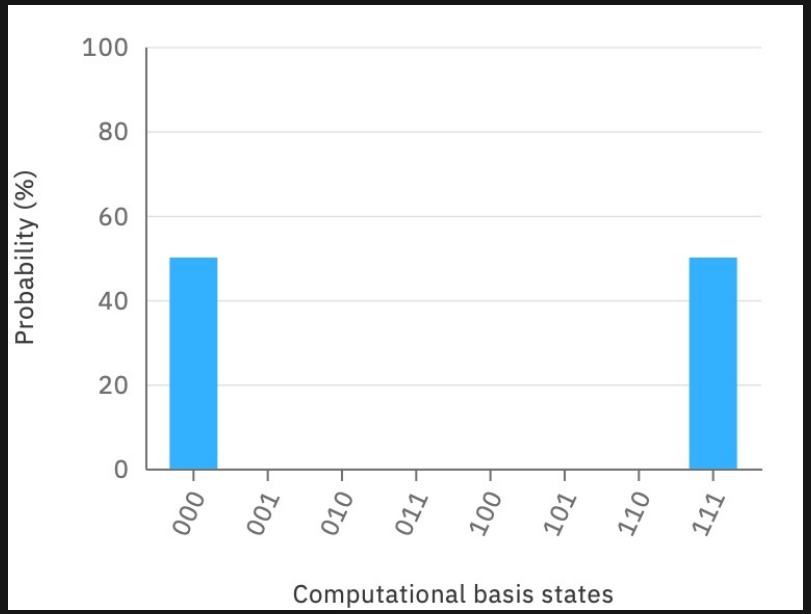






GHZ state circuit





Qiskit logo circuit