IBM Quantum Computing

Anna Phan

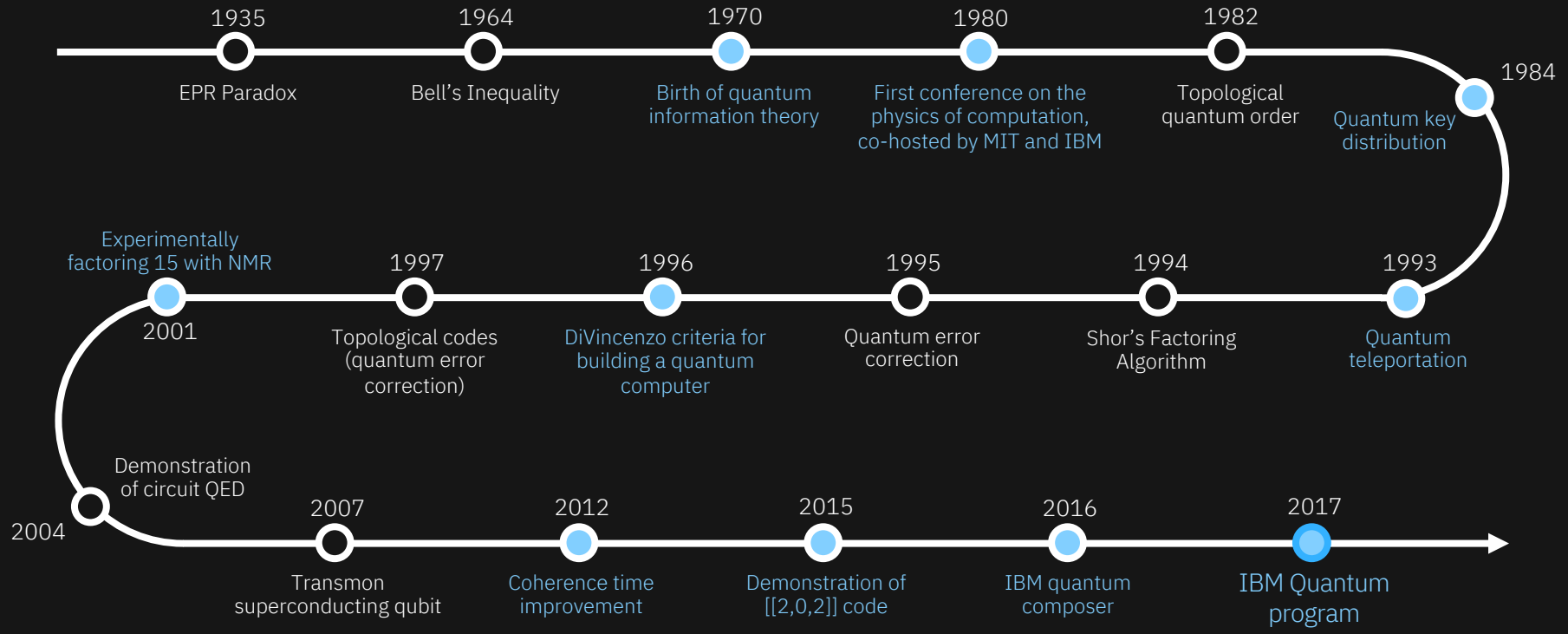
Quantum Researcher | Education Developer | Australia Community Lead

IBM **Quantum**

IBM & Quantum Computing

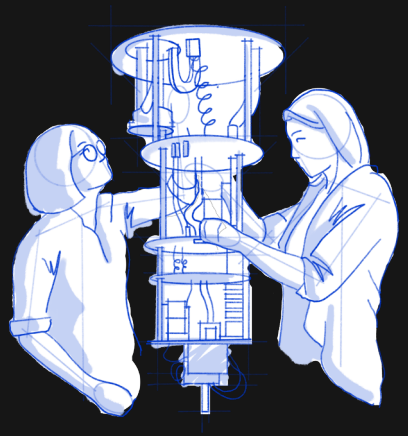
IBM **Quantum**

"Nature isn't classical, dammit, and if you want to make a simulation of nature, you'd better make it quantum mechanical, and by golly it's a wonderful problem, because it doesn't look so easy." - Richard Feynman, Physics of Computation Conference, co-hosted by MIT and IBM, 1981

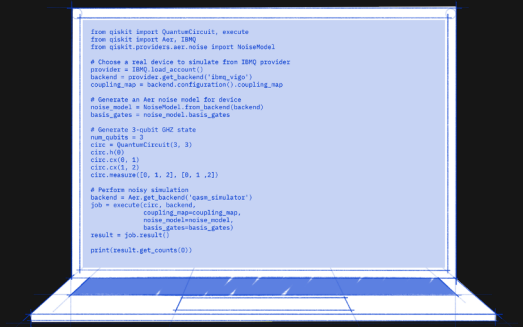


IBM Quantum Computing Program

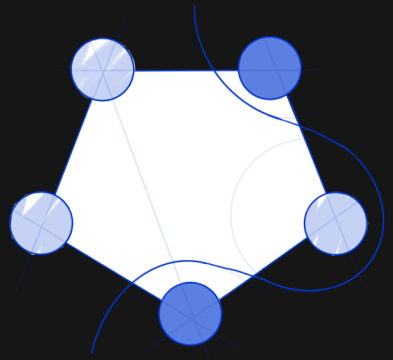
IBM **Quantum**



Hardware
&
Engineering



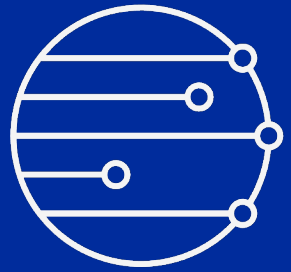
Software
&
Ecosystem



Algorithms
&
Applications

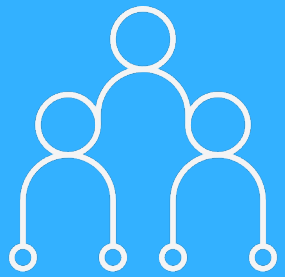
IBM Quantum Network

Accelerate quantum research



Develop commercial applications

Education and prepare



IBM Quantum Network Today

147 members

- 12 industry partners
- 19 hubs
- 37 members
- 38 startups
- 41 academic members and partners

Partners

JP Morgan Chase & Co.

ExxonMobil

Samsung

Daimler

JSR Corp

Accenture

Goldman Sachs

Woodside Energy

BP

Amgen

Boeing

Paypal

Hubs

University of Tokyo

Fraunhofer

Cleveland Clinic

US Air Force Research Lab

Oak Ridge National Lab

Keio University

NC State Univ.

Munich Hub at U. Bundeswehr

National Taiwan University

Iberian Nanotech Lab

CSIC Spain

Los Alamos National Laboratory

Pacific Northwest National Lab

Brookhaven National Lab

U. Melbourne

U. Oxford

U. Sherbrooke

SKK University

CERN

Members

Delta
Anthem
Wells Fargo
Barclays
Mizuho
MUFG
Mitsubishi Chem
Argonne Lab
Fermilab
Berkeley Lab
US Naval Res Lab
ITRI
III Taiwan
Quemix
Flight Profiler
SVA
Archer
A*Quantum
Tradeteq
Grid
CMC
Lockheed Martin
Sandia National Lab
DIC
Toyota
Hitachi
Toshiba
Yokogawa Electric
General Atomics
SuMiTB
Sony
AIS
CMU-SEI
GE Research
Deloitte
Keysight
Molecular Forecaster

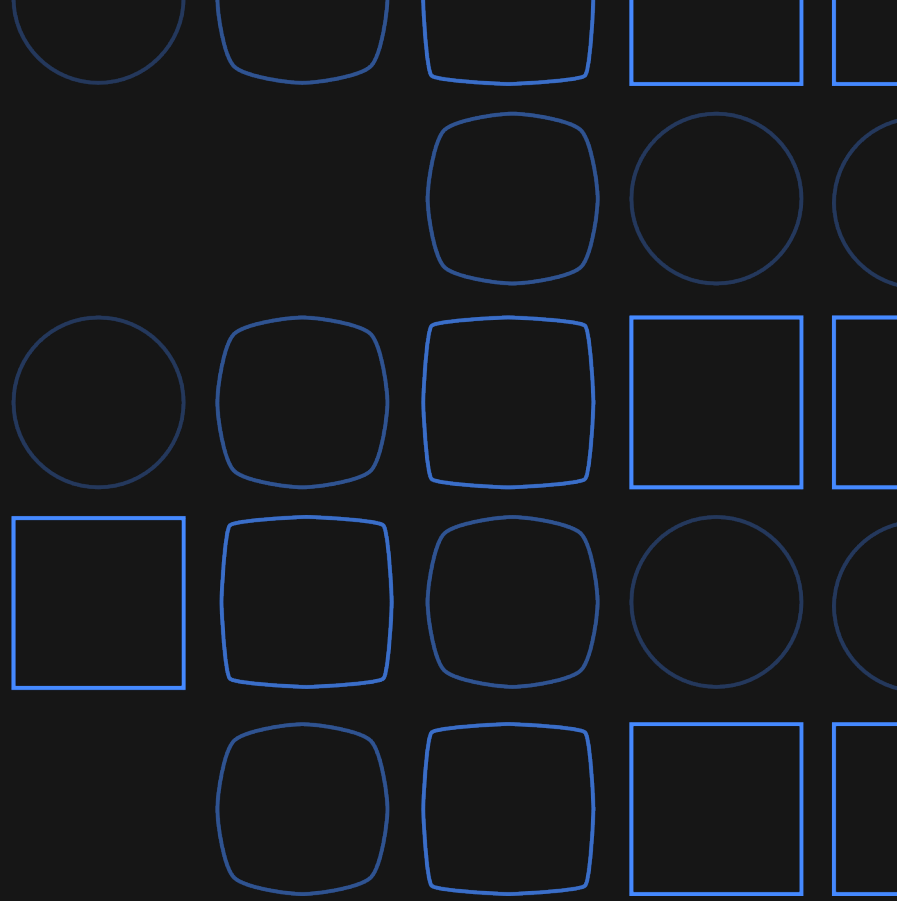
Startups

CQC
QC Ware
1QBit
Zapata
Strangeworks
Q-CTRL
Quantum Benchmark
Blueqat
Qu&Co
JoS Quantum
SolidStateAI
ProteinQure
MaxKelsen
Netramark
Entropica
Boxcat
Rahko
Qunasys
QuantFi
Agnostiq
AIQTech
Zurich Instruments
BEIT
Quantum Machines
Aliro
Xanadu
Apply Science
Multiverse
Equal1
Miraex
SoftwareQ Inc.
Super.tech
Nordic Quantum
Opacity
Phasecraft
ColdQuanta
Qedma
Horizon

Academic

MIT
EDX.org
Virginia Tech
U. Montpellier
Notre Dame
Harvard
Princeton
Florida State
U. Stony Brook
U. Chicago
Duke
CU Boulder
U. Waterloo
U. Illinois
Northwestern
NYU
Wits
Aalto University
U. of Turku
U. Basque Country
U. of Innsbruck
EPFL
Chalmers University
ETH Zurich
Saarland University
Johns Hopkins
Boston University
U. Autonoma Madrid
Stanford
Georgia Tech
U. New Mexico
National U. Singapore
U. Georgia
U. Minho
U. Tennessee
Cornell
Purdue
KAIST
New Mexico State Univ.
Northeastern University
Univ of Southern California

Quantum Computing Hardware

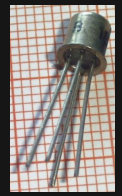


Quantum Computing Technology

Classical Bits

Relays

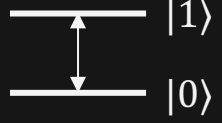
Vacuum Tube



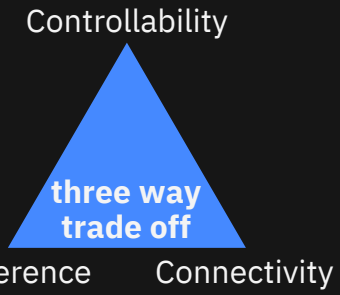
Transistor

Quantum Bits

Two-Level Systems



Example:
Atom orbitals with different energetic levels



Photons

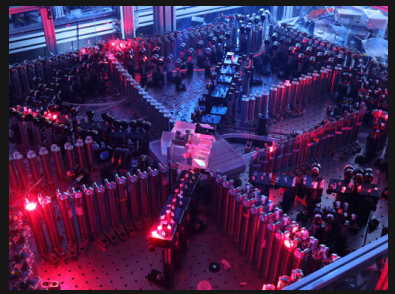


Photo: University of Science and Technology of China

Trapped Ions

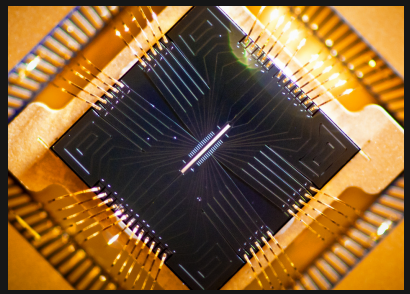
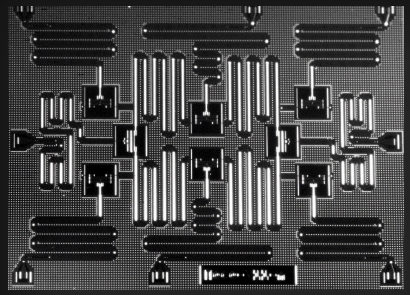


Photo: Joint Quantum Institute

Solid State Defects

Photo: University of New South Wales

Superconducting Circuits

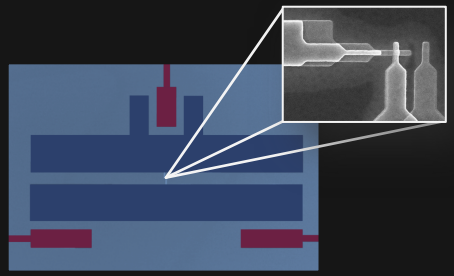


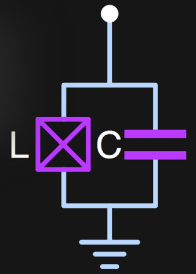
Superconducting Quantum Processor

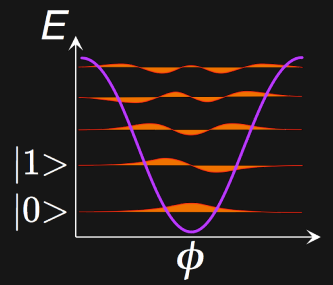
IBM **Quantum**

Superconducting transmon qubit:

- non-linear Josephson Junction (inductance)
- anharmonic energy spectrum => qubit
- nearly dissipationless



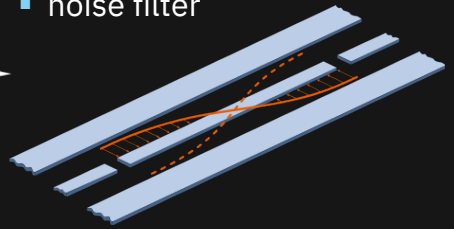


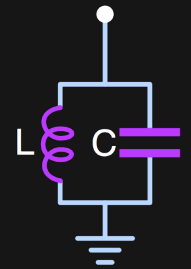


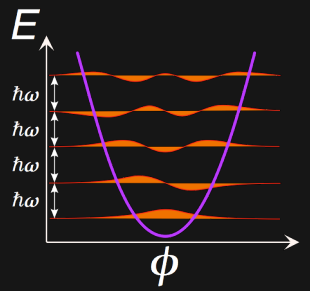
$E_{01} \approx 5\ Ghz \approx 240\ mK$

Microwave resonator:

- read-out of qubit states
- multi-qubit quantum bus
- noise filter

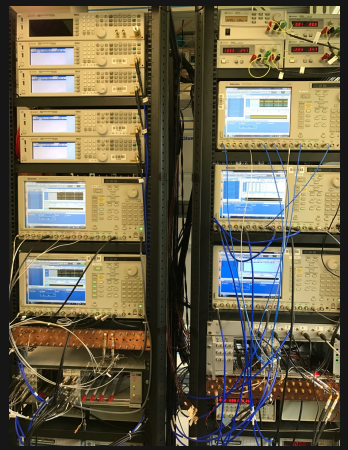


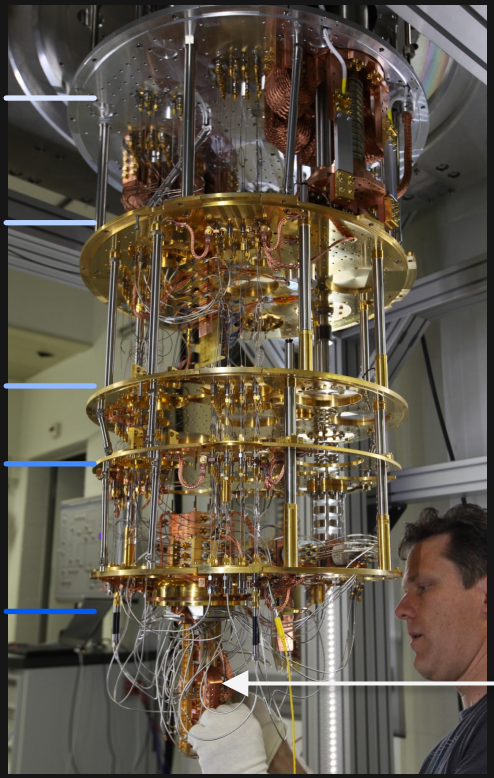




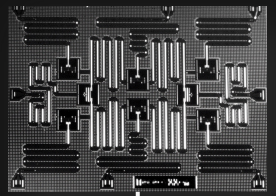
Challenging Engineering Environment

Microwave electronics

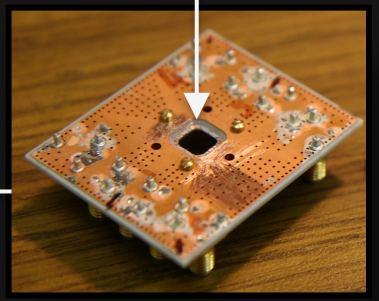




Refrigerator to cool qubits to 10 - 15 mK with a mixture of ^{3}He and ^{4}He



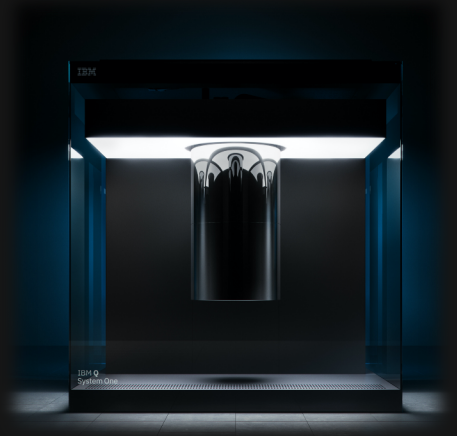
Chip with superconducting qubits and resonators



Printed circuit board with the qubit chip at 15 mK

Protected from the environment by multiple shields

The Complete System



connector

Input Module (coax cables, filters, attenuators)

Output module (isolators, amplifiers)

connector

quantum processor

dilution refrigerator

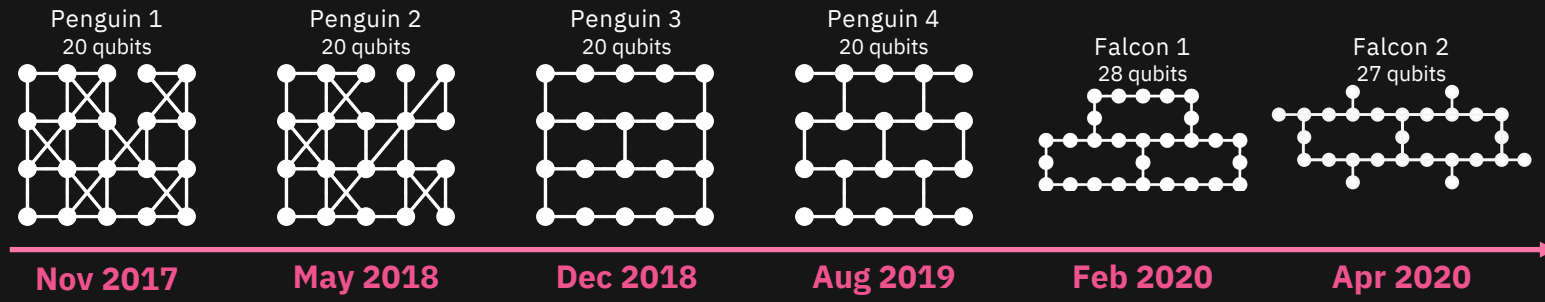
Room temperature control stack (FPGAs, RF sources, amplifiers, switch networks)

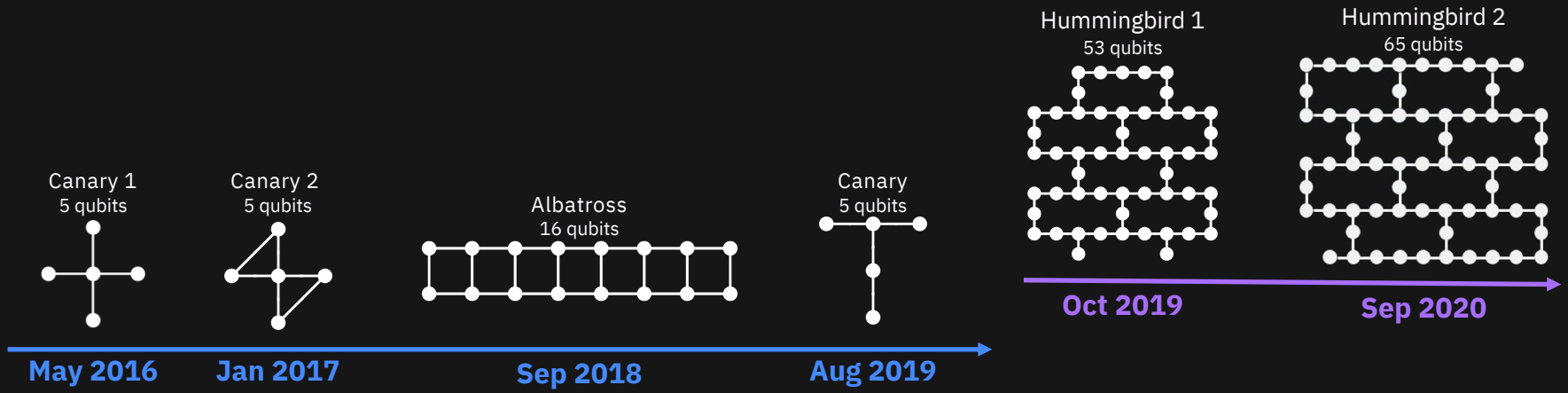
Classical computer system controller and server

Cloud

IBM System Evolution

IBM **Quantum**

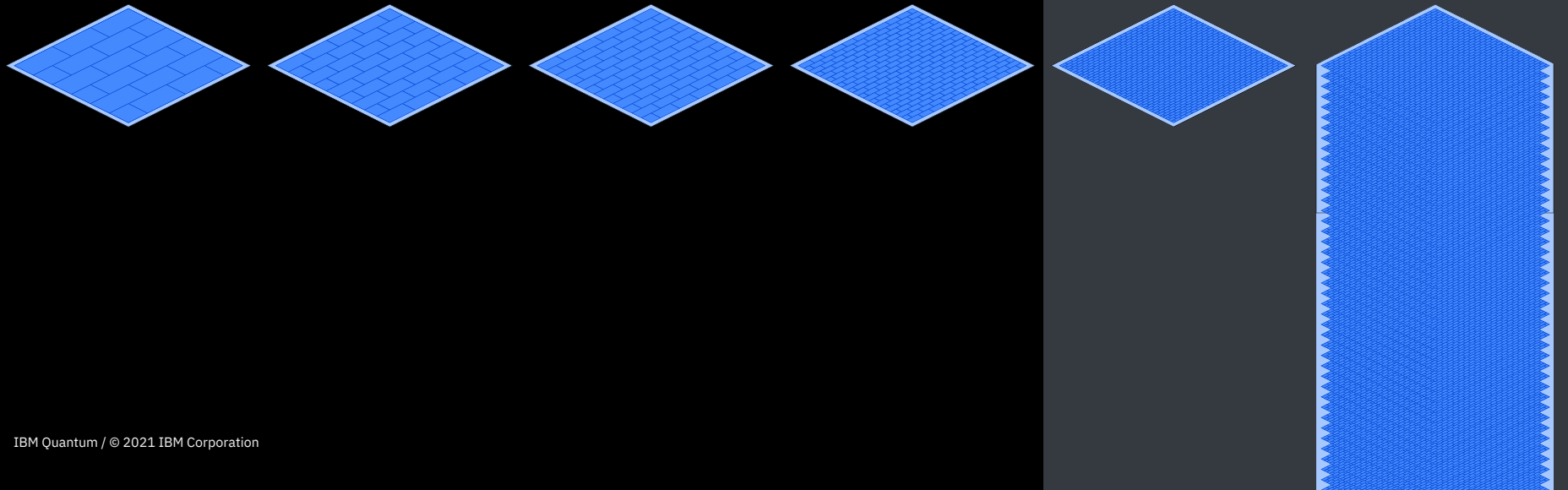




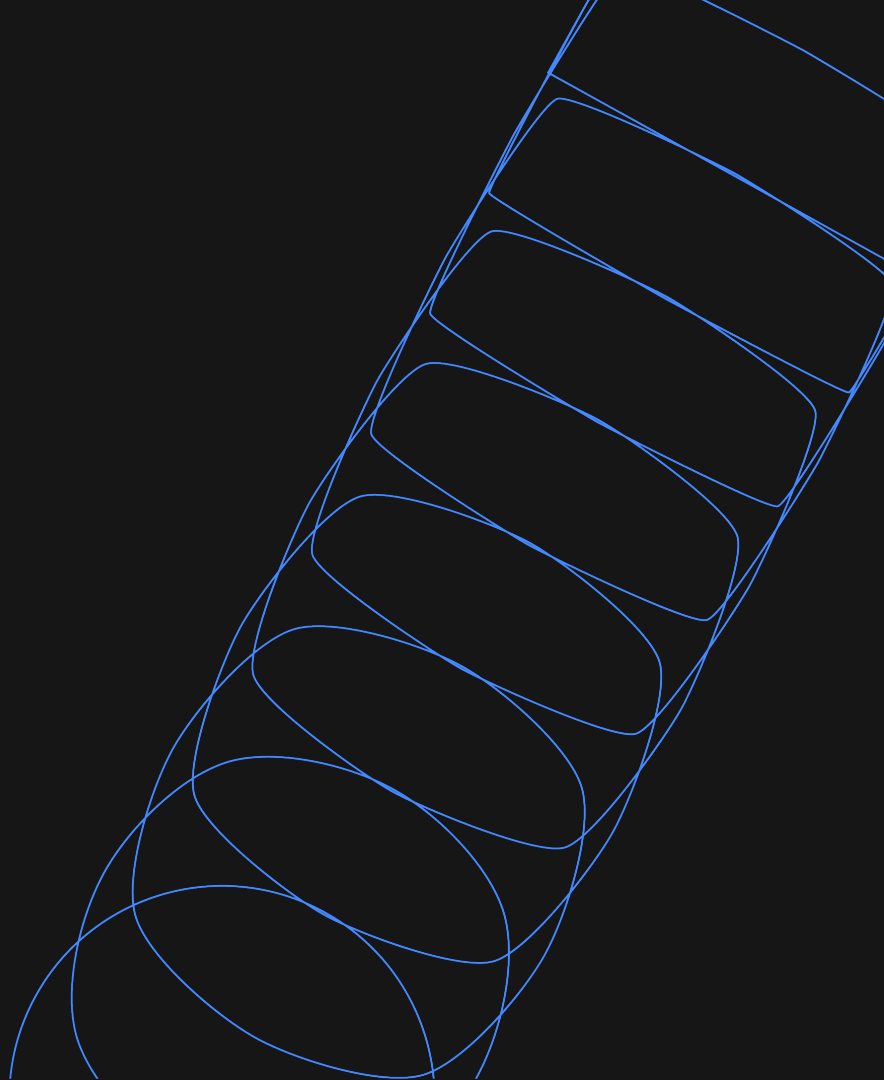
IBM System Roadmap

IBM **Quantum**

Released		In development		Next family of IBM Quantum systems	
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*

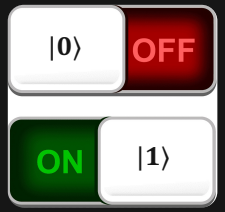


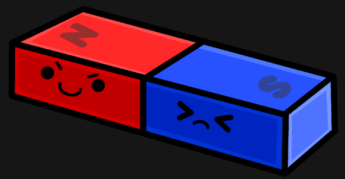
Quantum Computing Software



Bits and Qubits

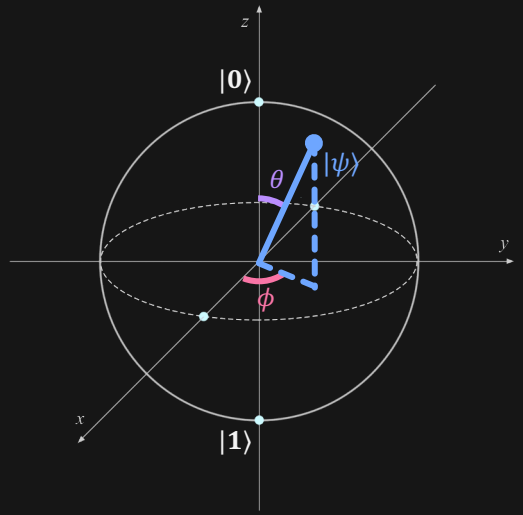
Classical Bits

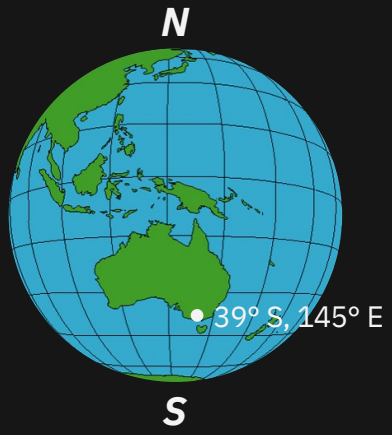




Quantum Bits

- The state of a qubit, $|\psi\rangle$, can be an arbitrary point on the surface of a sphere.
- The state of a qubit is therefore defined by two angles like longitude, θ, and latitude, ϕ, on a globe.





Classical and Quantum Logic

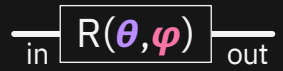
Classical logic

1-bit gates

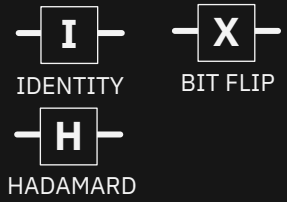
2-bit gates

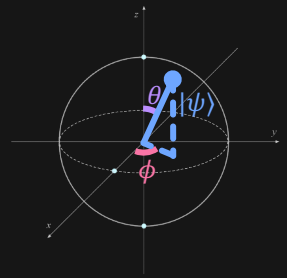
Quantum logic

1-bit gates

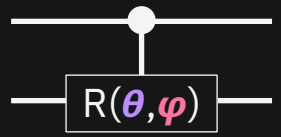


correspond to rotations on the Bloch sphere

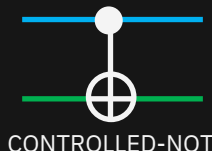


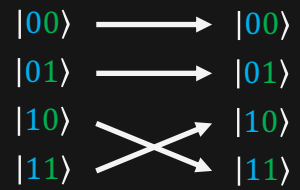


2-bit gates



the state of the second qubit depends on the first





Classical and Quantum Computation

IBM **Quantum**

C++, Java, Python, Swift, SQL,

Javascript, Ruby, PHP, Go, R, Scala,

Rust, Julia, Haskell ...

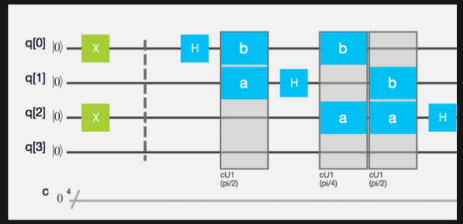
HIGH-LEVEL PROGRAMMING LANGUAGE

?

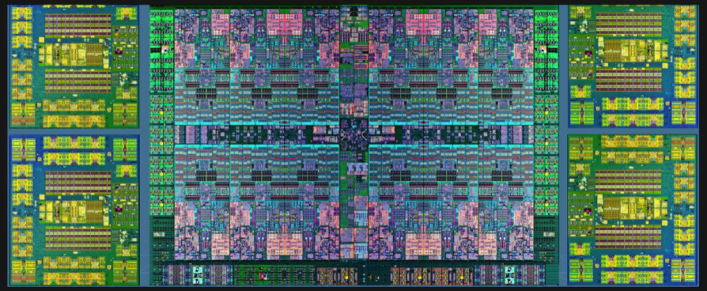
```
449a:   ff40 4e00 0400 mov.b     #0x4e, 0x4(r15)
44a0:   ff40 2f00 0500 mov.b     #0x2f, 0x5(r15)
44a6:   ff40 2900 0600 mov.b     #0x29, 0x6(r15)
44ac:   cf43 0700      mov.b     #0x0, 0x7(r15)
44b0:   3041           ret
44b2 <get_password>
44b2:   3e40 6400      mov       #0x64, r14
44b6:   b012 8445      call      #0x4584 <getsn>
44ba:   3041           ret
```

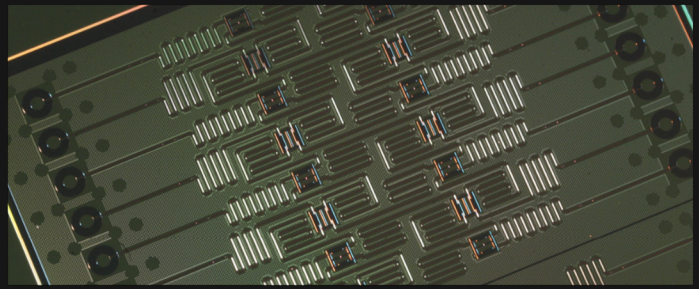
LOW-LEVEL PROGRAMMING LANGUAGE

```
IBMQASM 2.0;
include "qelib1.inc";
qreg q[4];
creg c[4];
x q[0];
x q[2];
barrier q;
h q[0];
cu1(pi/2) q[1],q[0];
h q[1];
cu1(pi/4) q[2],q[0];
```



HARDWARE





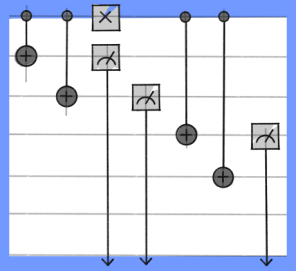
Qiskit

(www.qiskit.org)

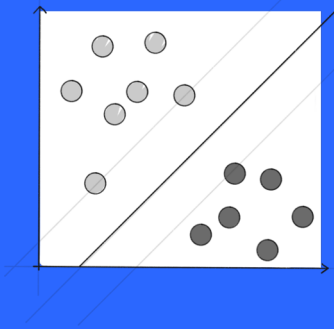
Qiskit is an open source software development kit for working with quantum computers at the level of pulses, circuits and application modules.

Qiskit accelerates the development of quantum applications by providing the complete set of tools needed for interacting with quantum systems and simulators.

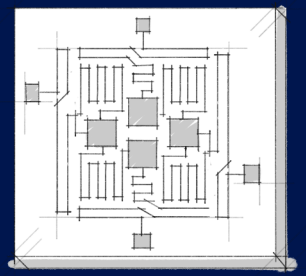
Circuit Library



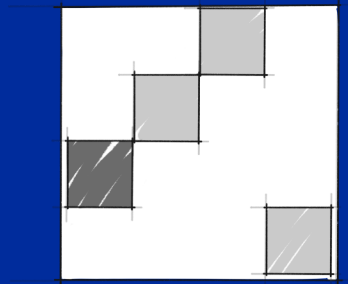
Quantum Algorithms



Hardware Access



Noise Mitigation



IBM Quantum

(https://quantum-computing.ibm.com/)

1st quantum computers on the cloud

300k+ registered users

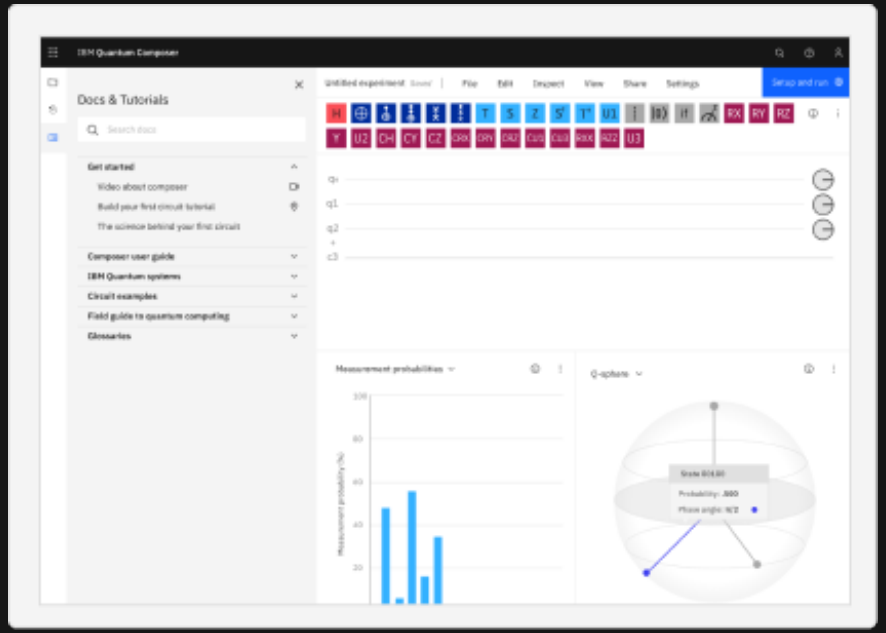
500B+ circuit executions

20+ quantum devices

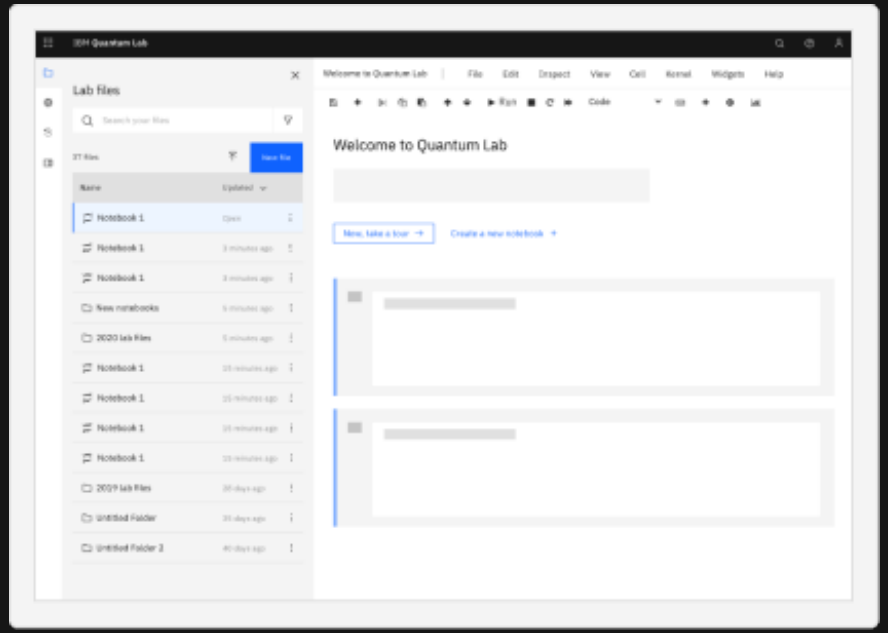
500+ research papers

Quantum Tools

Quantum Composer



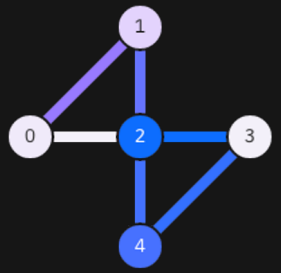
Quantum Lab



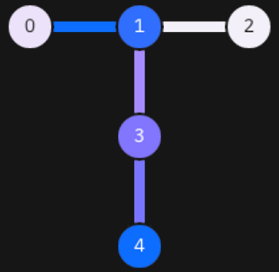
Quantum Systems

5 qubit devices

Bow configuration (*yorktown*)



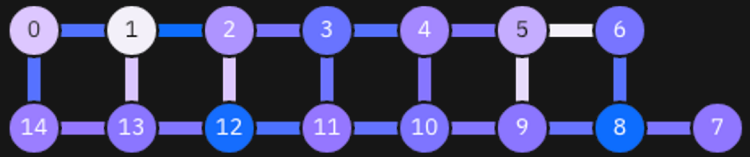
T configuration (*lima, quito, belem*)



Line configuration *(athens, santiago)*

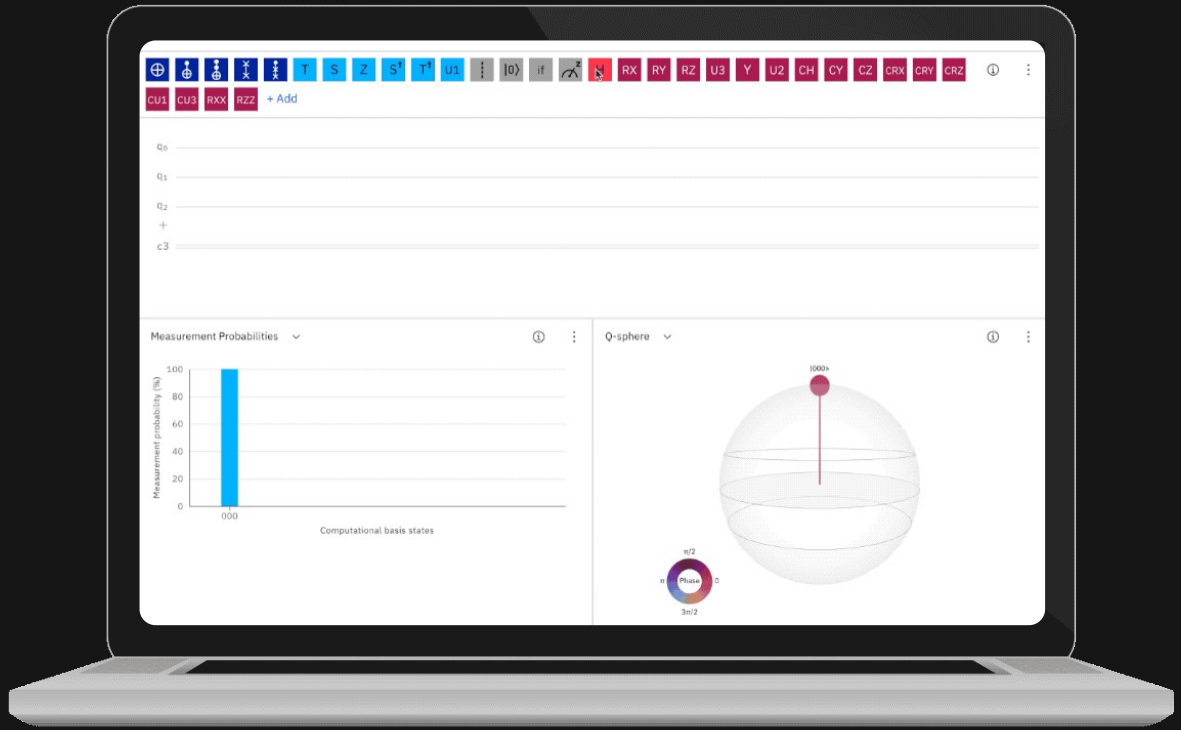
15 qubit device

Ladder configuration (*melbourne*)



Demonstration

IBM **Quantum**



Resources and Events

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

- Qiskit https://qiskit.org/
- Qiskit YouTube https://www.youtube.com/qiskit

- Qiskit Textbook https://qiskit.org/textbook/
- Qiskit Lectures https://qiskit.org/learn/intro-qc-qh

- 40th Anniversary Physics of Computation Conference https://qiskit.org/events/physics-of-computation/

- IBM Quantum Challenge, May 20 – 27 https://challenges.quantum-computing.ibm.com/iqc21

- Qiskit Global Summer School, July 12 - 23 https://qiskit.org/events/summer-school/