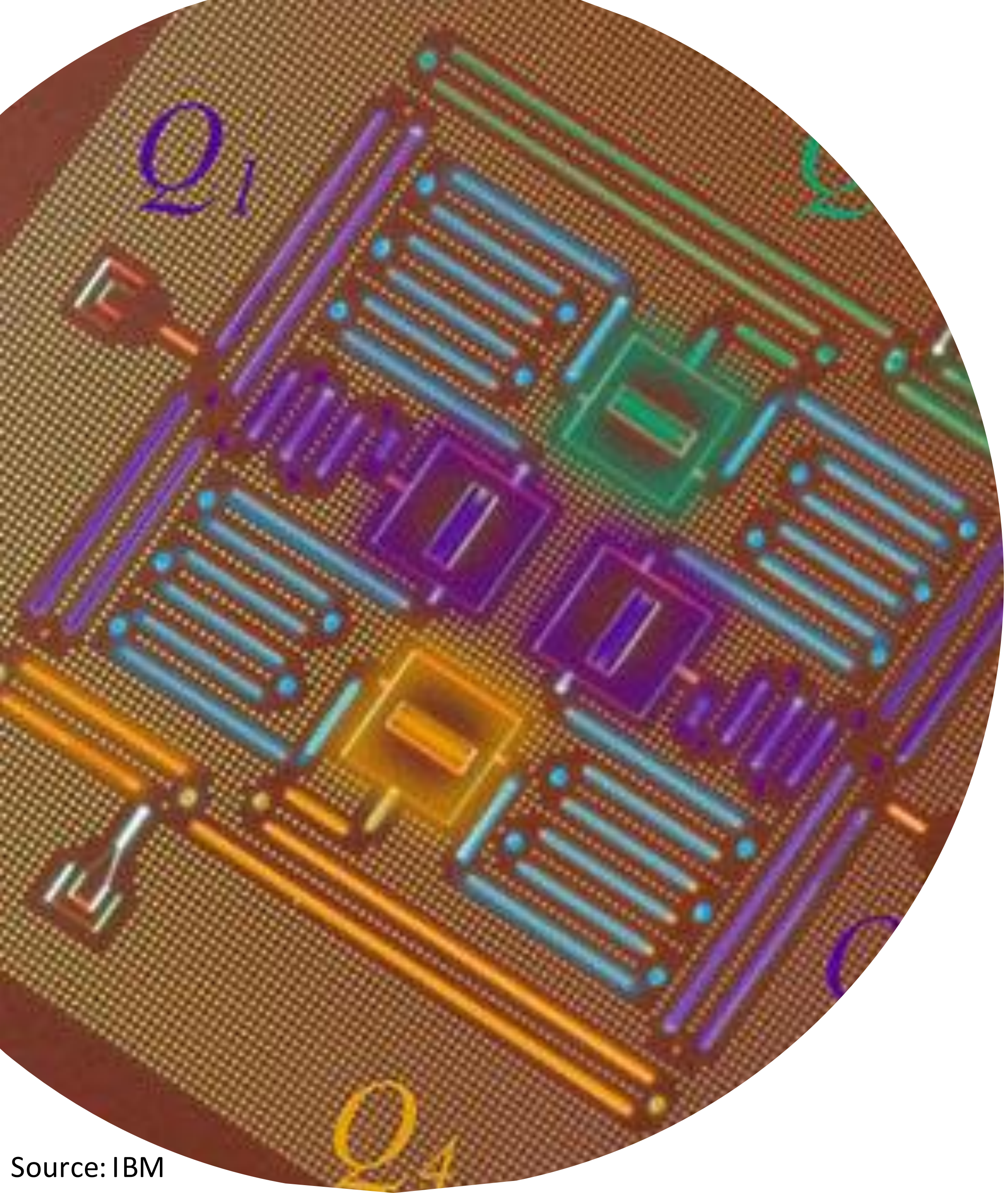
WELCOME EVERYONE!



Source: IBM

Skill Surf

ENTC

Electronic and Telecommunication Engineering

University of British Columbia QUANTUM CLUB

IEEE Sri Lanka Section

A GENTLE INTRODUCTION TO QUANTUM INFORMATION AND COMPUTING

WORKSHOP SESSION 1: January 21, 2023

Acknowledgements

University of British Columbia
QUANTUM CLUB

www.ubcquantum.com

PILLARS

Community

Access to Training

Opportunity

MEMBERS BASE (EST. 2021)

270+ Community Members

(BC Universities & Beyond)

40+ Official Members

(UBC Undergraduates)

About Myself

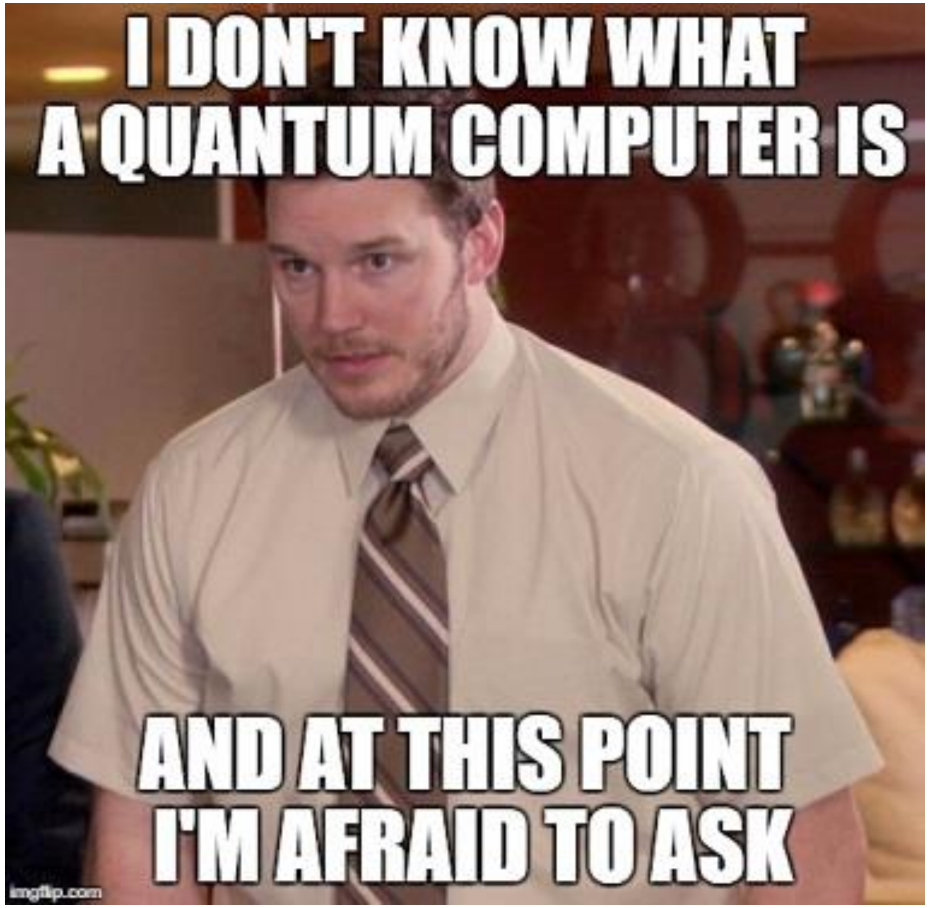
Kithmin Wickremasinghe

MASc Student in Electrical and Computer Engineering
The University of British Columbia

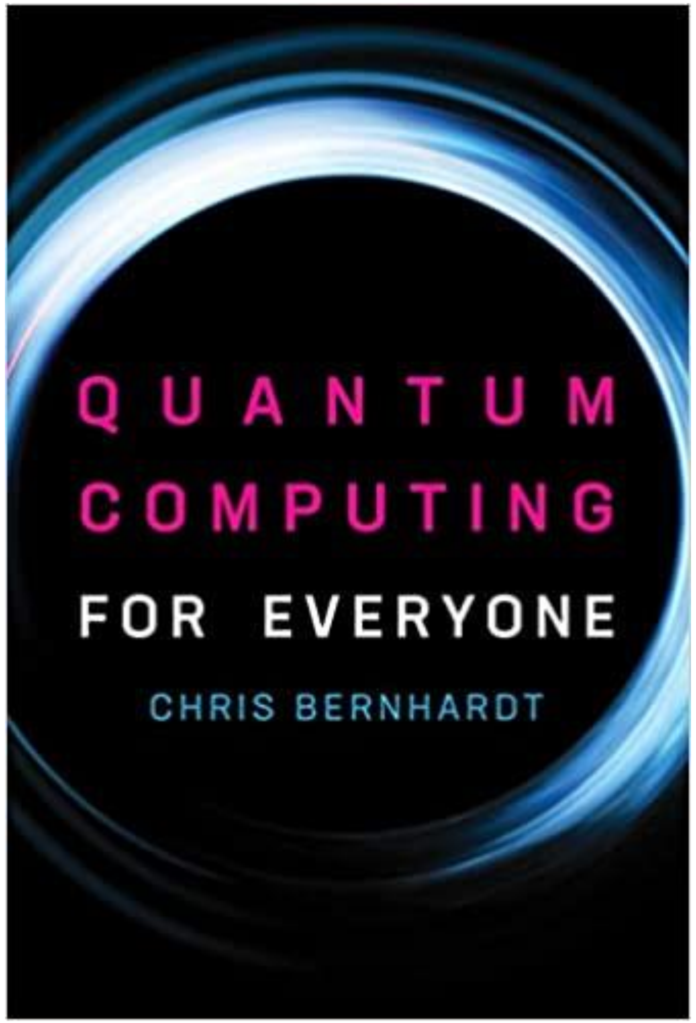
ENTC Lecturer and Alumni (15' Batch)

THE UNIVERSITY OF BRITISH COLUMBIA

Please Ask Questions; We are also still learning about QC everyday! :D

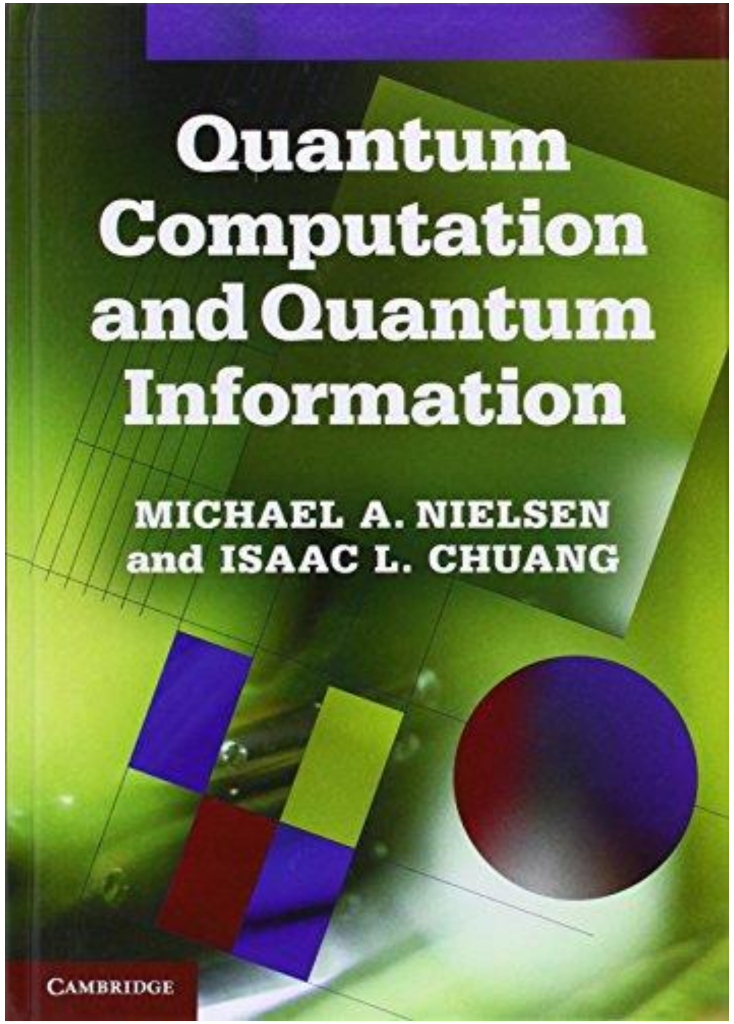


Interesting Resources



Many many more resources on this subject can be found on the Internet; Check the workshop registration email for some helpful links to study further!

Optional pre-requisites!



Optional Prerequisites

- Some basic knowledge in linear algebra is beneficial (but not required), a review can be found at https://qiskit.org/textbook/ch-appendix/linear_algebra.html (up to and including Matrices and Matrix Operations)

- Basic knowledge of programming in Python is beneficial and highly recommended (just the basics, like iterating through list, write a function, and understand what are attributes of Python class) - https://learn.qiskit.org/summer-school/2020/qubits-states-circuits-measurements

Workshop Agenda

SESSION 1

1. Introduction and Motivation for Quantum Computing
2. Diving into Quantum Bits: Polarization of Light
3. The mathematical background of Quantum Computing
4. Visualizing Qantum Gates Interactively

SESSION 2

1. Introduction to IBM QISKIT
2. Demonstration Session using Python Notebooks
3. Scientific Challenges of Quantum Computing

Instructors for the Workshop

Kithmin

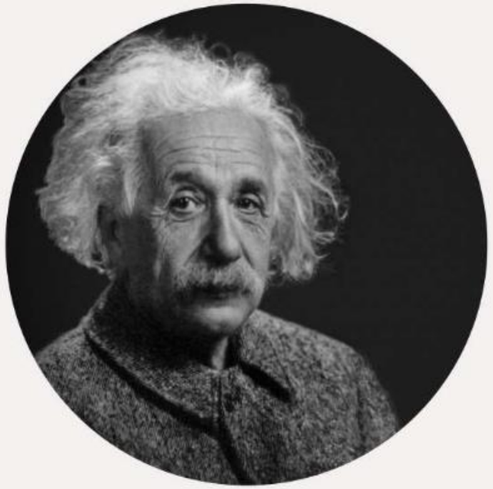
Ravi

Theshani

SESSION 1

SESSION 2

The Story of Quantum Computing



Albert Einstein
1879 - 1955

Niels Bohr
1885 - 1962

Max Planck
1858 - 1947

Werner Heisenberg
1901 - 1976

COPENHAGEN

1941

Classical Mechanics

force = mass x acceleration

$$F = ma$$

Issac Newton
1643 - 1727

Quantum Mechanics

change is proportional to energy

$$i\hbar\frac{\partial}{\partial t}\left|\Psi\right\rangle = \hat{H}\left|\Psi\right\rangle$$

Erwin Schrödinger
1887 - 1961

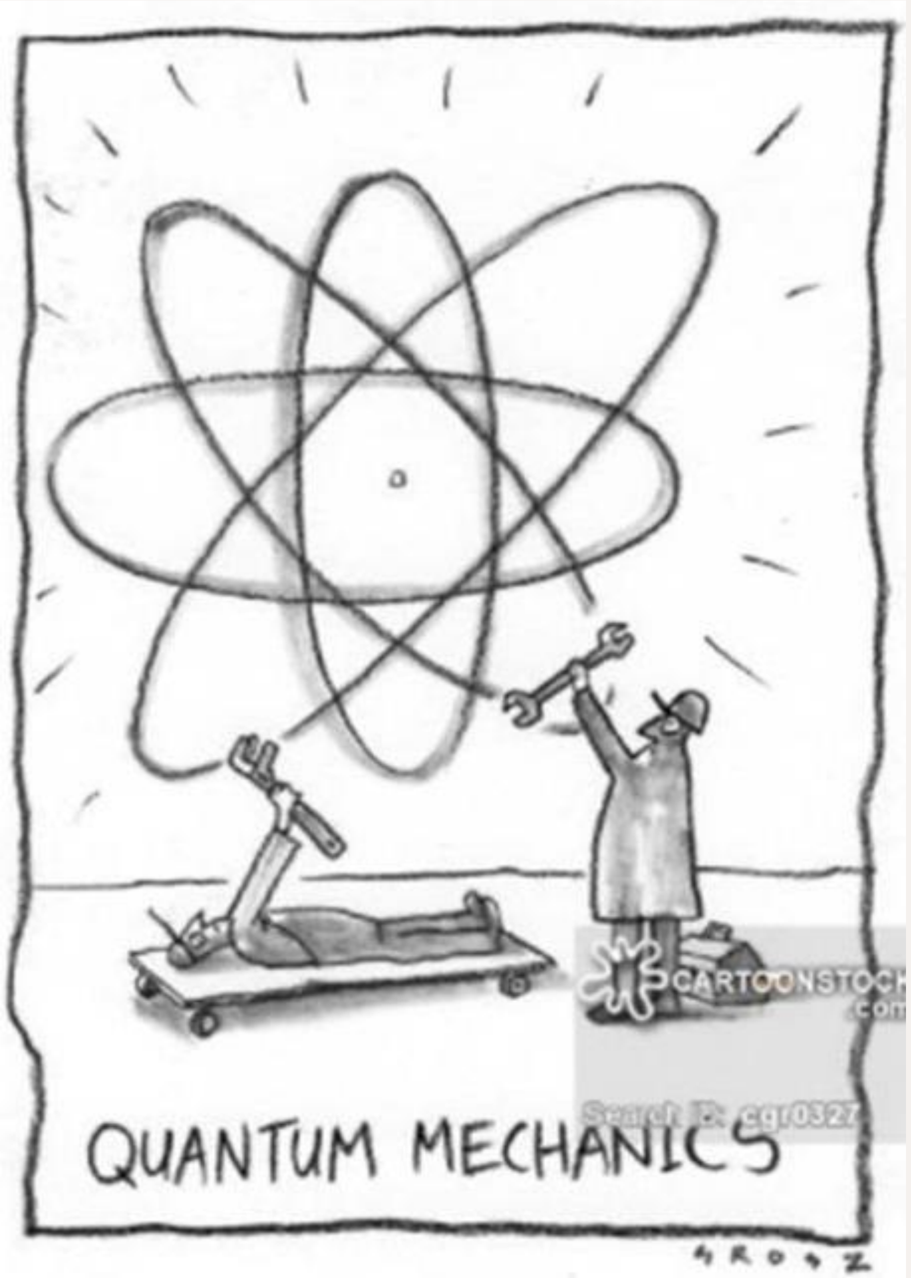
Postulates of Quantum Mechanics

Quantum State?

…is the status of something as described using quantum mechanics

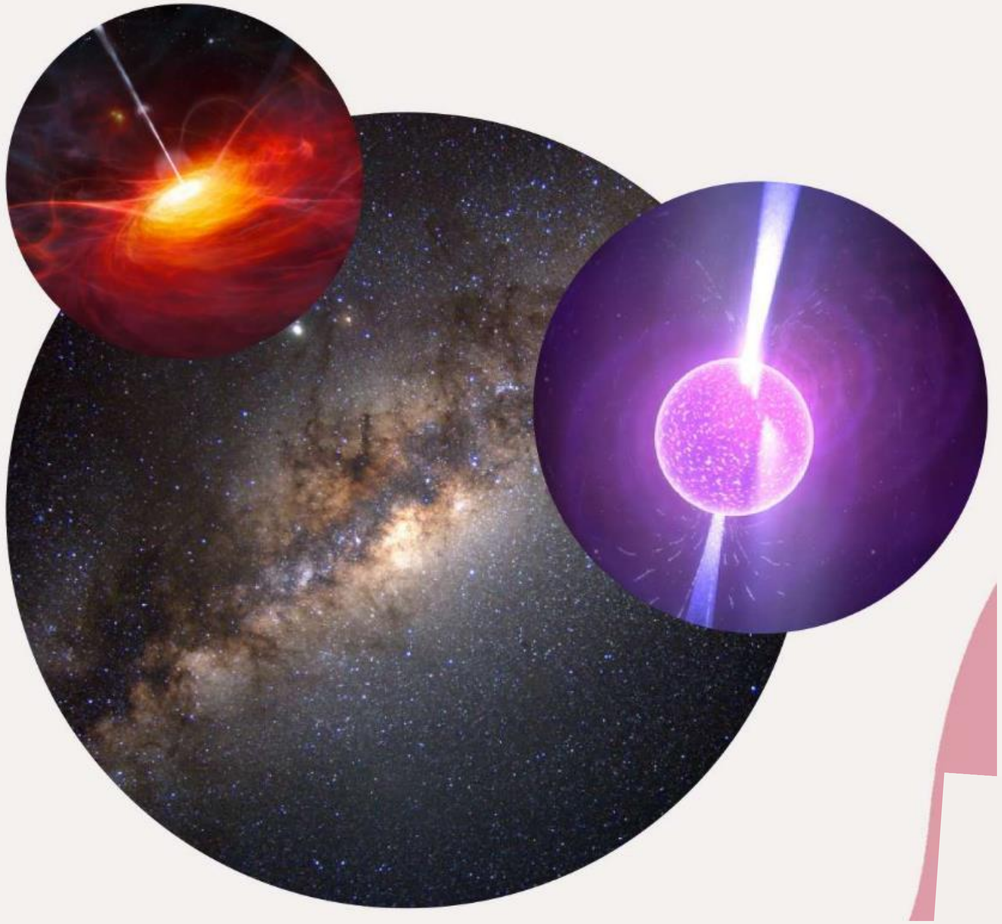
Quantum Theory

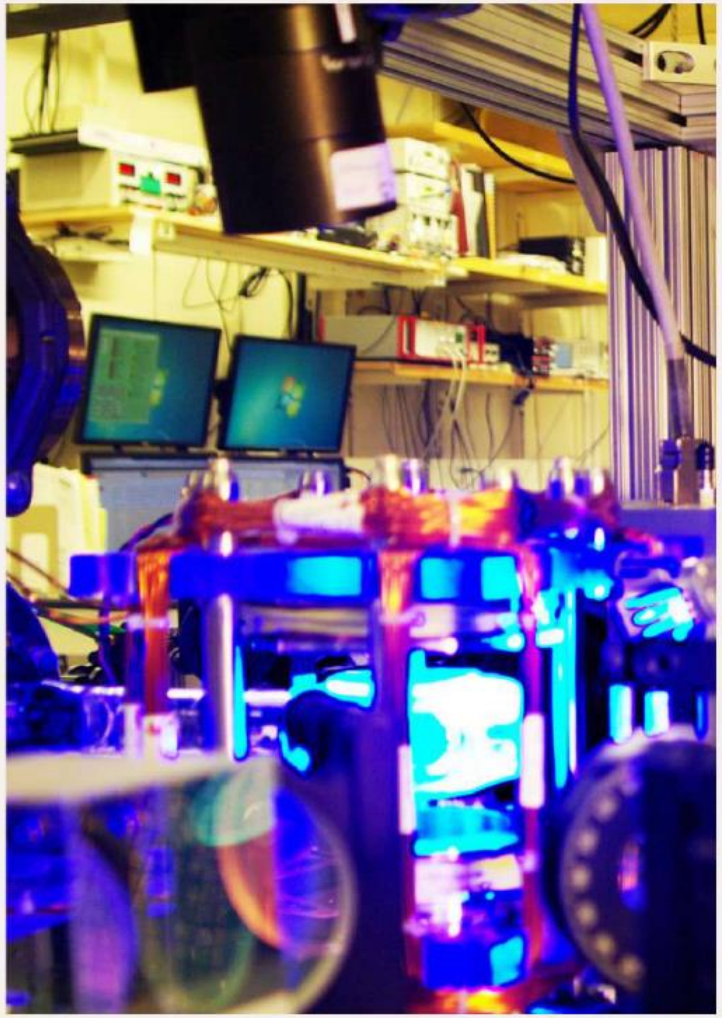
the foundation of everything



Radio Astronomy

1930-1940s





Control over single quantum systems

?

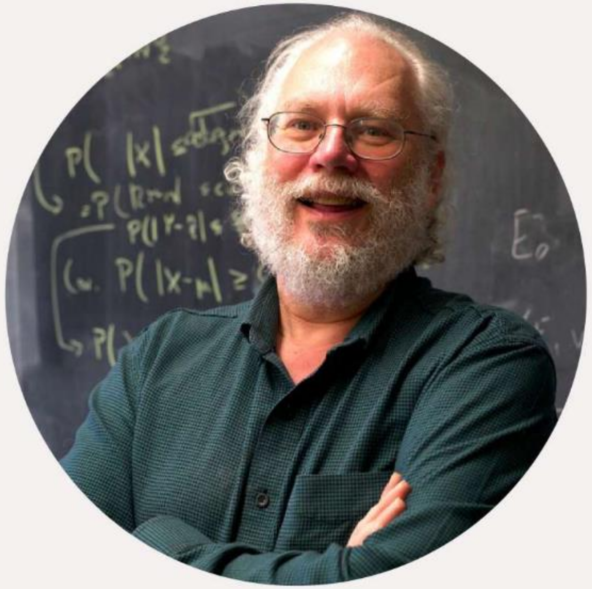
1985

David Deutsch

Efficiently simulating an arbitrary physical system?

1994

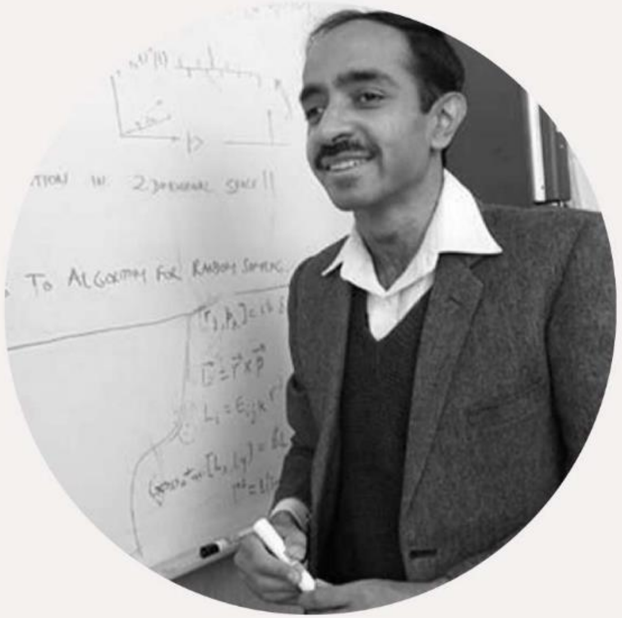
Peter Shor



Shor's algorithm for find prime factors of an integer

1995

Lov Grover



Search algorithm in unstructured space

1990s

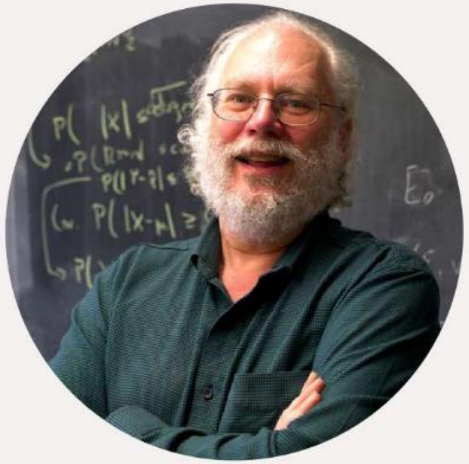
Various Groups

Simulation of quantum systems

Error-correcting Code

Enables the modern quantum computers

1996



Peter Shor

Robert Calderbank

Andrew Steane

NOBELPRISET I FYSIK 2022

THE NOBEL PRIZE IN PHYSICS 2022

KUNGL. VETENSKAPS-AKADEMIEN

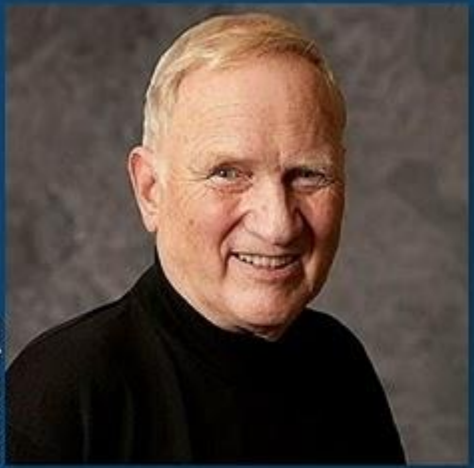
THE ROYAL SWEDISH ACADEMY OF SCIENCES

Photo: Royal Society

Alain Aspect

Université Paris-Saclay & École Polytechnique, France

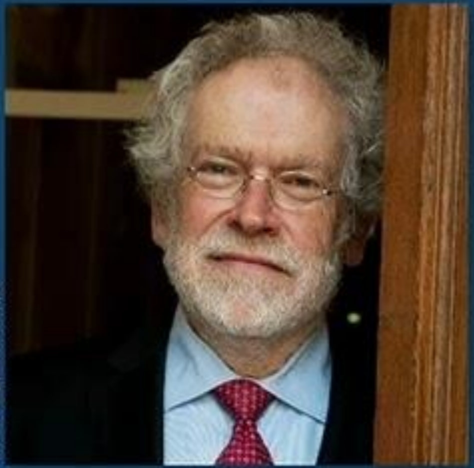
Photo: Peter Lyons



John F. Clauser

J.F. Clauser & Assoc., USA

Photo: Sepp Dreissinger



Anton Zeilinger

University of Vienna, Austria

”för experiment med sammanflätade fotoner som påvisat brott mot Bell-olikheter och banat väg för kvantinformationsvetenskap”

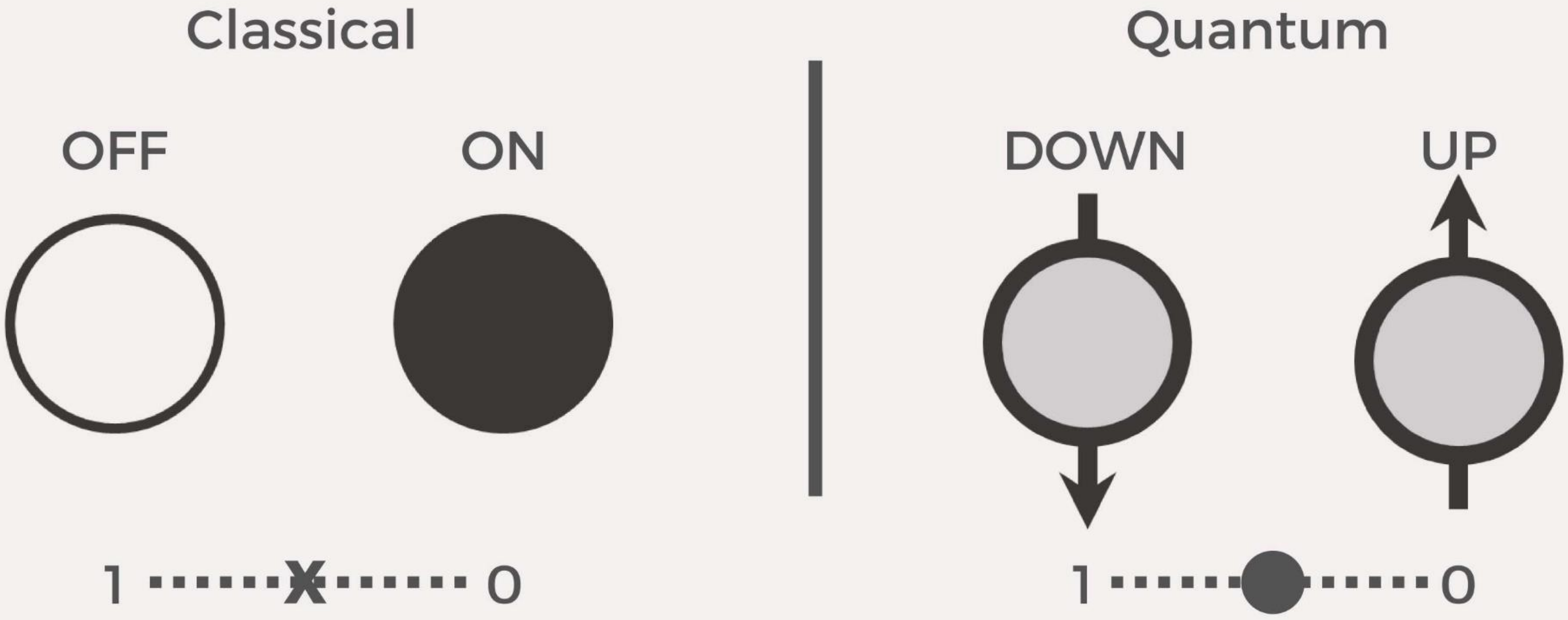
“for experiments with entangled photons, establishing the violation of Bell inequalities and pioneering quantum information science”

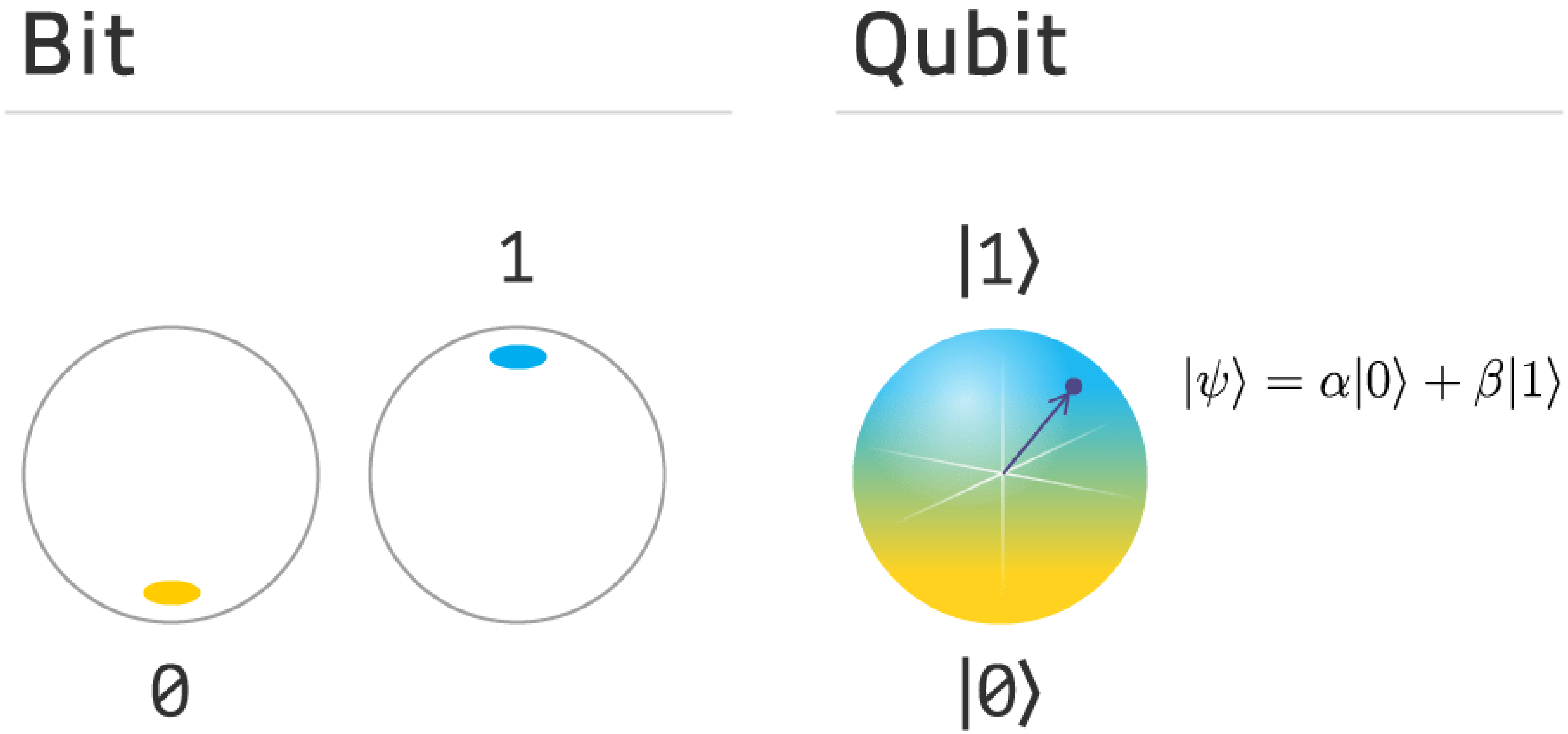
#nobelprize

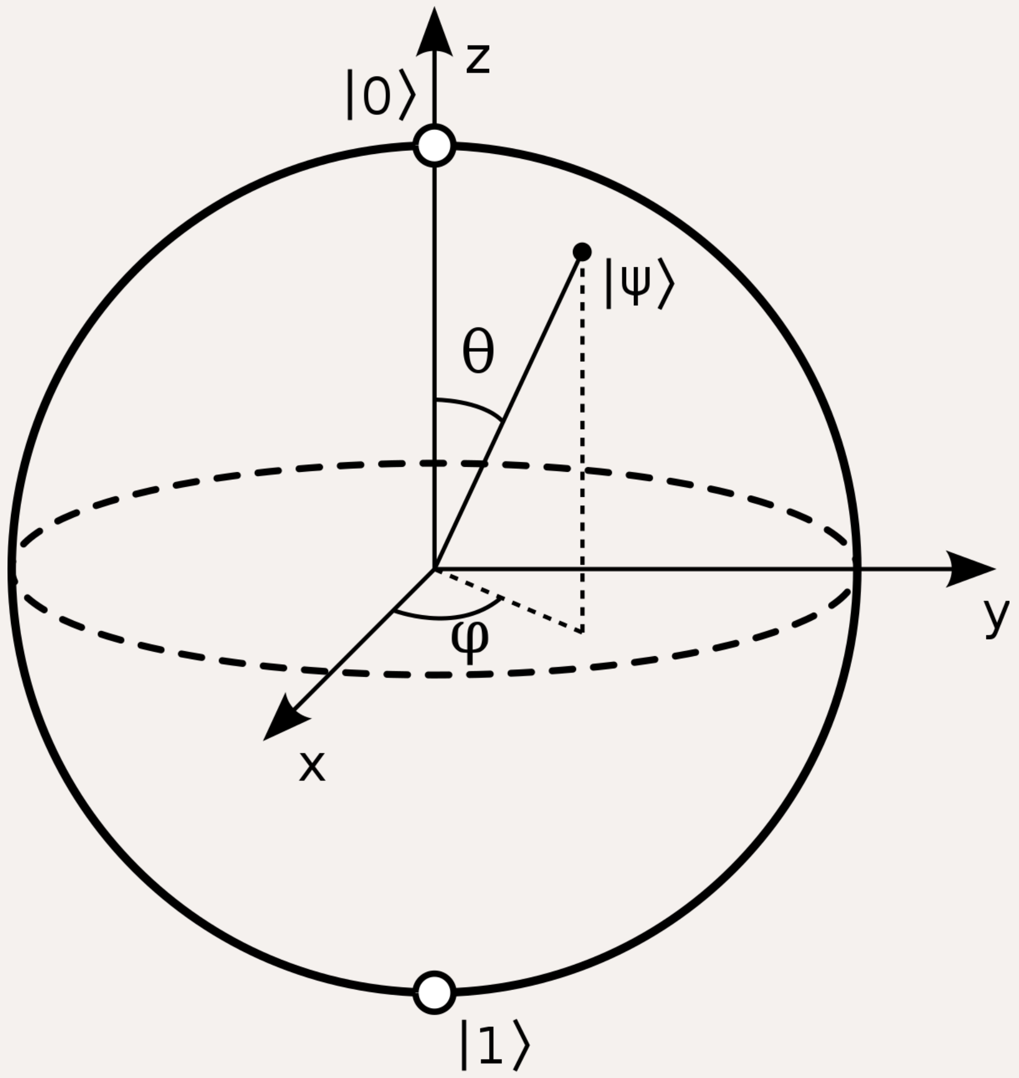
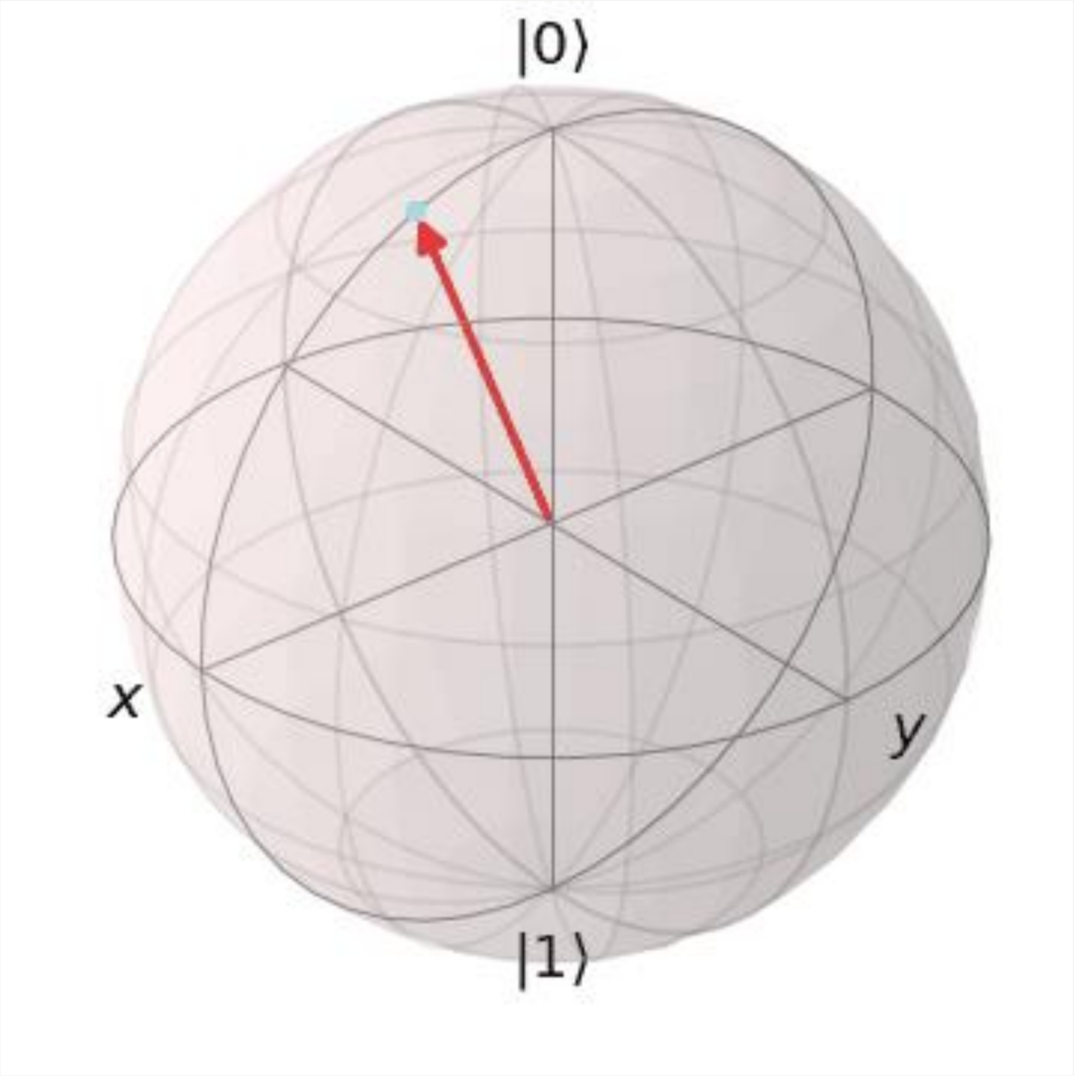
THE NOBEL PRIZE

Explaining Qubits: In Brief

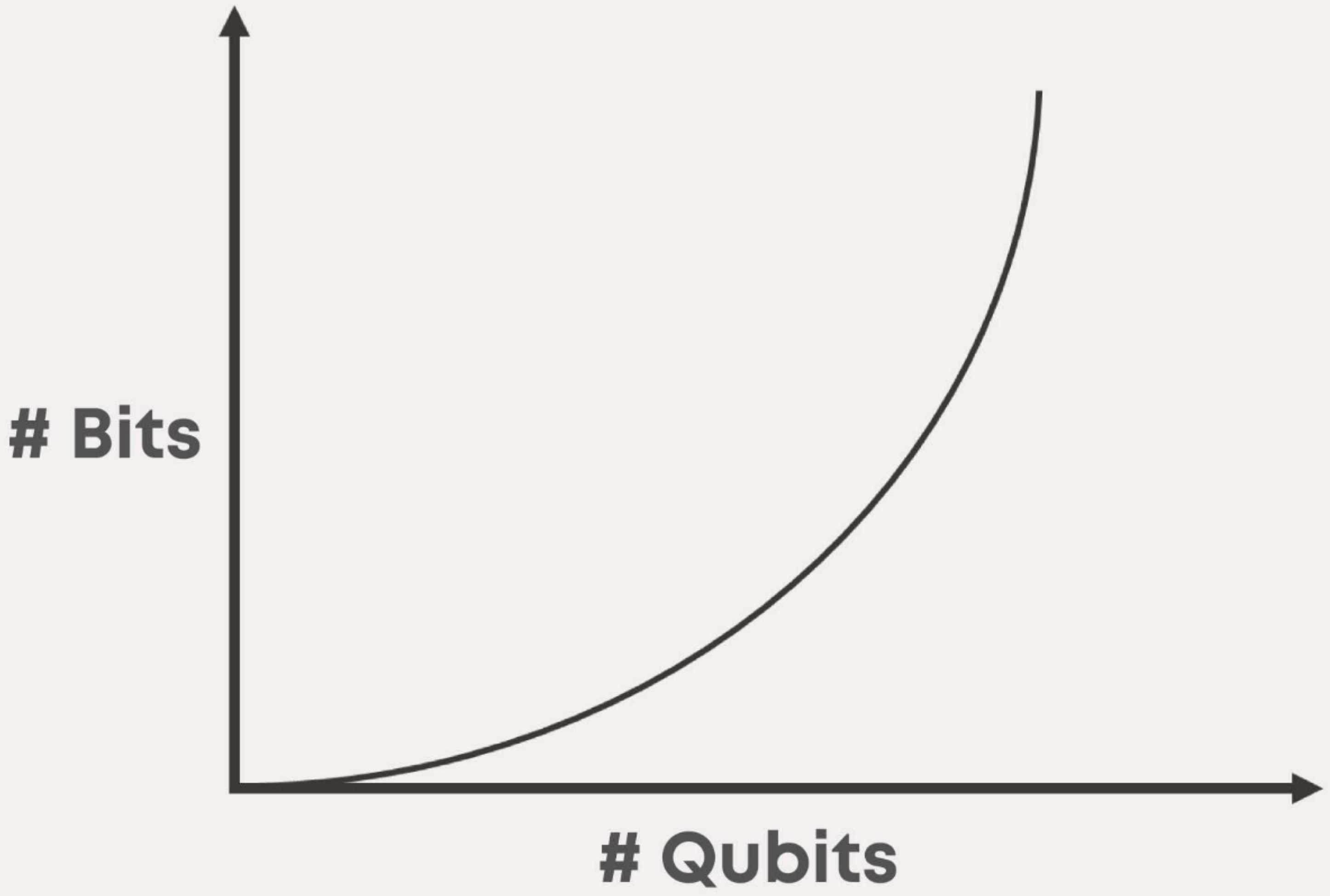
Unit of Computation




Bit
Qubit
1
0
|1⟩
$|\psi\rangle = \alpha|0\rangle + \beta|1\rangle$
|0⟩


z
|0⟩
|ψ⟩
θ
y
φ
x
|1⟩

|0⟩
x
y
|1⟩

Exponential Information Resources Initially Motivates QC



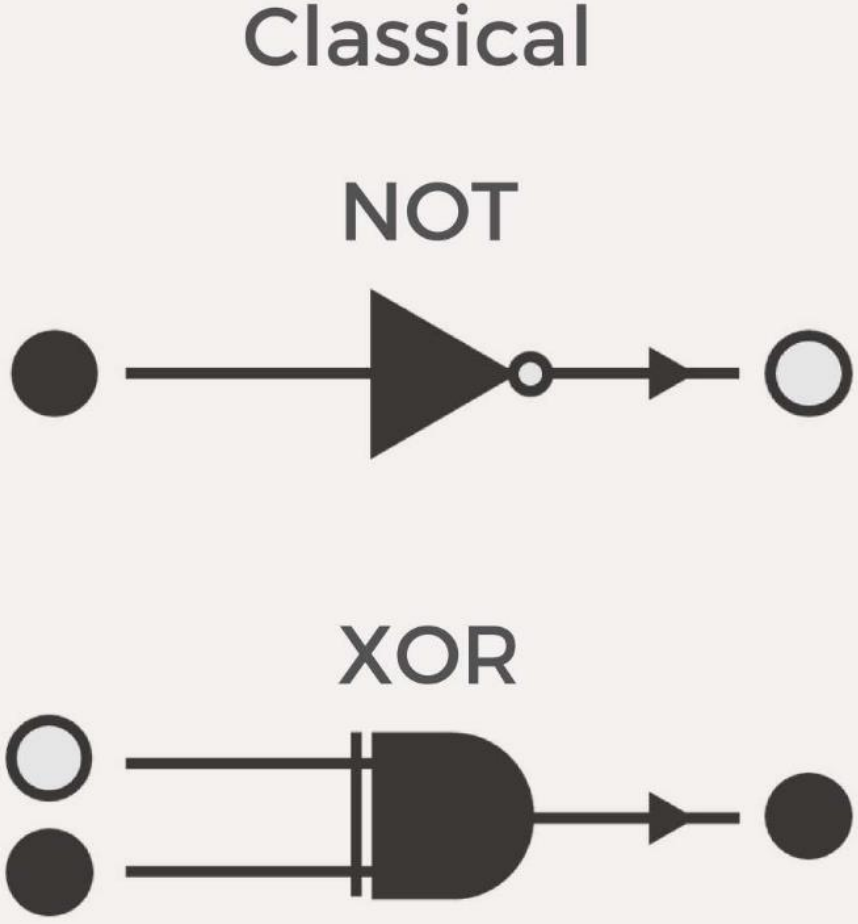
kurzgesagt

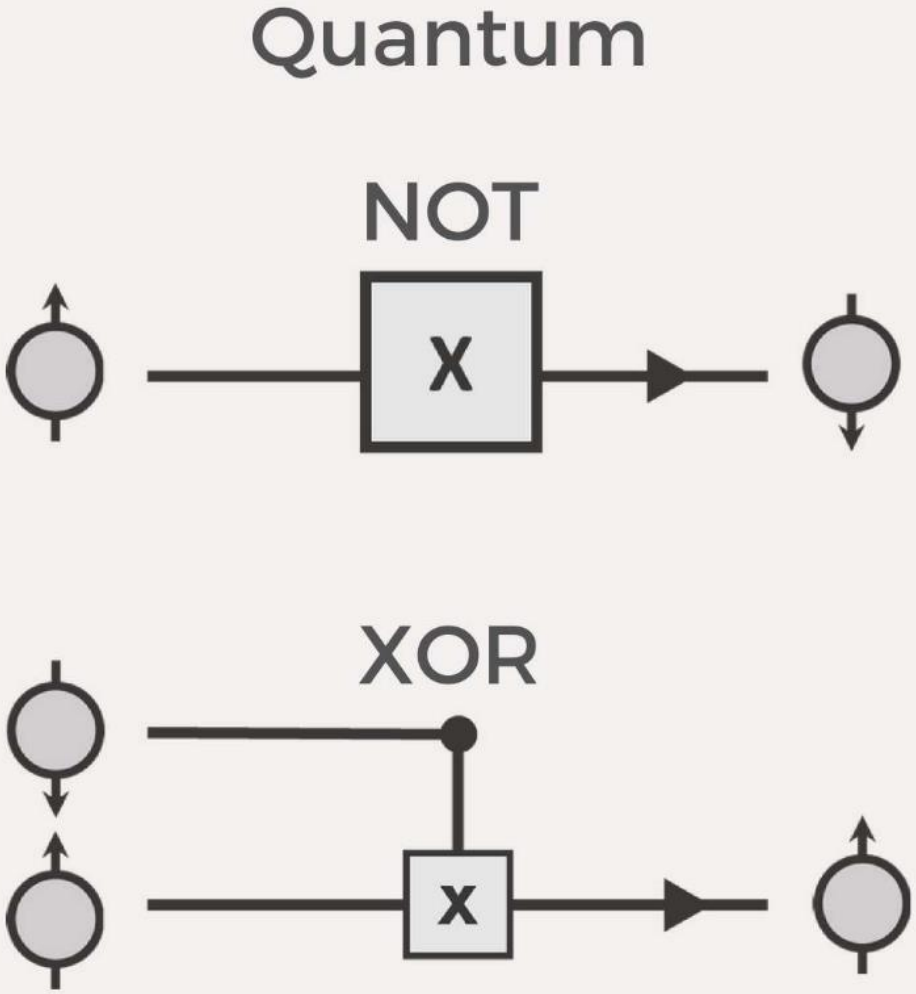
in a nutshell

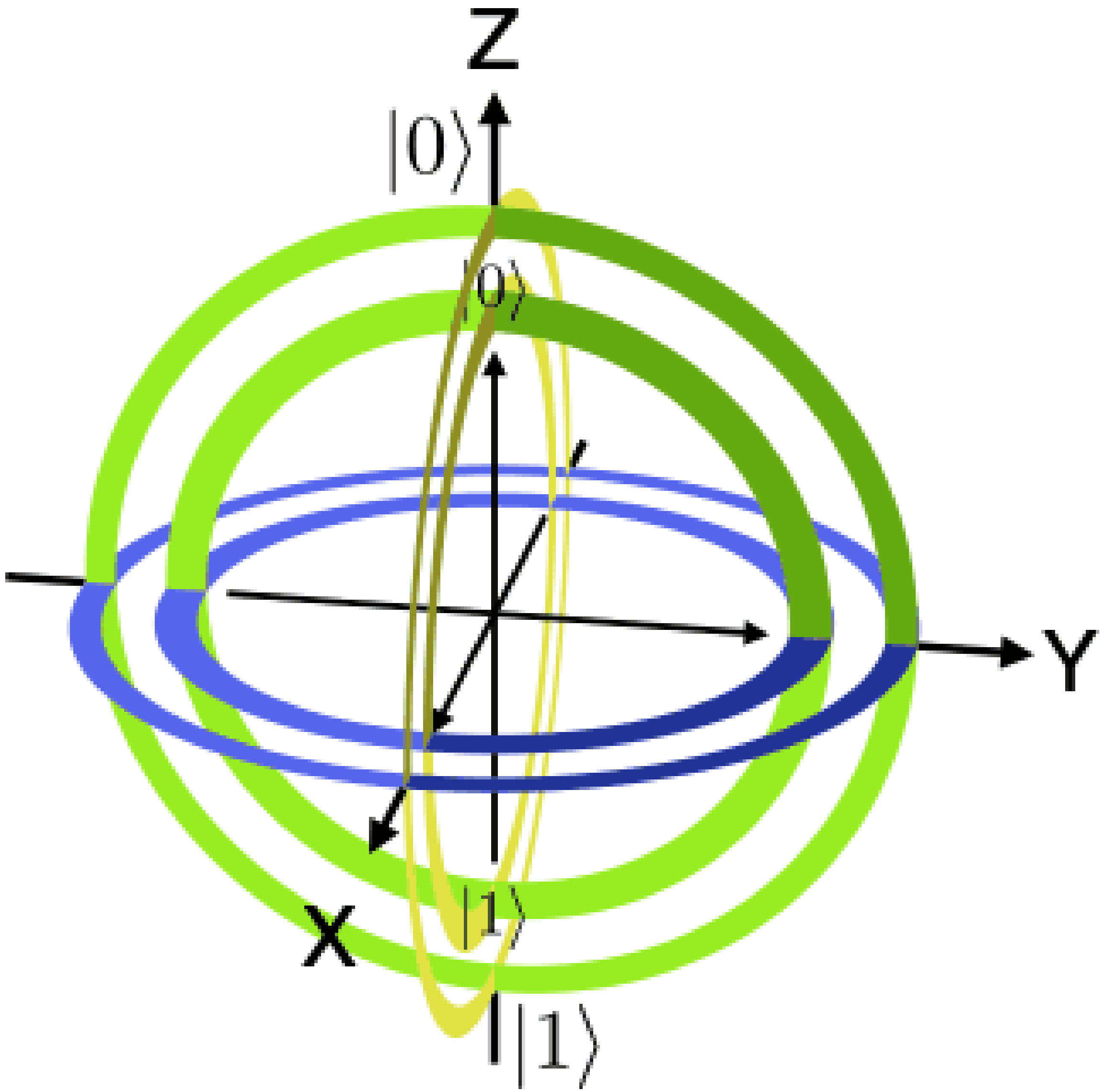
https://www.youtube.com/watch?v=JhHMJCUmq28

circuit chip

Operations on Qubits



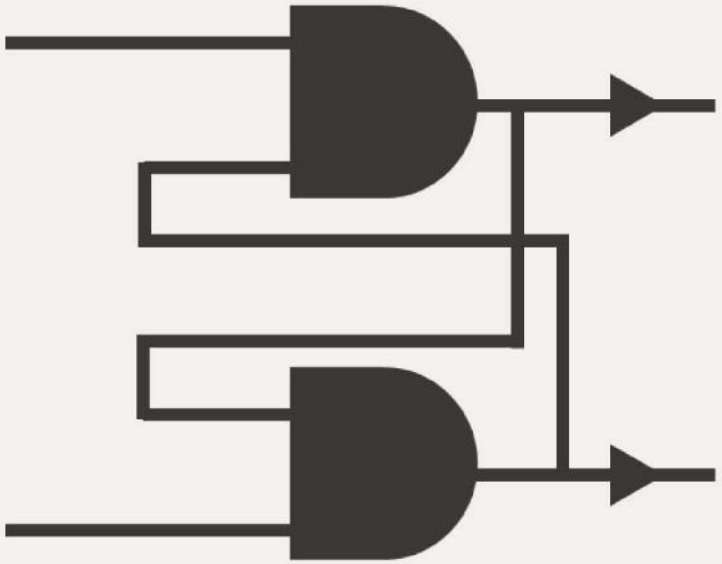



Z
$|0\rangle$
$|0\rangle$
Y
X
$|1\rangle$
$|1\rangle$

Algorithm: Combination of operations

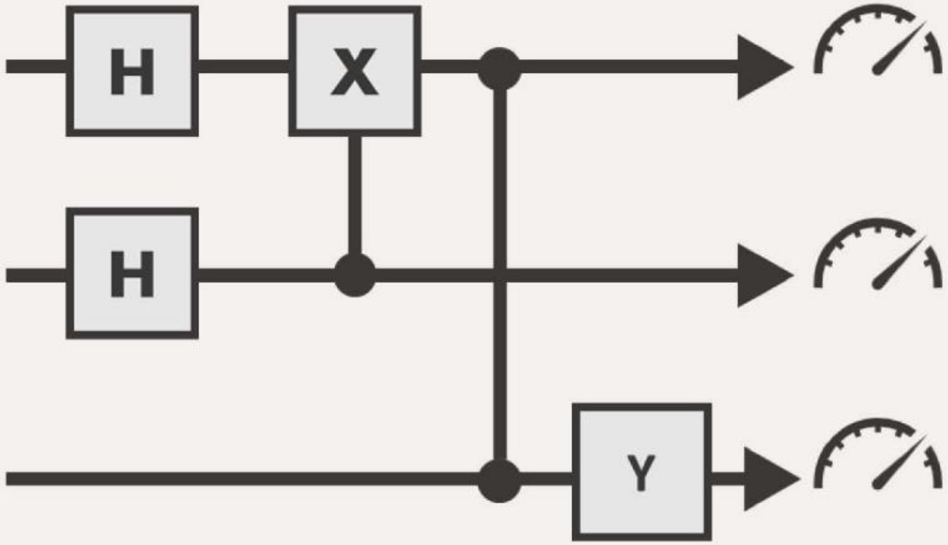
Classical

"Circuit"



Quantum

"Quantum Circuit"




1
0
1
H
H

Quantum Computing

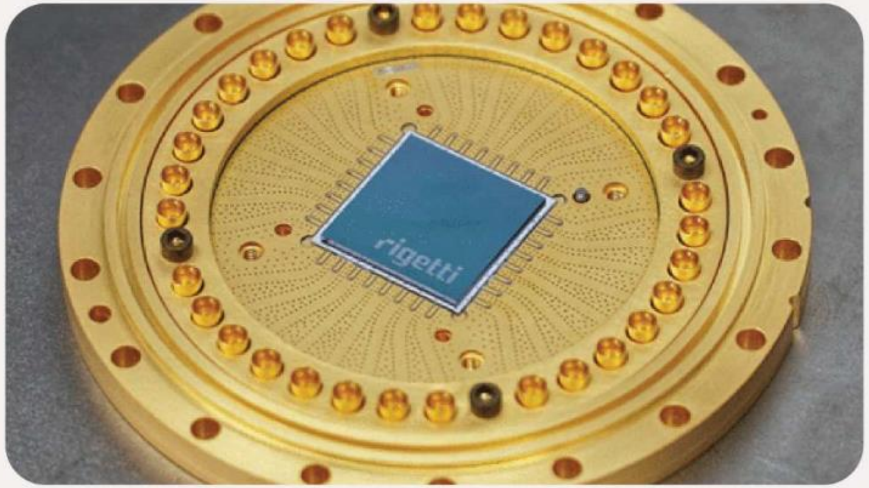
- Operates with qubits that can represent 0 and 1 or both simultaneously
- Power increments dramatically with the number of qubits
- High error rates and need to be stored at ultracold temperature
- Best for complex tasks like optimization, data analysis and simulation

Vs.

Classical computing

- Operate transistors that can only depict either 0 or 1
- Power increments in 1:1 ratio with the number of transistors
- Low error rates and can perform at room temperature
- Best at performing everyday tasks

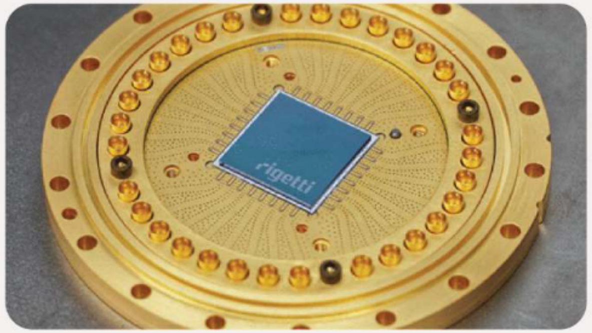
Quantum Computers are NOT to replace classical computers (even if they want to)

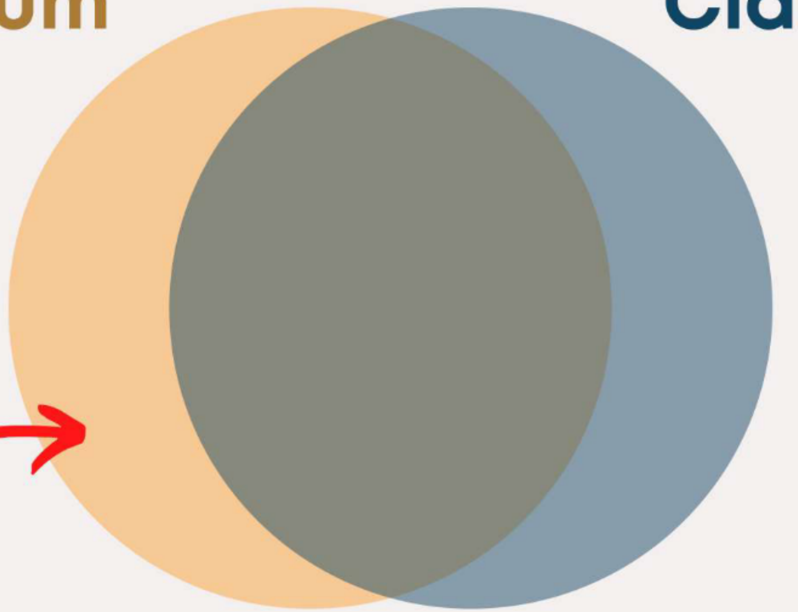


?

Ref:
L. Gomes, "Quantum computing: Both here and not here," in IEEE Spectrum, vol. 55, no. 4, pp. 42-47, April 2018, doi: 10.1109/MSPEC.2018.8322045.

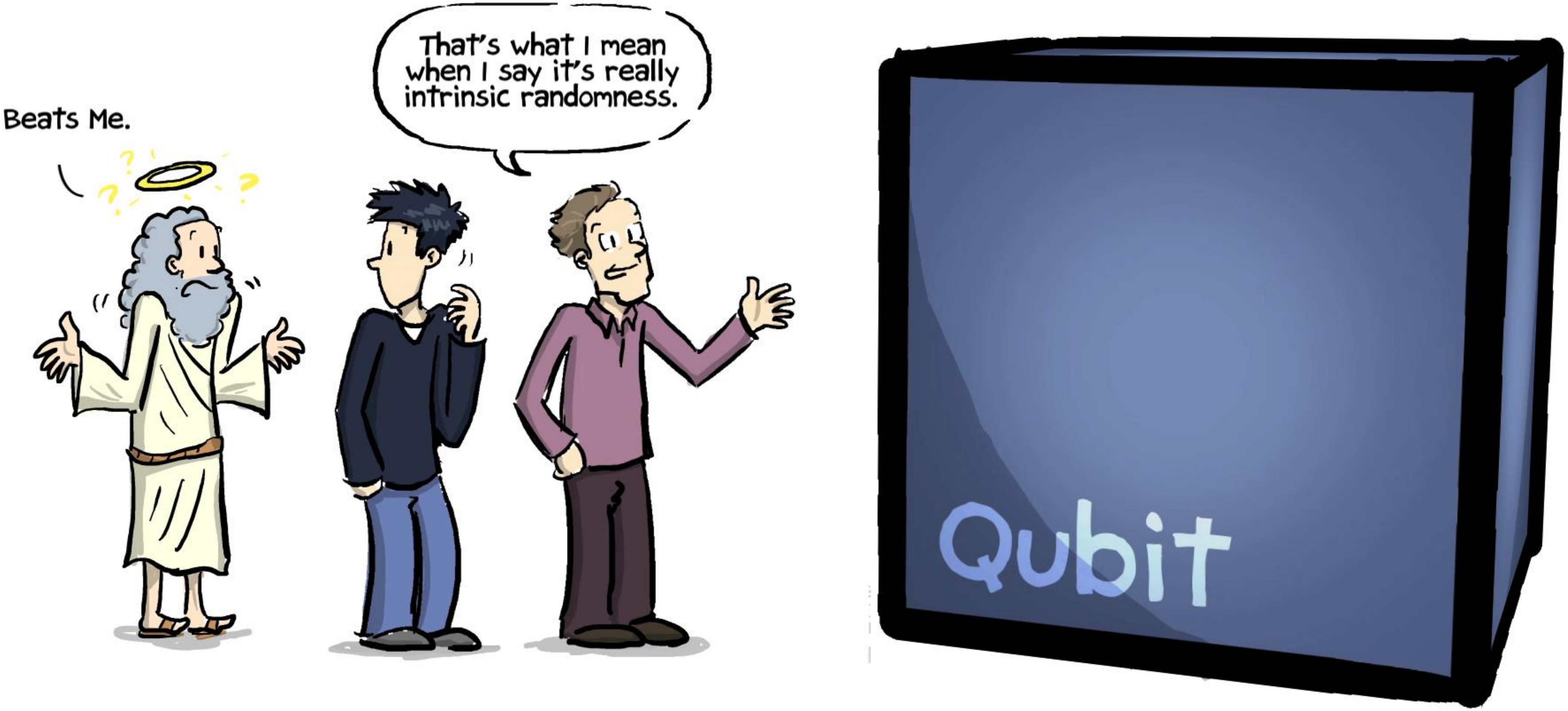
Quantum Computers are special-purpose machines



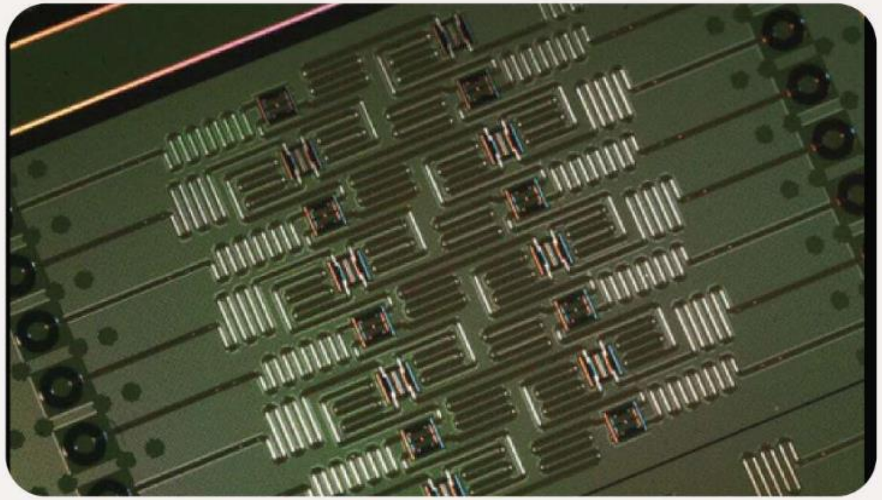


(oversimplified)

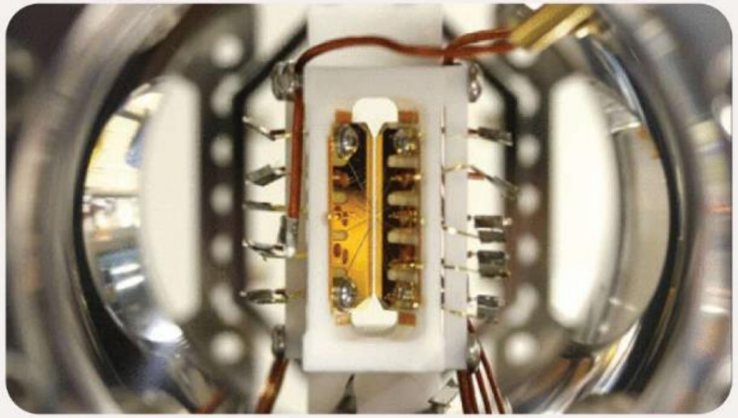
Ref:
L. Gomes, "Quantum computing: Both here and not here," in IEEE Spectrum, vol. 55, no. 4, pp. 42-47, April 2018, doi: 10.1109/MSPEC.2018.8322045.


Beats Me.
That's what I mean when I say it's really intrinsic randomness.
Qubit

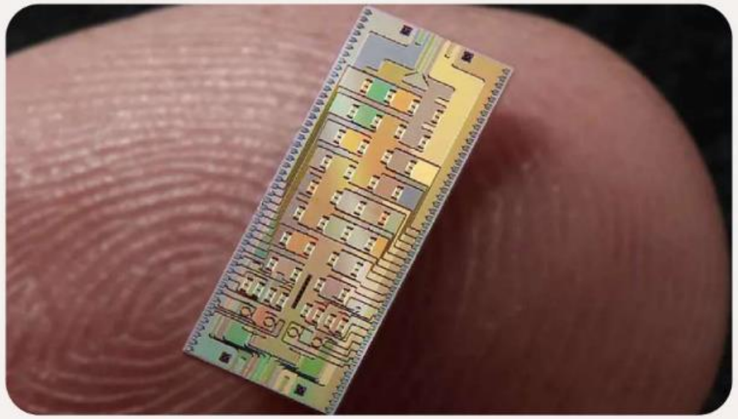
How does quantum computer chip look like?



Google (Superconducting)



IonQ
(Ions Trap)

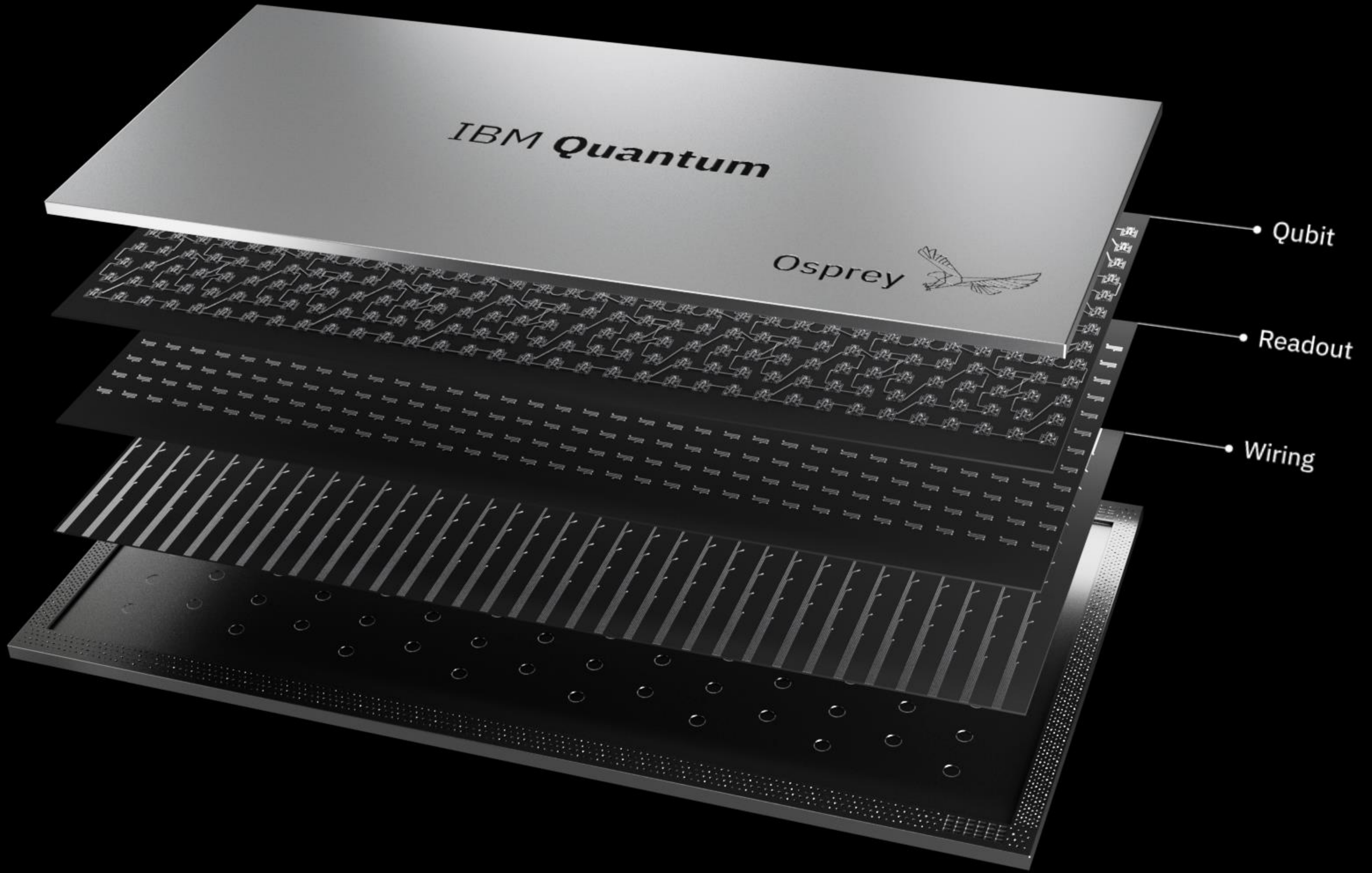


Xanadu
(Photonics)

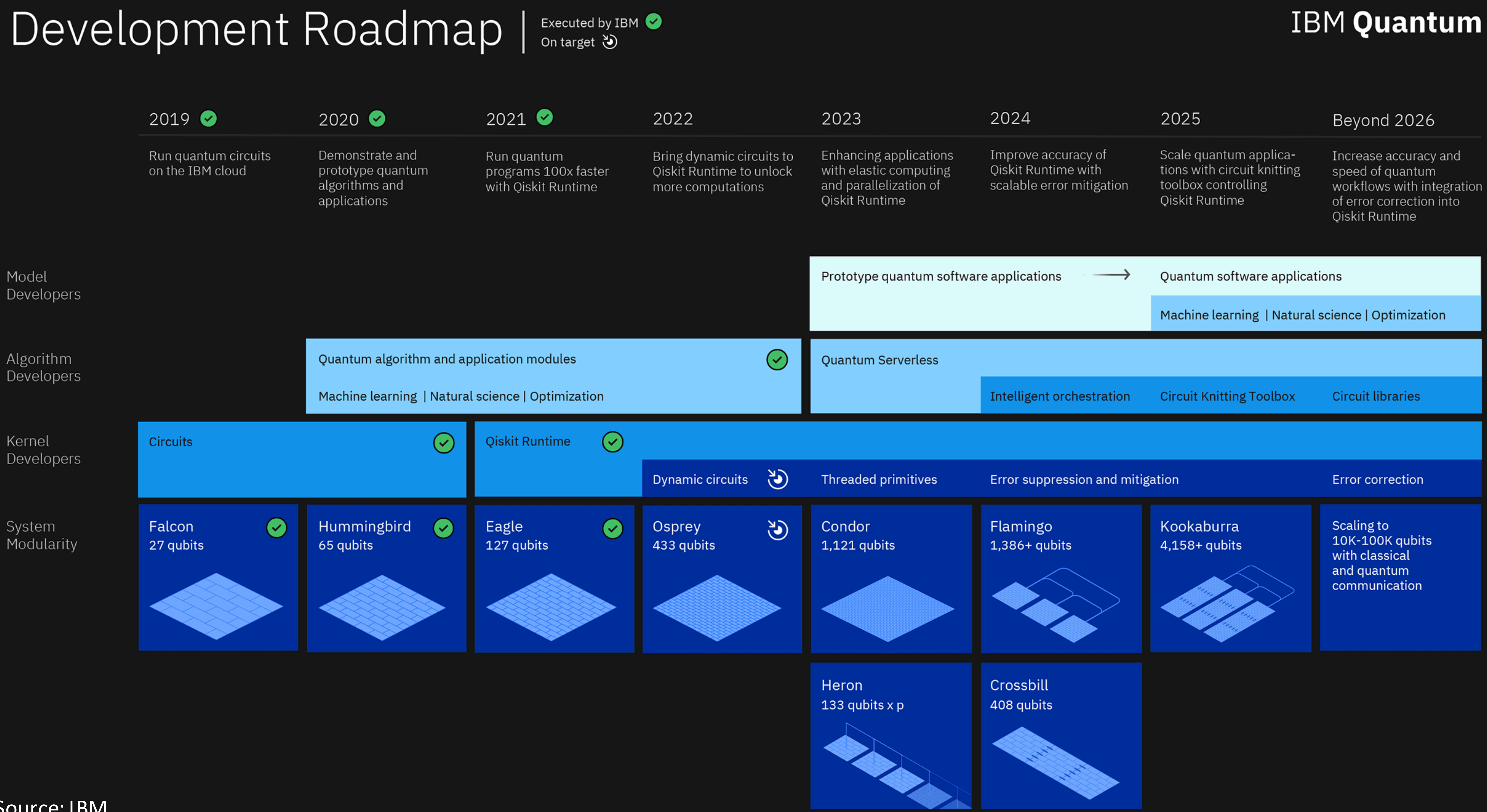
Ref:
L. Gomes, "Quantum computing: Both here and not here," in IEEE Spectrum, vol. 55, no. 4, pp. 42-47, April 2018, doi: 10.1109/MSPEC.2018.8322045.

Qubit Scaling on Quantum Processors

NO. OF QUBITS



Source: IBM


Development Roadmap
Executed by IBM
On target
IBM Quantum
2019
Run quantum circuits on the IBM cloud
2020
Demonstrate and prototype quantum algorithms and applications
2021
Run quantum programs 100x faster with Qiskit Runtime
2022
Bring dynamic circuits to Qiskit Runtime to unlock more computations
2023
Enhancing applications with elastic computing and parallelization of Qiskit Runtime
2024
Improve accuracy of Qiskit Runtime with scalable error mitigation
2025
Scale quantum applications with circuit knitting toolbox controlling Qiskit Runtime
Beyond 2026
Increase accuracy and speed of quantum workflows with integration of error correction into Qiskit Runtime
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
Error suppression and mitigation
Error correction
System Modularity
Falcon
27 qubits
Hummingbird
65 qubits
Eagle
127 qubits
Osprey
433 qubits
Condor
1,121 qubits
Flamingo
1,386+ qubits
Kookaburra
4,158+ qubits
Scaling to 10K-100K qubits with classical and quantum communication
Heron
133 qubits x p
Crossbill
408 qubits

Source: IBM

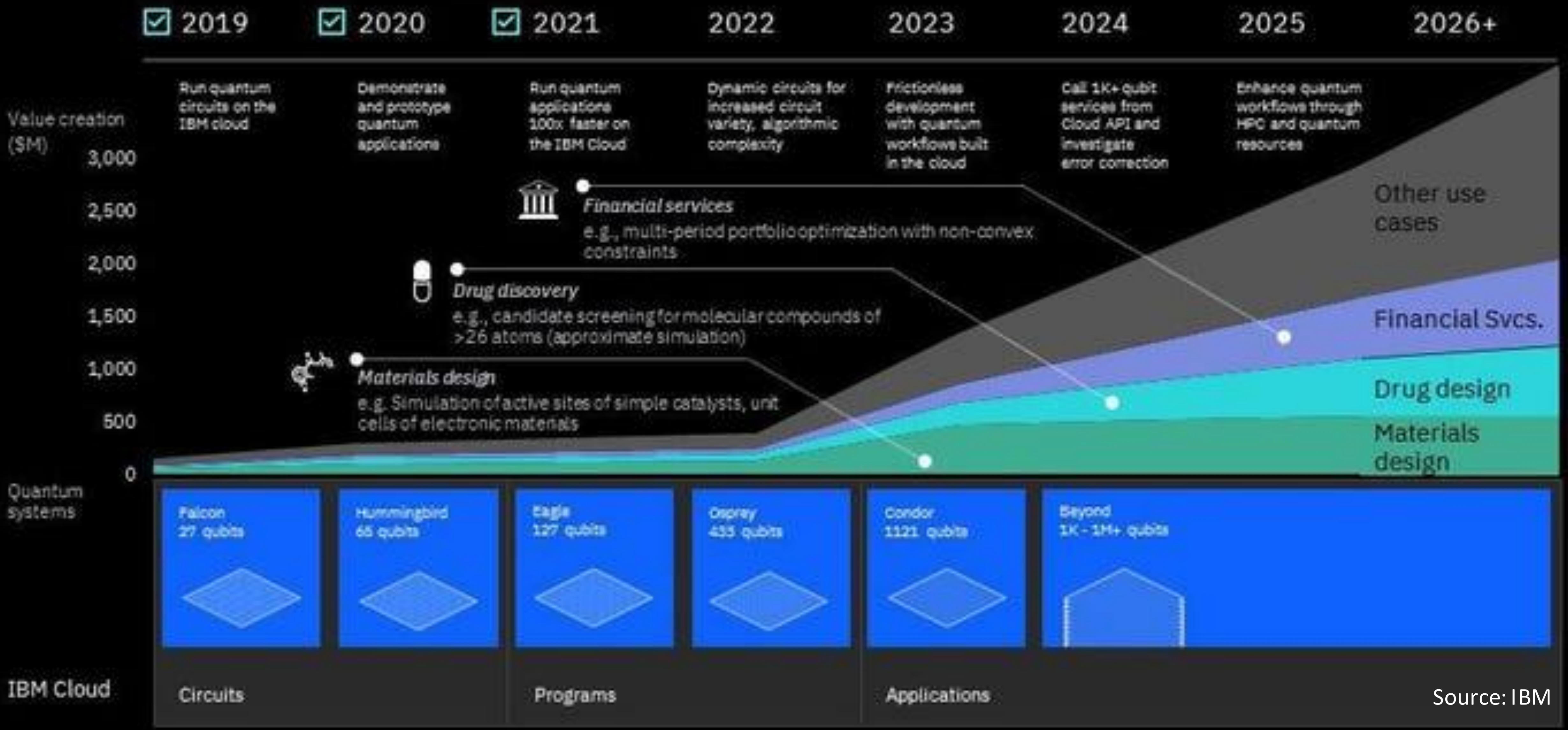
Market Analysis by Boston Consulting Group

BCG predicts Quantum computing's inflection point around the corner

→ poised to create $3B+ value by 2024

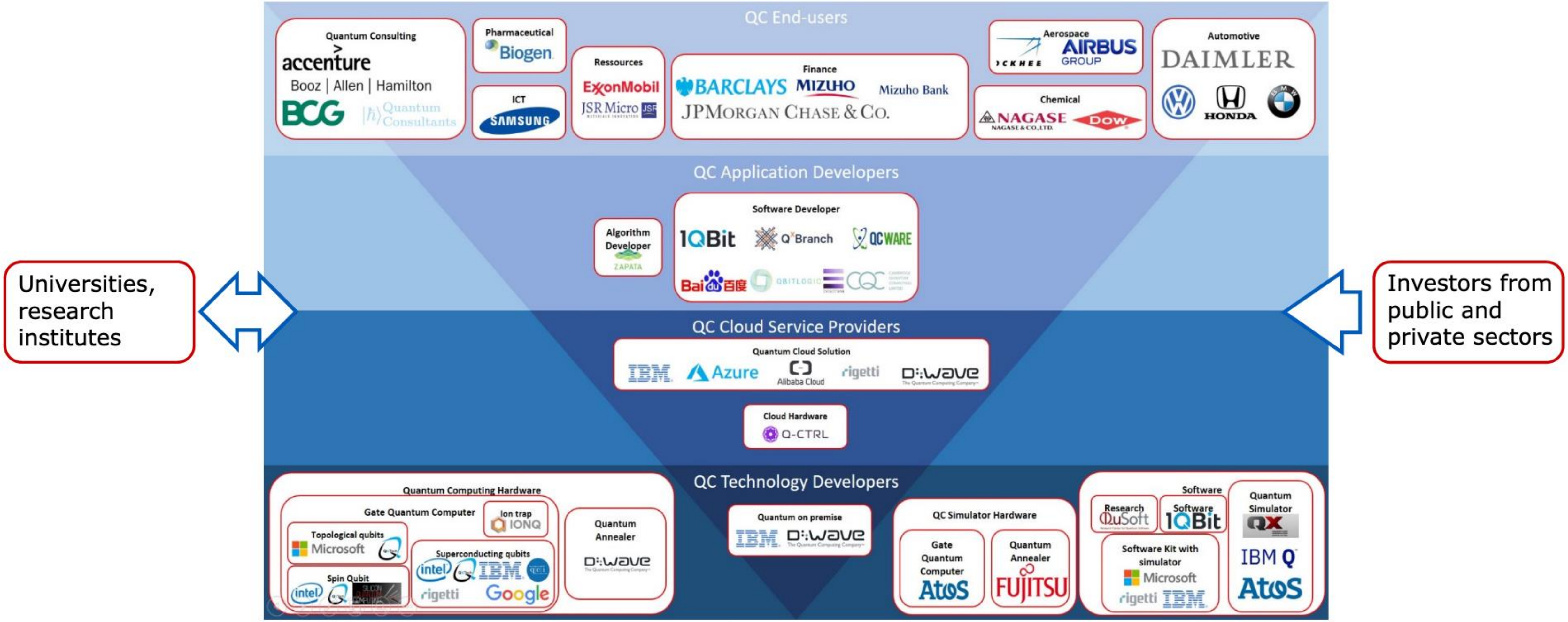
IBM **Quantum**

BCG BOSTON CONSULTING GROUP



Source: IBM

Quantum Computing Ecosystem

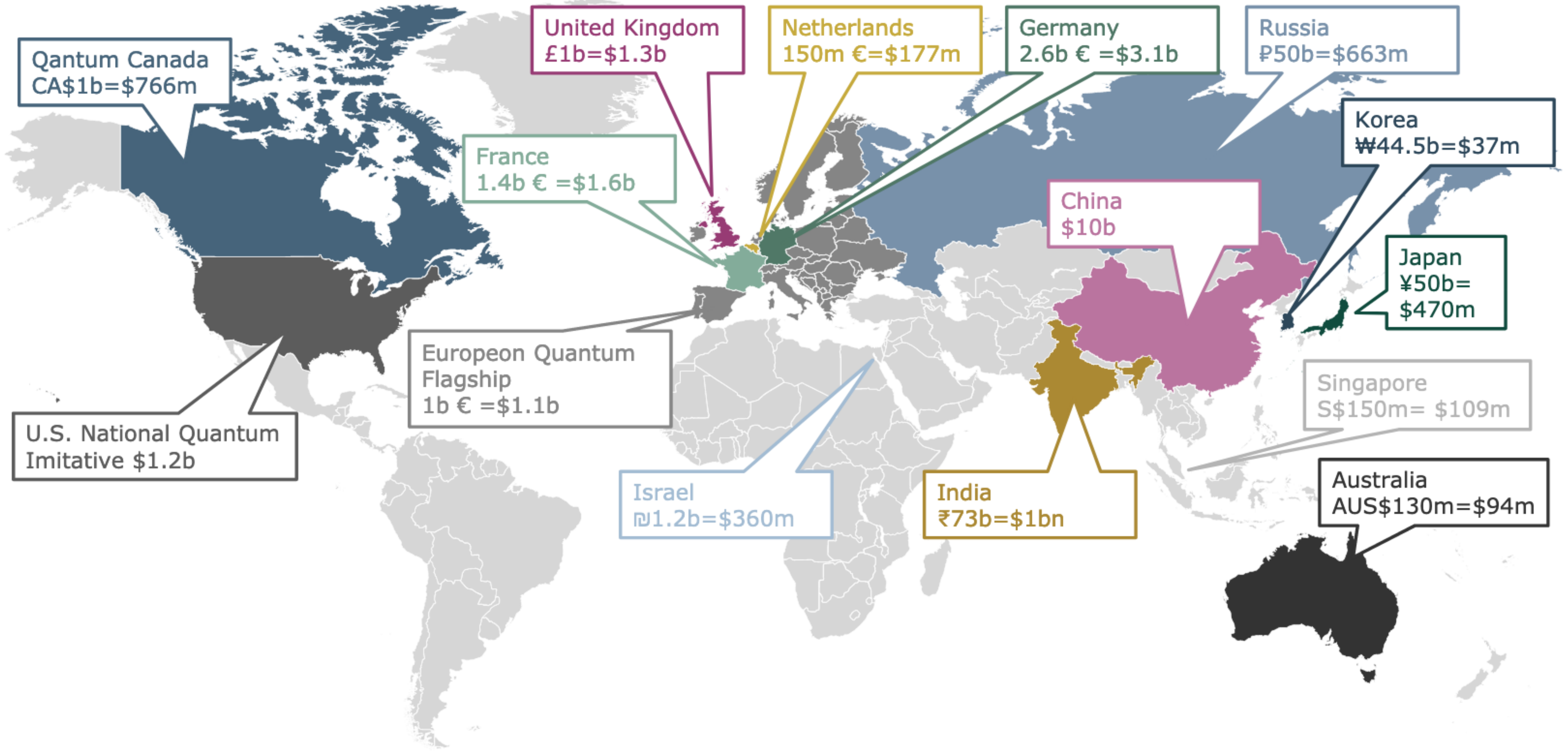


Non exhaustive examples

Source: https://digitaleweltmagazin.de/

Quantum Computing Efforts Worldwide

Global effort 2020 $22b (estimate)



Source: https://thequantumdaily.com/2020/09/10/global-quantum-ecosystem-an-overview-on-quantum-initiatives-worldwide/

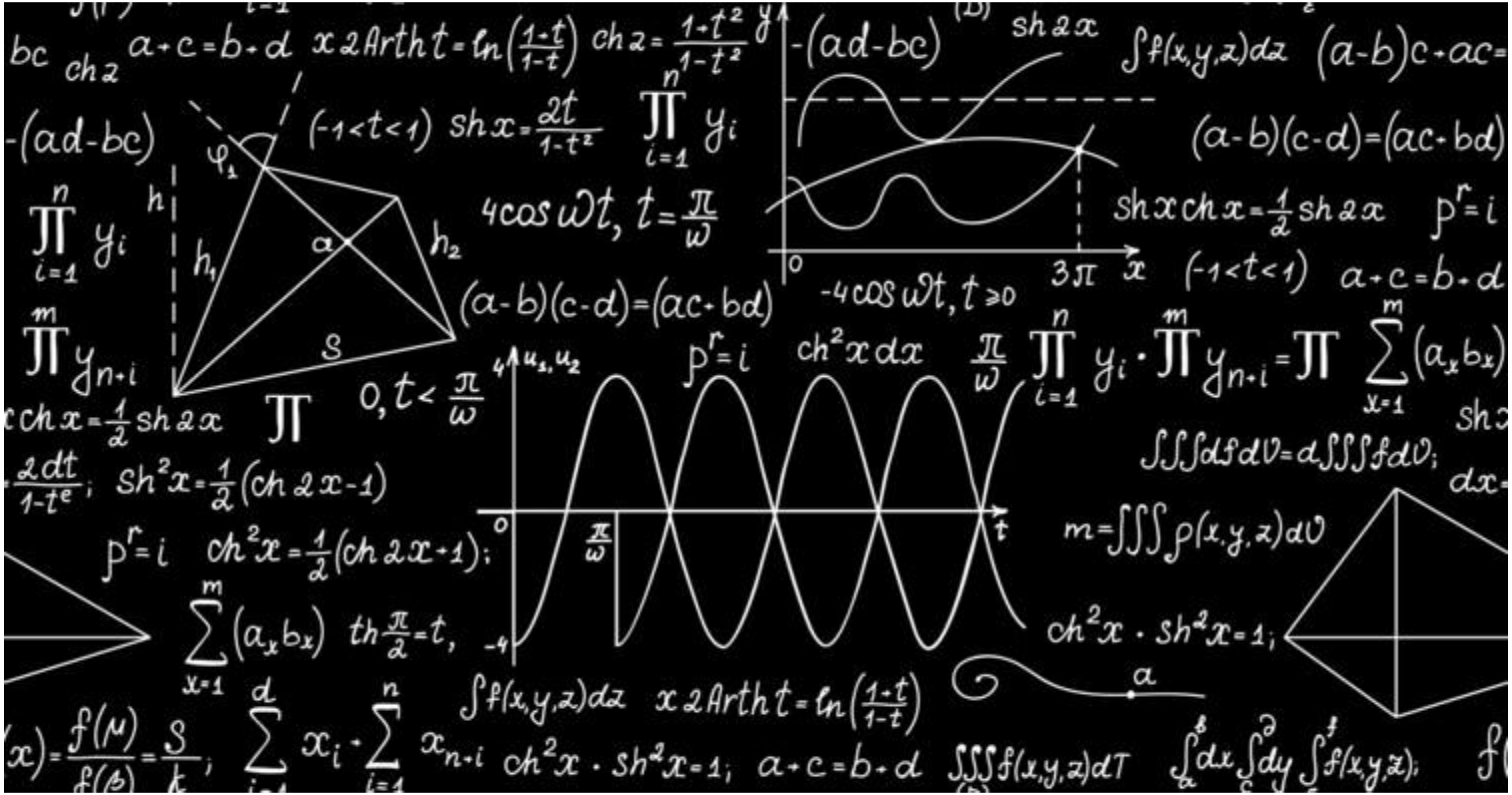
What to look forward to in the workshop?


This is weirder than you think

DON'T BE OVERWHELMED!

LOOK AT HARD CONCEPTS IN SIMPLE TERMS

https://www.linkedin.com/pulse/math-quantum-computing-hard-concept-simple-terms-teddy-porfiris/



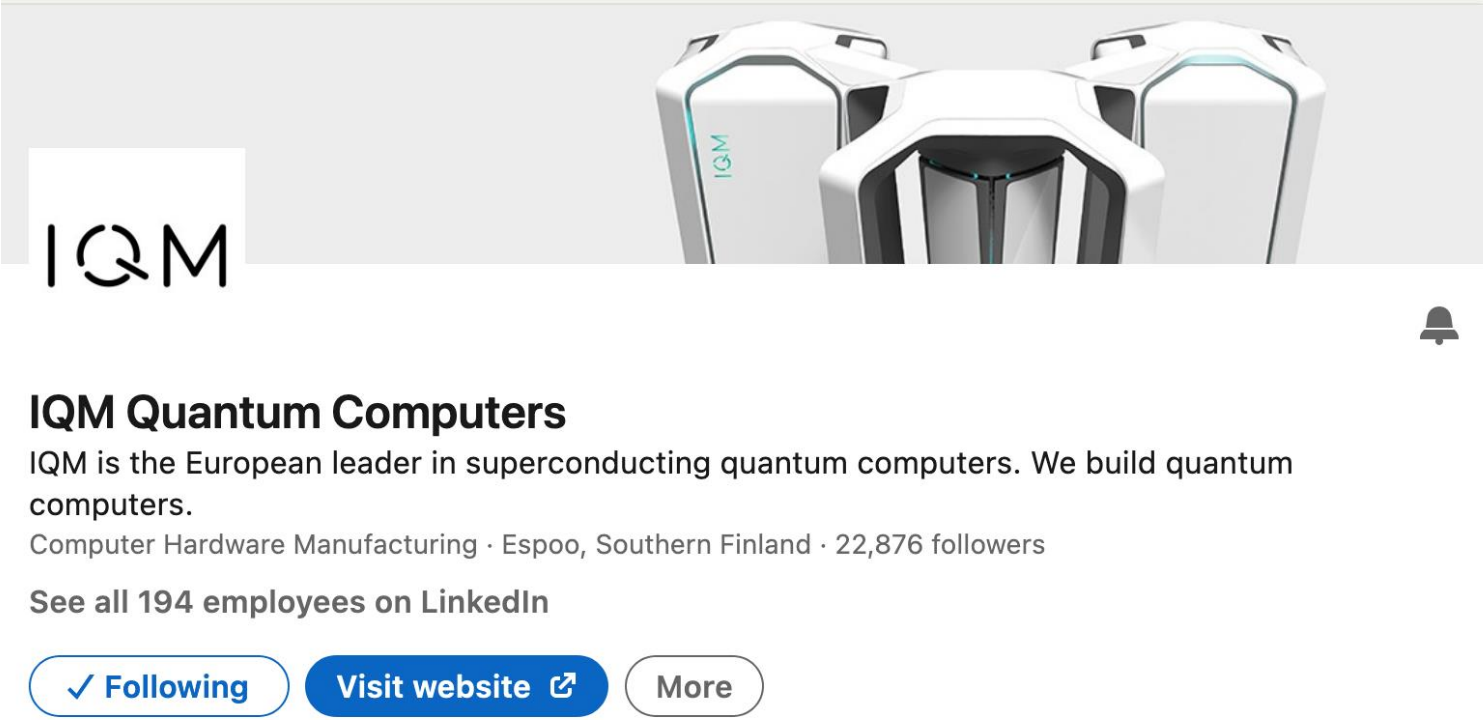
Open-source python-based frameworks for quantum computing

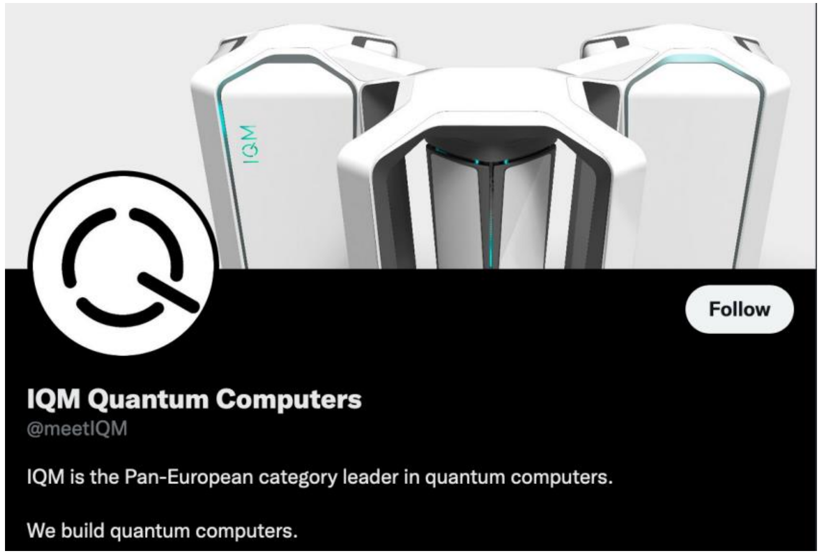
https://qiskit.org/

https://pennylane.ai/

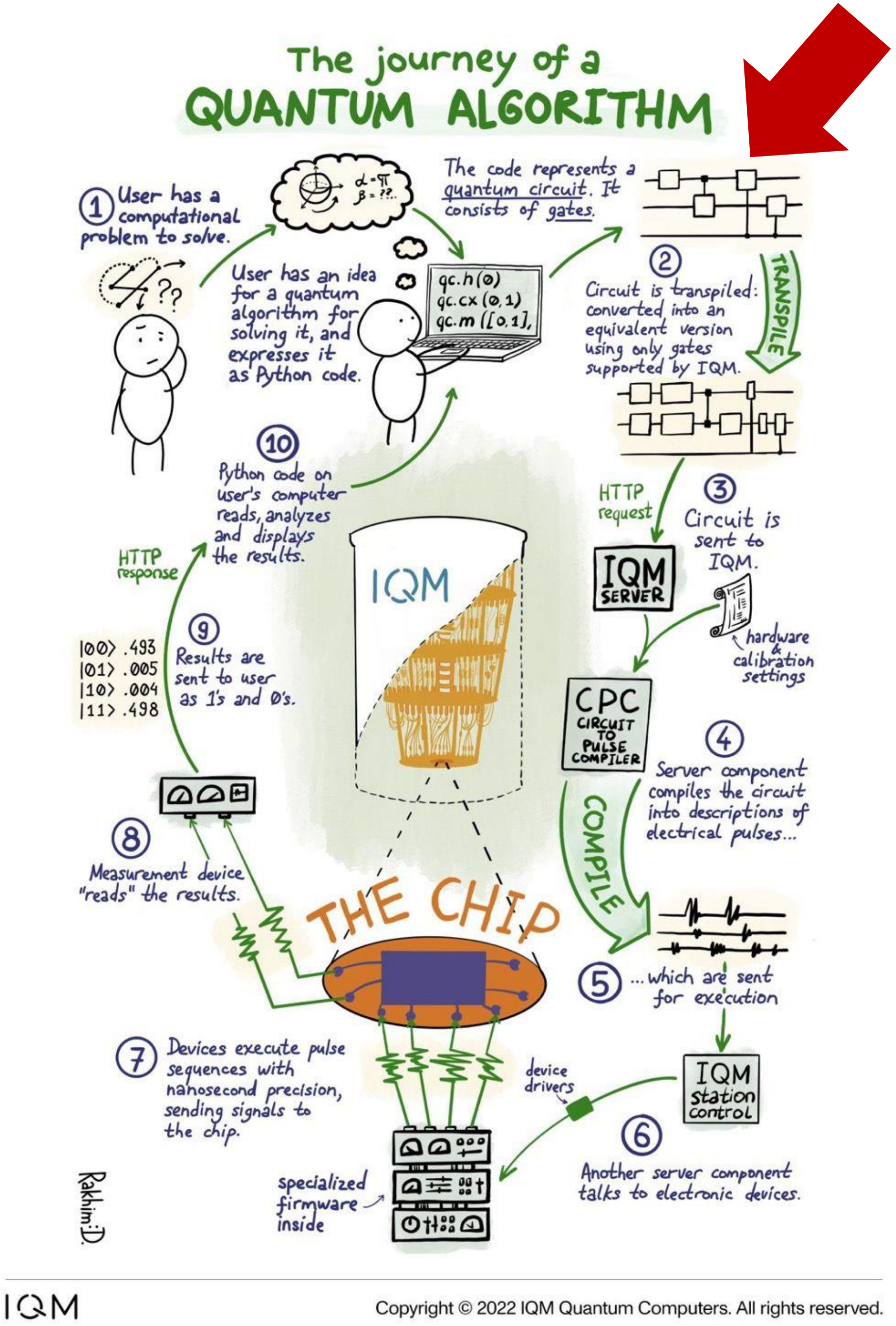
https://quantumai.google/cirq

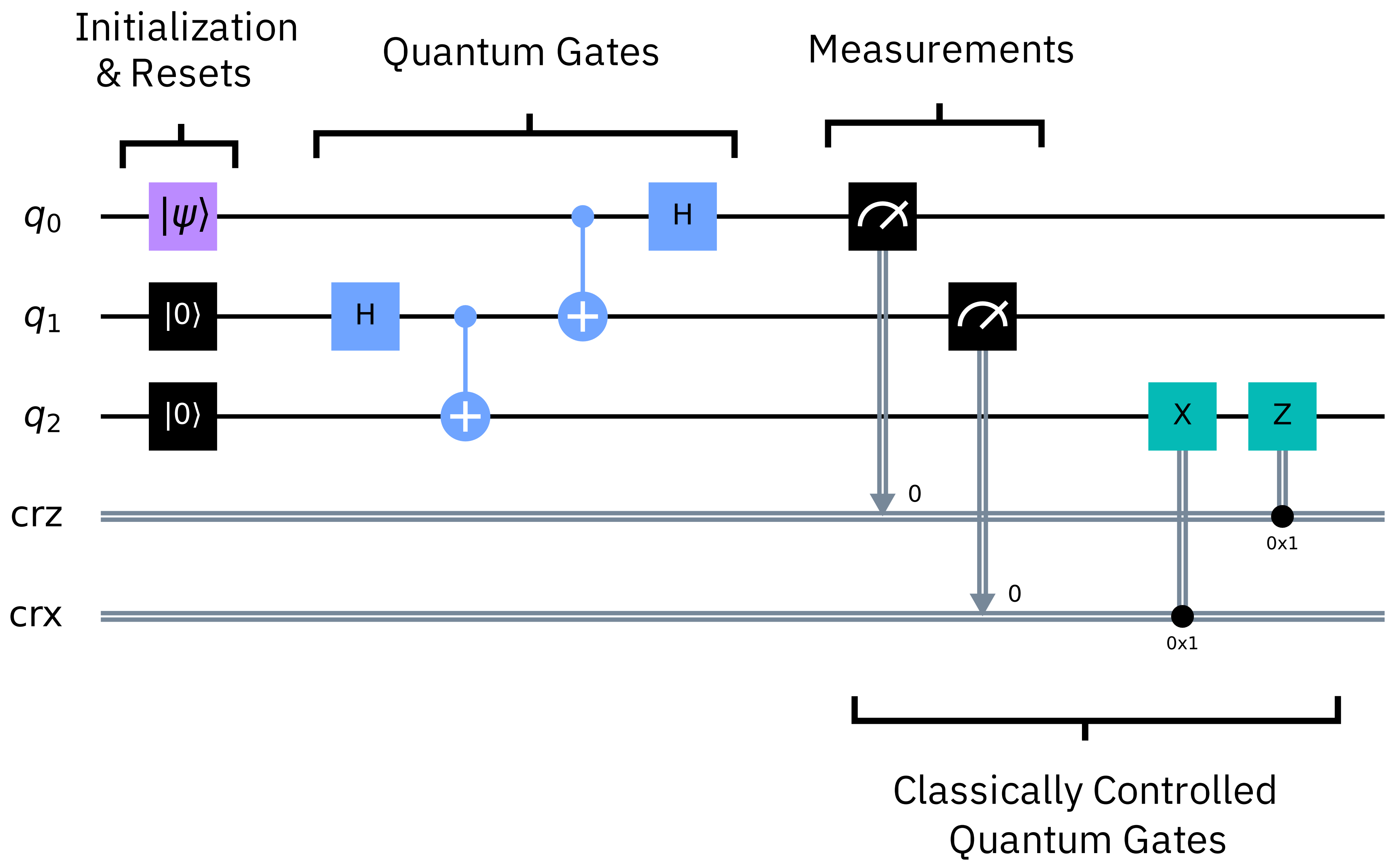
The Journey of a Quantum Algorithm



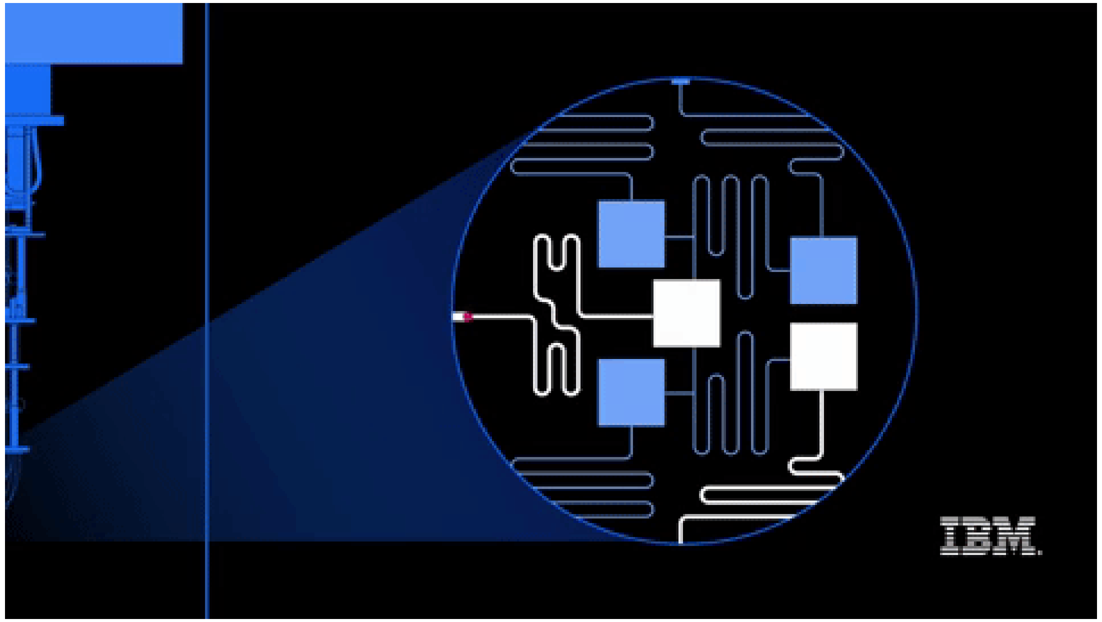


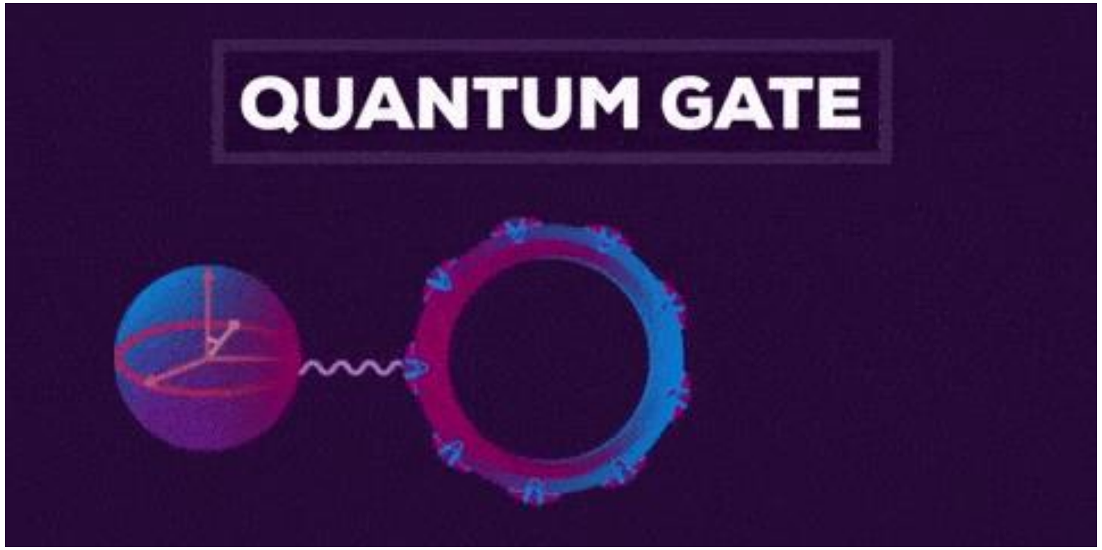
Source: www.meetiqm.com





Initialization
& Resets
Quantum Gates
Measurements
q0
q1
q2
crz
crx
|ψ⟩
|0⟩
|0⟩
H
H
H
X
Z
0
0
0x1
0x1
Classically Controlled
Quantum Gates

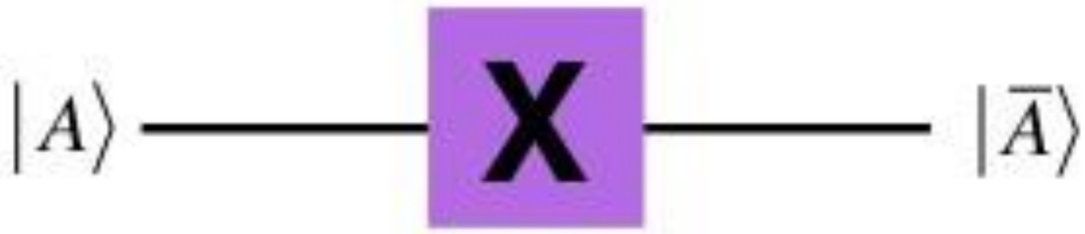




Hadamard	$-\boxed{H}-$	$\frac{1}{\sqrt{2}}\begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}$
Pauli-X	$-\boxed{X}-$	$\begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}$
Pauli-Y	$-\boxed{Y}-$	$\begin{bmatrix} 0 & -i \\ i & 0 \end{bmatrix}$
Pauli-Z	$-\boxed{Z}-$	$\begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix}$
Phase	$-\boxed{S}-$	$\begin{bmatrix} 1 & 0 \\ 0 & i \end{bmatrix}$
$\pi/8$	$-\boxed{T}-$	$\begin{bmatrix} 1 & 0 \\ 0 & e^{i\pi/4} \end{bmatrix}$

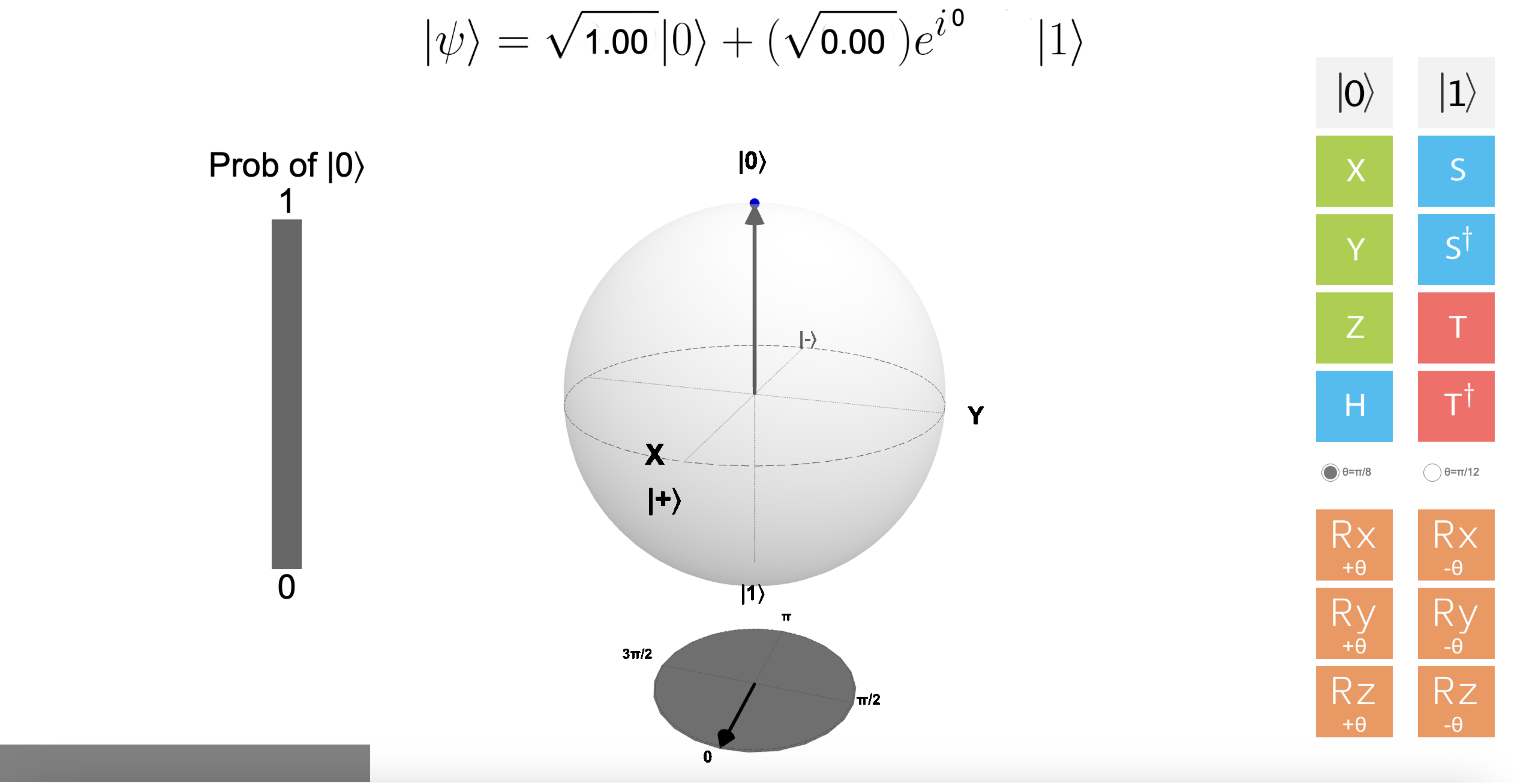
A	$\bar{A}$
0	1
1	0

PAULI X GATE

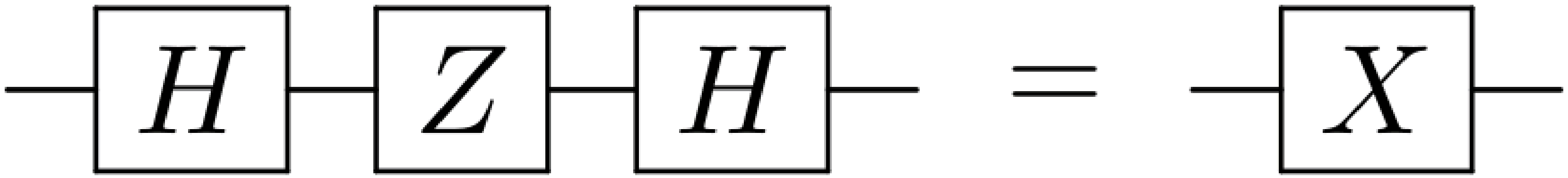


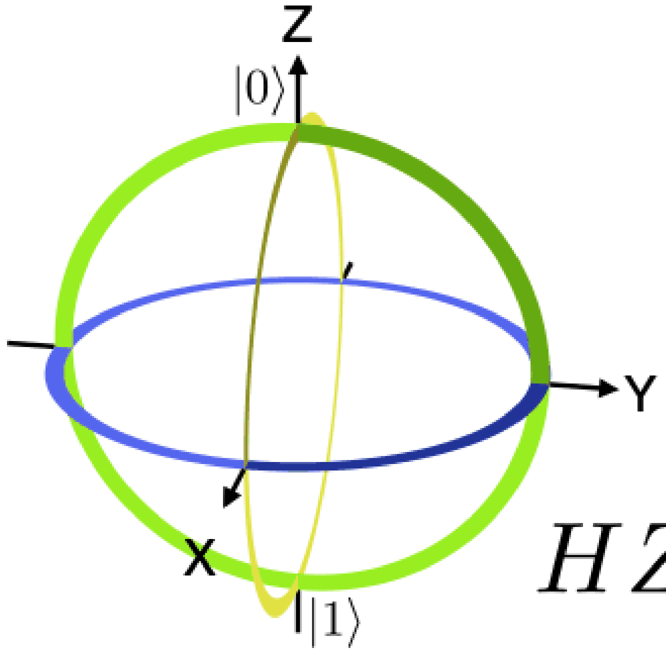
$\lvert A\rangle$	$\lvert\bar{A}\rangle$
0	1
1	0

https://lewisla.gitbook.io/learning-quantum/quantum-circuits/single-qubit-gates



https://javafxpert.github.io/grok-bloch/





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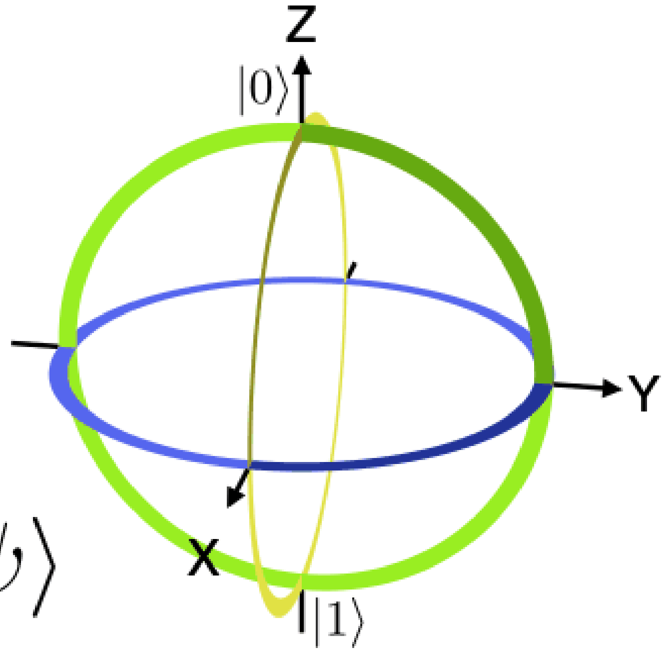
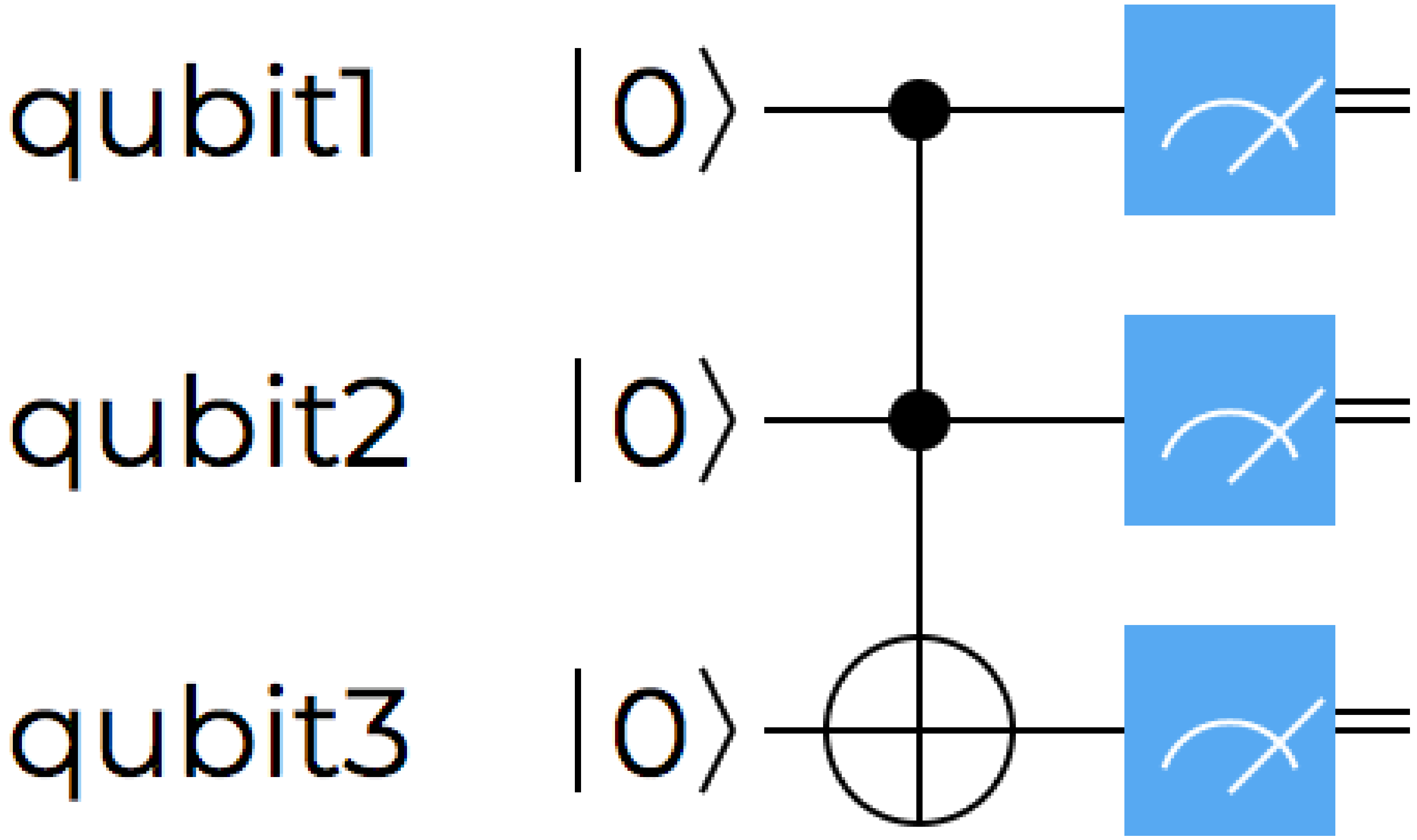
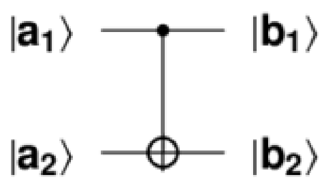
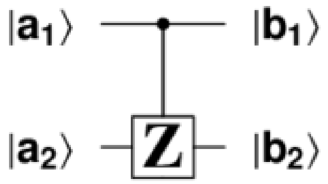
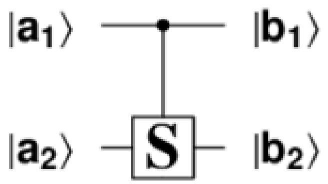
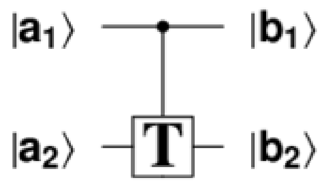
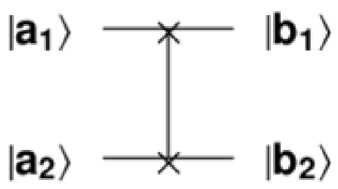
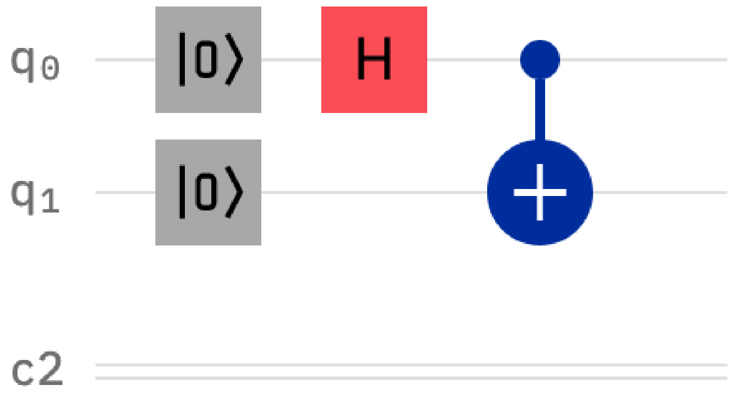


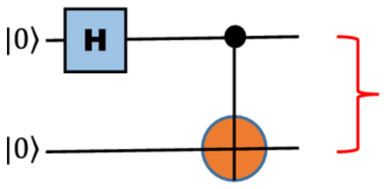
$$HZH\left|\psi\right\rangle = X\left|\psi\right\rangle$$

Two-Qubit and Multi Qubit Gates

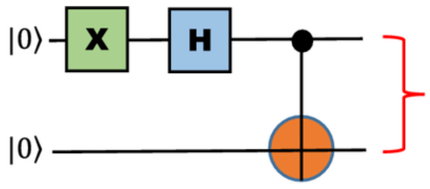


CNOT gate		$\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{pmatrix}$
Controlled - Z		$\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & -1 \end{pmatrix}$
Controlled - S		$\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & i \end{pmatrix}$
Controlled - T		$\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & e^{i\frac{\pi}{4}} \end{pmatrix}$
SWAP gate		$\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$

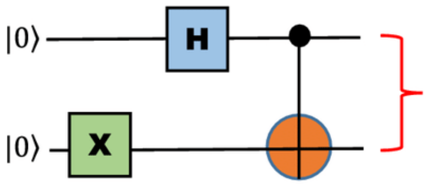




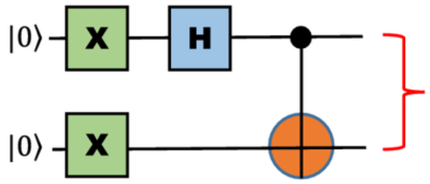
$$|\psi^+\rangle = \frac{|00\rangle + |11\rangle}{\sqrt{2}}$$



$$|\psi^-\rangle = \frac{|00\rangle - |11\rangle}{\sqrt{2}}$$

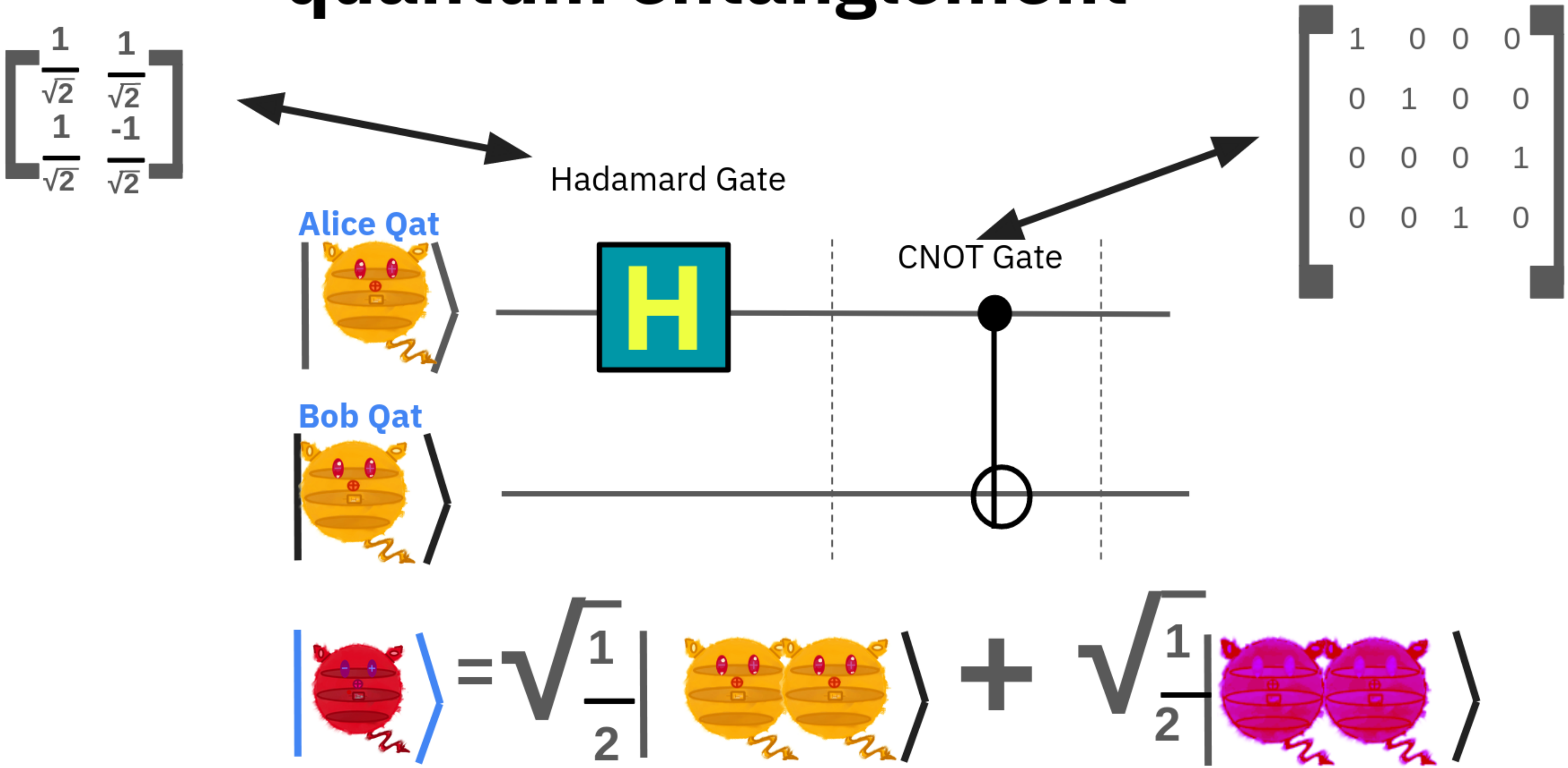


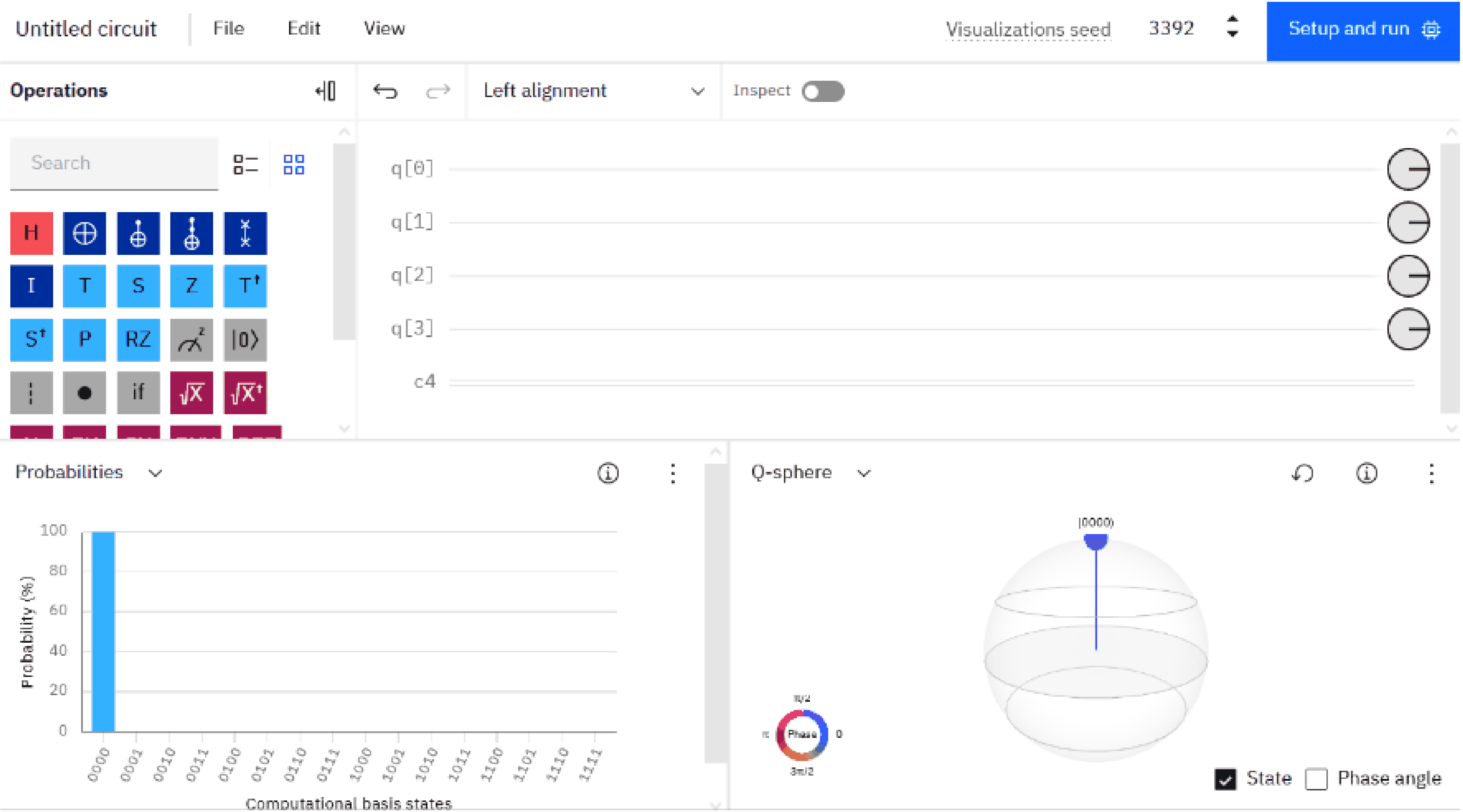
$$|\phi^+\rangle = \frac{|01\rangle + |10\rangle}{\sqrt{2}}$$



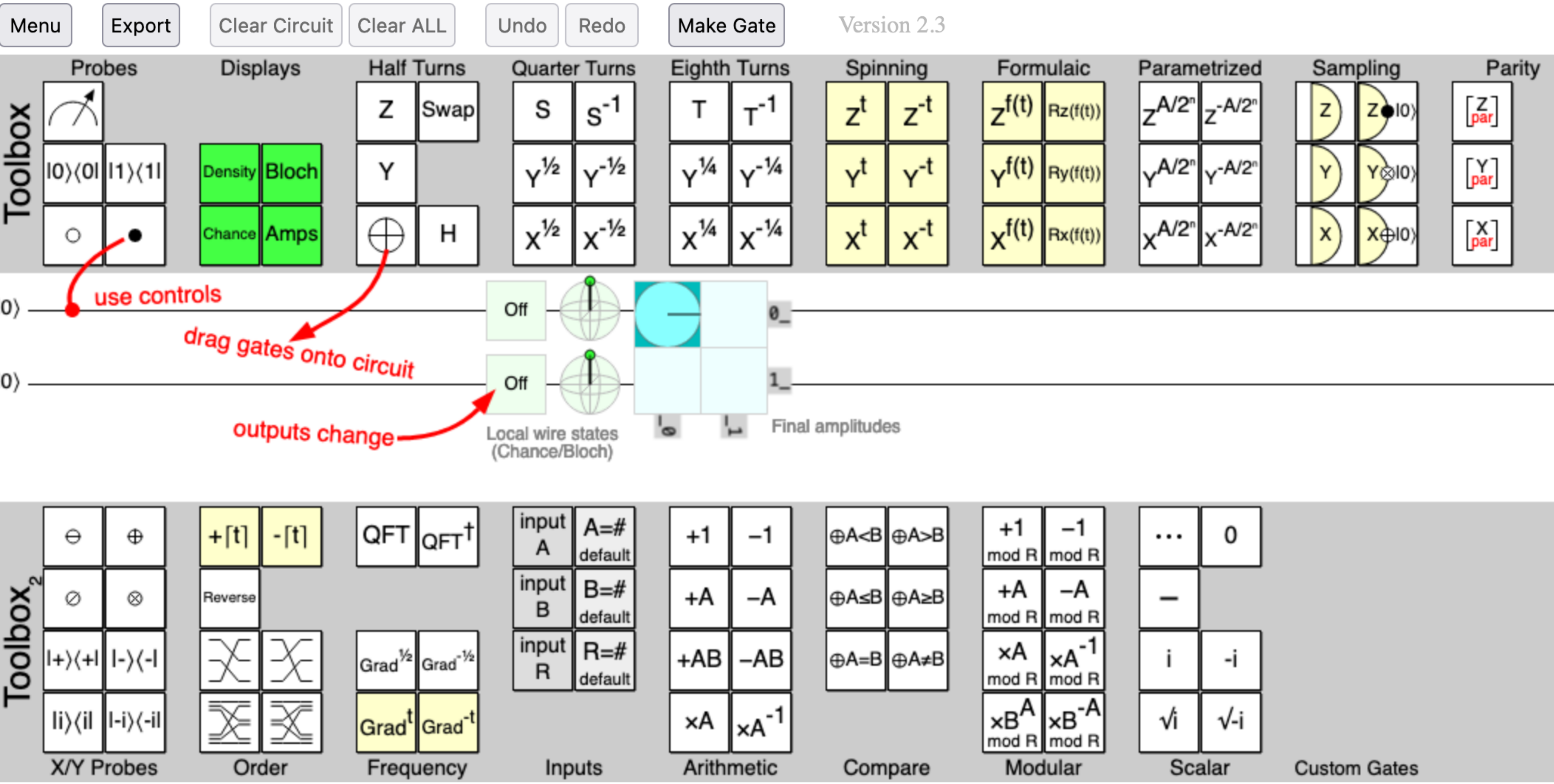
$$|\phi^-\rangle = \frac{|01\rangle - |10\rangle}{\sqrt{2}}$$

quantum entanglement





https://quantum-computing.ibm.com/composer/docs/iqx/



https://algassert.com/quirk#circuit={%22cols%22:[]}

Universal Quantum

The universal quantum computer is the most powerful, the most general, and the hardest to build, posing a number of difficult technical challenges. Current estimates indicate that this machine will comprise more than 100,000 physical qubits.

The true grand challenge in quantum computing. It offers the potential to be exponentially faster than traditional computers for a number of important applications for science and businesses.

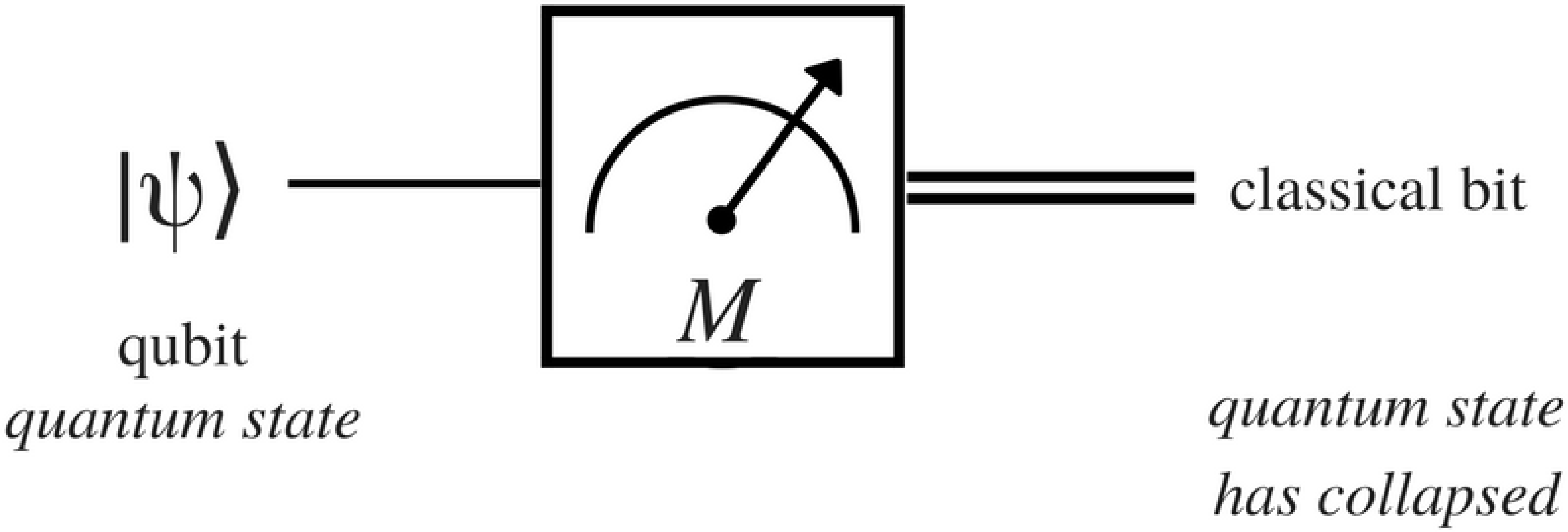
APPLICATIONS
Secure computing
Machine Learning
Cryptography
Quantum Chemistry
Material Science
Optimization Problems
Sampling
Quantum Dynamics
Searching

DIFFICULTY LEVEL

GENERALITY
Complete with known speed up

COMPUTATIONAL POWER
Very High

Quantum Measurements

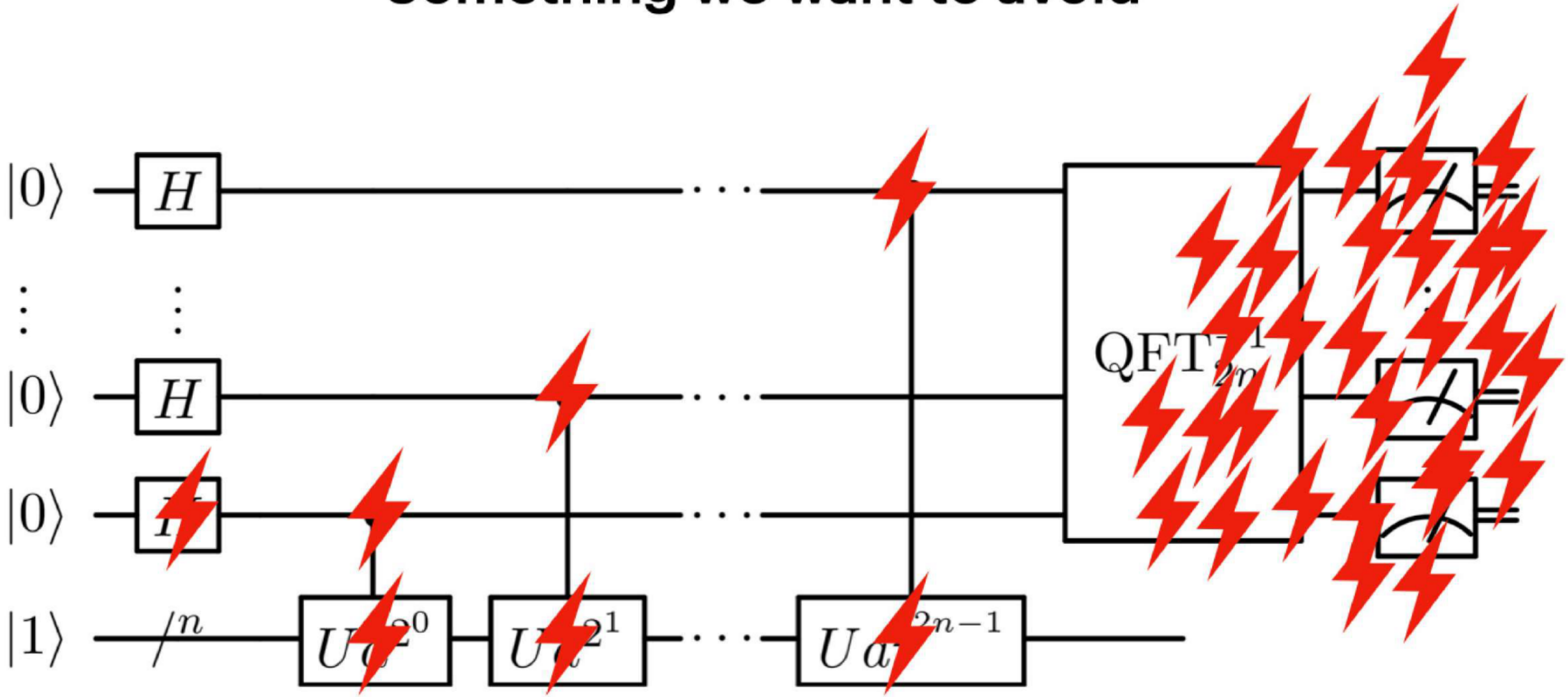


Noise is the big challenge

Protect the qubits! 🛡️⚔️

The avalanche of errors 📈

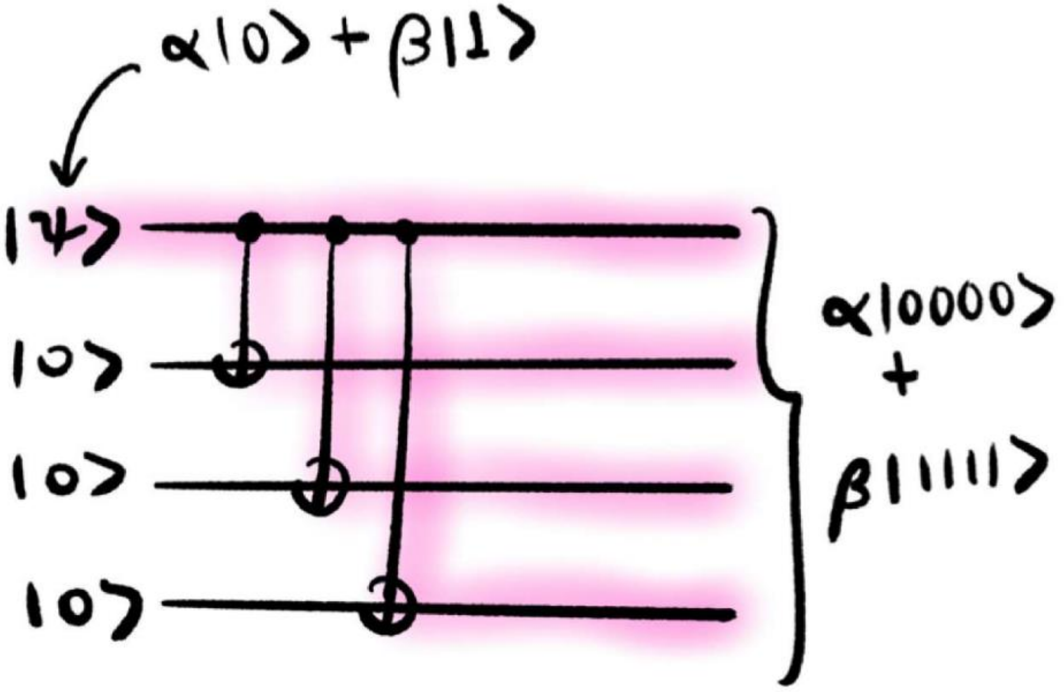
Something we want to avoid



Quantum error correction

Needs to correct infinite types of errors

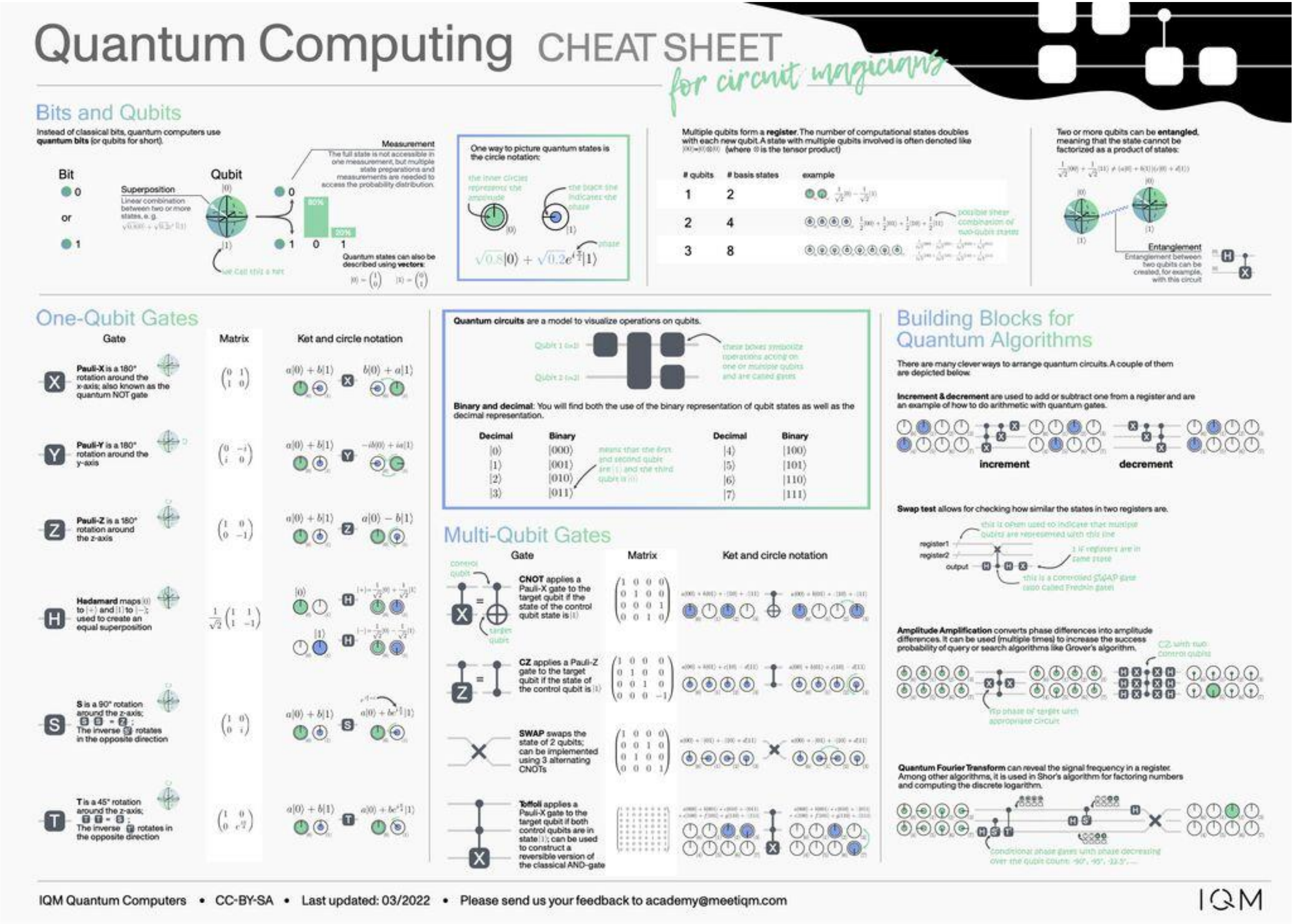
$$[[n, k, d]]$$



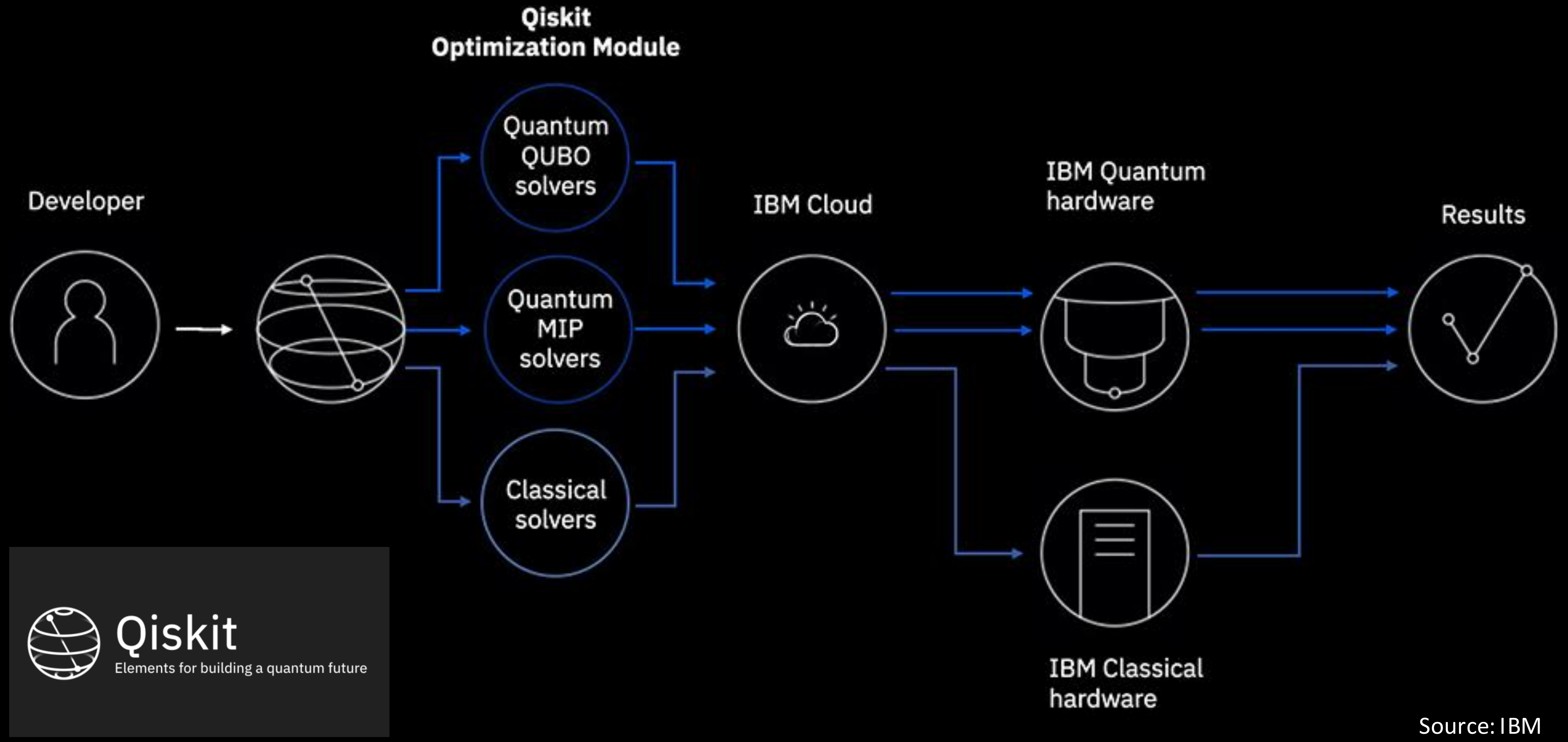
Go below threshold

The holy grail of fault tolerance

If **hardware** is below threshold, then **software** can kick in to fix errors.



www.meetiqm.com/articles/blog/quantum-computing-cheat-sheet-for-circuit-magicians/


Qiskit
Optimization Module
Developer
Quantum
QUBO
solvers
Quantum
MIP
solvers
Classical
solvers
IBM Cloud
IBM Quantum
hardware
IBM Classical
hardware
Results
Qiskit
Elements for building a quantum future

Source: IBM

THANK YOU!