A Guided Tour on the Map of Quantum Computing

ND-MIT Lecture Series

Zhixin Song

07/14/2022

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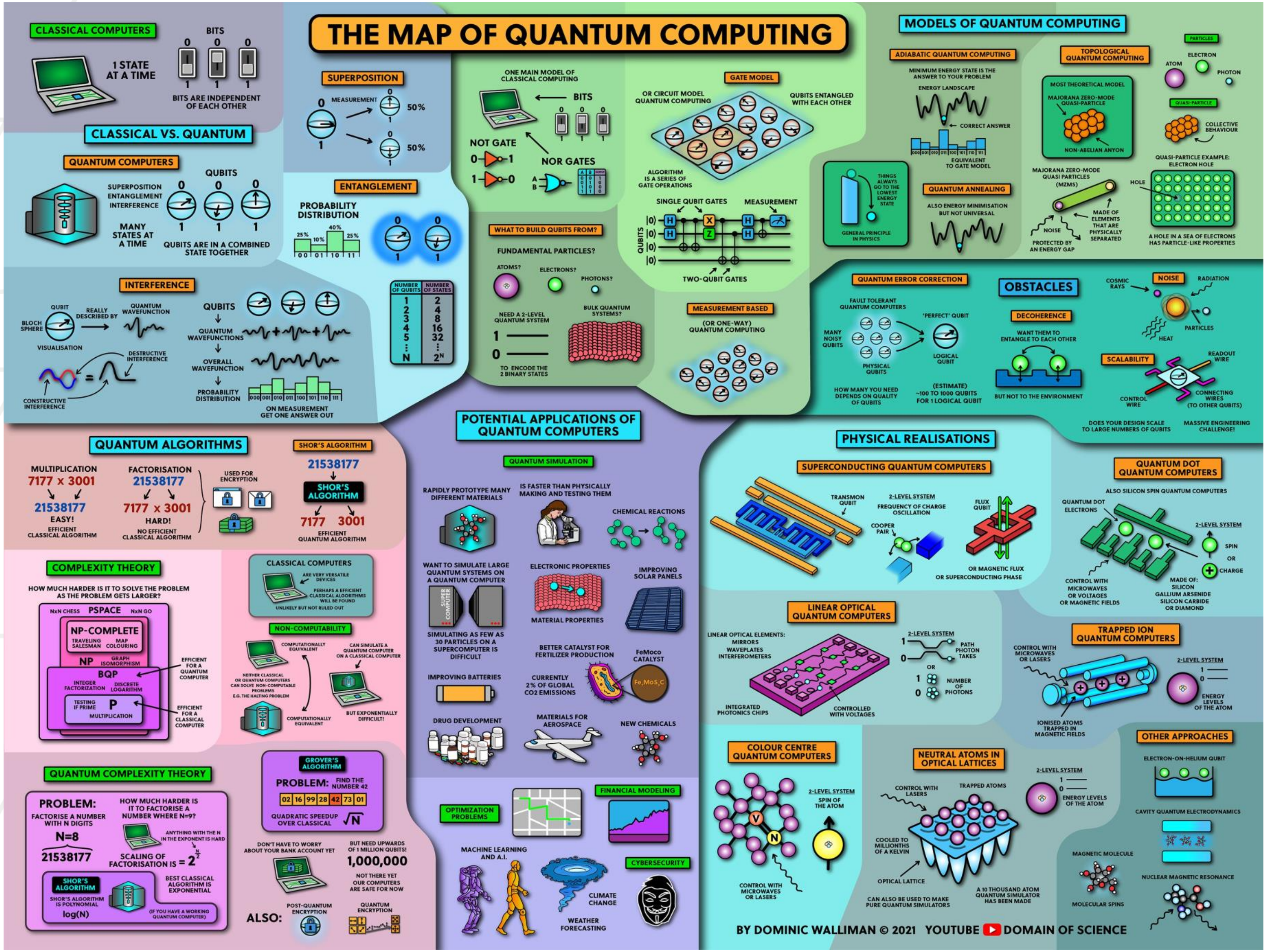

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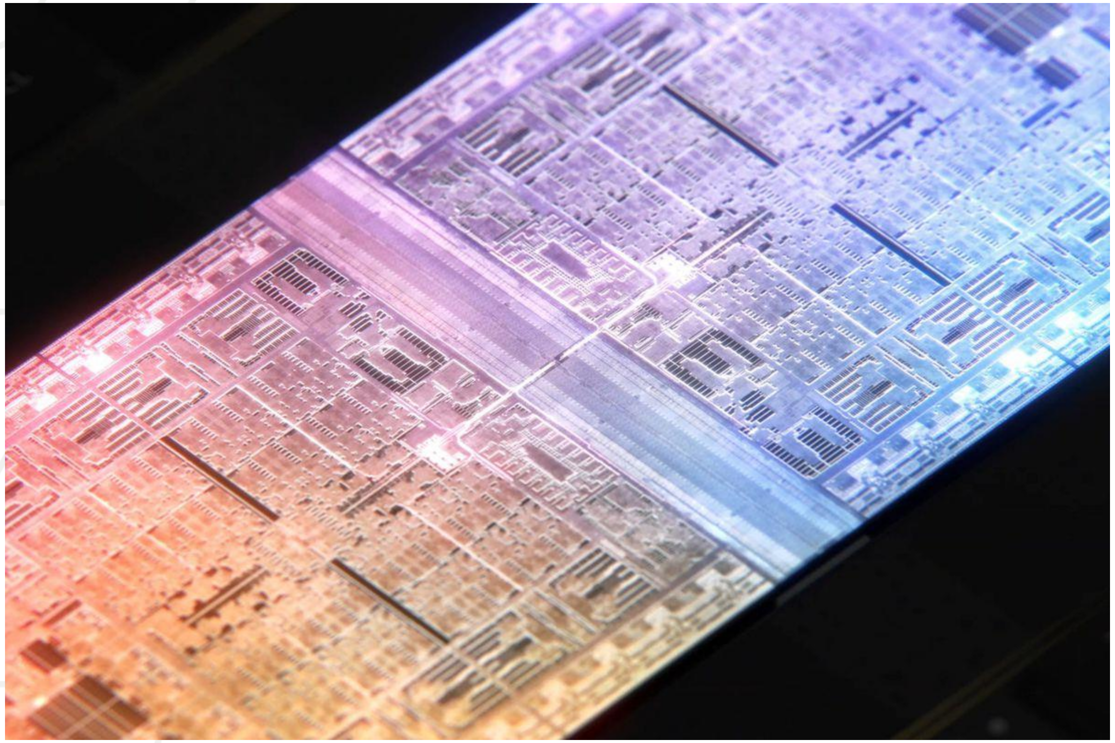
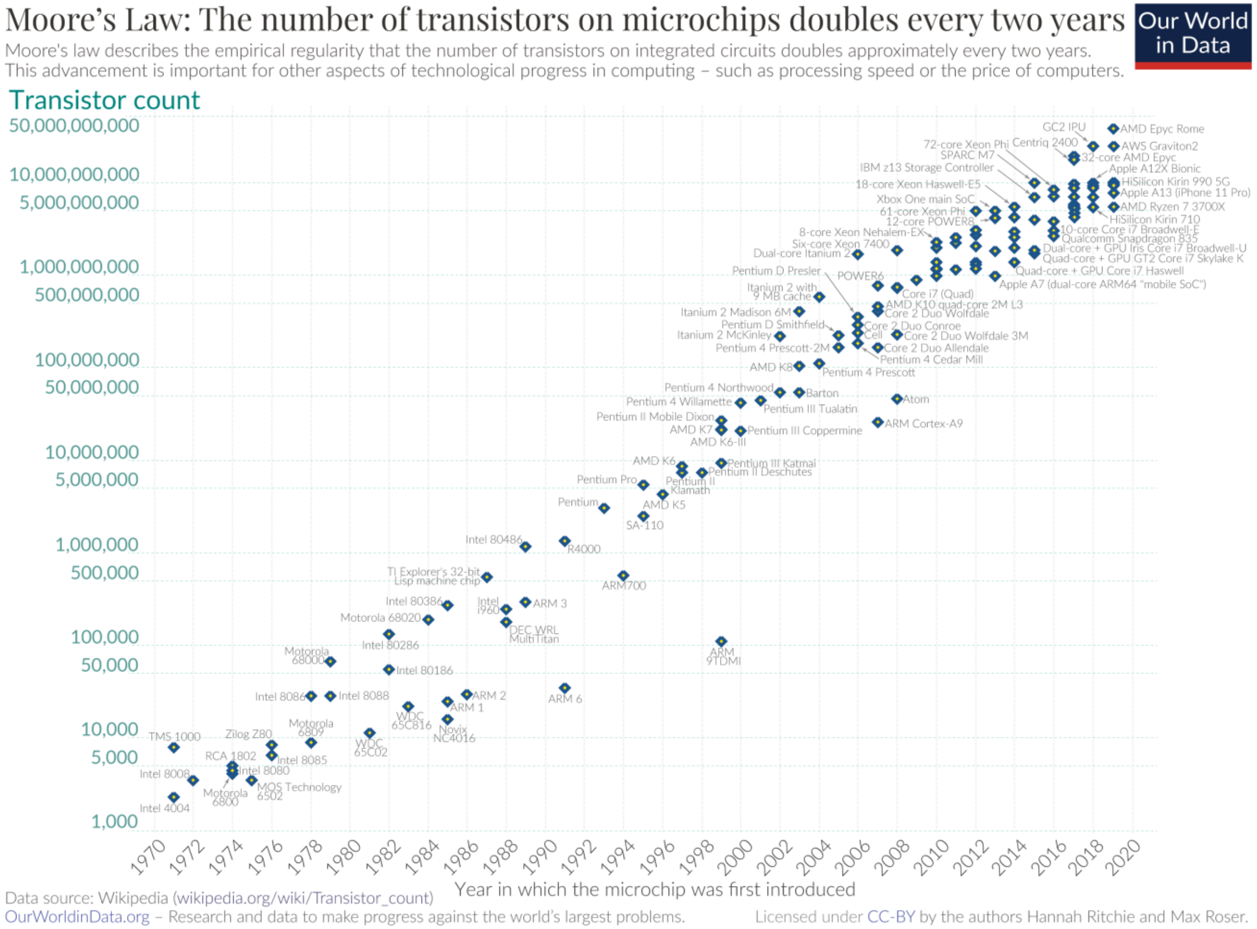
Outline

- **Basic concepts**
- Quantum Hardware
  - Benchmarks
  - Comparisons
  - Accessibility
  - Scalability
- Near-term Algorithms
  - Variational Quantum Algorithm (VQA)
  - Quantum Machine Learning (QML)
  - Challenges
- Intermediate Level Research
  - Quantum Optimal Control
  - Error Mitigation
  - Resource Reduction
- Resources
  - QC Market
  - Internship
  - Summer School
  - Community

Why Quantum Computing?



Apple’s 5nm process M1 Ultra chip contains 114 billion transistors [1]. As the size of transistors gradually shrinks to a few atoms, it will no longer be a reliable bit due to quantum tunneling.



https://www.techspot.com/news/93755-exploring-apple-m1-ultrafusion-chip-interconnect.html

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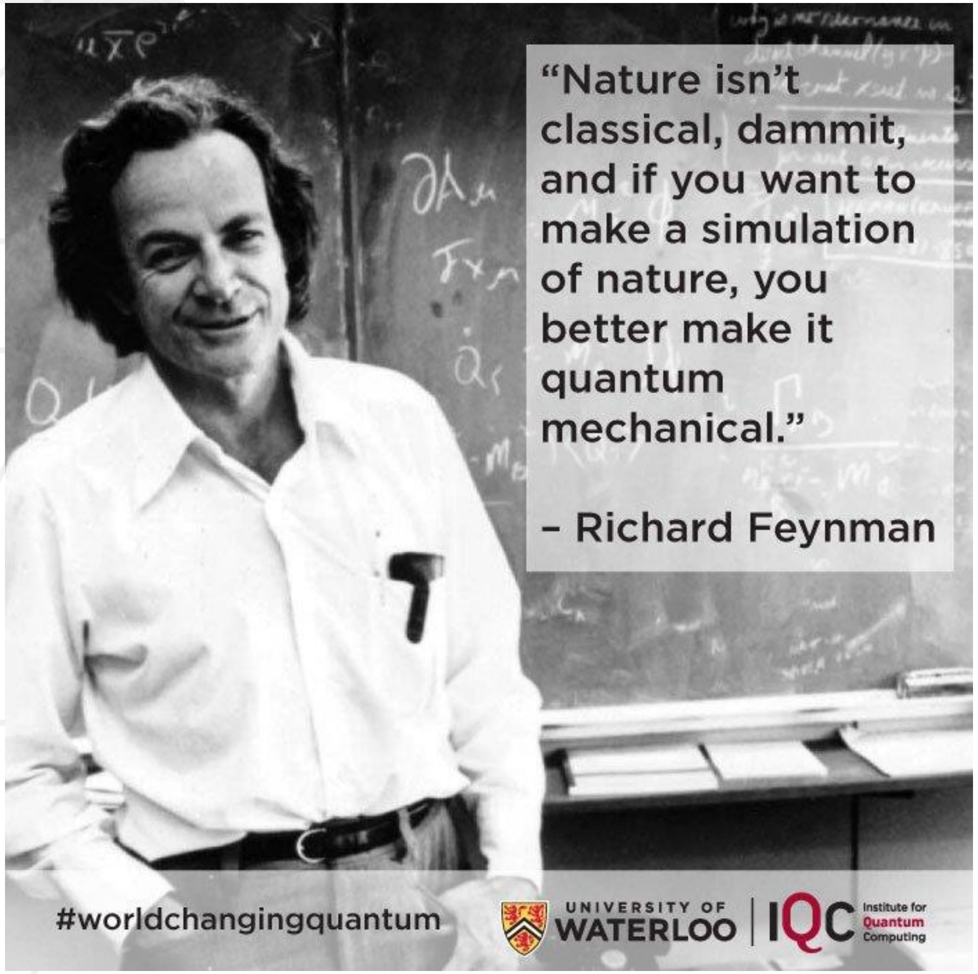
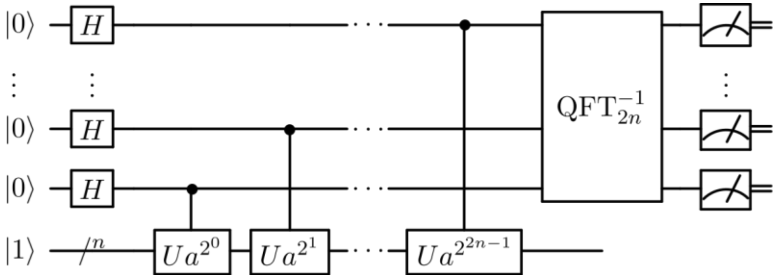
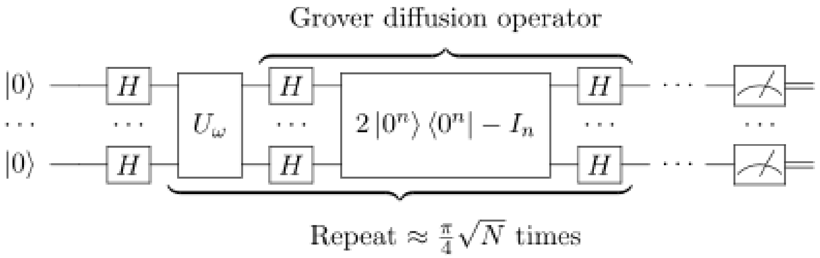
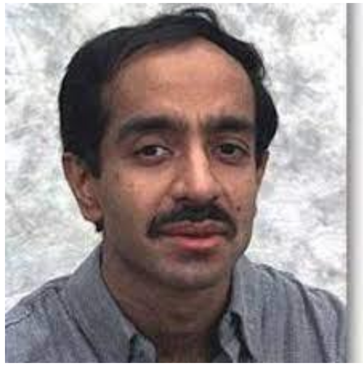
Why Quantum Computing?





Shor's Algorithm (1994) for integer factorization gives an exponential speedup.





Grover's Algorithm (1996) for unstructured search gives a quadratic speedup.

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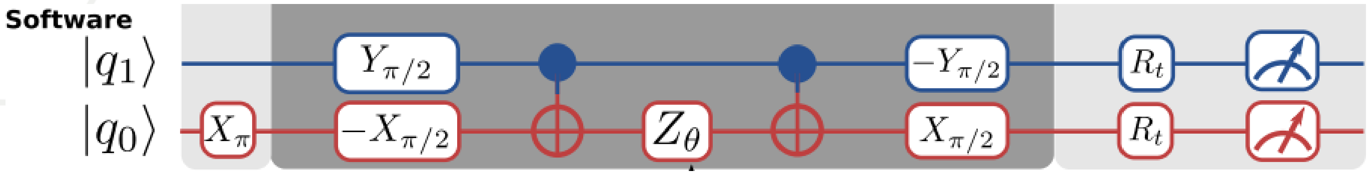
What is a quantum algorithm?

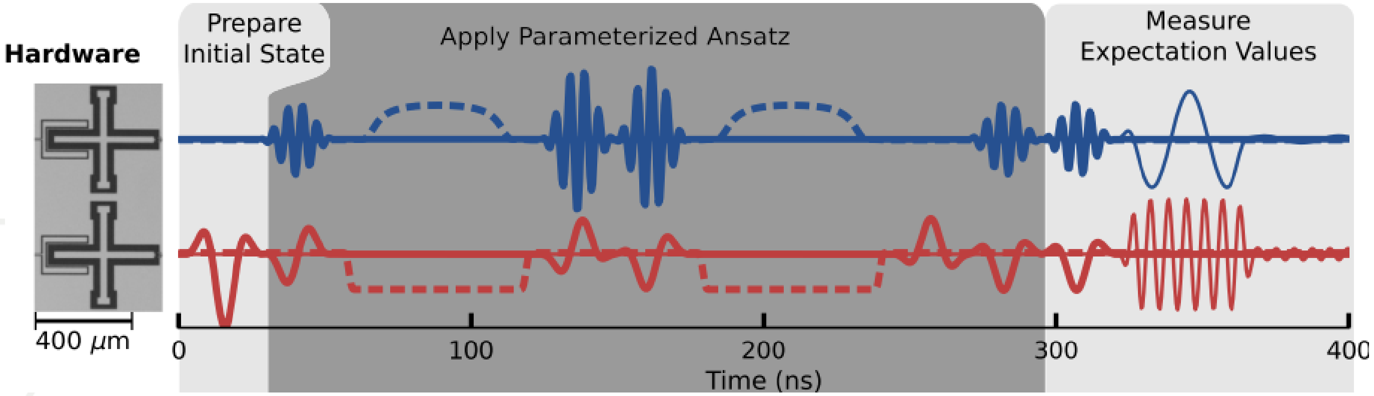
*Quantum Circuit Model



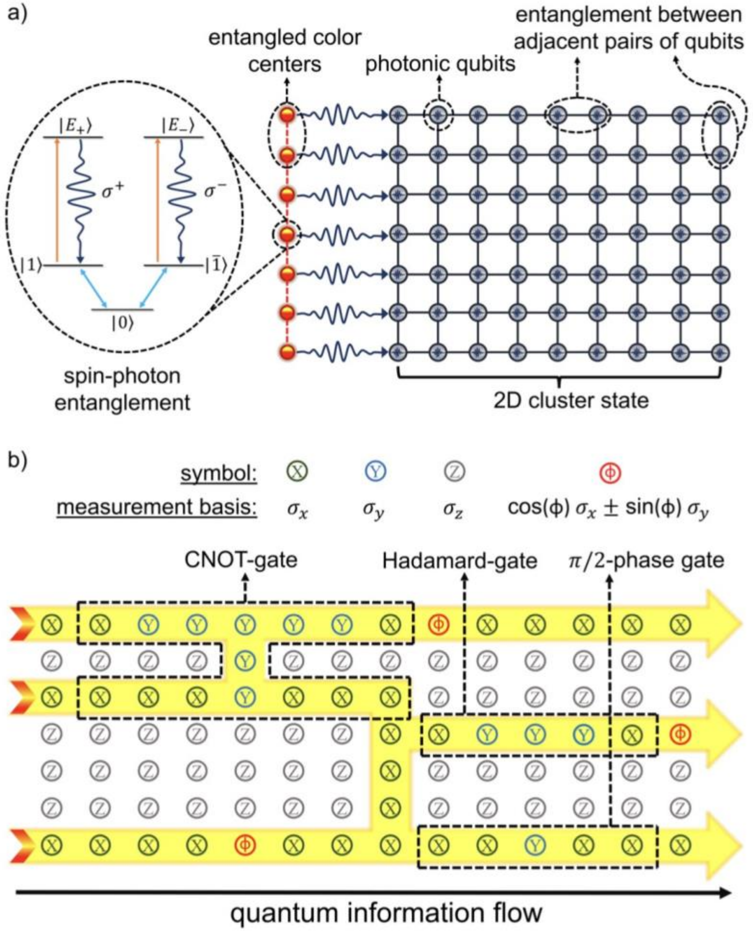
Each line represents a qubit

Gate sequence timeline

Transpiler [1]



Measurement-Based Quantum Computing (MBQC) [2]



[1] O'Malley, Peter JJ, et al. "Scalable quantum simulation of molecular energies." *Physical Review X* 6.3 (2016): 031007.
[2] Majety, Sridhar, et al. "Quantum information processing with integrated silicon carbide photonics." *Journal of Applied Physics* 131.13 (2022): 130901.

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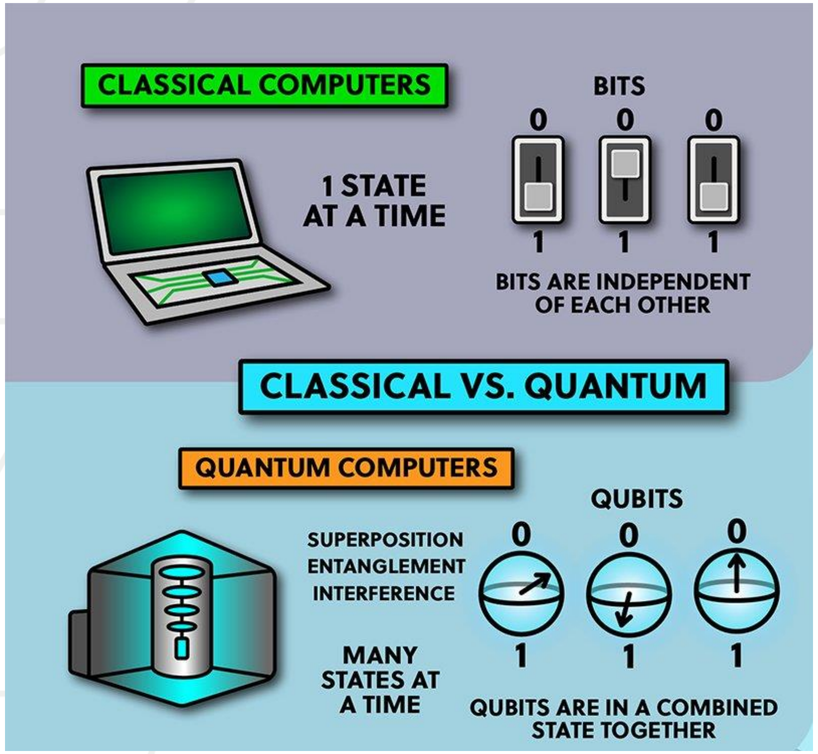
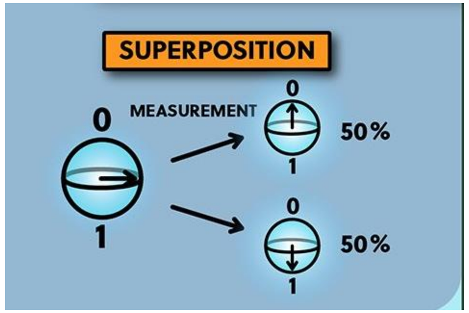
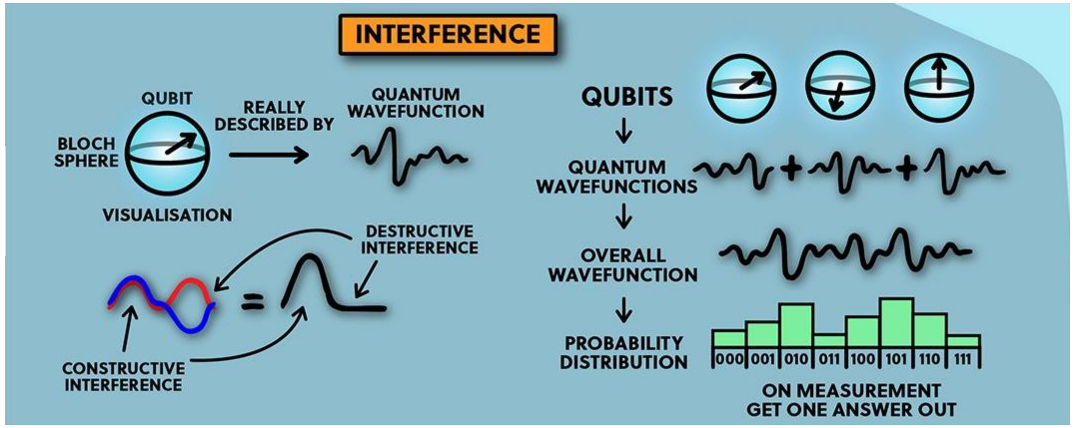
Qubit (Data)



$$|0\rangle := \begin{bmatrix} 1 \\ 0 \end{bmatrix}, \quad |1\rangle := \begin{bmatrix} 0 \\ 1 \end{bmatrix}.$$



$$|\psi\rangle = \alpha|0\rangle + \beta|1\rangle := \begin{bmatrix} \alpha \\ \beta \end{bmatrix}.$$



$$\left\{ |00\rangle = |0\rangle \otimes |0\rangle := \begin{bmatrix} 1 \\ 0 \\ 0 \\ 0 \end{bmatrix}, \quad |01\rangle = |0\rangle \otimes |1\rangle := \begin{bmatrix} 0 \\ 1 \\ 0 \\ 0 \end{bmatrix}, \quad |10\rangle = |1\rangle \otimes |0\rangle := \begin{bmatrix} 0 \\ 0 \\ 1 \\ 0 \end{bmatrix}, \quad |11\rangle = |1\rangle \otimes |1\rangle := \begin{bmatrix} 0 \\ 0 \\ 0 \\ 1 \end{bmatrix} \right\}.$$

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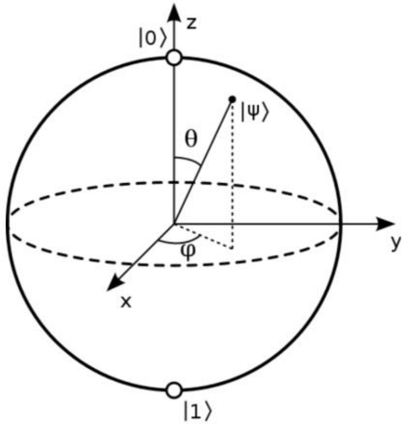
Quantum Gates (Unitary Operations)

Start with the simplest NOT operation. Implement the gate is mathematically equivalent to matrix multiplication. Another important gate is the Hadamard gate H for preparing superposition states.

$$X|0\rangle := \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix} \begin{bmatrix} 1 \\ 0 \end{bmatrix} = \begin{bmatrix} 0 \\ 1 \end{bmatrix} = |1\rangle, \quad \text{and} \quad X|1\rangle := \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix} \begin{bmatrix} 0 \\ 1 \end{bmatrix} = \begin{bmatrix} 1 \\ 0 \end{bmatrix} = |0\rangle.$$



Each quantum gate is a unitary matrix which satisfies

$$U^\dagger U = UU^\dagger = I, \quad \text{and} \quad \| |\psi\rangle \| = \| U|\psi\rangle \| = 1.$$

Single qubit rotation around x,y,z axis

Then, we can introduce a 2-qubit CNOT gate for entanglement

$$\text{CNOT} := \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{bmatrix}, \quad R_x(\theta) := \begin{bmatrix} \cos\frac{\theta}{2} & -i\sin\frac{\theta}{2} \\ -i\sin\frac{\theta}{2} & \cos\frac{\theta}{2} \end{bmatrix}, \quad R_y(\theta) := \begin{bmatrix} \cos\frac{\theta}{2} & -\sin\frac{\theta}{2} \\ \sin\frac{\theta}{2} & \cos\frac{\theta}{2} \end{bmatrix}, \quad R_z(\theta) := \begin{bmatrix} e^{-i\frac{\theta}{2}} & 0 \\ 0 & e^{i\frac{\theta}{2}} \end{bmatrix}.$$

They form a universal gate set!

CNOT is the Controlled NOT gate, depends on the state of 1st (control) qubit to apply (or not) a NOT gate on the 2nd qubit

$$\text{CNOT}|00\rangle = |00\rangle, \quad \text{CNOT}|01\rangle = |01\rangle, \quad \text{CNOT}|10\rangle = |11\rangle, \quad \text{CNOT}|11\rangle = |10\rangle.$$

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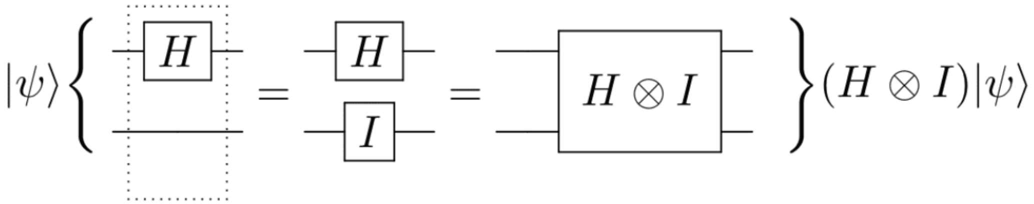
Quantum Gates (Unitary Operations)

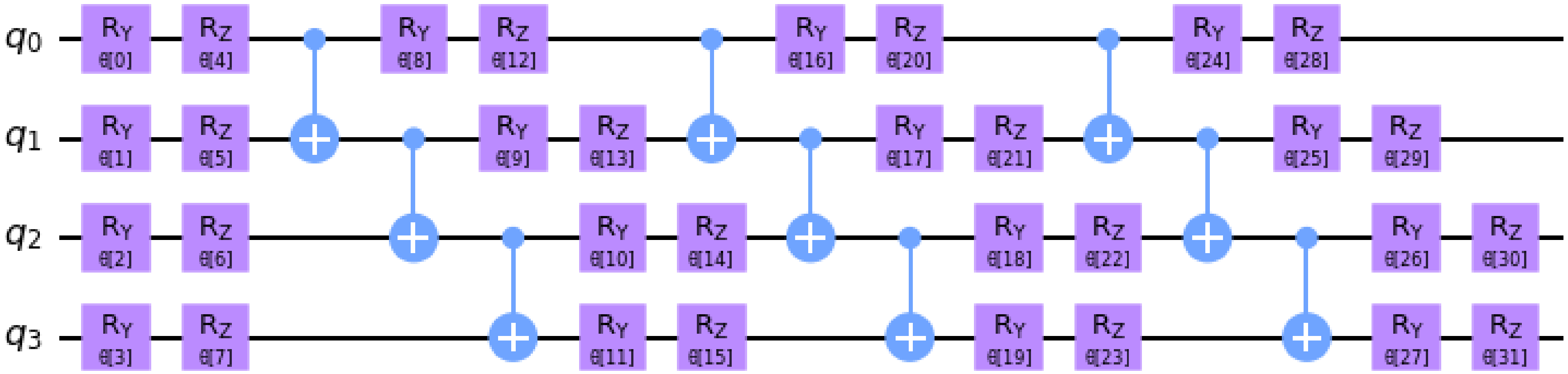
Another case is when we have an idle qubit



Then, the corresponding unitary matrix should be written as

$$U = H \otimes I = \frac{1}{\sqrt{2}}\begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix} \otimes \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} = \frac{1}{\sqrt{2}}\begin{bmatrix} 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 \\ 1 & 0 & -1 & 0 \\ 0 & 1 & 0 & -1 \end{bmatrix}.$$

Let's look at a more useful quantum circuit, where all the single qubit rotation parameters θ_j forms a vector.
We call such an Ansatz a Parametrized Quantum Circuit (PQC) $\mathrm{U}(\theta)$



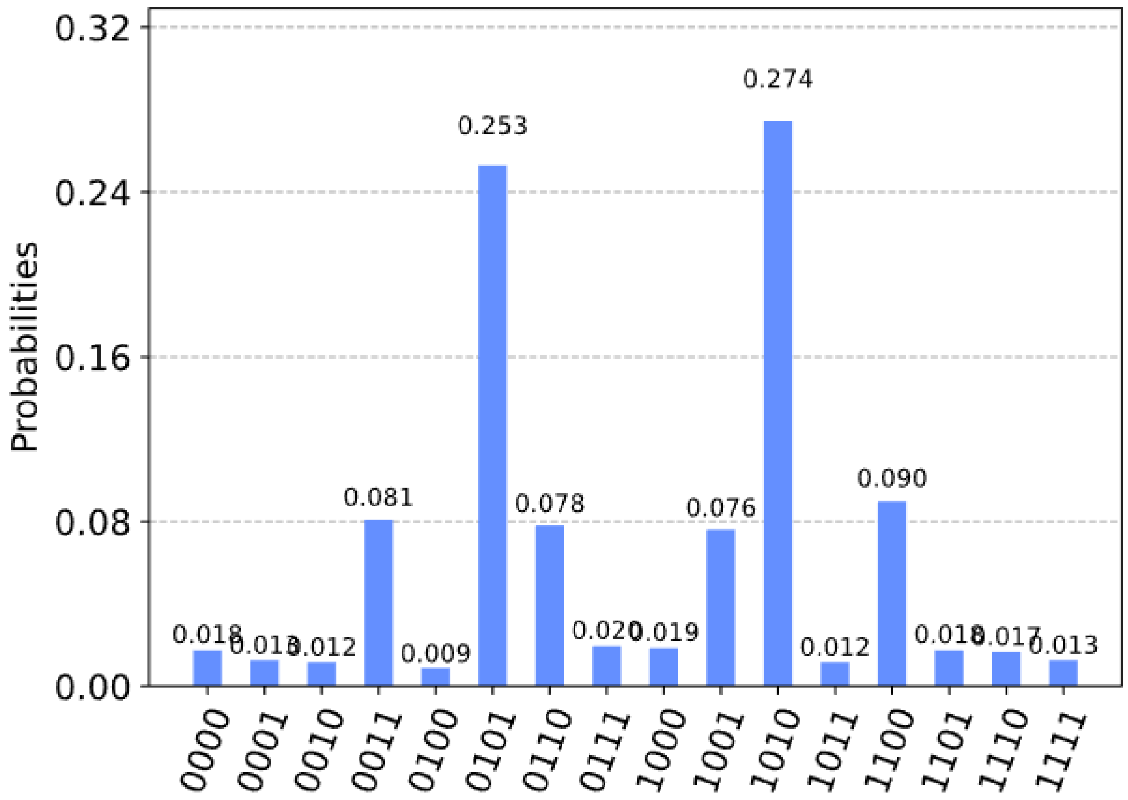
*This is also an example of Hardware-Efficient Ansatz (HEA) where only nearest-neighboring CNOT gates are used. This will make it easier to be transpiled to a superconducting quantum computer.

Quantum Measurement (Results)

- Single measurement will return a classical bit string with a certain probability (magnitude square of the linear combination coefficient) and collapse the quantum state.

- Typical measurement statistics (a discrete probability distribution) from a quantum computation by repeating computation + measurement N times. N is usually called the shot number.

- Since we can only repeat the measurement with finite cycles, we will not be able to recover the exact distribution.



https://qiskit.org/textbook/ch-applications/qaoa.html

DiVincenzo's Criteria

1. A scalable physical system with well-characterized qubit
2. The ability to initialize the state of the qubits to a simple fiducial state
3. Long relevant decoherence times
4. A universal set of quantum gates
5. A qubit-specific measurement capability

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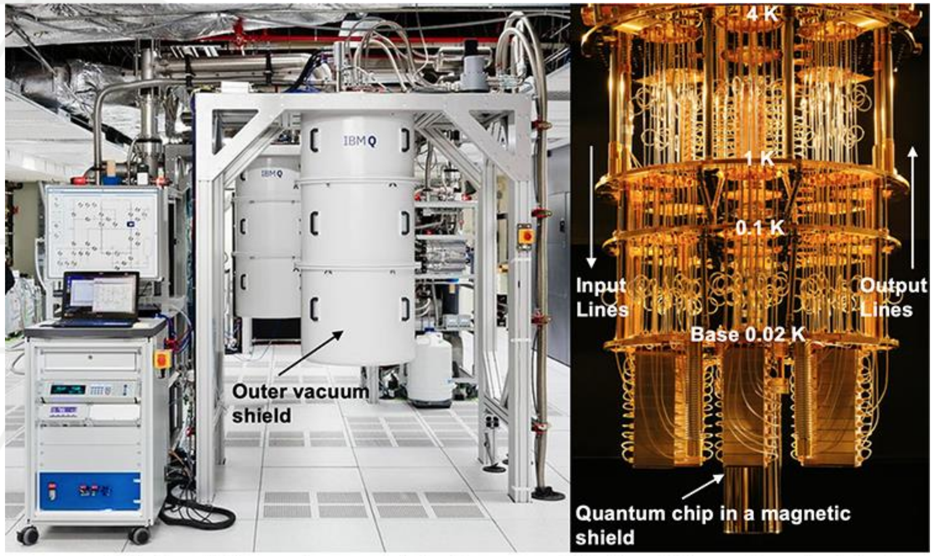
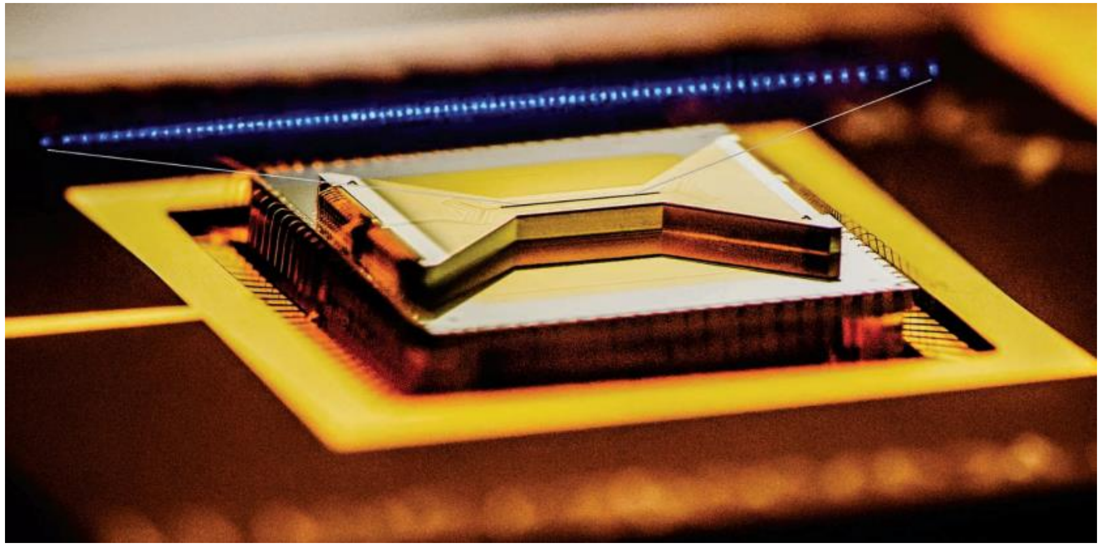
Quantum Hardware



Dilution fridge setup: outside view Dilution fridge setup: inside view

Photos of a dilution fridge that houses and cools down superconducting quantum processors. The left photo shows an outside view of the dilution fridge. [1]

Krantz, Philip, et al. "A quantum engineer's guide to superconducting qubits." *Applied Physics Reviews* 6.2 (2019): 021318.



A semiconductor chip ion trap, fabricated by Sandia National Laboratories, is composed of gold-plated electrodes that suspend individual atomic ion qubits above the surface of the chip. [2]

Bruzewicz, Colin D., et al. "Trapped-ion quantum computing: Progress and challenges." *Applied Physics Reviews* 6.2 (2019): 021314.

[1] https://www.ibm.com/blogs/research/2020/01/quantum-limited-amplifiers/
[2] Monroe, Christopher, Michael G. Raymer, and Jacob Taylor. "The US national quantum initiative: From act to action." *Science* 364.6439 (2019): 440-442.

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Quantum Computing Market Map

THE QUANTUM INSIDER

Non exhaustive and in no particular order. Excludes details on control systems, assembly languages, circuit design, etc.

Users
Select examples

Material Science
Merck, OTI, Airbus, BMW

Finance
Goldman Sachs, Bank of America, J.P.Morgan, Wells Fargo

Life Sciences
Odyssey Therapeutics, Boehringer Ingelheim, AstraZeneca, gsk

Other
VW, Johnson Electric, Denso

Applications
Not mapped to verticals

Software offerings
Includes control software

Not strictly categorized given diversity of operations[1]
Multiverse Computing, QC Ware, 1QBit, NQCG, Aliro Quantum, HQS Quantum Simulations, Zapata, Horizon Quantum Computing, QCi Ready-to-run Quantum Software, Entropica Labs, river lane, Strangeworks, QuantFi, Phasecraft, aq, QunaSys, Terra Quantum, ⟨b| e^iπ, Keysight Technologies, ProteinQure, Qubit pharmaceuticals, Q-CTRL, Classiq, Quantum-South, menten.AI, ParityQC

Cloud access to QPUs
aws, Azure, Google Cloud

Simulators / q-inspired / etc
Atos, Fujitsu, NVIDIA, Huawei Cloud

QPUs[2]

Superconducting
rigetti, Google AI Quantum, OQC, QILIMANJARO Quantum Tech, IBM Q, IQM, Origin Quantum, Nord Quantique, aws, seeqc, D-Wave The Quantum Computing Company, Alibaba.com Global trade starts here.

Ion Trap
Quantinuum, IONQ, Universal Quantum, AQT, oxford ionics, QUDOOR 启科量子, eleQtron

Neutral Atoms
atom computing, ColdQuanta, QuEra, PASQAL

Silicon
Silicon Quantum Computing, intel, Quantum Motion, equal 1, photonic

Photonics
PsiQuantum, QC82, Xanadu, ORCA Computing, Quandela, TuringQ

Other
EeroQ Quantum Hardware — Electrons on helium
Quantum Brilliance — NV Diamond

Hardware / components
Select examples only – not representative of entire ecosystem

Cryogenics (includes testing)
Oxford Instruments, FormFactor, Lake Shore Cryotronics, Bluefors, Montana Instruments, ICE, Maybell

Lights and lasers
Vescent Photonics, NKT Photonics, M Squared, Coherent, Qant, Toptica Photonics, Ligentec

Other componentry (examples)
Delft Circuits Hardware for quantum engineers, Keysight Technologies, Quantum Machines, Quantum Design, CryoCoax A division of Intelliconnect, ZNF, QBLOX, QDevil, Zurich Instruments

[1] Software offerings can be further classified into SDKs, firmware / enablers, algorithms / applications, simulators etc. but many companies are offering a mixture across the stack

[2] Many QPU providers are offering full stack services (e.g. Pasqal acquired Qu&Co, Quantinuum was originally CQC prior to merger with HQS, etc.

https://thequantuminsider.com/2022/05/09/quantum-computing-market-map-and-data-2022/

Benchmarks

Three core metrics

Scale | **Number of qubits**
Amount of information that can be encoded in a quantum system

Quality | **Quantum volume**
Quality of circuits implemented in hardware with low operation errors

Speed | **Circuit Layer Ops per Second**
Number of circuits that can run on hardware in a given time

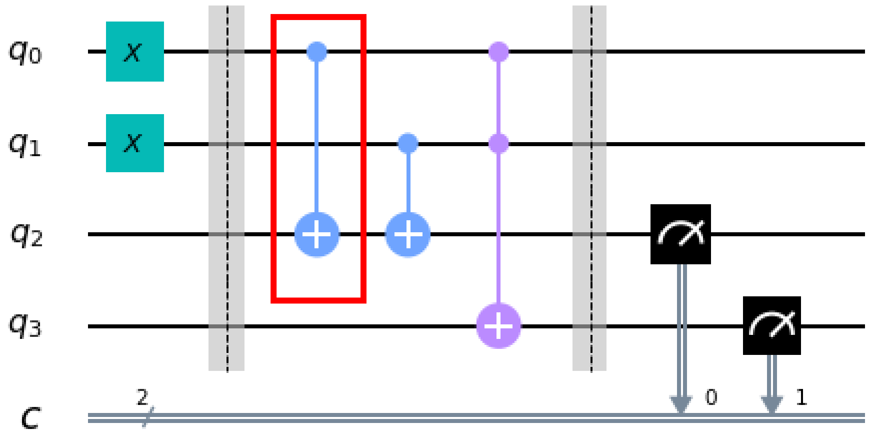
IBM system performance over time

Comparison

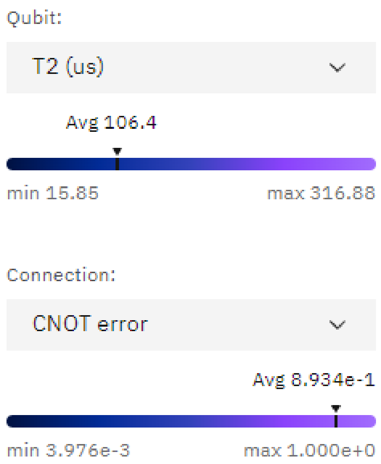
		Superconductors	Ion traps	Photonics	Quantum dots	Cold atoms
% of potential users who consider technology "promising"		61%	35%	34%	26%	16%
Qubit quality[1]	*Qubit lifetime*	~1 ms	~50+ s	N/A	~1-10 s	~1 s
	Gate fidelity	~99.6%	~99.9%	~99.9%	~99%	~99%
	Gate operation time	~10-50 ns	~1-50 µs	~1 ns	~1-10 ns	~100 ns
Connectivity		Nearest neighbors	All-to-all	All-to-all[2]	Nearest neighbors	Near neighbors
Strengths		✓ Engineering maturity ✓ Scalability[3]	✓ Stability ✓ Gate fidelity ✓ Connectivity	✓ Horizontal scalability ✓ Established semiconductor tech	✓ Stability ✓ Established semiconductor tech	✓ Horizontal scalability ✓ Connectivity
Challenges		× Near absolute zero temperatures × Connectivity limitation in 2D	× Gate operation times × Horizontal scaling beyond one trap	× Noise from photon loss	× Requires cryogenics × Nascent engineering	× Gate fidelity × Gate operation time
Example players		IBM, Google	Honeywell, IonQ	PsiQuantum, Xanadu	Intel, SQC	ColdQuanta, Pasqal

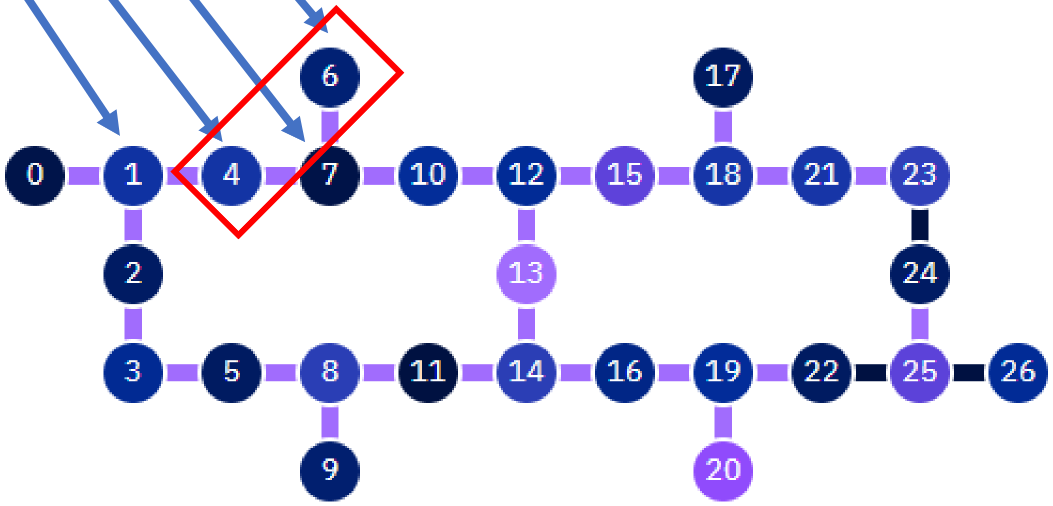
https://www.bcg.com/publications/2021/building-quantum-advantage

Connectivity and Qubit Mapping



Qubit Mapping Problem [1]:
But they are not directly connected with each other!





[1] Li, Gushu, Yufei Ding, and Yuan Xie. "Tackling the Qubit Mapping Problem for NISQ-Era Quantum Devices. arXiv." *arXiv preprint arXiv:1809.02573* (2018).

Accessibility: IBM Quantum

Pulse level access

Open Plan:

ibm_nairobi
System status: Online
Processor type: Falcon r5.11H
Qubits 7 | QV 32 | CLOPS 2.6K

ibm_oslo
System status: Online - Queue paused
maintenance
Processor type: Falcon r5.11H
Qubits 7 | QV 32 | CLOPS 2.6K

ibmq_jakarta
System status: Online
Processor type: Falcon r5.11H
Qubits 7 | QV 16 | CLOPS 2.4K

ibmq_manila
System status: Online
Processor type: Falcon r5.11L
Qubits 5 | QV 32 | CLOPS 2.8K

ibmq_quito
System status: Online
Processor type: Falcon r4T
Qubits 5 | QV 16 | CLOPS 2.5K

ibmq_belem
System status: Online
Processor type: Falcon r4T
Qubits 5 | QV 16 | CLOPS 2.5K

ibmq_lima
System status: Online
Processor type: Falcon r4T
Qubits 5 | QV 8 | CLOPS 2.7K

simulator_stabilizer
Simulator status: Online
Simulator type: Clifford simulator
Qubits 5000

Paid Plan:

ibm_washington (Exploratory)
System status: Online
Processor type: Eagle r1
Qubits 127 | QV 64 | CLOPS 850

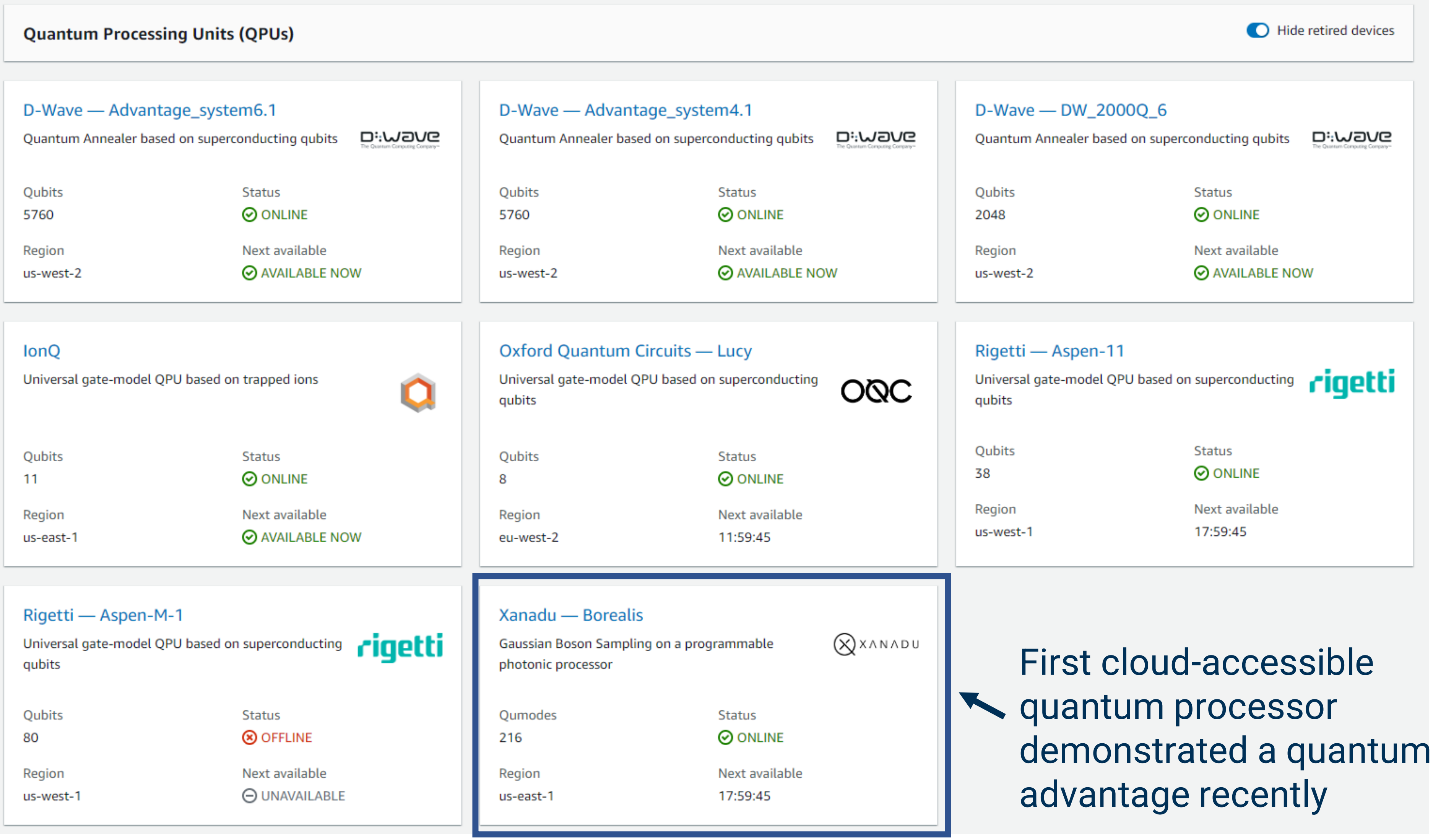
ibm_ithaca (Exploratory)
System status: Online
Processor type: Hummingbird r3
Qubits 65

ibmq_kolkata
System status: Online
Processor type: Falcon r5.11
Qubits 27 | QV 128 | CLOPS 2K

ibmq_montreal
System status: Online
Processor type: Falcon r4
Qubits 27 | QV 128 | CLOPS 2K

https://quantum-computing.ibm.com/services/resources?tab=systems

Accessibility: Amazon Braket



First cloud-accessible quantum processor demonstrated a quantum advantage recently

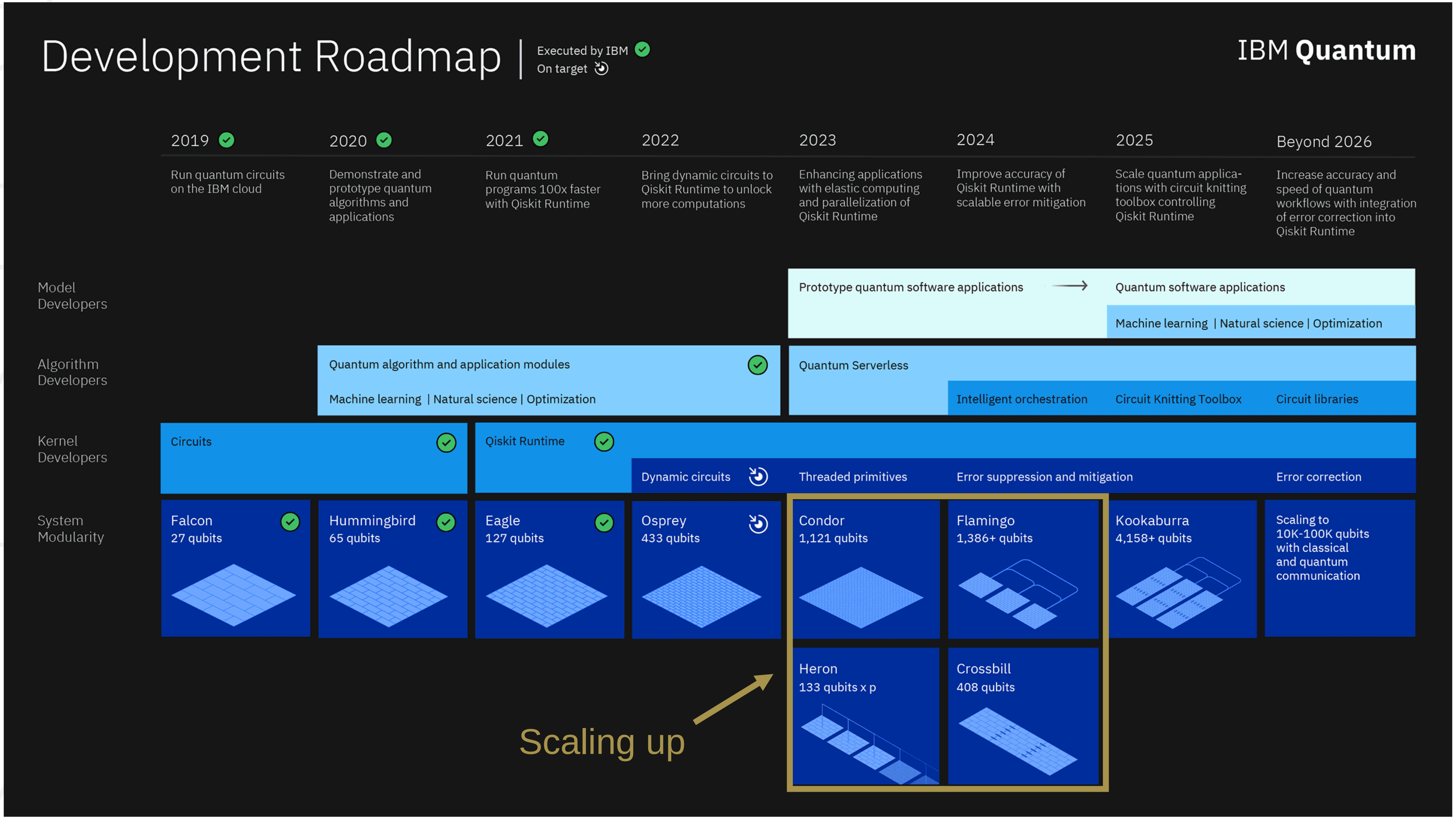
All Paid Plans:

IonQ
$0.30 / task +
$0.01 / shot

D-Wave
$0.30 / task +
$0.00019 / shot

Rigetti
$0.30 / task +
$0.00035 / shot

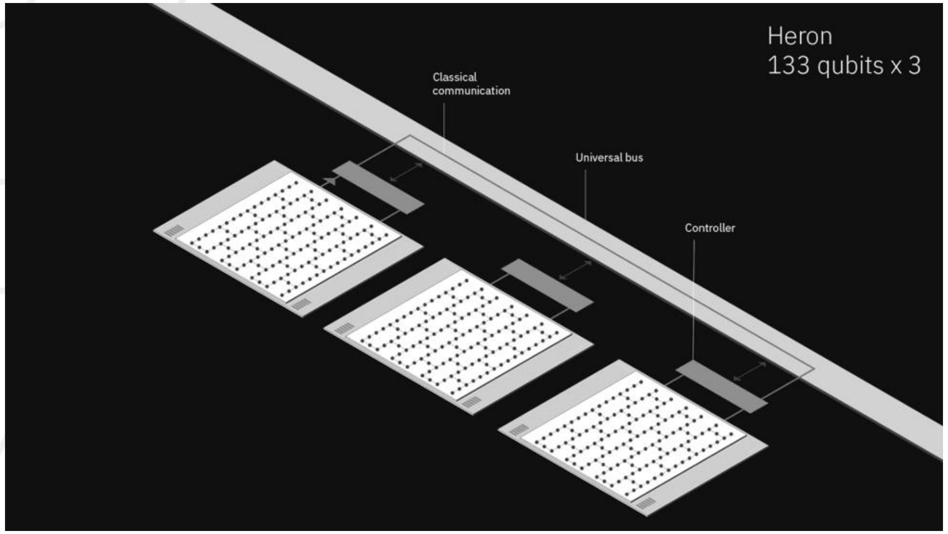
IBM Quantum Roadmap 2022

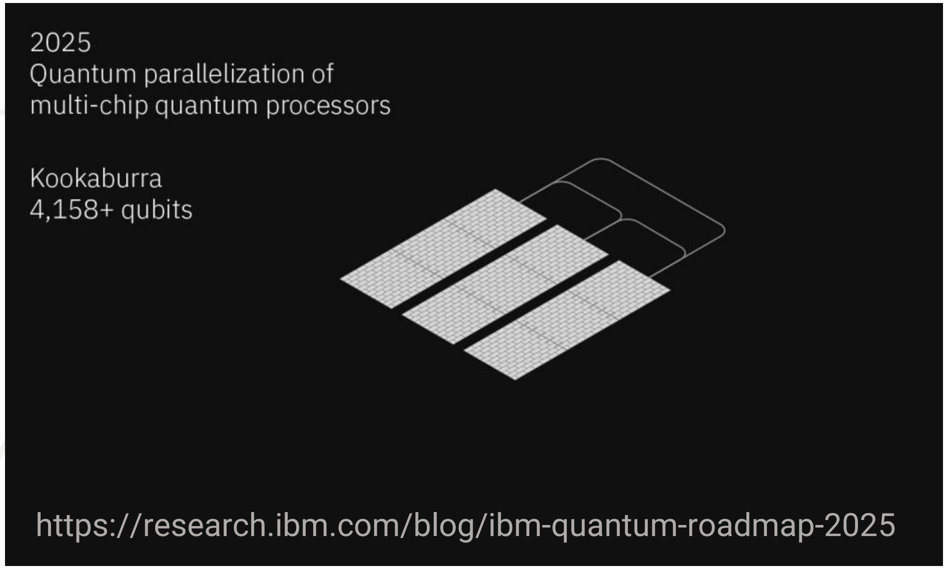


https://research.ibm.com/blog/ibm-quantum-roadmap-2025

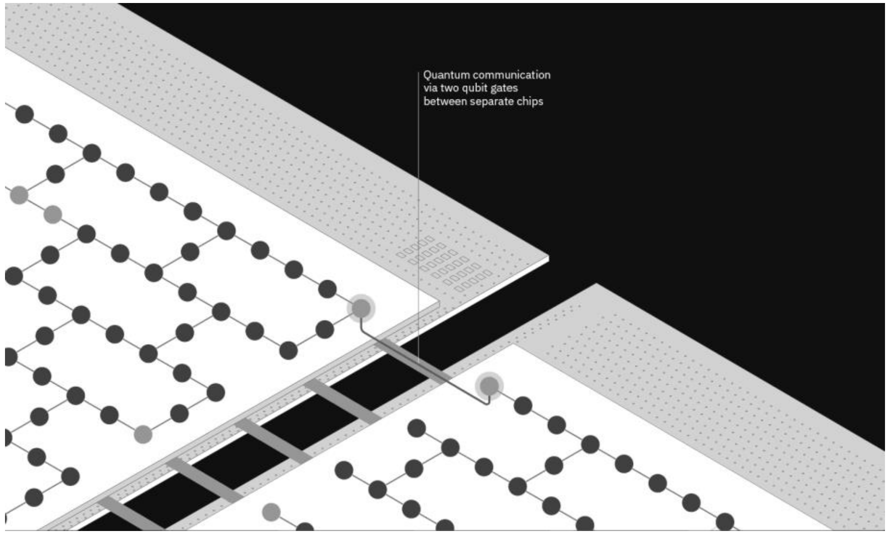
An illustration of scalability

1. Classical parallelization

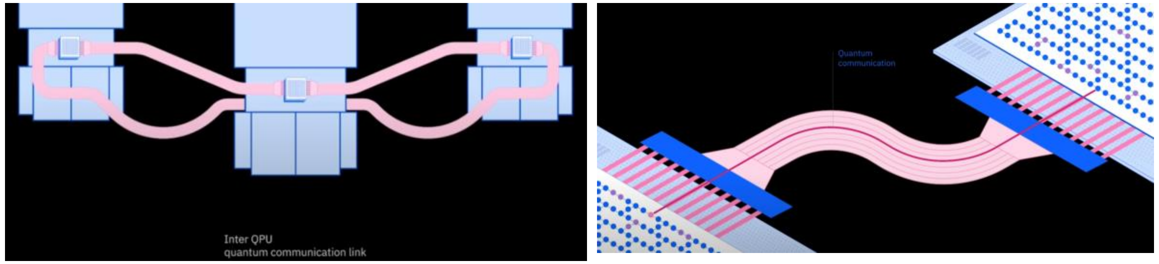




2. Chip-to-chip connection



3. Quantum parallelization



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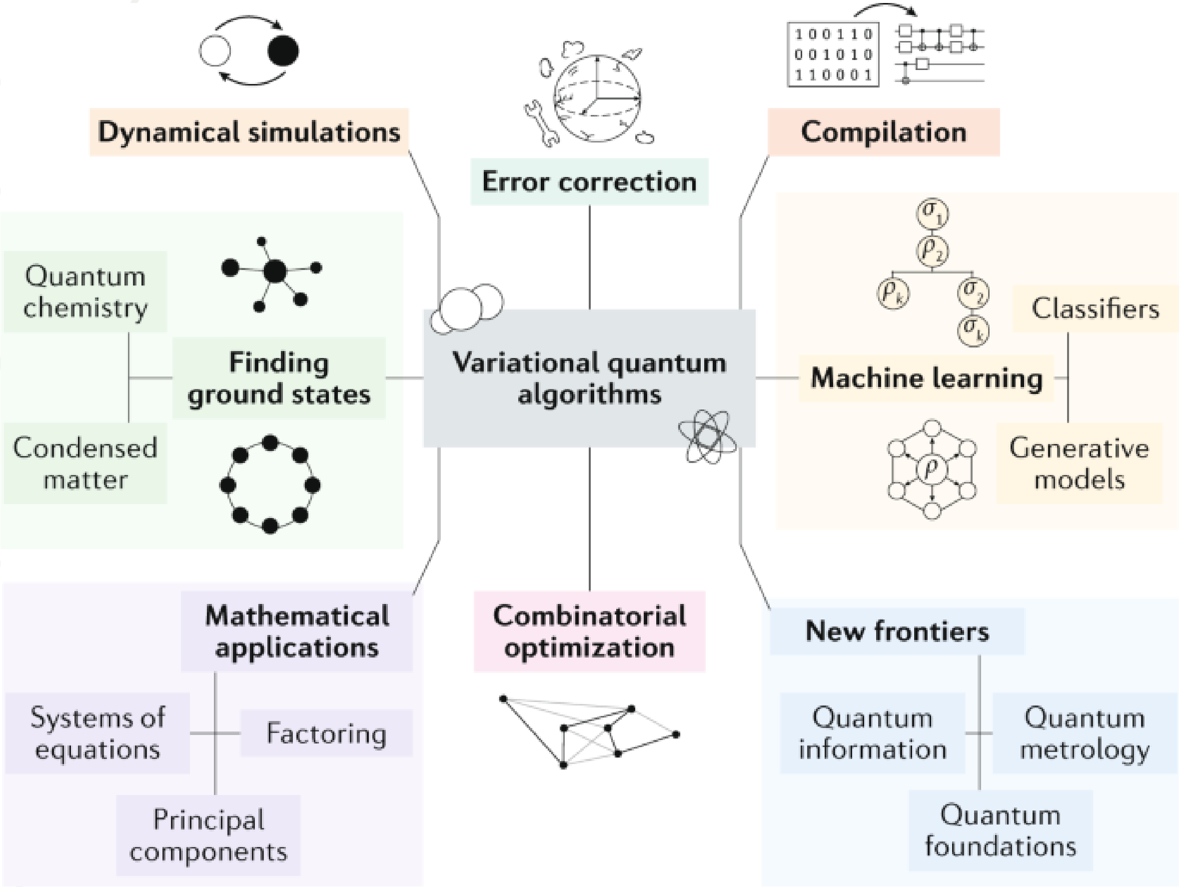
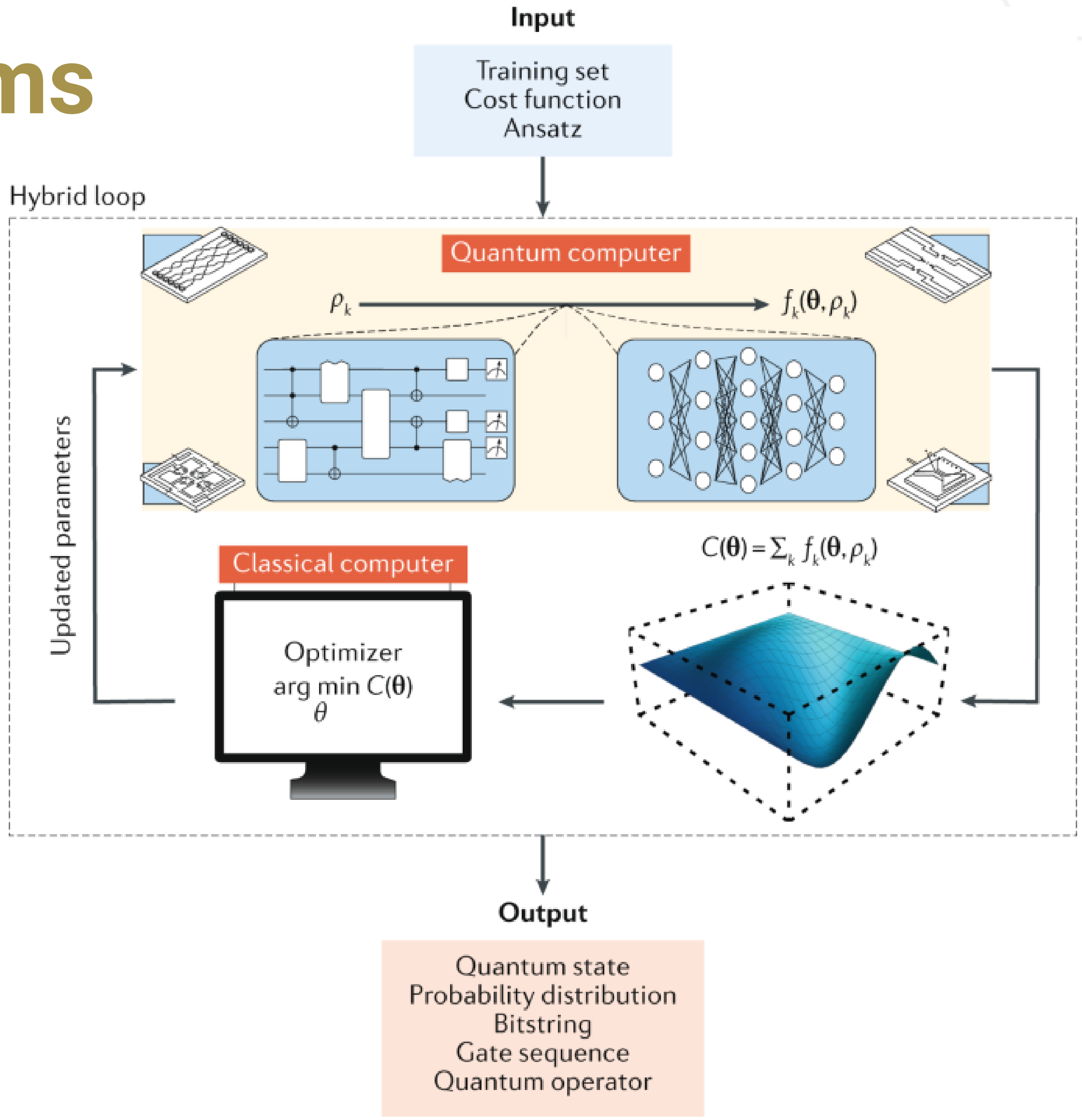
Near-term Quantum Algorithms

In most cases, people are referring to some Variational Quantum Algorithms (VQAs) [1].

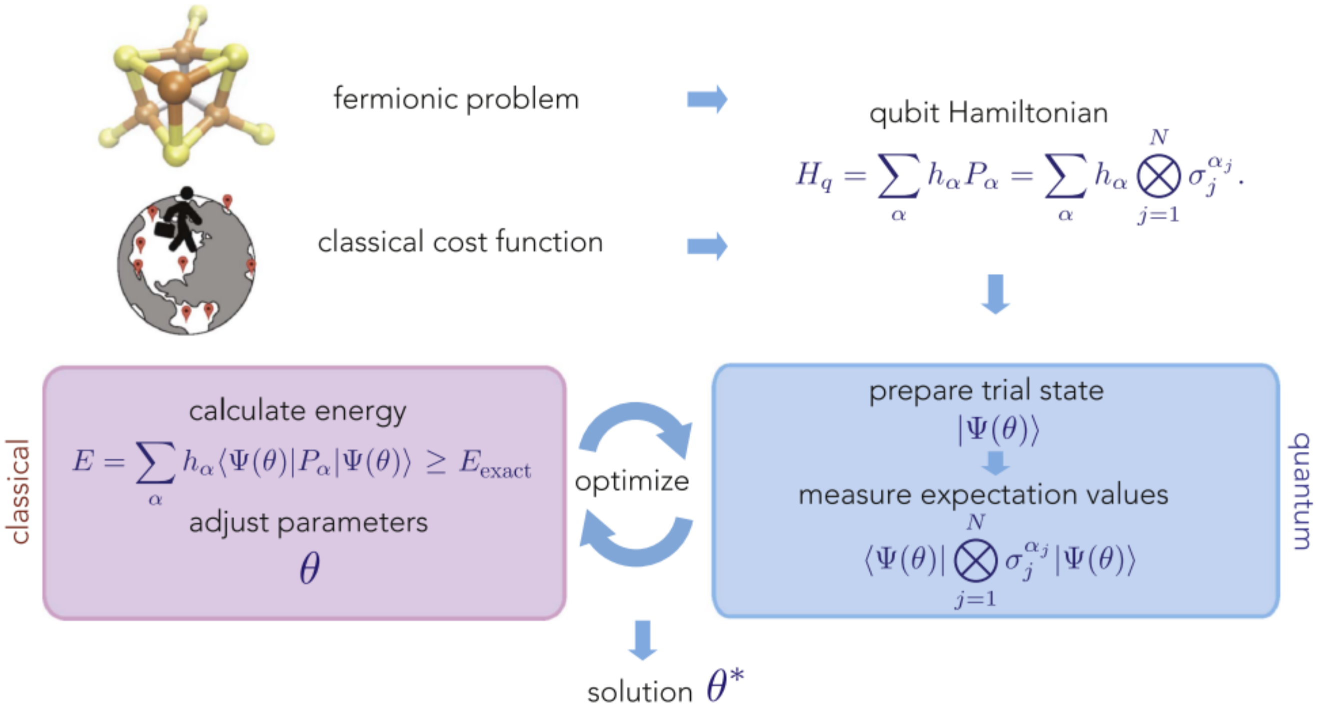


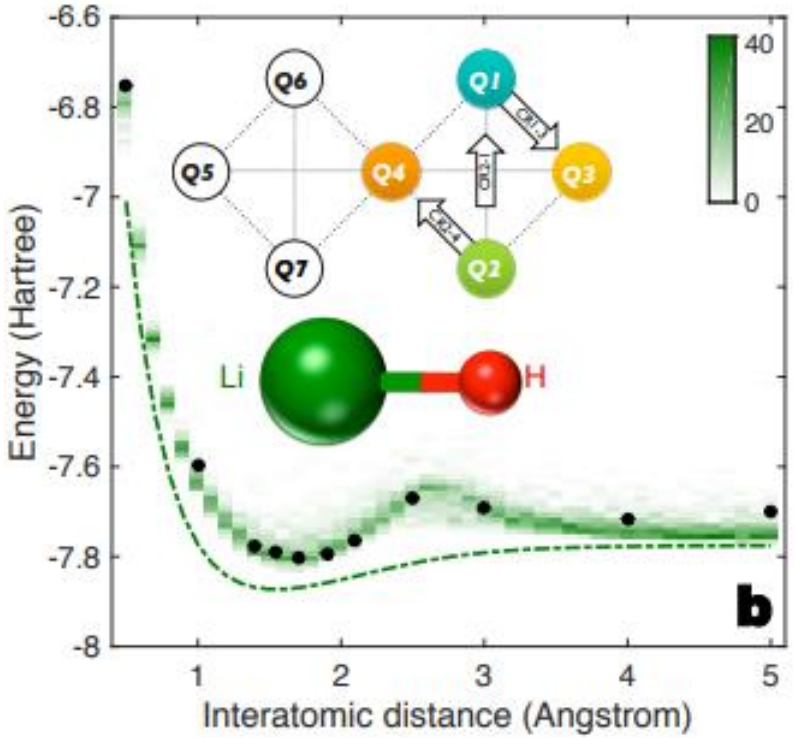


[1] Cerezo, Marco, et al. "Variational quantum algorithms." *Nature Reviews Physics* 3.9 (2021): 625-644.

Example: Variational Quantum Eigensolver (VQE)

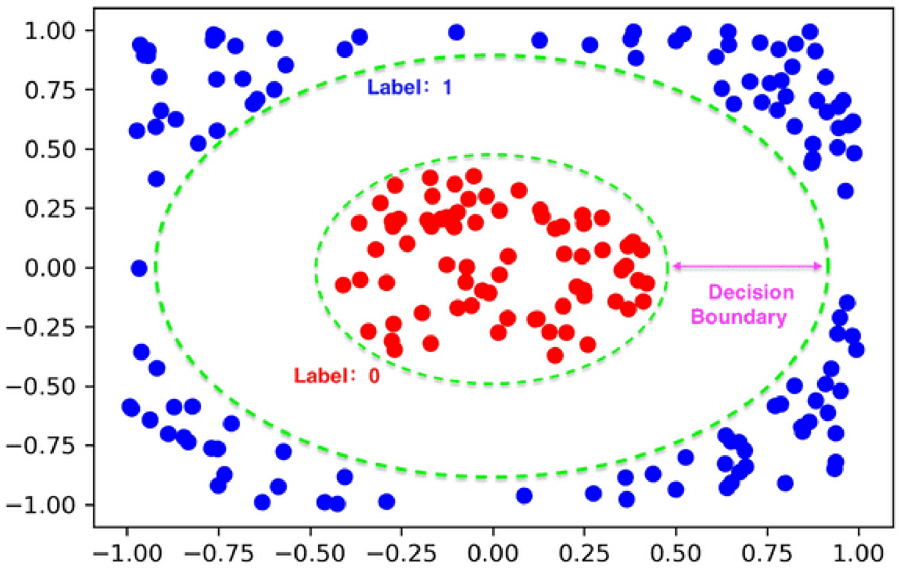
VQE adopts the variational principle to estimate the ground state energy of molecules [1].

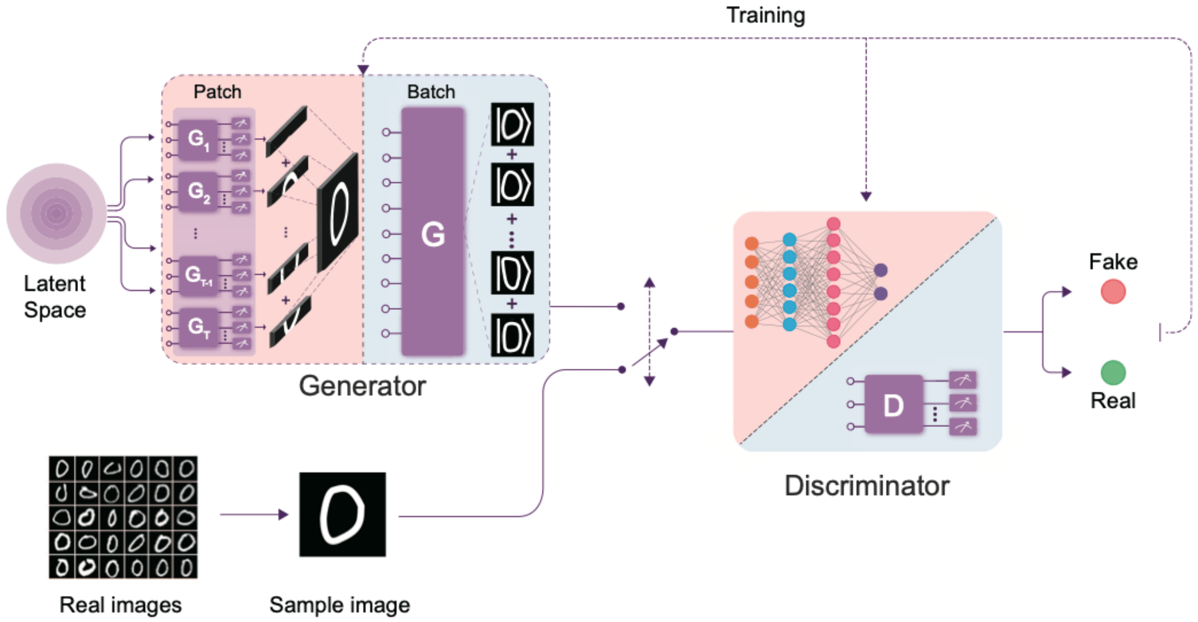




[1] Peruzzo, Alberto, et al. "A variational eigenvalue solver on a photonic quantum processor." *Nature communications* 5.1 (2014): 1-7.
[2] Moll, Nikolaj, et al. "Quantum optimization using variational algorithms on near-term quantum devices." *Quantum Science and Technology* 3.3 (2018): 030503.
[3] McArdle, Sam, et al. "Quantum computational chemistry." *Reviews of Modern Physics* 92.1 (2020): 015003.
[4] Kandala, Abhinav, et al. "Hardware-efficient variational quantum eigensolver for small molecules and quantum magnets." *Nature* 549.7671 (2017): 242-246.

Quantum Machine Learning





- Quantum Supervised Learning for Classification [1]
- Quantum Generative Learning [2]
- Quantum Natural Language Processing (QNLP) [3]
- Quantum Reinforcement Learning (QRL) [4]
- More coming…

[1] https://qml.baidu.com/tutorials/machine-learning/quantum-classifier.html
[2] Huang, He-Liang, et al. "Experimental quantum generative adversarial networks for image generation." *Physical Review Applied* 16.2 (2021): 024051.
[3] Li, Guangxi, Xuanqiang Zhao, and Xin Wang. "Quantum Self-Attention Neural Networks for Text Classification." *arXiv preprint arXiv:2205.05625* (2022).
[4] Dong, Daoyi, et al. "Quantum reinforcement learning." *IEEE Transactions on Systems, Man, and Cybernetics, Part B (Cybernetics)* 38.5 (2008): 1207-1220.

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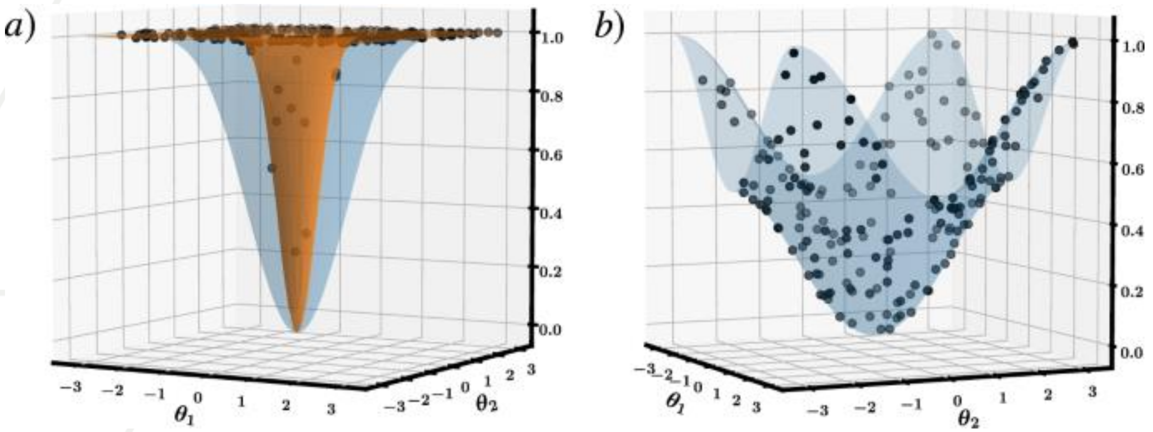
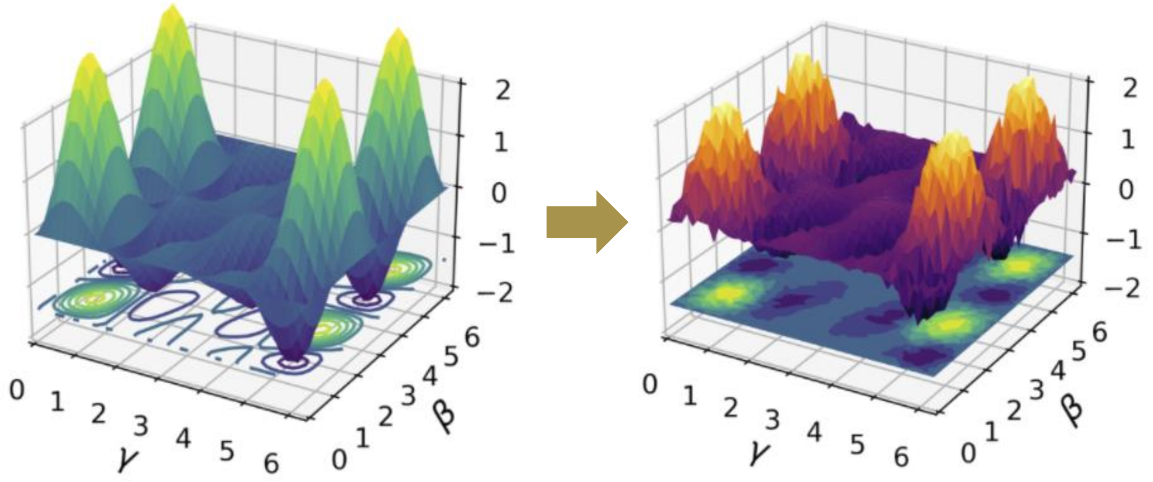
Challenges

- Barren Plateau (BP)

When a given cost function exhibits a BP, the magnitude of its partial derivatives will be, on average, exponentially vanishing with the system size [1-2].



- Noise



The optimization landscape of QAOA for a Max-cut problem is corrupted by noises.

- Ansatz Design

Finding an optimal problem-specific circuit structure is difficult due to a large search space [3].

[1] McClean, Jarrod R., et al. "Barren plateaus in quantum neural network training landscapes." *Nature communications* 9.1 (2018): 1-6.
[2] Cerezo, Marco, et al. "Cost function dependent barren plateaus in shallow parametrized quantum circuits." *Nature communications* 12.1 (2021): 1-12.
[3] Wang, Hanrui, et al. "Quantumnas: Noise-adaptive search for robust quantum circuits." *2022 IEEE International Symposium on High-Performance Computer Architecture (HPCA)*. IEEE, 2022.

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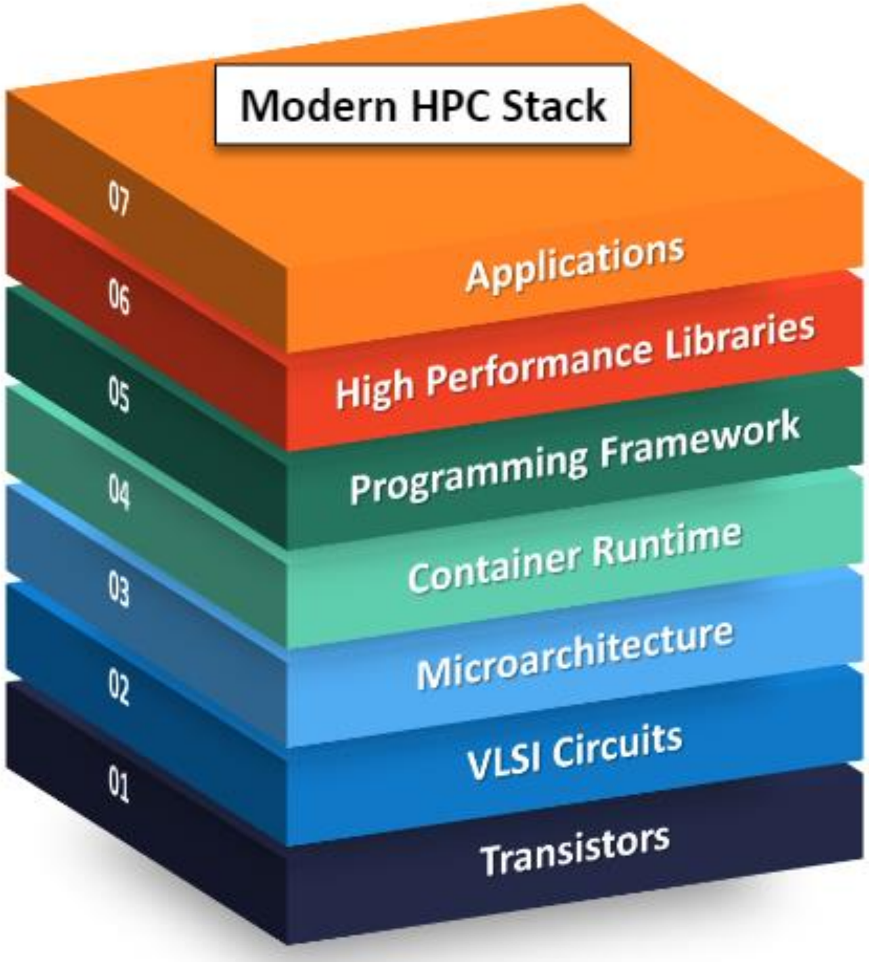
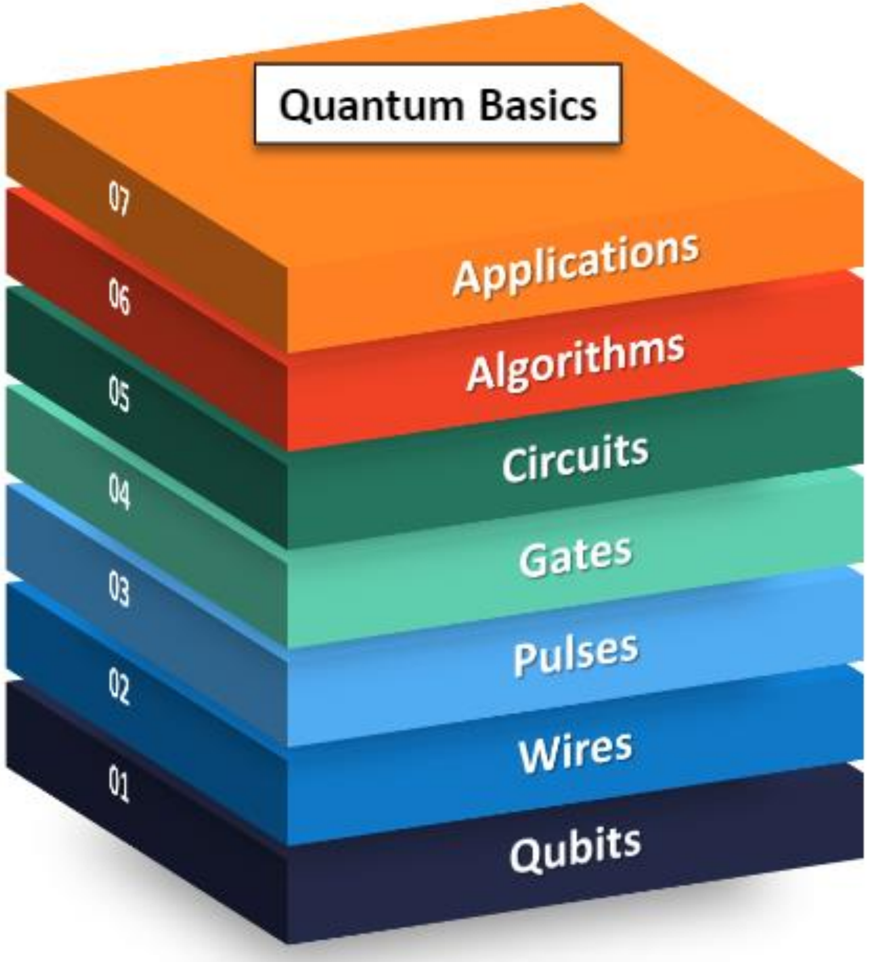
Next

- Basic concepts
- Quantum Hardware
  - Benchmarks
  - Comparisons
  - Accessibility
  - Scalability
- Near-term Algorithms
  - Variational Quantum Algorithm (VQA)
  - Quantum Machine Learning (QML)
  - Challenges
- **Intermediate Level Research**
  - Quantum Optimal Control
  - Error Mitigation
  - Resource Reduction
- Resources
  - QC Market
  - Internship
  - Summer School
  - Community

Stack Design





https://www.factbasedinsight.com/quantum-software-outlook-2022

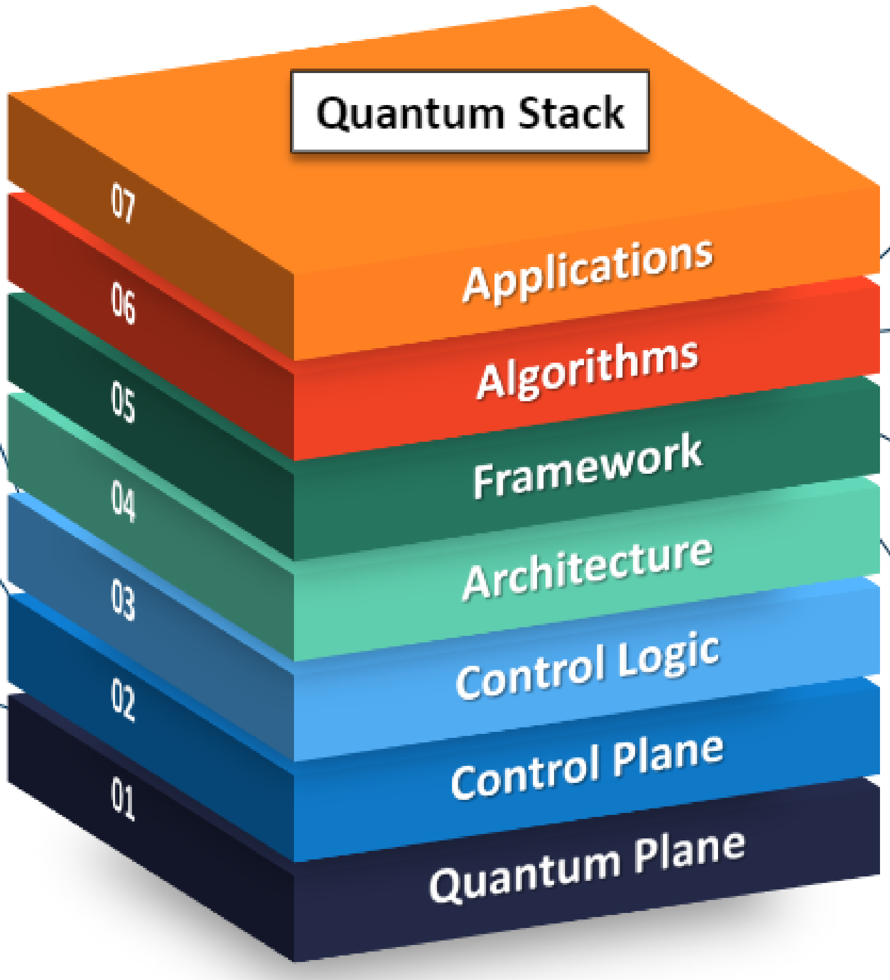
Quantum Stack

CONTROL LOGIC
Pulse & timing calibration
Optimal Control
Decoding

CONTROL PLANE
Crosstalk
Wiring/integration
Heat management

QUANTUM PLANE
Fidelity
Native gates
Connectivity
Interconnects

SIMULATOR
Verification & validation
Performance



APPLICATIONS
Development mgt.
Workflow mgt.

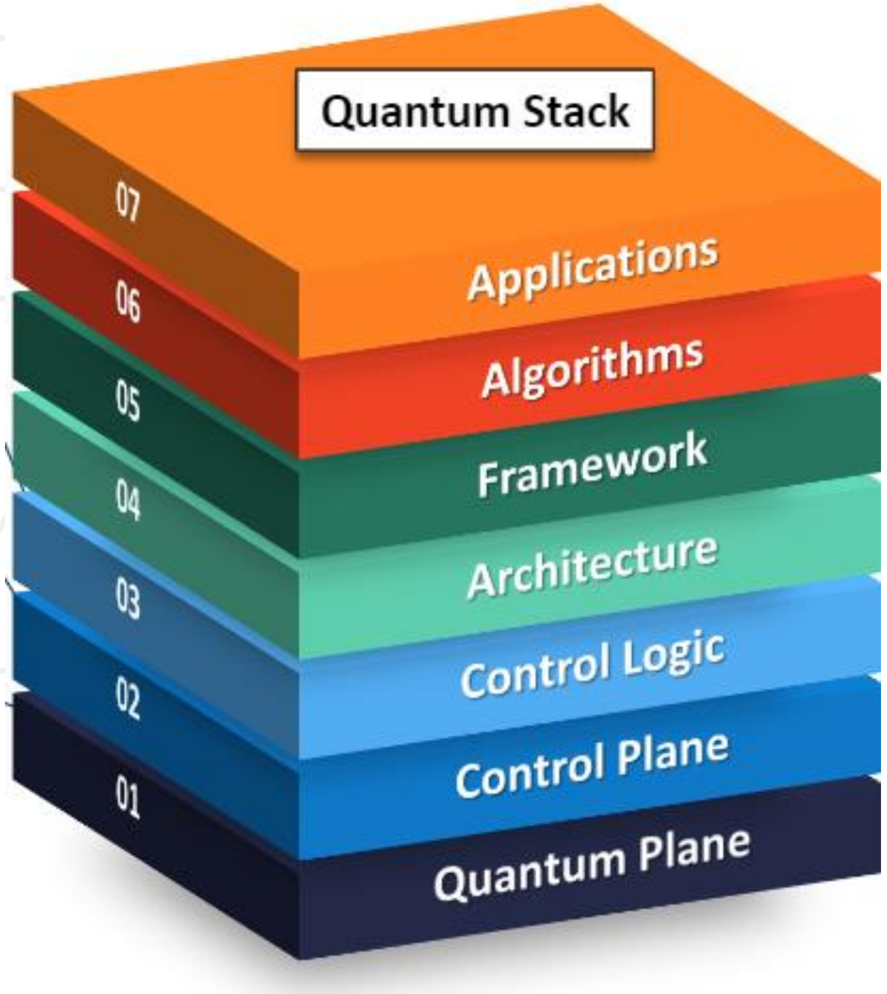
ALGORITHMS
High level languages
Libraries

FRAMEWORK
Circuit model & alternatives
Optimising compilers

ARCHITECTURE
QPU kernel
Quantum error correction
Magic state factories
QRAM

https://www.factbasedinsight.com/quantum-software-outlook-2022

Recap from Prof. Ding's Lecture



Summary - Quantum Engineer's Survival Kit

Gate-Level Error Cancellation:
- Dynamical Decoupling [Viola et. al. Arxiv: 9803057]
- Composite Pulses [Brown et. al. Arxiv: 0407022]

Circuit-Level Optimization:
- Qubit Mapping and Gate Scheduling [Murali et. al. Arxiv: 1901.11054, Wu et. al. Arxiv: 2010.15876]

Pulse-Level Shaping:
- Quantum Optimal Control [Werschnik et. al. Arxiv: 0707.1883]
- Quantum Signal Processing [Low et. al. Arxiv: 1606.02685]

Error Engineering:
- Bias-Preserving Gates [Puri et. al. Arxiv: 1905.00450]
- Randomized Compiling [Wallman et. al. Arxiv: 1512.01098]

Learning-Based:
- Variational Ansatz [Peruzzo et. al. Arxiv: 1304.3061, Gokhale et. al. Arxiv: 1909.07522]
- Parametrized Quantum Circuits [Ravi et. al. Arxiv: 2112.05821, Wang et. al. Arxiv: 2107.10845, 2110.11331]

Data-Processing:
- Zero-Noise Extrapolation [Temme et. al. Arxiv: 1612.02058]
- Probabilistic Error Cancellation [Endo et. al. Arxiv: 1712.09271]

There are many intermediate levels between the algorithm and hardware.

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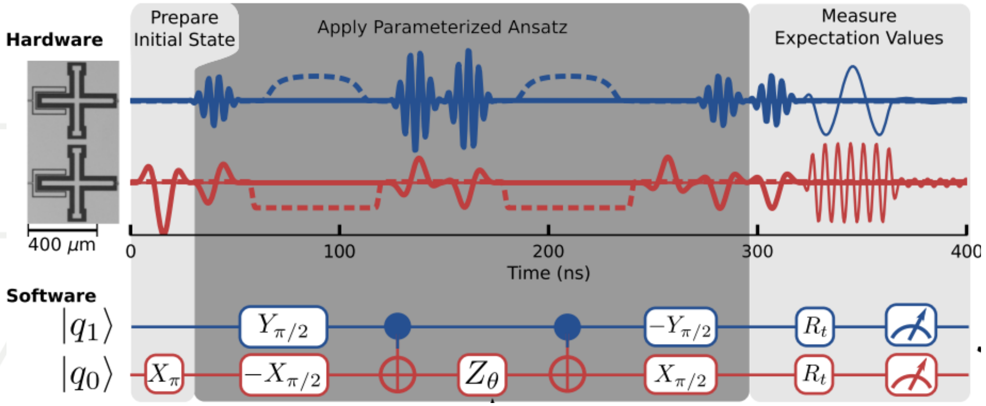
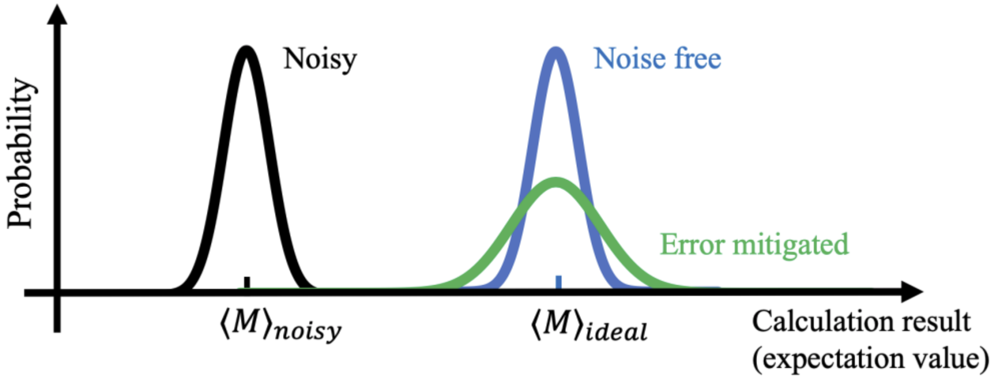
Intermediate Level Research

1. Quantum Optimal Control



2. Error Mitigation:



3. *Resource Reduction:

- Classical Shadows [1]
- CutQC [2]
- Simultaneous Measurement for VQE [3]
- More coming…

There are many research opportunities at these levels to make QC practical.

[1] Huang, Hsin-Yuan, Richard Kueng, and John Preskill. "Predicting many properties of a quantum system from very few measurements." *Nature Physics* 16.10 (2020): 1050-1057.
[2] Tang, Wei, et al. "Cutqc: using small quantum computers for large quantum circuit evaluations." *Proceedings of the 26th ACM International conference on architectural support for programming languages and operating systems*. 2021.
[3] Gokhale, Pranav, et al. "Optimization of simultaneous measurement for variational quantum eigensolver applications." *2020 IEEE International Conference on Quantum Computing and Engineering (QCE)*. IEEE, 2020.

Where are we going?

- There is a clear tendency to start from NISQ devices and demonstrate a certain level of error correction.
- New error correction codes more suitable for Ion Traps.
- More computer scientists and engineers join the game and work together on various levels of the quantum stack.
- Still looking for killer apps to demonstrate a quantum advantage in industry problems.

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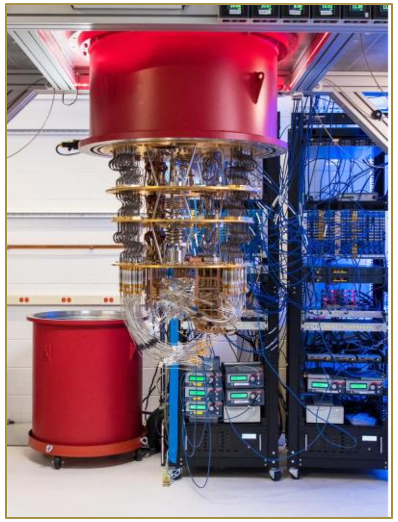
Long-term Vision

- We will probably not see personal quantum computers even in the fault-tolerant era.
- Those quantum computers are more likely to sit around some supercomputers and form a hybrid computing center.
- Most users will access them through some cloud environments which is similar to how we use supercomputers nowadays.

+



Outline

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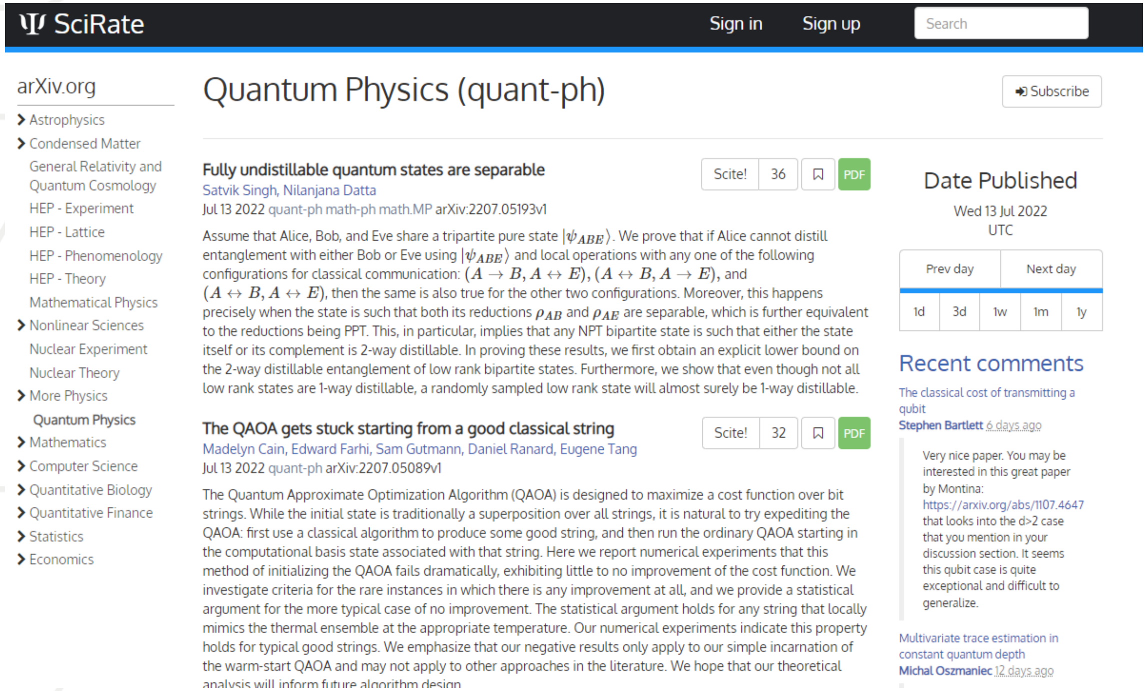
Daily Input

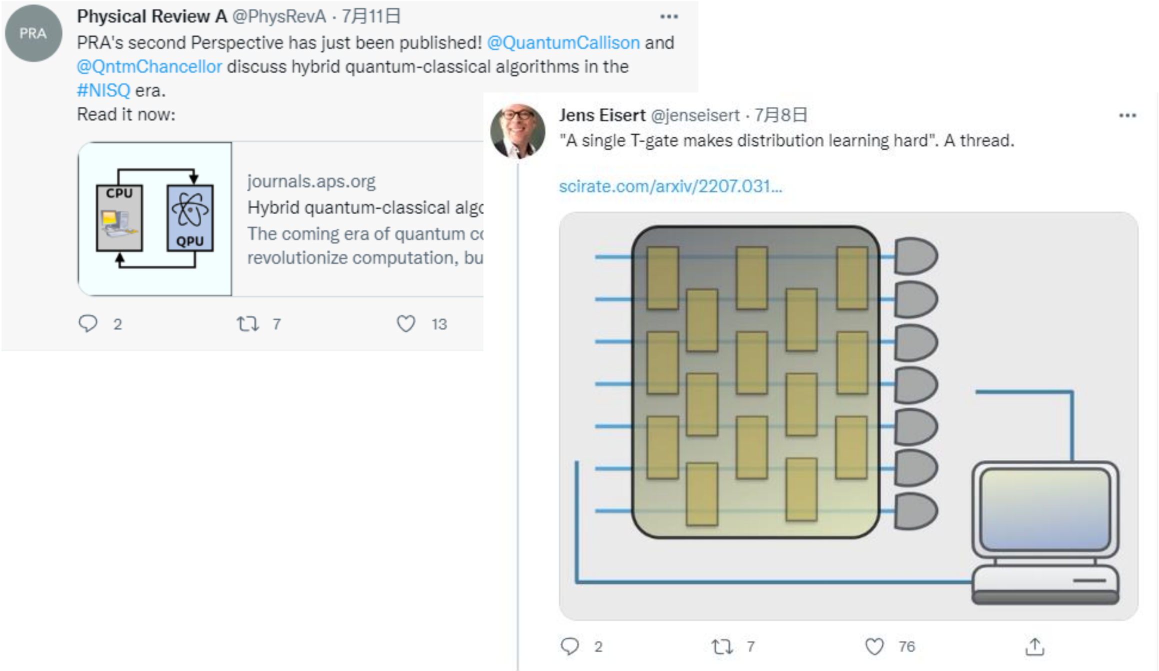
Scirate:

A more selective arXiv.



Twitter:

Many researchers use Twitter to post their opinions on recent progress and advertise their work.



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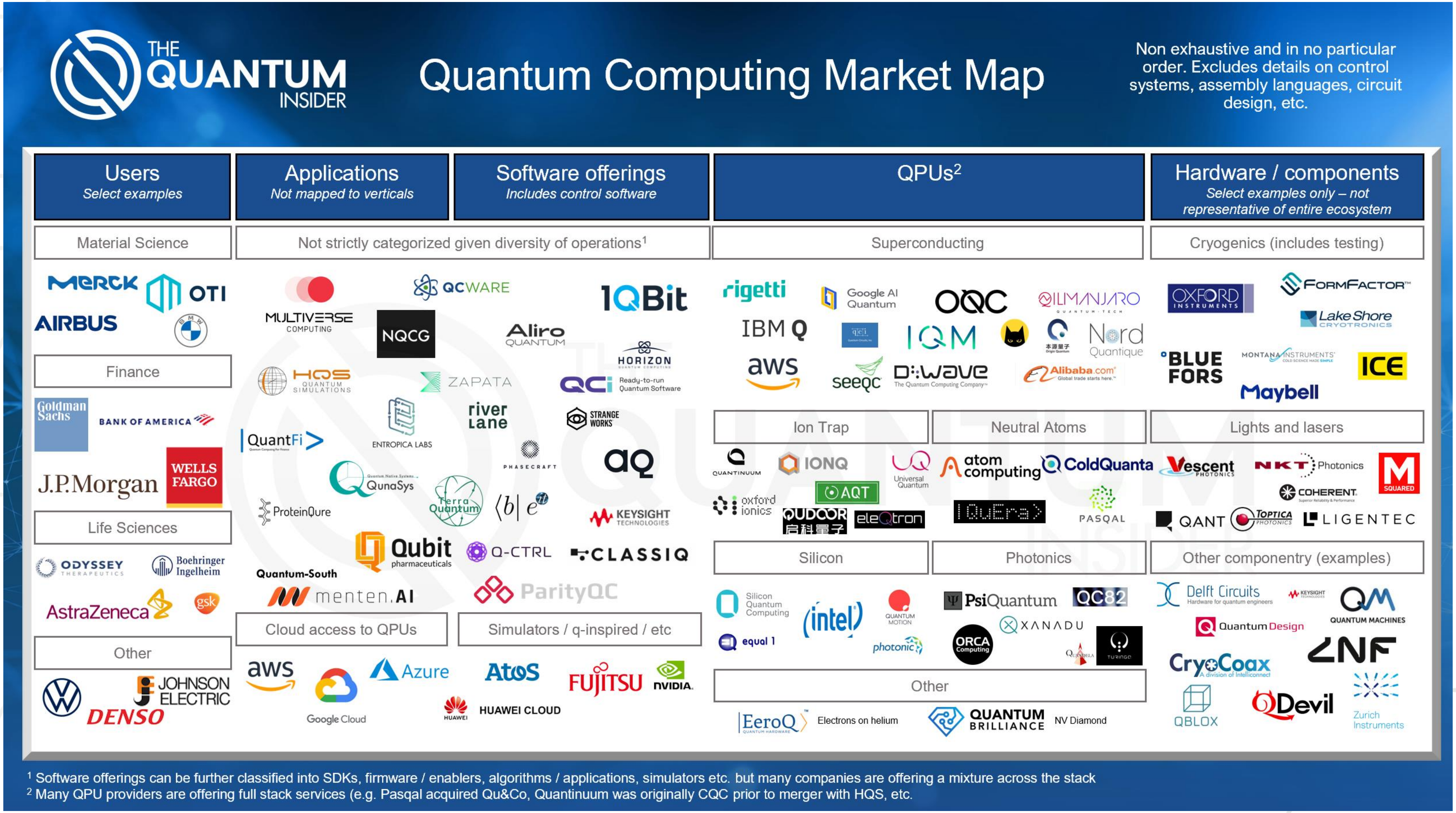
QC Market

https://thequantuminsider.com/2022/05/09/quantum-computing-market-map-and-data-2022/



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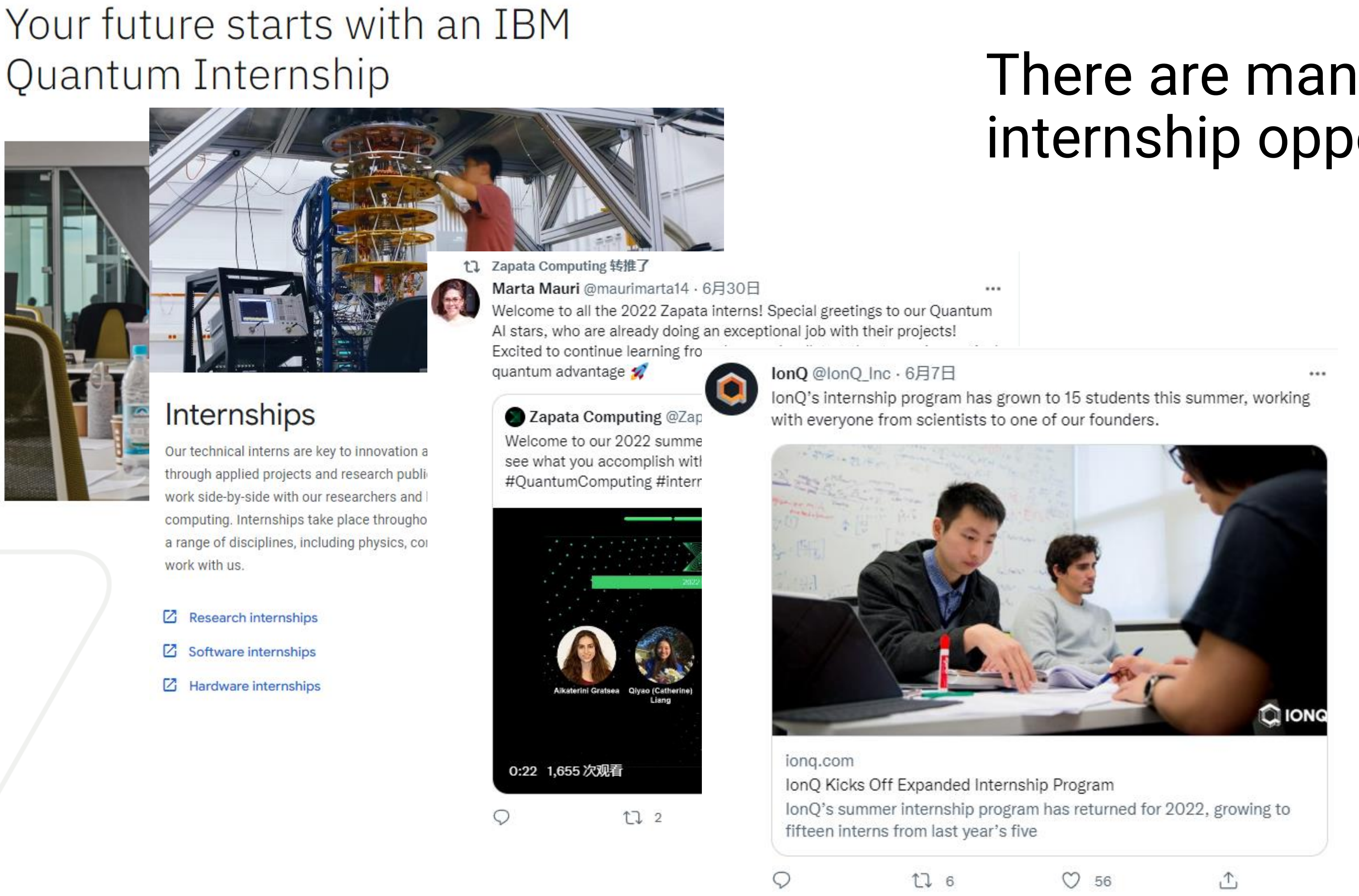
Internships



There are many industry internship opportunities!!

Summer School

Quantum Computing Summer School Fellowship

Developing new leaders in the theory, application, and programming of quantum computers

CONTACTS

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Program Co-Lead
Marco Cerezo
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Advisor
Candace Culhane
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Summary of Program

The Quantum Computing Summer School is an immersive 10-week curriculum that includes tutorials from world-leading experts in quantum computation as well as one-on-one mentoring from LANL staff scientists who are conducting cutting-edge quantum computing research. Summer school fellowship recipients will be exposed to the theoretical foundations of quantum computation and will become skilled at programming commercial quantum computers, such as those developed by D-Wave Systems, Rigetti, and IBM. Roughly twenty students (with the precise number determined based on the applicant pool) will be awarded a fellowship from LANL for the summer school. The fellowship value ranges from $7,500 to $13,000, based on academic rank (junior, senior, 1st year graduate student, etc.).

Applications for 2022 are open until January 17th, 2022.

Highlights from 2021 School

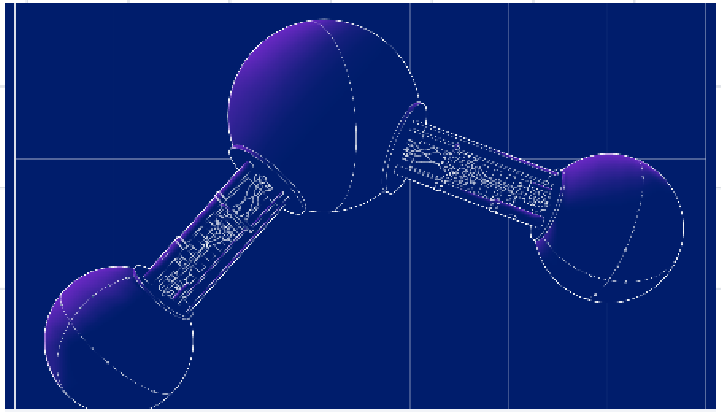
Invited speakers: Tameem Albash (University of New Mexico), Andrew Childs (University of Maryland), Elizabeth Crosson (University of New Mexico), Jens Eisert (Free University of Berlin), David Gosset (University of Waterloo), Shelby Kimmel (Middlebury College), Raymond Laflamme (Institute for Quantum Computing), Pavel Lougovski (Amazon Web Services), Mohan Sarovar (Sandia), Kristan Temme (IBM)

QUANTUM COMPUTING

How to Apply

LANL Summer School
(research-focused)

About the event:



Qiskit Global Summer School 2022: Quantum Simulations

The Qiskit Global Summer School returns as a two-week intensive course focused on Quantum Simulations and more!

Online

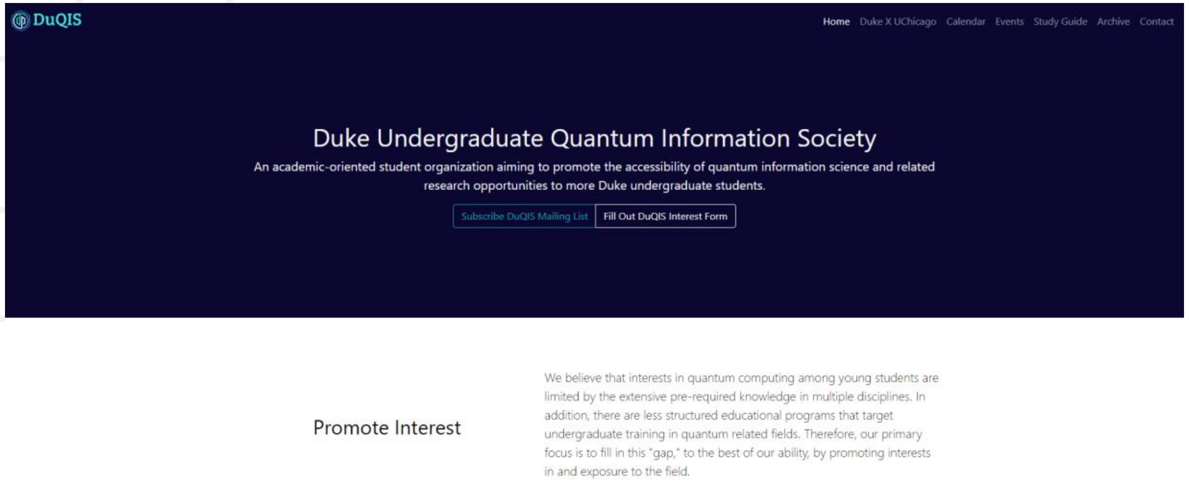
July 18 - 29, 2022

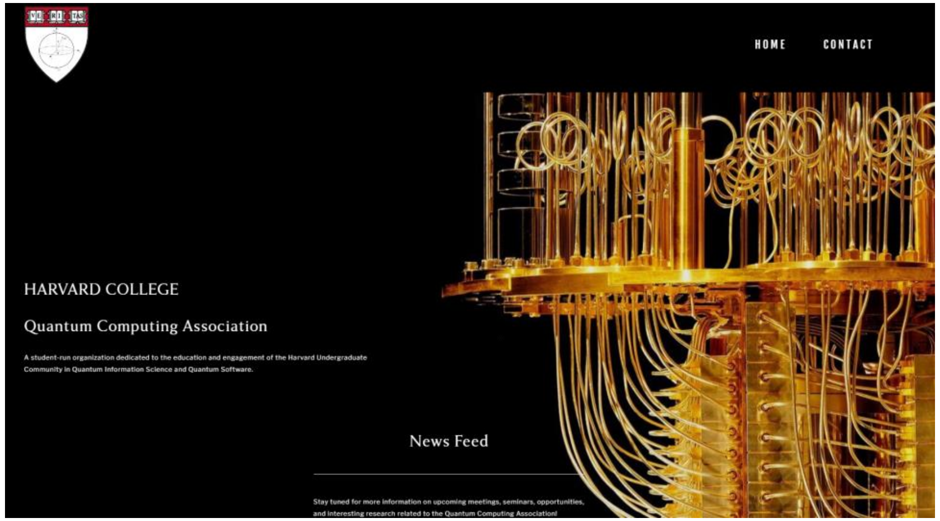
Learn more

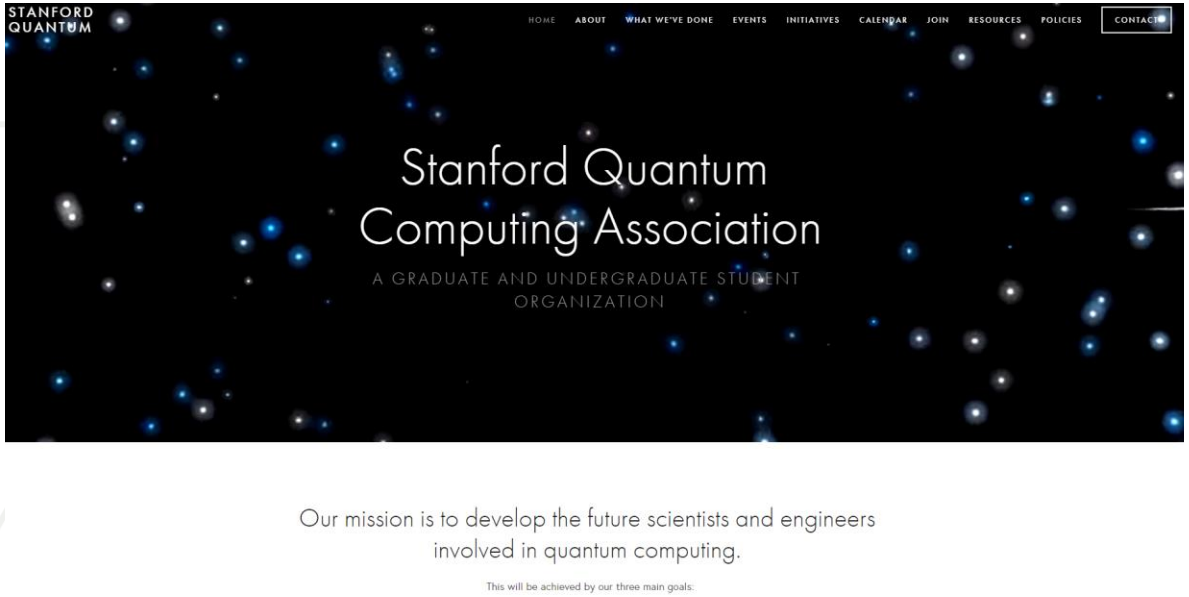
Qiskit Global Summer School
(course-focused)

Community

Join the quantum computing association in your school or build one!







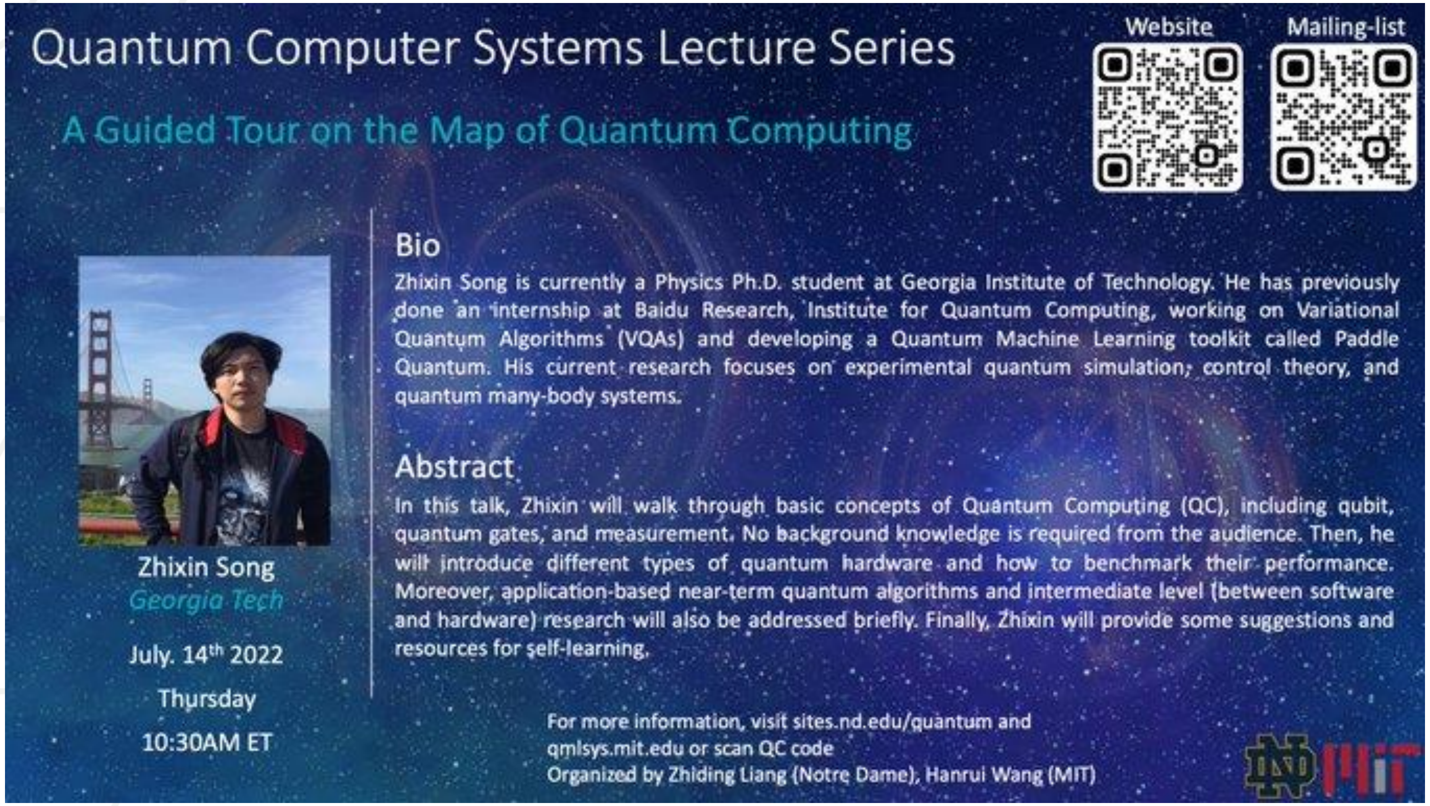
QUANTUM COMPUTING ASSOCIATION EPFL

Welcome to the Quantum Computing Association! Your journey through quantum starts right here with us!

Suggestions

- Qiskit Textbook is a very good resource for coding-based learning.
- Check tutorials from other platforms (Paddle Quantum, PennyLane)
- Attend some Quantum Challenges or Hackathons
- Implement your own QC software stack if possible
- Build a QC learning community around you and keep yourself updated on the latest research

Thank you! Q&A



See u next week!

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