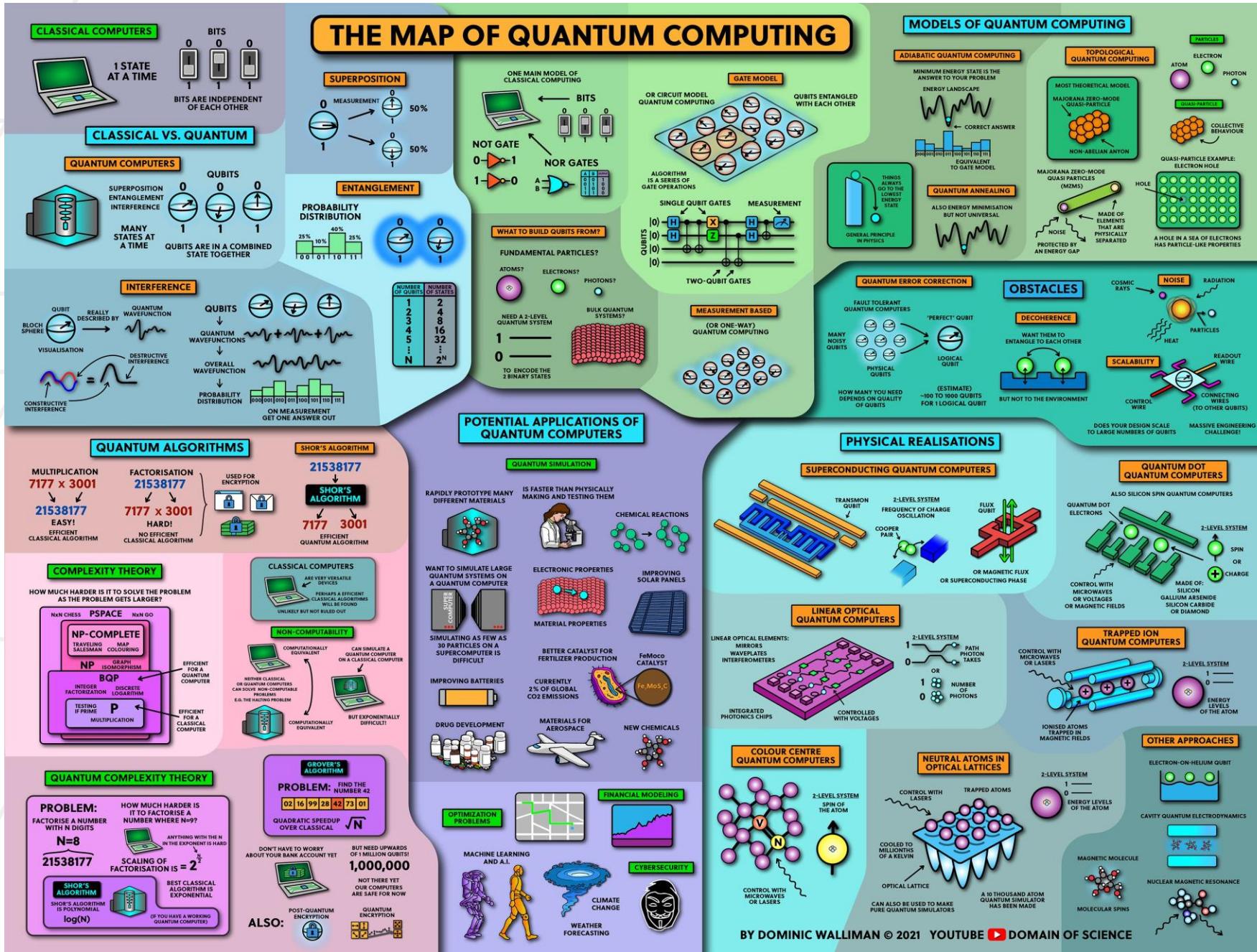


# A Guided Tour on the Map of Quantum Computing

ND-MIT Lecture Series  
Zhixin Song  
07/14/2022

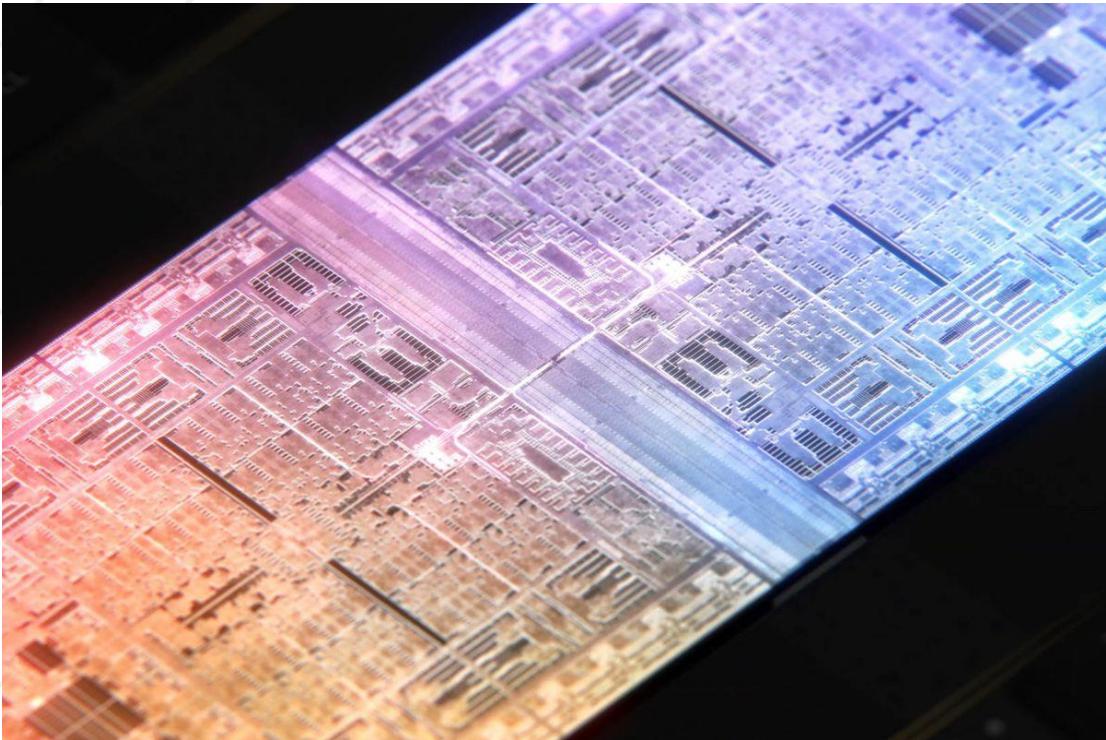




# Outline

- 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?

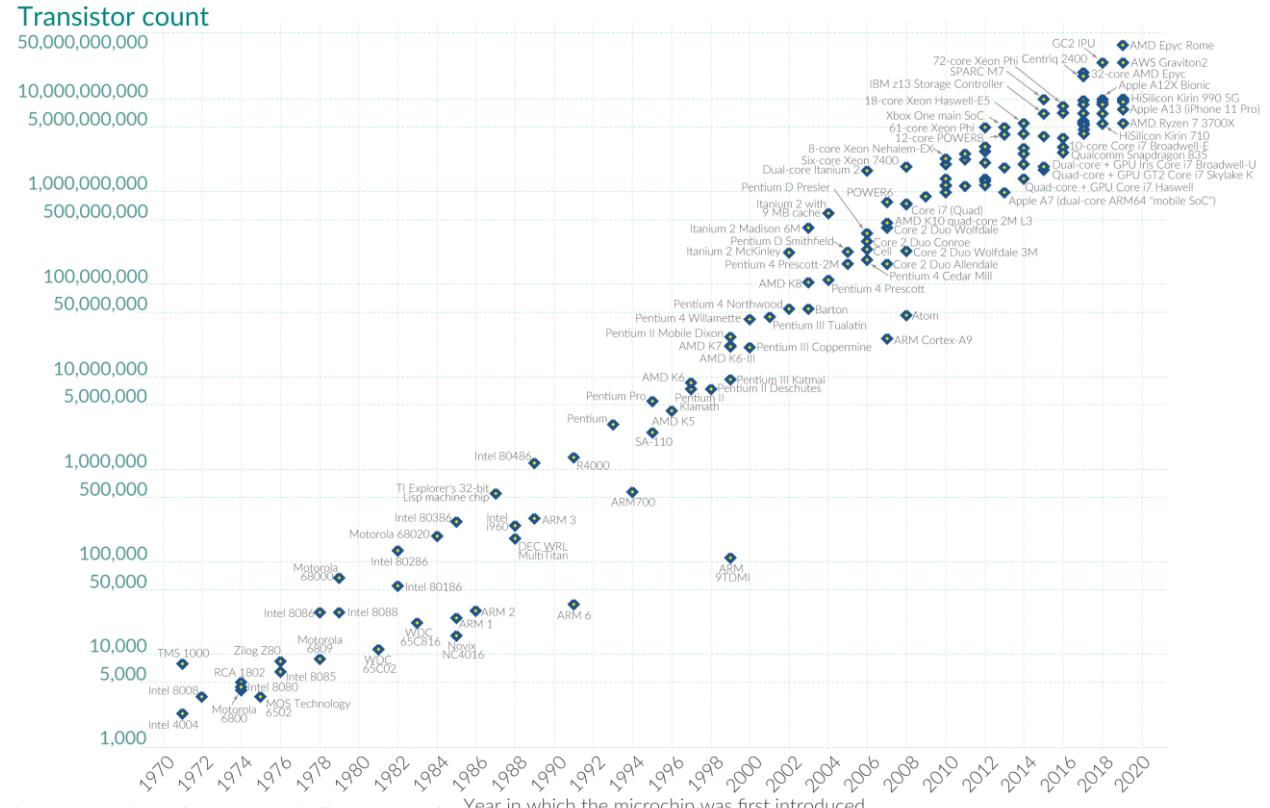


Apple's 5nm process M1 Ultra chip contains 114 billion transistors [1]. As the size of transistors gradually shrinks to a few atoms, it will no longer be a reliable bit due to quantum tunneling.

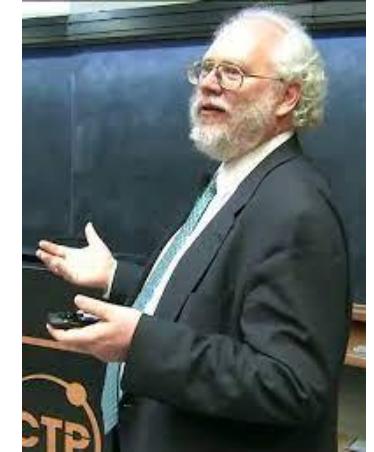
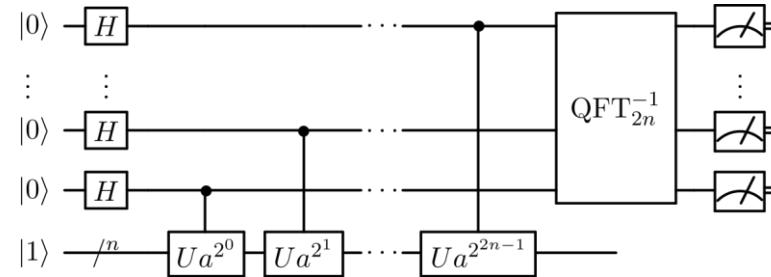
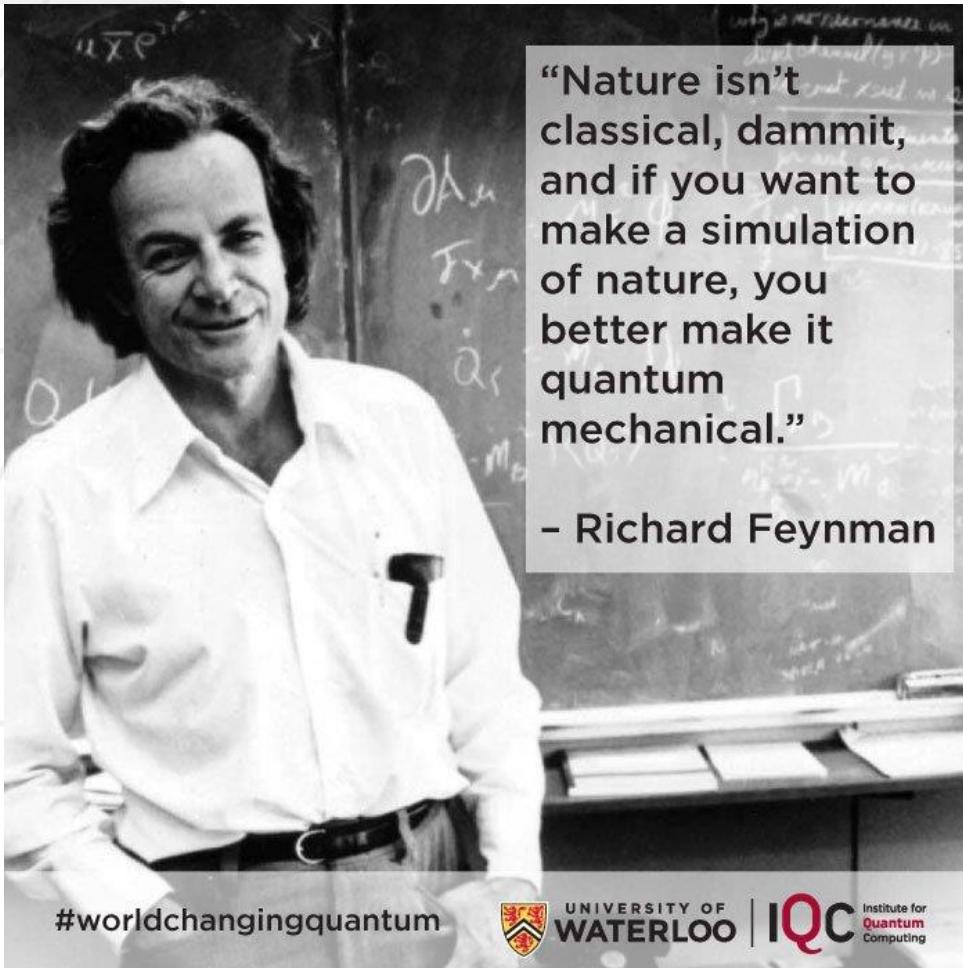
## Moore's Law: The number of transistors on microchips doubles every two years

Moore's law describes the empirical regularity that the number of transistors on integrated circuits doubles approximately every two years. This advancement is important for other aspects of technological progress in computing – such as processing speed or the price of computers.

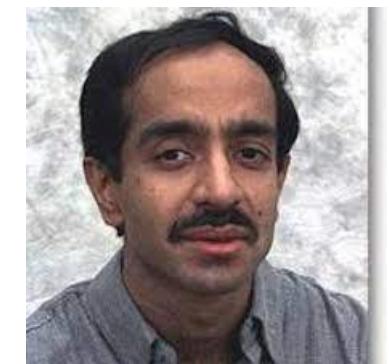
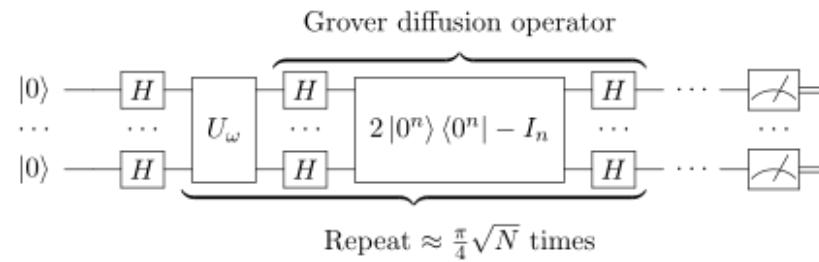
Our World  
in Data



# Why Quantum Computing?



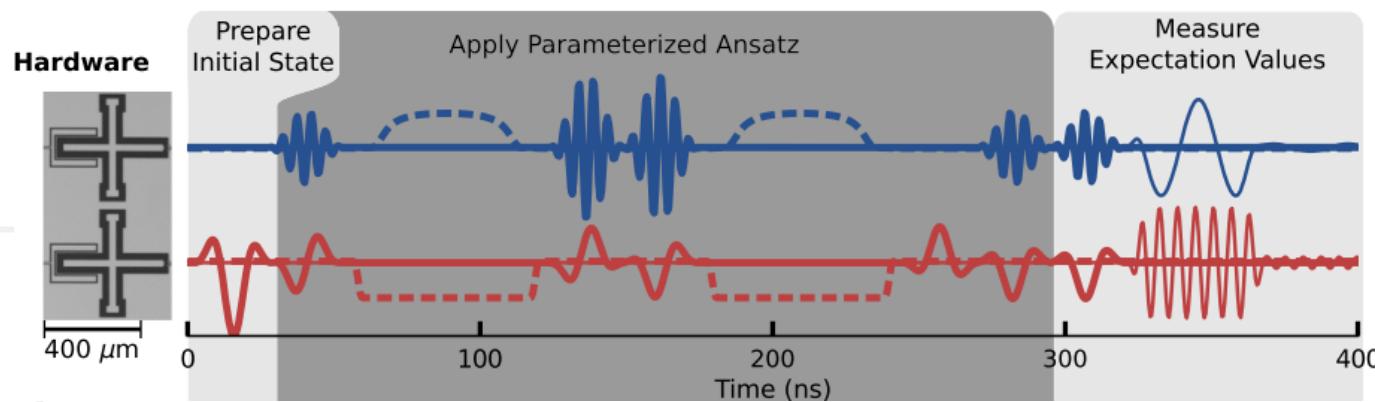
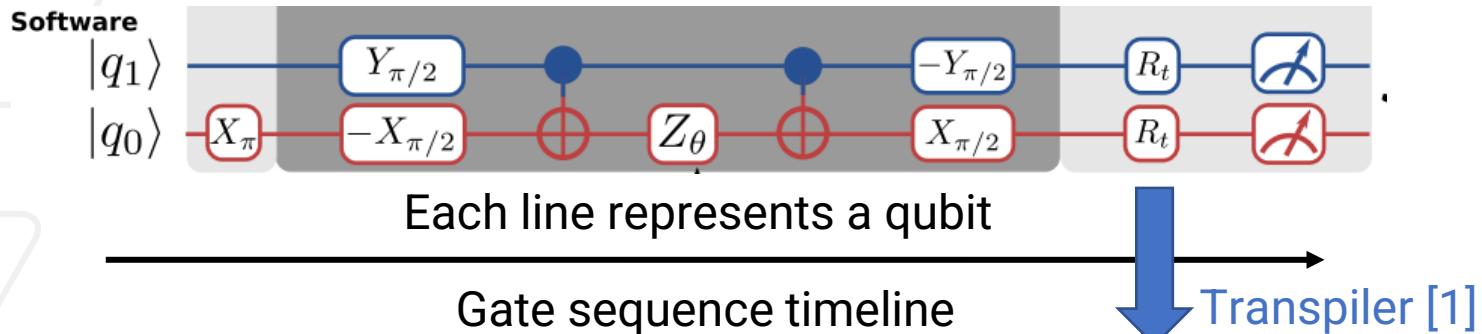
Shor’s Algorithm (1994) for integer factorization gives an exponential speedup.



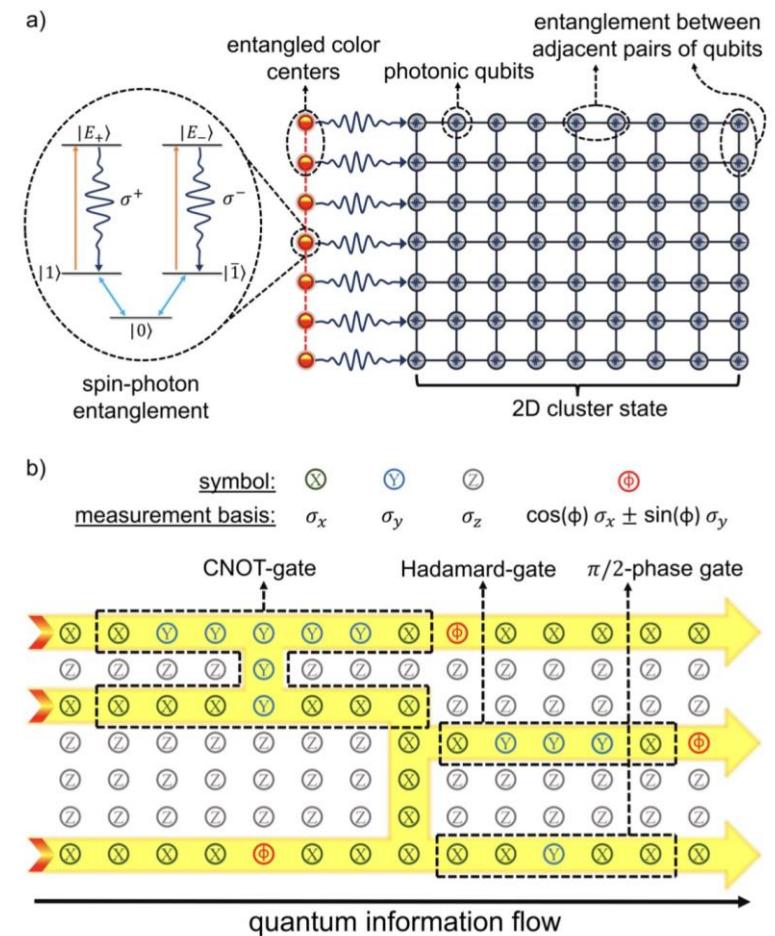
Grover’s Algorithm (1996) for unstructured search gives a quadratic speedup.

# What is a quantum algorithm?

## \*Quantum Circuit Model

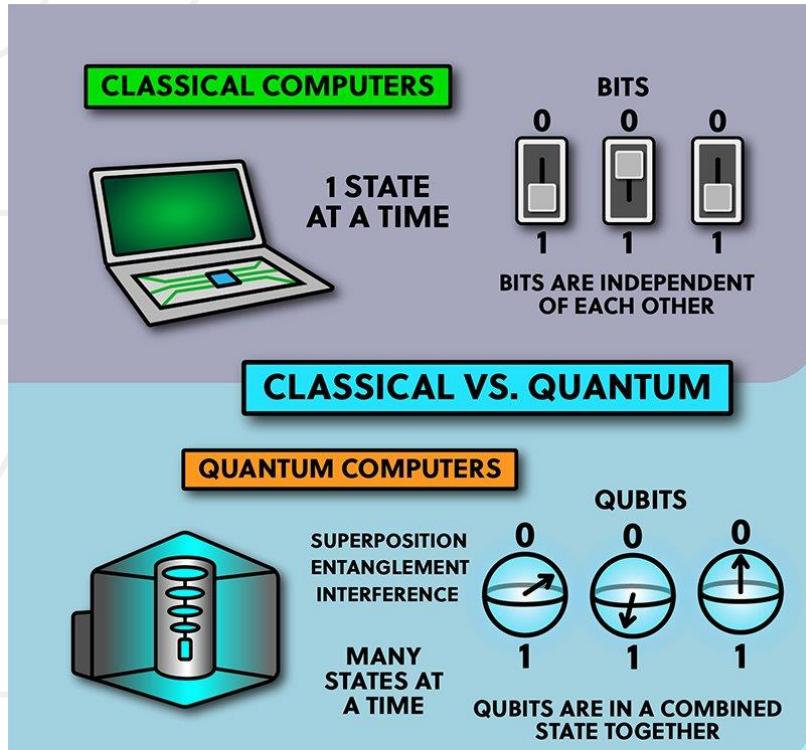


## Measurement-Based Quantum Computing (MBQC) [2]



- [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.

# Qubit (Data)



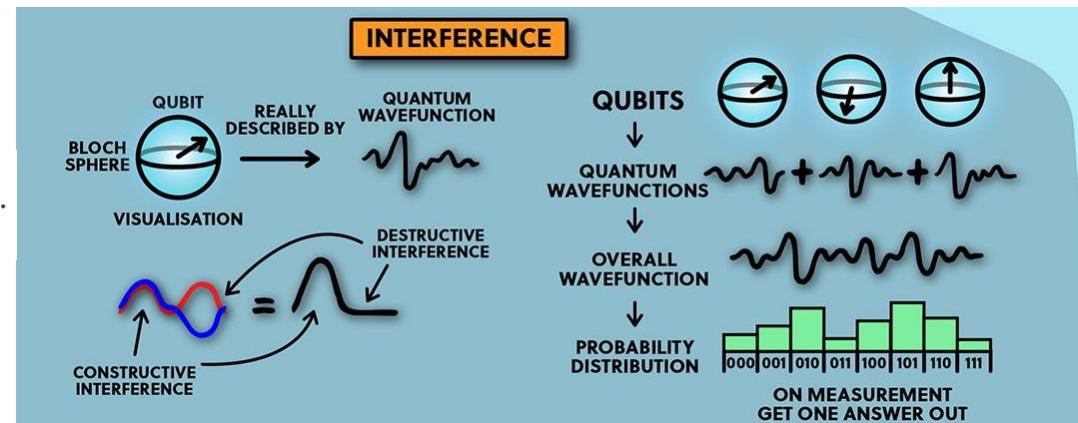
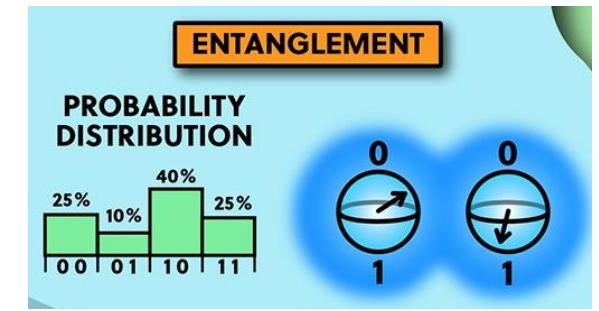
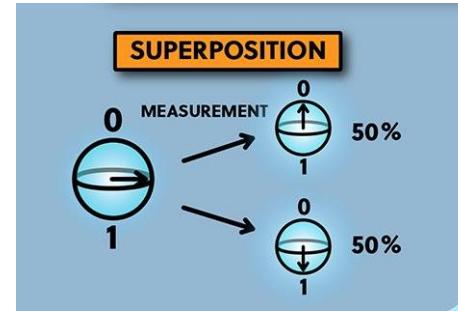
$$|0\rangle := \begin{bmatrix} 1 \\ 0 \end{bmatrix}, \quad |1\rangle := \begin{bmatrix} 0 \\ 1 \end{bmatrix}.$$



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



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



# 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

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

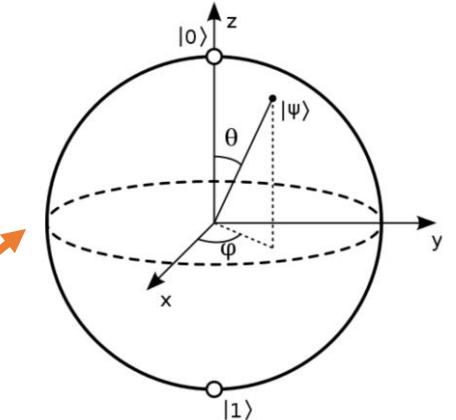
Then, we can introduce a 2-qubit CNOT gate for entanglement

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

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

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

Single qubit rotation around x,y,z axis



They form a universal gate set!

# Quantum Gates (Unitary Operations)

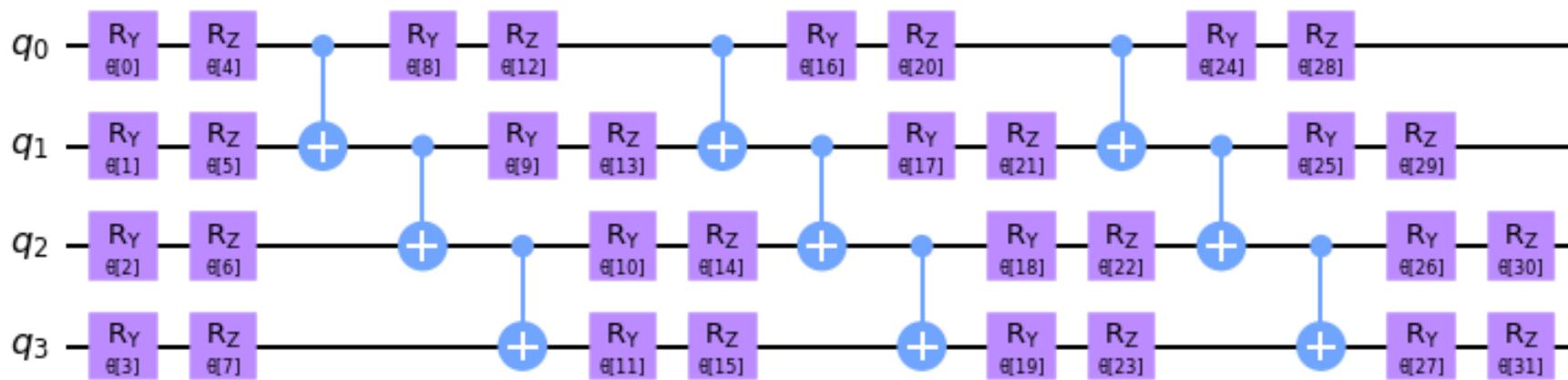
Another case is when we have an idle qubit

$$|\psi\rangle \left\{ \begin{array}{l} \text{---} \boxed{H} \text{---} \\ | \qquad \qquad | \\ \text{---} \boxed{I} \text{---} \end{array} = \begin{array}{l} \text{---} \boxed{H} \text{---} \\ | \qquad \qquad | \\ \text{---} \boxed{I} \text{---} \end{array} = \begin{array}{l} \text{---} \boxed{H \otimes I} \text{---} \end{array} \right\} (H \otimes I)|\psi\rangle$$

Then, the corresponding unitary matrix should be written as

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

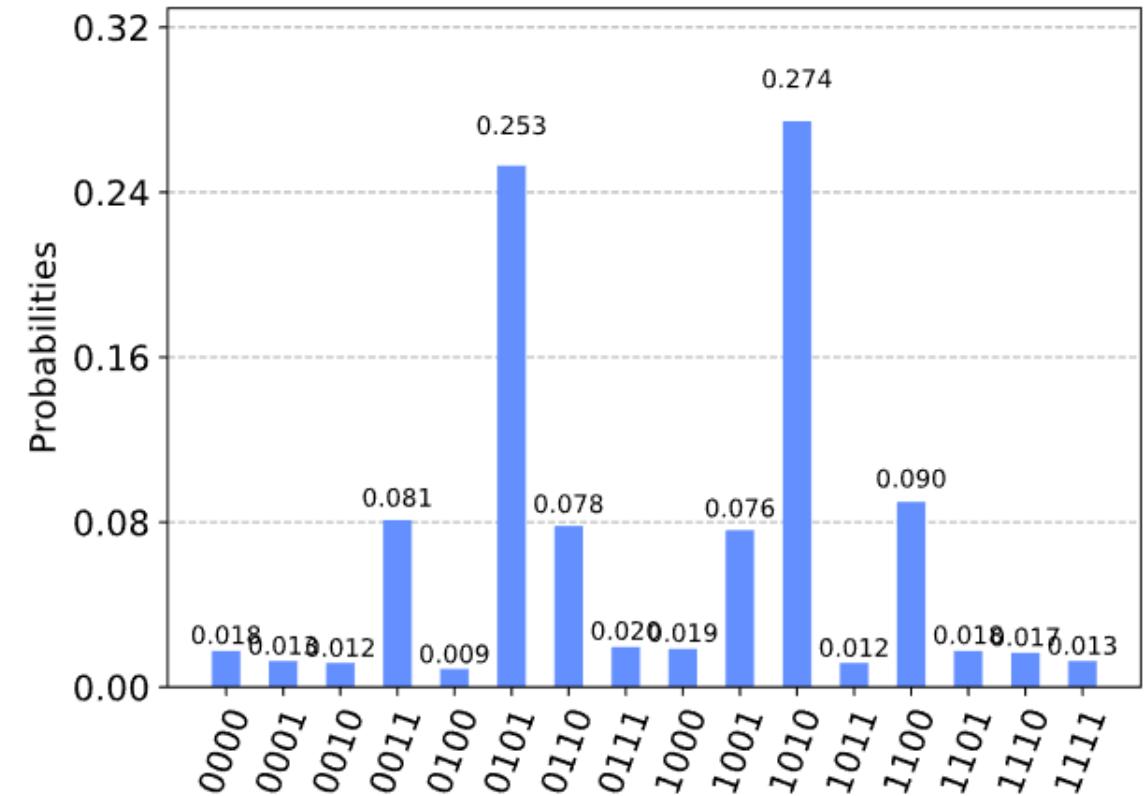
Let's look at a more useful quantum circuit, where all the single qubit rotation parameters  $\theta_j$  forms a vector. We call such an Ansatz a Parametrized Quantum Circuit (PQC)  $U(\theta)$



\*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.



# 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

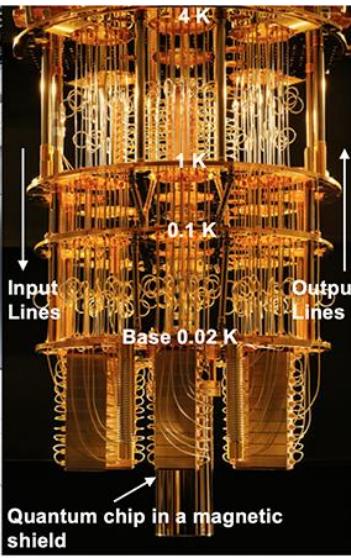
# Next

- Basic concepts
- **Quantum Hardware**
  - Benchmarks
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# Quantum Hardware



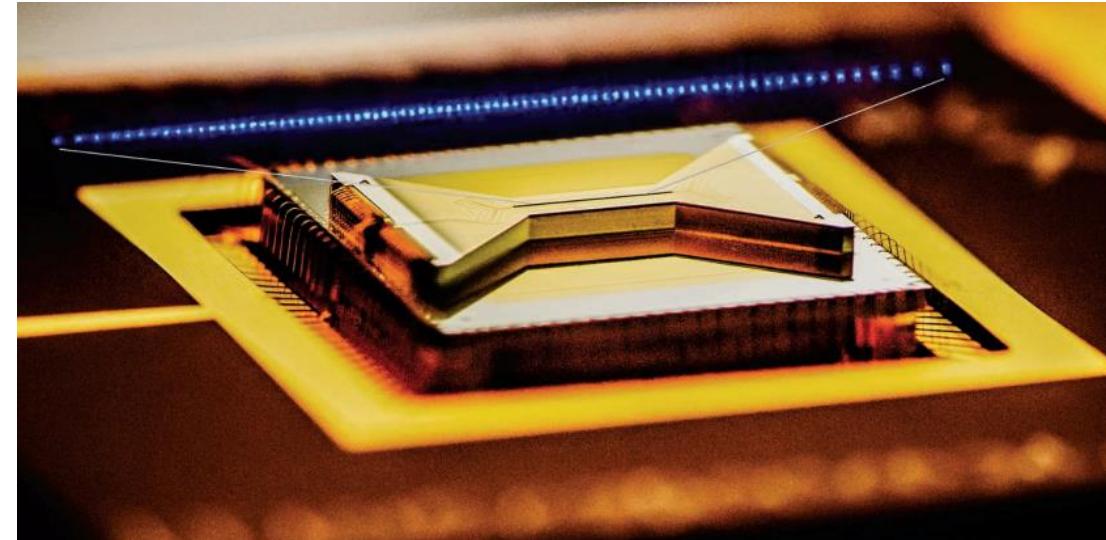
Dilution fridge setup: outside view



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.](#)

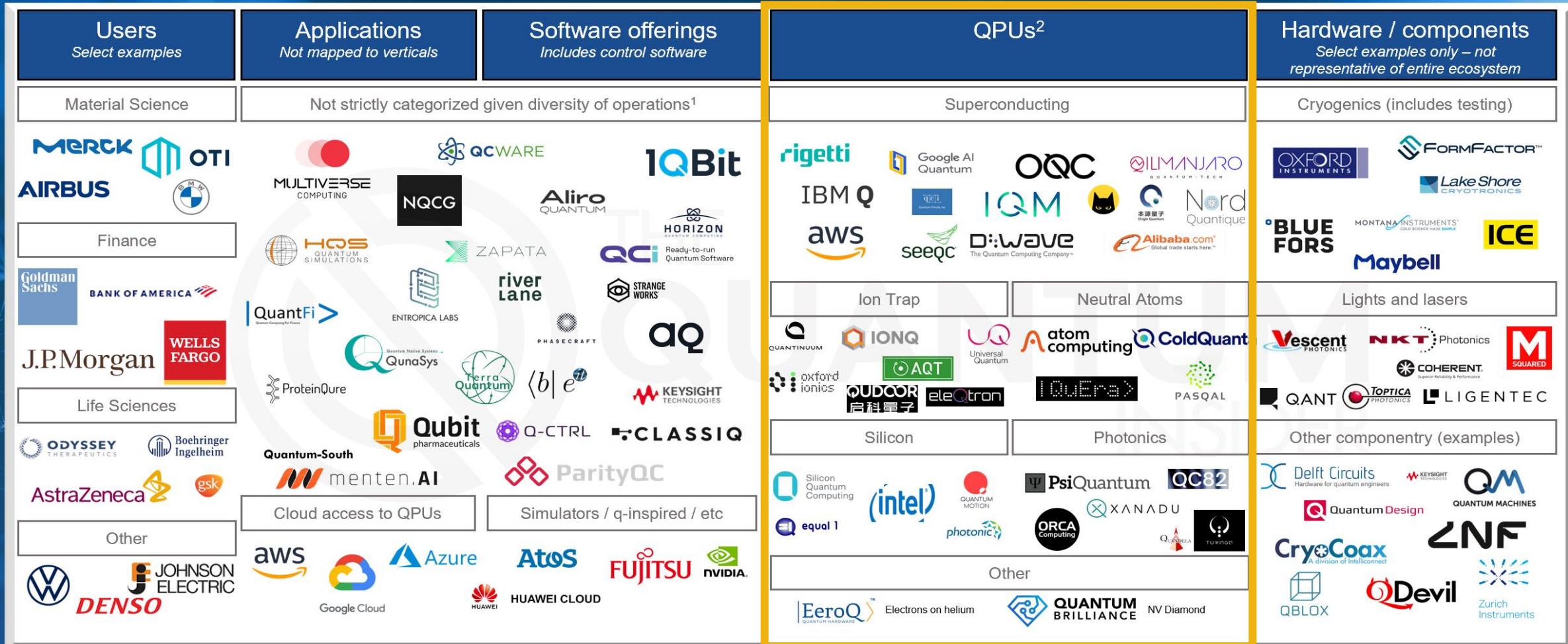
[1] <https://www.ibm.com/blogs/research/2020/01/quantum-limited-amplifiers/>

[2] Monroe, Christopher, Michael G. Raymer, and Jacob Taylor. "The US national quantum initiative: From act to action." *Science* 364.6439 (2019): 440-442.



# Quantum Computing Market Map

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



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

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

# 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

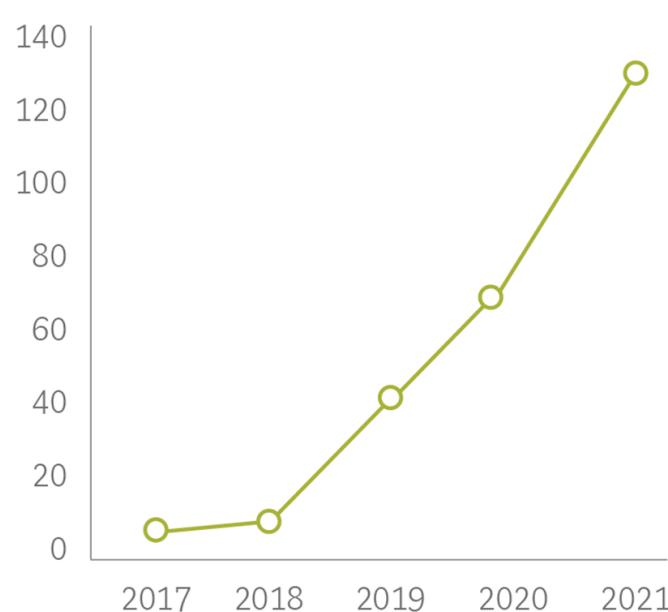


## Speed | Circuit Layer Ops per Second

Number of circuits that can run on hardware in a given time

IBM system performance over time

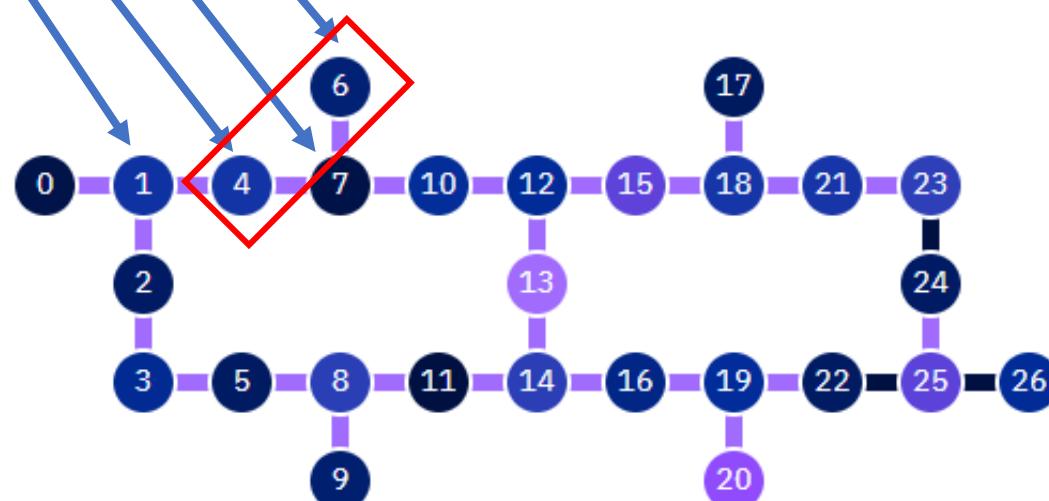
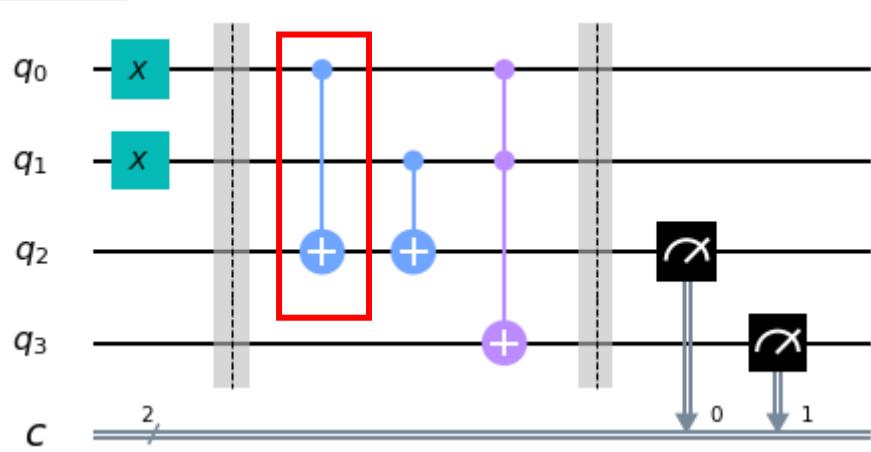
Quantum volume



# Comparison

	Superconductors	Ion traps	Photonics	Quantum dots	Cold atoms	
% of potential users who consider technology "promising"	61%	35%	34%	26%	16%	
Qubit quality <sup>1</sup>	<i>Qubit lifetime</i>	~1 ms	~50+ s	N/A	~1-10 s	~1 s
	<i>Gate fidelity</i>	~99.6%	~99.9%	~99.9%	~99%	~99%
	<i>Gate operation time</i>	~10-50 ns	~1-50 µs	~1 ns	~1-10 ns	~100 ns
Connectivity	Nearest neighbors	All-to-all	All-to-all <sup>2</sup>	Nearest neighbors	Near neighbors	
Strengths	<ul style="list-style-type: none"> <li>✓ Engineering maturity</li> <li>✓ Scalability<sup>3</sup></li> </ul>	<ul style="list-style-type: none"> <li>✓ Stability</li> <li>✓ Gate fidelity</li> <li>✓ Connectivity</li> </ul>	<ul style="list-style-type: none"> <li>✓ Horizontal scalability</li> <li>✓ Established semiconductor tech</li> </ul>	<ul style="list-style-type: none"> <li>✓ Stability</li> <li>✓ Established semiconductor tech</li> </ul>	<ul style="list-style-type: none"> <li>✓ Horizontal scalability</li> <li>✓ Connectivity</li> </ul>	
Challenges	<ul style="list-style-type: none"> <li>✗ Near absolute zero temperatures</li> <li>✗ Connectivity limitation in 2D</li> </ul>	<ul style="list-style-type: none"> <li>✗ Gate operation times</li> <li>✗ Horizontal scaling beyond one trap</li> </ul>	<ul style="list-style-type: none"> <li>✗ Noise from photon loss</li> </ul>	<ul style="list-style-type: none"> <li>✗ Requires cryogenics</li> <li>✗ Nascent engineering</li> </ul>	<ul style="list-style-type: none"> <li>✗ Gate fidelity</li> <li>✗ Gate operation time</li> </ul>	
Example players	IBM, Google	Honeywell, IonQ	PsiQuantum, Xanadu	Intel, SQC	ColdQuanta, Pasqal	

# Connectivity and Qubit Mapping

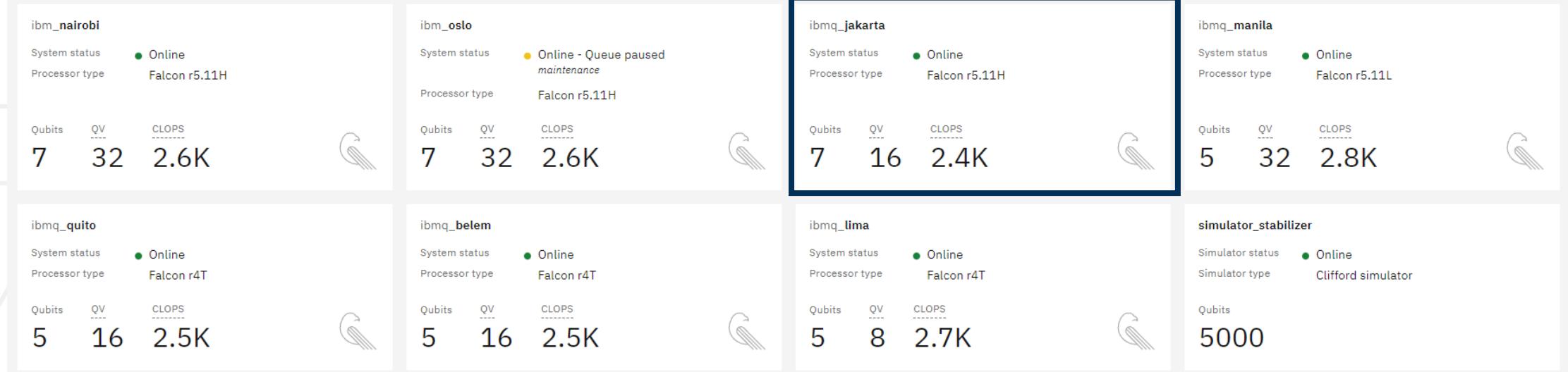


**Qubit Mapping Problem [1]:**  
But they are not directly connected with each other!

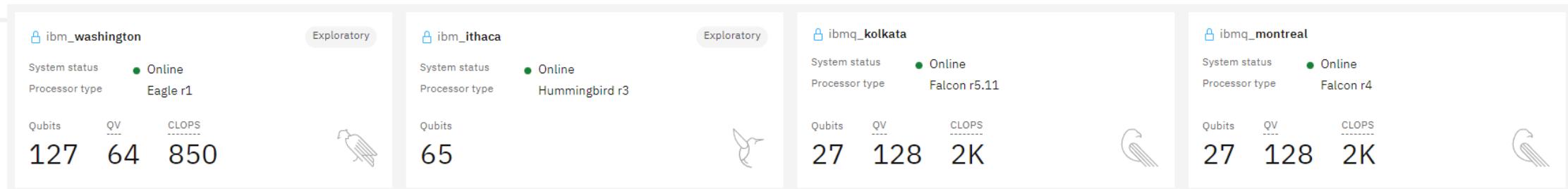
[1] Li, Gushu, Yufei Ding, and Yuan Xie. "Tackling the Qubit Mapping Problem for NISQ-Era Quantum Devices. arXiv." *arXiv preprint arXiv:1809.02573* (2018).

# Accessibility: IBM Quantum

Open Plan:



Paid Plan:



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

# Accessibility: Amazon Braket

Quantum Processing Units (QPUs)

Hide retired devices

QPU Type	Description	Qubits	Status	Region	Next available
D-Wave — Advantage_system6.1	Quantum Annealer based on superconducting qubits	5760	ONLINE	us-west-2	AVAILABLE NOW
D-Wave — Advantage_system4.1	Quantum Annealer based on superconducting qubits	5760	ONLINE	us-west-2	AVAILABLE NOW
D-Wave — DW_2000Q_6	Quantum Annealer based on superconducting qubits	2048	ONLINE	us-west-2	AVAILABLE NOW
IonQ	Universal gate-model QPU based on trapped ions	11	ONLINE	us-east-1	AVAILABLE NOW
Oxford Quantum Circuits — Lucy	Universal gate-model QPU based on superconducting qubits	8	ONLINE	eu-west-2	11:59:45
Rigetti — Aspen-11	Universal gate-model QPU based on superconducting qubits	38	ONLINE	us-west-1	17:59:45
Rigetti — Aspen-M-1	Universal gate-model QPU based on superconducting qubits	80	OFFLINE	us-west-1	UNAVAILABLE
Xanadu — Borealis	Gaussian Boson Sampling on a programmable photonic processor	216	ONLINE	us-east-1	17:59:45

All Paid Plans:

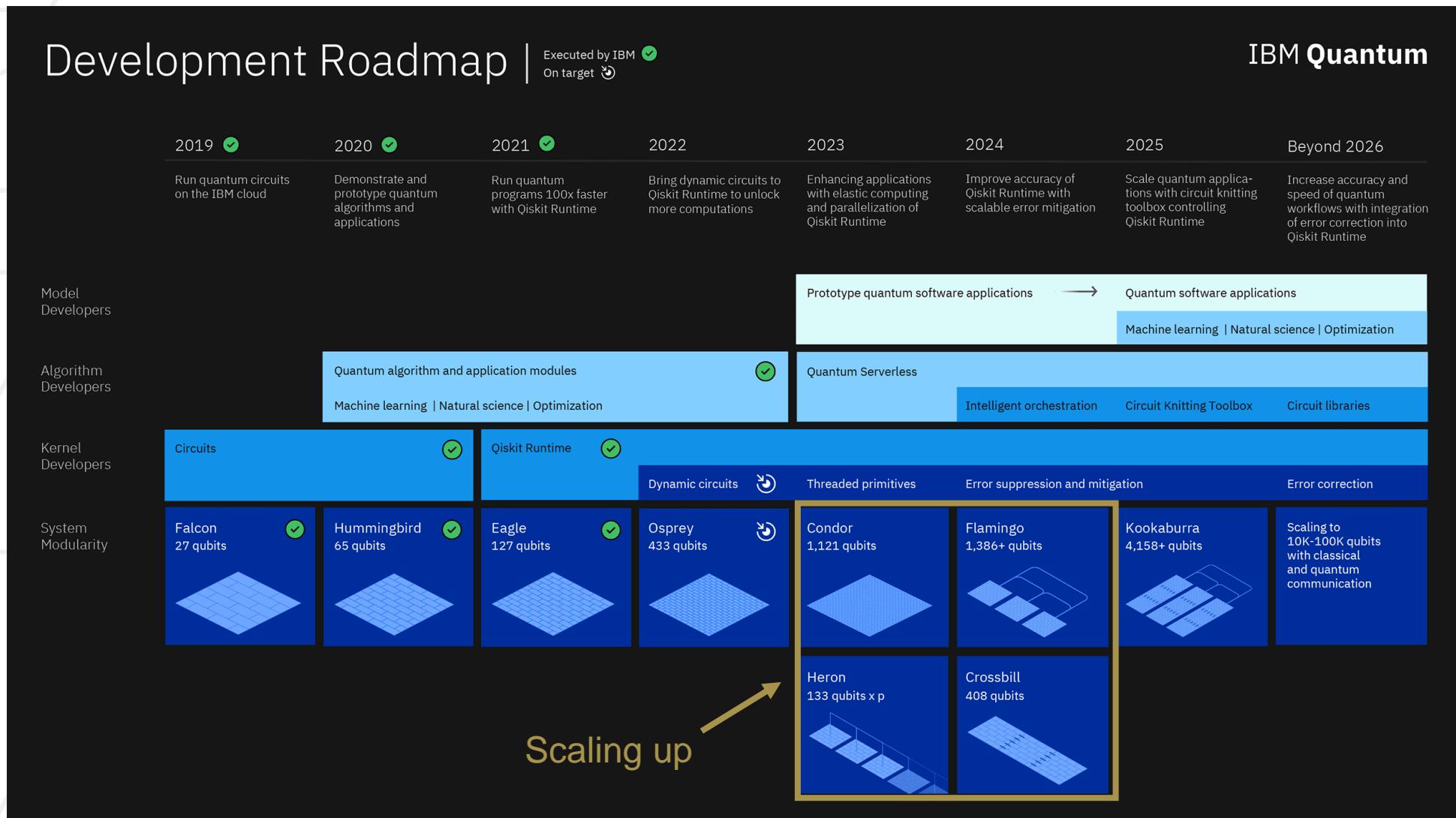
IonQ  
\$0.30 / task +  
\$0.01 / shot

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

Rigetti  
\$0.30 / task +  
\$0.00035 / shot

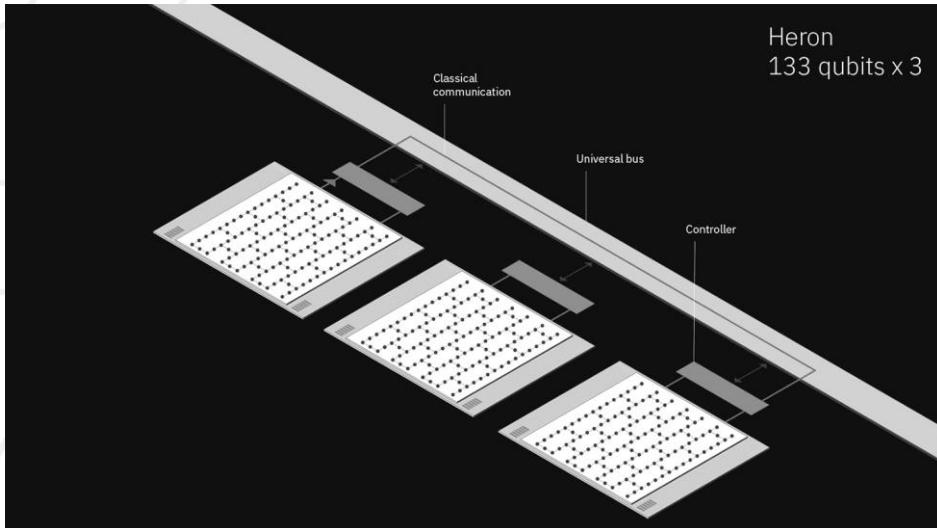
First cloud-accessible  
quantum processor  
demonstrated a quantum  
advantage recently

# IBM Quantum Roadmap 2022



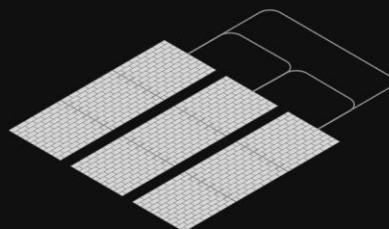
# An illustration of scalability

## 1. Classical parallelization



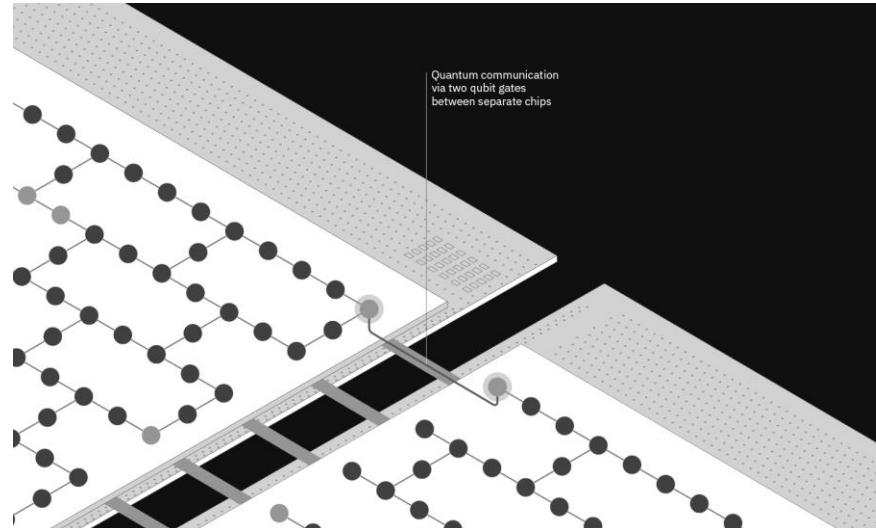
2025  
Quantum parallelization of  
multi-chip quantum processors

Kookaburra  
4,158+ qubits

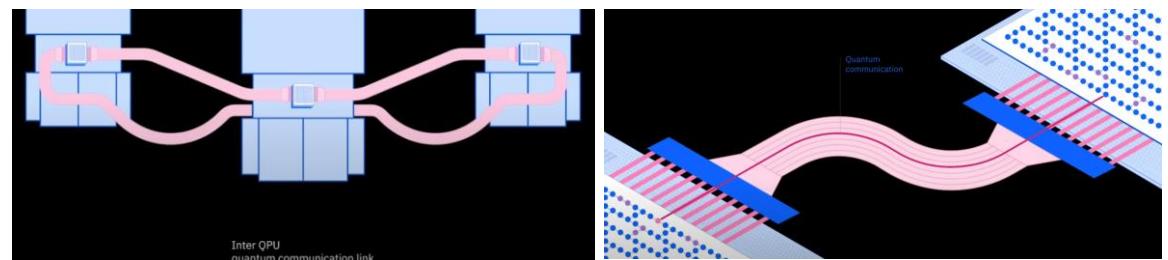


<https://research.ibm.com/blog/ibm-quantum-roadmap-2025>

## 2. Chip-to-chip connection



## 3. Quantum parallelization

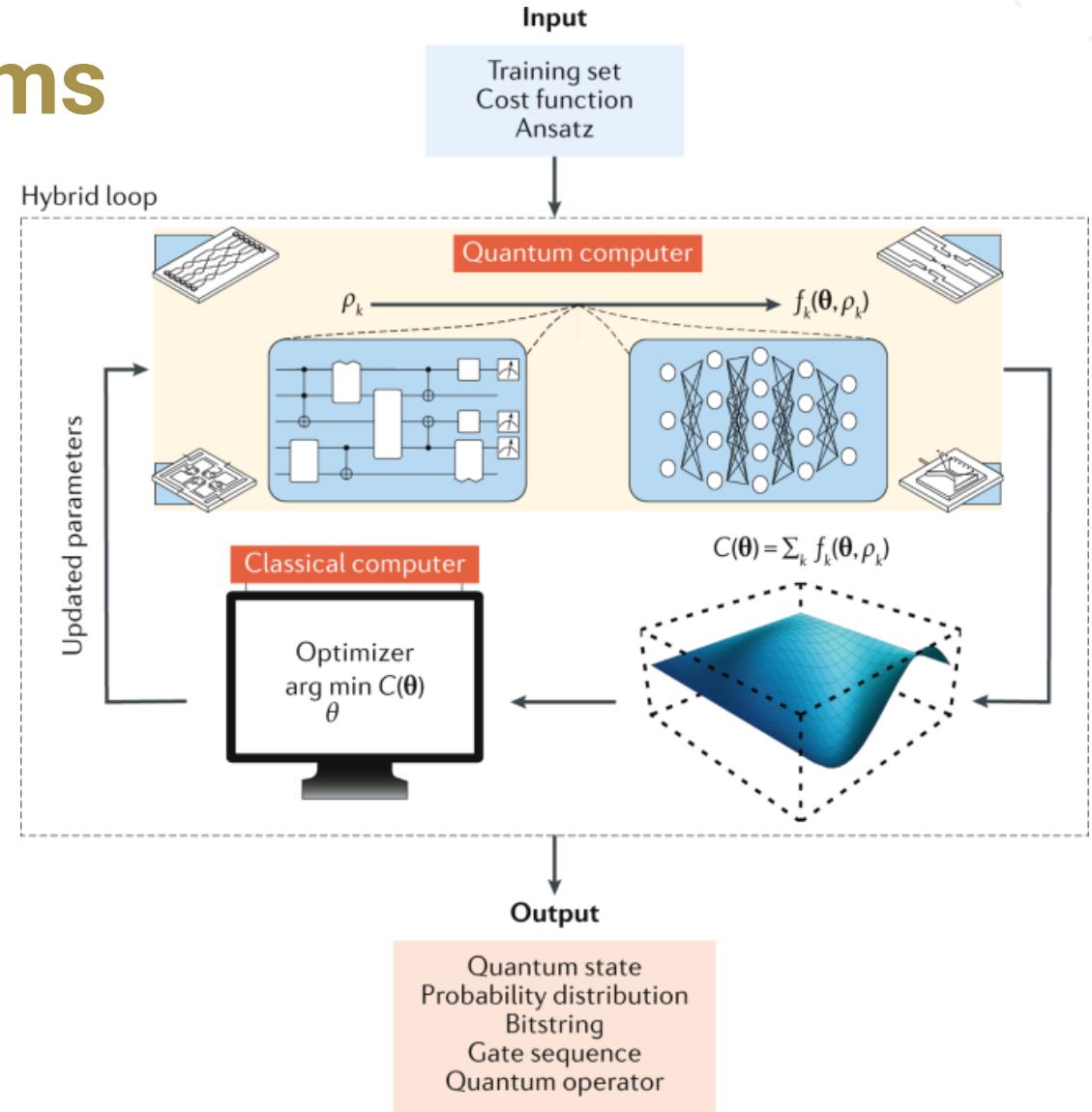
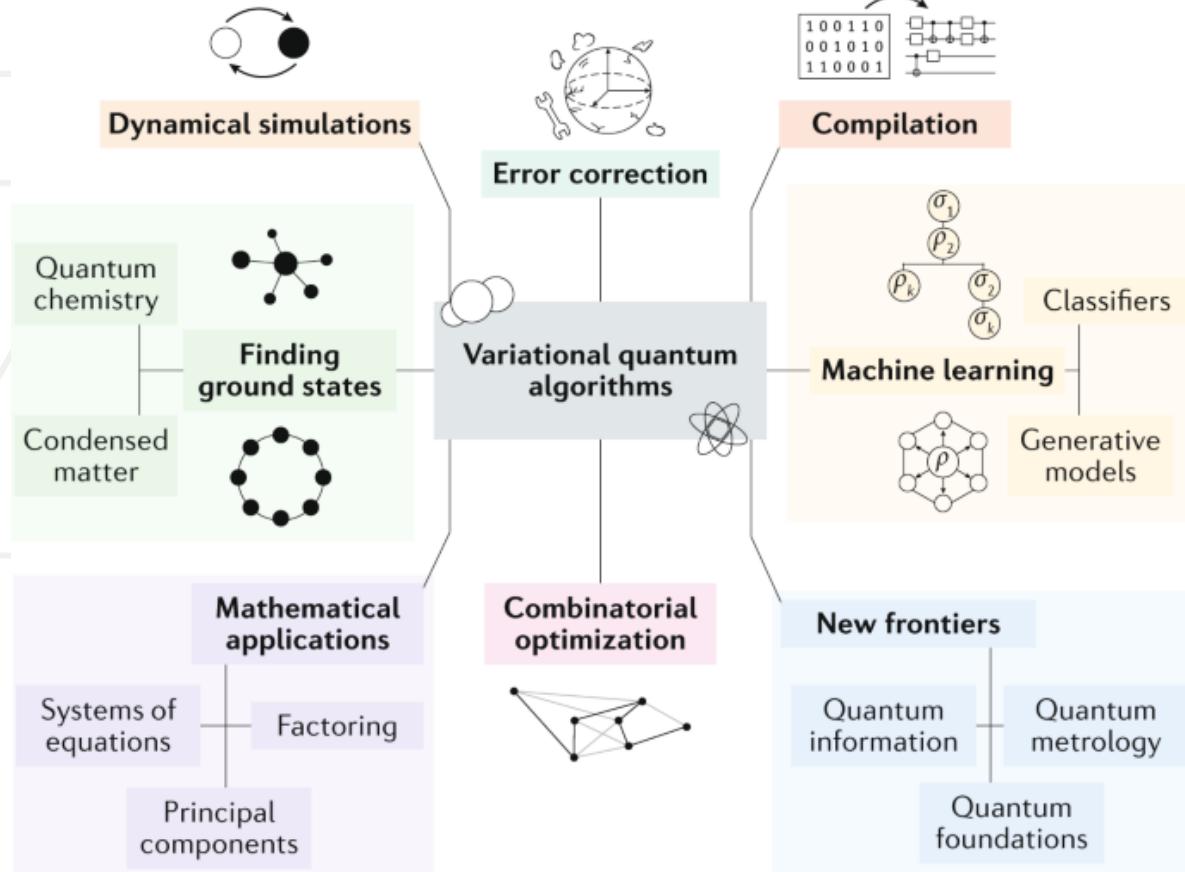


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# Near-term Quantum Algorithms

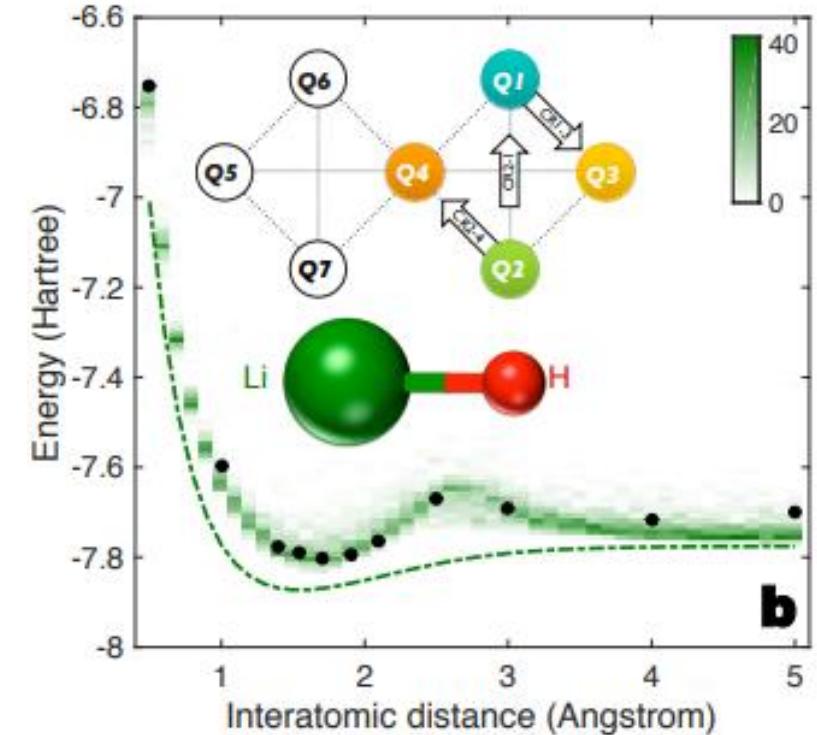
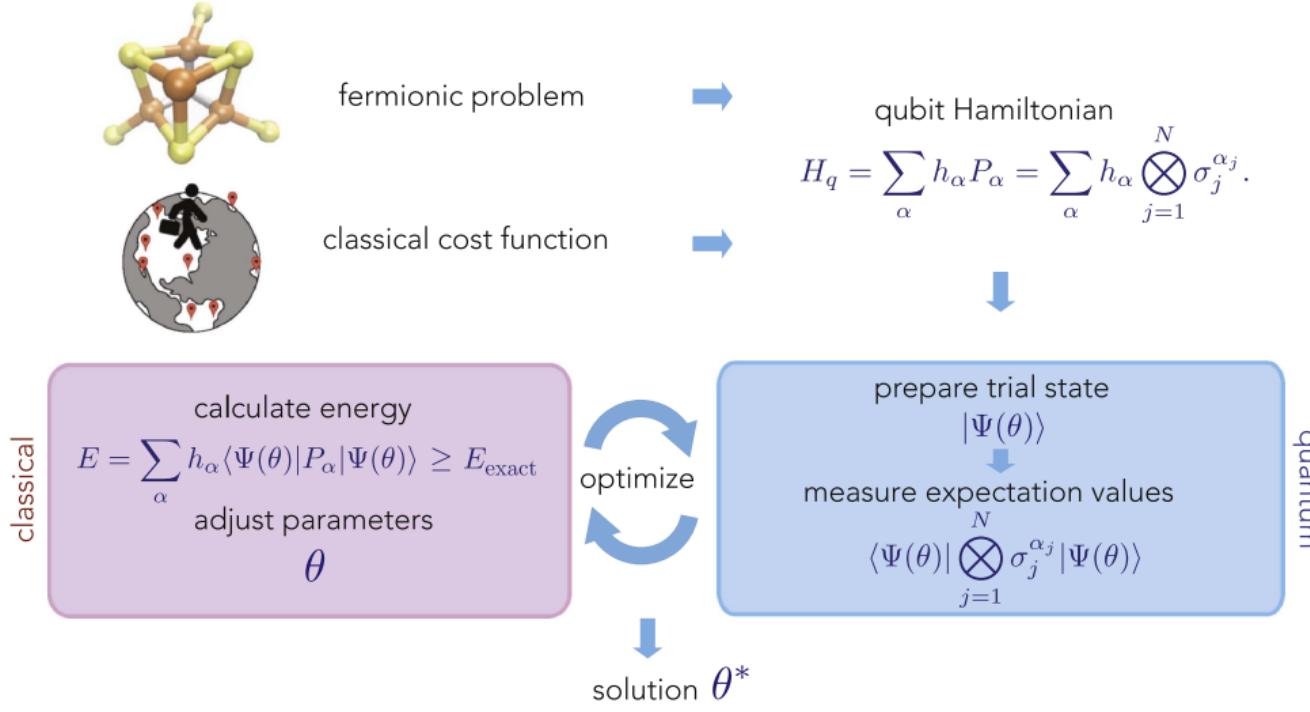
In most cases, people are referring to some Variational Quantum Algorithms (VQAs) [1].



[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].



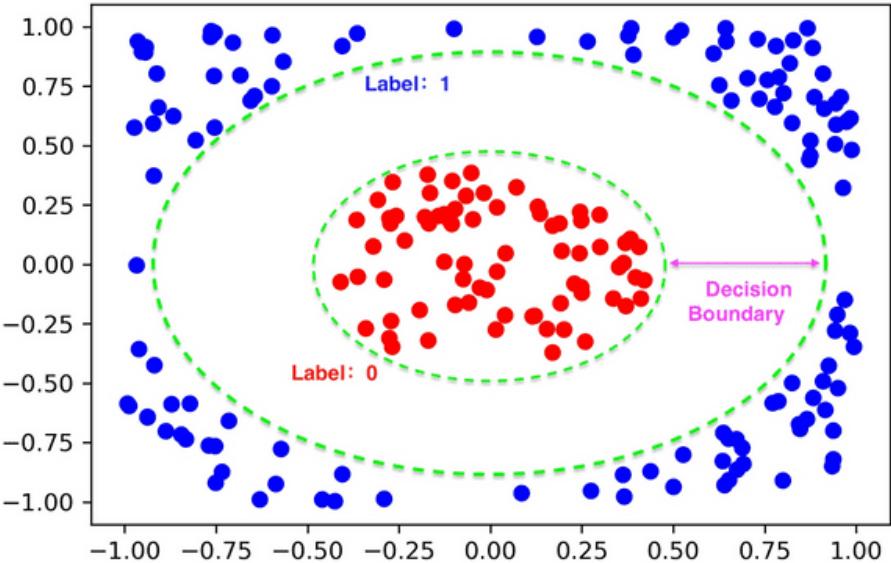
[1] Peruzzo, Alberto, et al. "A variational eigenvalue solver on a photonic quantum processor." *Nature communications* 5.1 (2014): 1-7.

[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



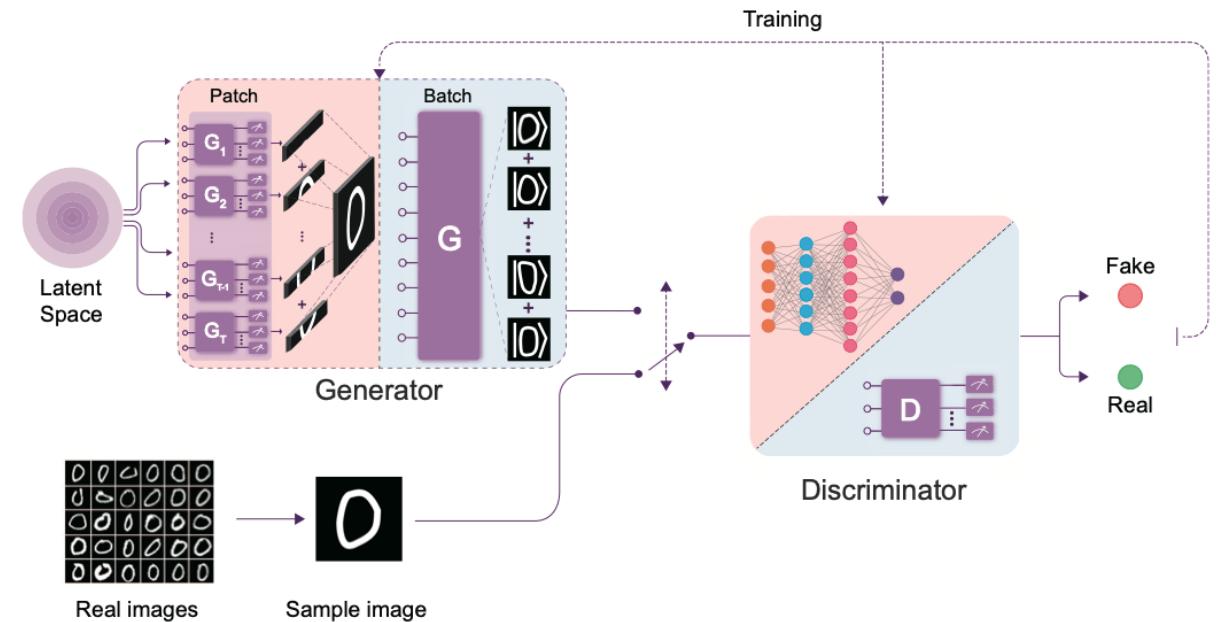
- Quantum Supervised Learning for Classification [1]
- Quantum Natural Language Processing (QNLP) [3]
- Quantum Reinforcement Learning (QRL) [4]
- More coming...

[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.

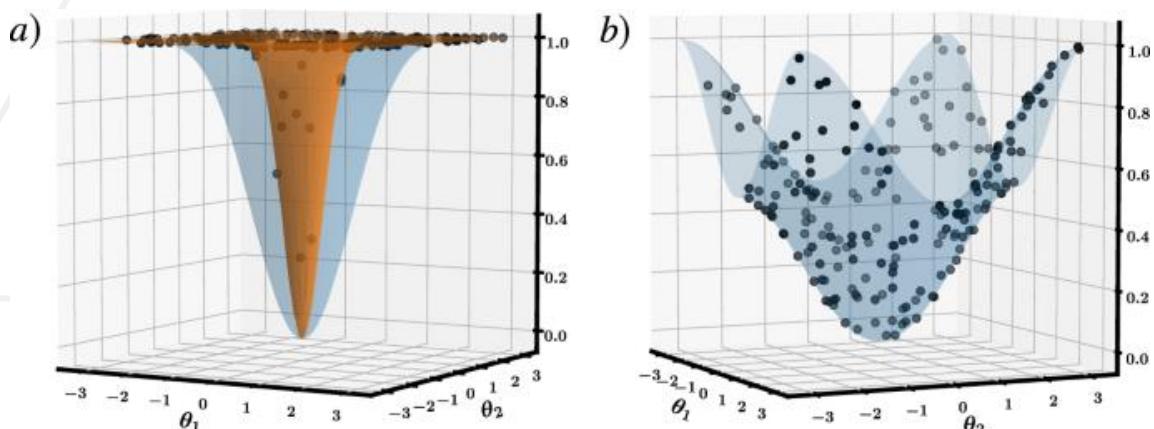


- Quantum Generative Learning [2]

# Challenges

- Barren Plateau (BP)

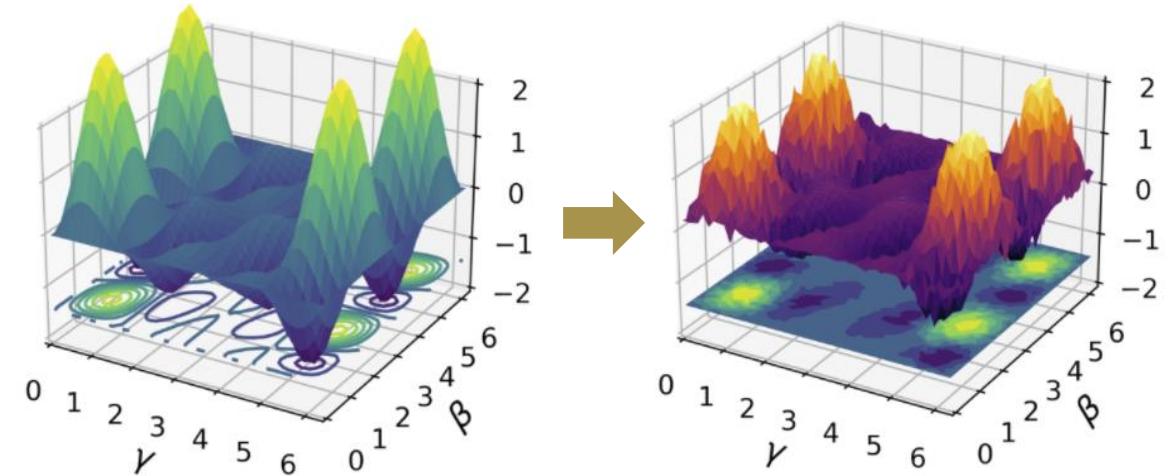
When a given cost function exhibits a BP, the magnitude of its partial derivatives will be, on average, exponentially vanishing with the system size [1-2].



- Ansatz Design

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

- Noise



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

[1] McClean, Jarrod R., et al. "Barren plateaus in quantum neural network training landscapes." *Nature communications* 9.1 (2018): 1-6.

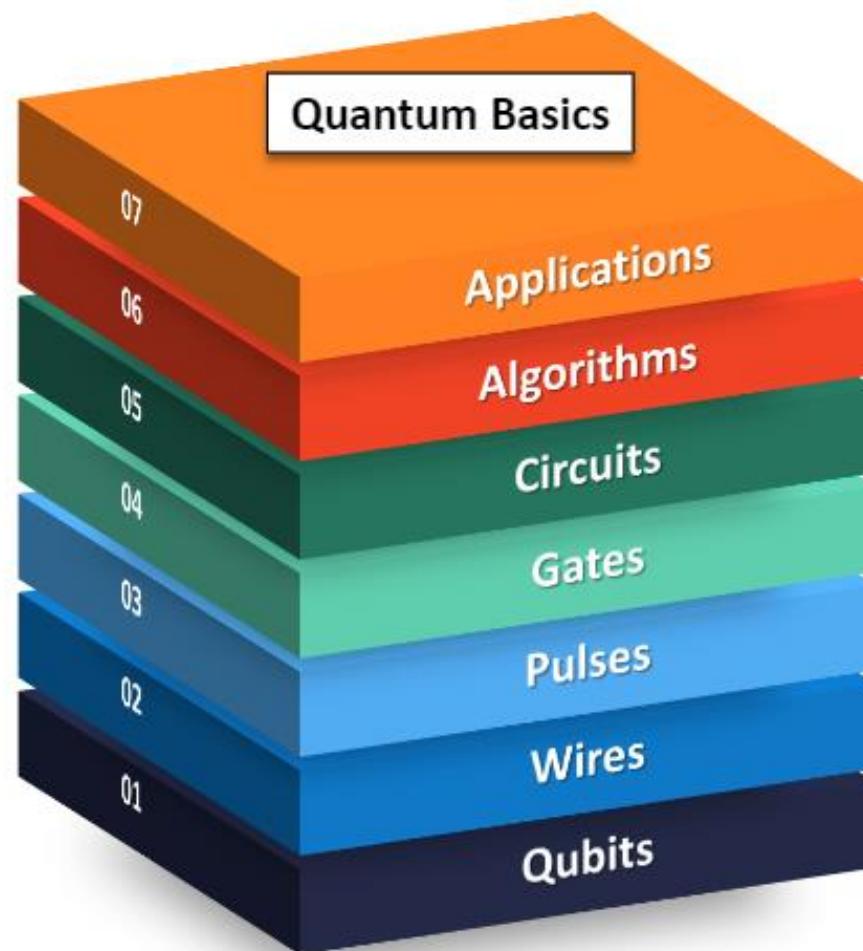
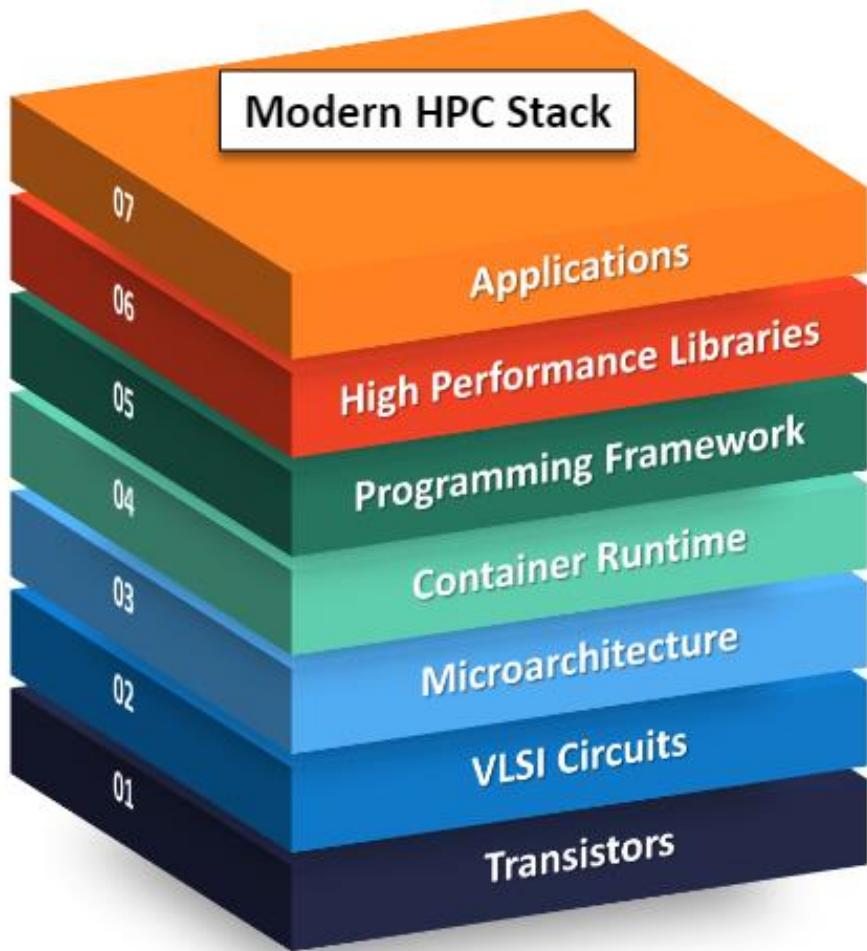
[2] Cerezo, Marco, et al. "Cost function dependent barren plateaus in shallow parametrized quantum circuits." *Nature communications* 12.1 (2021): 1-12.

[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.

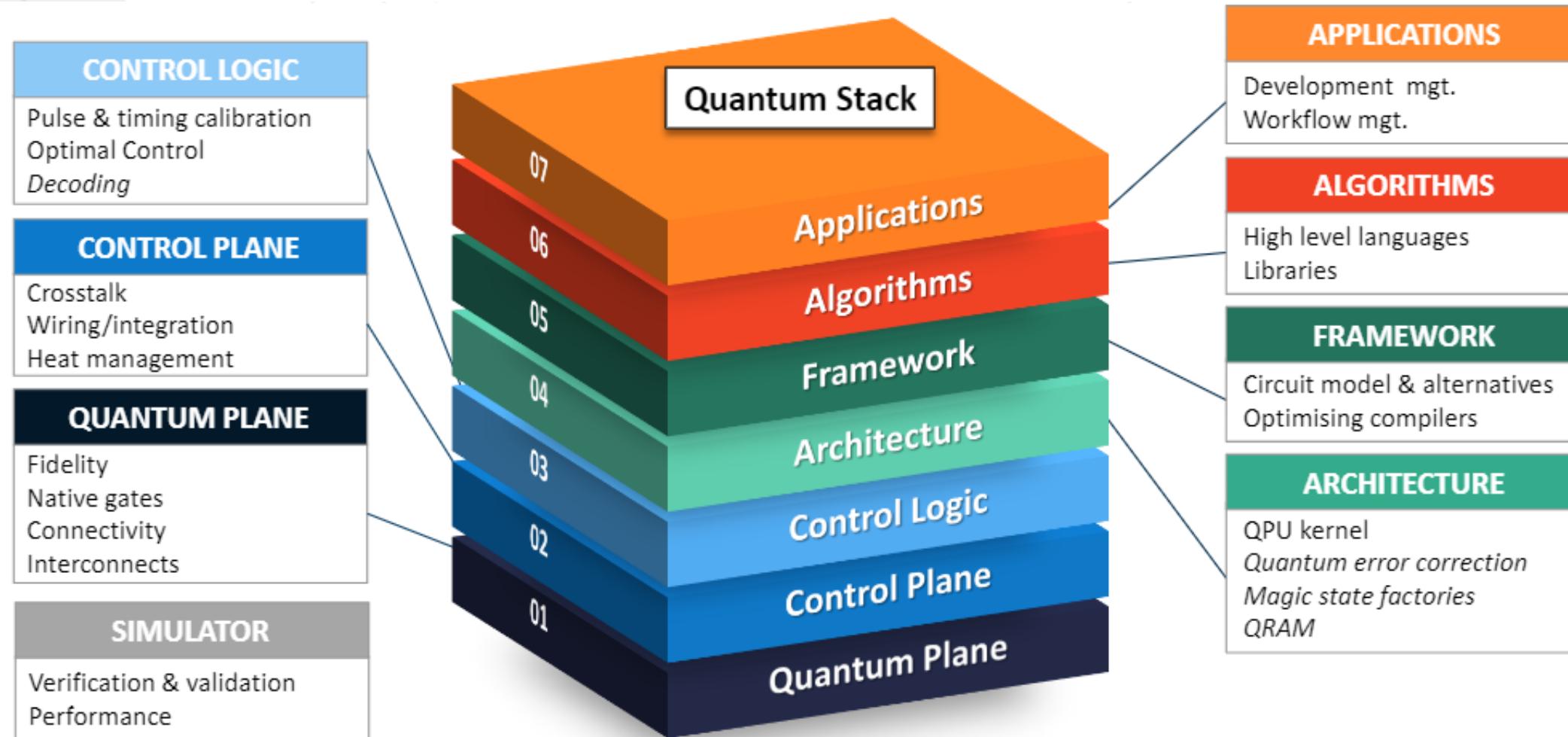
# Next

- 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

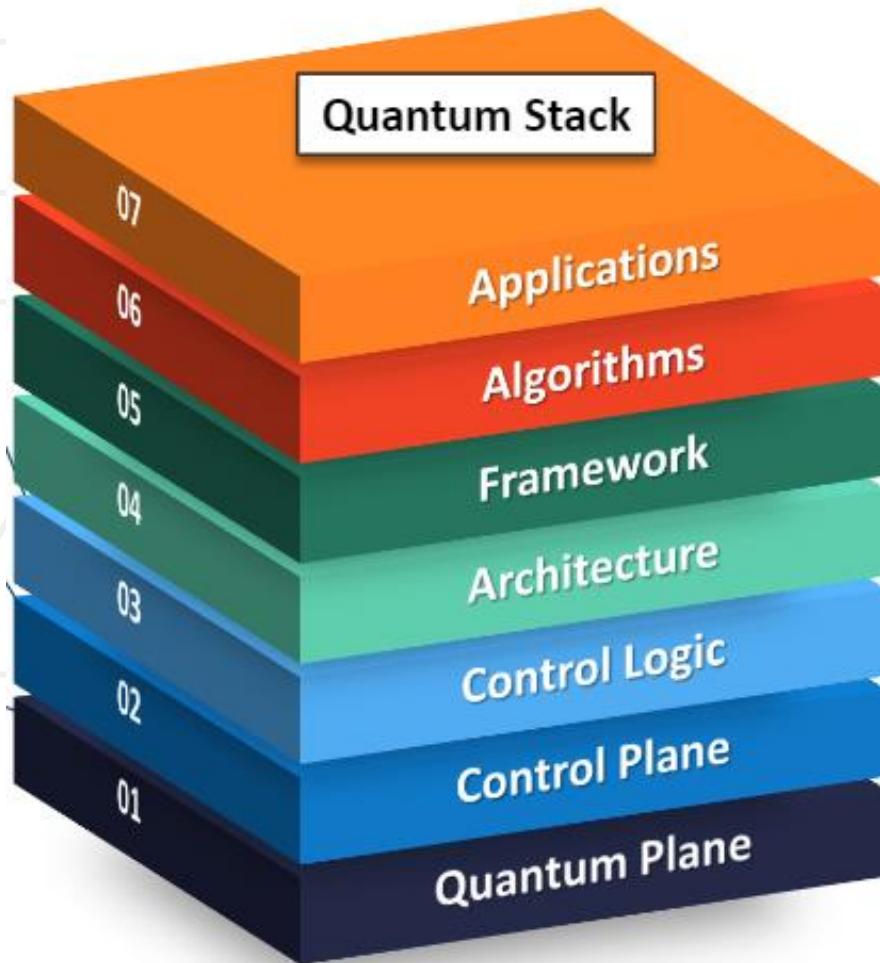
# Stack Design



# Quantum Stack



# 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]

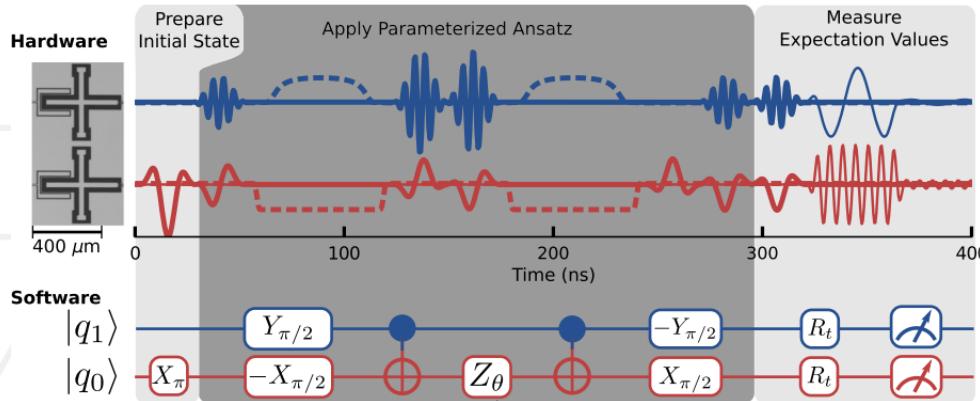
### Data-Processing:

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

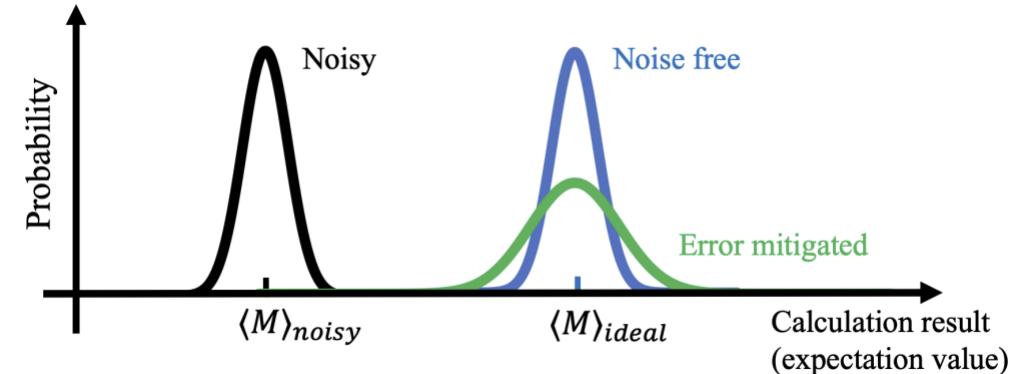
**There are many intermediate levels between the algorithm and hardware.**

# 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.

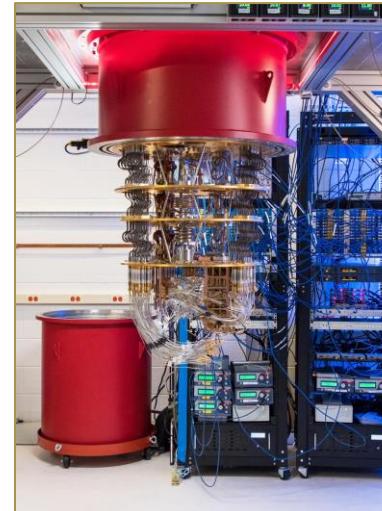
[3] Gokhale, Pranav, et al. "Optimization of simultaneous measurement for variational quantum eigensolver applications." *2020 IEEE International Conference on Quantum Computing and Engineering (QCE)*. IEEE, 2020.

# 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.

# 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

- Basic concepts
- Quantum Hardware
  - Benchmarks
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  - Internship
  - Summer School
  - Community

# Daily Input

## Scirate:

A more selective arXiv.

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Quantum Physics (quant-ph)

Fully undistillable quantum states are separable

Satvik Singh, Nilanjana Datta

Jul 13 2022 quant-ph math-ph math.MP arXiv:2207.05193v1

Assume that Alice, Bob, and Eve share a tripartite pure state  $|\psi_{ABE}\rangle$ . We prove that if Alice cannot distill entanglement with either Bob or Eve using  $|\psi_{ABE}\rangle$  and local operations with any one of the following configurations for classical communication:  $(A \rightarrow B, A \leftrightarrow E)$ ,  $(A \leftrightarrow B, A \rightarrow E)$ , and  $(A \leftrightarrow B, A \leftrightarrow E)$ , then the same is also true for the other two configurations. Moreover, this happens precisely when the state is such that both its reductions  $\rho_{AB}$  and  $\rho_{AE}$  are separable, which is further equivalent to the reductions being PPT. This, in particular, implies that any NPT bipartite state is such that either the state itself or its complement is 2-way distillable. In proving these results, we first obtain an explicit lower bound on the 2-way distillable entanglement of low rank bipartite states. Furthermore, we show that even though not all low rank states are 1-way distillable, a randomly sampled low rank state will almost surely be 1-way distillable.

The QAOA gets stuck starting from a good classical string

Madelyn Cain, Edward Farhi, Sam Gutmann, Daniel Ranard, Eugene Tang

Jul 13 2022 quant-ph arXiv:2207.05089v1

The Quantum Approximate Optimization Algorithm (QAOA) is designed to maximize a cost function over bit strings. While the initial state is traditionally a superposition over all strings, it is natural to try expediting the QAOA: first use a classical algorithm to produce some good string, and then run the ordinary QAOA starting in the computational basis state associated with that string. Here we report numerical experiments that this method of initializing the QAOA fails dramatically, exhibiting little to no improvement of the cost function. We investigate criteria for the rare instances in which there is any improvement at all, and we provide a statistical argument for the more typical case of no improvement. The statistical argument holds for any string that locally mimics the thermal ensemble at the appropriate temperature. Our numerical experiments indicate this property holds for typical good strings. We emphasize that our negative results only apply to our simple incarnation of the warm-start QAOA and may not apply to other approaches in the literature. We hope that our theoretical analysis will inform future algorithm design.

Date Published

Wed 13 Jul 2022 UTC

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Prev day Next day

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Recent comments

The classical cost of transmitting a qubit

Stephen Bartlett 6 days ago

Very nice paper. You may be interested in this great paper by Montina: <https://arxiv.org/abs/1107.4647> that looks into the d=2 case that you mention in your discussion section. It seems this qubit case is quite exceptional and difficult to generalize.

Multivariate trace estimation in constant quantum depth

Michał Oszmaniec 12 days ago

Scite! 32 PDF

## Twitter:

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

Physical Review A @PhysRevA · 7月11日

PRA's second Perspective has just been published! @QuantumCallison and @QntmChancellor discuss hybrid quantum-classical algorithms in the #NISQ era.

Read it now:

Jens Eisert @jenseisert · 7月8日

"A single T-gate makes distribution learning hard". A thread.

journals.aps.org Hybrid quantum-classical alg The coming era of quantum co revolutionize computation, bu

Very nice paper. You may be interested in this great paper by Montina: <https://arxiv.org/abs/1107.4647> that looks into the d=2 case that you mention in your discussion section. It seems this qubit case is quite exceptional and difficult to generalize.

Multivariate trace estimation in constant quantum depth

Michał Oszmaniec 12 days ago

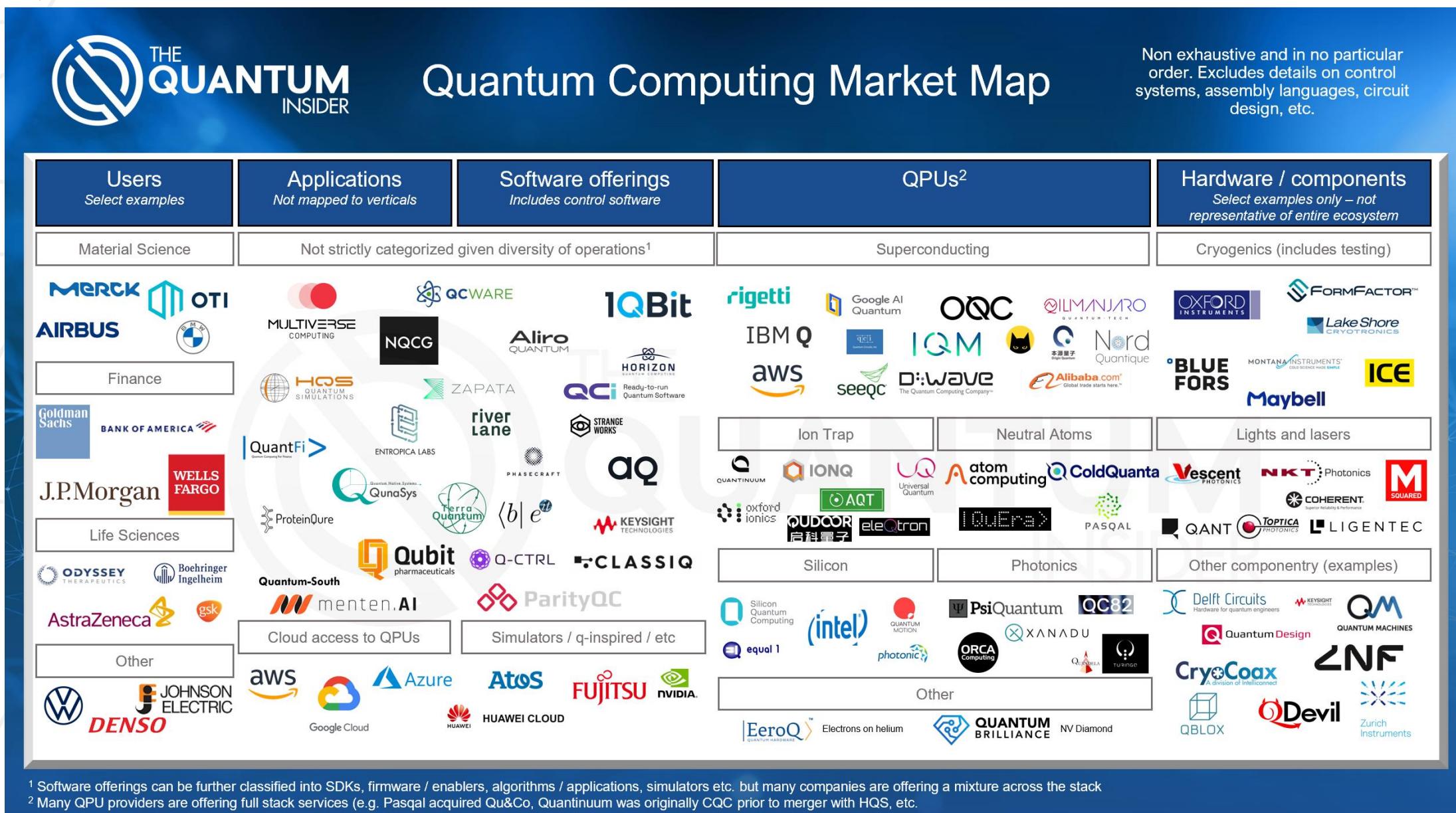
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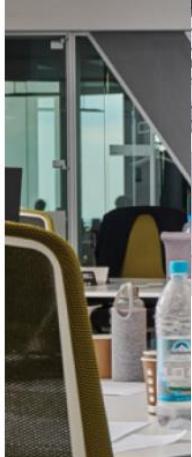
# QC Market

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



# Internships

Your future starts with an IBM  
Quantum Internship



## Internships

Our technical interns are key to innovation at IBM through applied projects and research publications. Interns work side-by-side with our researchers and engineers on quantum computing. Internships take place through a range of disciplines, including physics, computer science, and more. We're excited to work with us.

- Research internships
- Software internships
- Hardware internships

Zapata Computing 转推了  
Marta Mauri @maurimarta14 · 6月30日  
Welcome to all the 2022 Zapata interns! Special greetings to our Quantum AI stars, who are already doing an exceptional job with their projects!  
Excited to continue learning from quantum advantage 🚀

Zapata Computing @Zap  
Welcome to our 2022 summer interns! See what you accomplish with #QuantumComputing #interns

0:22 1,655 次观看

0 2

## There are many industry internship opportunities!!

IonQ @IonQ\_Inc · 6月7日  
IonQ's internship program has grown to 15 students this summer, working with everyone from scientists to one of our founders.

ionq.com  
IonQ Kicks Off Expanded Internship Program  
IonQ's summer internship program has returned for 2022, growing to fifteen interns from last year's five

0 6 56

# Summer School

## Quantum Computing Summer School Fellowship

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

### CONTACTS

#### Program Lead

Lukasz Cincio

[Email](#)

#### Program Co-Lead

Patrick Coles

[Email](#)

#### Program Co-Lead

Marco Cerezo

[Email](#)

#### Advisor

Yigit Subasi

[Email](#)

#### Advisor

Candace Culhane

[Email](#)

### 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

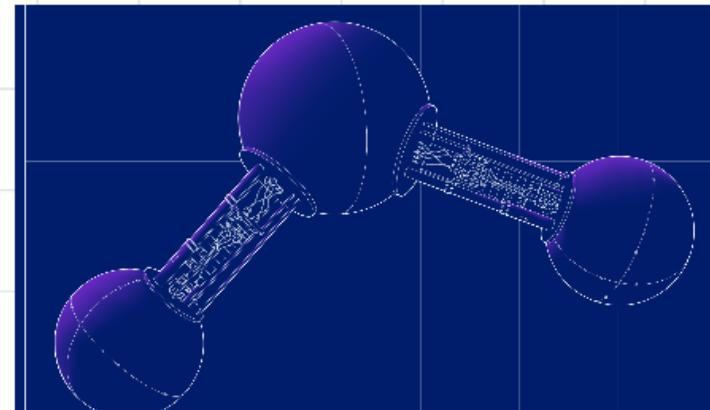
Invited speakers: Tameem Albash (University of New Mexico), Andrew Childs (University of Maryland), Elizabeth Crosson (University of New Mexico), Jens Eisert (Free University of Berlin), David Gosset (University of Waterloo), Shelby Kimmel (Middlebury College), Raymond Laflamme (Institute for Quantum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

## LANL Summer School (research-focused)

### QUANTUM COMPUTING

[How to Apply](#)

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

The screenshot shows the DuQIS homepage with a dark blue header featuring the logo and navigation links: Home, Duke X UChicago, Calendar, Events, Study Guide, Archive, Contact. Below the header, the title "Duke Undergraduate Quantum Information Society" is displayed, followed by a brief description: "An academic-oriented student organization aiming to promote the accessibility of quantum information science and related research opportunities to more Duke undergraduate students." Two buttons are present: "Subscribe DuQIS Mailing List" and "Fill Out DuQIS Interest Form".

## Promote Interest

We believe that interests in quantum computing among young students are limited by the extensive pre-required knowledge in multiple disciplines. In addition, there are less structured educational programs that target undergraduate training in quantum related fields. Therefore, our primary focus is to fill in this "gap," to the best of our ability, by promoting interests in and exposure to the field.

The screenshot shows the Stanford Quantum Computing Association homepage with a dark background featuring a starry pattern. The title "Stanford Quantum Computing Association" is prominently displayed, along with the subtitle "A GRADUATE AND UNDERGRADUATE STUDENT ORGANIZATION". Navigation links include HOME, ABOUT, WHAT WE'VE DONE, EVENTS, INITIATIVES, CALENDAR, JOIN, RESOURCES, POLICIES, and CONTACT.

Our mission is to develop the future scientists and engineers involved in quantum computing.

This will be achieved by our three main goals:

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

The screenshot shows the Harvard College Quantum Computing Association homepage. It features the Harvard crest at the top left and navigation links: HOME and CONTACT. A large image of a quantum computing hardware setup is on the right. The text "HARVARD COLLEGE Quantum Computing Association" is displayed, followed by a description: "A student-run organization dedicated to the education and engagement of the Harvard Undergraduate Community in Quantum Information Science and Quantum Software." A "News Feed" section is visible below the main text.

Stay tuned for more information on upcoming meetings, seminars, opportunities, and interesting research related to the Quantum Computing Association.



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

Quantum Computer Systems Lecture Series  
A Guided Tour on the Map of Quantum Computing



Zhixin Song  
*Georgia Tech*

July. 14<sup>th</sup> 2022  
Thursday  
10:30AM ET

**Bio**  
Zhixin Song is currently a Physics Ph.D. student at Georgia Institute of Technology. He has previously done an internship at Baidu Research, Institute for Quantum Computing, working on Variational Quantum Algorithms (VQAs) and developing a Quantum Machine Learning toolkit called Paddle Quantum. His current research focuses on experimental quantum simulation, control theory, and quantum many-body systems.

**Abstract**  
In this talk, Zhixin will walk through basic concepts of Quantum Computing (QC), including qubit, quantum gates, and measurement. No background knowledge is required from the audience. Then, he will introduce different types of quantum hardware and how to benchmark their performance. Moreover, application-based near-term quantum algorithms and intermediate level (between software and hardware) research will also be addressed briefly. Finally, Zhixin will provide some suggestions and resources for self-learning.

For more information, visit [sites.nd.edu/quantum](http://sites.nd.edu/quantum) and [qmlsys.mit.edu](http://qmlsys.mit.edu) or scan QC code  
Organized by Zhiding Liang (Notre Dame), Hanrui Wang (MIT)

Website  Mailing-list 

See u next week!