AWS re:Invent

CMP213-R

Introducing Quantum Computing with AWS

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Amazon Web Services

AWS re:Invent

Agenda

Quantum computing – why should you care?

Where are we today?

Introducing Amazon Quantum Technologies

Related breakouts

Thursday, December 5th

CMP213-R1: [REPEAT 1] Introducing Quantum Computing with AWS
2:30 PM - Bellagio, Grand Ballroom 5 Black

Quantum Computing

AWS re:Invent

Quantum computing

… explores the intricate physical laws of the microscopic world to perform computation in novel and improved ways

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Potential for a new paradigm in computing:

not 10X performance improvement but 10^X

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Hard scientific and engineering challenge to build quantum hardware at scale

Quantum computing

… explores the intricate physical laws of the microscopic world to perform computation in novel and improved ways

Potential for a new paradigm in computing:

not 10X performance improvement but 10^X

Hard scientific and engineering challenge to build quantum hardware at scale

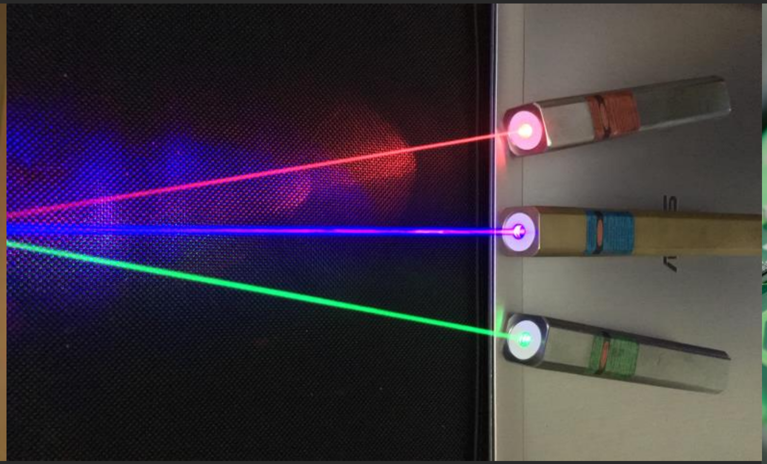
We just entered the “Noisy Intermediate-Scale Quantum” (NISQ) era:

far from end goal but promising for early explorations

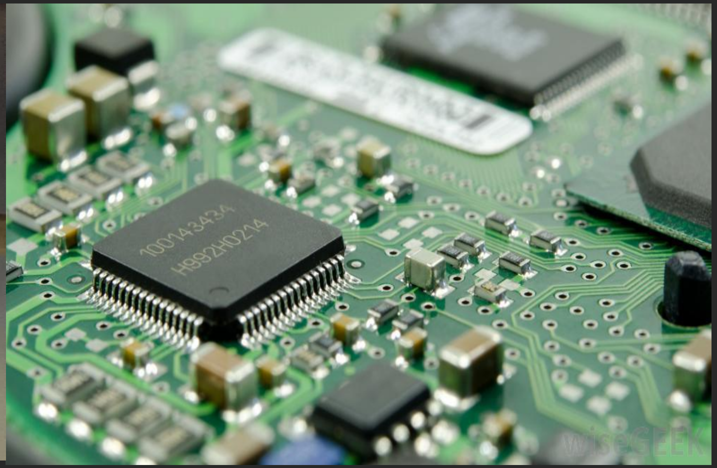
Quantum technologies from last century

Quantum mechanics already key to many technological advances

NMR



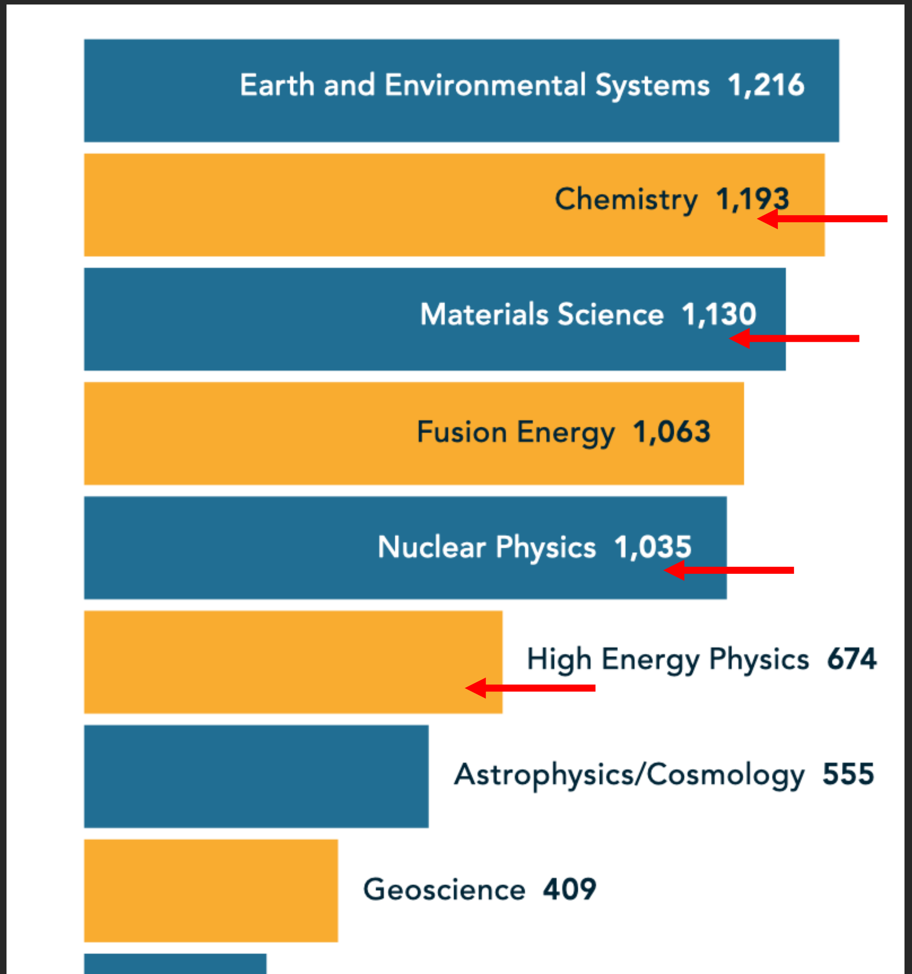
laser



transistor

Simulating quantum is hard

Use of DOE supercomputer by area in 2018



Large fraction devoted to simulating quantum systems

Cost grows exponentially with size of system

$\sim 2^n$ steps to simulate system of n qubits (electrons, photons, …) because of phenomenon of entanglement between qubits

30 qubits: 16 Gb

40 qubits: 16 Tb

50 qubits: 16 Pb

333 qubits : 10^{100}

Simulating physics with computers

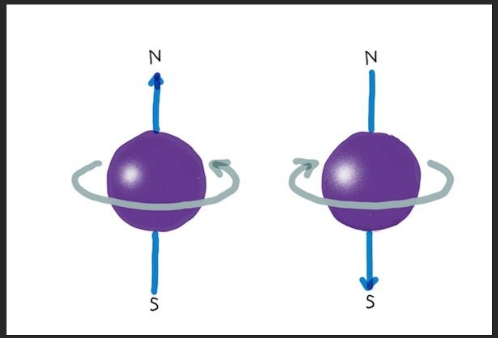
"trying to find a computer simulation of physics seems to me to be an excellent program to follow out (…) Nature isn't classical, dammit, and if you want to make a simulation of Nature, you'd better make it quantum mechanical, and by golly it's a wonderful problem, because it doesn't look so easy"

R. Feynman, Simulating Physics with Computers, 81

Quantum mechanics

Basic unit: Qubit $|\psi\rangle = \alpha|0\rangle + \beta|1\rangle$

$$\underbrace{|\alpha|^2}_{\Pr(0)} + \underbrace{|\beta|^2}_{\Pr(1)} = 1$$



$|0\rangle$ $|1\rangle$

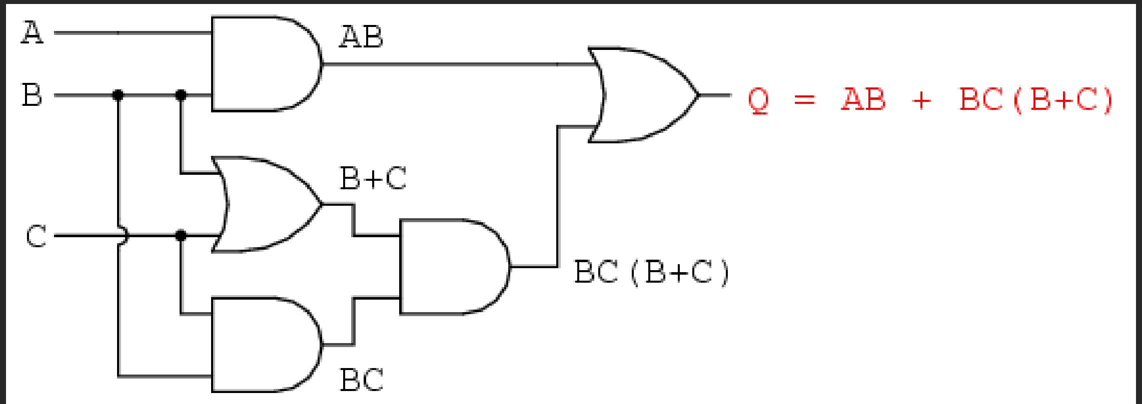
Amplitudes instead of probabilities.

Unique features: superposition, interference, entanglement

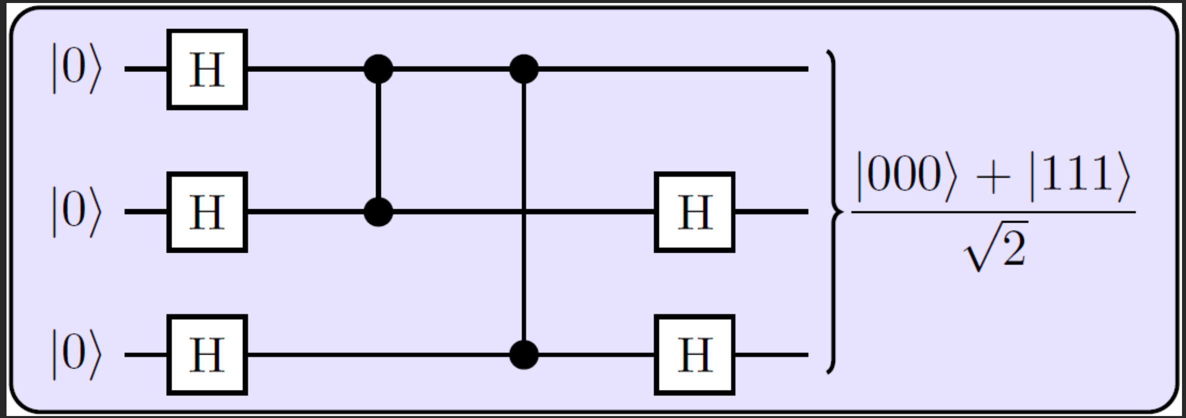
n-qubit system: $$|\psi\rangle = \sum_{i_1,\ldots,i_n=0}^{1} c_{i_1\ldots i_n} |i_1,\ldots,i_n\rangle$$

Quantum technology of this century

Quantum computing uses well-controlled quantum systems for computation

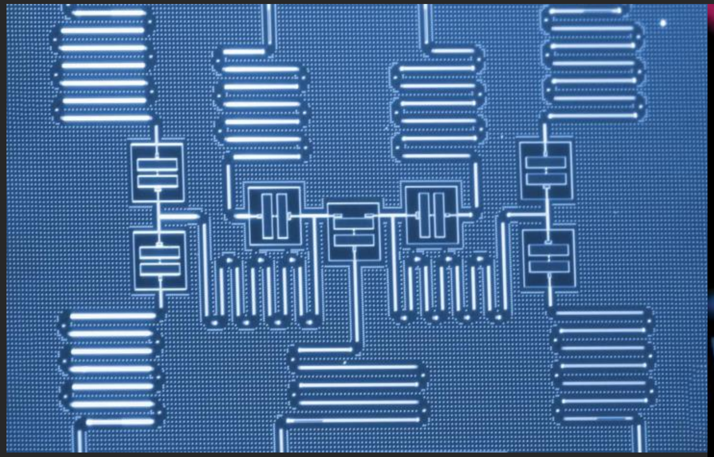


boolean circuit

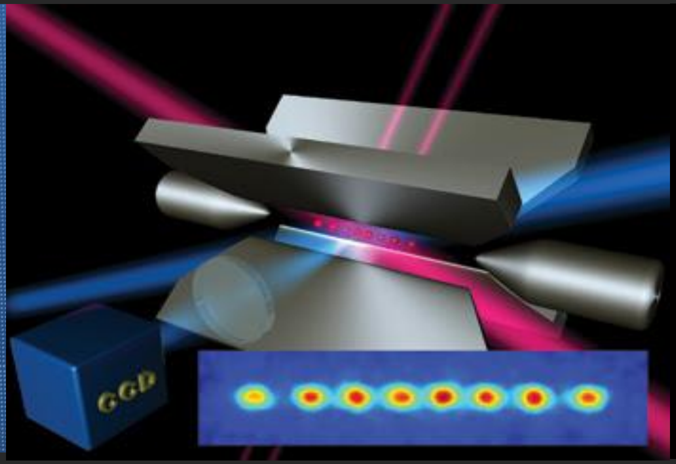


quantum circuit

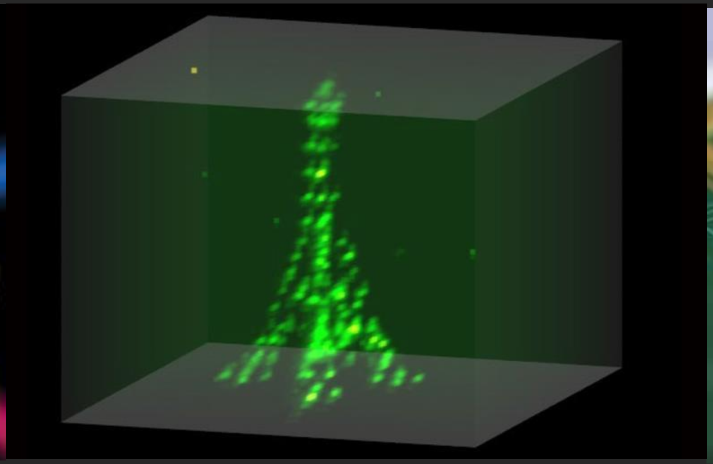
Quantum Computers in the Lab



superconducting qubits



trapped ions



Rydberg atoms

silicon photonics

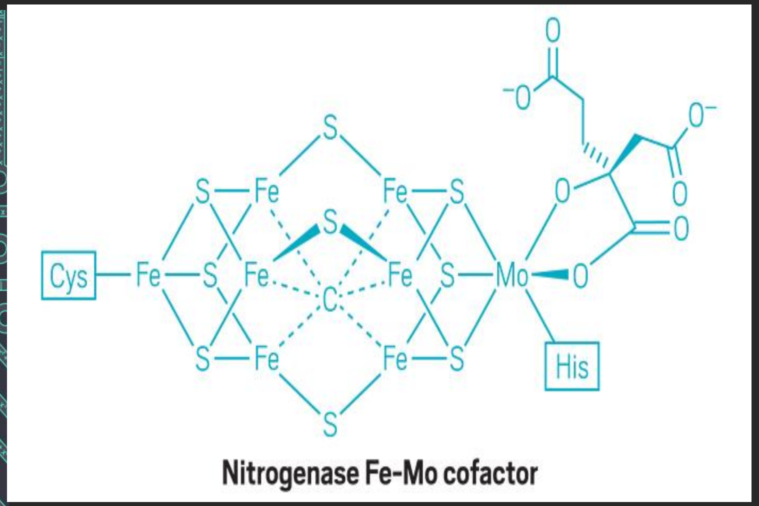
Applications Quantum Computing

Cryptography

Break 2048 RSA

~ 6000 qubits

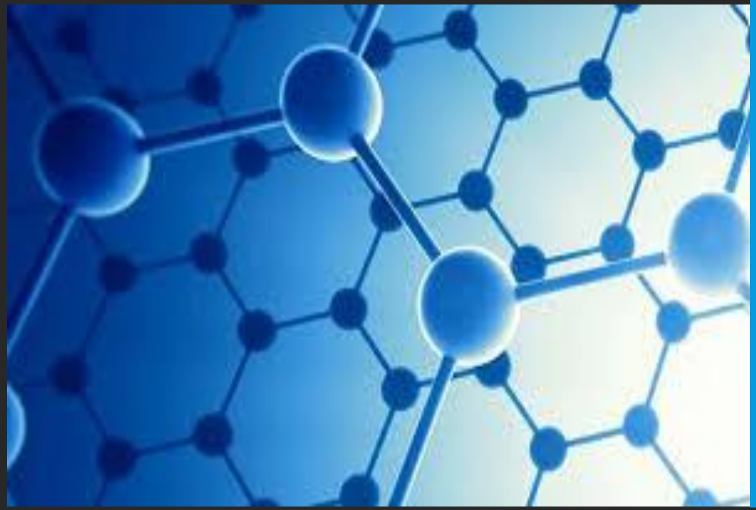
Physics/Chemistry



Simulate FeMoco

~ 200 qubits

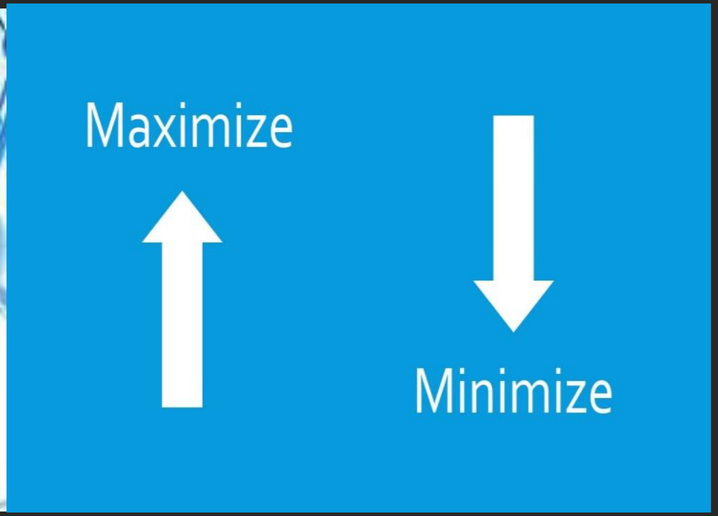
Material Science



Simulate High-T superconductors

~ 70 qubits

Optimization



Searching, ranking, learning

~ 100 qubits

Catch: perfect qubits with no noise. Change order

Applications Quantum Computing

Cryptography

Break 2048 RSA

~ 6000 qubits

Security of RSA based on hardness of factoring large numbers

Factoring: 15 = 5 x 3

509284477619 = 217421 x 234239

Best algorithm for n digit number: $\exp(1.9\ n^{1/3})$

To factor 2048 digit number ~ quadrillion years

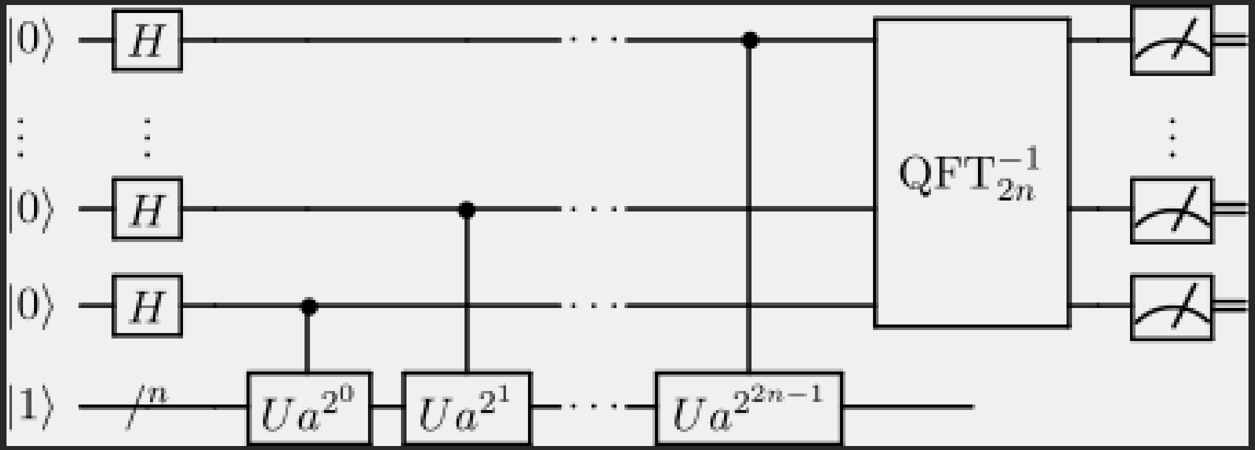
Applications Quantum Computing

Cryptography

Break 2048 RSA

~ 6000 qubits

Shor's quantum algorithm for factoring n digit number: $72\ n^3$



To factor 2048 digit number ~ few minutes

Post-quantum crypto being develop to address this threat

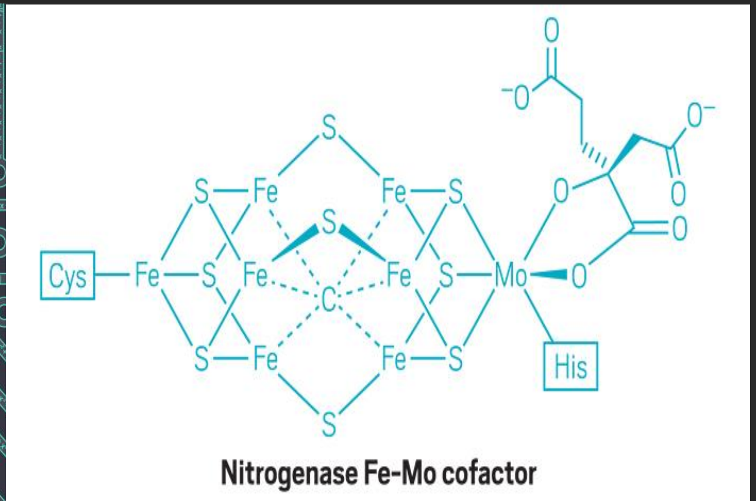
Applications Quantum Computing

Cryptography

Break 2048 RSA

~ 6000 qubits

Physics/Chemistry



Simulate FeMoco

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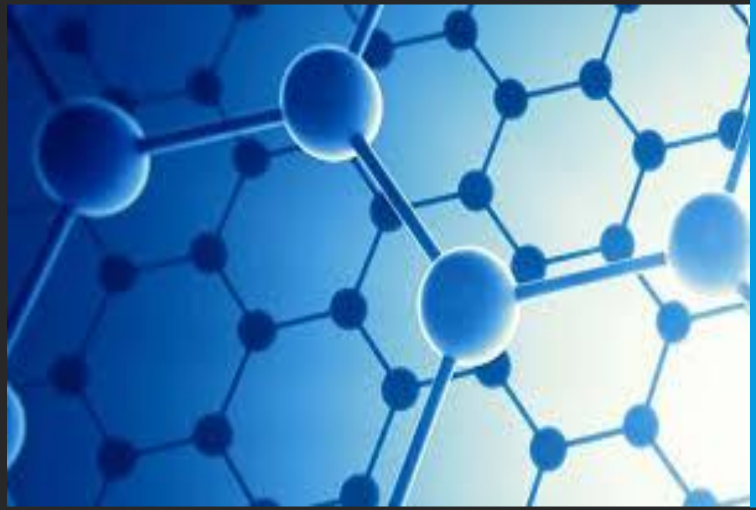

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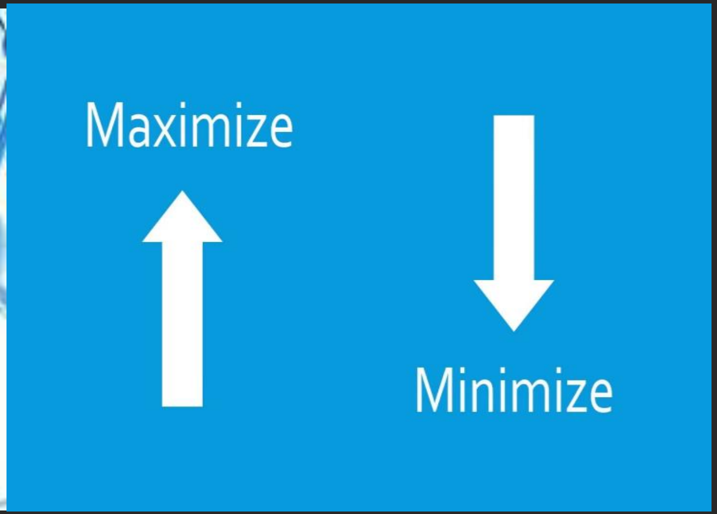


Scheduling, ranking, learning

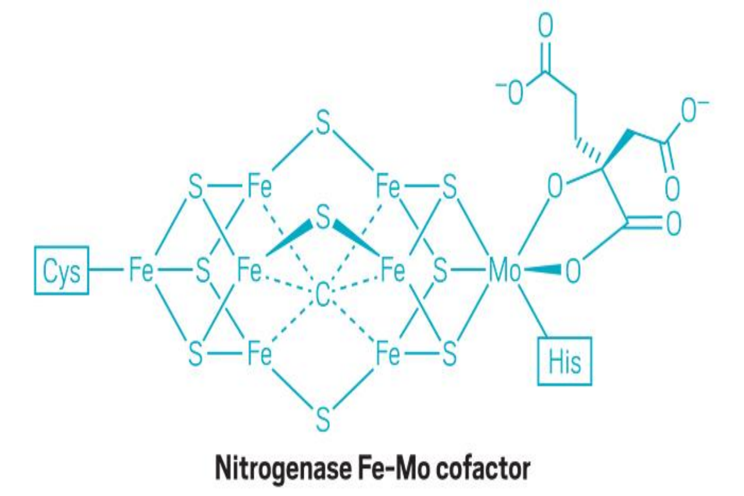
~ 100 qubits

Catch: perfect qubits with no noise

Applications Quantum Computing

Haber-Bosch process to produce ammonia fertilizer from nitrogen very costly

Physics/Chemistry

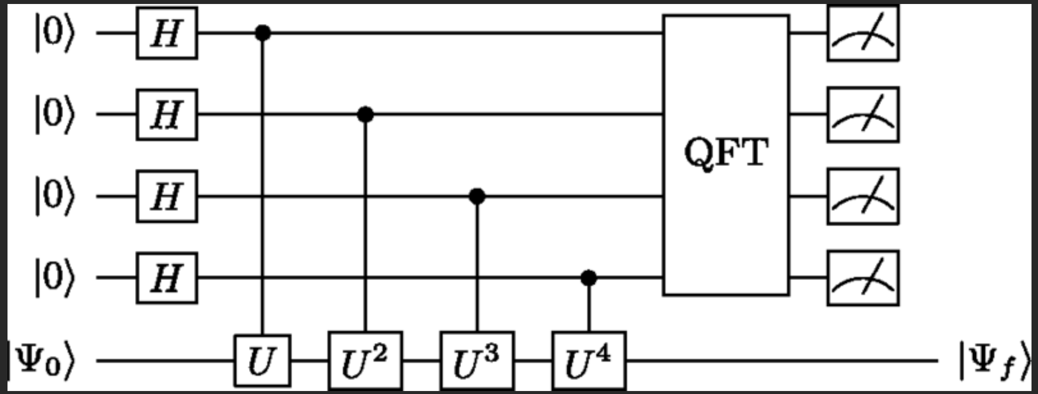


Simulate FeMoco

~ 200 qubits

Nitrogenase does it naturally. But out of reach with HPC (FeMoco > 70 electronic states).

Quantum computing can simulate FeMoco



Quantum Error Correction

Error rate: probability of error during execution of gate

Bit flip: 0 -> 1, 1 -> 0

Qubit bit flip: $\alpha|0\rangle + \beta|1\rangle \rightarrow \alpha|1\rangle + \beta|0\rangle$

Qubit phase flip: $\alpha|0\rangle + \beta|1\rangle \rightarrow \alpha|0\rangle - \beta|1\rangle$

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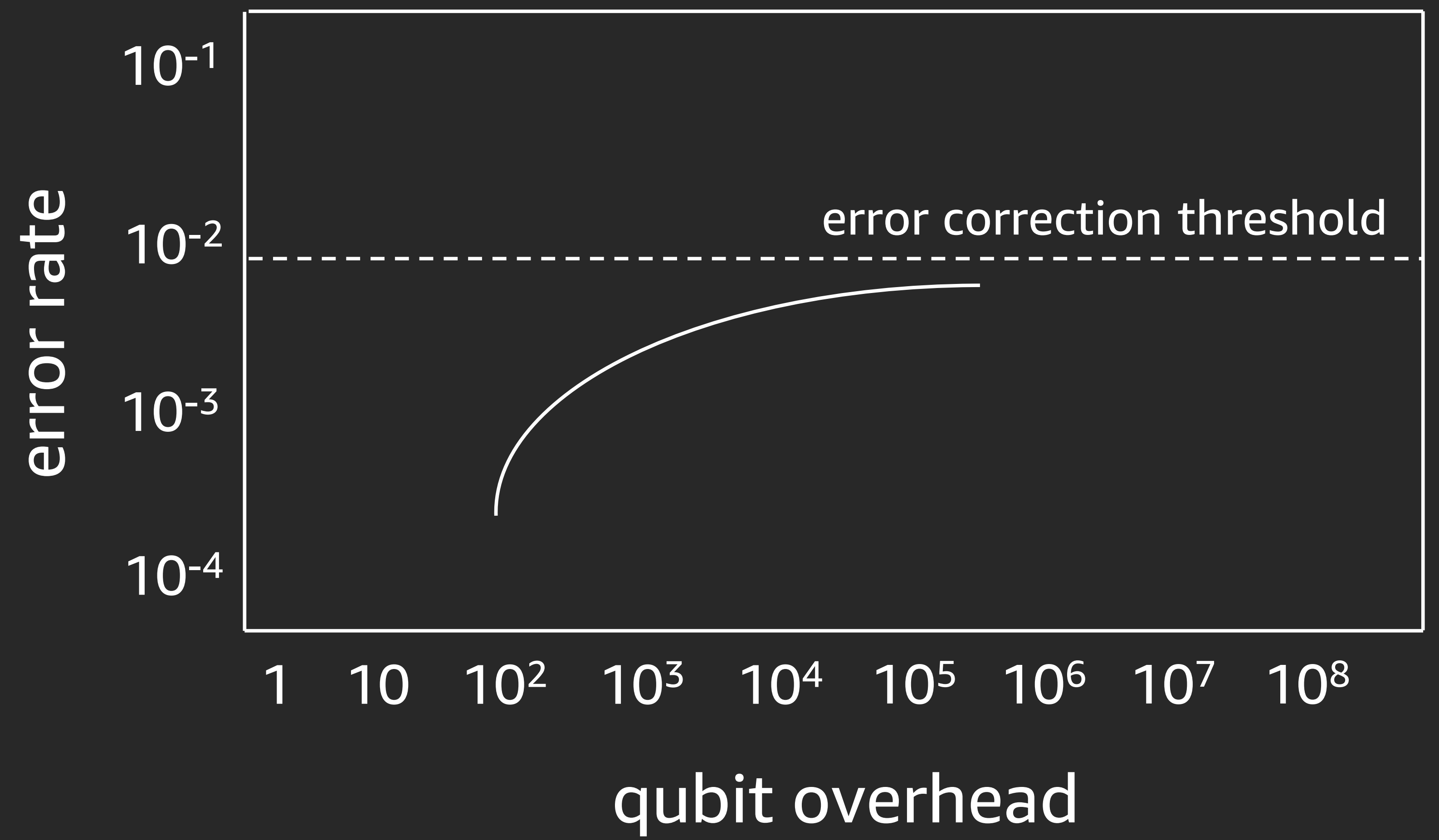
Error correction: protect information by redundant encoding

Repetition code for a bit: 0 -> 00000 1 -> 11111

Quantum Error Correction



Target: one billion gates with no error

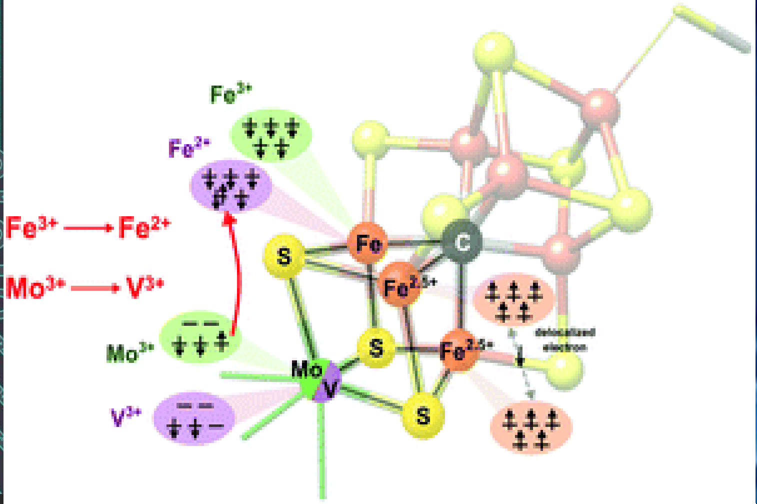
Applications Quantum Computing

Cryptography

Break 2048 RSA

~ 10M qubits

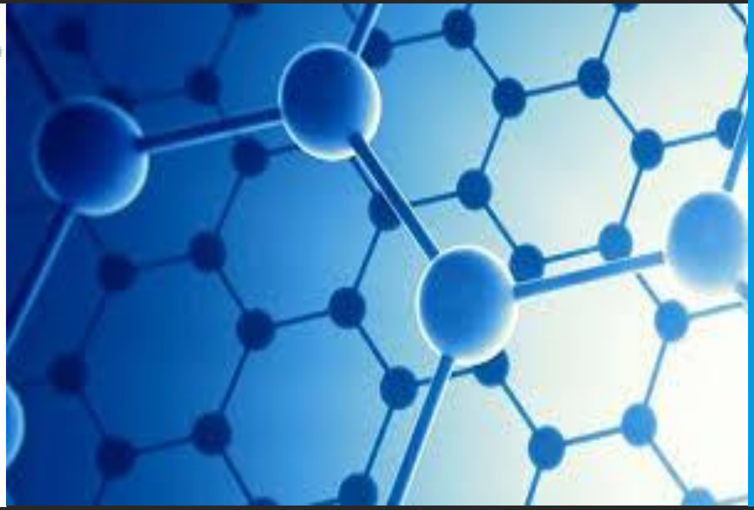
Physics/Chemistry



Simulate FeMoco

~ 200k qubits

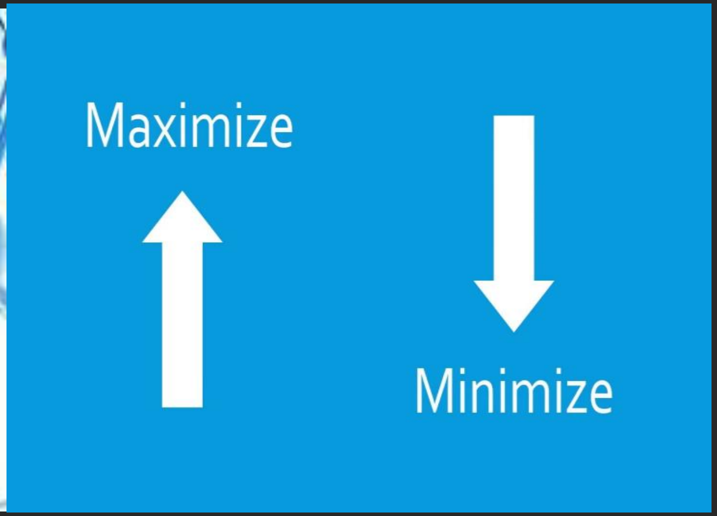
Material Science



Simulate High-T superconductors

~ 100k qubits

Optimization

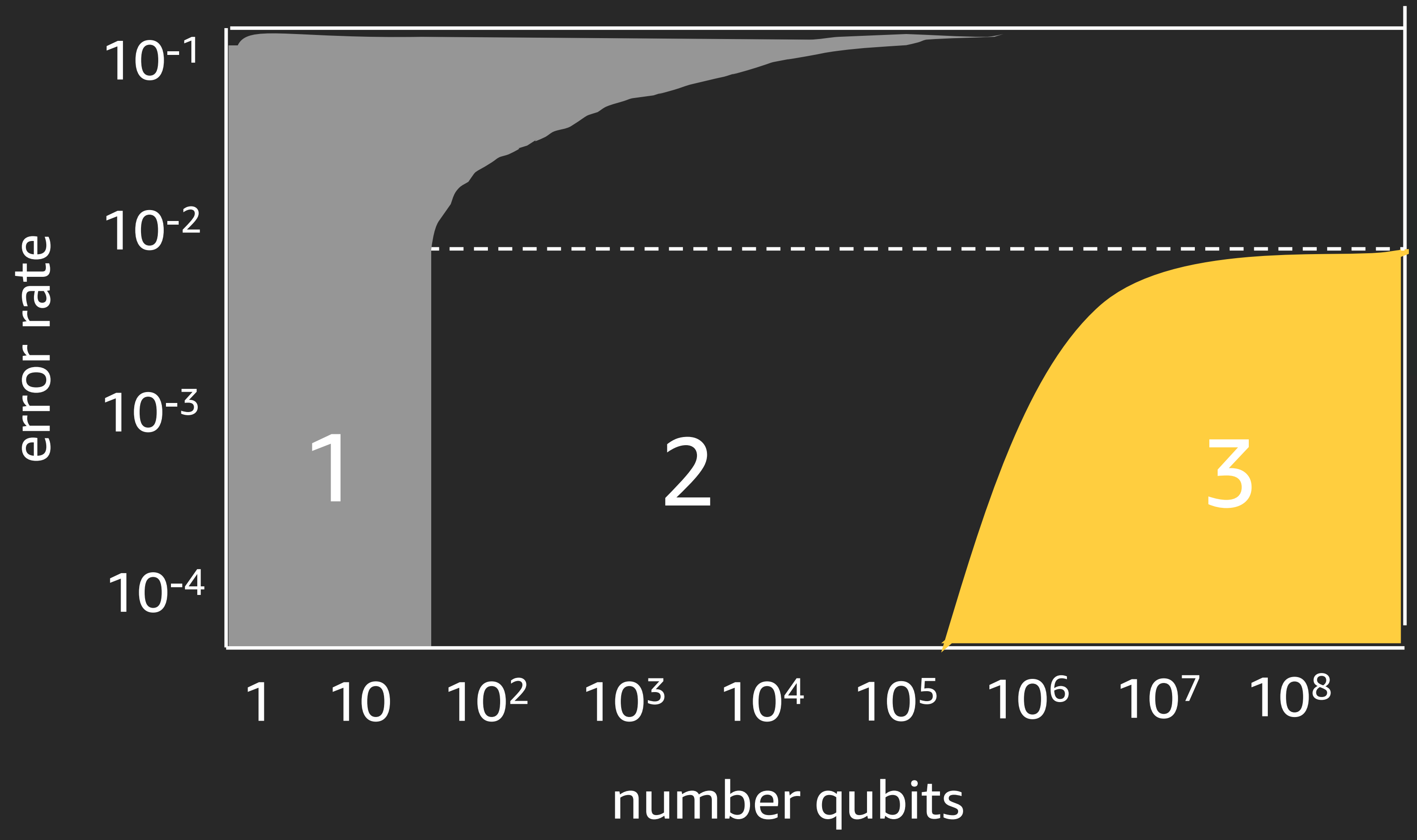


Scheduling, ranking, learning

~ 500k qubits

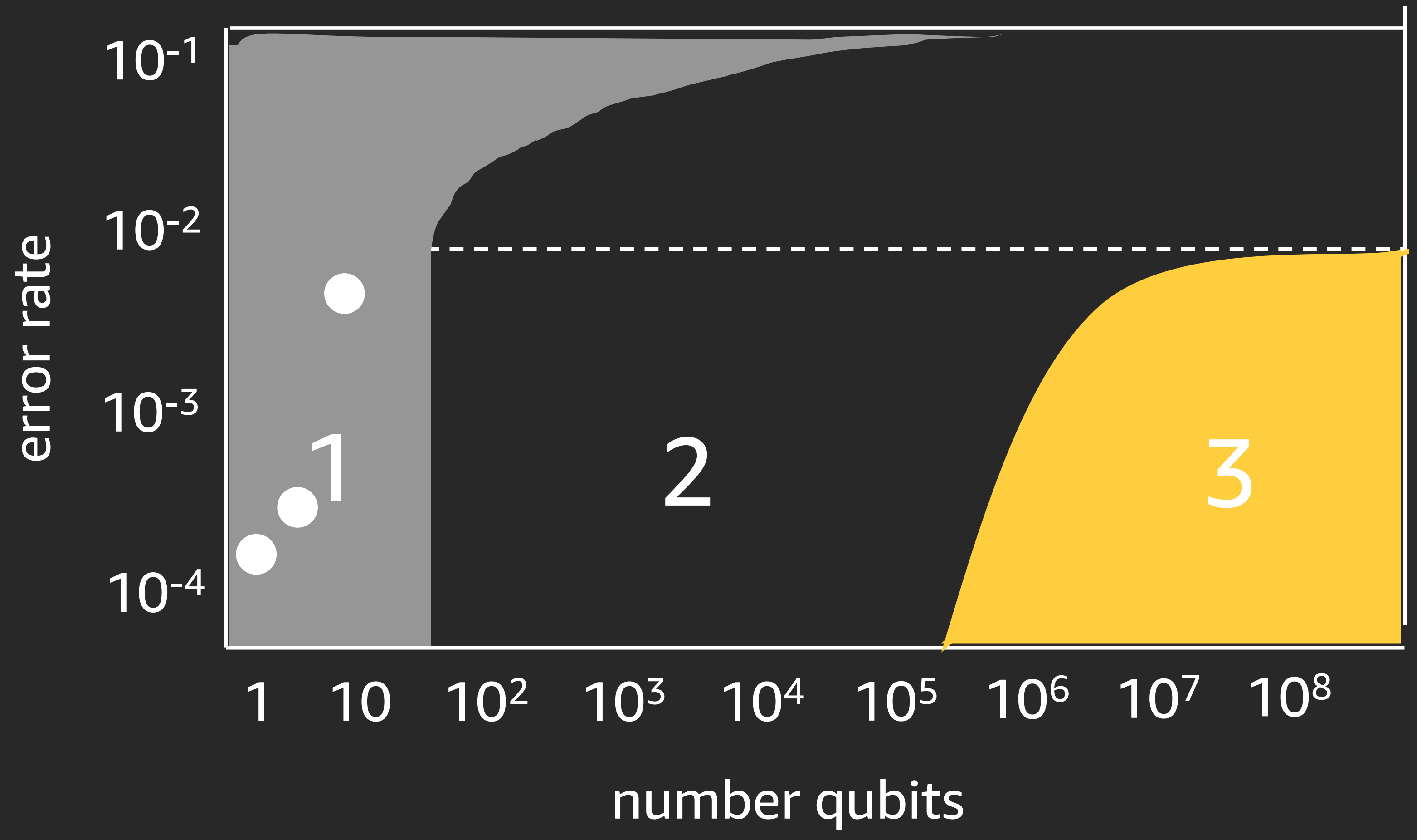
with 0.1% error rate

Quantum Computing Eras



1: classical simulatable
2: Noisy Intermediate-Scale Quantum (NISQ)
3: error-corrected quantum computing

Quantum Computing Eras



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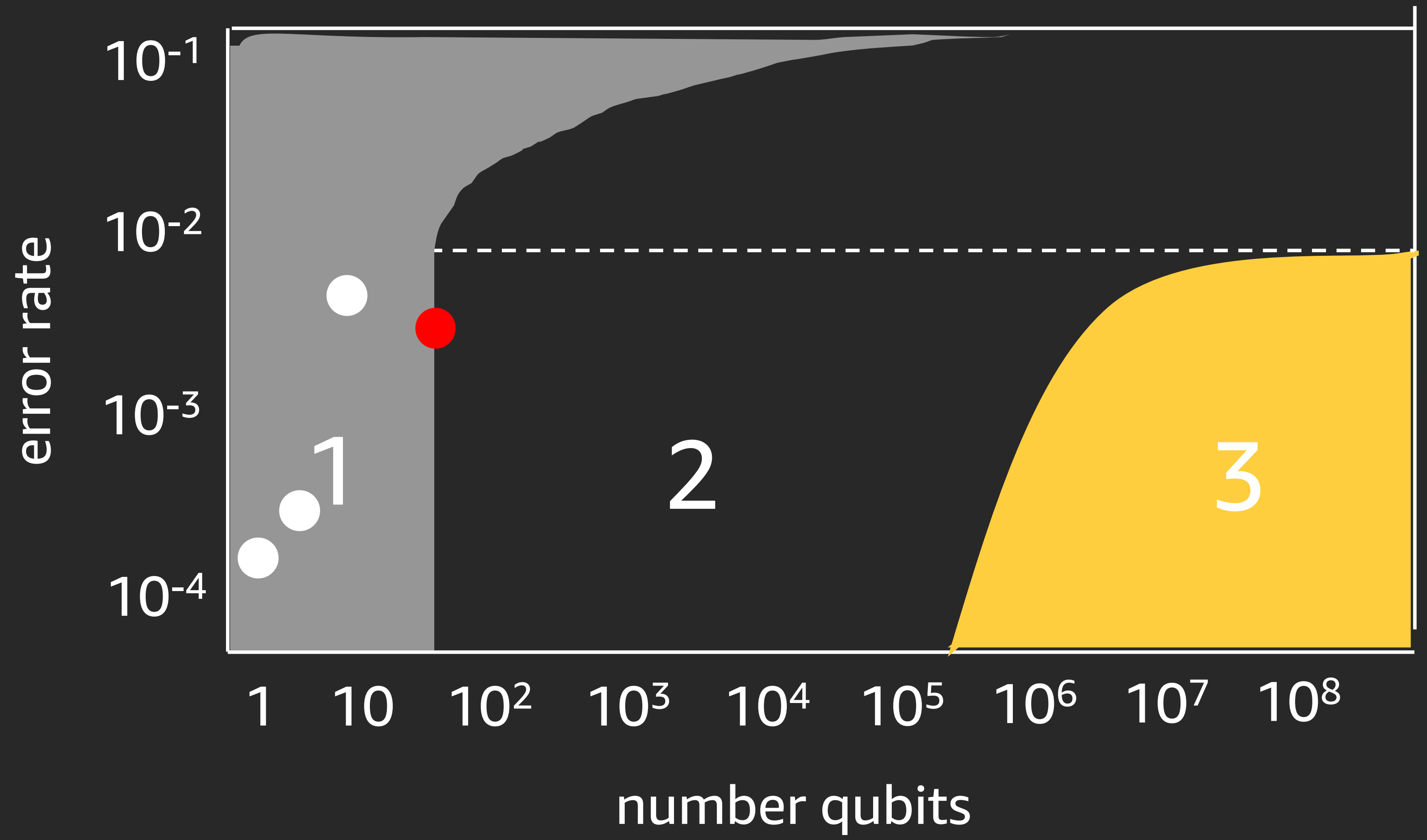
Quantum Computing Eras



1: classical simulatable
2: Noisy Intermediate-Scale Quantum (NISQ)
3: error-corrected quantum computing

Quantum Supremacy

Are current quantum hardware better than classical at *anything*?

Analogy: ‘Savant” versus pocket calculator competition

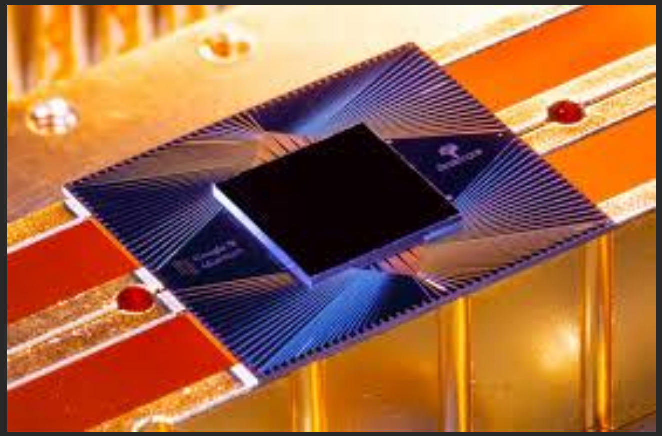
Problem: Multiply large numbers

“Supremacy” of calculator over human brain

Quantum Supremacy

Are current quantum hardware better than classical at *anything*?

Problem: Sampling from outputs from “random circuits”



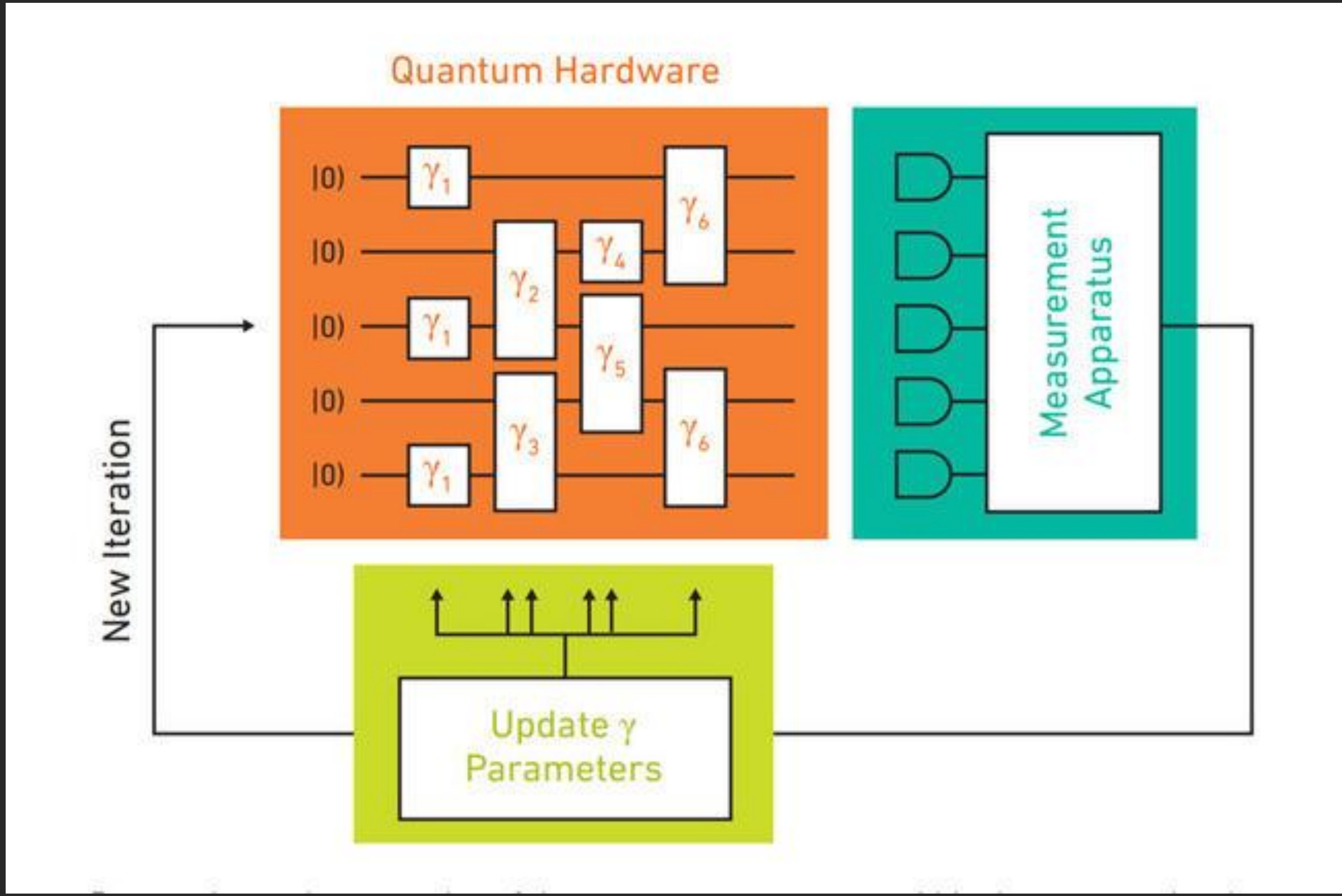
Google’s 53 qubits “Sycamore”
quantum “pocket calculator”
3 minutes

Summit Supercomputer
classical computing “savant”
3 days – 10,000 years

Noisy Intermediate-Scale Quantum

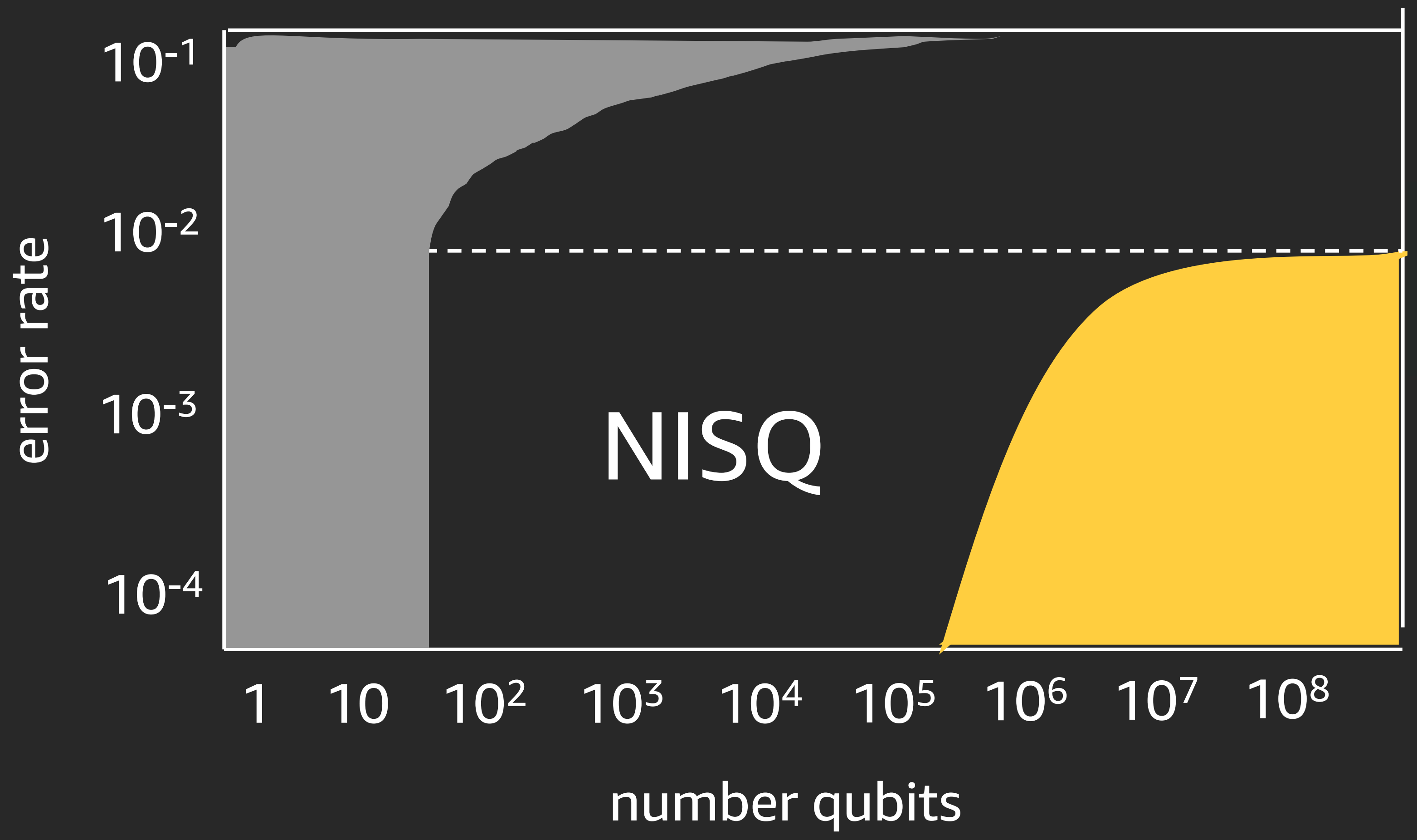
Hybrid classical-quantum methods for optimization and quantum simulation. Heuristics. But can be run much sooner!

Better hardware -> Richer class of circuits



(Olson et al, arXiv:1706.05413)

Noisy Intermediate-Scale Quantum



<50 qubits:

no application possible

>100k qubits:

Applications provably possible

First applications somewhere in between

Now it's time to get started!

Amazon Quantum Technologies

AWS re:Invent

aws

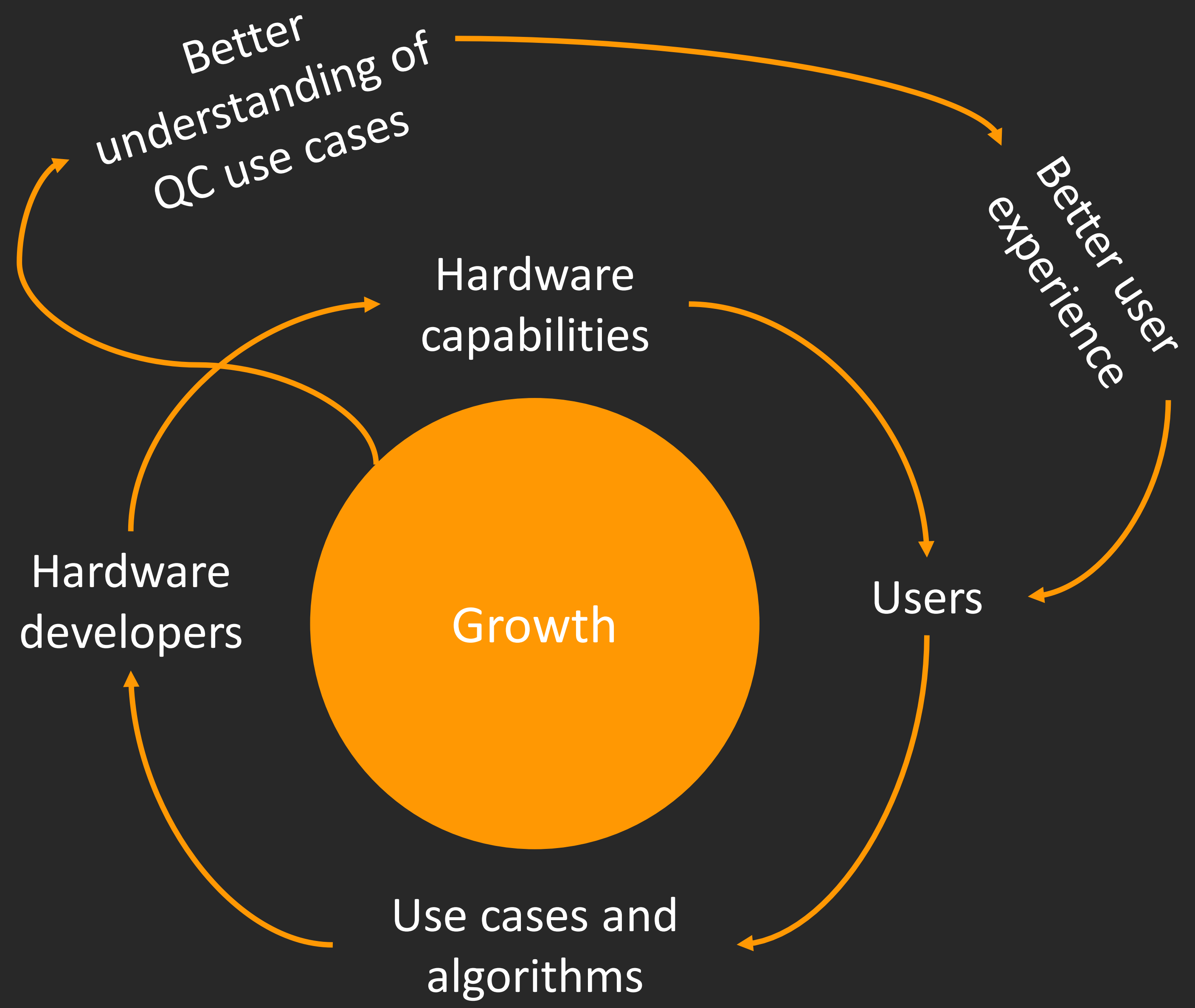
Quantum Computation: Why now?

Long-term transformative potential

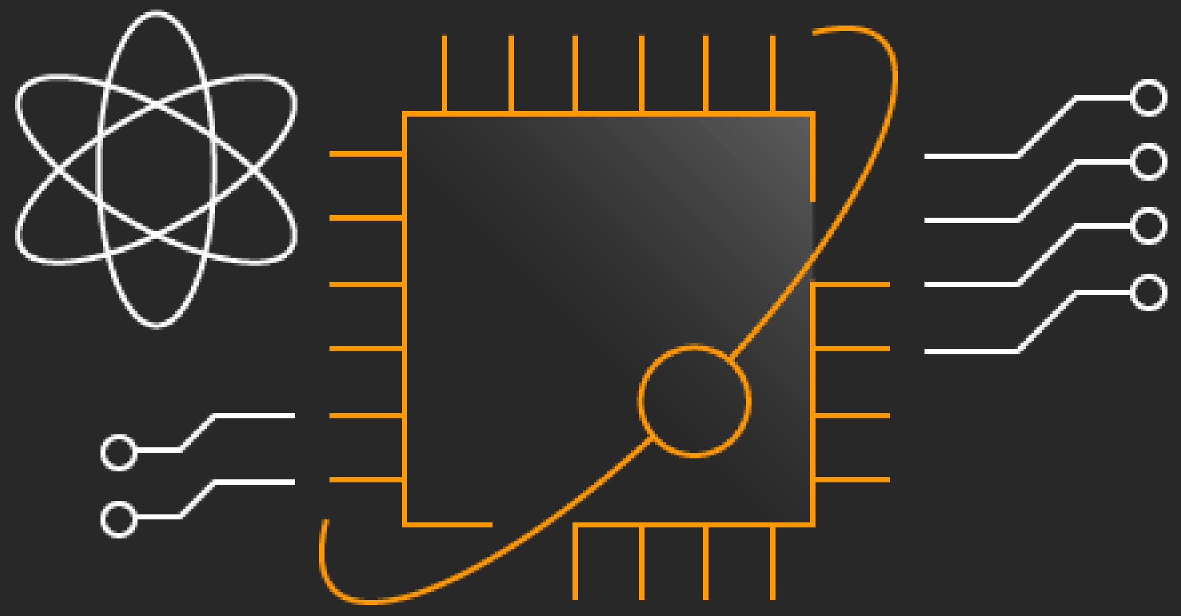
Quantum computers enter supremacy regime

Learn and build expertise

Develop new algorithms and IP



Introducing Amazon Braket



Amazon Braket puts quantum computing in the hands of every developer and scientist

Fragmented developer tools

Simulators are hard to configure and compute intensive

Quantum hardware is scarce and hard to access

Amazon Braket puts quantum computing in the hands of every developer and scientist

Fragmented developer tools

Design

Managed development environments

Simulators are hard to configure and compute intensive

Test

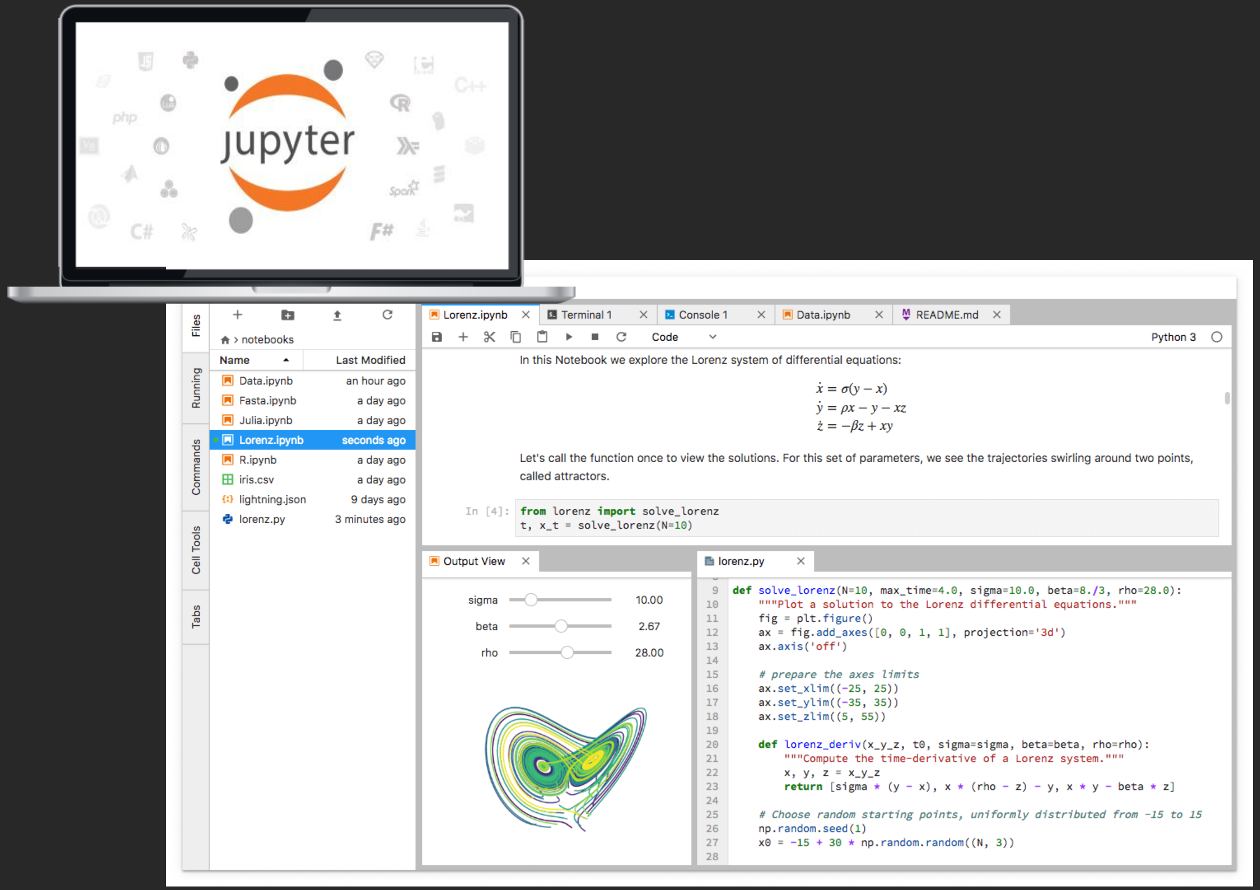
High-performing circuit simulators

Quantum hardware is scarce and hard to access

Run

Hybrid workloads on secure, on-demand quantum hardware

Design - Managed Jupyter Lab environments



Fully managed infrastructure

Pre-built environments

Learning resources

Build and test algorithms

Test - Hosted circuit simulators

Serverless execution

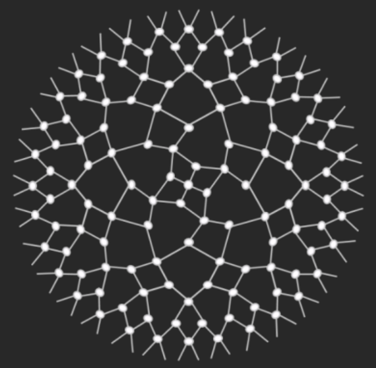
Optimized performance

Individual circuits and hybrid jobs

Schrödinger simulator

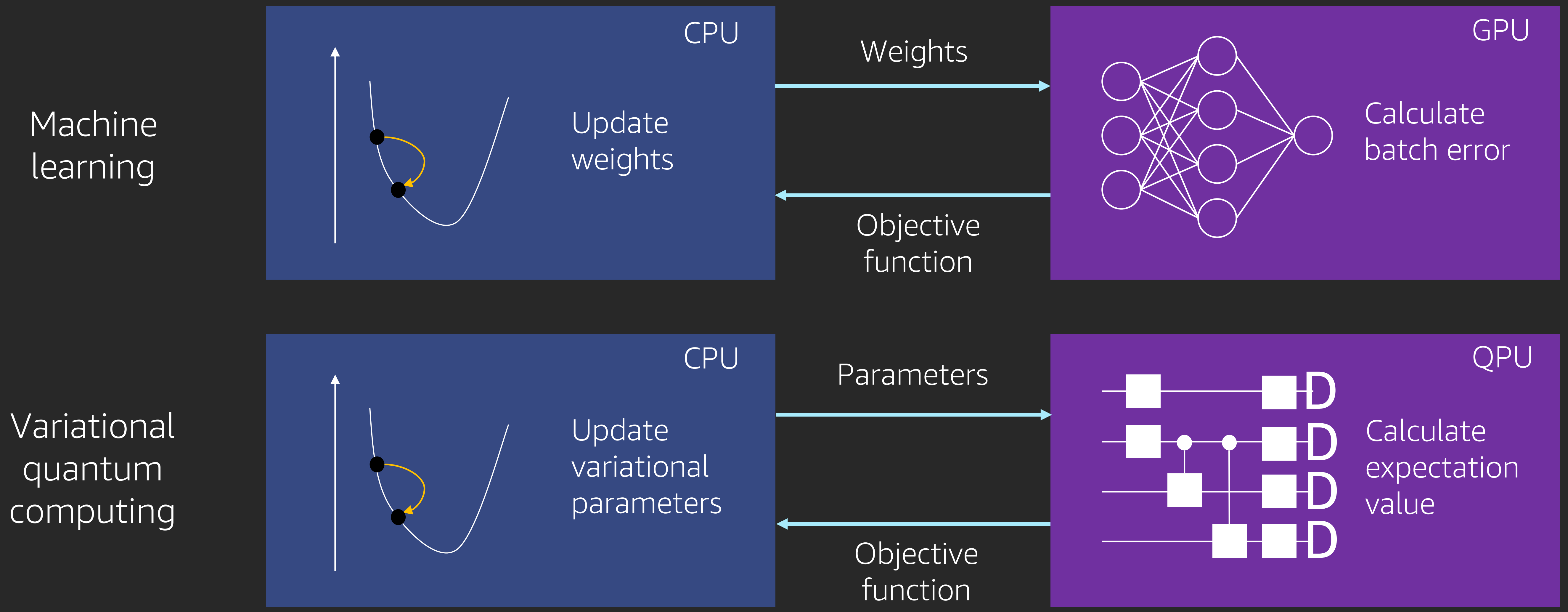
$|\Psi\rangle$

Tensor network simulator

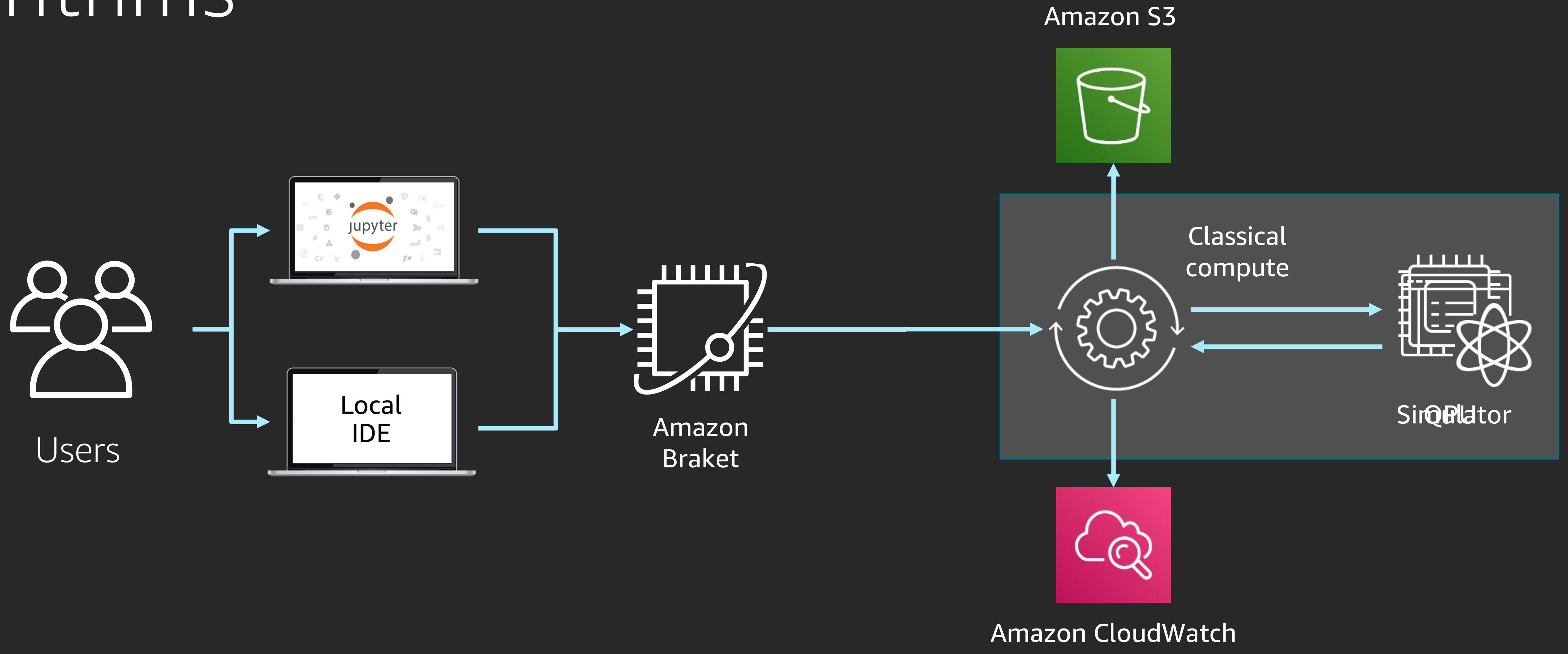


...

Near-term quantum computers will be used as co-processors



Run – Managed execution of hybrid quantum algorithms

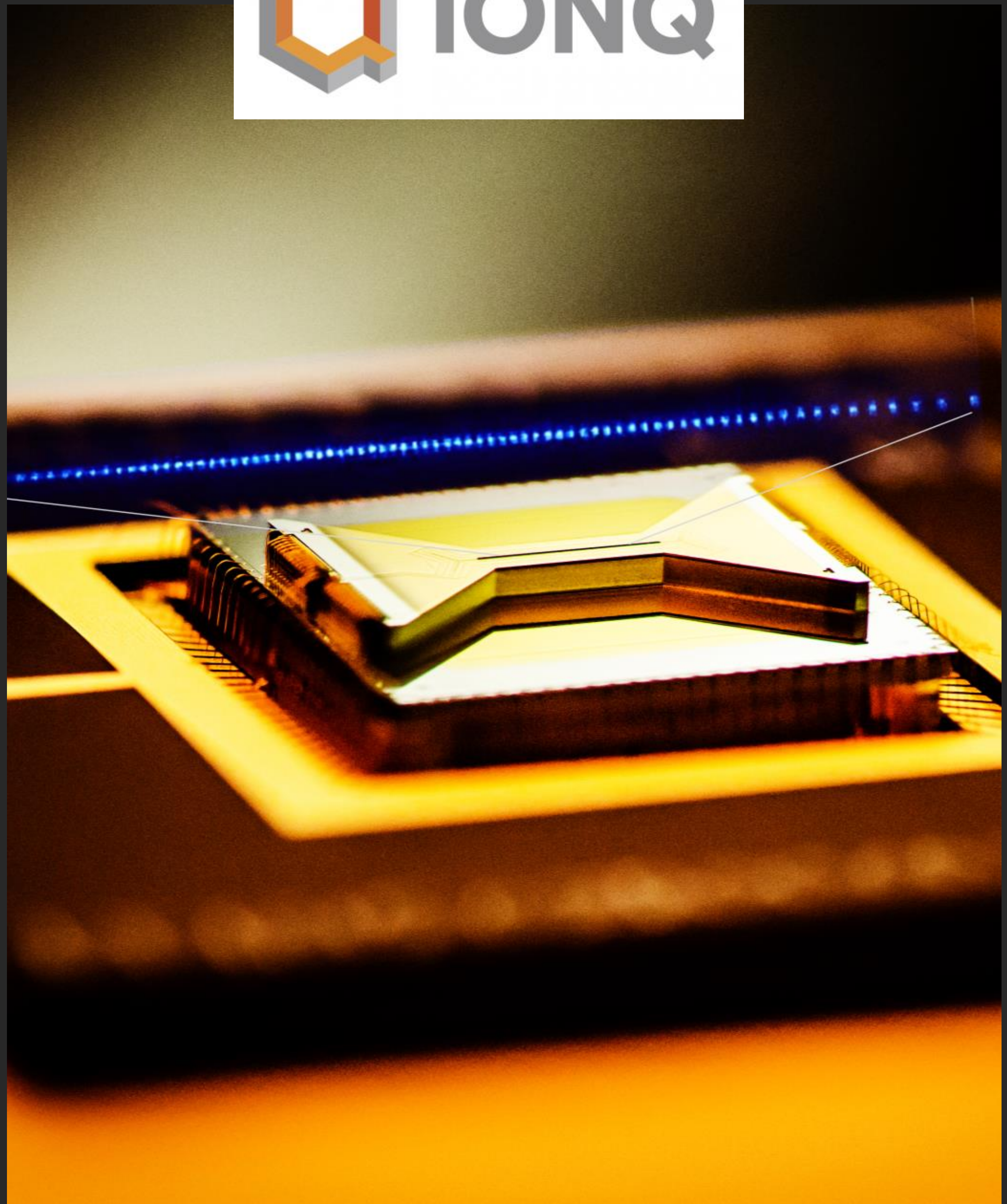


Fully managed execution

Pay only for what you use

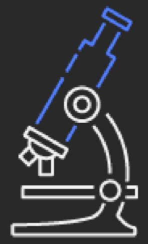
Change backend with a single line of code

Amazon Braket provides secure, on-demand access to different quantum computing technologies

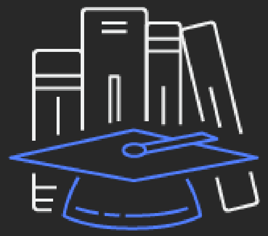


Introducing Amazon Quantum Solutions Lab

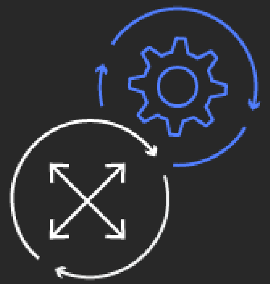
A collaboration and research program that connects Amazon quantum computing experts with AWS customers



Collaboration



Education



Solutions

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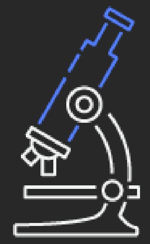
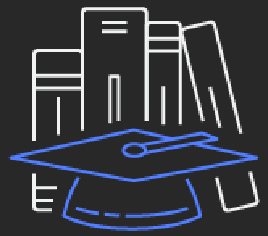


Collaboration



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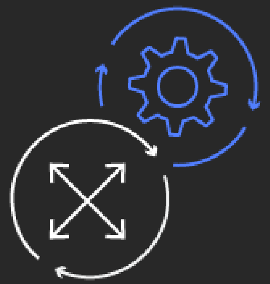
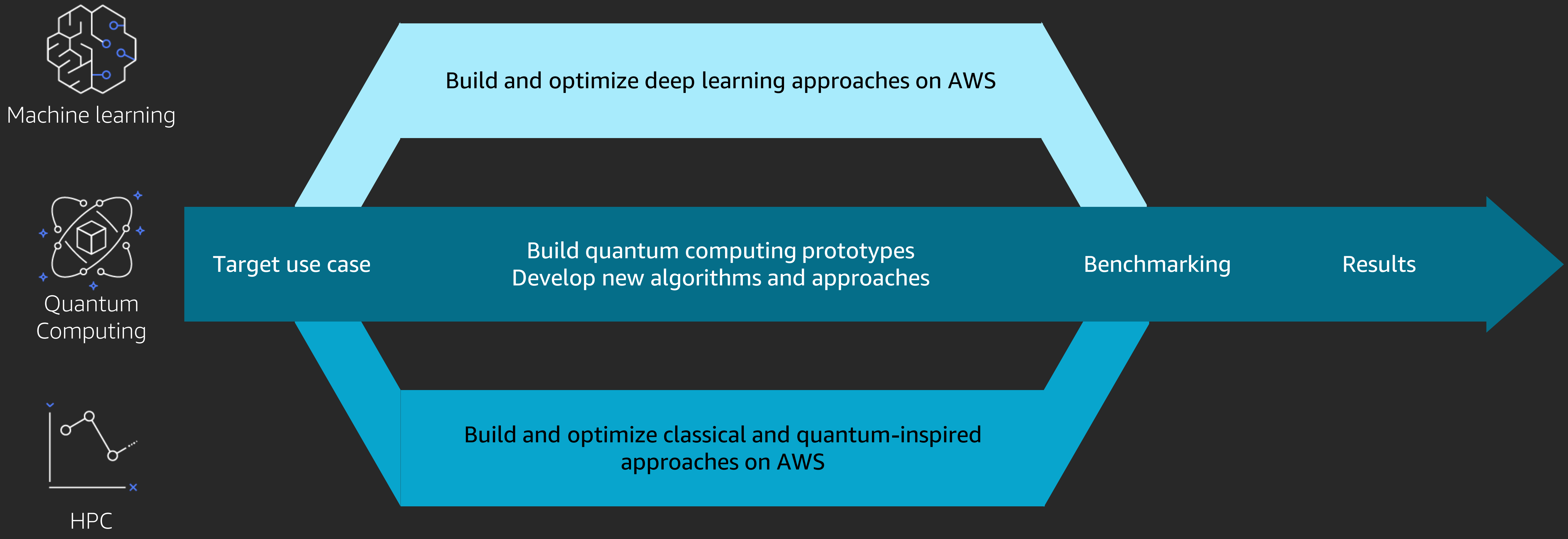


Solutions

Working backwards: quantum computing with Amazon Quantum Solutions Lab



Technology and consulting partners provide software and service solutions on Amazon Braket

XANADU

ZAPATA

rigetti

QCWARE

QSIMULATE

rahko

1QBit

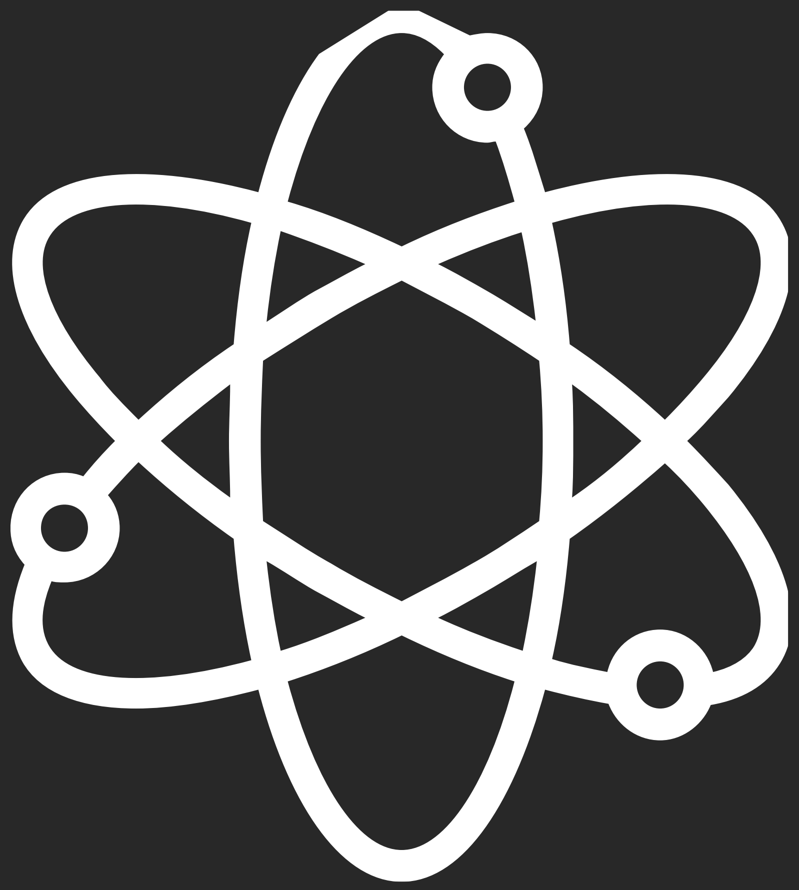
aws partner network

Introducing AWS Center for Quantum Computing

Near-term applications

Error correction & programming models

Quantum hardware and technologies



What’s next?

“It’s a marathon, not a sprint”

Amazon Braket in preview

Start researching the potential of quantum computing for your business with AWS

Thank you!

AWS re:Invent

Please complete the session survey in the mobile app.