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QCM201

Is now the right time to explore quantum computing?

Grant Salton

Quantum Research Scientist

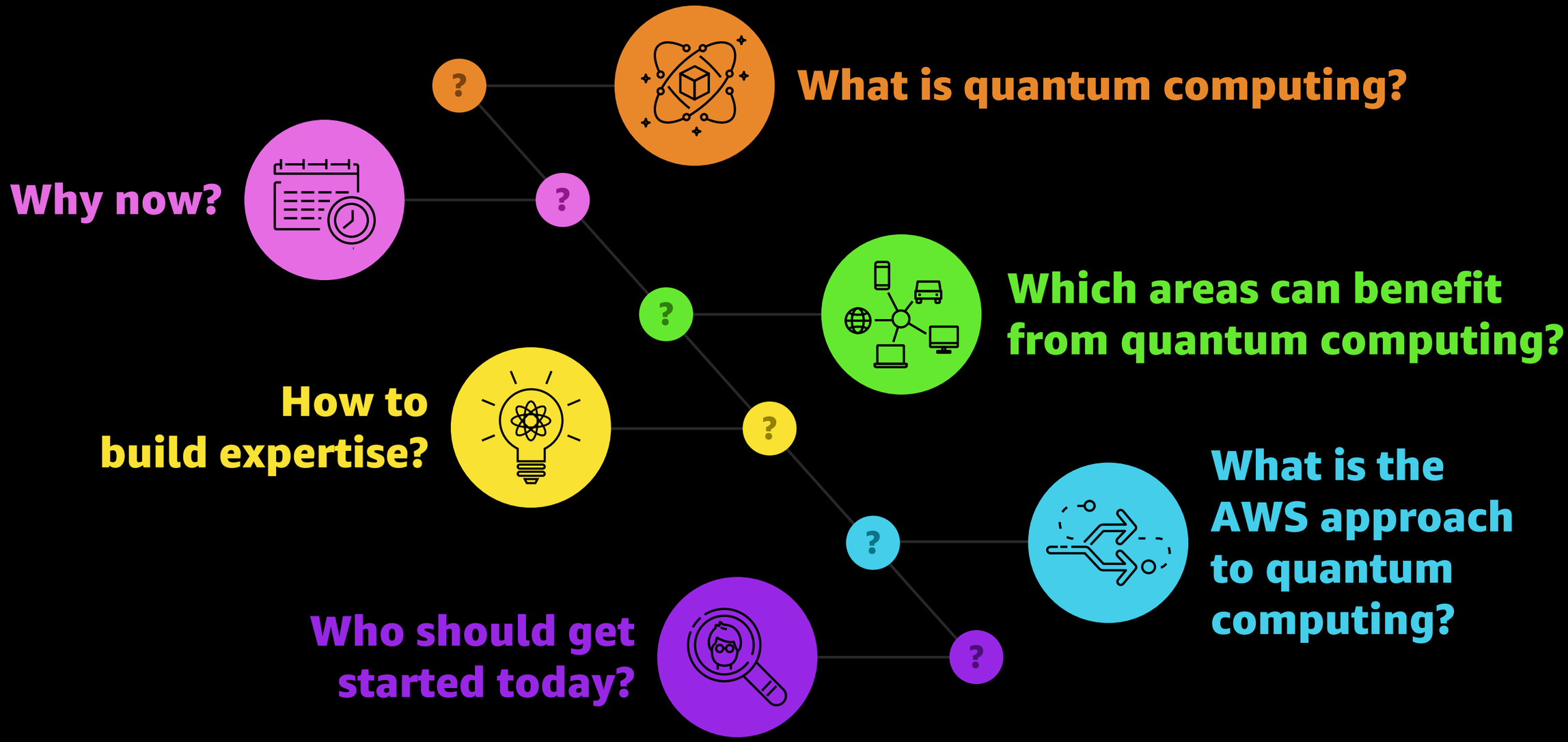
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Outline

QUESTIONS WE'LL TRY TO ANSWER





What is quantum computing?

A new paradigm for computation that leverages the laws of quantum physics

Solve problems in novel ways and access a new class of problems

Strong evidence that the **extended** Church-Turing Thesis is false

Building these sensitive devices is a difficult scientific challenge



Why now?

The field is advancing rapidly

- Technology milestones are being achieved
- Increasing choice of competing technologies
- Government initiatives stimulate activity

Starting now allows forward-thinking customers to

- Understand the long-term transformative potential
- Plan ahead, manage risk, and identify strengths and weaknesses
- Learn new skills, build expertise, and collect resources
- Develop new algorithms and IP

We have algorithms for the long haul

SOME WELL-KNOWN QUANTUM ALGORITHMS:

Number theory
Factoring
Discrete log
Subset sum
Cryptanalysis
…

Optimization
Constraint satisfaction
Solving linear systems
Machine learning
Solving ODEs, PDEs
…

Oracular
Search
Hidden subgroup
Hidden shift
Order finding
…

Simulation/ approximation
Knot invariants
QAOA
SDPs
Direct simulation
…

These algorithms will be useful when we have a universal fault tolerant quantum computer, and they can be applied to a variety of use cases



Quantum computing is broadly applicable

WE HAVE USE CASES ACROSS MANY VERTICALS

Financial Services
Automotive
Energy and Gas

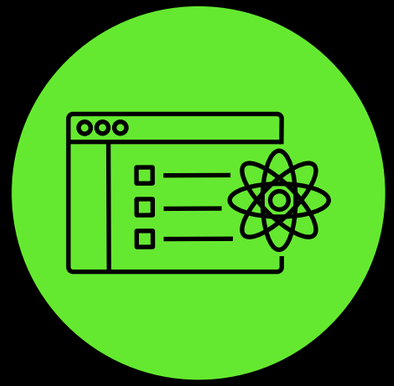
Pharmaceutical
Biotechnology
Manufacturing

Academic Research
Government
…

…YET WE SEE THE STRONGEST USER SIGNALS IN



Optimization (esp. finance)



Computational chemistry



Hybrid methods



Building expertise

Optimization



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Near-term approaches to quantum optimization



Optimization (esp. finance)

EXAMPLE USE CASES

Option pricing	Vehicle routing
Portfolio optimization	Oil & Gas reservoir simulation
Candidate drug selection	Manufacturing logistics

EXAMPLE:

In the near-term many problems can be formulated in terms of:

Quadratic Unconstrained Binary Optimization (QUBO)

$$\text{minimize/maximize } Y = \sum_{i,j} Q_{i,j} X_i X_j = X^\top Q X, \text{ where } X_i \in 0, 1 \text{ and } Q_{i,j} \in \mathbb{R}$$

Need to understand the QUBO formalism and mapping

Solve QUBO problems with quantum hardware and physics-based methods

Solving QUBO problems on quantum hardware

Quadratic Unconstrained Binary Optimization (QUBO)

$$\text{minimize/maximize } Y = \sum_{i,j} Q_{i,j} X_i X_j = X^\top Q X, \text{ where } X_i \in 0, 1 \text{ and } Q_{i,j} \in \mathbb{R}$$



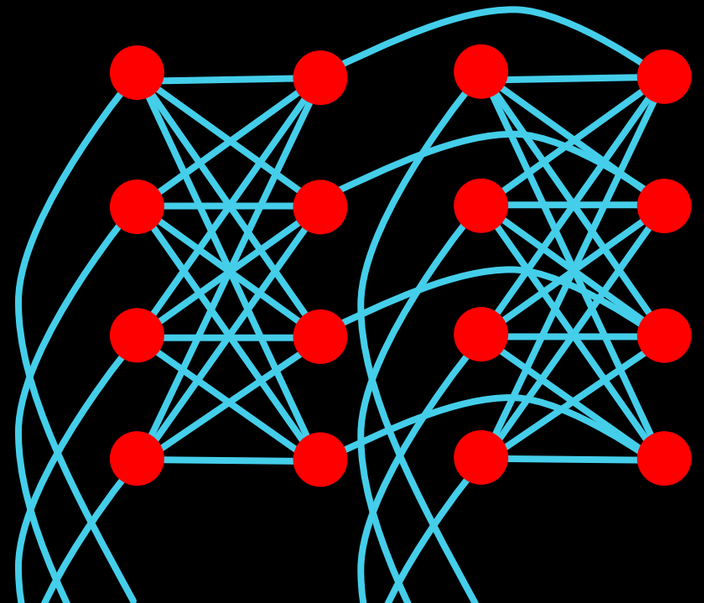
Optimization (esp. finance)

TWO SUBPROBLEMS:

Reduction: Map the problem onto a QUBO

Embedding: Embed QUBO onto a Chimera or Pegasus graph (lower connectivity)
NP-hard!

D-Wave
The Quantum Computing Company™



Nature-inspired techniques can also be used



Optimization (esp. finance)

Quadratic Unconstrained Binary Optimization (QUBO)

$$\text{minimize/maximize } Y = \sum_{i,j} Q_{i,j} X_i X_j = X^\top Q X, \text{ where } X_i \in 0, 1 \text{ and } Q_{i,j} \in \mathbb{R}$$

Physics-inspired classical solutions use a novel approach, but they rely on classical backends to compute

Some solvers can handle large QUBO problems with ~10^4 variables



QUBO Solver

By: Meta-Analytics Latest Version: 1.2.0

State of the art QUBO solver.

Linux/Unix ☆☆☆☆☆ 0 AWS reviews

Alternatively, use gate-based approach via QAOA

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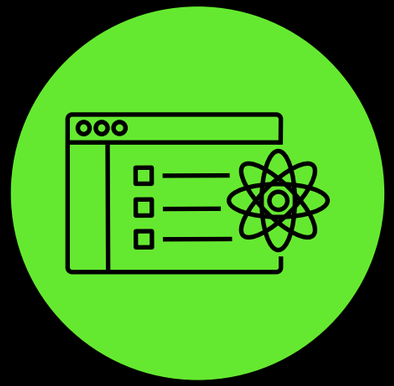
Computational chemistry



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Quantum computing & computational chemistry



Computational chemistry

EXAMPLE USE CASES

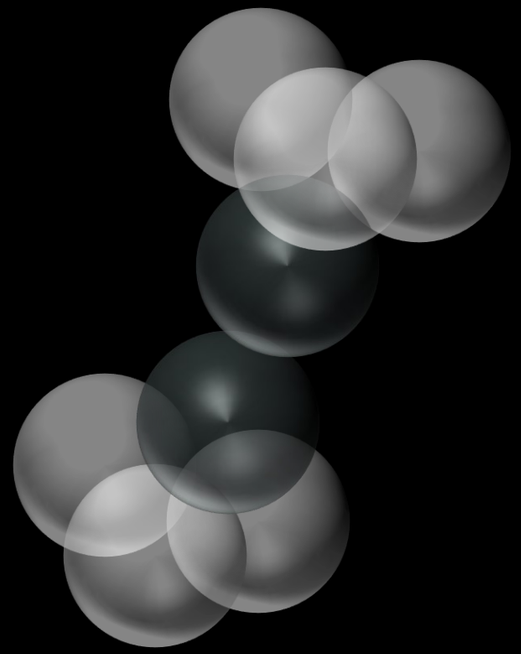
Ground state energy computation

Electronic structure simulation

Antigen binding energy

Molecular similarity for virtual screening

Lattice protein folding



Substantial progress has been made in classical approaches to chemistry

Use cases benefit from ML and HPC classical solutions

Quantum approaches are largely hybrid quantum methods

Hybrid algorithms



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Hybrid methods are promising NISQ algorithms

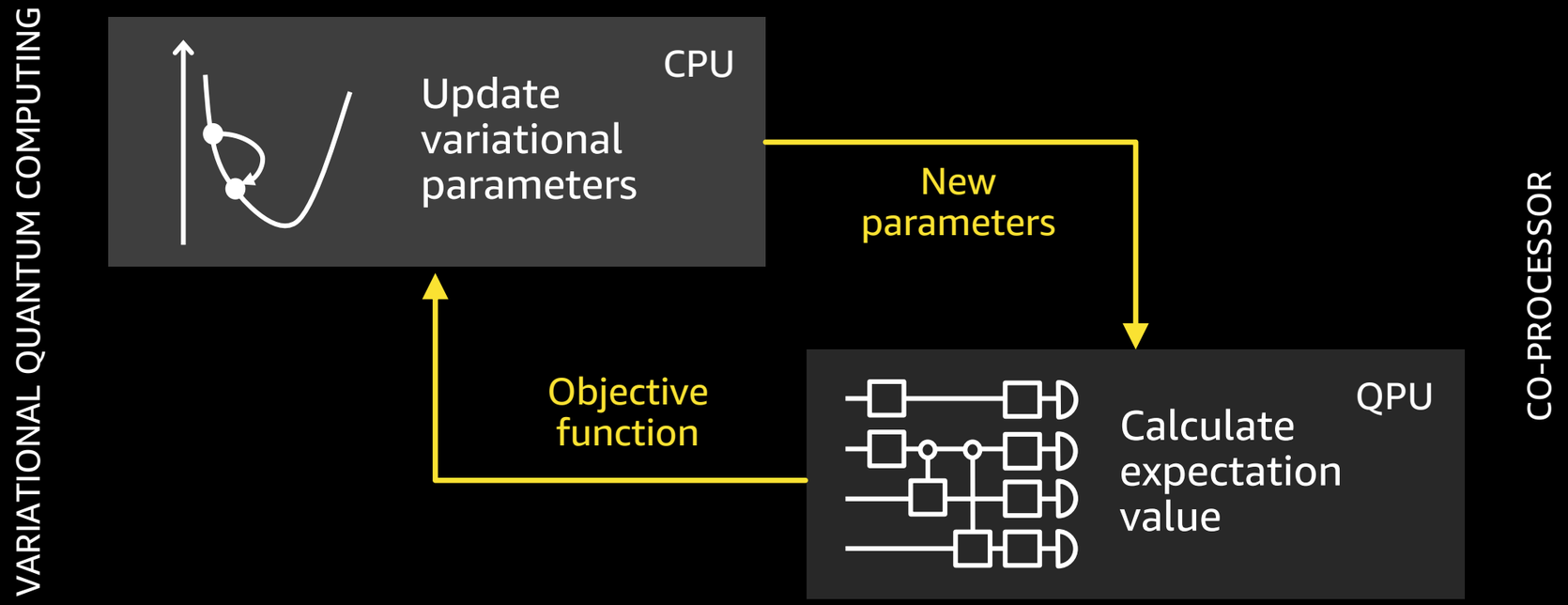


Hybrid methods

Noisy Intermediate Scale Quantum (NISQ)

Variational methods like the Quantum Approximate Optimization Algorithm (QAOA) and Variational Quantum Eigensolver (VQE) will likely make the best use of quantum hardware

QUANTUM COMPUTERS AS A CO-PROCESSORS:



Building expertise



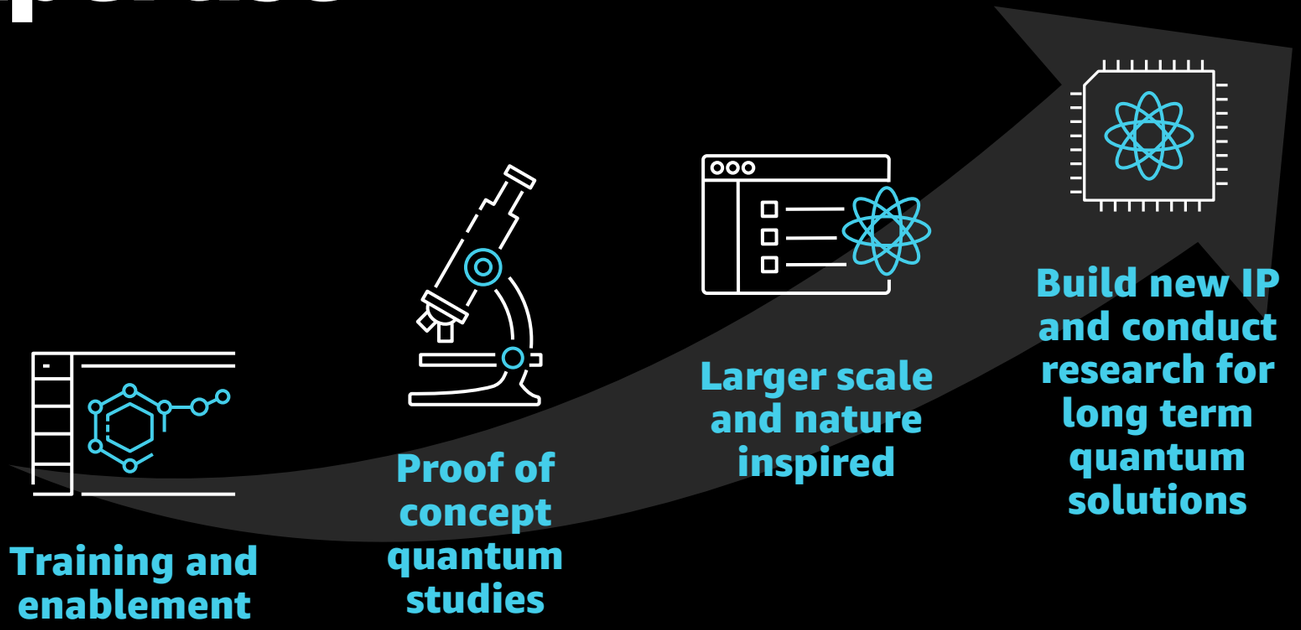
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How to build expertise



Building expertise



USERS ARE LOOKING TO LEARN BY DOING

Small-scale proof of concepts (PoC) or reproduce known results

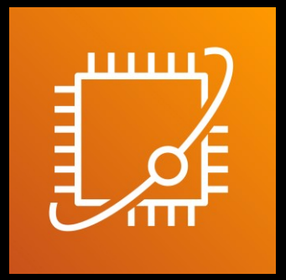
Map PoC onto a use case. Modify or scale up

Push boundaries using state-of-the-art classical methods

Iterate and innovate; Discover applications and build IP

Quantum computing at AWS

Amazon Braket



Democratize quantum computing

Fully managed service that makes it easy to explore and experiment

Amazon Quantum Solutions Lab



Provide expert guidance

Practical and cross-discipline support and collaboration

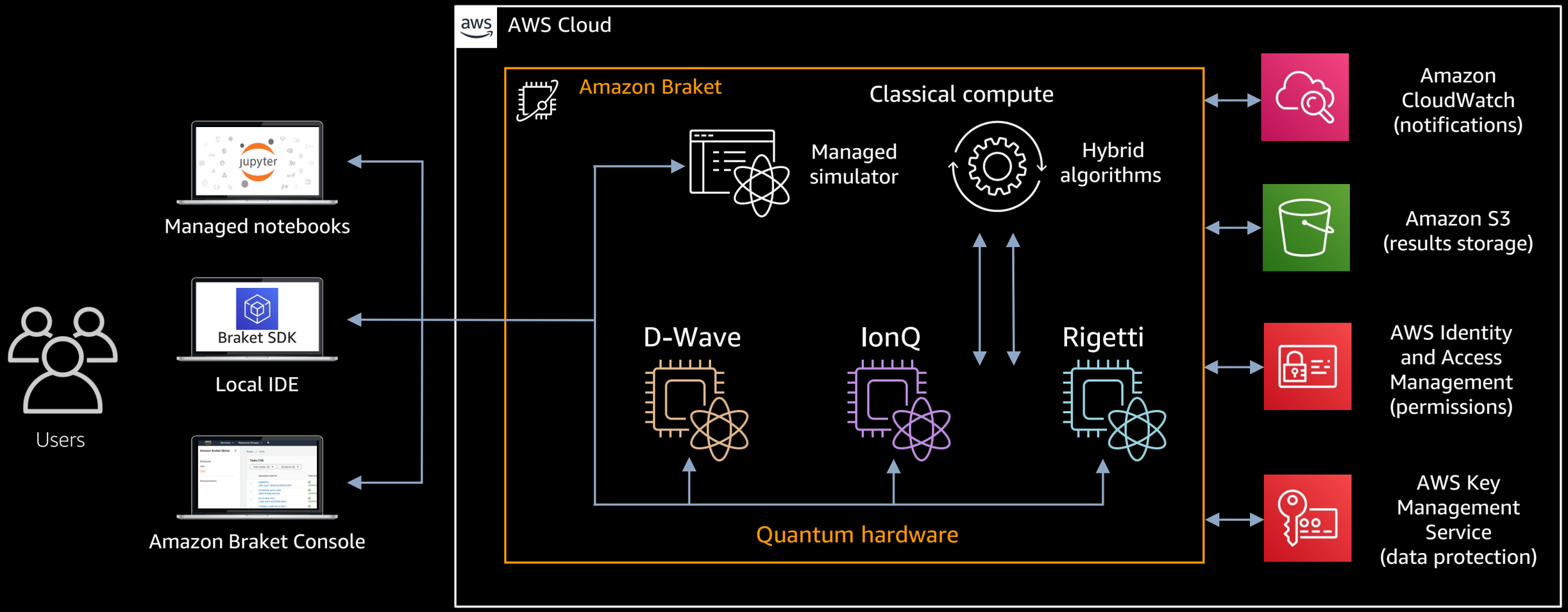
AWS Center for Quantum Computing



Push the boundaries

Research quantum algorithms and hardware

Amazon Braket is fully integrated in AWS

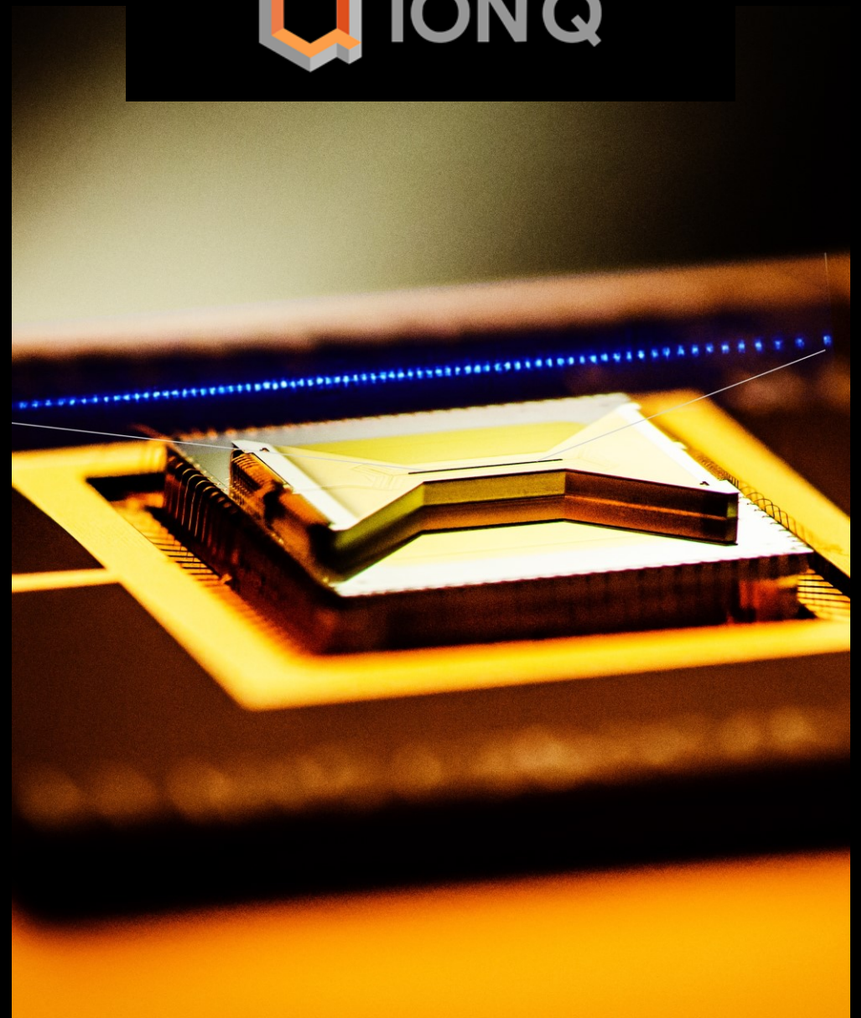


Secure, on-demand access to different quantum computers via Amazon Braket

D-Wave
The Quantum Computing Company™



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Amazon Quantum Solutions Lab approach

WORKING BACKWARDS



Machine learning



Quantum Computing



HPC

Build and optimize deep learning approaches on AWS

Target use case

Build quantum computing prototypes
Develop new algorithms and approaches

Benchmarking

Results

Build and optimize HPC and nature inspired approaches on AWS

What can be done with quantum computing

Today

- Design and test solutions
- Run hybrid classical/quantum workflows
- Small proof of concept projects
- Push boundaries of classical methods
- Potential NISQ applications?

Tomorrow

- Larger, early applications
- First demonstration of commercially relevant quantum advantage
- Eventually:
  Full, fault tolerant quantum computation



“Every new thing creates two new questions and two new opportunities.”

Jeff Bezos

Founder and CEO of Amazon

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YES!

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Thank you!



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