AWS re:Invent

NOV. 29 – DEC. 3, 2021 | LAS VEGAS, NV

QTC301

Deep dive on quantum computing on AWS with Amazon Braket

Richard Moulds
General Manager, Amazon Braket
AWS

Tyler Takeshita, PhD
Specialist Solutions Architect, Quantum Computing
AWS

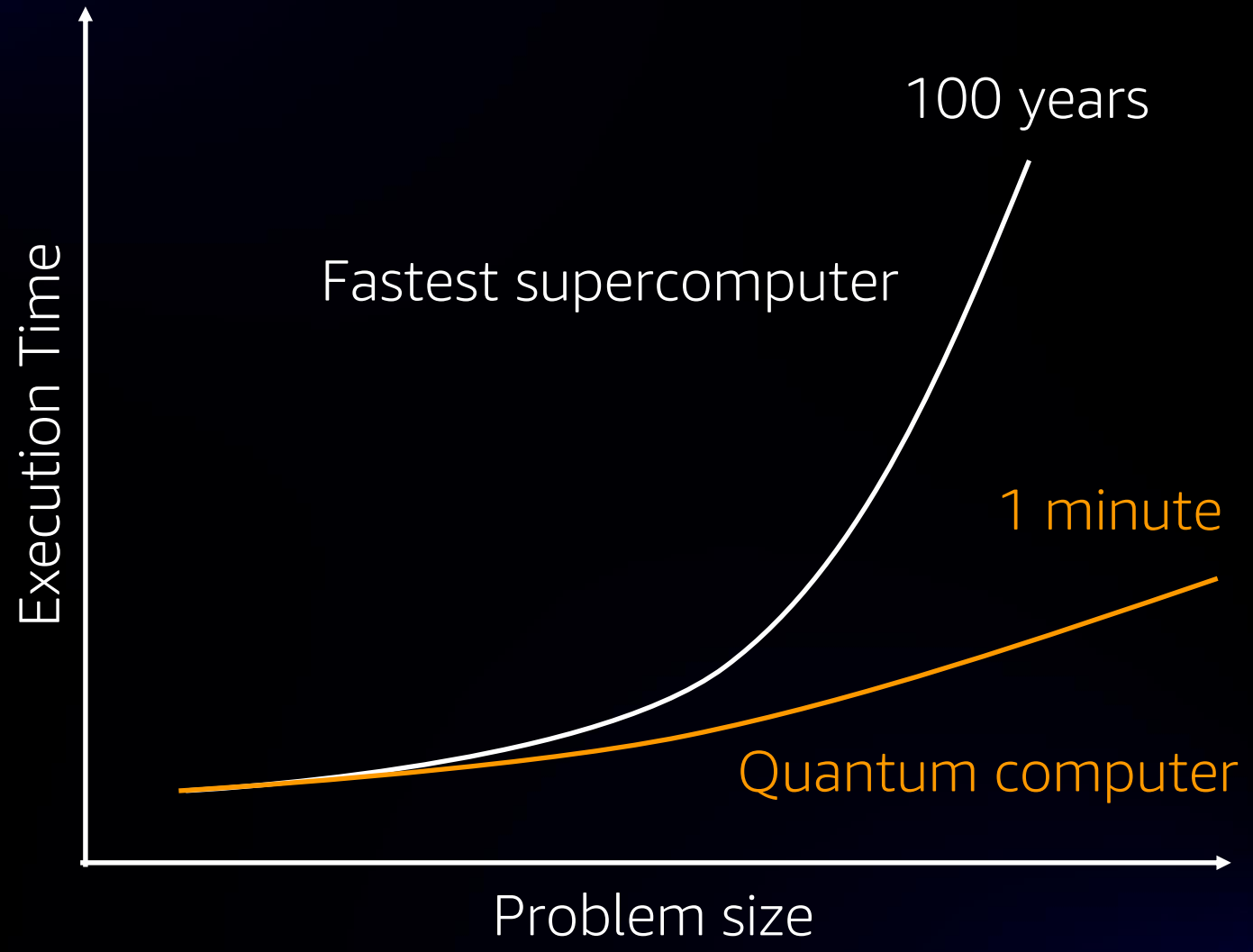
Marco Pistoia, PhD
Head of Research & Quantum Computing, Distinguished Engineer
JPMorgan Chase & Co.

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Potential to disrupt



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Potential applications



Logistics

Traffic routing, network optimization, manufacturing workflow



Machine learning

Reinforcement learning, search, sampling, neural networks



Finance

Portfolio selection, risk management, trading decisions

Agriculture

Manufacture fertilizer with less energy



Energy

Model photosynthesis for cheaper solar cells, battery tech, materials for carbon capture





Pharma

Time-to-market for new drugs, molecular simulation to find stable configurations

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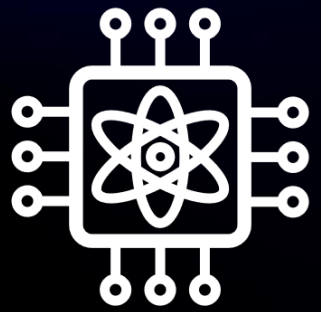
What does it mean for me?

When should I get involved?

How can I get started?

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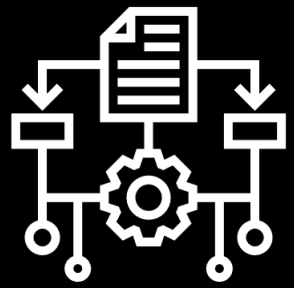
Quantum community



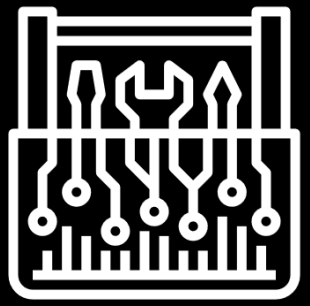
Hardware providers



Industry



Application specialists



Tooling developers



Governments



Researchers



Educators

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Catalyst for innovation

Build on Braket

Enterprises 

Solution providers 

Research on Braket

Researchers 

Teach on Braket

Educators 

Secure and private

Operational consistency

Integrated services

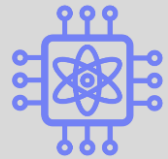
Technical support

Simple pricing

Marketing platform

Developer environment

Amazon Braket

Quantum hardware providers 

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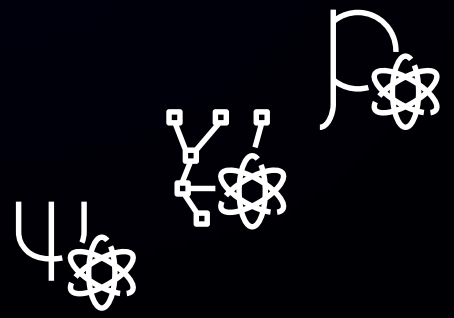
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Amazon Braket



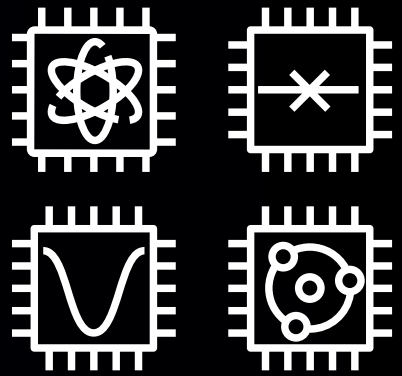
Build

- Managed notebooks
- Example algorithms
- Tutorials



Test

- Free simulator in the SDK for debugging
- Fully managed, high-performance simulators



Run

- Access multiple quantum computers
- Integrate quantum and classical resources



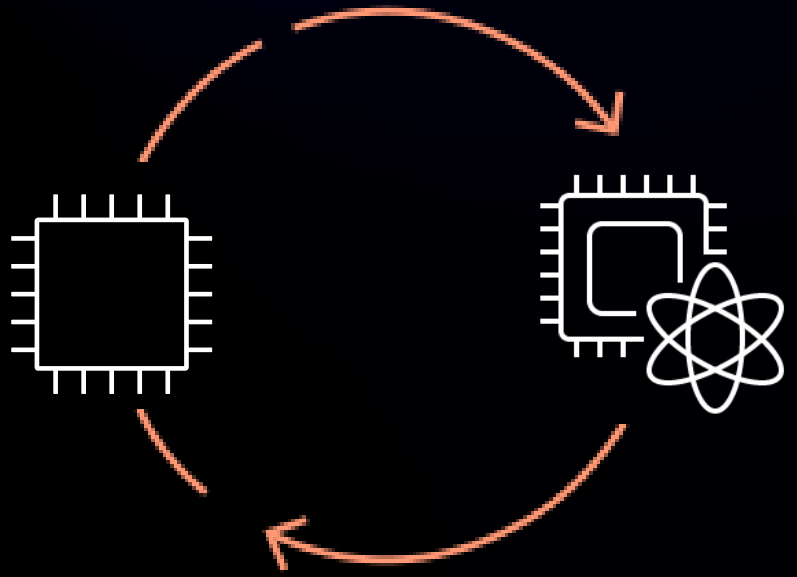
Analyze

- Monitor progress
- Notify on completion
- Measure performance

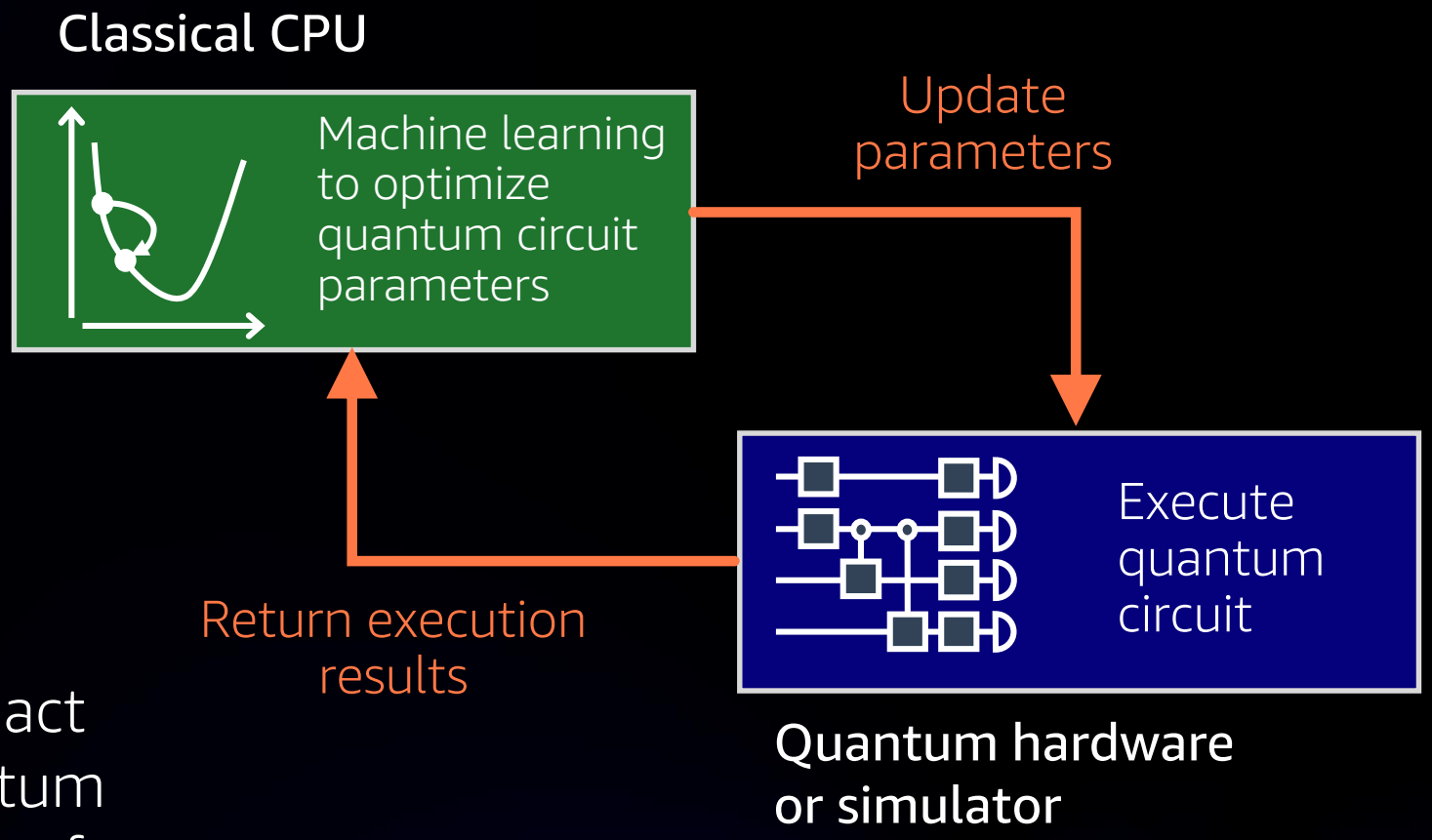
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Hybrid classical-quantum algorithms

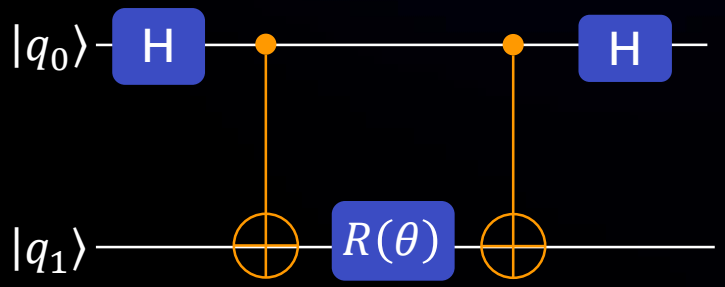


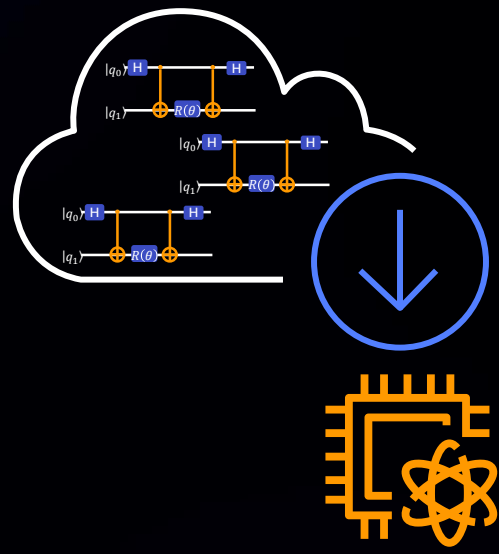
Classical and quantum processors act as co-processors, optimizing quantum algorithms to minimize the impact of noise and errors

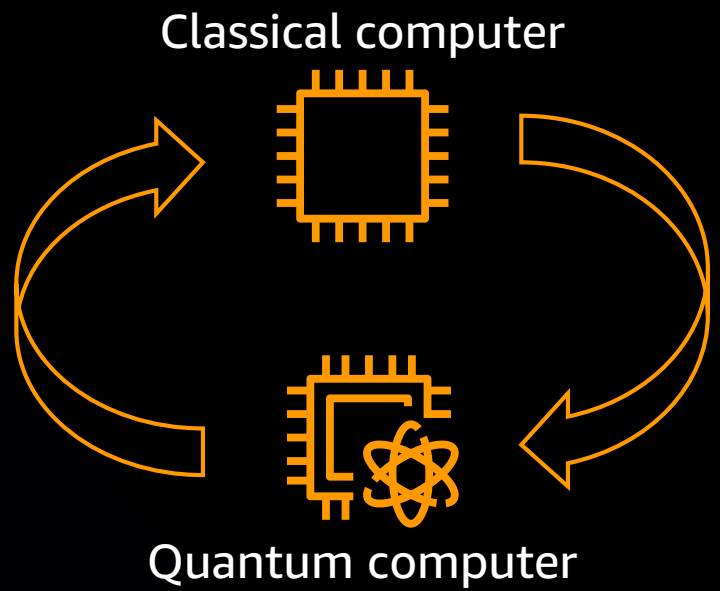


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Shots – tasks – jobs







Shot

Single execution of quantum operation on a device

Task

Series if repeated shots on a device
(10s–10,000s shots per task)

Hybrid job

Sequence of classical and quantum compute cycles
(10s to 1,000s of tasks per job)

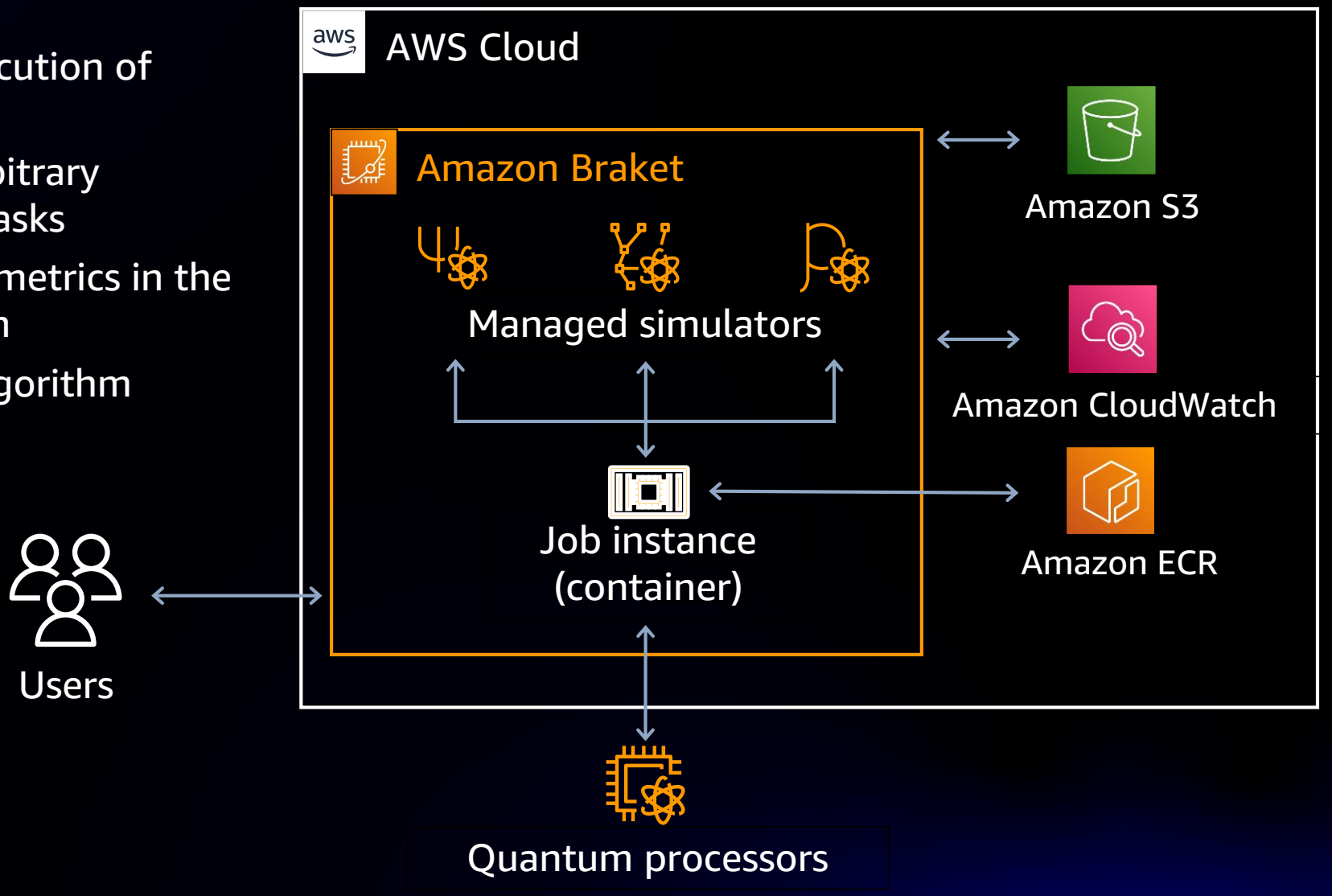
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Amazon Braket hybrid jobs

Easily design and manage the execution of hybrid algorithms

- Fully managed execution of arbitrary algorithm code and quantum tasks
- Job monitoring and algorithm metrics in the Braket console and CloudWatch
- Prebuilt or “bring your own” algorithm
- On-demand priority access



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Submitting an Amazon Braket hybrid job

Submitting a quantum task

- Define device
- Provide circuit
- Run quantum task

```
device = AwsDevice("arn:aws:braket:::device/quantum-simulator/amazon/sv1")
result = device.run(bell, s3_folder, shots = n_shots)
```

Submitting a hybrid job

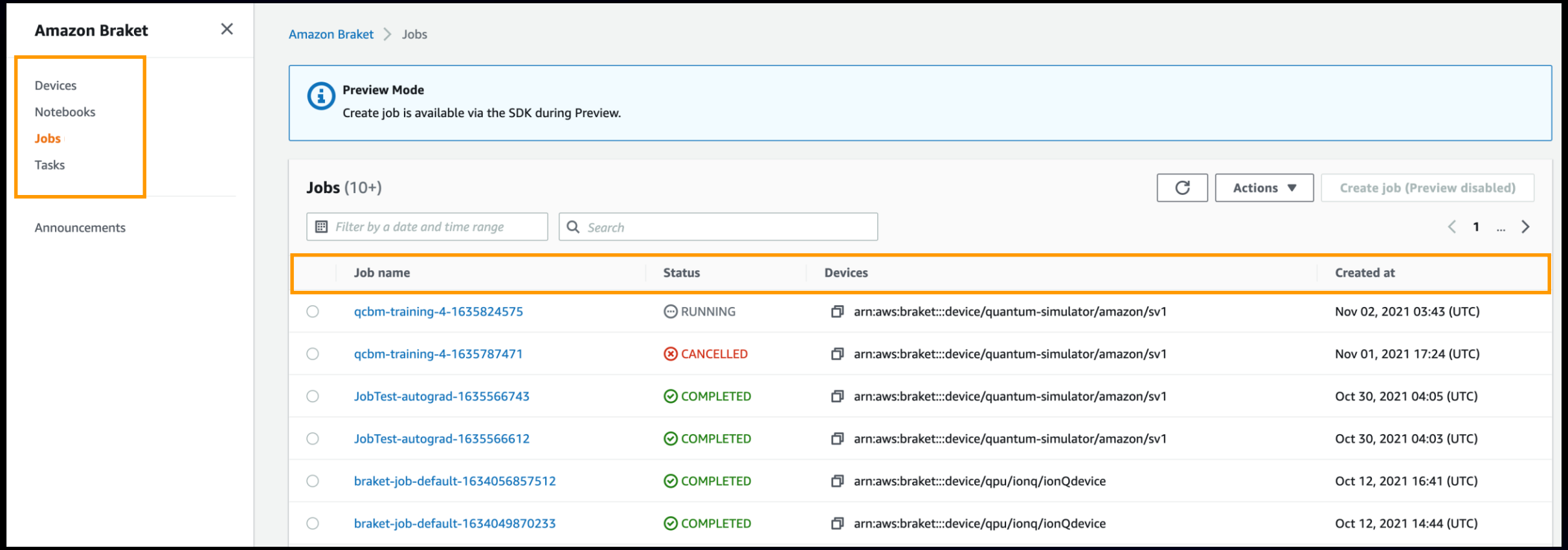
- Define device
- Select your container image
- Provide input data
- Provide algorithm code
- Create hybrid job

```
job = AwsQuantumJob.create(
    device_arn=device_arn,
    source_module="qcbm_job.py",
    job_name=f"qcbm-training-{n_qubits}-" + str(int(time.time())),
    image_uri=image_uri,
    entry_point="qcbm_job:main",
    hyperparameters=hyperparams,
    input_data_config=input_data(),
    wait_until_complete=True,
)
```

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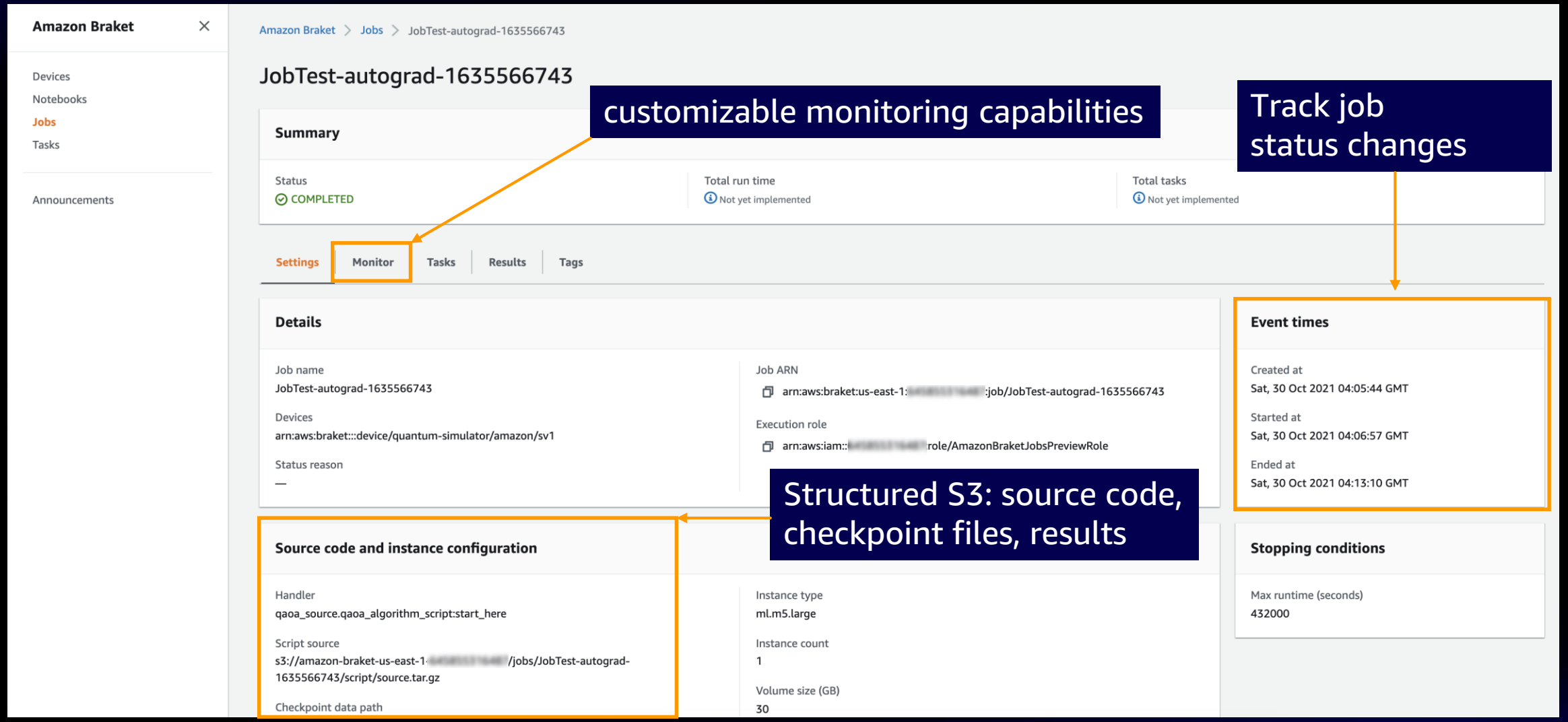
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Check the status of your Braket jobs



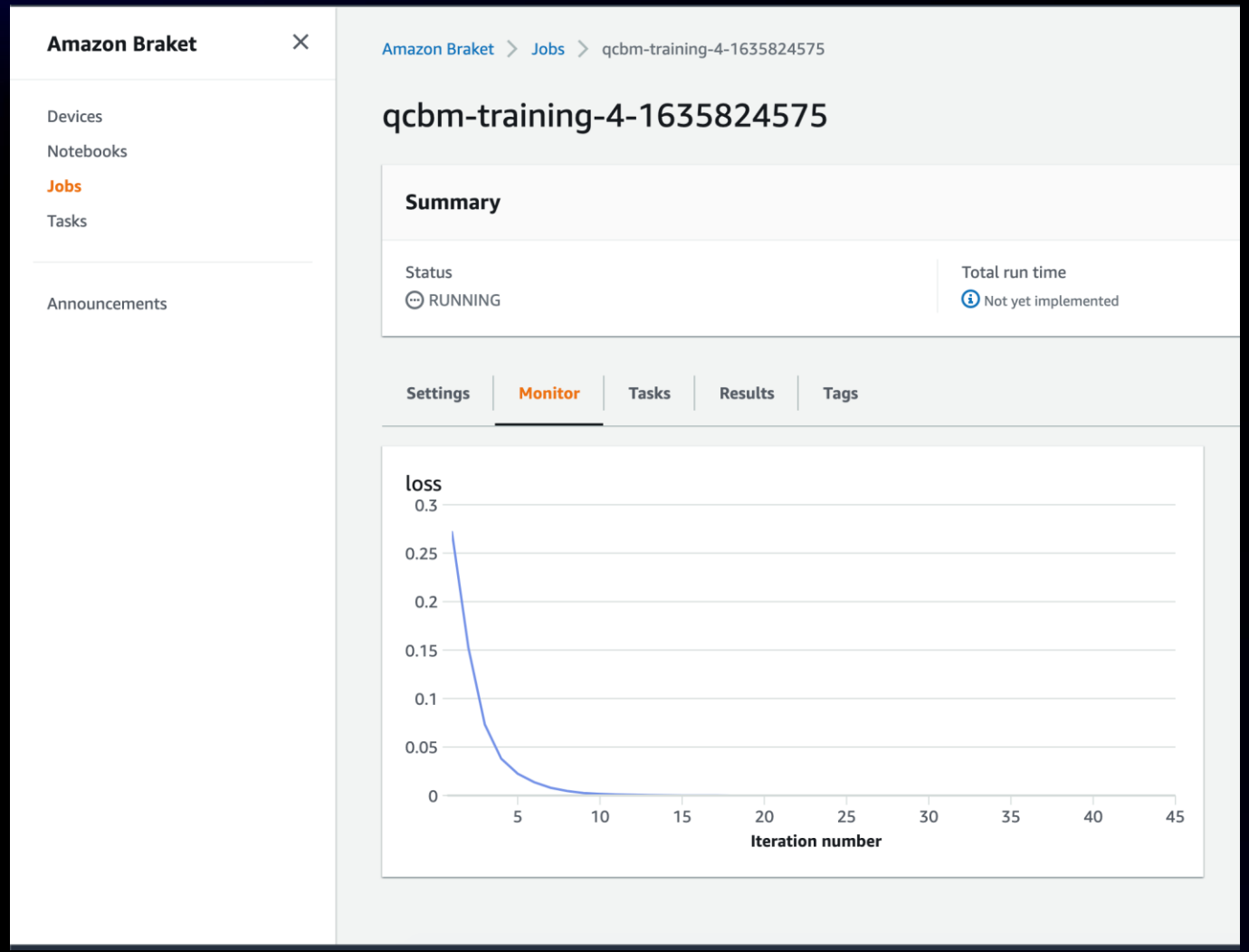
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Results stored in Amazon S3



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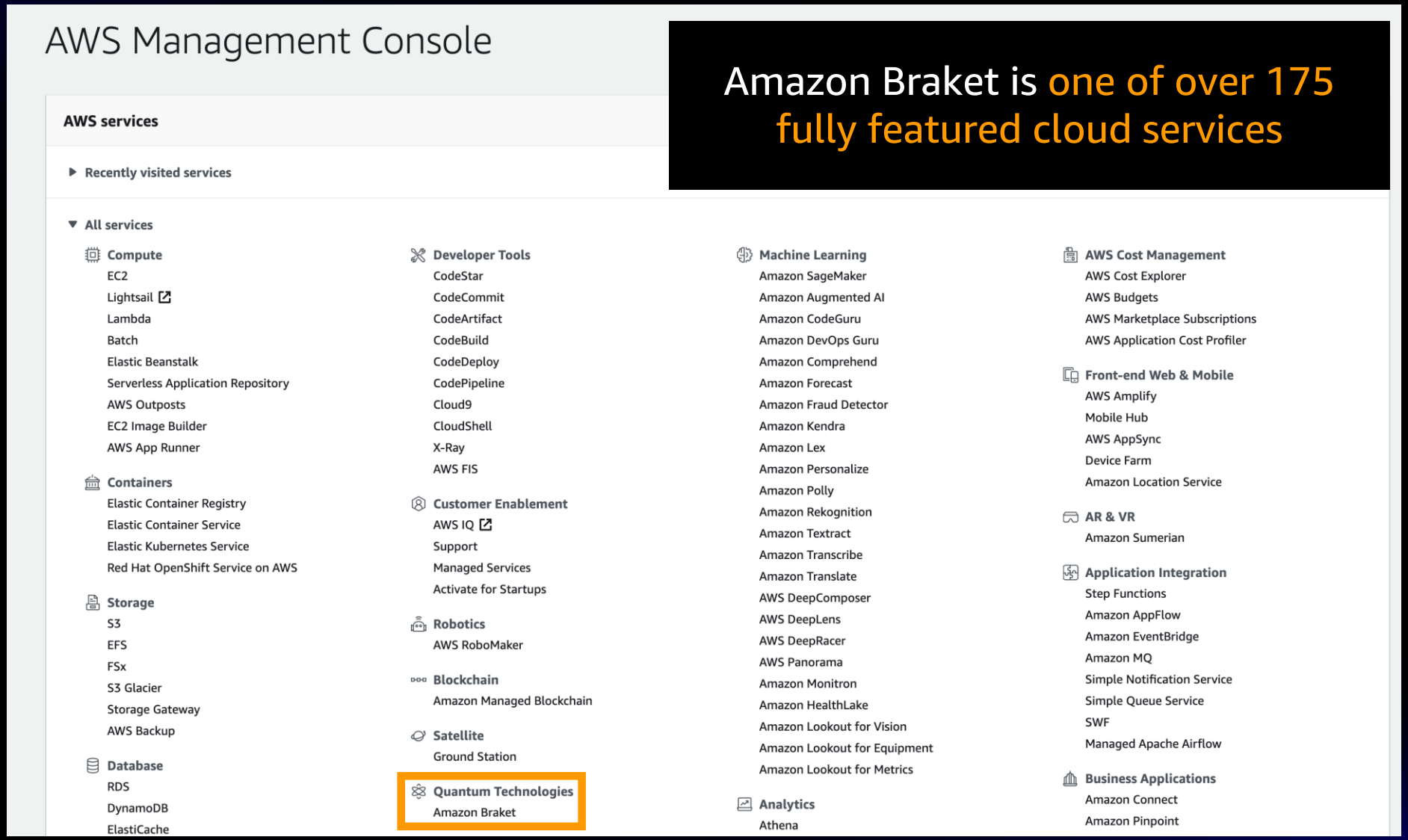
Monitor quantum algorithms



- Customizable
- Define how to monitor progress
- Real time in CloudWatch and the Amazon Braket console
- Ability to intervene or make adjustments if your algorithm isn't converging (or has converged early)
- Access logs from your container

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Building cloud solutions with Amazon Braket

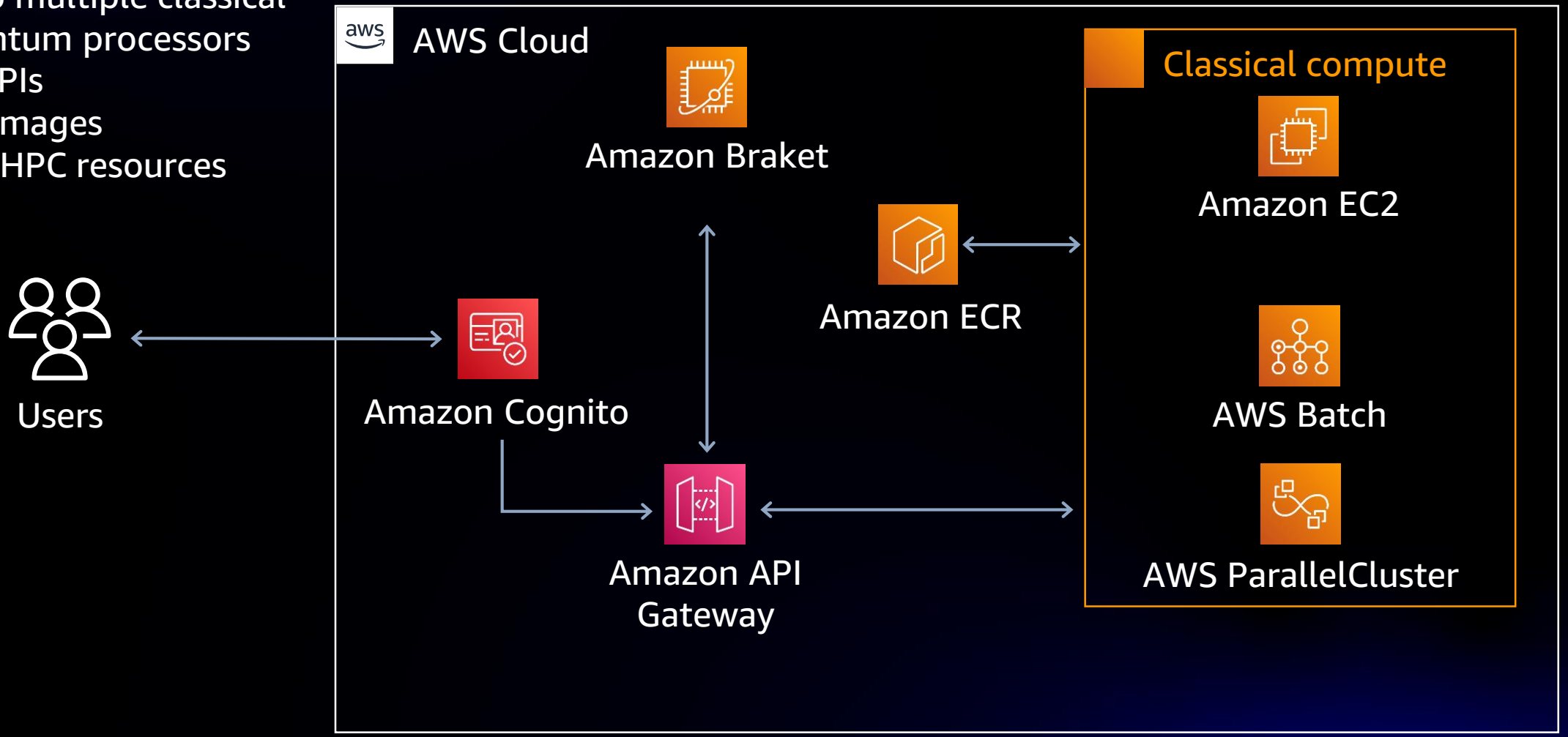


Amazon Braket is one of over 175 fully featured cloud services

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Custom APIs for quantum and HPC resources

- Access to multiple classical and quantum processors
- Secure APIs
- Custom images
- Multiple HPC resources

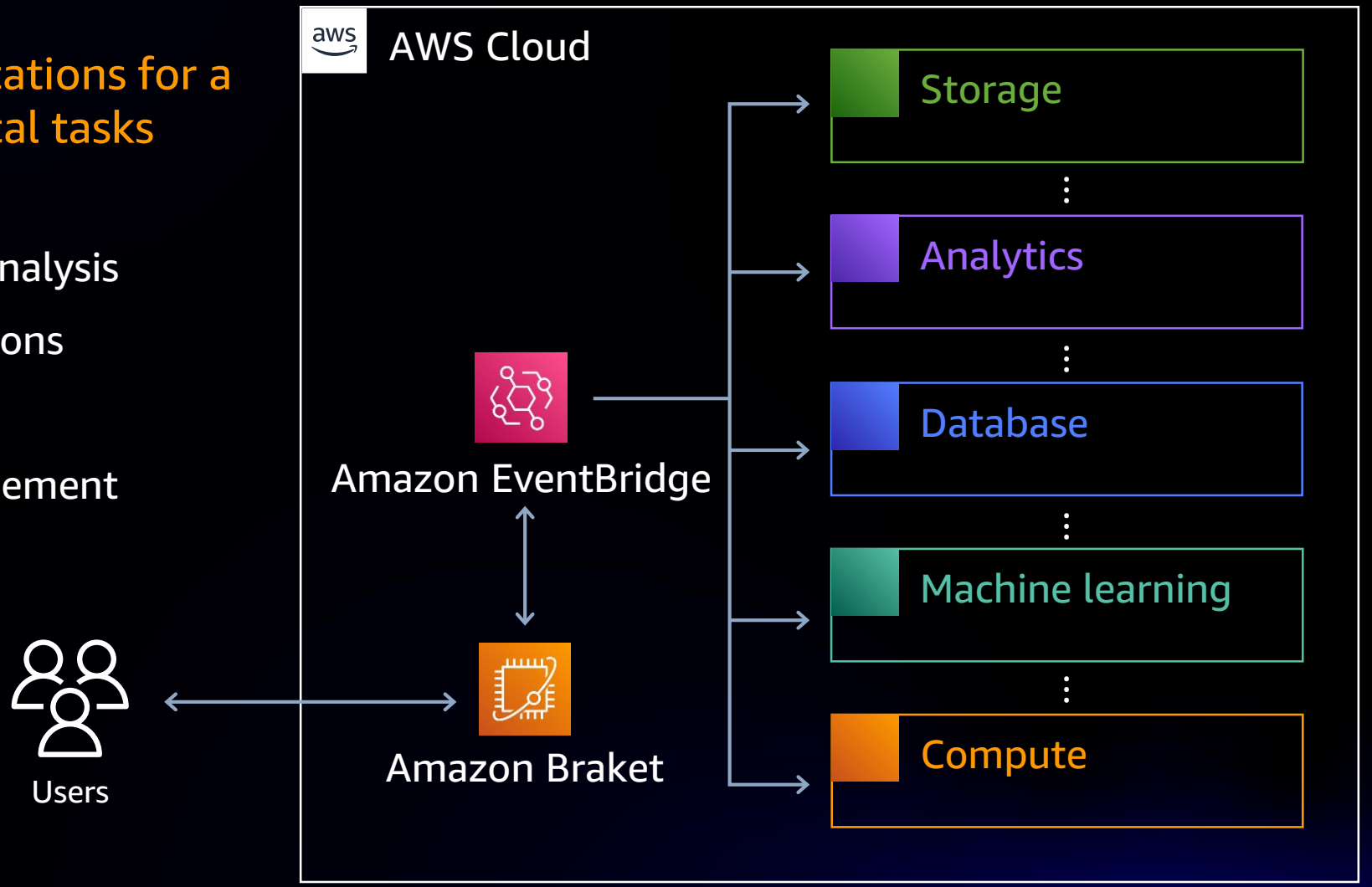


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Build event-driven applications

Customize event-driven applications for a variety of quantum and classical tasks

- Store data and results
- Classical post processing and analysis
- Classical HPC and ML comparisons
- Analytics pipelines
- Organization-level user management



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Quantum computing at JPMorgan Chase & Co.

Marco Pistoia, PhD

Head of Research & Quantum Computing,
Distinguished Engineer

JPMorgan Chase & Co.

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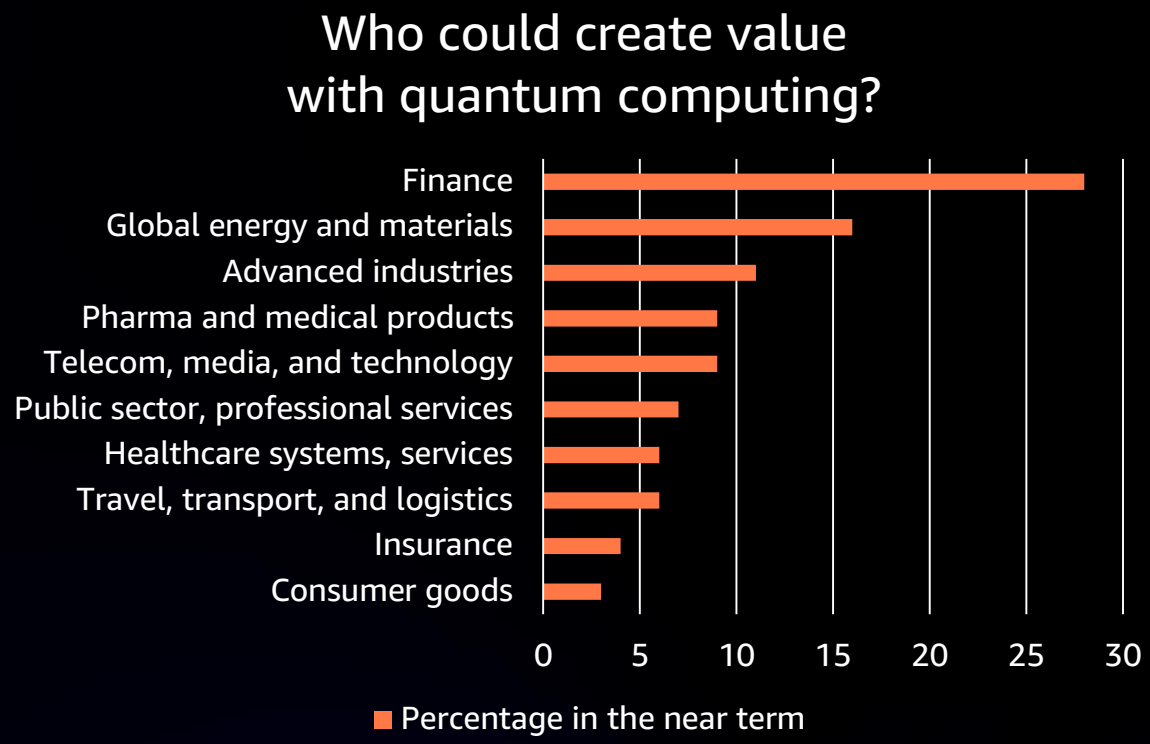
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Quantum investment in financial services

The financial industry is predicted to be the first sector to benefit from quantum computing, even in the short term

This is due to the abundance of high-complexity financial use cases that can be solved more efficiently and accurately with quantum computing, including

- Portfolio optimization
- Derivative pricing
- Risk analysis
- Machine learning



McKinsey & Company, "A game plan for quantum computing," https://www.mckinsey.com/business-functions/mckinsey-digital/our-insights/a-game-plan-for-quantum-computing

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The road to quantum advantage

Quantum science

- Create the fundamental theoretical and physical building blocks of quantum computing

Quantum readiness

- Build portfolios of quantum algorithms and applications for future use in production
- Remain on top of the hardware ecosystem
- Start transitioning research assets into business solutions

Quantum advantage

- Commercial advantage to solving real-world problems with quantum computers more efficiently and accurately than with classical computers

1900s 2010s 2020s

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Quantum algorithms and financial use cases

Problem	Best classical time	Quantum algorithm	Quantum time	Speedup	Considerations	Relevance to finance
Linear systems $A\vec{x} = \vec{b} : A \in \mathbb{C}^{N\times N}, \vec{x}, \vec{b} \in \mathbb{C}^N$	$O(N)$	HHL	poly(log(*N*))	Exponential	• Strict conditions, e.g., *A* well-conditioned and sparse in both classical and quantum	• Portfolio Optimization[1]
Combinatorial optimization over N elements	$O(2^N)$	QAOA	Heuristic	Unproven	• Empirical • Suitable for near-term devices	• Portfolio Optimization[2,3] • Natural Language Processing
		Grover's	$O(2^{N/2})$	Quadratic	• Data loading • Oracle for cost function	
Monte Carlo integration with error ϵ	$O\left(\frac{1}{\epsilon^2}\right)$	Amplitude Estimation	$O\left(\frac{1}{\epsilon}\right)$	Quadratic	• Data loading • Payoff function	• Derivative Pricing[4,5] • Risk Analysis

JPMorgan Chase Publications

[1] *NISQ-HHL: Portfolio Optimization for Near-Term Quantum Hardware*, arXiv:2110.15958, 2021

[2] *Grover Adaptive Search for Constrained Polynomial Binary Optimization*, Quantum 5, 428, 2021

[3] Contributed to Qiskit Open Source Project

[4] *Option Pricing Using Quantum Computers*, Quantum 4, 291, 2020

[5] *The Efficient Preparation of Normal Distributions in Quantum Registers*, arXiv:2009.06601, 2020

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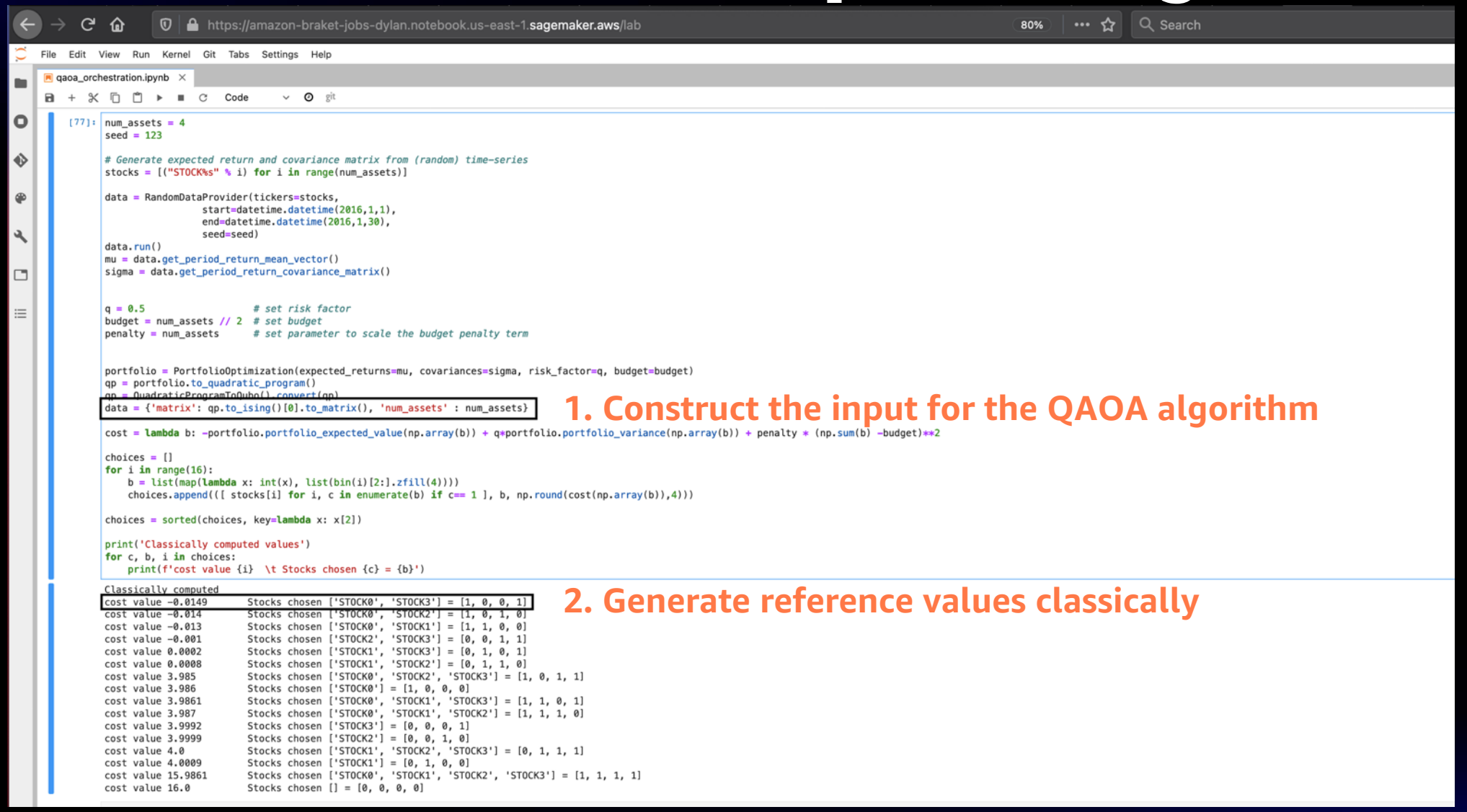
Walk-through: Portfolio optimization using QAOA in Amazon Braket

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Problem definition and input data generation



1. Construct the input for the QAOA algorithm

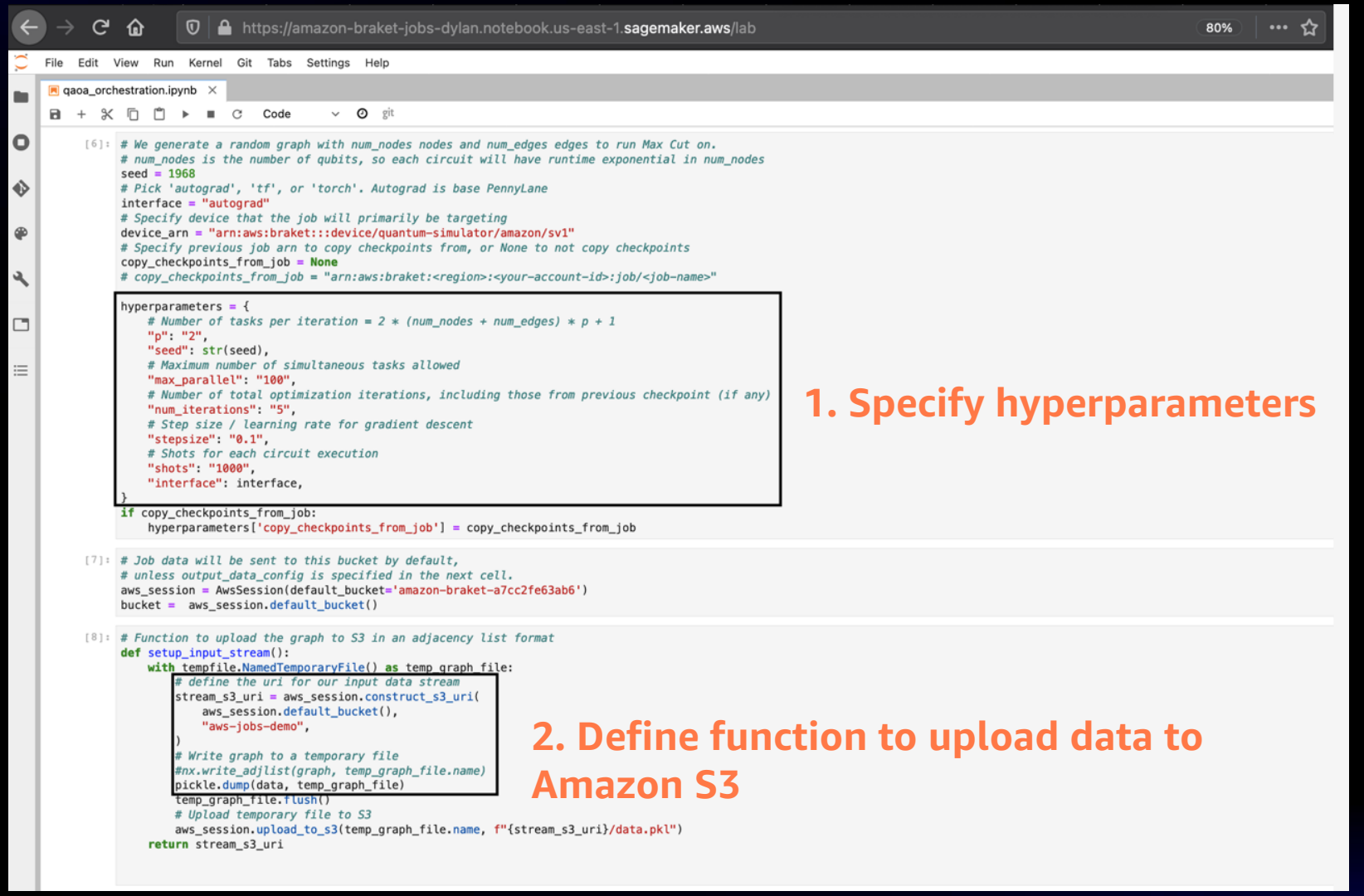
2. Generate reference values classically

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Hybrid job: Orchestration script – 1



1. Specify hyperparameters

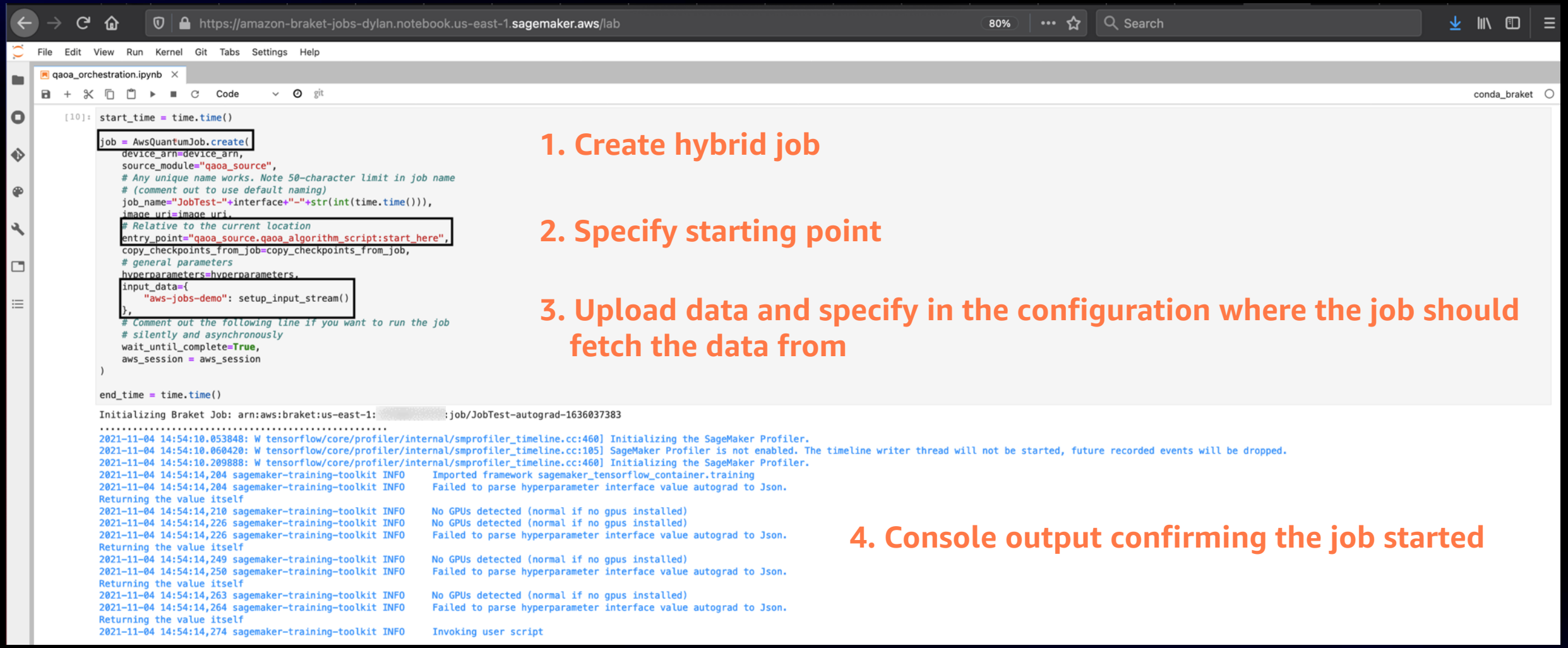
2. Define function to upload data to Amazon S3

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Hybrid job: Orchestration script – 2



1. Create hybrid job

2. Specify starting point

3. Upload data and specify in the configuration where the job should fetch the data from

4. Console output confirming the job started

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Hybrid job: Execution logs

Cost function decreases over successive steps

Console output showing the iterations of QAOA

```
Optimization start
Initial cost: 0.02040376407389139
Metrics - timestamp=1636037713.1740267; Cost=0.02040376407389139; iteration_number=0;
Completed iteration 1
Time to complete iteration: 35.639763593673706 seconds
Cost at step 1: -0.050990534176635974
Metrics - timestamp=1636037745.4867501; Cost=-0.050990534176635974; iteration_number=1;
Completed iteration 2
Time to complete iteration: 32.311508893966675 seconds
Cost at step 2: -0.01611511254042529
Metrics - timestamp=1636037790.0597692; Cost=-0.01611511254042529; iteration_number=2;
Completed iteration 3
Time to complete iteration: 44.57235908508301 seconds
Cost at step 3: -0.015259242152207439
Metrics - timestamp=1636037832.1883879; Cost=-0.015259242152207439; iteration_number=3;
Completed iteration 4
Time to complete iteration: 42.127984046936035 seconds
Cost at step 4: -0.24283593857634364
Metrics - timestamp=1636037864.922481; Cost=-0.24283593857634364; iteration_number=4;
Completed iteration 5
Time to complete iteration: 32.73350644111633 seconds
Metrics - timestamp=1636037867.595645; Cost=-0.6206844852675412; iteration_number=5;
Cost at step 5: -0.6206844852675412
Code Run Finished
```


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Hybrid job: Results – 1

https://amazon-braket-jobs-dylan.notebook.us-east-1.sagemaker.aws/lab 80%

File Edit View Run Kernel Git Tabs Settings Help

qaoa_orchestration.ipynb

Code git

[161]:
```
# May need to wait a bit before metrics show up
# If metrics aren't there, run a bit later
print(job.metrics())
```

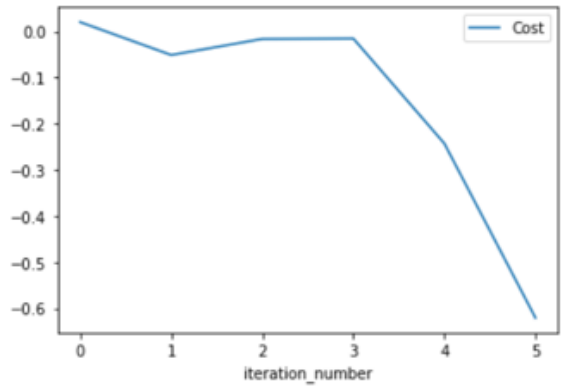
```
{'timestamp': [1635995216.907278, 1635995214.1605859, 1635995199.8321674, 1635995189.6867228, 1635995177.8122215, 1635995116.8680234], 'Cost': [-0.6687441596746455, -0.6536281298
242886644923], 'iteration_number': [5.0, 4.0, 3.0, 2.0, 1.0, 0.0]}
```

1. Print metrics

[51]:
```
# A demonstration of plotting the metrics
import matplotlib.pyplot as plt
from matplotlib.ticker import MaxNLocator
import pandas as pd

df = pd.DataFrame(job.metrics())

ax = plt.figure().gca()
ax.xaxis.set_major_locator(MaxNLocator(integer=True))
figure = df.plot(x='iteration_number', y='Cost', ax=ax)
```



2. Plot cost function value vs. iteration

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Hybrid job: Results – 2

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qaoa_orchestration.ipynb

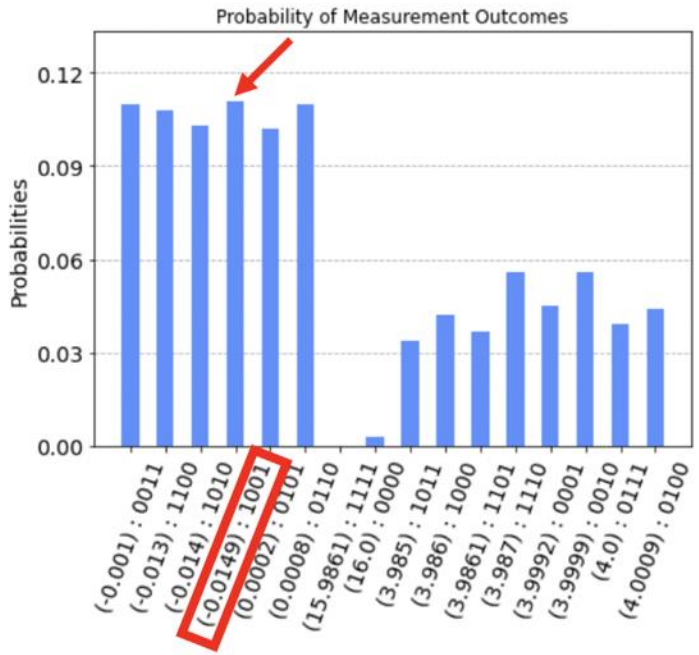
Code

[75]:
```
result = job.result()

answer = [ stocks[i] for i, c in enumerate(result['answer']) if c== '1' ]
b = result['answer']
print(f'QAOA chosen stocks: : {answer} = {b}')
```

```
QAOA chosen stocks: : ['STOCK0', 'STOCK3'] = ['1', '0', '0', '1']
```

[76]:



1. Fetch results and display portfolio chosen by QAOA

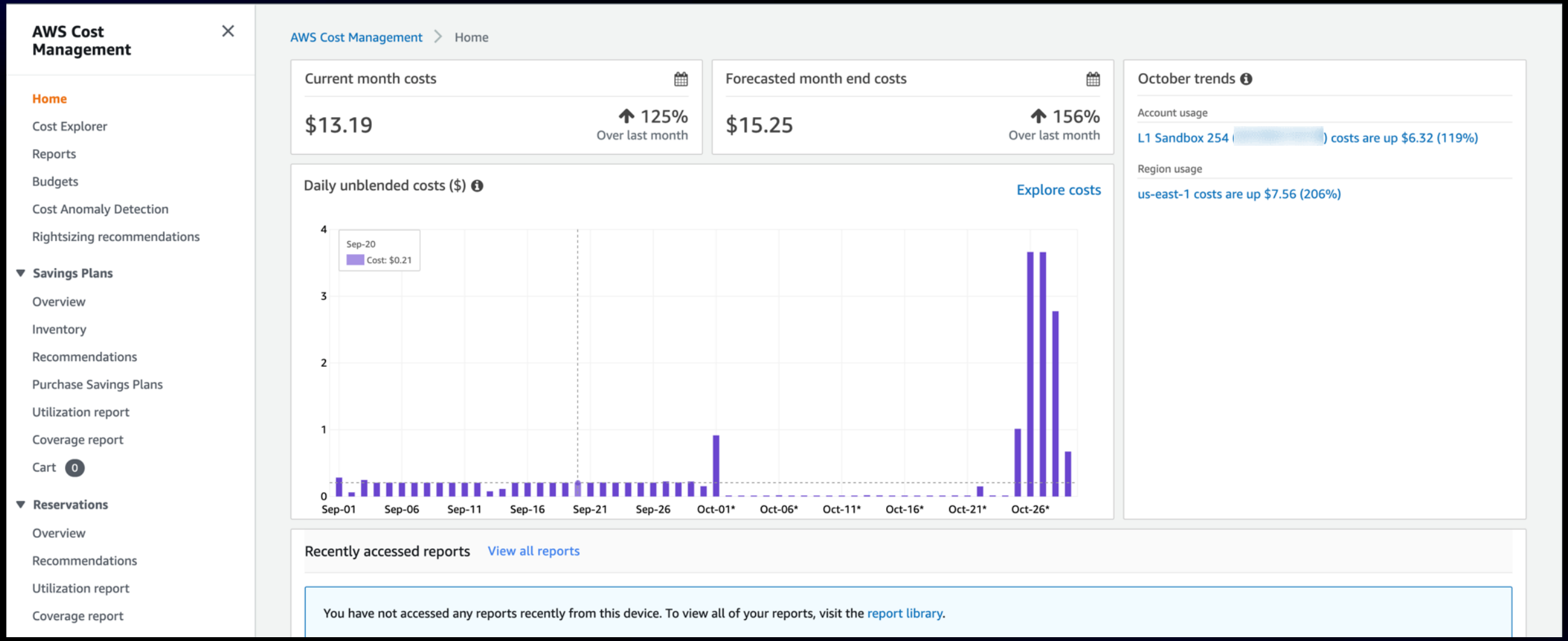
2. Identify the solution in the probability distribution corresponding to the best portfolio

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AWS Cost Management Console

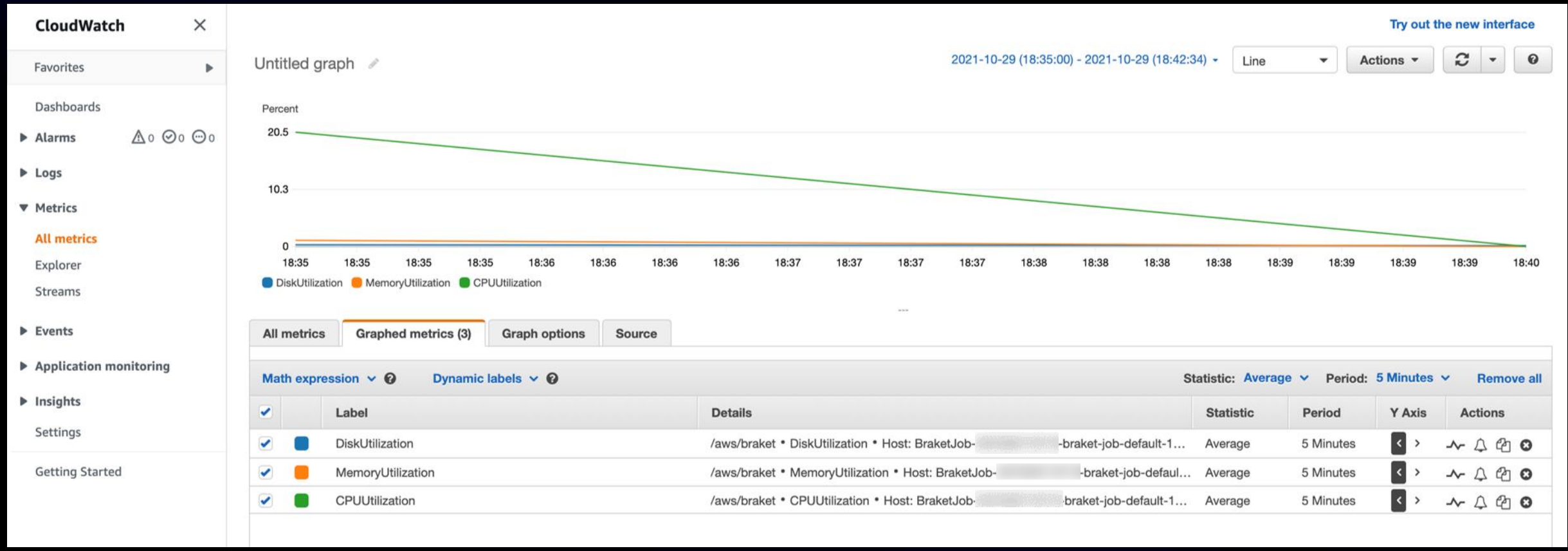


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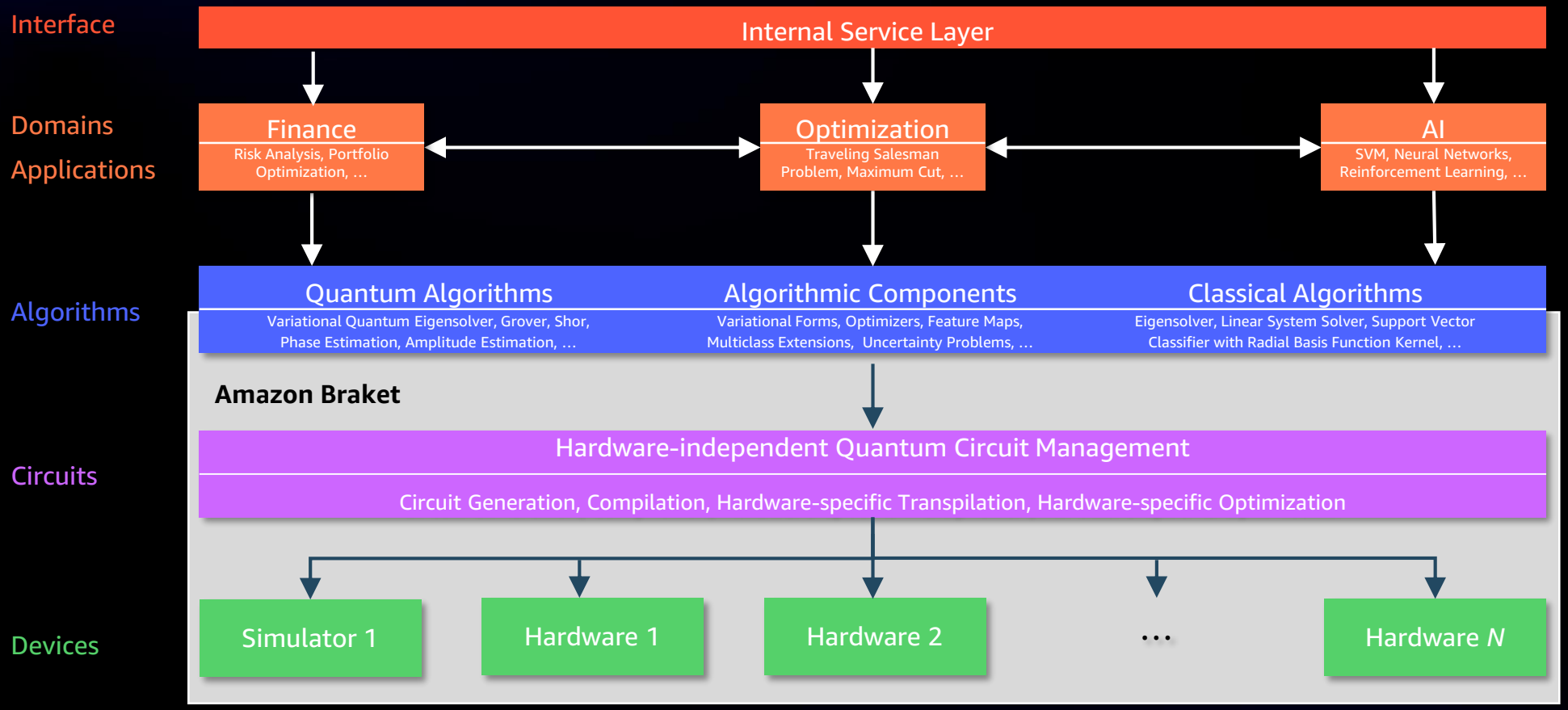
CloudWatch Resource Monitor



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The quantum stack



Cloud services

- No installation required with cloud-based access
- Environment consistency across all users
- Low runtime overhead when quantum is integrated into a cloud system
- Cloud services seamlessly integrated (billing, monitoring, access control)
- Support for diverse technical users, such as quantum researchers and domain experts

Hybrid computing

- Ideal in the NISQ era for executing algorithms on near-term devices while offering proper scaling
- Automatic resource management when executing classical/quantum hybrid applications

Hardware agnosticism

- Ability to run algorithms on multiple computers and simulators with minimal effort

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Actionable takeaways

- Urgency to become quantum ready now
  - Stay abreast of the growing quantum ecosystem and understand its effects
- Identify first-wave applications
  - Build internal connections with product teams and use case owners
- Support scaling of quantum technology
  - Identify your place in the quantum stack to build supporting assets

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What's your next step?

Quantum curious



Quantum enabler





Quantum pragmatists



Quantum pioneer

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Resources

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