The Quantum Leap
January 31, 2022

Cloud Based Quantum Computer Access – Available Today

If you have been following this blog, hopefully you have some broad appreciation for the promise and potential of Quantum Computing (QC). This is a rapidly evolving field and generally, the hype has been front-running the actual capabilities. While a narrow "quantum supremacy" has been achieved by Google and others, general "quantum advantage" (where a quantum computer can out-perform a classical computer for a given real-world problem) is still out of reach (for now).

That said, the purpose of this post is to highlight and showcase the fact that people are using actual working Quantum Computers every day. Each of Amazon and Microsoft offer cloud access to several QC hardware systems, while players like Google, IBM, IonQ, Rigetti, Honeywell and others offer direct access to their systems via direct web-based interfaces. I'm going to spell out some of the modes of access these firms have made available, not to be a definitive catalogue of all QCaaS (Quantum Computing as a Service) providers but to emphasize two facts:

1. Many people and companies are already using quantum computers to process real-world quantum algorithms. Results are generally less robust than can be achieved on existing classical computers, but routines are being run and occasionally, results surpass classical computing results.
2. The industry is moving towards a largely open-source software environment for programming and accessing quantum processors. Many quantum hardware manufacturers are offering cloud-based access to their systems, obviating the need to purchase physical quantum hardware. This substantially lowers the barriers to entry for companies seeking to begin exploring how QC can benefit their businesses, and "future-proofs" the investment since the providers continually upgrade the QC machines they provide via the cloud.

Working QCs are currently available to anyone (and as you'll see below, the costs of operating QCs can be quite modest). In fact, a recent study reviewed all the QC cloud access of IBM's Quantum systems over a two-year period and found over 6,000 jobs which contained over 600,000 quantum circuit executions and almost 10 billion "shots" (a shot is a single execution of a quantum algorithm on a QPU (quantum processing unit), further described below). IBM notes on their website that they have run over **1 trillion** circuits to date, which is clearly a non-trivial amount. And that is just at IBM.

The following tables highlight some aspects of the current state-of-play in using actual quantum computers to run algorithms via cloud-based access:

Multi-Platform Providers			
Provider	**Amazon**	**Microsoft**	**QC Ware**
Hardware Access	D-Wave	Honeywell	D-Wave
	IonQ	IonQ	IonQ
	Rigetti	QCI	Rigetti
			IBM/QC Ware Forge

Single Quantum Processing Unit (QPU) Providers				
Provider	**# Systems**	**Format**	**Max # Qubits**	**Country**
Google	**3**	Superconducting	72	US
Honeywell	**1**	Trapped Ion	10	US
IBM	**24**	Superconducting	127	US
IonQ	**n.a.**	Trapped Ion	11 (32 coming soon)	US
Rigetti	**8**	Superconducting	32	US
Xanadu	**3**	Photonic	24	Canada
D-Wave	**2**	Annealing	5000+ [1]	Canada

Note: Other providers include Alibaba Quantum Lab (China), Alpine Quantum Technologies (Austria), Origin Quantum (China)

[1] Quantum annealing is a different protocol than typical Quantum Computing gates so is not a direct equivalent when comparing numbers of qubits.

Quantum Computing Power Available Via the Cloud Today

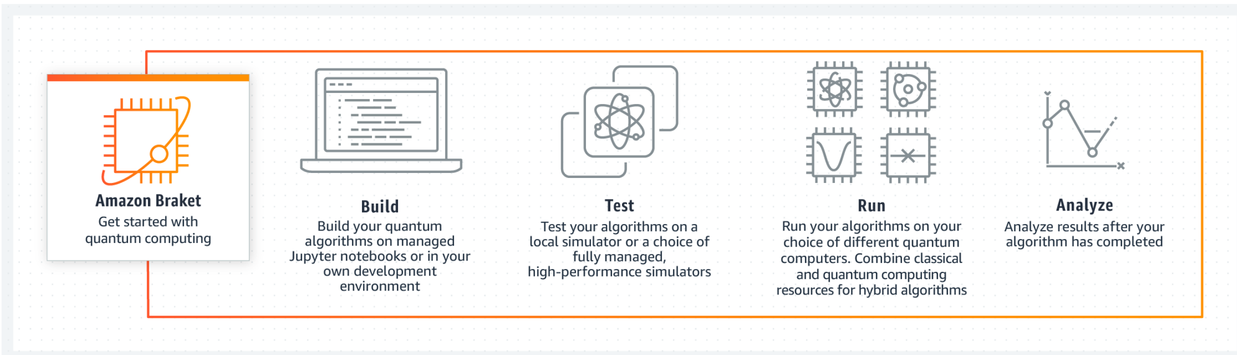
Before I get into details about specific methods for accessing working Quantum Computers, I want to review a few facts about the state of the industry vis-à-vis QC power. The current environment has been referenced as "NISQ" or noisy intermediate-scale quantum. Generally, this means that existing quantum computers operate with a lot of noise that interferes with qubit control and coherence, and that working quantum computers have a somewhat limited number of qubits. QC power can be increased both with the addition of more qubits and/or with the successful implementation of error-correction. Generally, a QC with about 50-60 working logical qubits (representing around a petabyte of processing power) should begin to achieve consistent quantum advantage. Some expect this will require as many as 1,000x more qubits per logical qubit to handle the error-correcting overhead, although as control and error-correction improves, this number should decrease. In any case, today's working QCs provide 10's of working qubits not 100's or 1000's, but they are working, accessible machines, nonetheless and beginning to yield significant computing power.

To emphasize how existing Quantum Computers are already showing real-world promise, Rigetti Computing recently used their machines to augment a portion of GSWR (Global Synthetic

Weather Radar) analysis using their 32 qubit QC, and in select instances, were able to modestly outperform results achieved using only classical computing power. Similar select improvements over classical computing have also been noted in certain portfolio/security valuation algorithms. So real-word real benefits are beginning to appear even in this early NISQ environment.

What does it Cost to run Quantum Algorithms via the Cloud?

In order to provide an example of how you can begin accessing Quantum Computers and running quantum algorithms, the following describes access via Amazon Braket:



You can use an account with Amazon Braket to access the Quantum Computers provided by IonQ, Rigetti or D-Wave. Once you construct a quantum algorithm, it is recommended that you test and debug it on a simulator, which is generally available for no cost. Once you are ready to run the algorithm on a bona fide quantum machine, there are some cost factors to keep in mind. There are generally two pricing components when using a quantum computer or quantum processing unit (QPU) via the cloud: a “per-shot” fee and a “per task” fee.

As you may recall from prior posts, quantum algorithms are “probabilistic” not deterministic. There is no single correct result from a quantum operation, rather outputs are aggregated and averaged to determine the correct output. For this reason, algorithms are usually run many, many times (10,000 times is a standard number). A shot is a single execution of a quantum algorithm on a QPU. For example, a shot is a single pass through each stage of a complete quantum circuit on a gate based QPU. The per-shot pricing depends on the type of QPU used but is not affected by the number or type of gates used in a quantum circuit or the number of variables used in a quantum annealing problem.

A task is a sequence of repeated shots based on the same circuit design or annealing problem. You define how many shots you want included in a task when you submit the task to Amazon Braket. The current pricing to run algorithms via Amazon Braket are as follows:

D-Wave 2000Q: $0.30/task; $0.00019/shot
D-Wave Advantage: $0.30/task; $0.00019/shot
IonQ: $0.30/task; $0.01/shot
Rigetti: $0.30/task; $0.00035/shot

For example, a scientist runs a quantum algorithm on the Rigetti Aspen-11 quantum computer in the AWS US West (N. California) Region. This task includes 10,000 repeated shots of the same circuit design. The cost to run this task includes a per-task charge of $0.30, plus 10,000 shots at a per-shot price of $0.00035.

> The cost to run this algorithm:
> Task charges: 1 task x $0.30 / task = $0.30
> Shots charges: 10,000 shots x $0.00035 / shot = $3.50
> **Total charges: $3.80**

Competing quantum cloud providers have similar pricing constructs or charge a fixed amount for a certain level of access/time. Naturally there is no guarantee that your circuit or algorithm will provide the desired results, or useful results, but the table stakes to begin testing QC for your business is quite modest. Naturally these costs may increase in the future, but it is a very low bar considering the potential upside, and certainly less expensive (or risky) than purchasing a dedicated Quantum Computing machine today.

Conclusion

By providing access to actual Quantum Computers via the cloud, a handful of QC hardware makers are providing QC access to virtually anyone. With a basic working knowledge of Python (a common programming language, particularly good at connecting various components), a user can investigate many free open-source resources and QDKs (quantum development kits), begin compiling "quantum algorithms" and test/debug them for free on any number of cloud-based simulators. Once ready to run on an actual, working Quantum Computer, you can then sign up directly at some QC providers or via Amazon or Microsoft's web platforms (or others) and have the algorithm run on an actual QC for a very modest cost. Such access eliminates the capital and technology risks of purchasing a Quantum Computer.

This is already happening with, literally, trillions of circuits run to date. While the power of the machines currently accessible is modest relative to common high-performance classical computers, real-world achievements are becoming increasingly possible. As more users are provided with broader access to ever larger QCs, and as advances in error correction and control continue, it is only a matter of time before consistent quantum advantage is available to nearly anyone.

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