The Quantum Leap
May 23, 2023

Quantinuum – Company Update and System Model H2 Release

In January of 2022 the Quantum Leap published a profile on **Quantinuum** (see original post here), where it was assigned the highest rating with an **Alpha of 0.95** which equates to "Exceptional Performance Expected". Earlier this month I was invited to the official launch of Quantinuum's newest Quantum Computer, referred to as their System Model H2, and was quite impressed with the Company's progress so I am pleased to say that **Quantinuum continues to earn this highest rating** (see "Rating" section for further details).

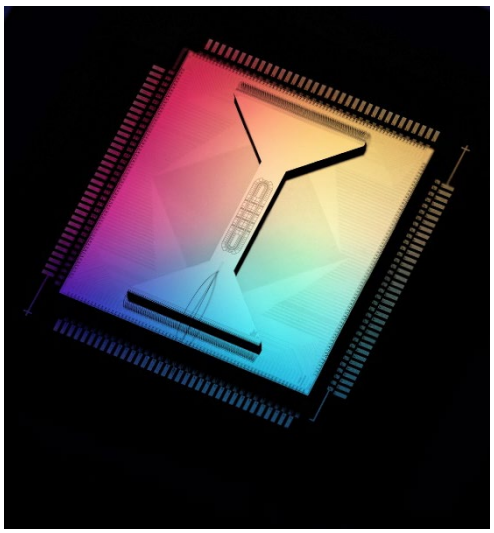
Background

In October of 2020, **Honeywell Quantum Solutions (HQS),** a division of **Honeywell,** introduced its first quantum computer, the System Model H1, which featured 10 fully connected qubits and a quantum volume of 128, which was the highest reported at the time (surpassing IBM's prior record of 64). In June of 2021, after a series of successful collaborations, **Cambridge Quantum Computing (CQC)** reached an agreement to merge with **HQS.** Then in November of 2021, Honeywell spun out HQS to formally combine the businesses into a new stand-alone company called "**Quantinuum**" (the **Company**) and capitalized it with $300m. Then in December of 2021, the Model H1-2 successfully passed the quantum volume benchmark of 2,048, a new global record and consistent with the Company's stated timeline of annual 10x increases in quantum volume. At the time of Quantinuum's formation, a long-term roadmap was published and on May 9th the Company announced the release of the Model H2, meeting their previously committed timeline for this model.

System Model H2 Commercial Release

I attended the Quantinuum press/analyst day earlier this month at their headquarters in Broomfield, Colorado, where the Company announced its latest quantum machine, the System Model H2. Quantinuum uses ytterbium ions to create its trapped ion quantum computer and this new machine builds on the success of the previous models and now features a novel "racetrack" design (which can be seen in the center of the photo below right) and some impressive, industry leading performance metrics:

- 32 Qubits
- 1Q Fidelity 99.997%
- 2Q Fidelity 99.8%
- SPAM 99.8%
- Crosstalk error 0.0005%
- All-to-all connectivity
- Mid-circuit measurement
- Qubit reuse
- Long coherence times



System H2 Chip – © Quantinuum

The day included the unveiling of the actual H2, an engineering marvel, as well as unfettered access to virtually the entire management team and the leading scientists involved with H2. It was an impressive and informative day, and I was especially struck by the transparency the Company exhibited, both with access to its team members as well as via the benchmarking of the H2's performance metrics.

The all-to-all connectivity, facilitated by their quantum charge-coupled device (QCCD) architecture, with 32 qubits that have impressive fidelities and decent coherence times, has enabled Quantinuum to do some remarkable things including:

- Achieving a record quantum volume of 65,536 (2^{16}),
- Creating a 32-qubit GHZ state (a non-classical state with all 32 qubits globally entangled), the largest on record; and
- Creating non-Abelian anyons, a new state of matter, for the first time ever.

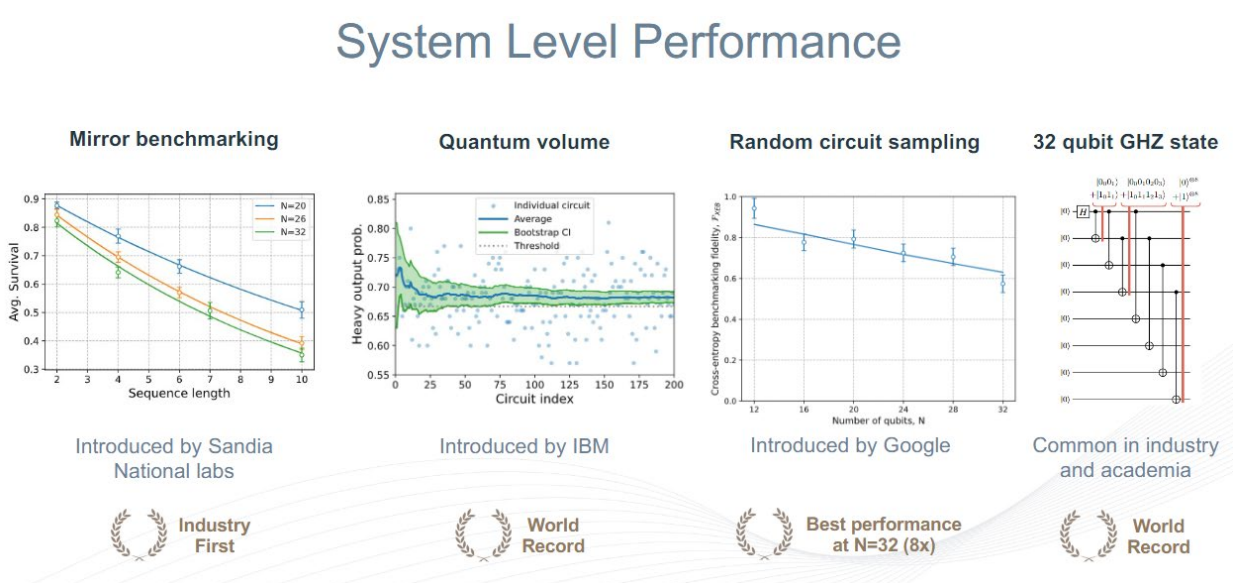
The Company plans to expand the H2 to 50 qubits sometime next year. **At that level, it should begin to perform computations that are beyond the reach of any classical simulations by the most powerful supercomputers**. This would be no small feat and makes the broader Quantum Computing leap to new realms imminently possible.

Quantinuum has had an over-arching philosophy, as emphasized by Ilyas Khan, founder and chief product officer, in the press release accompany the formal announcement of the H2, "that when incredible tools are given to brilliant people, they will find something amazing to do…". Quantinuum had been working with certain of their clients on the H2 including JPMorgan Chase which published a paper on using the machine for portfolio optimization. The H2 is now available via cloud-based access directly from Quantinuum and will be available through Microsoft Azure Quantum beginning next month. I am excited to see what amazing and creative things users are able to do with this new quantum computing power.

Company Philosophy Around Transparency

As noted above, Quantinuum provided access to much of their senior team and encouraged direct communications. I was able to engage in meaningful conversations with key employees including Dr. Russell Stutz, Director of Commercial Products, Dr. Steve Sanders, Senior Director for Hardware Technology Development, Dr. Patty Lee, Chief Scientist for Hardware Technology Development, Dr. Chris Langer, Fellow and Chairman of the Technology Board, Dr. Jenni Strabley, Senior Director of Offering Management, Dr. Brian Neyenhuis, Commercial Operations Group leader and of course Raj Hazra, CEO and Tony Uttley, President and COO, among others. The team was engaging and shared many insights and descriptions of their process and achievements.

In addition to personnel, the team provided access to a wealth of academic papers and detailed presentations including the performance metrics that the Company undertook on their own deep dive into the machine's capabilities and limits. This included a presentation by Dr. David Hayes, Senior Manager for Architecture and Theory, who was introduced by Tony Uttley as the person they gave the directive to "kick the tires as hard as you possibly can on this [new H2] system so that when we release it to the world we can say 'here are all the specs, everything that you can do under all different conditions' and then make that transparent to the entire community." During Dr. Hayes' portion of the presentations, he shared their benchmarking approach which was summarized and published in a detailed 24-page report. They dug into the component/processor metrics (i.e., 1 and 2 gate performance), the system-level performance (i.e., complex logic operations) and algorithm/application performance. Below are some highlights:



Of note was their robust approach to benchmarking and performance metrics. Rather than just cherry-picking favorable results, they presented deep and wide methodologies for performance measurement and made it all publicly available. **This transparency is an important philosophy for the industry and is the best way to separate performance from hype**. As the

Company noted, they hope this unprecedented level of openness becomes a new standard for Quantum Computing. For those interested in the specific benchmarking results, they are published here.

Some Details and Commentary around H2 Achievements

Some of the announced achievements of the H2 were noted on page 2 and I expect additional achievements will be uncovered as broader access to the H2 is provided next month. Below are some added details around the announced capabilities:

1. A record quantum volume of 65,536: Quantum computers are difficult to compare so "quantum volume" was derived is a single number designed to show the overall performance of a quantum computer. It is a measurement and not a calculation and takes into account several features of a quantum computer, including number of qubits, gate and measurement errors, crosstalk and connectivity. Roughly speaking, it is an exponential of the circuit size. IBM was the first company to espouse this metric and they achieved a quantum volume of 32 on their 28 qubit "Raleigh" QC in 2020. As recently as October 2022, Quantinuum set a quantum volume record of 8,192, which it increased to 32,768 on the H1-1 in February of this year and then to 65,536 on the H2 this month. This >2,000x improvement in quantum volume in less than 3 and ½ years suggests a very rapid scaling in QC capabilities.
2. 32-Qubit GHZ State: In physics, a Greenberger-Horne-Zeilinger state (GHZ state) is a certain type of entangled quantum state that involves at least three subsystems. This GHZ metric is a demanding test of qubit coherence that is widely measured and reported across a variety of quantum hardware and becomes increasingly difficult to achieve as qubit count increases. The verification of the entangled GHZ state on all 32-qubits confirmed the all-to-all connectivity of the platform, which combined with ultra-precise control mechanisms enabled the team to achieve an entangled state of 32 qubits with a fidelity of 82% setting a new world record.
3. Creation of Non-Abelian Anyons: This was perhaps the least expected performance metric, given that it represents an entirely new form of matter, which had been theorized but never before shown experimentally. Interestingly, both Quantinuum and Google announced this breakthrough achievement days apart (see Google announcement here), and Microsoft has long been working on topological based qubits. While the physics describing this state are beyond the scope of this write-up, there are two important implications of this achievement:
    a. Anyons are exotic quasi-particles that, as Quantinuum noted, "can theoretically store quantum information in their internal states which can only be changed by "braiding" them around each other in spacetime. Small perturbations in the trajectory of these braids would then leave the topology of the braid unchanged, making this paradigm inherently robust. It is as if they are "deaf" to the noise of the system." It has been suggested that this could be **a viable system for creating universal, fault-tolerant quantum computers**. The problem was that non-abelian anyons had never been detected, much less controlled, until now.

b. Given that this is a new form of matter, this discovery/achievement also has the potential to pave new paths for research within condensed matter and high-energy physics, akin to the discoveries of the Large Hadron Collider.

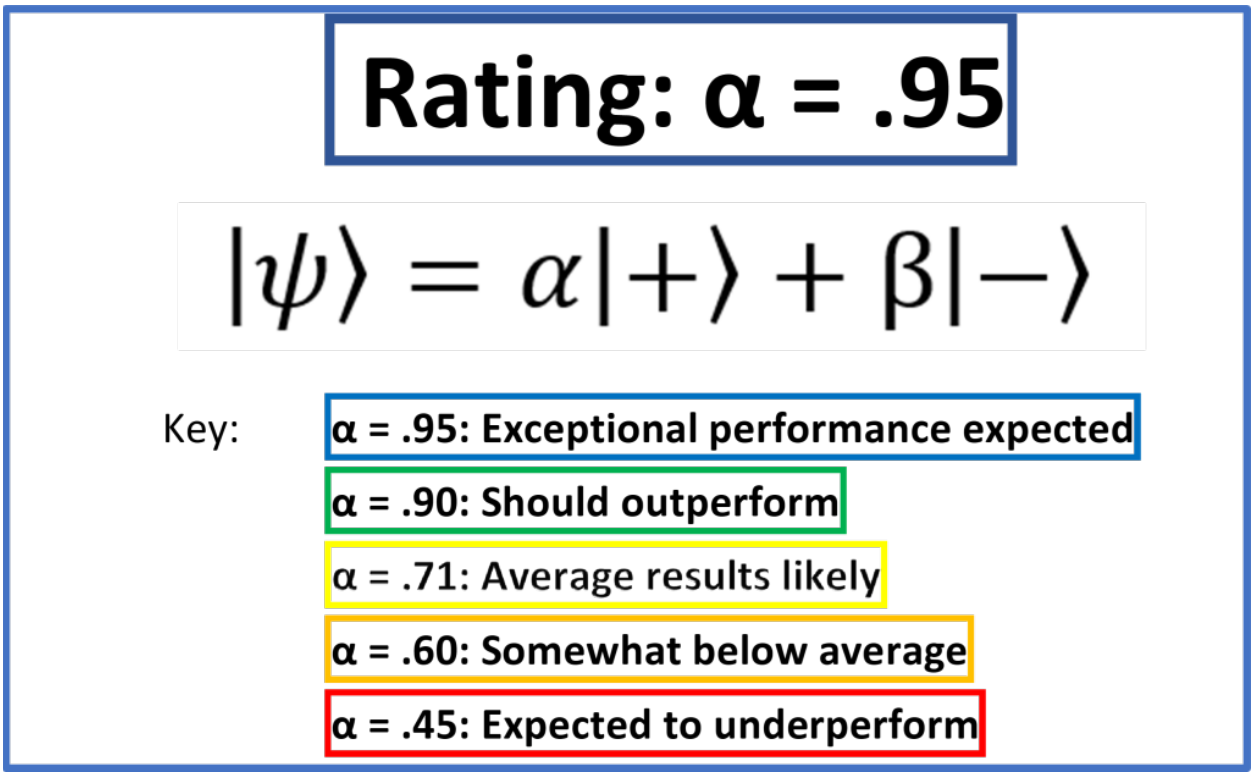
Summary

There are more than 25 different quantum hardware companies working on creating Quantum Computers and at least 6 different core modalities (e.g., superconducting, trapped ions, neutral atoms, photonics, etc.) behind these devices. While it is still unclear which modality and which company will eventually create an enterprise-grade Quantum Computer, Quantinuum has shown that it is not afraid to publish their roadmap and to-date, prove it can meet its release and performance goals. Their transparency is both refreshing and vital in these early stages of the NISQ (noisy intermediate-scale quantum) era. The Company has continued to show impressive performance metrics, meet its development timeline, and now introduce non-Abelian anyons as a possible tool for fault-tolerant quantum computing, all of which confirms Quantinuum is currently in a very strong market position.

Quantinuum released its new H2 machine with 32 qubits with a commitment to increase this to 50 qubits by next year. As noted above, a 50-qubit quantum computer with all-to-all connectivity and high fidelities will begin to exceed the simulation capabilities of classical computers. And, they are well on their way to additional H-Model machines including the H3 which will include a grid-like architecture. This increasingly powerful quantum computing platform, combined with Quantinuum's close association with beta customers and making the H2 available to all via Azure Quantum in coming weeks, will allow users to push the H2 capabilities to its limits and begin to obtain actionable results. I expect Quantinuum will continue to share important details which I look forward to following and reporting on.

Rating

Apropos of the probabilistic nature of quantum algorithms, *The Quantum Leap* has created a company rating system to provide overall assessment of a company's potential. Accordingly, it uses the formula below when reviewing companies, whereby the "alpha" coefficient correlates with "positivity" (and the formula adheres to the Born rule). Given the overall assessment of Quantinuum including its strong position as a full-stack player, the strengths of the legacy businesses, the latest record-setting achievements, and most importantly, its ability to continue to hit previously stated performance achievements, I am confirming the highest rating for Quantinuum, with an **Alpha of 0.95** which equates to an "Exceptional Performance Expected".



***Disclosure**: I have no beneficial positions in stocks discussed in this review, nor do I have any business relationship with any company mentioned in this post. I wrote this article myself and express it as my own opinion.*

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Finke, Doug, Quantinuum Announces Next Generation 32 Qubit H2 Processor Along with Application Research Results from Using It, *Inside Quantum Technology*, May 9, 2023.

Hughes-Castleberry, Kenna, Quantinuum Releases New H2 Quantum Computing System with 32 Qubits, *Quantum Computing Report*, May 9, 2023.

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Moses, S.A; Baldwin, C.H.; Allman, M.S., et al, A Race Track Trapped-Ion Quantum Processor, arXiv:submit/4875448 [quant-ph] May 5, 2023.

Quantinuum.com, Press Releases from May 9, 2023 including: "For the First Time Ever, Quantimuum's New H2 Quantum Computer Has Created Non-Albelian Topological Quantum Matter and Braided its Anyons," "Quantinuum Launches the Most Benchmarked Quantum Computer in the World and Published All the Data," "Quantinuum Researchers Demonstrate a new Optimization Algorithm that delivers solutions on H2 Quantum Computer," and "Quantinuum demonstrates the first creation and manipulation of non-Abelian anyons."

Presenters Hazra, Raj; Uttley, Tony; Dreyer, Dr. Henrik; Amaro, Dr. David; Hayes, Dr. David; Stutz, Dr. Russell; Sanders, Dr. Steve, Quantinuum Press and Analyst Event, May 3, 2023.

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Russ Fein is a venture investor with deep interests in Quantum Computing (QC). For more of his thoughts about QC please visit the link to the left. For more information about his firm, please visit Corporate Fuel. Russ can be reached at russ@quantumleap.blog.