The Quantum Leap
January 9, 2022

Quantinuum – Company Evaluation

When I established this blog in November of last year, I noted that I would present posts regarding details underlying Quantum Computers (QC), the immense potential they hold, and advances being made. I hope you have enjoyed those posts which will continue, but I also stated an intention to reflect on current events, companies, and breakthroughs. I thought it fitting that **Quantinuum** be the first company profile presented in this series.

Background

In June of 2021, after a series of successful collaborations, **Cambridge Quantum Computing (CQC)** reached an agreement to be acquired by **Honeywell** for $300m, representing a $545m post-money valuation. Honeywell merged CQC with its **Honeywell Quantum Solutions (HQS)** division and in November of 2021, spun out the combined businesses into a new stand-alone company called "**Quantinuum**". In addition, Honeywell invested $300 million in Quantinuum which is now 54% owned by Honeywell and 46% by CQC shareholders.

CQC, founded in 2014, is a global Quantum Computing software company which designs enterprise applications in the areas of quantum chemistry, machine learning and cybersecurity, among others. Honeywell is a multinational conglomerate with operations in aerospace, building technologies, performance materials, and safety and productivity solutions. Its diverse industrial footprint included expertise in cryogenic systems, ultra-high vacuum systems, photonics, RF
(radio-frequency) magnetic systems, and ultra-high precision control systems, all of which turned out to be extremely well suited for building a quantum computer. In ~2010 Honeywell Quantum Solutions was secretly formed, reached some critical technical milestones in 2015 and was publicly disclosed in 2018. By 2020 HQS released it first QC, the "Model H1", a modest 10-qubit trapped ion QC and it has been on an aggressive timetable for scaling up its QC portfolio, recently showcasing the achievement of quantum volume of 2,048 using its 12 qubit Model H1-2 which was a 10x increase in less than one year.

Details on Honeywell Quantum Solutions

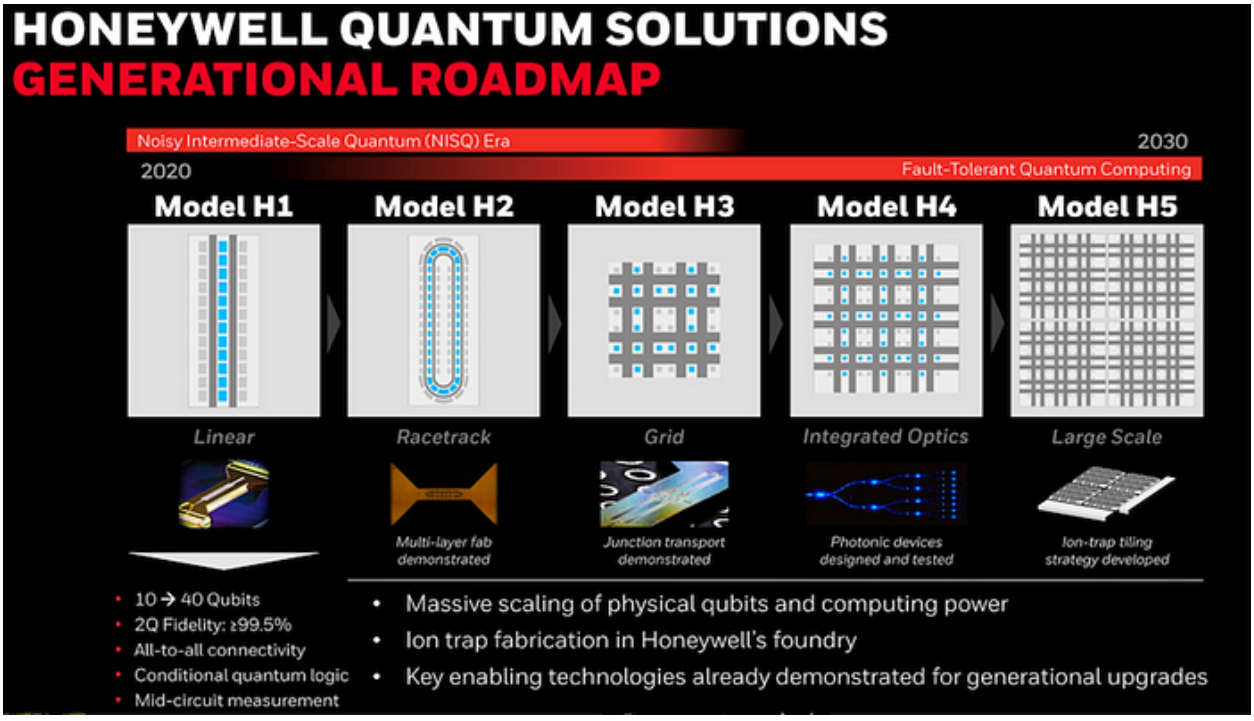
Leveraging its 130 years of innovation including strengths in science, engineering and research, Honeywell has developed trapped-ion quantum computers using individual, charged atoms (ions) to hold quantum information. Their system uses electromagnetic fields to hold (trap) each ion so it can be manipulated and encoded using microwave signals and lasers. These trapped-ion qubits can be uniformly manufactured and controlled more easily compared to alternative qubit

technologies that do not directly use atoms and it does not require cryogenic cooling (although an ultra-high vacuum environment is required).

In October of 2020, HQS 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). By this past December, 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. The hardware roadmap includes four key milestones to be achieved before the end of the current decade:

1. **Model H1**: Creation of a linear device with 10 computational qubits [achieved], eventually scaling to 40 qubits.
2. **Model H2**: Using the same lasers to perform operations on two sides of a racetrack configuration. Once achieved, quantum volume should exceed that possible with classical computers (i.e., will not be able to be simulated on classical machines).
3. **Model H3**: Geometries change to a grid, which will be much more scalable than linear or racetrack configurations.
4. **Model H4**: Aim to integrate optics via photonic devices that allow laser sources to be an integrated circuit.

The following chart showcases the planed roadmap:



Details on Cambridge Quantum Computing

The team at CQC has been developing the theoretical foundations of Quantum Computing for over 25 years. They design, engineer and deploy algorithms and enterprise level applications leveraging TKET, their hardware-agnostic software development platform, along with other technologies. They have developed application specific quantum software across a number of

fields including quantum chemistry, quantum artificial intelligence and quantum cybersecurity. Here is a brief overview of their products and solutions:

TKET: is a leading open-source development toolkit that enables optimization and manipulation of quantum circuits for current quantum computers. As a platform-agnostic tool, TKET can integrate with most commercially available quantum hardware platforms including IBM, Honeywell, Google, IonQ and others, as well as third-party quantum programming tools including Cirq, Qiskit and Pennylane.

Quantum Origin: is an industry-defining, cryptographic key generation platform that employs quantum computers to generate quantum-enhanced cryptographic keys. Using the Quantum Origin platform, both classical algorithms (e.g., RSA or AES) and post-quantum algorithms (e.g., CRYSTALS-Dilithium and Falcon) can be seeded to provide cryptographic keys that offer superior protection against even the most powerful of adversaries (see more on Quantum Origin below in the Strangeworks Collaboration section).

QNLP: The rapidly emerging field of Quantum Natural Language Processing, and its underlying theoretical foundations, has been pioneered by the team at CQC. **lambeq** is the world's first software toolkit for QNLP capable of converting sentences into a quantum circuit. It is designed to accelerate the development of practical, real-world QNLP applications, such as automated dialogue, text mining, language translation, text-to-speech, language generation and bioinformatics. Their structural approach takes advantage of mathematical analogies between theoretical linguistics and quantum theory to design "quantum native" NLP pipelines. Combined with advances in Quantum Machine Learning (QML), CQC has successfully trained quantum computers to perform elementary text classification and question-answering tasks, paving the way for more scalable intelligence systems.

Quantum Artificial Intelligence: (QAI) is one of the most promising and broadly impactful application areas of quantum computing. CQC is simultaneously pioneering the highly interconnected areas of quantum machine learning, quantum natural language processing, quantum deep learning, combinatorial optimization and sampling (i.e., Monte Carlo simulations) to build intelligence systems of the future.

QA: The Quantum Algorithms division is seeking to realize definitive and unequivocal quantum computational advantage as soon as possible. Although ultimately interested in all quantum algorithms, at present, the focus is on three problems which show promise for early quantum advantage, including Monte Carlo estimation, optimization and solving Partial Differential Equations (PDEs).

QML: The Quantum Machine Learning division, in collaboration with industrial, academic and governmental partners, designs and engineers novel, application-motivated Quantum Machine Learning algorithms across industries such as finance, healthcare, pharma, energy and logistics.

EUMEN: Currently in advanced beta testing, EUMEN is an enterprise-grade quantum computational chemistry package and development ecosystem, enabling a new era of molecular and materials simulations. Developed in close collaboration with Fortune 500 partners, EUMEN's modular workflow enables both computational chemists and quantum algorithm

developers to easily mix and match the latest quantum algorithms with advanced subroutines and error mitigation techniques to obtain best-in-class results. Current applications in development with clients include new material discovery for carbon sequestration, drug design and discovery, and hydrogen storage.

The Combined Companies as Quantinuum

Quantinuum has the benefit of CQC's software and algorithm expertise combined with HQS's hardware expertise, creating the largest full-stack dedicated quantum computer company. Quantinuum has about 400 employees in 7 offices in the US, UK and Japan. On the hardware side, the Model H series of quantum computers are available via the cloud, facilitating broad access and ensuring it is "future-proof" for customers as the product evolves and advances. On the software side, the open-source platform-agnostic approach will continue, ensuring customers always have access to the best tools for the target application and will not be dependent on a single company's machines.

The predecessor companies had a long history of collaboration. In fact, CQC was the first external user to run a quantum circuit on the System Model H0, Honeywell's inaugural commercial system. No organization outside of Honeywell had used the H-Series hardware more than CQC, so the formal combination of the businesses seems like a natural extension of their legacy collaborations. By spinning the business out into a stand-alone company, you can expect to see a Quantinuum IPO some time this year.

Strangeworks Collaboration

Quantum Origin is the first commercially available product based on verifiable quantum randomness, a capability essential to securing existing security software and to protect enterprise systems from threats posed by quantum computing-based attacks. Announced just this past week, Strangeworks, a global quantum computing software company, announced a collaboration to implement Quantinuum' s quantum-enhanced cryptographic keys, Quantum Origin, into the Strangeworks ecosystem. By implementing Quantum Origin, Strangeworks will be the first to implement a seamless path to quantum-generated cryptographic keys and it expects to expand the relationship between the parties enabling rapid adoption and insights.

Select Customer Usage Cases

Quantinuum has listed a few case studies on their website, including the following:

Nippon Steel: Has collaborated with the Company to optimize scheduling. As the recent global supply-chain disruptions have highlighted, complexities in managing manufacturing and supply often requires companies to juggle resources. Nippon Steel produces over 50 million metric tons of steel annually and has been using an algorithm co-developed with Quantinuum and run on a System Model H1, to schedule the intermediate products it uses. Having the right balance of raw materials and intermediate products is essential and is a delicate balancing act facilitated by Quantinuum.

Samsung: The electronics giant teamed up with Imperial College London to investigate new battery materials using a System Model H1. The team created a simulation of the dynamics of an interacting spin model to examine changes and effects of magnetism. They were able to run

deep circuits and use as many as 100 two-qubit gates to support the calculations, confirming the Model H1 can handle complex algorithms with a high degree of accuracy.

BMW: Entropica Labs, a Singapore-based quantum software startup, and the BMW Tech Office, teamed up to develop and run a Recursive Quantum Approximate Optimization Algorithm (R-QAOA) to benchmark logistics and supply chain optimization via number portioning, a classic combinatorial problem that is an entry point to many logistics challenges. More complex versions of R-QAOA are now being explored.

This is just a small sampling of current projects and customers, with more than 750 overall collaborations currently underway, suggesting substantial customer uptake and potential.

Summary

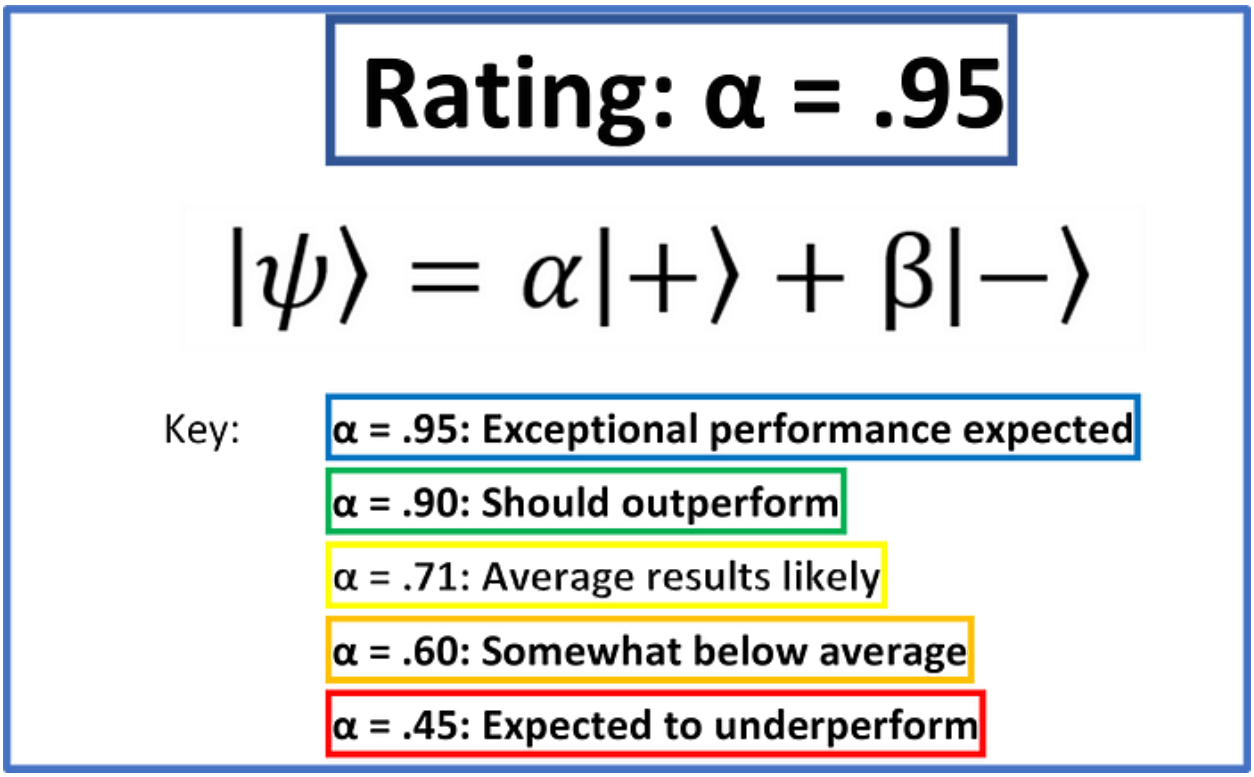
Cambridge Quantum Computers and Honeywell Quantum Solutions were each already formidable players in the evolving QC space and have been generating meaningful revenues from this nascent field. CQC is/was a reputable and well-established quantum software and algorithm provider and HQS has created advanced QC devices which continue to scale and surpass performance records. Assuming they can achieve synergies as a combined company, the upward trajectory should accelerate. That said, the QC industry is still quite immature, and many players are dedicating substantial resources, so any early market leads will remain vulnerable to new technologies or competitive advances. If Quantinuum can successfully leverage the broad client portfolio and historical industrial legacy of Honeywell with the substantial history and success of CQC, it should remain a leader in this growing field. The following table highlights some of the key attributes of Quantinuum:

Strengths:	Opportunities:
• The merger creates the largest full-stack quantum computing company. • The open-source, platform-agnostic software should continue to attract a broad array of customers and users. • There are already over 750 collaborations underway with major companies in diverse fields, suggesting snowballing momentum. • An aggressive product roadmap, including 10x quantum volume per year, suggests consistent quantum advantage during this decade. • With the $300m infusion from Honeywell, the business is well capitalized; an imminent IPO may also facilitate attracting additional capital.	• Quantum Origin is a first mover in QRNG (quantum random number generation), an area that should garner growing attention; the Strangeworks collaboration seems to be an excellent way to leverage this capability. • The Model H roadmap is hitting its early milestones and continued advances should bring increasing attention to the Company. • Fully integrating the hardware side with the software/application side should yield increasing synergies and advances. • The company is well capitalized, and Honeywell remains a key investor and partner. Leveraging Honeywell's long industrial history should accelerate adoption. • The recently announced real-time error correction seems like a strong first step towards fault-tolerant QC and has strong future commercial potential.
Weaknesses:	**Threats:**
• Trapped ions have long coherence times but longer switching times, providing scaling challenges. While early advances on the product roadmap have been met, this will be increasingly difficult as the platform continues to scale. • The companies come from very different cultures so integration may be challenging. Maintaining "dual headquarters" in Cambridge and Colorado exacerbates these challenges.	• Formally uniting the businesses may take away some of the prior entrepreneurial energy. • While the software is still platform agnostic, the dedication to trapped ions for the hardware platform may leave the business vulnerable to advances by other methodologies.

Rating

Apropos of the way qubits are described, I wanted to leverage the nomenclature to create a company rating system and assign a probabilistic scale to my overall assessment of a company's potential. Accordingly, I am going to use the formula below when reviewing companies, whereby the "alpha" coefficient correlates with "positivity" (and the formula adheres to the Born rule). Given my overall assessment of Quantinuum including its strong position as a full-stack

player and the strengths of the legacy businesses, I am assigning the highest rating to Quantinuum at this time, 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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