The Quantum Leap
February 7, 2022

Quantum Advantage is Closer than you Think

I recently had the pleasure of speaking with Anisha Musti, a delightful and empowering 16-year-old CEO and Co-Founder of Q-munity, a 501(c)(3) non-profit that is introducing and teaching young individuals about Quantum Computing (I encourage you to check out Anisha and her project(s) at the Q-Munity website). She hopes to expose her peers to QC so that they will consider careers in the field, or "if they learn about it from us but choose not to pursue it, at least they will be making an educated assessment." Anisha's poise and wisdom belie her age.

The fact that a 16-year-old, along with a few of her friends and co-students, have established a robust and constructive free resource is one of the topics I highlight below. But I am starting this post highlighting this conversation because it was an interesting multi-generational dialogue. She asked a bit about my QC journey, and I began explaining my first computer courses in college (COBOL and FORTRAN) where we used "punch cards" to store and retrieve commands. The conversation went along generally as follows:

> Me: I started in computers when we still used punch cards to record the commands.
> Anisha: Huh?
> Me: You know, that was before we even had floppy discs.
> Anisha: I have no idea what a floppy disc is.

Which certainly made me chuckle. I reflected on the amazing advances we've seen in just my lifetime. Born in the 60's, I entered college before personal computers (or GPS or cell phones or the Internet, etc.) and have witnessed amazing technological progress ever since. Sometimes, when I consider the power contained in my iPhone, I am awed by it and it feels like we can't possibly need any more technological advances…I can do almost anything, virtually instantly, in the palm of my hand.

But time and technology invariably move forward. And in fact, we appear to be on the cusp of even more profound technological capabilities in the form of working, powerful Quantum Computers. Using the growth in power and capacity of some electronics over the past 20 years, the following table provides a level of growth-speed context:

	2002	2012	2022	20-Yr Growth
Typical CPU Clock Speed	1.2GHz	3.9GHz	5.2GHz	**4.3x**
Average Internet Speed	800Kbps	10Mbps	106Mbps	**132.5x**
Average Hard Drive Capacity	8GB	128GB	6.1TB	**762.5x**
Average Cellular Data Speed	14Kbps	2Mbps	60Mbps	**4,285x**
Avg. Gaming Console Memory	16MB	32MB	825GB	**51,562x**

You may notice that the growth-rate of the speed of the processor of your PC, while substantial at 4.3x, is a tiny fraction of the rate of growth in cellular data speeds. This is a nuance of these sorts of growth rates, which are more explosive earlier in the life cycle, but eventually slow down and physical limits become more difficult to overcome. There is also a relative utility factor, in that PC's created in 2002 were pretty good at basic office program usage (email, word documents, spreadsheets, etc.) so the utility of speed increases was less valuable. Compare that to gaming consoles. While the graphics of Grand Theft Auto: Vice City (#2 videogame of 2002) may have made your mother cringe, it is a far cry from the realism experienced by today's FIFA22. In other words, the consumer utility of increased speeds and capacity is still a steep demand-curve for certain technologies, especially for those with substantial headroom in progress and need.

Given the utility of improved Quantum Computing, it is my opinion that the rate of growth will continue to accelerate at a phenomenal rate. We are already seeing 10x/year increases in quantum volume (albeit over a short window of time) and I expect that pace to remain or accelerate in the near term, as I'll explain below. While there has been much written on this topic, and many billions of dollars invested, many still speak of a "quantum winter" where the hype overshoots the reality. Readers of my posts know that I am mindful not to contribute to the hype, but **I truly believe that useful, practical Quantum Computing applications are imminent** (i.e., by the end of this decade or sooner). Let me explain a few reasons why.

1. **The Quantum Evolution is Quite Mature**

In 1879, electricity was first harnessed for home use to power Edison's electric light bulbs. During the period of 1920-1935 the US went on an electrification campaign bringing power to 70% of US homes. So, in about 50 years, a profound new technology became ubiquitous. Nobody could have imagined the impact electricity would have on daily life in those early years. Yet today we take for granted that we can plug a cord into any wall in our home and have instant, nearly free power. Personal Computers and the Internet have had similar, profound impacts on our daily lives, generally over shorter and shorter spans of time.

Quantum Computing has the potential to be a next profound disruptor. Many authors, including me, have covered the power and potential of QC, so that is not the focus of this post. Rather, the concept to keep in mind, is that while "Quantum Computing" is relatively new, the utilization of quantum physics/mechanics has been progressing for the past 130 years. We have had great success utilizing the dual wave-particle nature of electrons and photons for a variety of purposes

including MRI's, lasers and GPS, among many others. As that prior post noted, today we are already using quantum mechanics in Quantum Sensing for precise measurement probes (even where GPS is unavailable), ghost imaging and quantum illumination. It is also being used today for certain applications of Quantum Communication. And yes, while current Quantum Computers are not as powerful as we'd like, there are dozens of companies offering access to their working Quantum Computers today, with the power of the machines increasing quite rapidly. While it is difficult to get consensus over exactly when the QC's will become powerful enough to surpass classical computers for real-world problems, nearly everyone in the field will confirm it is just a matter of "when" not a matter of "if".

2. **Cutting edge Quantum Processors are Available in the Cloud**

As noted above in in a prior post, there are a variety of QC companies offering their latest QCs via cloud-based access. This is important because it "socializes" access to QCs. Today, anybody with some basic computing chops, can access actual, working QCs for modest, or in some cases, no cost. Quantum algorithms are being written and run every day. Furthermore, because many QC makers are providing their latest QCs via the Cloud, commercial users do not have to deal with a large CapEx (capital expenditure) cost up-front nor do they have to worry about obsolescence. When mainframe computers became available to commercial users in the early part of the 21st century, they were extremely expensive, difficult to operate, and subject to being outdated relatively quickly. The same was generally true of desktop computers, which often were made obsolete due to advanced software, well before they stopped "working."
By utilizing QCs over the cloud, this cycle of CapEx →Obsolescence → CapEx can be eliminated, which should spur greater utilization and adoption of QC than otherwise might occur.

3. **Open Source is the Default**

I mean this in a broader sense than you might expect. On the one hand, most of the existing QDKs (quantum development kits) are both open source (i.e., free to use) and cross-platform compatible. What this means from a practical perspective, is that the learning curve for QC proficiency is much less steep because whatever skills are acquired can be used across many different platforms. In addition, someone who creates a QC algorithm to access via a cloud provider such as Amazon's Braket or Microsoft's Azure Quantum can have the same algorithm run over a variety of QC hardware provider platforms. Contrast this with early PC access where PCs did not speak to Mac's or Linux boxes. In addition, they required competing software, input devices and physical plugs in many cases. All of that "confusion" made it difficult for the industry to scale at the same pace it might have, if all power users spoke the same language and used fully compatible hardware.

Even more profound and telling in the current QC environment is the "open" nature of so many of the participants. Access to the programs offered by Anisha's Q-Munity, noted in the opening paragraph, is free. Many authors have published complete textbooks on Quantum Computing (Thomas G. Wong's Introduction to Classical and Quantum Computing, and Brian Siegelwax's Dungeons-n-Qubits are but two examples) for free. And there are innumerable fist-rate on-line courses and programs about Quantum Computing for free. In addition to all the free resources, I

have found that the players and participants in the industry are also generally open, friendly, and eager to help folks on their quantum journeys. This spirit of community and cooperation is refreshing, especially around an industry with such tremendous commercial potential. Perhaps this openness will be less pervasive once the industry gets more mature (and companies are competing more vigorously for QC customers), but the essence of this post is to suggest that point arrives quickly, and this current state of openness certainly accelerates access to, and development of, quantum technologies.

4. QC is Leveraging Adjacent Technologies

In addition to leveraging the historical progress in taming quantum mechanics for commercial use, recent advances in machine learning, artificial intelligence and big data are quite complementary to Quantum Computing. Many advances and breakthroughs in these industries can be accelerated or improved by applying QC technology, so the pool of well experienced, advanced computing talent, is quite larger already, even in the relatively early stages of QC evolution. Similarly, we see certain quantum hardware strategies leveraging existing advances in semiconductor technology (i.e., quantum dots) and optics (photonic qubits) to create QCs. As the hardware advances and applications continue to evolve, I expect many to also converge.

5. Quantum Advantage is a Continuum not a Milestone

As a refresher, while there is no definitive guide to definitions about QC, "quantum supremacy" is generally referred to as a QC being able to tackle a problem, even one without real-life application, faster than a classical computer. This was achieved in by Google in 2019 and repeated by others since. "Quantum advantage" on the other hand, is meant to denote when QCs can out-perform classical computers in actual, useful applications. The QC world is anxiously awaiting this Quantum Advantage threshold without clear consensus on when that might occur. However, as those who study quantum effects well know, things are never so binary! It is more constructive to think about QC progress as a continuum, not a specific threshold to be achieved.

I am not the first to suggest this perspective. In a recent Harvard Business Review podcast, host Azeem Azhar interviewed Rigetti Computing founder and CEO Chad Rigetti. In it, Rigetti noted select instances where a QC offered a very slight performance advantage to a small part of a broader problem. He discusses how this happened with Rigetti's attempt to improve weather forecasting. While this is certainly not Quantum Advantage, it is a real-world example, today, of QC contributing to real analysis. Chad elaborated on some of his thoughts around "narrow" versus "broad" quantum advantage, which I found very compelling. Specifically, he referred to "narrow advantage" where a specific use case might benefit from QC, such as in the pricing of derivatives. Any small advantage could produce outsized financial benefits in portfolio allocation or timing of trades and could occur well before "broad advantage" is achieved. While financial markets are just one example, the finance industry is already very computing advanced and the underlying data is already in computing format, so this sort of narrow quantum advantage could be quite close. Broader quantum advantage, where QCs can generally outperform classical computers, is more difficult and therefore further away, but I imagine we will see many steps up a spectrum of advances on the way to full quantum advantage.

6. Calling Dr. Evil…

The final point I want to make, is the enormous economic impact that a powerful QC will make. The heading of this section, using a tongue-in-cheek reference to Austin Powers movies, is meant to evoke the massive commercial gains that can be made with a powerful QC. Much has been written about using Shor's algorithm to break current encryption protocols and the "HNDL" (hack now, decrypt later) movement, which unfortunately is a real thing. A bad actor or nation-state could command enormous power if they were the first to create a powerful QC. They could break most encryption, mine all remaining bitcoin and other cryptocurrency and skim untold profits from financial systems by front-running traders, just to name a few powers. In fact, the US and China are currently engaged in a ferocious race to develop the most powerful QC capabilities, each fearing the other's ability to get there first with each establishing nationally supported quantum initiatives.

Naturally I hope and expect that the "good guys" will have the most powerful QCs and will focus their powers on good use such as better medicines, more efficient car batteries and optimized logistics, among other things. Certainly, the rewards and upside for constructive use of QCs is enormous, and smart people are busy at work to protect us from those bad actors. The point is that the massive financial upside for access to powerful QCs will spur accelerated development.

So, can we say with any certainty, what a QC timeline looks like? Unfortunately, not. But as this post points out, the foot is on the accelerator, billions of dollars are being invested and super smart people are working on creative solutions to existing progress rate delimiters. For these reasons and those enumerated above, I am confident that we will begin seeing quantum advantage in our daily lives more and more over the next few years.

***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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