The Quantum Leap
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The Quantum Computing Elevator Pitch

Readers of this blog may have read prior posts where I attempt to summarize the features and benefits of Quantum Computing (QC) that underly its ability to transform computing with enormous power and potential. I have tried to do so without layering in too much math or physics and I hope you have found these posts helpful.

In this post I will summarize the key aspects of QC in an "elevator pitch" without any math or physics, intended to help pique your interest in digging in and learning more. Before I launched this site/blog, I wanted to understand some of the underlying quantum physics, linear algebra, computational theory and related physics associated with qubits to satisfy my own curiosity, but none of that is essential to appreciate the power of QC. Here is the "pitch" (useful if the elevator is only going up a couple of floors):

"**Quantum Computers will transform the way we use computers by massively accelerating certain computations and, more importantly, by enabling a wholly new form of computing.**"

That is the headline and take-away message. Many have conveyed the first part (speedup of computing), but the second part is less noted, although more potent. Here are some further details to support this statement (if the elevator trip is slightly longer):

- Taming tiny particles (atoms, electrons, photons, etc.) enables transformative computational power.
- At this tiny scale, matter behaves both like a particle and a wave. We are familiar with both but have challenges understanding and describing actions where particle and wave features happen at the same time, as in QCs.
- This particle-wave duality underpins the features of superposition and entanglement, which is where the power of QC is derived. Superposition simply means that each computing bit or 'qubit', can be either 1 or 0 or a combination of both. Entanglement simply means that qubits can be connected and dependent on each other, enabling simultaneous processing/computation.
- Mankind has refined this ability to control these tiny particles over the past 100 or so years, and actual working quantum computers now exist and can be accessed today over the cloud, albeit these early QCs do not yet contain more power than classical computers.
- Now that QC has moved from being theoretical, to being practical, billions of dollars and enormous resources are being funneled into the QC space by governments, major corporations, new companies, venture investors and academic institutions, in order to perfect and leverage this new computing power.
- Over the next few years, QC power should increase to the point where it can be used to understand chemical reactions in a way that leads to new medicines, design highly specialized materials to improve batteries, solar power, fertilizers and other important things, as well as other amazing advances.
- However, the really exciting applications of QC will not be because QCs can do current computing faster (which is immensely valuable) but that **QCs will let us tackle problems**

> **that at present we don't even bother trying with regular computers because we know they are much too hard or enable us to provide answers to questions we haven't even thought to ask**. [Rudolph, 2017]

This is the spine tingling, wide open blank canvas, that makes Quantum Computing so exciting for me (and by the time you finish this post, hopefully for you too).

Now, let's break this down into a few baby steps.

You don't need to understand the physics of most technologies in order to use and benefit from them.

New technologies are hard to appreciate and understand but can be transformative to society even without a user's understanding of how they work. Many people that are new to QC get tripped up trying to understand exactly how the underlying quantum mechanics "work". Unfortunately, understanding the quantum physics is extremely challenging because it involves a scale so small that it is not easy to relate to using our current person-sized orientation. However, if you think back to prior transformational technologies, you likely will note that most were (and still are) not understood by lay people. Here are a few examples:

- Radio (and television)
- Electricity
- Integrated Circuits

In the late 1800's man mastered "waves" in order to transmit voice signals across long distances. We are all familiar with AM/FM radios but likely do not understand the physics of "amplitude modulation" for AM or "frequency modulation" for FM. We cannot see radio waves with our eyes. Yet we can all enjoy listening to music in our cars or speaking with loved ones on our phones.

Also, in the late 1800's (specifically on September 4, 1882) New York City was illuminated by electrical light for the first time, showcased by the lighting of the New York Times building (as depicted in episode 7 of the *Gilded Age* on Hulu). During the subsequent decades, there was raging debate about the dangers of electricity and the relative benefits/weaknesses of AC vs DC power. Despite these debates, electrical wires were installed throughout the country/world and today's electrical grid is a complex and inter-connected wonder.

You take for granted that you can plug a lamp into a power socket in your home, and instantly have "light". You may not realize that the electrons flowing over the filament in the bulb arrived there nearly instantly from many, many (maybe thousands of) miles away. You do not need to know anything about electricity to turn on that lamp and enjoy its benefits. Similarly, when PCs were first released, many critics were baffled why anyone would want to buy a home computer, and certainly did not understand how they worked. Yet today, nearly everyone has access to PCs and they are ubiquitous in business and education. People use them daily without any underlying appreciation for how integrated circuits function.

The power and potential of QC has to ability to rival the transformative impacts of radio, electricity, and integrated circuits, and it will do so whether users understand the inner physics or not.

What's with the Particle/Wave Duality? I thought you promised no math or physics…

Yes, I understand this sounds very "science-y" but it is quite straight forward. We are all familiar with the way particles behave. We don't have to understand the underlying Newtonian physics to appreciate the way billiard balls move on the pool table, the way the golf ball travels when you hit it, or for that matter, the way the tides happen in response to the movement of the moon. The actions and reactions of "particles" that we experience in our frame of reference is intuitively understood even if the underlying physics are not.

Similarly, we understand and appreciate the behavior of waves. If we throw two stones into a pond, we can see the resulting ripples (waves) in the water and we can see how those waves interact with each other. We can wave a streamer and see the waveform in the ribbon. And for anyone who has used noise-cancelling headphones, we can appreciate how the noise is removed once we engage that feature. The way this noise cancellation happens is the unit is "listening" and then creates a sound wave that is opposite to the sound it hears. When the two "waves" are both transmitted to the ear, one out of phase (opposite) with the other, they "cancel" each other, and we hear silence.

In Quantum Computing, the physical qubits (electrons, atoms, or photons, etc.), because they are so tiny, behave a bit like particles and a bit like waves. It is not important to understand precisely how, but the "wave" aspect, like the "cancellation" that happens in noise cancelling headphones, is part of what empowers Quantum Computers to process information so much faster than classical computers by amplifying what is being sought and/or cancelling out what is not.

Transformative technologies create transformative wealth

It is certainly not an overstatement to say that integrated circuits have wildly transformed society. There are now integrated circuits in nearly every powered device. Everything from kids' toys to smart thermostats to cell phones is dependent on integrated circuits. And this transformation is evidenced in enormous wealth creation. Look at the top ten companies, by market capitalization (as of 3/20/22):

· Apple ($2.8 trillion)
· Saudi Aramco ($2.3 trillion)
· Microsoft ($2.2 trillion)
· Alphabet/Google ($1.8 trillion)
· Amazon ($1.7 trillion)
· Tesla ($1.0 trillion)
· Berkshire Hathaway ($771 billion)
· NVIDIA ($675 billion)
· Meta/Facebook ($608 billion)
· Taiwan Semiconductor ($555 billion)

Seven of these top ten companies are directly in the "integrated circuit" business, either as a manufacturer or for their primary value proposition (Aramco, Tesla and Berkshire Hathaway are the exceptions, although you might argue that Tesla's could not operate without integrated circuits and Berkshire has large positions in tech companies). These seven companies have created over **$10 trillion** dollars in wealth, which is a staggering amount, and this has been done in an astonishingly short period of time. Those seven companies combined are larger than every country on the planet (as measured by GDP) with the exceptions of the US and China. I won't be so bold as to definitively say that QC will do the same (or more accurately, won't predict when), but the potential for QC to create these levels of wealth is certainly possible.

A Quantum Computer, by definition, is a Computer. What is so Different?

Today's personal computers are awesome and have power that may have been considered unimaginable just a few decades ago. My current PC (a Dell OptiPlex 7780) has 64 GB of RAM and can operate at 2.90GHz. That means its RAM or rapid access memory (the playing field of the computational power of my machine) has 64,000,000,000 bytes of computing memory or 64 billion units. It can process those bytes at the rate of 2.9 billion per second. Think about that. My basic desktop computer has billions of computing units and can process them at the rate of 2.9 billion per second. That means that in the 6 seconds it took me to type this sentence, my computer could perform over 17 billion calculations.

That sounds unfathomably powerful and fast to me, and it is. So why could we possible need even faster calculations and what can't I already do on my Internet-connected machine that I might want to do? Answers to that question are where Quantum Computing gets fun and exciting. The purpose of today's post is not to explain all of the details, physics or specific use cases, but rather to excite you enough to want to learn more about those things. So, let's change the perspective a bit (pun intended for those of you familiar with the Hadamard gate).

Because QCs approach calculations differently and can utilize entangled qubits, it approaches calculations/algorithms differently from classical computers. As a reminder: a) qubits operate in three dimensions; b) QC gates are more complex than the AND/NOT/OR gate functions of classical computers; c) quantum algorithms are bi-directional; and d) results are probabilistic (not deterministic) [see here for prior post which explains these features in greater detail].
So, what do these features do that make QCs so much different than classical computers? Let's use an analogy to help convey this. Classical computers are a bit like radios that existed before television. You could listen to sports events live without going to the stadium. You could hear the news and listen to stories about faraway lands. And you could be entertained for hours. These were deeply satisfying activities in the day but compare those machines with today's high-definition big screen televisions and the evolution of information and entertainment is massive.

To extend this thought exercise a bit further, consider the evolution of the Internet. When AOL was distributing their enrollment CDs seemingly everywhere and was the first company to make e-mail a household thing, most people did not imagine such technology would also let you sell your junk (eBay), get a ride to the airport (Uber), or find the answer to nearly any basic question nearly instantly (Google).

Putting it all Together

To paraphrase Terry Rudolph (Imperial College quantum physics professor and co-founder of Psi Quantum), explaining how quantum computers work is a bit like having someone describe van Gogh's "Starry Night" after only seeing a black and white photograph of it, which has been chewed by a dog. It is difficult to do it justice.

There are countless articles about the power of Quantum Computers and the marvels society will enjoy once they are powerful enough. This is generally framed in terms of combinatorics and what can be achieved if such calculations can be sped up considerably. I am extremely excited about this aspect of QC and much of my blog writing has been to sing those praises. However, what is most exciting to me, is to contemplate the "eBays" and "Googles" of Quantum Computing. What will we be able to do with this completely new form of computing? What new questions can we ask and have answered? What types of products, companies and industries will be created? What programming masterpieces will the computing programmers create with this new medium?

I look forward to finding out and hope you continue to join me on the journey.

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.*

References:

Rudolph, Terry, "Q is for Quantum", 2017

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