

## The Quantum Leap June 24, 2022

# The Metaphysics of Quantum Computing

When I created this blog, my stated purpose was to follow Quantum Computing (QC) from the perspective of an investor. To date, I have generally posted blogs that either covered technical aspects of QC (e.g., this <u>post</u> explaining superposition and entanglement), or showcased the companies involved in commercializing QC (e.g., this <u>post</u> on the evolving ecosystem). However, I hope you'll indulge me a bit for this latest post, which approaches QC from a philosophical perspective. It's an aspect of this field that originally gripped my attention and which underlies much of why quantum mechanics conjures such non-intuitive conclusions. Here are a few concepts that will be covered, each of which likely induces headscratching:

- Wave/Particle Duality
- Matter/Energy Equivalence
- Superposition and Entanglement
- The Observer Effect
- The Uncertainty Principle
- "Imaginary" Numbers

As many of you may already know, a core feature of quantum mechanics concerns the "duality" between particles and waves. Certain aspects also deal with the interchange of matter and energy (you are already likely familiar with Einstein's E=MC^2 equation which famously and simply showed the equivalence between matter and energy). These somewhat non-intuitive principals underpin some fascinating philosophical questions regarding QC. That said, I am approaching this as a lay person, so will not debate any of the theological roots or delve deeply into the underlying physics. However, I hope you will enjoy this mental exercise and that it will spur your curiosity to dig in deeper yourself.

## The Quantum "Chicken-and-Egg" Quandary

If you search for resources about the origin of Quantum Computing, you will invariably come across a quote by Richard Feynman, generally cited as the father of QC. In April 2012, Feynman said:

"Nature isn't classical, dammit, and if you want to make a simulation of nature, you better make it quantum mechanical..."



Most current descriptions about how QCs work approach it from the qubit perspective. How to harness the quantum mechanical features of the underlying qubit, be it an atom, electron, or photon. A new form of computing paradigm, where we use machines to solve problems or equations that current classical computers would take too long to solve. While this is truly fascinating, and I am confident it will unlock massive opportunities (and value), it is a bit "backwards" from what Feynman was suggestion. His premise was focused on "simulating nature" and since nature is governed by quantum physics, he was suggesting we needed to use quantum physics to better understand nature. It is expected that as QCs become larger and more powerful, we will be able to simulate nature to create better batteries, fertilizers, and medicines, among other things. But QCs will also enable us to answer questions we've never thought to ask, and which would essentially be gibberish to classical computing processes.

The metaphysics of this concept revolves around using QCs to create better QCs. As we work to scale existing QCs which currently contain tens or hundreds of qubits, an obvious early question is "how do we build better and larger configurations of qubits?" As industry drives towards 1,000,000-qubit machines, it seems obvious (at least to me) that it will take QCs to optimize the configurations of these larger QCs. What is the upper limit of the capabilities such a self-supporting loop can create? This 1,000,000-qubit goal assumes "noisy" qubits, so it is thought that we need 1 million qubits to net-out to 100 logical qubits, and much has been written about the awesome power of 100 logical qubits…but why stop there? What if we had 1,000 or even 1,000,000 logical qubits? The power of such a machine would, essentially, be so massive as to be indescribable.

#### More on Wave-Particle Duality

Quantum computers derive their power from quantum mechanics, which is the study of the physical properties of nature at the scale of atoms, photons and subatomic particles. Many of the fundamental properties of quantum mechanics revolve around the



behaviors of these particles, which exhibit characteristics of both particles and waves. Intuitively, we understand particle behavior which guides the path of a baseball or the motion of a billiard ball. Similarly, we are familiar with waves and how they can sometimes cancel each other or enhance each other. However, when particles exhibit both properties simultaneously, non-intuitive things happen, such as superposition and entanglement. While non-intuitive, these features are well proven experimentally and can be explained and predicted using established mathematics so we must wrestle with the fact that something so non-intuitive is occurring at the smallest scales. Conversely, I have yet to find a satisfactory explanation or formula to describe "the observer effect". For those of you not familiar with this feature of quantum mechanics, it essentially says the act of measuring something (i.e., observing it) changes it. An example of how this manifests in Quantum Computing can be seen if we apply two sequential Hadamard gates. Skipping over the linear algebra and matrix multiplication, if you input a  $|0\rangle$  to two sequential Hadamard gates,  $|0\rangle$  is output 100% of the time (i.e., it is mathematically equivalent to the identity matrix). However, if you measure the qubit between the two Hadamard gates, the output becomes a superposition that is  $|0\rangle$  half of the time and  $|1\rangle$  the other half of the time. The mere act of "observing" the qubit between gates changes the outcome! How does the qubit know it is being observed?

## The Y-Gate and "Imaginary" Numbers

Nearly any "Intro to Quantum Mechanics" course, book, or article, will mention the Stern-Gerlach experiment as one of the first topics. It's a fascinating subject that is well covered elsewhere, so I won't provide much detail here (if interested in learning more, the Wikipedia post on the subject is a great intro and a link is included in the References at the end of this post). The Stern–Gerlach experiment involves sending a beam of silver atoms through a magnetic field and observing the deflection. The results show that particles possess an angular momentum that is similar to the angular momentum of a classically spinning object, but that it has only certain quantized values. Another important result is that only one component of a particle's spin can be measured at one time, meaning that the measurement of the spin along the z-axis destroys information about a particle's spin along the x and y axes.

Now, if you'll bear with me a bit as I reference linear algebra (don't worry, you don't need to understand linear algebra to appreciate this point), I want to highlight a very metaphysical aspect of this concept. You'll note below the matrix notation for two essential "gates" or basic QC functions. The first is known as the "X-Gate" which is analogous to the "NOT" gate in classical computing. If you apply a NOT gate in classical computing, it switches a 1 to a 0 or a 0 to a 1. In Quantum Computing the X-Gate essentially flips the qubit on its head, also switching a  $|1\rangle$  to a  $|0\rangle$  or a  $|0\rangle$  to a  $|1\rangle$ . This is straight forward only requiring the most basic familiarity with matrix multiplication to prove it. However, the "Y-Gate" is quite different. The Y-Gate essentially turns the qubit <u>on its side</u>, and its matrix representation is suddenly quite foreign. The matrix representation of these two gates is shown below:



Pauli X-GatePauli Y-GateFlips qubitTurns qubit on its side

You will note for the Y-Gate the introduction of "i" (and -i) which is the symbol for the unfortunately named "imaginary" number. "i" is mathematically defined as the solution to " $x^2$  +

1 = 0." Although there is no "real" number that can solve this equation, it can still be used for certain mathematical functions. It likely would be more fitting to call these "complex" numbers instead of imaginary. Mathematicians would likely describe "i" as "lateral" or "perpendicular" to the plane where the "Real" number lay. Evoking this concept of "Real" versus "Imaginary" suggests the imaginary numbers are surreal or mystical, and while that is itself a metaphysical concept, it is the fact that the information is quite different when orienting along the X-Axis versus orienting perpendicularly on the Y-Axis. Again, for those familiar with linear algebra, this is rudimentary matrix multiplication and for those studying quantum physics, it is one of the first topics covered and proven by the Stern-Gerlach experiments back in the 1920's. The take-away for this post is that the same quantum "thing", oriented in one direction, contains different information if you orient it in a perpendicular manner.

#### **Back to the Beginning**



As in the beginning of time. That tiny fraction of an instant before the Big Bang. It is generally believed that our current universe was preceded by a reality where everything (all energy and matter) was confined to an infinitesimally small point. For reasons still largely unexplained, this super-concentrated point exploded and expanded into what is now the observable universe. From apparent nothingness came a stupendously large amount of space, time, energy, and matter. Have you ever considered why that happened? Surely many of you studied this as you learned about your religion, and largely consider it from a spiritual perspective. But "something" led to the conversion of the pre-universe composition into the current universe comprised of matter and energy. What force led some aspects of the original pinpoint to manifest as matter and some to manifest as energy? Why isn't it all "energy" or all "matter"? I like to believe that "quantum" was the driving force even at this time-zero. Let me explain.

Most introductory texts to quantum mechanics refers to the "uncertainty" principal. It is referenced by Heisenberg in the context of never quite knowing both the speed and position of a particle, and leads to QC calculations being probabilistic and not deterministic. This is the concept Einstein was referring to in his famous "God doesn't play dice…" quote. Imagine for a moment that the original laws governing the Big Bang were completely deterministic. In that

case it would seem likely to me, that the universe would not today be made of various "stuff" but would rather be all of one thing. However, nothing interesting can be built from just one component, and certainly nothing organic. So, the propensity of uncertainty may have led to the creation of energy and of matter of varying configurations which spurred a universe made of a dizzying array of particles, forces, stars, planets, black holes and the other various wonders of nature. It's this "quantum-ness" that allows for variability and it's the variability that creates differing "things".

## **Surfing Across Dimensions**

This has just been a sampling of some of the head-scratching aspects of quantum and is intended to spur questions to contemplate as opposed to provide answers. The mathematics which helps explain quantum mechanics, also govern the addition (or subtraction) of spatial dimensions, which also challenge our current world view. Perhaps some of the remaining unanswered questions in quantum can be explained by action/forces in dimensions we cannot see? Perhaps someone will come up with a "grand unified theory" to explain how the strong, weak, and electromagnetic forces all work and interact and how they relate to gravity, and perhaps that will help us understand these questions from an intuitive perspective.

In any case, despite the challenging mathematics, the non-intuitiveness of certain features, and the inability to definitively tie together all the disparate features of matter and energy, Quantum Computers continue to scale and to successfully run algorithms. As these devices become more powerful, perhaps they will help uncover some of these mysteries. In the meantime, I hope this post helps stimulate your wonder, and that you dig in deeper to learn and understand more. I welcome your feedback and ponderings and you can reach me at russ@quantumleap.blog.

**Disclosure**: The views expressed herein are solely the views of the author and are not necessarily the views of Corporate Fuel Partners or any of its affiliates.

## **References**:

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Image sources: <u>www.ifunny.co</u> (Bohr); <u>@qphysicsmza</u> (Feynman); <u>www.theworldweekly.com</u> (Einstein)

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