A Brief Introduction to Quantum Computing from the Perspective of Ladder Logic

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Abstract

While Quantum Computing is a fairly advanced topic, it suffers from a perception of complexity beyond what is reasonable for the actual subject matter. This paper provides a means to take that perception and bring it down to a more realistic level. The primary targets of this paper are students currently enrolled in or freshly graduated from an electrical engineering or similar program; however, any individual with a base knowledge in programming or digital logic should be able to gain some level of benefit.

Keywords: Quantum, QISKit, Computing, Ladder, Logic, QASM, Introduction

1 Introduction

Make no mistake, quantum physics as a whole is an exceptionally advanced topic. The type of scenarios it brings to the table can be almost mind boggling at times [8]. Add to this a slew of misleading analogies and the fact that "Qubit" may refer to any number of technologies, such as ion traps, superconducting qubits, or spin qubits and it's no wonder that people get confused. With all of that said, while quantum computing does use the underlying principals of quantum mechanics, it is still nothing more than a programming architecture. To put this statement in another context, an individual does not need to understand how to bias a transistor to be good at programming in C.

1.1 Use Case for Quantum Computing

Quantum computing is what's called a Disruptive Emergent Technology. Meaning, as far as industry is concerned, the implementation of these concepts have not only never been seen in any technology prior, but they also have the potential to revolutionize how things are done should these implementations prove successful. Quantum computing is not a magic bullet that can handle every problem; however, it does have the potential to be exceptionally good at problems that current technology has issues solving. Examples of such problems can be as varied as weather prediction, factoring [5], or even protein folding [9].

1.2 Relevance to Reader

To avoid mincing words or dancing around the point, all that is fine, but this leads to the famous words (paraphrased ,of course) uttered at one point by nearly every person between the ages of twelve and nineteen: "Why should I care?". To that, there are two primary categories of answers. First, advances in technology usually creates a higher standard of living, in the case of quantum computing, these advances may end up finding the cure to debilitating ailments, reducing cost of living, or even allowing for a faster, more secure means to transport data (Quantum Internet [3]). The second category deals with economics, the reality of the situation is that there aren't enough people who are skilled in this area to fit the demand [2]. Meaning, not only are jobs available to those with the skills to fill the required roles, but due to the shortage of supply when compared to the demand, these jobs generally pay quite well.

2 Background Concepts

In order to avoid excessive noise, this paper assumes the reader has some basic knowledge of programming as well as electronics. It will not go into depth with much of the math, instead focusing primarily on the act of programming itself. There are many topics which should be covered if one wishes to become skilled in quantum computing, most of which the reader will need to research on their own time; however, the sections below should provide enough context in order to provide a suitable foothold should one wish to continue with the subject.

2.1 Removing Misleading Assumptions

The first and easily one of the most important concepts in quantum computing is to understand that the general public and most media 'experts' do not work in the field of quantum computing. Therefore, it is important to note that many of the common assumptions people tend to have can be misleading or plain wrong due to lack of context or the background knowledge required to properly articulate the concepts at hand.
One prime example of this is Erwin Schrödinger and the concept of Schrödinger's cat. To preface, this is not at all meant to downplay or discredit his work, merely to illustrate that without proper context even an otherwise correct statement from a Nobel laureate can be misconstrued.

To briefly summarize, Schrödinger's cat is a brilliant thought experiment meant to illustrate a potential paradox present within the Copenhagen interpretation of quantum mechanics. This thought experiment was meant to highlight the bizarre nature of EPR (Einstein, Podolsky, Rosen), or superposition states. This is demonstrated via a cat, radioactive particle, flask of poison, and a Geiger counter being sealed in a theoretical box. Should the counter detect radioactivity, the flask would be broken causing the cat to die immediately. Under the Copenhagen interpretation of quantum mechanics, this cat should be considered simultaneously both alive and dead, however, looking into the sealed box will reveal either a very scared cat, or a testament to animals killed in the name of science.

In context, this is meant to demonstrate the concepts of complex, superimposed states collapsing upon measurement. For better or worse, this concept of a not dead, yet dead cat in a box has spread like wildfire, it has become the cornerstone of what the public sees as quantum computing. This has allowed the idea that the quantum state is both 1 and 0 to become the very first thing that anyone learns in regards to quantum computing. While this statement is not technically wrong, it is fundamentally incomplete. In many ways, it's similar to the question "which came first: the chicken, or the egg?", the answer to which can only be something along the lines of 'invalid question', as it not only fails to define what denotes the term chicken, but it also leads the individual being asked to assume the term 'egg' is specifically in the context of a chicken egg.

In reality, a better way to think of this is through vectors and complex numbers. The value is in fact both 1 and 0, but it's that way not because it is two things in a binary sense, but because it is a complex mixing of both. To put this back into cat analogies, let's take the premise back to the start. There is a cat, that cat is now infected with a zombie pathogen. For all purposes, the cat is neither alive, nor dead, as it cannot cleanly fit into either category, yet it does have many of the defining characteristics that comprise both. From here, the cat is injected with an antidote, being a rushed marvel of medicine meant to save the feline race, it will near instantly result in either a complete cure or certain death for our kitten subject. For this analogy, the zombified state represents the ability of qubits to be in a mixed state, the antidote representing the act of measuring this mixed state and thus collapsing the end result into a binary value: 1 or 0, alive or dead.

2.2 Balanced Ternary

Balanced Ternary is not, strictly speaking a part of quantum computing, so with that knowledge, it may seem like a strange item to include as background information when discussing the subject. However, given this author's personal experience, it is nearly ideal to serve not only as a bridge to more advanced concepts but also as a demonstration of why said concepts are important.

To do this, a brief nod to what numbers are at their core is needed. It's pretty obvious to most, but numbers are nothing more or less than a way to categorize quantity. This concept of quantity is important as it is independent of stylistic choices such as base or notation. In programming, binary is frequently used as it reflects the power state of transistors within the register. For most general cases, this works quite well allowing for any number of tricks, or bit-hacks, to be employed to speed things up. However, unsigned binary does have an Achilles' heel in that due to its basis in positive numbers, there is no simple way to show when a number is negative on hardware [1]. To do so, one needs to employ a tactic such as the IEEE 754 standard, adding much more complexity than would otherwise be necessary. One way to circumvent this issue is to use a balanced number system such as balanced ternary.

[1] Note: the "-" symbol seen in both binary and standard decimal is not a representation of quantity, it's more akin to a shorthand for the operation of 0 - Quantity, and thus it's fairly difficult to represent in hardware

Signed Decimal	Binary (IEEE 754*)	Balanced Ternary
0	0	0
3	11	10
5	101	+ 0 -
-254	11000011011111100000000000000000*	- 0 0 - + -

Table 1: comparison table showing equivalent numbers in different display forms

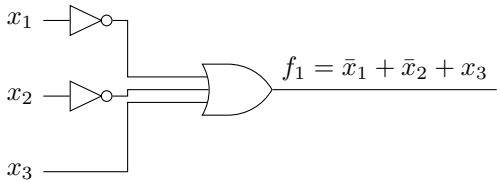

Figure 1: Digital Logic Circuit

These systems work by designating symbols as pre-signed. In the case of balanced ternary, the symbols are designated as "0; +; -" and they represent "$3^{(s*n)}$" with "n" being the index number starting at zero from right to left and "s" being the sign as denoted by the "+" for positive, "-" for negative, or "0" for null quantity [2]. From there it is a simple matter of adding the positive and negative values up in order to get the end result (see Table 1, for example and comparison between bases).

3 Advanced Concepts

3.1 Reversible Logic Gates

A more advanced concept that is still core to quantum computing is the idea of reversible logic gates. Normally when it comes to digital logic inputs and outputs are decoupled. Consider the digital logic circuit as seen in Figure 1. In this circuit, there are three inputs and a single output, even knowing the gate layout and the end value of f_1, the best that could be done for determining the input values is narrowing it to a range of possibilities as all the values have been combined into one, irreversible output. Now consider the reversible logic circuit as seen in Figure 2, while the notation may be unfamiliar[3], each input has its own unique output. Due to this, so long as one knows what gates are in the circuit and what the output values are, the input values can be derived relatively easily.

[2]This notion of sign being a property of quantity will become relevant in later sections (3.2), but for now, it is acceptable to use this idea as a base case.

[3]This notation is that of a simple quantum ladder logic circuit, the elements of which will be covered in a following section

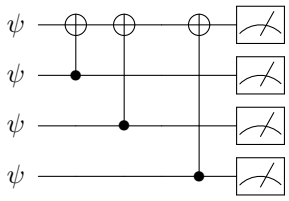

Figure 2: Reversible Logic Circuit

3.2 Probability Amplitudes

4 Experiment 1-2 pages

5 Results and interpretation 2-3 pages

Show a graph of the longitudinal resistivity (ρ_{xx}) and Hall resistivity (ρ_{xy}) versus magnetic field, extracted from the raw data shown in figure **??**. You will have the link to the data in your absalon messages, if not e-mail Guen (guen@nbi.dk). Explain how you calculated these values, and refer to the theory.

6 Discussion 1/2-1 page

Discuss your results. Compare the two values of n_s that you've found in the previous section. Compare your results with literature and comment on the difference. If you didn't know the value of the resistance quantum, would you be able to deduce it from your measurements? If yes/no, why?

References

[1] University of New Mexico. *"Q-circuit Tutorial"* ARXIV, August 24 2004, eprint arXiv:quant-ph/0406003. Bryan Eastin, Steven T. Flammia, Department of Physics and Astronomy. Accessed May 20 2018. https://arxiv.org/pdf/quant-ph/0406003.pdf

[2] Google Quantum AI Laboratory. *"Commercialize quantum technologies in five years"*. March 03 2017. Masoud Mohseni, Peter Read, Hartmut Neven, Sergio Boxio, Vasil Denchev, Ryan Babbush, Austin Fowler, Vadim Smelyanskiy, John Martinis. Accessed May 06 2018. https://www.nature.com/news/commercialize-quantum-technologies-in-five-years-1.21583

[3] Castelvecchi, Davide. *"The quantum internet has arrived (and it hasn't)"*. February 14 2018, Nature. Accessed February 20 2018. https://www.nature.com/articles/d41586-018-01835-3

[4] Aaronson, Scott. *"Shor, I'll do it"*. February 24 2007, Shtetl-Optimized. Accessed December 02 2016. https://www.scottaaronson.com/blog/?p=208

[5] Shor, Peter W. *"Polynomial-Time Algorithms for Prime Factorization and Discrete Logarithms on a Quantum Computer"*. ARXIV, August 30 1995, eprint arXiv:quant-ph/9508027. Accessed August 30 2017. https://arxiv.org/abs/quant-ph/9508027

[6] Forum Users. *"Prime Numbers: In Layman's Terms, How does Shors Algorithm Work?"*, October 9 2012. Cryptography Stack Exchange. StackExchange, Accessed March 4 2017. https://crypto.stackexchange.com/questions/3932/in-laymans-terms-how-does-shors-algorithm-work

[7] Richard Newrock, *"What are Joesphson Junctions? How do they work?"* Scientific American

[8] Moskowitz, Clara. *"New Particle Is Both Matter and Antimatter"*. October 2 2014, Scientific American. Accessed April 4 2018. https://www.scientificamerican.com/article/majorana-particle-matter-and-antimatter/

[9] Brumfiel, Geoffrey. *"D-Wave quantum computer solves protein folding problem"*. August 17 2012. Nature. Accessed August 1 2017. http://blogs.nature.com/news/2012/08/d-wave-quantum-computer-solves-protein-folding-problem.html

[10] Shor, Peter. *"Quantum Computation"*. MIT OpenCourseware. Massachusetts Institute of Technology, 2003,18.435J / 2.111J / ESD.79J, https://ocw.mit.edu/courses/mathematics/18-435j-quantum-computation-fall-2003/

[11] O'Donnell, Ryan. Wright, John. *"Quantum Computation and Information"*. Carnegie Mellon University, 2015, 15-859BB, https://www.cs.cmu.edu/ odonnell/quantum15/

[12] Jordan, Stephan. *"Quantum Algorithm Zoo"*. National Institute of Standards and Technology (NIST), https://math.nist.gov/quantum/zoo/

[13] QISKit. *"QISKit."* https://github.com/QISKit. Accessed: February 14 2018

[14] Wooten, James. *"Using a Simple Puzzle Game to Benchmark Quantum Computers"*. Medium, January 16 2018. https://medium.com/@decodoku/understanding-quantum-computers-through-a-simple-puzzle-game-a290dde89fb2

[15] Gidney, Craig. *"Algorithmic Assertions"* Google AI, http://algassert.com/. Accessed: May 31, 2018

For extended reading list, consult source code, available at:
https://www.github.com/Macrofarad/ABriefIntroductionToQuantumComputingFromThePerspectiveOfLadderLogic