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A REVIEW: A BEGINNER'S JOURNEY TO THE FASCINATING WORLD OF "QUANTUM COMPUTING"

Subhasish Sarkar
Senior SQA Engineer
BMC Software India Pvt Ltd, Pune, Maharashtra, India

Abstract— **The world of "Quantum Computing" is a fascinating, exciting and challenging one. A Quantum Computer operates based on the science of Quantum Physics. Therefore, it is inevitable that people willing to dive into the world of Quantum Computing need to have at least a very basic understanding of the concepts of Quantum Physics. The objective of this technical article is to enable people, having no knowledge of Quantum Physics, grasp the very basic concepts that enable the functioning of a Quantum Computer and thus, generating an interest in further pursuing this new field of computing technology.**

Keywords— **Quantum Computing, Qubit, Quantum Bit, Quantum Computer, Superposition and Uncertainty**

I. INTRODUCTION

Just like you, the reader who is reading this technical article, the author has always been curious to learn about the fascinating and exciting world of Quantum Computing. And, the author assumes that the reader is reading this technical article probably because you also get drawn to the world of Quantum Computing from time to time. And, yes, why not? The world of Quantum Computing seems to be an interesting and challenging one.

So, follow along and read the rest of the article to gain a basic understanding of how things behave and work in the world of Quantum Computing.

The author wishes to present a beginner's perspective into the world of Quantum Computing in a simple, easy-to-understand concept that the author hopes would be easily grasped by people having no knowledge of the science of Quantum Physics and its relevant application in Quantum Computing. Readers willing to pursue an in-depth study and understanding of the field could immensely benefit by referring to some of or all the materials specified in the 'REFERENCE' section below [1 – 15].

II. SYSTEM AND METHOD

A. 'Classical' or 'Normal' Computers –

For a moment, let us concentrate our focus and attention to the world of 'normal' or 'Classical' computers that we interact with and work on, every day. The 'classical' computers use or employ 'Bits' for data processing, manipulation and calculation. Let us suppose that we have a 'classical' computer consisting of two bits. That means, at a point in time, the state of the two bits would be either of the following.

Bit 1	*Bit 2*
0	0
0	1
1	0
1	1

Fig. 1. Bit-state combination representation for a classical computer with two Bits

If our 'classical' computer had three bits, the state of the three bits at a point in time would be either of the following.

Bit 1	*Bit 2*	*Bit 3*
0	0	0
0	1	0
1	0	0
1	1	0
0	0	1
0	1	1
1	0	1
1	1	1

Fig. 2. Bit-state combination representation for a classical computer with three Bits

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And, in case our 'classical' computer had four bits, the state of the four bits at a point in time would be either of the following.

Bit 1	Bit 2	Bit 3	Bit 4
0	0	0	0
0	1	0	0
1	0	0	0
1	1	0	0
0	0	1	0
0	1	1	0
1	0	1	0
1	1	1	0
0	0	0	1
0	1	0	1
1	0	0	1
1	1	0	1
0	0	1	1
0	1	1	1
1	0	1	1
1	1	1	1

Fig. 3. Bit-state combination representation for a classical computer with four Bits

Mathematically, if our 'classical' computer had **n** bits, the total number of states that those n bits could have would be $\mathbf{2^n}$.

B. 'Quantum' Computers –

Now, the question that we could go into asking ourselves is, what is a Quantum Computer? Before answering that question, let's look at what 'Quantum Physics' is. Quantum Physics is the study of the behavior of atoms and fundamental particles like electrons and photons. A Quantum Computer is one that operates by controlling the behavior of the fundamental particles but in a way that is completely different from that of the classical computers. In short, a quantum computer operates based on the science of quantum physics.

And, now, the time has probably come to be introduced to this new term called "Qubit". A 'Qubit' stands for Quantum Bit – A Qubit is to a Quantum Computer, just like a Bit is to a Classical Computer. However, there is a fundamental difference between a Bit and Qubit. At a point in time, the state of a Bit could be either a 0 or 1. A Qubit, on the other hand, has a fluid, non-binary identity; a Qubit can also exist in a state of 0 or 1, but what makes the Qubit completely stand out from a classical computer 'normal Bit' is the ability of the Qubit to exist in a state that is a combination of 0 and 1, with some probability of being 0 and some probability of being 1. This special Qubit state is what is referred to as a '**Superposition**' in the world of Quantum Physics. In short, a Qubit's identity is spread over a spectrum between 0 and 1. For example, a Qubit could have a 75% chance of being 0 and 25% chance of being 1; or 80% chance of being 0 and 20% chance of being 1; or 60% chance of being 0 and 40% chance of being 1. Theoretically speaking, there are endless possibilities.

The fundamental aspect of the operation of a classical computer's 'normal Bit' is that it sticks to a precise value of either a 0 or 1 at any point in time, whereas a quantum computer Qubit operates on the core principle of giving up on the precise values of 0 and 1, allowing for some level of uncertainty. A quantum computer operates by harnessing the powerful quantum properties of 'Superposition and Uncertainty' using Qubits.

Fig. 4. Identity and States of a normal classical computer Bit and Quantum computer Qubit

III. Experiment: Trying to Visualize the Quantum Idea of 'Superposition'

Now, does the idea of 'Superposition', that is, a Qubit existing in a state that is a combination of 0 and 1 at the same time, sound weird and confusing to you? Let us do this experiment ourselves to understand this then.

Let us toss a coin. One side of the coin is the HEAD and the other side TAIL. While the coin is in the air, it is HEADS and TAILS at the same time, and we are not concerned about that at all until the coin comes down collapsing in our hand that we then OBSERVE the coin and see that it has either revealed its HEAD or TAIL position.

So, does it mean that the coin must be always either a HEAD or TAIL? No. In quantum physics perspective, it is, in fact, always existing in a combination of HEAD and TAIL; however, we come up with a certain measurement of it being either HEAD or TAIL through our sense of observation and that is from the perspective of classical physics.

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IV. QUANTUM COMPUTER: APPLICATION & HOW IT COMPARES AGAINST ITS CLASSICAL COUNTERPART

So, now, a very important question – what do all these (Qubits, Superposition and Uncertainty) have to do with computers? Well, to answer that question, let us go back to our preliminary assumption of a 'classical' computer consisting of only one bit. That means, at a point in time, the state of the bit would be either 0 or 1 and the bit can have a maximum of two individual states. For a Qubit, it can be a combination of both 0 and 1 at the same time; the Qubit, therefore, represents both the states at the same time.

Let us now extend the analogy to a 'classical' computer consisting of four bits and consider all the 16 individual 'bit state' combinations (0000, 0100, 1000, 1100, 0010, 0110, 1010, 1110, 0001, 0101, 1001, 1101, 0011, 0111, 1011 and 1111). What if we used a Quantum computer consisting of four Qubits? That would mean that the four Qubits can represent all the 16 individual 'bit state' combinations, all at the same time.

Thus, in our example, if the classical computer were to switch to the 'bit state' combination 1111 (following the strict 'bit state' combination switching in the exact order of 0000, 0100, 1000, 1100, 0010, 0110, 1010, 1110, 0001, 0101, 1001, 1101, 0011, 0111, 1011 and 1111), it would take the classical computer 16 turns/processing cycles whereas just one turn/processing cycle for the quantum computer. In fact, for that single turn/processing cycle, the quantum computer holds both the right (one right answer) and wrong (15 wrong) answers at the same time. By a technique called the "Grover Operator", the quantum computer can sweep away all the 15 wrong answers and what it is left behind with is the single right answer (1111). Now, that is the beauty of quantum computing. Instead of trying each of the 16 values that a classical computer would, a quantum computer tries all the 16 values at the same time.

Table -1 Result depicting how a Quantum Computer compares against its Classical counterpart

Desired Activity	**Classical Computer**	**Quantum Computer**
Switching to the 'bit state' combination 1111 (following the strict 'bit state' combination switching in the exact order of 0000, 0100, 1000, 1100, 0010, 0110, 1010, 1110, 0001, 0101, 1001, 1101, 0011, 0111, 1011 and 1111)	**Number of turns/processing cycles consumed**	**Number of turns/processing cycles consumed**
	16	**1**

A quantum computer is always going to have a classical computer next to it and they must go together, hand in hand. So, you have a classical set of Bits, representing the problem that you are trying to explore. What the quantum computer is going to allow us to do is to explore the exponential number of bit states (2^n), where n is the number of Qubits that the quantum computer has. However, at the end, after the quantum computer explores all the number of states, it must ultimately go back to a classical output – a string of 0s and 1s that can be interpreted by a classical computer.

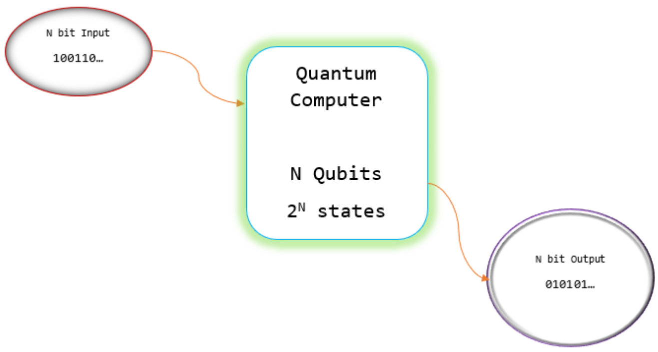

Fig. 5. Co-existence of 'Classical' and 'Quantum' Computers

V. CONCLUSION

Quantum computers are perfect for solving such problems that have the characteristics to blow up exponentially and there are indeed a lot of such problems that exist in the world. These 'exponential' type of problems are the ones that classical computers find it really difficult to solve – 'difficult' in terms of how much time it might take for a classical computer to solve those problems or the extraordinary amount of computing resources and capability that the classical computer might need to spend to be able to solve such problems. And, there are obviously certain problems (that have the 'infinitely exponential' state built into them) that classical computers might never ever be able to solve. Quantum computers are the new ray of hope to help tackle such problems.

So, these were our first footsteps into the exciting, challenging and fascinating world of 'Quantum Computing'. And, I would like to conclude by saying what IBM says about quantum computers – that building quantum computers is not about building faster computers; building quantum computers is something that is fundamentally different with respect to how they operate when compared to that of a classical computer.

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VII. REFERENCE

[1] Abramsky S.; Duncan R. (2006). A categorical quantum logic – Mathematical Structures in Computer Science, Volume 16, Issue 3; Cambridge University Press, (pp.469 – 489).

[2] Acín A. (2001). Statistical distinguishability between unitary operations – Physical Review Letters, 87, art. no. 177901; American Physical Society, (https://doi.org/10.1103/PhysRevLett.87.177901).

[3] Aerts D.; Czachor M. (2004). Quantum aspects of semantic analysis and symbolic artificial intelligence, Volume 37, Number 12; Journal of Physics A: Mathematical and General, (pp. L123-L132).

[4] Aïmeur E.; Brassard G.; Gambs S. (2006). Machine learning in a quantum world, vol. 4013; Conference of the Canadian Society for Computational Studies of Intelligence - Proceedings of Canadian AI 2006, (pp. 431-442).

[5] Altenkirch T.; Grattage J. (2005). A functional quantum programming language; Proceedings of the 20th Annual IEEE Symposium on Logic in Computer Science (LICS), (pp. 249–258).

[6] Andresen S.L. (2002). John McCarthy: Father of AI; IEEE Intelligent Systems, (pp. 84-85).

[7] Baltag A.; Smets S. (2006). LQP: The dynamic logic of quantum information - Mathematical Structures in Computer Science, Volume 16, Issue 3; Cambridge University Press, (pp. 491-525).

[8] Barenco A.; Bennet C.; Cleve R.; DiVincenzo D.P.; Margolus N.; Shor P.; Sleator T.; Smolin J.A.; Weinfurter H. (1995). Elementary gates for quantum computation, Physical Review A 52, 3457; American Physical Society, (pp. 3457-3467).

[9] Benioff P.A. (1980). The computer as a physical system: A microscopic quantum mechanical Hamiltonian model of computers as represented by Turing machines; Journal of Statistical Physics, 22, (pp. 563-591).

[10] Abramsky S. (2004). High-level methods for quantum computation and information; Proceedings of the 19th Annual IEEE Symposium on Logic in Computer Science, (pp. 410–414).

[11] Abramsky S.; Coecke B. (2004). A categorical semantics of quantum protocols; Proceedings of the 19th Annual IEEE Symposium on Logic in Computer Science, (pp. 415–425).

[12] Benjamin S.C.; Hayden P.M. (2001). Multiplayer quantum games, Physical Review A, 64, 030301(R); American Physical Society, (art. no. 030301).

[13] Bennet C.H. (1973). Logical reversibility of computation; IBM Journal of Research and Development, 17, (pp. 525-532)

[14] Bernstein E.; Vazirani U. (1997). Quantum complexity theory; SIAM Journal on Computing, 26, (pp. 1411-1473)

[15] Bertoni A.; Mereghetti C.; Palano B. (2003). Quantum computing: 1-way quantum automata; Proceedings of 7th International Conference on Developments in Language Theory, LNCS, vol. 2710, Springer, (pp. 1-20).