Exploring the current state and application of quantum computing

V S Magomadov

Faculty of information technology, Chechen State University, 32 Sheripov Street, Grozny, 364024, Russia

Email: vmagomadov@gmail.com

Abstract. This paper is focused on the field of quantum computing which is an important area of research these days. The paper gives a brief history of this phenomenon and discusses how it has been developing since its conception. Furthermore, the paper describes the principles on which the quantity computer is built, such as qubits, entanglement, and superposition. It also discusses the necessity to build a quantum computer and how it could an improvement upon the existing computers. In addition, the paper covers some of the fields in which quantum computing could be particularly beneficial. Finally, some of the problems and challenges associated with the development of quantum computing are addressed.

1. Introduction

Quantum computing has been one of the most challenging areas of research in computing science for many years. However, quantum computing is not just about developing some new technology based on the same old principles. Not that these principles are irrelevant but a whole paradigm shift has to take place for quantum computing to become our everyday reality just like the computers we are currently using [1].

The concept of quantum computing was first introduced in 1980 by Paul Benioff, and has been a subject of interest for many influential scientists ever since. One of these many scientists was Richard Freyman who said that the quantum computer could potentially perform computations that cannot be performed by the traditional computer. That is, of course, if such a computer can be built which, according to some experts appears to be a distant possibility despite the fact that there has been some progress in the last couple of decades. This is understandable because a lot of things would have to change because this is a paradigm shift as it was mentioned above. Some sceptics even go so far as to express doubts that scalable quantum computers could ever become a reality [2].

Quantum computers that have been built so far take up most of the space of the rooms they are located in, and they only have small-scale capabilities. One of the examples is IBM's quantum computer which has 65 qubits. There is also a quantum processor called Zuchongzi that was developed in China and it has 66 qubits. At present, none of the existing quantum computers have a number of qubits that exceeds 100. This number is miniscule since it has been suggested by some researchers that for the quantum computer to be of any real value, it would need millions of qubits [3].

1.1. Quantum computer

Owing to some of the principles of quantum physics, it has become possible to build a quantum computer, a machine which is capable of solving problems which are too difficult for existing computers including supercomputers. The idea behind building this technology is utilizing matter and energy at the subatomic level because at that level they manifest differently compared to what happens in our ordinary reality [4].

Those familiar with the field of computing science know that a regular computer consists of bits, algorithms, registers, etc. The quantum computer has features that are similar to them. One major difference is that the quantum computer utilizes what is known as quantum bit or qubit [5].

1.1.1. Qubits

Either one or zero can be stored in a bit of a regular computer. However, a qubit is capable of storing one, zero, one and zero, simultaneously. Furthermore, there can be multiple states and an infinite number of values all at the same time in a qubit. These numbers and multiple values that are stored simultaneously can also be processed simultaneously. As opposed to what is usually done by computers where things are processed one at a time. All that is possible due to a physics concept known as superposition [5].

1.1.2. Superposition

This phenomenon in which qubits can be one, zero, both one and zero, at the same time, is called superposition. In the state of superposition all variations of data can exist simultaneously. This capability leads to a much easier representation of complex problems which is not possible by means of traditional computers [6].

1.1.3. Entanglement

Another physics concept that is an integral part of quantum computing is called quantum entanglement. In terms of qubits it means that if an entangled qubit is changed, the paired qubit immediately changes. This leads to quantum computers having a greater processing speed. Algorithms for quantum computing are based on this concept which means that complex problems could be solved a lot faster than it would be possible in a different scenario [7].

2. Need for quantum computing

Quantum computers should be able to do things that normal computers can. However, most importantly, they should be able to do things that normal computers cannot, and there is enough research to indicate that one of the things in which quantum computers clearly outperform normal computers is combinatorics [8].

The problem of combinatorics is something that modern computers struggle with no matter how advanced they are. According to experts, addressing this problem by means of quantum computing is going to have significant benefits for a lot of crucial areas of modern life, such as pharmaceuticals, finance, artificial intelligence, etc [9].

2.1. Cybersecurity

Cyber-attacks are not a rare occurrence these days and they happen on a regular basis. Companies invest a lot of resources in security but it is becoming harder and harder for regular computers. These threats keep increasing as the world becomes more and more dependent on digital technologies. This is where quantum computing in conjunction with machine learning could be of great assistance [10].

Another side of the coin is that the current encryption technologies can easily be cracked with quantum computing. This means that while quantum computing can be beneficial for cybersecurity, it also brings about new security threats. In fact, there is a new industry taking shape to assist companies in dealing with these new threats [11].

2.2. Financial modelling
One of the first areas to make use of Big Data was finance, and combinatorics plays one of the major roles in how the prices of complex financial assets are calculated. A calculation that is often applied in these situations is referred to as Monte Carlo method the purpose of which is to make projections based on a simulation of what is happening in the market. Speed is of utmost importance in these matters and quantum computing can boost that speed in ways that have never been attempted before [12].

2.3. Artificial intelligence
Artificial intelligence could potentially benefit from the development of quantum computing. Fraud detection and facial recognition are domains where AI is an integral part. In these domains, large amounts of data are processed by means of combinatorics calculations to predict and make decisions better. There is ongoing research the objective of which is to show that quantum computing algorithms can improve the speed of AI. However, it is important to point out that the existing limitations make the combination of AI and quantum computing a distant possibility but according to researchers, it is certainly not something that is beyond our reach [13].

2.4. Biochemical engineering
Biochemical engineering is a type of engineering the main purpose of which is the exploration of molecules. This process is related to subatomic particles and their behaviour towards one another which means that quantum mechanics is at play here. This leads us back to combinatorics to deal with combinations that increase exponentially as molecules become more and more complex. This is where the quantum computer can be used for these calculations. In fact, simple chemical reactions have already been simulated successfully by quantum computers [14].

3. Various quantum computers
There are a couple of versions of quantum computers in existence today, and those that are expected to be built in the near future. Some of these computers are discussed below.

3.1. Annealing quantum computer
This is a basic quantum computer which is by comparison not very complex. This one is the easiest to build but it is not that capable. In fact, there are supercomputers today that can work better than this quantum computer in terms of email, video editing, gaming, etc. However, even supercomputers cannot compete when it comes to factoring extremely large numbers which can easily be done by the annealing quantum computer [14].

3.2. Analog quantum computer
This is the most researched type of quantum computer and many well-known corporations have invested in its development. Unlike the aforementioned annealing quantum computer, the analog quantum computer is not easy to build but it is much more powerful [14].

3.3. Universal quantum computer
This quantum computer is extremely complicated and is very difficult to build with the current technology. This, of course, means that it is much more powerful than the quantum computers mentioned above. Most quantum computers at present can only have around 100 qubits but the universal quantum computer is expected to have a number of qubits exceeding 100,000 [14].

4. Challenges
It is obvious that quantum computing faces a lot of challenges and problems today that hinder its development. One of the main challenges for quantum computing is its reactivity to environment. For a quantum computer to function correctly, certain environmental requirements have to be met. For

example, they have to be located in costly refrigerators where the temperature comes close to absolute zero [15].

Another major challenge is that the field of quantum mechanics is extremely complex. Even scientists with many years of experience have serious difficulties working with it [15].

Of course, there are many more challenges that will need to be overcome for the successful development of quantum computing.

5. Conclusion

It is safe to say that quantum computing is only at the beginning of its development despite the fact that the concept itself has been around for over thirty years. Even though there has been some progress some of which is covered in this paper, it is difficult to say how feasible a working quantum computer that can solve real world problems is. The challenges that quantum computing has to deal with are extremely difficult. In fact, they are so difficult that some researchers doubt that it is even possible to build such a computer. These researchers are not in the majority but it still goes to show that the issue is an extremely complex one. However, there are researchers who are more optimistic and believe that with enough time, effort and investment, it can become a our everyday reality, just like classical computers which were considered an impossibility at some point in human history.

References

[1] Grumbling E and Horowitz M 2019 *Quantum Computing: Progress and Prospects* (Washington, D.C.: National Academies Press) pp 101-2
[2] Johnston E R, Harrigan N and Gimeno-Segovia M 2019 *Programming Quantum Computers: Essential Algorithms and Code Samples* (Sebastopol: O'Reilly Media) pp 73-4
[3] Hughes C, Isaacson J, Perry A, Sun R F, Turner J 2021 *Quantum Computing for the Quantum Curious* (Cham: Springer International Publishing) pp 37-8
[4] Hidary J 2019 *Quantum Computing: An Applied Approach* (Cham: Springer International Publishing) pp 44-5
[5] Sutor R S 2019 *Dancing with Qubits: How Quantum Computing Works and how it Can Change the World* (Birmingham: Packt Publishing) pp 51-2
[6] Bernhardt C 2020 *Quantum Computing for Everyone* (Cambridge: MIT Press) pp 31-2
[7] Chong F T and Ding Y 2020 *Quantum Computer Systems: Research for Noisy Intermediate-Scale Quantum Computers* (San Rafael: Morgan & Claypool Publishers) pp 63-4
[8] Bera R K 2020 *The Amazing World of Quantum Computing* (Berlin: Springer) pp 67-8
[9] Krishnakumar A 2020 *Quantum Computing and Blockchain in Business: Exploring the Applications, Challenges, and Collision of Quantum Computing and Blockchain* (Birmingham: Packt Publishing) pp 38-9
[10] Mehta N 2020 *Quantum Computing: Program Next-gen Computers for Hard, Real-world Applications* (Boston: Pragmatic Bookshelf) pp 43-4
[11] Silva V 2018 *Practical Quantum Computing for Developers: Programming Quantum Rigs in the Cloud Using Python, Quantum Assembly Language and IBM QExperience* (New York City: Apress) pp 51-2
[12] Kurgalin S and Borzunov S 2021 *Concise Guide to Quantum Computing: Algorithms, Exercises, and Implementations* (Cham: Springer International Publishing) pp 65-6
[13] Swan M, Dos Santos R P and Whitte P 2020 *Quantum Computing: Physics, Blockchains, And Deep Learning Smart Networks* (London: World Scientific Publishing Company) pp 81-2
[14] Scherer W 2019 *Mathematics of Quantum Computing: An Introduction* (Kingston: Springer International Publishing) pp 73-4
[15] Clegg B 2021 *Quantum Computing: The Transformative Technology of the Qubit Revolution* (London: Icon Books Limited) pp 91-2