IBM Q System One

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Abstract --The objective of this paper is to talk about the newly released quantum computer by IBM known as Q System One, to explain its use of quantum physics principles, restrictions on its design and implementation, and its packaging. Then it talks about a particular implementation of a quantum computer core and the needed cooling system for its operation. After that, it talks about the effects of creating a quantum computer on humanity and the world, its advantages on science and other fields, but also its disadvantages regarding the security of online information.

Keywords—quantum computer, qubit, IBM, Q System One, entanglement, design, quantum algorithm, encryption, effects, quantum physics, restrictions, benefits, sciences, solutions.

I. Introduction

Introduced on January 2019, IBM Q System One is the world's first circuit-based 20-qubit universal quantum computer for commercial applications, and it has been decided to be kept on the cloud. [1] [2]

Q System One has used the same approach used by classical computers, which is combining multiple components that work together in an integrated architecture, to serve as the first cloud-based quantum computer available. [3]

The invention of the idea of a quantum computer started by 2 scientists called Richard Feynman and Yuri Manin in the 1980s, saying that a quantum computer would be able to simulate problems that a classical computer cannot. [4]

But since then there was no reliable and solid quantum computer that could be used in real world applications. And this is due to the hardships faced when creating a quantum computer.

A quantum computer is one that uses the quantum mechanics phenomena to perform its computations. [4] Quantum mechanics, on the other hand, is defined as the science of the very small, where it explains the behavior of matter and how it interacts with energy on very small scales like atoms and sub-atoms. [5]

II. STATE OF THE ART SOLUTION

There was a need to create a revolution in the field of physics when there were contradictions between classical theory of physics, and the observed phenomena. The classical theory of physics explains the behavior of matter and its interactions with energy on large scales including astronomical scales. While we still use classical physics, the need to explain the phenomena that it could not explain led humans to the creation of quantum mechanics.

From the creation of quantum mechanics to the invention of quantum computers there was not much time, but it took humans more than 20 years to implement a quantum computer with a small error rate to be considered finished. This was because of the many problems scientists faced when they were working on creating one, which includes the need to isolate and control a component that implements a qubit, which is the core component of a quantum computer.

Qubit or quantum bit is the basic unit of quantum information, and it is the quantum representation of the classical binary bit that is used in a two state device. So, a classical bit would have one state, either zero or one. But a qubit can have three states: zero, one or both at the same time, which is known as superposition. Now, maintaining the state of a qubit and decreasing errors requires cooling it down to the absolute zero. And even when the temperature is cold enough, a qubit cannot maintain its state for a long time, and this limits programmers when they write quantum programs because they need to keep rereading the values of the qubits.

Q System One has come to solve this, and solve one of the hardest problems in quantum mechanics known as decoherence. Decoherence can be explained as the fragility of the qubit which causes it to be affected by the smallest disturbances. So, creating a quantum computer with a small amount of errors is a great challenge IBM could overcome to achieve one of the lowest error rates ever measured by IBM which is 1.69% two qubit gate error according to the company, which is 25% improved error rate than previous designs. [6]

Figure 1. Q System One. (from [7])

Elegantly and beautifully designed by a group of researchers, engineers, architects, and manufacturers inside the labs of IBM in collaboration with several designing studios, this computer was made to achieve reliability, stability and commercial use.

All the content of this computer are put inside a 2.7 meters box, created using half-inch thick borosilicate glass, which is mainly used to resist thermal stress and handles high temperatures. [8] This box has two doors, back and front, and they both can open simultaneously, which allows engineers ease of access to the content of the computer. These doors open using a motor-driven rotation, which minimizes downtime when there is need for upgrades and maintenance, and this is a great feature that allows Q System One to be suitable for commercial use. [9]

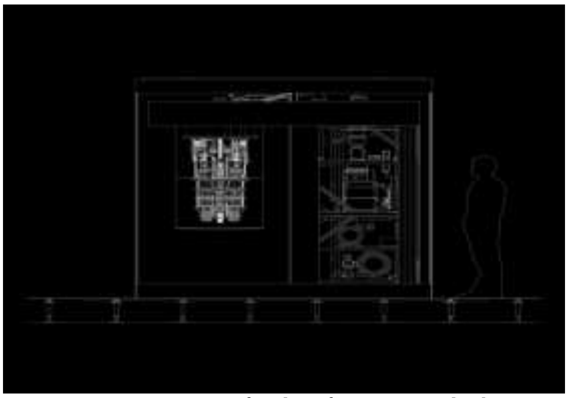

Figure 2. Representation of order of content inside the outer packaging (from [3])

The glass box has the core of the quantum computer – which consists of thousands of components- in the front-, and many cooling and control utilities hidden in the back.
Inside this box, the temperature must be kept around -273.14 C [10], which is a bit greater than the absolute zero, any vibrations or change in temperature would lead to failure of the all the work. And this achieved by the glass that this box is made of, which works on isolating inner components, which results in more stability of the computer because it will reduce the number of errors during experiments and thus make it more reliable for commercial use.

Figure 3. The core of Q System One (from [10])

The Q System One is still an experimental computer, so no one can buy one of it yet. But IBM has tried to give it a beautiful packaging with a huge window to look inside and see the results of the amazing work done on it.

III. Quantum Computer Design

As mentioned before, a quantum computer relies in its implementation on the superposition of a qubit, and there are many possible implementations of a quantum bit, like: single electrons, quantum dots, single photons, and nuclear spins. Here, we will talk about the single photons' implementation and that is because light, in quantum levels, is a well-studied subject and humans know much about noise in such implementation, and because all components we need to build a quantum computer with single photon design are available for humans today. [11]
Now that we have a quantum bit, the question is how to make it communicate with another quantum bit. Scientists are studying the idea of using more than one way to make 2 qubits communicate, like: electron spin, magnetic flux, and photon polarization. [12]
In classical computers we address bits, we change their values, and we read them, how can we do this in a quantum computer? This is implemented using a large group of circuits that surround a group of qubits which consists of a group of switches; these switches choose qubits by passing magnetic fields which hold information to the correct qubit and save this data on it. In quantum mechanics, if some sort of device used to read a qubit during computation, this will cause the state of the qubit to change and decoherence will happen, and this will cause wrong results. So, to read a qubit, there is a special device used for reading qubits attached with each qubit in the computer, but this device is shut down as long as computations are happening, and only when operations finish this device can read the value of the qubit, which as quantum mechanics laws state, this qubit will be no longer in superposition state anymore after reading its value, and it will only diverge to become zero or one.

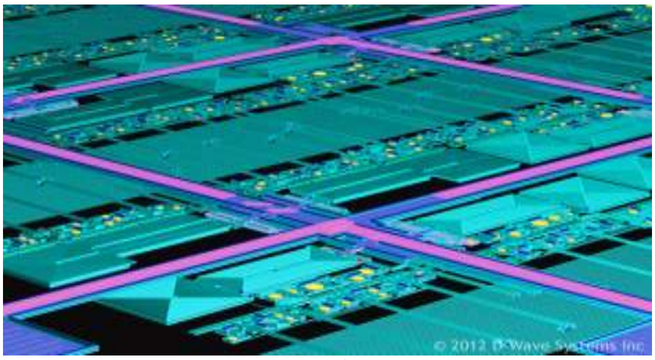

Figure 4. A drawing shows design of a quantum computer core circuit (from [13])

Figure 4 shows qubits as long stripes of pink, and the yellow components are the ones used to communicate and read or address qubits as mentioned above. We would notice – of course- the difference between the design of a quantum computer and a classical one, especially when it comes to memory. When a classical computer has huge amounts of bits, a quantum computer has only a few of quantum bits. But we should not forget that the abilities of a quantum bit which include superposition are impossible for a classical bit. So here, apparently, the focus is on the quality and power of a quantum bit rather than the quantity in a computer. All the components mentioned before if put together create something called quantum processing unit (QPU). A QPU is fabricated using silicon, but the process of fabrication is not exactly as the fabrication of a classical computer components.

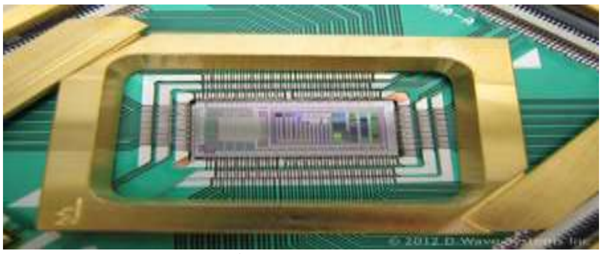

Figure 5. QPU packaging (from [13])

Once a QPU is fabricated, it is put into special packaging that contains signal lines connected with the board that will be connected with the QPU.

As mentioned previously, a quantum computer needs to work on very low temperatures around absolute zero, and this is needed to reduce the errors and increase the quality of computations. This cooling is done using a refrigeration system called dilution refrigerator. This refrigerator uses liquid helium, and this liquid is put inside a closed cycle where it can be reused many times and this makes a quantum computer more suitable for commercial use.

As for the interaction between the user and the quantum computer, this is implemented using a group of components, starting with the front end server that takes input and instructions from the user, then a group of filters and electronics to remove noise and convert signals, then the wires that will take the resulting signals to the quantum core. The implementation of this series of layers is never easy, because the environment is very sensitive, and it requires components to be made using specific types of materials and to operate of specific temperatures each.

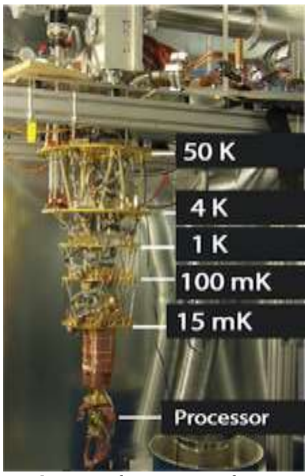

Figure 6. Temperatures that specific sections of a quantum core need to operate on in Kelvin. (from [13])

In addition to the restrictions of temperatures and materials, a quantum computer core is very sensitive to outer magnetic fields, and the elimination of such fields is implemented using multi-layered cylindrical shields that cover the quantum core and create a counter magnetic field to end up with a zero total magnetic field inside the covered core.

IV. EFFECTS ON HUMAN LIVES

IBM Q was designed to tackle problems that were and are still seen as impossible to solve using available resources. And this allows us to create algorithms run very fast on a quantum computer compared to a classical computer by exploiting the nature of qubits.

Quantum computers have the ability to run algorithms that classical computers cannot even run, these functions have great abilities and could solve problems that could not be solved before, one of these algorithms is called Shor's algorithm, which solves the problem of finding prime factors of a given number. The power of Shor's algorithms is in the amount of time it takes, as the fastest classical algorithm to find prime factors of some number is still exponential, Shor's algorithm takes polynomial amount of time only, and this has huge amount of difference in time for a very big given number. [14]

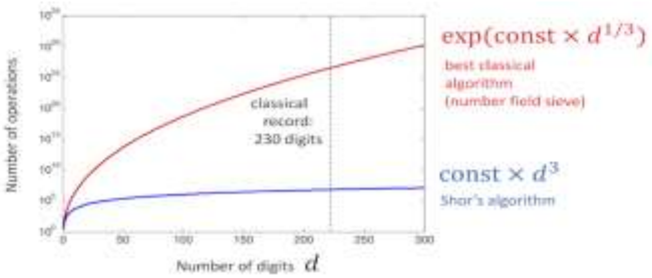

Figure 7. Classical Vs. quantum prime factorization algorithms (from [15])

There are many problems that have been solved using classical algorithms with exponential time complexities, and new classical algorithms were invented to solve these problems with much less time, like: Grover's algorithm, estimating Gauss sums, and many more. These algorithms, once used, will cause a huge development in many fields and applications that face the problems solved frequently in their programs.

Another great benefit of a quantum computer is quantum simulation. Richard Feynman observed that if you want to simulate a many-particle quantum system on a classical computer you will need an exponential amount of time. So, quantum algorithms were invented to simulate quantum physical situations and processes like the simulation of Bosonic systems and the simulation of chemical reactions. [16] These simulations only require a few hundred qubits on a quantum computer, while they are not even possible to be implemented on a supercomputer, let alone a classical one. These amazing capabilities would have a huge impact on the study of nuclear researches and studies on quantum levels.

The idea that Q System One is available online for researchers and students to use in their work is in itself a great benefit for science, because this would help in increasing the number of researches in the field, which would lead to the creation of new applications that use the Q System One in particular and quantum computers in general, allowing us to use the great abilities of quantum computers and eventually embed them in our everyday lives.

The existence of such a power in our hands would have great and very effective solutions to many existent problems and it will revolutionize many fields like medicine, cryptography, financial applications, and weather prediction which keep looking for effective solutions and new tools to increase effectivity and decrease the cost. [9]

But on the other hand, having a quantum computer would also put all cyber information in danger because of Shor's algorithm and its ability to find prime factors of some number in polynomial time. This would require humans to find other encryption methods that will not compromise hidden data if a quantum computer can reach it. Because prime factorization is a very time consuming process, and it might take time larger than the age of the earth to factorize some large enough numbers, humans have used this fact to create and use encryption algorithms that are broken if you take all the time needed to find the prime factorization of some number which is called a key. [17] With a classical computer and a very wise and powerful choice of a key, an encryption algorithm might never be broken and thus the encrypted data is safe. A quantum computer that runs Shor's algorithm can break such a widely used encryption algorithm and its user can find the key to decrypt the data and read it. Now this fact means that the development of such quantum computer would cause paying an enormous amount of money and time on creating defense against it, if that was possible before any harmful attacks happen. If the defense – even if theoretical- against a quantum computer was not found, this would lead to a global disaster, because almost all information passed through the internet will be compromised, like: bank accounts, classified files, social media accounts, and emails. [18] A huge reveal of such data would cause a global chaos that might lead to results no one would want, because the nearest thing one would think of happening is for a country to develop a quantum computer capable of running Shor's algorithm for starters, then this country can read classified files and data passed in all other countries in the world, and this would lead to many negative results I would not want to imagine.

V. CONCLUSIONS

In this paper, I have talked about a newly released quantum computer by IBM called Q System One, which has the minimum error score in the whole world. [6] I have explained its structure, packaging, and restrictions scientists faced when they created it, like the need for a very cold temperature to preserve the state of a quantum bit, which is implemented using a cooling system, and how Q System One packaging inside a glass box helps it in keeping this low temperature and forbids air from interfering with computations.

I have also talked about one particular design of many, to implement a quantum bit which is the single photon design, and have mentioned that scientists chose this way specifically because their understanding of light and noise in quantum levels is high, and the resources needed are available. How qubits communicate with each other in this design is mentioned, and also how they are addressed, read, and how their values are changed. A main component in a quantum computer core is responsible for the aforementioned operations and it is called a quantum processing unit (QPU). I, then, talk about the refrigeration system in the quantum computer and the specific temperatures that parts of the core operate on.

After that, this paper takes us to the effects of a quantum computer like Q System One on the world and humans lives. How the speed of a quantum computer in running algorithms is very promising and expected to change the world and revolutionize many fields, but also how this very ability is putting all data passed online in danger of being compromised because of its ability of performing prime factorization in polynomial time and how this is going to require wasting a very big amount of money and time on securing data from such attacks.

I believe that Q System One is going to be the first quantum computer in a whole series of other powerful and more promising quantum computers manufactured by many other parties around the world, and all of them will be competing to create the best and more powerful one. And this makes me hopeful, because developing such great machines that have amazing abilities will help the world and humans in solving many of the problems they are facing today and are trying to find solutions for, starting with medicine, moving to mere sciences, and ending with the creation of new and innovative applications to make our lives easier.

But as with every powerful tool humans have created in the past, it can be used for good and bad, so will countries put rules that will restrict the usage of such a powerful tool for only good causes for humanity in general and not just a particular group of it? This question would remain unanswered until quantum computers become in the hands of many parties that do not agree on the same goals, and only then we would know what is the reaction of humans around the world towards this issue. Until we reach that day, I will remain hopeful that our species will not let the creation of a very amazing and beautiful tool like a quantum computer be the cause of our suffering.

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