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An initial impression of Quantum Computing

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Abstract: ***Since last years, computers reduce the human efforts and give improvement in its performance day by day. Quantum computers are those computers who perform computing which is based on the phenomenon called Quantum Mechanics. It is a fusion of classical computing which we were using now days, physics and mathematics. And the computing they performed by integrating these fields is termed as Quantum Computing. Quantum computers perform their computing on the basis of the microscopic particles like ions, photons, electrons, protons, neutrons etc which ultimately give exponentially high computation power and other advantages too like less consumption of electricity which we will discuss in the same paper in brief over the classical computers, which we were using till day. In this paper we will briefly explain the quantum computers, its history, its properties in which its computing is based upon, its advantages& disadvantages, its limitation, its real world application, the difference between classical computers and Quantum computers and the challenges it faced and at last we conclude it with its future scope.***

Keywords: Quantum computing, real time application, properties, future scope, Teleportation

1. Introduction to Quantum Computers

Quantum computers are basically those computers which are based on the properties of quantum mechanics which was described by the Schrodinger wave function equation [1]. This is a mathematical equation which describes the position and energy of an electron in the space at a given time when an electron inside an atom has the wave nature and tells us how these waves were influenced by external environment.

This external environment is the system Hamiltonian which is mathematically describes forces experience by any electron or sub atomic particles within an atom [2].

So, to make a Quantum system we need to work on its environment by isolating it by its own external environment [3]. Since last years we have notices several amount of changes is done on classical computers or the computers which we were using now a days in terms of their size, cost, power consumptions, efficiency etc. By comparing with earlier computers, today‟s computers werecompact in size, low in cost, consume fewer amounts of power, more efficient etc than earlier computers which were very large in size, high in cost, not so user friendly, consume more electricity and were very less efficient [4].

These kinds of changes is because of electronic devices which were used within them, earlier these devices are quite huge in size whereas now these devices are becoming more and more compact which directly or indirectly focus on our computation. The size of the electronic circuit is now reached to a limit and we can‟t reduce it anymore any if reduce it [5], it can only reduceup to the size of an atom and if we do so they start teleporting since atom is not stable it will move from one state to another or we can atom can exist in more than one position to the another at the same time and to handle the state of that atom classical computers architecture and algorithms were not enough [6]. Therefore a quantum computer comes into play.

Quantum Computers computational bits

Unlike classical computers, quantum computers use binary bits like 0 and 1 for computation in which the system at a given amount of time will be either in state 0 or in state 1 but quantum computer work on both the state at the same time i.e. it can be in state 0 and state 1 at the same time [7]. The bits which were used by quantum computers for their computation is called quantum bits or Qubits. Due to the quantum bits or Qubits the computation performed by the quantum computer will be exponentially higher than the classical computers because we have 3 states rather than 2 in quantum. So the complex problem can be solved in practical amount of time by using quantum computer which is nearly impossible for classical computer to solve.

The quantum state is represented by the Dirac Notation. In this the state‟s 0 or 1 will be kept between the symbol | &
>. So, the states can be written as |0> & |1>.

$|c\rangle = a|0\rangle + b|1\rangle$

a, b are the coefficient of the state 0 and 1 respectively [8].

The probability of the occurrence of state 0 is directly proportional to the square of the coefficient magnitude of the state 0 i.e. $(a)^2$ is for the state 0 and the probability of the occurrence of state 1 is directly proportional to the square of the coefficient magnitude of the state 1ie $(b)^2$for the state 1 [9].
The total of these 2 probabilities are always equal to

1i.e. $\{a\}^2 + \{b\}^2 = 1$

Properties of Quantum Computers

Quantum computers are those computers in which are based on the phenomena of Quantum Mechanics. These computers perform computing by using Qubits (0 and 1) which can be in more than one state at the same time unlike classical computers where bits (0 and 1) are at one state at one time. Due to this property, the quantum computers easily solve those complex mathematical problems in exponentially smaller time which is rather impossible for classical computers to solve. And therefore quantum computers have million times more computation power than super computers. There were 3 major properties of quantum computers.

Superposition

Superposition is one of the properties of the quantum mechanics which make quantum computers different from classical computers in terms of high computational power. In quantum computers, qubits is the basic unit for calculation, memory management and processing [10]. Qubits were not like binary bits i.e. 0 and 1 which can be in one state at one time like at a given time they can be either at 0 or OFF state or at 1 or ON state or vice versa. Due to the phenomena of superposition in quantum mechanics it is possible for the qubits to be in more than one state at a time and therefore perform parallel processing at a very high speed and we well get wonderful results [11].

In traditional computers we have only 2 bits and the possible number of states can be formed by using these 2 states were 4 and at 1 time we can be only in 1 state whereas in quantum computers we have 2 qubits i.e. |0> and |1> and possible number of sates can be formed is 4, but here we can be at all the 4 states at a time due to which computation power will increase and will give us amazing results [12].

Lets us take one example of a puzzle, the classical bits can take various paths but one after the other whereas quantum computers can take all the possible path at once at the same time which will not only increase the computation but also decrease the computation time. This is possible because of superposition [13].

2. Entanglement

As far we are now aware that quantum computer performs their computing by using quantum bits or qubits which can be superposed in any state or all the states at the same time [14]. They can do this because the qubits are not stable they were in motion in each and every amount of time. And therefore they experience the force from the environment as well, so to control the movement of the photons we need to isolate them from the environment so that, they so don‟t experience the force from the environment but isolating the whole system is a challenging task. As qubits as superposed in more than one state at a same time than the behavior of each photon is correlated to the other photon so if we want to get to know the working or the information of one particle we can easily characterize it‟s with the other one even if they are separated from a long distance [17]. This phenomenon where all the particles are correlated to one another and the behavior of one particle is reflected by the other is called Entanglement in quantum mechanics.

Because of Entanglement there is a quite strong correlation among the photons or the qubits that even when they isolate from each other we can get to know about one by the reference of the other due to this they create a strong communication channel [18]. In today‟s computer, if we add extra binary bits than the computational power also get increased accordingly but if we add extra qubits in quantum computers than computation power will increase exponentially which is just beyond over expectation.

3. Interference

According to the quantum mechanics the electron poses dual nature i.e. they can be act like particle and they can act like a wave. When two more than 2 waves in the same medium intersect each other they can either get cancelled or they can get doubled this phenomena is called interference [16]. Wave interference can be constructive and destructive. It is termed as constructive interference if two waves in the same medium travel in the same direction and if they intersect or meet at any point then the resultant wave is the sum of the two waves or the resultant wave we get doubled [15]. It is termed as destructive interference if two waves in the same medium travel in the opposite direction and if they intersect each other they just cancelled one another. So we can say that resultant wave is either large or smaller which is completely dependent on the type of interference it is going through with.

Quantum Teleportation

Up to here we get to know what quantum computer is, how they perform quantum computing, what is the basic or fundamental unit of computing in quantum and the properties of quantum computing.

When the quantum bits or qubits move from one state to the other state is termed as quantum teleportation. Quantum teleportation is done because of entanglement as the qubits are link to one another and the links between them is very- very strong and if we separated, through a small or a large distance still the information is encoded by the one will get teleported to other one too [19]. Teleportation is possible only up to atomic or sub atomic particles like electron, proton, neutron etc. till

now but teleportation of humans is still a friction which we mainly seen the Hollywood movies. Till now only teleporting of information is possible and teleporting of objects is still a challenging task [20].

Quantum Algorithm

The step by step procedure to complete any task in a specified time and in a specified manner is termed as Algorithms. The algorithm which we will use for quantum computers for their computing is called Quantum Algorithms. The algorithm for traditional computers and quantum computers is almost same. To make any classical algorithms quantum we need a single step either of quantum entanglement or quantum superposition [21]. All the classical algorithms can easily run in quantum computers but the vice versa is not possible.

Quantum circuit is the representation of quantum algorithm. A quantum circuit is a dummy model for quantum computing where quantum gates act like a step by step procedure for quantum algorithm [22]. Quantum gates are those operations which will be applied on the quantum bits or qubits for the computation; they can even change the state of quantum bits or qubits.

As compared to the classical algorithms; quantum algorithms have many advantages like if we didn‟t get an optimal solution for our problem we can even backtrack the number of steps at once but in case of quantum algorithms it won‟t be possible to backtrack. And the otherthing is, the problems which were not been solved by classical computers algorithms will also not get solved by quantum computers algorithms too. The quantum algorithms only speed up the computation and decrease thetime of computation to solve any problems which can be solved by traditional algorithms respectively with very less computation speed and very large amount of time [23].

Limitations of Quantum Computers

First limitation: - when all the quantum bits were getting entangled with each other, the coefficient of Dirac Notation raises exponentially according to the number of quantum bits we were increasing, but it can be only possible when all the quantum bits are entangled with eachother, but it can‟t be done directly because it is very hard to generate a direct link between them.

Second Limitation: - because of no cloning principle it was not possible to copy the number of quantum bits from one state to another, if we do so rather than being copied the states move from one location to the other one. In classical computer we can copy its binary bits but in Quantum Computers the copying of quantum bits is not possible so the quantum bits to be copied we need the help of classical computer binary bits and this is again a challenging task and not successful till now.

Third Limitation: - as there is no noise protection in quantum bits. The small noises can create the disturbance in the quantum circuit which will ultimately disturbs the calculation, efficiency and measurement of the problems from which quantum computers were dealing with [24].

Difference Between Classical and Quantum Computers

Quantum Computers	**Classical Computers**
They perform computing by using quantum bits or qubits.	They perform computing by using binary bits.
Qubits were need to be isolated from the environment and has to kepat a temperature which is below 0^0 C.	Binary bits were not needed to be kept in isolation, they can easilykept or work in room temperature.
Computing speed of Quantum Computers is much higher than the Classical Computers.	Computing speed of Classical Computers is lower than Quantum Computers.
Qubits can be at all the possible 4 states at the same time.	Binary bits of classical computers can only be in 1 state at a time.
Copy of qubits from one state to another is almost impossible.	Copy of binary bits from state to another is possible and even easy too.
Information gets processed in quantum circuit or Quantum Logic gates in a parallel manner.	Information gets processedin Classical Compute Sequentially.
Backtracking is possible	Backtracking is not possible
The quantum computers were based on the quantum mechanics and its properties like superposition, Interference and Entanglement.	The classical computers were not based on the quantum mechanics and its properties
Data teleportation is possible because of Quantum Entanglement	In Classical Computers Data Teleportation is not possible.
Quantum Computer performs its computing in a parallel way becauseit has both wave as well as particle nature.	Classical computers have only particle nature therefore they performcomputing sequentially.

Merits of Quantum Computers

1. Because of the property called Quantum Entanglement, the quantum computers perform computing exponentially faster than the traditional computers.
2. Quantum computers used the phenomena called Quantum Tunneling for parallel computing which saves lot of electricity like 100 to 1000 times as compared to Traditional Computers [25].
3. A Quantum Computer is 1000 times more efficient, reliable and faster than Traditional Computers.
4. As compared to the Classical Computers, Quantum Computers were kept at a temperature less than 0 degree Celsius so that it can solve complex and lengthy problems in reasonable amount of time without getting overheated.
5. As Compared to the Traditional Computers the Quantum Computers with help of Entanglement solve Optimization problems by finding best path

among all the possible paths, like in the game of chess it can make almost more than 1 trillion moves in one second. Because of Quantum Mechanics properties it will break the cryptographic encoded security too [26].

6. It will bring the evolution in many industries like petroleum, drugs etc by inventing new drug and even bring even ample amount of changes in the field of Data Mining and Artificial Intelligence.

Demerits of Quantum Computers

1. By using the phenomena called Quantum Entanglement, the quantum Computers can also act like curse for Government, banks, Defense etc as it can easily and within some seconds it can break their cryptographic based encoded security which will be very much horrible for our future [27].
2. We cannot entirely replace the Traditional Computers with the Quantum Computers, as the Traditional Computers were best in terms of MS Word, MS Excel, and Electronic Mail etc.
3. As compared to the Classical Computers the Quantum Computers were not completely developed only few portion of its has been developed and executed yet and it creates a feeling of Curiosity among all the users [28].
4. Quantum Computers were very fragile and vulnerable to error, that any noise from the environment disturbs the Qubits or the Sub atomic particles which can lead to uncertain, less efficient, less reliable and less precise solutions to the number of problems it was dealing with [25].
5. Quantum Computers perform computing by using sub atomic particles which were always superposed and they were not stable, due to which it is very difficult to test any problem or information. So, for the stability we need to kept it isolate and make the temperature very much lower than Zero Degree Celsius which somewhat near about the temperature of the Universe which is Quite Costly and Hard to maintain. Due to this the price of Quantum Computer becomes very- very high which is almost impossible for the user to afford it and buy it for their personal use.

Real World Applications of Quantum Computers in Various Fields

1. Cyber Security

Quantum Computer solve those problems very- very easily and in a reasonable amount of time which is very much complex for the Classical Computers to solve in reasonable amount of time [27]. The security behind any information, data can be achieved by encrypted them and for encryption a large mathematical formulas will be used which is quite time consuming for classical computers to decrypt, whereas Quantum Computers can solve it in exponentially less time.

We were being aware that the information which we send from here to there need to be encrypted by using hard security framework so that our information or data will not get hacked or mislead by the others. But for classical computers it will be very-very challenging to encode and decode it in reasonable amount time so classical computers can be replaced by quantum computers as by using machine learning technology, quantum computers an easily encode and decode the security framework which make our data or information safe from hackers [29].

2. Artificial Intelligence and Machine Learning

Artificial Intelligence and Machine Learning were working outstanding in various fields now days. All the new technologies were either based on Artificial intelligence or machine learning which makes our lives easy and fast. Some of the popular and mainly used applications of Artificial Intelligence and Machine Learning are Image Recognition, Voice Recognition, and Fingerprint Recognition etc.

However these technologies are upgrading day by day and it was becoming challenging for the classical computers to handle them, so we need something better than Classical Computers, which help the new technologies to work properly and efficiently [30].

3. Drug Design and Development

One of the most tough task is to design and develop the new Drug as most of the time when we have to discover a new drug and we want to test that particular drug on a human body we need to use trial and error method whichis very much dangerous but if we do so with the help of the Quantum Computer it will only not become less dangerous but also saves a lot of money so Quantum Computers can bring Drastic change in the design and development of new Drugs [30].

4. Optimization Problem

Optimization problems are those problems where we have to find the best solution among all the possible solutions. Optimization problem can be solved by the classical as well as by quantum computers but the difference is that classical computers take lot of time to find the optimal solution or route and can"t be able to back track it where quantum computers will give optimal solution or route within seconds. Example- In traffic management, air traffic control, fleet operation etc have very complex functioning and finding the best route among all the routes for classical computers it is quite time consuming but for Quantum computers it is an easy task as it traverse all the routes in one go [23].

5. Financial Modeling

In Financial Marketing risk plays an extreme rule in getting profit or loss in the investment they have done. The Classical Computers were used in the Financial Marketing for dealing with the investment, returns and the risk associate with them for this classical computers used a technique called Monte Carlo, this technique not only deal with the complex data of the market but it consume a lot of time to give fruitful results. For saving time and to reduce the complex calculations we can use Quantum Computers rather than Classical Computers.

Challenges faced by Quantum Computers

In quantum computers the qubits can be out reach over the number of possible states at the same time as compared to the traditional computers whose binary bits can be at one state at a time due to which computation performed by the quantum bits in quantum computers is very much impressive as it can work in a vast space. For performing computation in a vast space, we need to interconnect all the qubits or all the qubits should be interconnected with each other‟s so that data and information will be teleported among the qubits. But creating this strong network among the qubits is quite hard and yet it is not been successful enough. So we can say this is one of the challenges faced by quantum computers because of qubits.

As the Quantum Computer perform its computing by the subatomic particles and these sub atomic particles were not stable and can get distracted even with the small disturbance in the environment or we can say that it can show error even because of small crash and therefore it will go in the condition of Decoherence, in which subatomic particles or Qubits lost their Quantum Properties and they will act like binary bits of Classical Computers. In classical computers the bits can either be in ON state or in OFF state hence they were noise free, but for making Quantum Computer noise free we have to insulate its Quantum Bits or Qubits from the surrounding by keeping its temperature below Zero degree Celsius which is again a challenge face be the quantum Computer because of the noise [18].

Bits used in Classical Computers are binary i.e. 0 or 1 whereas Qubits used in Quantum Computers is neither completely digital nor binary; they have analog properties within them. If in classical computer we get the value as
0.8 than it would be considered as 1 because it has only two options. But qubits can have the value between 0 and 1 and each value between them has its own meaning, therefore 0.8 will be treated as 0.8 rather than 1. And if we will treat it as 1 it will show error [12]. Therefore we need an algorithm for error correction in Quantum so that they can run in quantum computer and make it error or noise free by eliminating its error or noise present in it. But creating this kind of algorithm is again a challenging task because for achieving this we need huge amount of Qubits and many new operations which will be performed on that and ultimately we require more resources to achieve it. So,creating a Quantum Algorithm for error free Quantum Computer is a challenging task.

4.Future Scope

1. Creating new algorithms which will work on noise and help to eliminate it from the quantum computers so that it will become noise free.
2. Teleporting of data and information is already achieved but teleporting of Objects need to be performed.
3. Quantum Computers can work in the field of Cryptographic Security by building more secure network for government, defense, bank etc rather than breaking their present Securities associated with them.

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