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Quantum Computing : The Next Era of Computing

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Abstract

Quantum computing is a Quantum Mechanism based computational framework, which has acquired a lot of interest in the early few decades. In contrast with the conventional computers, it has obtained an enhanced performance on various tasks. The study of Quantum Computers is Quantum Computing. Annealing, Entanglement, Tunneling and Superposition are some of the phenomena of Quantum mechanics used in Quantum computers to give the solutions to the problems which were unable to solve by human in their lifetime. The main objective of this paper is to reveal a brief idea about what is occurring in the Quantum Computing field and also the current state. In addition, the features of Quantum computing like Quantum parallelism, reverse computing and qubit computation is also summarized. The article also reveals the cause of great computing capabilities of Quantum computers in view of utilization of quantum entangled state. Based on the review concludes that the research on quantum computers requires the advanced sciences like Mathematics, Micro-Physics and Computer Technology.

Key Words: Quantum Computers, Quantum computing, Quantum Parallelism, Entanglement, Qubit.

I. INTRODUCTION

As science and technology had attained a phenomenal growth during the past, which leads, the components like Chips, Transistors etc., had drastically changed in its shapes, sizes and complexity [1]. By which, the computers become very compact. In addition, achieved high speed, greater performance and enhanced efficiency. But still, computers do computation with bits (0 and 1) and will be in one state at a time. In contrast with classical computers, the Quantum computers perform computation with qubits that will be in various states concurrently. Due to which, the quantum computers are capable to handle the complex mathematical problems in less time than the traditional computers. As a result, the computational capacity of the Quantum computers is million times greater than supercomputers. The three main characteristics of Quantum computers are:

The Quantum computing uses quantum physics which in turn uses physical world's stochastic and erratic character. When compared with classical mechanics,

quantum mechanics is more comprehensive model of physics. Hence Quantum computing has enhanced ability to tackle the issues that the traditional computers failed to tackle.

In contrast with traditional computers which use classical computing and works on bits (0 and 1), the quantum computers works on quantum bits which are known as qubits[2].

As in traditional computers, the logic gates, transistors and integrated circuits are not used in Quantum computers. As a result, it works on the bits which are made of atoms, electrons, photons and ions collectively with the information on their spins and states. They are more efficient because they are superimposed and work in parallel when using memory.

1. Current State of Art

The potential of the Quantum computers to do the calculations are far beyond the potential of any supercomputer. Researchers may examine the development of novel alternatives to emulate matter's behavior in atomic level. They have the power to threaten the security and cryptography by cracking the unbreakable codes. However, currently the focus of researchers given towards developing the powerful Quantum computers which is well enough to perform the tasks that was not able do by the classical computers [3]. The study lists some Quantum Computers currently existing in the laboratory level. IBM uses the quantum events that happen in the superconducting material. In January 2018, the IBM Q quantum cloud services were launched. It comprises of two processors with five superconducting qubits namely ibmqx2 - a 16-qubit processor and ibmqx5 – a 20-qubit processor [4].

The D-Wave 2000Q is a commercially available Quantum computer that uses the quantum dynamics to rapidly address the issues of sampling, discrete optimization and machine learning [5]. Quantum annealing was the technique employed in D-Wave 2000Q to address these issues. The world's well known companies including NASA Ames, Google, The university of Southern California and Los Alamos National Laboratory are all using D-Wave system for their advanced research. In addition, the world's top corporations like Microsoft and Intel shows interests in investing huge on Quantum technology. Among all, Quantum computing, Quantum Circuits, Ion-Q, Cryptography and teleportation are the well funded corporations.

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Fig.1. IBM's quantum computer

2. Representation of Information

In the classical computing the information is represented in bits and the value of the each bit is either 0 or 1. In Quantum computing the information is represented in Qubit. A Qubit is a basic unit of Quantum information which signifies the subatomic particles like atoms, electrons as memory of the computer. The Qubits can take a value of 0, 1 or both concurrently. They obtain both, digital as well as analog nature that provides more power to the quantum computer. The analog nature of the Qubits indicates that quantum gates do not have noise limit and its digital nature provides a guidelines to get rid from this serious weakness [6]. Hence, the logic gates and abstraction produced for classical computing is of no use in quantum computing.

Qubit have two quantum states and the state labels are represented in the symbols | and ⟩ . Hence the quantum states are written as $|0\rangle$ and $|1\rangle$. A qubit can be in state $|0\rangle$, $|1\rangle$ or in a combination of both states. The combination of both states is termed as superposition.

The quantum system is a spin particle which has two levels. The states are spin-down and spin-up represents the quantum states $|0\rangle$ and $|1\rangle$ respectively.

In general, the state of qubit expressed as $\psi = a|0\rangle + \beta|1\rangle$

Where, α and β are complex numbers, satisfying $|\alpha|^2 + |\beta|^2 = 1$

3. Properties of Quantum Computing

Quantum computers employ on three properties to store, represent and perform operations on data, by which the computational capacity enhanced exponentially when compared with the classical computers [7]. The three properties are

4.1. Superposition

Superposition refers to the capability of a quantum system where in qubit can be present in two different or multiple states at the same time. It provides an efficient and effective parallel processing. Qubits obtain superposition with the help of lasers so that it can simultaneously store 0 and 1. In the traditional computing, if two bits are there then by combining the bits there will be four possible values. Out of which only one value is viable at any point of time. Whereas, in Quantum computing if two qubits are there then by combining the qubits there are four possible values. All the values are viable at any point of time.

4.2. Entanglement

Entanglement is the ability of two particles to work together instantly on any distance. In other words Entanglement is a significant property of Quantum computing. It states about the strong association live in between two qubits or quantum particles [8]. They are associated together with direct connection, even if they are separated at larger distance and present at the opposite end of the Universe. The qubits are entangled by which the state of one qubit influence the state of other qubit which in turn establishes

physically powerful communication between the qubits. Once the qubits are entangled, they all keep on associated even after isolated at any distance. In traditional computers, if bits are doubled then the computational capability also doubled. Whereas, in case of Entanglement including additional bits to the quantum computers enhances the computational capability exponentially.

4.3. Quantum Parallelism

Superposition is another important property which was exploited to propose new microprocessor by extending the idea of parallelism [9]. Atoms in the macroscopic universe move in several orientations and in several pathways. The main idea is that the quantum computer should utilize these atoms to carry out various computations at the same time. In other words, quantum computer can do various computations concurrently. By using the idea of parallelism, quantum computers are able to factorize big numbers which the traditional computers cannot attain. For example, a supercomputer is able to factorize the number with 500 digits in billions of years, whereas the same can be achieved in one year by the quantum computer. Similarly, the idea of quantum parallelism can be utilized in searching the information in a huge unsorted database.

4.4. Quantum Circuits

The quantum state symbolizes one or more qubits. It carries out various operations using the sequence of unitary operators which is known as quantum gate. As shown fig -2, the quantum circuit is the result of a series of unitary operators.

Fig.2. Simple form of quantum circuit

A quantum circuit is a succession of operations obtained at the output on n-qubits state. Each operation is unitary and the same can be expressed in terms of matrix with size 2^m X 2^n. The abstract wire was represented by lines and the boxes represent the quantum logic gates [10]. The construction of quantum circuit and the implementation of the quantum algorithms may be done using the wires, quantum gates, input states and measurements. Even though it is probable to restructure the quantum circuits, the measurements are done at the end of the circuit.

4.5. Quantum Gates

Apart from the conventional logic gates which recognize 1's and 0's, there are quantum logic gates which support the construction and greeting of quantum bits. The only constraint that these gates must face is that they must be unitary, where a unitary matrix is one which faces the prerequisite underneath. This opens up a plethora of potential gates [11].

$U\dagger U=I$

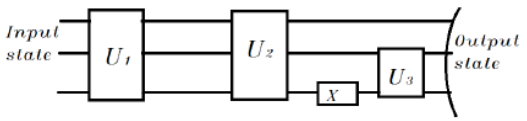
The matrix executes the quantum operator on a qubit. The output values of the operation should meet the normalizing condition [12]. The probability amplitudes must be the total of one if it is unitary. Before the gate is applied, the state of a particular qubit is

$|\psi\rangle = a|0\rangle + \beta|1\rangle$

$||a|^2 + |\beta|^2 = 1$

After the gate is applied

$$|\psi'\rangle = U\ |\psi\rangle = a'|0\rangle + \beta'|1\rangle$$
$$||\ a|^2 + |\ \beta\ |^2 = 1$$



4. Quantum Algorithm

Generally, quantum computers have the ability to execute all the classical algorithms. But the algorithms should have at least one quantum step that will be called during the property of entanglement or superposition. The algorithms are categorized by the quantum circuit [13]. The quantum circuit is the model for computation that adds quantum gate for each step of the algorithm. In turn, Quantum gate performs the operation on qubits. That changes the state of the qubit.

A Quantum algorithm is reversible with contrast to the classical algorithm. Which state that if the measurement is not considered then the quantum circuit will navigate back that revert all the operations which were done in the forward navigation of the circuit. As per the quantum algorithm, it is not state that all the problems which are unsolvable by classical algorithms will be solved [14]. But it state that solution can be given to the problems extensively faster than the classical algorithms. The following are the some list of quantum algorithms available.

1. Fourier transform-based quantum algorithms
2. Amplitude amplification-based quantum algorithms
3. Quantum walks based algorithm
4. BQP-complete problems
5. Hybrid quantum/classical algorithms

5. Challenges in Quantum computation

A quantum computer achieves a considerable development in the usage of computational resources such as memory, time and energy. In a single piece of quantum gear, a massive parallel computation may be obtained [15]. This means that execution of the mathematical operation will be performed on 2L inputs recorded during logical superposition of L qubits in one step. Because it has 2L processors which performs parallel processing to handle very complicated tasks. Even then, quantum computations have the following challenges; which are still a hot research area.

1. Building quantum computer
2. Qubit implementation
3. De coherence
4. Measurements

II. CONCLUSION

The review observed plenty of computational approaches of quantum computing and the changes which happen in quantum bit characteristics during the computation. A quantum computer has the speculative ability of replicating the physical system and hold the information needed to build an intelligent computer. The ability of quantum computers to perform operations transversely a numerous of parallel worlds facilitate them to carry out jobs quickly that the traditional computers never be capable to efficiently complete. The review reveals an idea about quantum entanglement computation, quantum reverse computing and quantum gates. The review also expressed the vital role of qubits on quantum circuits, which is enormously significant in the field of research.

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