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Research on Quantum Computers Characteristic

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Abstract. Quantum computing is the engineering of utilizing the properties of a quantum, as so could be understood as the using the rules of nature at the scale of an atom, to calculate faster and more complicated problems than traditional computers. These new inventions are not merely a device that calculates faster than the speed convention computers, the only similarity between them might only be some essential hardware and their names, because unlike conventional computers that uses classical physics to transmit electronic information, quantum computers utilize quantum physics to perform calculations. Quantum computing has the potential to replace conventional computers in solving important problems in fields such as chemistry, cryptography, materials science, medicine, and artificial intelligence, which are all task that are uneasy and sometimes devastating for conventional computers to do. Quantum computers' characteristics includes but are not limited to: stronger information processing abilities and a faster calculation speed. Compared with traditional computers, the greater the amount of information it processes, the better a quantum computer can calculate a more accurate result. This paper is focused on researching and explaing the characteristics of quantum computers and their possible contributions to the human society.

Keywords: Quantum computers, Quantum superposition, Quantum entanglement, Qubit, Quantum correlation.

1. Introduction

Quantum computers, just like conventional computers are composed of two main parts: the software and the hardware. On the software side, instead of bits doing algorithms and codes, the quantum computer has quantum algorithms and quantum codes. On the hardware side, the quantum computers has its own transistors, memories, and effectors that severs the same purpose as they do in conventional computers but are built differently [1]. But there are more than simply differences in their construction that differs quantum computer to conventional computers. This article will be analyzed from the advantages of Quantum Computers, and then introduces the application of Quantum Computers.

2. Advantages of Quantum Computers

As we can see the distinctive difference between a classical computer and a quantum computer according to table 1.

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Table 1: The differences between Conventional Computers and Quantum Computers.

Conventional Computers	Quantum Computers
Classical computers realize the distinction between 0 and 1 through integrated circuit and its basic unit is a silicon chip.	A quantum computer uses qubits to calculate, a qubit can represent both 0 and 1 simultaneously.
Conventional computing is based on the phenomenon of classical physics, that its units are being in a single state at a given time, either on or off.	Quantum computing is based on the phenomenon of quantum mechanics, where its units are possible to be in more than one state at a time.
In conventional computers, data is processed by the central processing unit (CPU), which consists of arithmetic–logic units (ALU).	In quantum computers, data processing is processed by the quantum processing unit (QPU), which consists of several interconnected qubits.

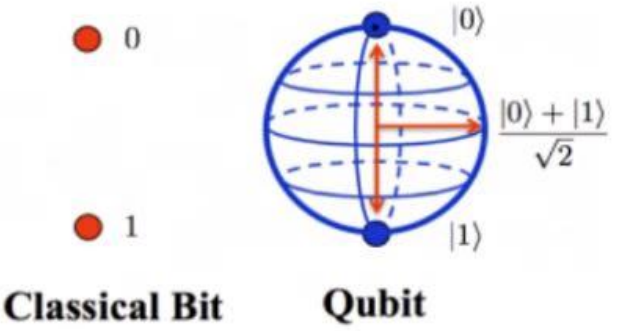

Figure 1. The Difference Between a Classical Bit and A Quantum Bit (Qubit).

According to figure 1, a qubit is like two bits in a quantum computer, while a bit can only represent a 1 or a 0, a qubit can represent 0 and 1 simultaneously. Consider a qubit as an electron in a magnetic field, the electron can have two states. It can be in a spin-up state, where the electron spin is aligned with the magnetic field, or a spin-down state, where the electron spin is opposite with the magnetic field. To change the electron's spin requires energy and let's say it requires one unit of energy to turn the spin competently, but if we only use half a unit of energy to turn the electron and ignore all external influences, the qubit then can take a superposition of both 0 and 1, this effect is called quantum superposition. An easy way to understand quantum superposition is with Schrodinger's Cat: a cat, a bottle of poison, and a computer is put in a box. If the box is then sealed, the computer will have a 50 % chance of breaking the bottle and releasing the poison, which would kill the cat. But no one would know if the cat would be dead or alive until they observe the cat, and until then, the cat is in a superposition of both dead and alive. Quantum superposition occurs because of quantum particle's interactions with the other particles around it, such as air molecules, and this interaction entangles the particles into a joint state. As a result, the two particles send out a wave into the environment. Rather like the wave an pebble drops into a lake, this spreading wave makes it impossible to see the original state unless close observation has been made [2].

So, quantum computers can be exponentially faster than conventional computers are because of quantum superposition. While a conventional computer can represent n amount of data, a quantum computer can represent 2n amount of data with the same number of qubits as bits used in conventional computers due to quantum superposition. This is simply permutations, while a qubit can simultaneously represent 1 and 0, a bit can only represent either 1 or 0. For example, if there is one

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qubit, than there would only be 2 kinds of state, only 1 or 0; if there is two qubits, than there would be 2*2 which is 4 states, (0,0) (0,1) (1,0) (1,1), while the same amount of sates needs 4 bits; if there is three qubits, than there would be 2*2*2 which is 8 states, (0,0,0) (0,0,1) (0,1,0) (0,1,1) (1,0,0) (1,0,1) (1,1,0) (1,1,1), while the same amount of sates needs 8 bits. So, if there are n qubits, there would be 2*2*2...*2 which is 2n states [3].

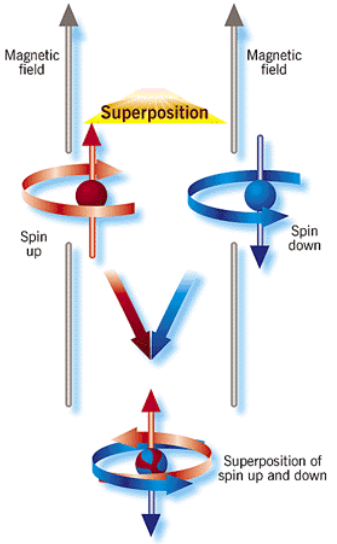

Figure 2. Quantum Superposition.

Two special characteristics of qubits are quantum entanglement and quantum correlation according to the figure 2. In quantum mechanics, after several particles interact with each other, since the characteristics of each particle have been integrated into the overall property, the properties of each particle cannot be described separately, but the properties of the overall system can only be described. This phenomenon is called quantum entanglement. In quantum computing, if the state of one of the entangled qubit is changed, the state of the whole paired would change. Thus, quantum entanglement can improve the speed of quantum computers. According to research, quantum entanglement is necessary for a quantum algorithm to have an exponentially increased speed over classical computations. And the ability of a quantum system to stay in the states of entanglement and superposition is called quantum coherence. Quantum correlation means that by observing one quantum, we can determine the state of all other quantum systems to which it is connected. In a sense, it is like quantum entanglement in a border perspective. Quantum correlation and entanglement allow us to check the results in a more efficient way [3].

However, there are some characteristics of qubits that make obtaining information difficult: one is quantum decoherence, and another is quantum unclonability. Quantum decoherence, as the name suggests, is the loss of quantum coherence of quantum entanglement. Due to quantum decoherence, the quantum correlation will no longer exist. Quantum decoherence may causes the behavior of the quantum system to change from quantum behavior into classical behavior. This loss of coherence can be caused by temperature fluctuations, electromagnetic waves, vibrations, and other external intervention. This effect can degrade quantum entanglement and ultimately destroys the quantum properties of the computer. Quantum unclonable means that any unknown quantum state does not exist in the process of copying, this is also referred to as the "No-Cloning Theorem," which was proposed by Werner Heisenberg in 1927. The quantum unclonable is the basic of quantum information. Quantum information is transmitted through a channel, and it is impossible to be copied by a third party to steal information without interfering with the current quantum information. Because the premise of copying is measuring, and measuring generally changes the state of the qubit. For quantum

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computers, this property of qubit ensures that the information will be safely stored, but the problems of quantum unclonable is also evident, there is no way for the process of replication functions and abilities similar to that which can be realized on a conventional computer to be realized in a quantum computer [4].

The interesting fact of quantum entanglement is a major reason why quantum computers are exponentially faster than classical computers. As mentioned before, quantum computers are exponentially faster because of quantum superposition, quantum entanglement is a special kind of superposition. For example, $\frac{1}{\sqrt{2}}$(|0>a|0>b + |1>a|1>b) is |0>a|0>b and |1>a|1>b 's superposition [4].

3. The Application of Quantum Computers

Although quantum computers are still in laboratories and not ready to meet the standards of military or civilian use yet, there are a wide range of fields that are expecting quantum computers to make their work easier. In theory, quantum computers can simulate any ecosystem system and are also the shortcut to artificial intelligence developing. Because of its powerful calculation capability, it can calculate enormous amount of data that faster which conventional computers are not capable. This advantage can suit quantum computers into a numbers of fields such as deciphering and encryption.

For one thing, quantum computer is beneficial in weather forecasting. Quantum computing may have the chance to improve meteorological tracking and predicting because of its ability to process tons of data that contains enormous amount of variables in a matter of seconds because of the characteristic of qubits. Such abilities would potentially save lives during extreme weather and reduce property damage. Secondly, quantum computers would help in developing new drugs. Quantum computers has the arithmetic ability to generate numerous compound equation of molecules and it has the ability, thanks to artificial intelligence, elect the most possible one among them. This approach would accelerate the speed for humans discovering new drugs. Confidential communication is also an area quantum computer would be useful. Due to the non-cloning theory for qubits, quantum computers will prevent intruders from copying down the information it contains.

One great application of quantum computers is artificial intelligence. Modern day AI is more trained than programmed, and the AI understands only the language that it has been trained with, so if the objective is for artificial intelligence to master a new language, it would require researchers to educate the artificial intelligence from the very beginning. Fortunately, with the help of quantum computers, artificial intelligence could break through its "language barrier" effortlessly.

Another use of quantum computing regarding artificial intelligence is quantum computer's potential to build better trained artificial intelligence that can make more accurate decisions. Quantum computing can train artificial intelligence with the use of big databases; therefore, artificial intelligence would make the most beneficial choice they've learned from the database to solve their problems, which often comes out the way we want due to the limited database that was used to train them. This method of training artificial intelligence has been proven effective with panting generating artificial intelligences. artificial intelligence doesn't just receive help from quantum computing, they are more in a "symbiosis relationship". For one reason, artificial intelligence can be capable of assigning task that can fit better for a quantum computer, thus those tasks can be optimized with the most satisfying results. Another reason is that artificial intelligence is capable to find shortcuts to the solutions to any problems, which is a important key characteristic because the speed of quantum computers is not that satisfying, but this problem is on its way to be fixed. Lastly, artificial intelligence can oversee the entire process of calculation, which would help scientists to make more effective use of quantum computing [5].

Although quantum computers are not yet ready to be used for civilian purposes, there have been achievements that are bringing them closer to our lives. On August 25, 2022, at the Quantum Developer Conference, Baidu officially released its first industrial-grade superconducting quantum computer, which integrates quantum hardware, quantum software, and quantum applications. On October 4, 2022, the European High Performance Computing Joint Enterprise announced that the

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Czech Republic, Germany, Spain, France, Italy, and Poland will built the first European quantum computer network in history. Existing supercomputers in these six countries, forming a quantum computing network, and it will be operational in 2023 [6].

4. Conclusion

This paper is an introduction to the field of quantum computing, and this preliminary exploration should have provided its readers with a basic understanding of what are conventional computers and quantum computers and how does they function. It briefly explained how and why quantum superposition similarities and differences and quantum entanglement in qubits allow quantum computers to work faster than conventional computers. It also identifies several ways that quantum computers can be used in society. Future work would be more specialized in understanding why quantum mechanics produces a superposition state and why it only appears in qubits.

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