Proceedings of the 2nd International Conference on Computing Innovation and Applied Physics (CONF-CIAP 2023)
DOI: 10.54254/2753-8818/5/20230555

Research on quantum computing and its development

Zhuoqiao Xie

Grimm Academy, Guangzhou, Guangdong, China, 510000

jackxzq0107@163.com

Abstract. Based on the rapid development of quantum computing and quantum communication all over the world, this paper studies the latest development of quantum computing on the basis of consulting a large number of literatures. By analyzing literature and summarizing, the basic knowledge and concept of quantum computing, the theory of time and data complexity, quantum computer, and the technical route of quantum computing are studied. Through the research, it is found that quantum computing is still in the primary stage, and the hardware of quantum computing, quantum error correction, anti-noise quantum computing and quantum simulation all need further research to improve quantum theory.

Keywords: quantum state, complexity, quantum entanglement, deep learning.

1. Introduction

The first quantum science and technology revolution began with the establishment of quantum mechanics in the 20th century. Einstein published the quantum explanation of photoelectric effect. Scientists such as Heisenberg, Schrodinger and Bohr basically completed the theoretical framework of quantum mechanics, and its direct application gave birth to modern technologies such as transistor, laser, nuclear magnetic resonance and satellite positioning system. With the progress of experimental technology and means, the second quantum revolution emerged at the beginning of this century. By precisely detecting and regulating the quantum state of the microscopic system, innovative applications such as quantum communication, quantum computation and quantum precision measurement were bred, and the positive electrode greatly changed and improved the way and ability of information acquisition, transmission and processing.

This paper discusses the history and concept of quantum computing, the complexity theory of quantum computing, deep learning and quantum computing. This paper discusses many aspects of quantum computing by analyzing literature and summarizing research methods. Through the research of this paper, people can have an overall study and understanding of the development, theory, application and technical route of quantum computing.

2. Introduction of quantum computing

The idea of quantum computing was first put forward by Feynman in the 1980s, and Deutsch defined and studied the quantum Turing machine and quantum circuit model[1]. In 1993, Bernstein and Vazirani began to consider the computational complexity of the quantum Turing machine[2]. In the same year, Yao Qizhi proved that quantum circuit model and quantum Turing machine are equivalent in computational complexity[3]. Thus, the theoretical foundation of quantum computer has been

DOI: 10.54254/2753-8818/5/20230555

completed. Early research on quantum algorithms includes Deutsch-Jozsa algorithm, Simon algorithm, etc[4-5]. The quantum polynomial time algorithm for large integer decomposition was proposed by Shor in 1994 and the fast quantum algorithm for searching disordered array elements proposed by Grover in 1996, Compared with the corresponding classical algorithms, these works show the potential ability of quantum computing to surpass classical computing[6-7]. Pan Jianwei team of University of Science and Technology of China, IBM, Intel and other companies are all developing quantum computing technologies such as quantum computer or quantum communication.

The biggest advantage of quantum computing is that it can test multiple possible solutions to the same problem in parallel. Through continuous sampling, the solution to the problem is finally obtained. Therefore, in theory, quantum computers have a speed advantage over traditional computers in solving some problems (such as decomposing large numbers, etc.)[8]. Quantum supremacy means that quantum computing devices have demonstrated the computing power beyond all traditional computers in specific test cases. Quantum hegemony achieved in 2019-Google created the world's first quantum computer that can surpass the computing power of today's most powerful supercomputer ummit , which was recognized as a major milestone in the development history of quantum computing by Nature[9-10]. The quantum computer reduced the calculation time that ummit needed to perform for 10,000 years to 200 seconds. Nevertheless, it is still necessary to realize soberly that the distance from quantum hegemony is far from enough, and the road from quantum hegemony to practicality is still very long.

3. Development of quantum technology at home and abroad

3.1. Development status of foreign countries

At present, quantum information has become the forefront of a new round of scientific and technological revolution and industrial transformation, and quantum computing is an important part of quantum information technology. Since Richard Feynman, the Nobel Prize winner, put forward the concept of the quantum computer for the first time in 1981, American and European countries have taken the lead in the quantum algorithm, programming and physical realization. In recent years, they have laid out the development strategy of quantum science and technology and seized the development opportunity of quantum computing technology.

As the birthplace of quantum theory in Europe, it is also devoting research and development resources to promote the development of quantum computing technology. The European Union's "Quantum Flagship Project" funded the first batch of four scientific research projects: Austrian ion trap quantum computation, German open superconducting quantum computer and large-scale quantum simulation of programmable atoms, and Italian cascade laser frequency comb quantum simulation. Researchers at Lancaster University, UK, made use of the mechanical effect of resonant tunneling quantum, and applied voltage to change the barrier from impenetrable to penetrable, and developed a universal memory, namely super random access memory. Fraunhofer Society of Germany commissioned IBM to develop a quantum computer with 27 qubits. Chancellor Merkel said that quantum computing helps the country to maintain "technical and digital sovereignty". The University of Dublin, Ireland has designed the first new quantum processor unit that can work in -269 S, which contains quantum bits of nano quantum dots created by standard silicon-based CMOS technology. The practical test of the Federal Institute of Technology in Lausanne, Switzerland shows that there is a perfect consistency between the optical measurement and the traditional high electron mobility transistor amplifier measurement, which opens up a new way to expand the future quantum system. The University of Innsbruck, Austria has developed an ion trap quantum computer prototype for an industrial server center, which is suitable for two 19-inch server racks.

3.2. Domestic development status

Since the "Nine Chapters" of quantum computer came out, China's quantum computing technology began to exert its strength all over the world. Compared with the superconducting quantum computer

DOI: 10.54254/2753-8818/5/20230555

published by Google, it has superior computing power, which is expected to explore its potential application value in the fields of graph theory, machine learning and quantum chemistry[11]. Institute of Quantum Information and Quantum Science and Technology Innovation, Chinese Academy of Sciences (Shanghai) teamed up with Jinan Institute of Quantum Technology and Guo Dun Quantum to upgrade the quantum computing cloud platform and access the 12-bit superconducting quantum computing physics machine. Beijing Institute of Quantum Information Science and Institute of Physics of Chinese Academy of Sciences also launched 8-bit and 10-bit superconducting quantum computing cloud platforms respectively. Academician Pan Jianwei of China University of Science and Technology recently successfully developed a 66-bit programmable superconducting quantum computing prototype "Zu Chongzhi", in which 56-bit were used to complete the "quantum computing superiority" experiment.

4. The latest development of quantum computing

In October 2019, Google Company officially published its paper on verifying quantum hegemony in the journal Nature. In this paper, Google announced that it realized quantum superiority by using 54 qubit processors Sycamore (as shown in Figure 1), and completed the prescribed operation within 200 seconds, while the same amount of computation on Summit, the largest supercomputer in the world today, would take 10,000 years to complete. This work is the first time in human history that quantum superiority has been verified in an experimental environment. It will be a milestone in the history of quantum computing, which means the arrival of the quantum computing era. A sycamore processor is a fully programmable processor with 54 qubits. Each qubit in its two-dimensional grid structure is connected with four other qubits. The dense connection ensures that the processor chip has good connectivity so that the qubit state can be quickly transferred and interacted on the whole processor. In order to ensure the success of the quantum hegemony verification experiment, Google has adopted a number of advanced measures to improve the gate with two qubits, thus improving the parallel processing capability. Even if many gates run at the same time, it can surely bring the highest performance so far; A new control section is introduced, which can close the interaction between adjacent qubits, thus significantly reducing the number of anomalies in the multi-connected qubits system. Optimize the overall architecture design of the chip to reduce crosstalk, and develop a new control calibration method to avoid qubit defects.

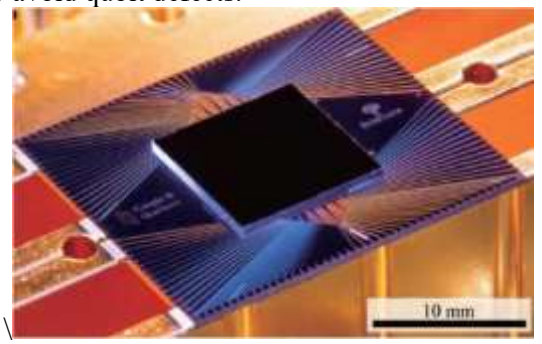

Figure 1. Sycamore processer with 54 qubits.

At present, Google is far from the only arranger and explorer in the field of quantum computing. All major technology giants have started theoretical research and application attempts in the field of quantum computing, and at the same time, they have accumulated practical experience step by step in qubit configuration and control technology solutions (such as low-temperature characterization, etc.).

In January 2019, IBM launched IBM Q System One, the world's first prototype of a commercial integrated quantum computing system (as shown in Figure 2), and successfully developed the first "all-in-one" form of all hardware devices needed to start a quantum computing experiment (including all devices needed to cool quantum computing hardware, etc.), becoming the world's first fully integrated universal quantum computing system, marking an important step in the commercialization

DOI: 10.54254/2753-8818/5/20230555

of quantum computing. Its main achievement is that a quantum computer in the laboratory stage is closer to a large quantum computer in reliability and stability, thus minimizing the interference of electromagnetic waves or physical vibrations on quantum computing and making the ambient temperature controllable (freezing point temperature). This achievement makes the use of universal approximate superconducting quantum computers beyond the scope of research laboratories for the first time.

Figure 2. The world's first commercial integrated quantum computing system prototype IBM Q System One.

In June 2020, Honeywell announced that it had built the most powerful quantum computer in the world. The company had previously predicted that the quantum volume of this quantum computer would reach at least 64. Quantum volume is an index used to measure the performance of quantum computers, not just the number of qubits. Quantum volume measures the ability of quantum computers more accurately and comprehensively, including measuring the complexity of solving problems.

5. Conclusion

Through the above discussion of quantum computing, people can see many application scenarios of quantum computing. Quantum computing is considered to be able to solve complicated problems that the current traditional computer system can't handle. Because of the potential value of quantum information technology, all countries in the world are actively integrating various sources and carrying out national-level collaborative research on quantum computing to ensure that their own development is not in a backward position. For example, the European Union launched the flagship project of quantum technology in 2016, and the United States officially adopted the National Quantum Action Plan in 2018. In December 2016, China issued the "13th Five-Year National Strategic Emerging Industry Development Plan", which raised quantum communication to the national strategic level and made it an important strategic emerging industry direction and a major scientific and technological project that reflected the national strategic intention.

In recent years, foreign high-tech giants, such as Google Inc., Microsoft Corp., IBM Corp., etc., have stepped in and deepened their research and application layouts in the field of quantum computing with frequent success. Google released the 72-qubit quantum computer in 2018 and achieved quantum hegemony in 2019. In 2021, the Galaxy Kunteng QW2020 quantum computing system led by the School of Computer of China National University of Defense Technology made its debut. China University of Science and Technology made progress in quantum computing of ultra-cold atomic optical lattice.

Quantum computing is a new computing mode, which follows the laws of quantum mechanics and controls quantum information units to calculate. Artificial intelligence has a great demand for computing power, and traditional CPU chips are becoming more and more incompetent. By developing new quantum algorithms, an excellent quantum machine learning model is built to promote the application of related technologies. Encrypting and deciphering passwords is an uninterrupted theme in the long history. Quantum computation has deciphered RSA and other public key systems, while cryptographers have constructed a new public key system. However, the absolute security of the

DOI: 10.54254/2753-8818/5/20230555

current cryptographic system is still difficult to guarantee. AI and machine learning are the keys to future quantum computing, and the future of quantum computing, like the quantum state itself, is still uncertain. But the prospect of quantum computing is bright.

At present, the research and application of quantum computing are still in the primary stage. Besides improving the performance of quantum computing hardware systems, quantum error correction, anti-noise quantum computing and quantum simulation will become the key research points in the next stage of quantum computing.

References

[1] Deutsch D. Quantum theory, the Church-Turing principle and the universal quantum computer. Proc Royal Soc A-Math Phys Eng Sci, 1985, 400: 97–117

[2] Bernstein E, Vazirani U. Quantum complexity theory. SIAM J Comput, 1997, 26: 1411–1473

[3] Yao A C-C. Quantum circuit complexity. In: Proceedings of the 34th Annual Symposium on Foundations of Computer Science, Palo Alto, 1993. 352–361

[4] Deutsch D, Jozsa R. Rapid solution of problems by quantum computation. Proc Royal Soc A-Math Phys Eng Sci, 1992, 439: 553–558

[5] Simon D R. On the power of quantum computation. SIAM J Comput, 1997, 26: 1474–1483

[6] Shor P W. Algorithms for quantum computation: discrete logarithms and factoring. In: Proceedings of the 35th

[7] Annual Symposium on Foundations of Computer Science, Santa Fe, 1994. 124–134, Grover L K. A fast quantum mechanical algorithm for database search. In: Proceedings of the 28th Annual ACM Symposium on the Theory of Computing. New York: ACM, 1996. 212–219

[8] Lin Xiong, Lin Shuai. Prospect of Quantum Computing and Quantum Computer [J]. Microcomputer and Application，2012，31（22）：4-6.

[9] Arute F. Quantum supremacy using a programmable superconducting processor［J］. Nature，2019，574：505-510.

[10] Charles H B，Ethan B，Djabeur M S Z，et al. Strengths and weakness of quantum computing［J］. Siam Journal onComputing，2016，26（5）：1510-1523.

[11] Ma yanin's quantum computer" nine chapters" is amazing: surpassing Google, China scientists have made a milestone progress in "the superiority of quantum computing"5 .2020-12-4(5).