Dream computer using quantum mechanics

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Recently, the amount of information and the number of information processes have been increasing year by year due to the utilization of information technology such as Internet of Things (IoT) and Artificial Intelligence (AI). This information society has been supported by improvements in electric power generation, transmission, storage, and semiconductor integration technologies. Especially, semiconductor integration technology has been improving in accordance with Moore's Law, which states that the integration density of semiconductors will double in 18 months. However, it is expected to reach its limit in the next two to three years as the semiconductor chips approach the size of an atom. Therefore, the speed of information processing could be a major problem if the demand for information processing continues to increase. Similarly, the issue of energy consumption cannot be ignored considering the finite amount of fossil

fuels in the world and its impact on global warming. Here, I will introduce "Quantum Computer" which is based on the principle of quantum mechanics as the dream computer which has the potential to solve these two major problems: energy consumption and speed of information processing.

Quantum computer proposed by Feynman et al. in the 1980s is a computer that utilizes superposition state which is peculiar to quantum mechanics [1]. While classical computers currently in use handle classical bit of 0 and 1, quantum computers handle qubit which can be not only 0 and 1 but also superposition of these which is very special state different from 0 and 1. There are two major advantages to use quantum computers. First one is that there is no energy consumption in the time evolution of quantum states. Second one is that high-speed calculations for specific problems can be realized by utilizing superposition states. For example, the algorithm "Shor's algorithm" that performs prime factorization at high speed is famous because it breaks RSA cryptography in principle [2], which is the basic cryptography of modern times. At the time of the proposal, the general opinion was that error correction can't be done because the quantum state will be broken after observation and the realization of quantum computer would be impossible. But in the 1990s, Peter Shor showed that quantum error correction was possible by using quantum entanglement. And after that, the study about quantum computing and quantum information processing accelerated at a stretch.

Here, I will introduce two application examples of quantum computer. The first one is drug discovery by quantum chemistry calculations. Quantum computers which are based on quantum mechanics, are compatible with understanding microscopic

substances using molecular simulations. Therefore, understanding the material structure by quantum computer is considered to be beneficial for pharmaceutical manufactures when developing new drugs.

The second point is the combinatorial optimization problems in logistics optimization and the like. It is generally difficult to solve combinatorial optimization problems using classical computer, which require brute force calculations because the number of calculations increases exponentially according to the number of elements. On the other hand, quantum algorithms that perform high-speed processing on combinatorial optimization problems have been developed, and if a quantum computer is realized, the range of combinatorial problems that can be solved will expand at once.

Due to its social impact, quantum computers are being researched by universities and companies all around the world in various physical systems and the technical improvements are remarkable. Google realized quantum supremacy, which is to prove that quantum computer can outperform classical computer in terms of computing power by experiment, using superconducting device in 2019, and research group in university of Science and Technology of China realized quantum supremacy using optical system in 2020 [3-4]. Nevertheless, at this stage there are still many difficulties in error correction and scalability, and quantum computer has not yet been put into practical use. The realization of a quantum computer will not only solve two big problems of power consumption and information processing speed already mentioned, but also bring about improvements in quantum state control and quantum measurement technology in various physical systems. If the microscopic quantum state will come to be controlled,

there is no doubt that various devices other than quantum computers will be also invented. Therefore, after the realization of “quantum computer”, we can say that humankind will have new strong weapon called quantum mechanics.

References

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