Next-generation computers will save our lives

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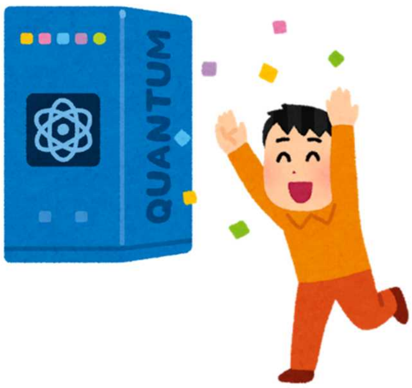
In recent years, the amount of computation required by modern society has been increasing rapidly with the advancement of artificial intelligence (AI), big data, and internet of things (IoT) technologies. Correspondingly, the computing power of supercomputers is also improving day by day as you may have heard the news that Japan's supercomputer, Fugaku, has the highest computing power in the world history. In such a situation, one of the major problems that humankind is currently facing is the enormous amount of electric power consumed by computers. It is said that the electric power required to run a single supercomputer is more than that of a nuclear power plant and the electric power consumption will continue to increase as supercomputer performance improves. The development of supercomputers that support the current accelerating demand for computation will surely reach its limit soon, eating up all our available energy.

Quantum computers are expected to be the solution to the serious energy problems of our computers. Quantum computers are completely different from the today’s widespread computers, in that they use the properties of quantum mechanics to perform calculations. Furthermore, another of the greatest advantages of quantum computers is that they do not consume any energy in principle when performing calculations. Today, quantum computers are being developed around the world as the savior of the global energy problem.



Quantum computers are being developed using various physical systems such as superconductivity, ions, electrons, and diamonds. One of the most promising physical systems is the quantum computer with light. Quantum computer with light has two advantages over other physical systems. The first is that they can work at room temperature. Quantum bits, which are based on atoms, ions, and electrons, are vulnerable to thermal disturbances, and can only be sustained at extremely low temperatures, close to absolute zero, to maintain the quantum states that are essential for quantum calculations. On the other hand, the energy of a single photon is equivalent to several tens of thousands of degrees when converted to temperature. Room temperature is rather close to absolute zero from a photon's point of view, and the effect of thermal noise can be almost ignored. Secondly, a quantum computer with light has a high compatibility with existing optical communication technology. Today, there are submarine cables all over the world, and the world is connected by optical communication. Since an optical quantum computer encodes quantum states into light, it can directly exchange information using existing optical communication technology without special converters.

Then, how much progress has been made in the development of quantum computers with light? In fact, light is one of the most advanced physical systems for the development of quantum computers. Generally speaking, there are three requirements for a practical quantum computer: a large computational scale, arbitrary quantum computation, and quantum error correction. Light has a large lead over other physical systems in the large-scale amount of computation. Photon is unique in that it always travels at the speed of light, unlike other physical systems. For this reason, light is also called a "flying qubit". At first glance, the fact that qubits fly around seems to be a disadvantage because it is difficult to control, but a study was reported in 2016[1] that successfully used this feature to generate large-scale computational resources called cluster states. Otherwise, when creating a large-scale computational resource in a fixed material system, it is necessary to use a method called spatial multiplexing, in which many qubits are arranged spatially. This method requires experimental equipment proportional to the scale of the computational resource, and from the viewpoint of scalability, there is a limit to the number of qubits. On the other hand, since light is always moving, multiplexing can be performed on the time axis, and theoretically, an infinite number of multiplexes can be performed with a certain size of experimental equipment. By using this time-domain multiplexing scheme, the generation of a large-scale computational resource of one million bits is reported in a 2016 study [1]. This is extremely large-scale compared to other physical systems, for example a quantum computer with superconductivity is limited under 100 bits.

Here, I have introduced the development of quantum computers with light. Although light is more advanced in the development of quantum computers than other physical systems, there are still many research issues to be solved, such as: how to achieve arbitrary quantum computation, and how to achieve fault tolerance computation. The way to achieve these requirements has not been established now, and not only experimenters but also theorists are working on the issue. It is said that it will take another 30 years to develop a practical quantum computer. However, once quantum computers are developed, the limitations of computing power due to energy problems will be broken down, and the world will undoubtedly be transformed into an even more prosperous and convenient society. We must keep an eye on the development of the next generation computer that totally changes the world.

[1] J.Yoshikawa, *et al*., Generation of one-million-mode continuous-variable cluster state by unlimited time-domain multiplexing, APL Photonics **1**. 060801 (2016)