NEC's Activities in Quantum Computing Technology

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Abstract

Quantum computing is a technology that uses features of quantum mechanics to compute certain problems much faster than conventional computers and has recently received a great deal of interest. Although the expectations are high, the world will not change right away with the current state of quantum computing due to limited computational performance caused by noise in quantum circuits. Because of this situation, conventional computing techniques called quantum inspired, where the essential quantum phenomena that provide the speedup are emulated by conventional algorithm, are also attracting attention. In this presentation, the quantum computing technologies that NEC is working on as well as technical trends in this field are introduced.

1 Introduction

Quantum computing is a technology that uses the properties of quantum mechanics, such as quantum entanglement, quantum superposition, quantum tunneling and so on. One of the milestones of quantum computing is quantum supremacy [1], which is the goal of demonstrating that a programmable quantum device can solve a problem that no conventional computer can solve in any feasible amount of time (irrespective of the usefulness of the problem). The quantum supremacy has already demonstrated with superconducting quantum bits (qubits) [2] and optical qubits [3]. The current state of quantum computing including them is referred to as the noisy intermediate-scale quantum (NISQ) era, where the number of qubits is around 100 and the noise in quantum circuits will limit the size of quantum circuits that can be executed reliably. Therefore, NISQ devices will be useful tools for some useful applications, however, 100-qubit quantum computing will not change the world right away. Quantum researchers will continue their efforts to reduce and correct errors in quantum circuits and achieve a fully fault-tolerant quantum computer (FTQC). One of the applications of the FTQCs is to speed up the cracking of the widely used public-key cryptosystems (*e.g.* RSA) using Shor's algorism [5]. The FTQC is very powerful, however, it is thought to take 10 years or more to realize FTQCs due to the difficulty of implementing error correction in quantum circuits.

While explanations above are for quantum gate systems, quantum annealing (QA) systems are also attracting attention [6]. QA is an optimization process for finding the global minimum of a given objective function over a given set of candidate states, utilizing a process using quantum fluctuations. QA is used mainly for solving combinatorial optimization problems, which are latent in social issues and are classified as NP-hard in terms of computational complexity theory. Because of their difficulty, they are often left as an unsolvable part of a social problem. Optimization of production planning is a concrete example of such problems. QA machines are realized using superconducting flux qubits [7]. NEC is also developing quantum annealing machines using Josephson parametric oscillators (JPOs)[8]. As to annealing, simulated annealing (SA) has longer history [9], where conventional computers are used but quantum phenomena not. As QA has gained attention, interest in SA has also increased, especially in Japan, where several vendors are developing this technology. NEC provides one of SA "Vector Annealing", an annealing-based algorithm implemented on NEC's own vector supercomputer.

In this presentation, NEC's activities in QA and SA as well as the technical trend in the quantum computing field are explained.

2 NEC's Activities in quantum and simulated annealing

2.1 QA based on JPOs

Recently, there are several proposals to use Kerr parametric oscillator (KPO) for gate-based quantum computers [10] and QA machine [11]. KPO can be implemented by JPO, which is superconducting nonlinear resonator. One of the challenges to realize QA using JPOs is how to implement all-to-all connectivity. A scheme called "LHZ scheme" to realize full connectivity with only local interactions was proposed [12]. Later, this scheme was applied to the theoretical proposal of QA using KPOs [13]. NEC has adopted the LHZ scheme built with JPOs for a QA machine and is trying to multi-qubit integration [14]. Recently NEC and Tohoku University started joint research on computer systems using an 8-qubit QA machine, to which researchers can access via the internet.

2.2 Vector annealing (simulated annealing)

The vector annealing runs software incorporating NEC's proprietary algorithm suitable for SA processing on the vector supercomputer "SX-Aurora TSUBASA." This performs matrix calculations with a large capacity memory, ultra-high-speed processing of large-scale combinatorial optimization problems can be carried out. The first version was all-to-all-connected 100,000-bit scale, and now it is a 300,000-bit scale. We have also improved algorithms, which have made solution performance up to 30 times faster than previous versions, including enhanced flip option functions that reduce unwanted annealing calculations. NEC is working with partners to explore use cases for this technology in the fields of manufacturing, logistics, financial, materials and so on.

3 Conclusion

NEC's activities in quantum computing technology including superconducting quantum annealing and vector annealing using NEC's own vector supercomputer are reviewed.

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