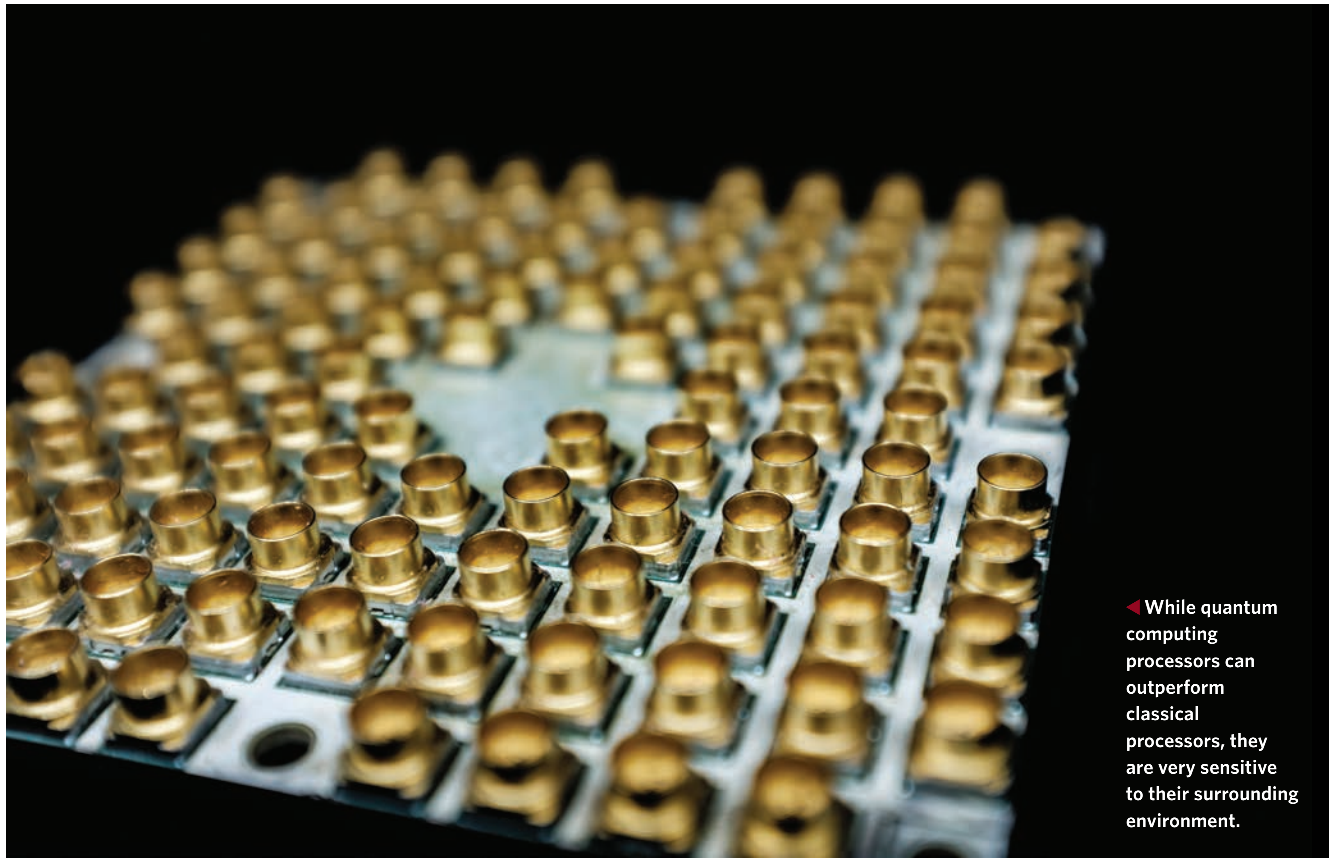

◀ While quantum computing processors can outperform classical processors, they are very sensitive to their surrounding environment.

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CUTTING THROUGH THE NOISE FOR EFFICIENT QUANTUM COMPUTERS

Optimization algorithms developed by Tokyo scientists are helping quantum computers navigate their way through THE MESSY IMPERFECTIONS OF THE QUANTUM WORLD.

As devices become more complex, computer hardware and code need to be able to make faster, more accurate calculations and decisions. For example, self-driving cars must process huge amounts of visual data in an instant to avoid collisions, and pharmaceutical experts need to model the behaviour of individual drug molecules within cells.

Quantum computers, which can vastly outperform classical processors, will help realize the full potential of these Industry 4.0 technologies. While quantum computing is still in its infancy, even the simplest devices can perform remarkable calculations, thanks to clever software design and insights from physics.

Now researchers at Waseda and Keio Universities, in the heart of Tokyo, are creating cutting-edge algorithms that are enabling quantum computers to tackle practical problems, despite their current limitations.

QUIETENING THE DIN

Calculations in quantum computing are performed on units of quantum information called qubits, which can be implemented in superconductors. What makes quantum computing so powerful is that qubits are more complicated than the simple 0 and 1 binary bits of classical computing. They can exist as a superposition of both states.

Most quantum processors contain up to a few hundred qubits, which is enough to outperform classical processors with billions of bits. The downside is that qubits are extremely sensitive to their surrounding environment — for example, temperature fluctuations or electronic noise can cause them to flip into other states and lose their quantum information.

While this 'decoherence problem' may eventually be resolved, for now we live in the NISQ (noisy intermediate-scale quantum) era, and researchers are trying to develop 'fault tolerance' algorithms to limit the impact of the noise. Such algorithms will accelerate the march towards quantum advantage — where quantum devices can quickly solve problems that would either be impossible on classical computers, or take an impractically long time to resolve.

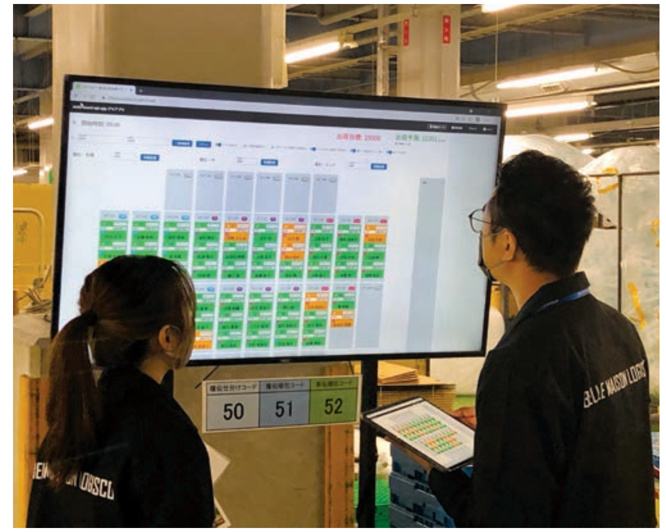
STRONGER TOGETHER

Developing the best algorithms to make quantum computers work requires tight collaborations between researchers in computer science and physics. This is the approach taken in the research group led by Nozomu Togawa in the Department of Computer Science and Communications Engineering, at Waseda University. Togawa's own research career began in computer science, specifically computer architecture and chip design.

"A chip is composed of billions of elements, and so a key issue is finding the best way to optimize them," says Togawa. "For this reason, I have recently been focusing on combinatorial optimization problems." To help in these efforts, Togawa works closely with physicists, including Shu Tanaka at the Department of Applied Physics and Physico-Informatics at Keio University.

"My research originally focused on statistical and computational physics," says Tanaka. "About seven years ago, I came across a paper on quantum annealing machines by a Canadian venture, D-Wave Systems, and I started researching quantum annealing."

Quantum annealing is a general term for algorithms that search for the minimum energy state of a system. The flow of quantum annealing is as follows. The problem to be solved is represented by a physical system. Next, a quantum fluctuation that realizes a quantum superposition state is introduced, which is then gradually weakened. As a result, the minimum energy state is searched for.



▲ Reviewing personnel shifts optimized by quantum computation.

ISING ON THE CAKE

The Ising model is used in the field of statistical mechanics as a fundamental model to describe macroscopic phenomena that emerge when many microscopic elements come together. In it, degrees of freedom called spins with bistable states interact with each other. The hardware implementation of the Ising model is the Ising machine, regarded as one of the best quantum annealing tools available.

"Various types of Ising machine have been developed," says Tanaka. "In 2011, the first commercial quantum annealing machine, D-Wave, came out, which triggered great interest in Ising machines. So the hardware development of Ising machines has been energetically advanced in recent years."

Some other examples of Ising machines making waves in industry include the Fujitsu Digital Annealer, the Hitachi CMOS Annealing Machine, the Toshiba Simulated Bifurcation Machine, and the Fixstars Amplify. The power of these machines is that they can quickly search lower-energy states for a system from many possible combinations. The potential applications for such rapid decision-making are easy to see, especially for automatic design in industry.

In developing their own Ising machines, Togawa's team constantly scours libraries of existing code to avoid having to re-invent the wheel by writing code from scratch in every case. In fact, they effectively apply the optimization ethos to their own work, examining and comparing several different codes before selecting the best ones.

"In software development, an important concept is 'Write once, run anywhere'," says Togawa. "Re-using software codes that are already written is very important. So our research focuses on making the software development for current and future quantum computing as efficient as possible. Our software platform assigns an 'optimal accelerator' — a kind of quantum computer — to every subprogram, assuming that future NISQ devices and fault-tolerant devices will be available."

REAL-WORLD INTERFACES

Recently, Togawa's team have been extending their prototype software to cyber-physical systems where computers interact with the real world — for example, smart homes that predict what householders will need at certain times, or smart medical devices that monitor health and deliver treatments automatically. Togawa says he has been in discussions with companies in the electrical, telecommunications and vehicle industries, although these talks remain confidential for now.

Another exciting application that the team is investigating employs their optimization protocols to work out the best sites for 5G transmitters. They are also looking into improving the efficiency of factory lines by varying the schedules of personnel shifts.

Optimization tools such as Ising machines essentially amount to a compromise that accepts the imperfections of the quantum world, while cleverly getting around its limitations. They will remain vital to making quantum computing a practical technology for a long time yet.

"In the near future, it seems very unlikely that devices integrating thousands of qubits with no errors can be realized," says Siya Bao, an associate professor in Togawa's lab. "This means that quantum annealers and NISQ devices will continue to be needed for many years to implement fault tolerant quantum computers." ■

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