Have an Open Mind and Don't Worry about Failure to Stay on the Cutting Edge of Science and Technology

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Overview

Researchers at NTT Basic Research Laboratories are aiming to create new technologies harnessing the power of quantum mechanics. In November 2020, they proposed a method for compressing quantum circuits to enable high-speed quantum computation and the miniaturization of quantum computers in the US scientific journal Physical Review X. In February 2021, the British scientific journal Nature Communications published a paper on the demonstration of a high-speed quantum random-number generator that achieves the highest levels of security by using the world's first practical optical device. We interviewed William John Munro, a senior distinguished researcher at the laboratories and leading figure in the broad field of quantum technology, about his research activities and his attitude as a researcher.

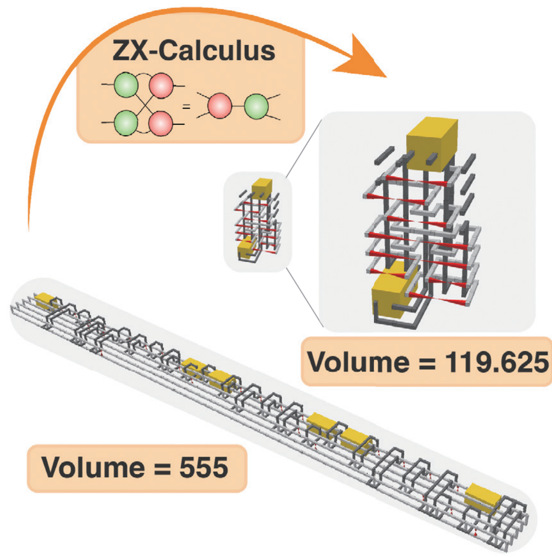
Keywords: quantum computer, noisy intermediate-scale quantum processor, time crystals

Research activities spanning a broad field of quantum technology—from quantum computers to secure communications

—Please tell us about the research you are currently working on.

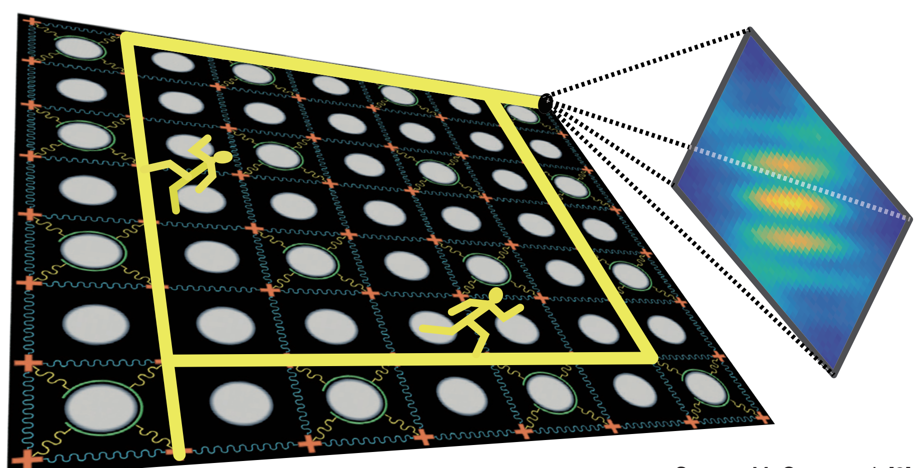
Quantum computers and quantum information processors are one of the research themes that we have been continuously focusing on. Noisy intermediate-scale quantum (NISQ) processors, which can be called medium-sized quantum computers, have been actualized and we are now focused on how we advance from these NISQ processors to future quantum supercomputers. Last year, for example, we proposed a method of compressing quantum circuits that significantly reduces both the time and resources required for a quantum computer to solve a problem (**Fig. 1**) [1].

We have also been investigating what applications can be run on these NISQ processors. This year, we were able to implement a *quantum walk** on a 62-qubit quantum processor (**Fig. 2**) [2]. This demonstration on the world's largest quantum computer of a quantum walk is a milestone research result that has attracted significant attention because it showed a



Source: M. Hanks et al. [1]

Fig. 1. Illustration of the compression of a quantum circuit.



Source: M. Gong et al. [2]

Fig. 2. A 62-qubit quantum computer executing a quantum walk.

different way to program these quantum processors.

I have also been researching the *quantum internet*—a quantum-enabled version of today's Internet. My focus is on how we design it and how it would work in practice. Quantum physics gives us new opportunities for how information can flow in such a quantum-enabled internet. We have introduced new concepts, such as quantum multiplexing, quantum routing, and quantum network aggregation, and studied their properties. We found that their unique properties can be exploited for quantum communication and allow us to overcome a number of weaknesses that were inherent in quantum computers. Although

* Quantum walk: A quantum version of a random walk, in which the position that a particle next steps to is determined randomly by rolling a die. It is one of the most-important quantum algorithms and is expected to be used to describe and analyze phenomena in a variety of fields, including diffusion and noise problems. Furthermore, quantum walks enable one to perform universal quantum computation.

the quantum internet has not received that much attention yet, it is an interesting research subject and one that will be very important in the future. Combining quantum computation and communication technologies is an area that must be investigated.

The study of *time crystals* is something a little different. You may have heard the word "time crystal" from Star Trek, but what we mean here is a little different. Salt and sugar are well-known examples of crystals—periodic arrays of atoms—, but time crystals are ones that are arranged periodically in time rather than space. The use of graph structures has proven to be an effective means to represent and visualize such time crystals. When a quantum system is used to generate a time crystal, it is possible to create an extremely large-scale network with more than one million nodes even if the number of qubits is as small as, say, 20. We found that when the time crystal melts, the network also changes and becomes scale-free [3]. This finding is important because scale-free networks are normally associated with today's Internet. We may have a means of exploring the properties of global-scale networks on a small quantum computer. This possibility is quite fascinating, and who knows where it could lead in the future; it could lead to a new approach to quantum simulation.

Another of our recent achievements is the development of a secure and high-speed quantum random-number generator [4]. Random numbers play an important role in a variety of information, computation, and communication technology tasks.

Quantum technology is expected to contribute to achieving communication networks with dramatically improved security. The concept of the Innovative Optical and Wireless Network (IOWN) calls for the construction of a new network and information-processing infrastructure using innovative technologies centered on photonics, and we believe that our research will enable a quantum-enabled IOWN, namely, qIOWN, which will allow us to construct a distributed quantum-information-processing system composed of quantum processors, sensor, and clocks all connected through a quantum network.

—Those research results are amazing. Quantum computers are being actively researched worldwide. What is required of researchers if they are to quickly produce research results that will benefit society as a whole?

The field of quantum computation is attracting a great deal of attention worldwide, and advanced efforts are being made in Europe, the United States, and China in particular. It's a shame that Japan is lagging a bit behind in this. At present, small-scale quantum processors with about 60 qubits have been fabricated, and they are available in some countries. These quantum processors are useful for exploring the possibilities offered by quantum mechanics and have been reported to execute tasks that would probably take thousands of years even on today's largest supercomputers. However, such processors generate noise during operation, so their use is limited to tasks that are not affected much by noise.

For quantum computers to develop, they will need to be scaled up to much larger-scale quantum processors, preferably consisting of millions of qubits. It is not clear yet how this will be done, but we know that it requires an approach that is fundamentally different from the way current NISQ processors are fabricated. I believe that it is essential for the scientific community to collaborate on a global scale. Keeping the research closed will only lead to delaying the actualization of large-scale quantum computers.

We do not yet fully understand the true potential of large-scale quantum computers, but we can expect them to have a profound impact on society. The impact could be as revolutionary as that of original computers on society in the 1940s and 50s. They will be able to solve complex problems that we can't even imagine today. I hope to see large-scale quantum computers before I retire.

A cup of coffee and a whiteboard can create a magical place

—What do you think a researcher is?

To be a researcher, you must have an inquisitive mind and want to solve problems, think outside the box, and find out how things work without being bound by existing ideas. I like the Cambridge dictionary definition which says a researcher is "someone who studies a subject, especially in order to discover new information or reach a new understanding." This is a very broad definition and obviously you are successful if you achieve that. How successful is however a different question!

I am not really sure I am a researcher in the sense you mean. I am more of a scientist/engineer, which is a little different. I want to understand how things work, be able to design and build interesting devices and technologies and more importantly have fun doing it. One of the differences between me and many other researchers is that I am more of a generalist than specialist. I cover many topics (optics & photonics, superconducting systems, computer science, chemistry, cryptography, system engineering, etc.) and can integrate them together. Other researchers typically have much more in-depth knowledge about a few specialist fields.

NTT allows us to choose large problems (grand challenges) that take an extended time to solve. At many universities, however, projects must be completed well before the end of the grant that lasts only a couple of years.

The research environment is very important for us researchers, and interaction with other researchers is critical. We can accomplish much more when we have researchers get together as a team. When researchers gather in the same place, a cup of coffee and a whiteboard is all that is needed to create a magical place. The research environment has changed as the amount of remote work has been increased as a measure to prevent the spread of the COVID-19. Although certain things can be done with electronic platforms, it is not the same. It is not spontaneous. The tools are just not there to achieve the same effect as face-to-face communication.

—How do you search for problems and themes during your ongoing research activities?

When looking for a research theme, I spend about 20% of my time checking out a wide range of research outside my field of expertise. This enables me to discover new and exciting trends coming through and investigate topics that I find to be interesting, some of which become new themes for me. International conferences also offer great opportunities to get in touch with the latest research. At large conferences, I try to attend sessions on topics outside my field of expertise. Invited talks and tutorials are especially useful because they accurately showcase what those fields have to offer and open problems in those fields.

In retrospect, most of my research has been focused on creating new trends, not following them. In other words, I always try to think ahead of the game. For example, in one of my previous research projects, which focused on quantum repeaters, it was thought that the performance of a quantum repeater would be limited by the time it takes for a signal to travel from one node to another. We tried for nearly five years to circumvent the limitation imposed by the signaling time; however, like most researchers in this field at that time, we concluded that it was impossible to remove this limitation. To overcome the limitation, we had to completely change the way we thought about quantum repeaters. In other words, we disregarded quantum memories, an element that was previously thought to be essential in quantum repeaters. Initially, that new way of thinking seemed too far-fetched and unlikely to work. However, a few simple calculations showed that it could work, and it has created a new subfield concerning quantum repeaters. What we showed would be extremely hard to physically achieve—but if we could do it, then the repeater's performance could be improved millions of times compared with previous approaches—a potential game changer.

A lot of potential is buried in unexplored fields

—Isn't it tough to take on challenges in unexplored fields? Do you ever feel pressured?

No, the opposite is true. A lot of potential is buried in unexplored fields, and anyone can be a pioneer. Stepping into those fields also means being on the cutting edge of science and technology. I think that is something every researcher wants to do. Uncharted territory is extremely rewarding no matter which angle you look at it from. However, naturally, there are risks, and you need to be prepared for the fact that there is no path before you.

Failure is part of research—especially if you are working at the cutting edge of it. You can't expect everything to work, and you will always face problems. Therefore, we should not criticize people for their failures, although we do need to be careful if there are repeated failures. In my case, about 20% of the projects I took on did not turn out the way I expected. However, I believe that we can learn valuable lessons from our failures and become better researchers.

I also believe that technology has the potential to change society for the better. Although natural evolution of technology can be expected, sometimes, a disruptive technology bursts onto the scene, causing profound changes. Quantum technology has such disruptive properties. If it is achieved, it will force a fundamental change in many aspects of e-commerce and how information is moved and stored. Quantum technology also provides new opportunities for the processing power of computers, such as using quantum laws as a means of privacy protection. We need to remember that technology is not one-sided; it can always be used in different applications beyond our imagination.

—What would you like to say to next-generation researchers?

Have an open mind and don't worry about failure. Choose a problem that you find interesting and enjoy trying to solve it. I also think it is important to broaden your knowledge by reading a wide variety of literature. This will help you explore new areas.

There is no single answer to the question of how to develop a new field. I have been developing themes at a pace of about one every five years. While focusing on my current research themes, I am simultaneously developing new ones. Over time, the new one would take over from the old one which would be retired. I recommend that you attend international conferences and read popular scientific magazines to determine areas you find fascinating. You will then see if you can find an interesting problem you want to try solving.

You might feel lost when jumping into a new field or facing a new challenge or you might have trouble organizing your thoughts or writing a paper. In such a case, it is useful to talk with the researchers around you. You may be able to receive advice on a new field or hints on how to construct your paper. However, it is up to you to start the conversation with them, then decide yourself what to do.

There are always highs and lows during research, and sometimes results will come easily, while at other times, it seems that nothing works out. Remember that this is natural. I always try to have several projects with different themes going at the same time. When there is an issue with one, I can focus on another. This allows me to take my mind off the issue and clear my head. I can then come back refreshed with new ideas.

Finally, I'd like you to keep in mind that there are many other researchers around you with whom you can talk and interact. As senior researchers, we are here to help you.

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■ Interviewee profile

William John Munro

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He received a B.Sc in chemistry, M.Sc and D.Phil in physics from the University of Waikato, New Zealand, in 1989, 1991, and 1995. After several years in the computing industry, he returned to physics as a research fellow at the University of Queensland, Australia from 1997 to 2000 before becoming a permanent staff scientist at Hewlett Packard Laboratories in Bristol, UK (2000–2010). He joined NTT Basic Research Laboratories in 2010 and was promoted to senior distinguished researcher in 2016. His research interests range from foundational issues in quantum science through to the design and development of quantum technology. He is a fellow of the Institute of Physics (IOP), American Physical Society (APS), and the Optical Society (OSA).