QUANTUM VISIONARY

KOHEI ITOH, President of Japan's Keio University, describes the potential and the challenge ahead.

In 1935, trying to discuss problems in quantum mechanics with Albert Einstein, Erwin Schrödinger first posed his now-famous thought experiment: Suppose a cat is trapped in box, its fate governed by a random quantum trigger. Before we open the box, he asked, is the cat alive or dead? A strange question, but the answer is even stranger: It is both. In that strangeness lies explosive potential for the world of computer science.

A traditional computer bit consists of either a 0 or a 1. Our most elaborate programming is built on that simple foundation. But a quantum bit, or "qubit," can be both 0 and 1 at the same time. The number of calculations that can be done in real time is vastly increased compared to traditional computing, requiring rewriting the most basic rules of programming.

Professor Kohei Itoh is on the front lines of the challenge of harnessing that concept toward constructive real-world goals. As President of Keio University and Founder of Keio Quantum Computing Center, he collaborates with numerous leading enterprises and researchers to solve problems in the emerging field of quantum computing. He envisions a profound impact, not only in terms of technological advancements but also in shaping industrial and geopolitical strategies.

Quantum computing promises a transformative future where geopolitics, industry collaborations and technological innovation converge.

"Especially at this stage—what I refer to as the 'open innovation stage'—we are collaborating with a diverse range of partners, including three mega-banks, two chemical companies—JSR and Mitsubishi Chemical—as well as major corporations like Sony, Toyota and SoftBank," he told us in a recent interview. "These companies are sending us their top scientists, and the caliber of talent we receive is remarkable. These outstanding scientists work alongside our postdoctoral researchers, faculty members and students, fostering an environment of dynamic collaboration and cutting-edge innovation."

The rise of quantum computing has been a global journey of discovery and transformation. Reflecting on his early work 25 years ago, the professor recalls that quantum computing was widely dismissed as little more than "pseudoscience." However, as some of the world's brightest minds began to take the field seriously, the momentum shifted and breakthroughs followed rapidly.

Today, with the computer processing demands of AI looming, quantum computing has moved from the fringes to the forefront of global technological innovation, with rising expectations for industrial applications. Companies like IBM and Google are developing functional quantum computers and industries are investing heavily.

ILLUSTRATIONS: DAVID PLUNKERT

By **AKIKO KARAKI, SHUDAI KOMORIYA & KEN WEINSTEIN.**

Professor Itoh founded the IBM Quantum Network Hub at Keio. In the following conversation, he shares his insights with us into the evolving landscape of quantum computing and its broad geopolitical implications.

He also highlights the unique role private institutions like Keio University can play in fostering industrial collaboration with private companies, a factor that could prove pivotal in the competitive race for quantum computing development and real-world application.

Could you share your background in quantum computing? What initially sparked your interest in pursuing this field of research?

My Ph.D. research was in astrophysics, searching for dark matter—missing particles in the universe. I was responsible for building a detector using germanium semiconductor materials, which tied into my expertise in materials science.

When I joined Keio University in 1995, I started looking for a new project for myself and came across "quantum computing." It seemed very exciting, so by 1998, I decided to dive into it. I was following this silicon semiconductor trend called Moore's Law and realized that the size of transistors—the bit's dimensions—would shrink to the size of an atom by around 2030.

When things get that small, they have to operate under the laws of quantum mechanics. I saw this as the future of transistors, leading inevitably to quantum computing.

Getting right to the point, what do you think are the main benefits of quantum computing? What's your vision for the ideal future it could help shape?

Quantum computing excels at solving problems that require testing an enormous number of variations—tasks that would take classical computers or even supercomputers thousands of years to complete, which in reality means unsolvable.

Consider finding correlations between stock prices, such as those of United Airlines and American Airlines, where a relationship might be somewhat intuitive. Quantum computing could also reveal unexpected correlations, like one between United Airlines and Coca-Cola.

Once the data is loaded into the quantum computer, the system can analyze correlations that would be impossible to explore using classical computers due to the sheer number of combinations. This approach could uncover new patterns that were previously unsuspected and unattainable, enabling transformative applications in fields such as finance, logistics, and more.

But when we input stock market price histories from various companies into a quantum computer for analysis, the process of transferring classical data into a quantum system is not only computationally costly but also becomes exponentially more complex as the data size increases. If this data transfer takes exponential time, any computational speed-up achieved with quantum computing is canceled out. This highlights two key challenges in quantum computing: developing faster, more efficient methods to transfer data into quantum systems and creating algorithms that deliver computational speed-ups.

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Given those challenges, what kinds of techniques used in quantum computing can help address the difficulties of transferring and analyzing such vast amounts of data?

Transferring data into a quantum computer is itself a complex mathematical algorithm. The idea is to assess how much "cheating" we can do to still achieve, for instance, the correct answer 50% of the time.

Consider problems that involve countless trials, like Monte Carlo simulations. These methods predict future dynamics, such as stock price movements, by creating mathematical models that include numerous parameters. You run the models filling in the variables with many different values. The combinations of these parameters can be infinitely large and require testing each variation.

For example, banks like Mitsubishi UFJ and Mizuho spend around eight hours overnight calculating prices for financial items they'll use the next day. Banks are eager to shorten this calculation period to make faster, more accurate predictions about stock market dynamics and other financial movements.

This potential is why three major banks—MUFG, Mizuho and Sumitomo Mitsui Trust—are collaborating with us alongside six other companies, at our Quantum Computing Center at Keio University.

Is it common for companies, including competitors, to collaborate in the field of quantum computing?

Our center began in 2018, and initially, these banks didn't know how to collaborate. They had never worked closely together before. At first, they thought they would need separate rooms, but soon they were sitting side by side, collaborating closely on shared problems—issues that cannot be solved with the extension of today's classical computing.

About a year and a half after we started, these banks brought us the problem of optimizing Monte Carlo calculations, like the eight-hour calculations I mentioned earlier. Together, we developed a

PHOTOGRAPH: COURTESY OF KEIO UNIVERSITY

quantum-based solution and published papers as a team—Keio, Mizuho and MUFG. It was a landmark moment. The CEOs of these banks were astonished, in a good way, as they never imagined publishing joint research papers with their competitors.

When they joined, I asked the CEOs of MUFG and Mizuho to send their best scientists to Keio full time. This approach benefits both sides: It creates true open innovation, where the scientists bring critical, real-world problems from their companies, and at the same time, they remain accountable to their companies.

This accountability pushes everyone to stay on the edge of innovation. University researchers often don't face strict deadlines, but these company scientists do, which drives results. They are exceptionally bright and enthusiastic, and their presence inspires our postdoctoral researchers, who are funded by the companies.

This collaborative structure has been incredibly effective. It's one of the reasons IBM in the US views our center as one of the best and most successful hubs for developing practical applications in quantum computing.

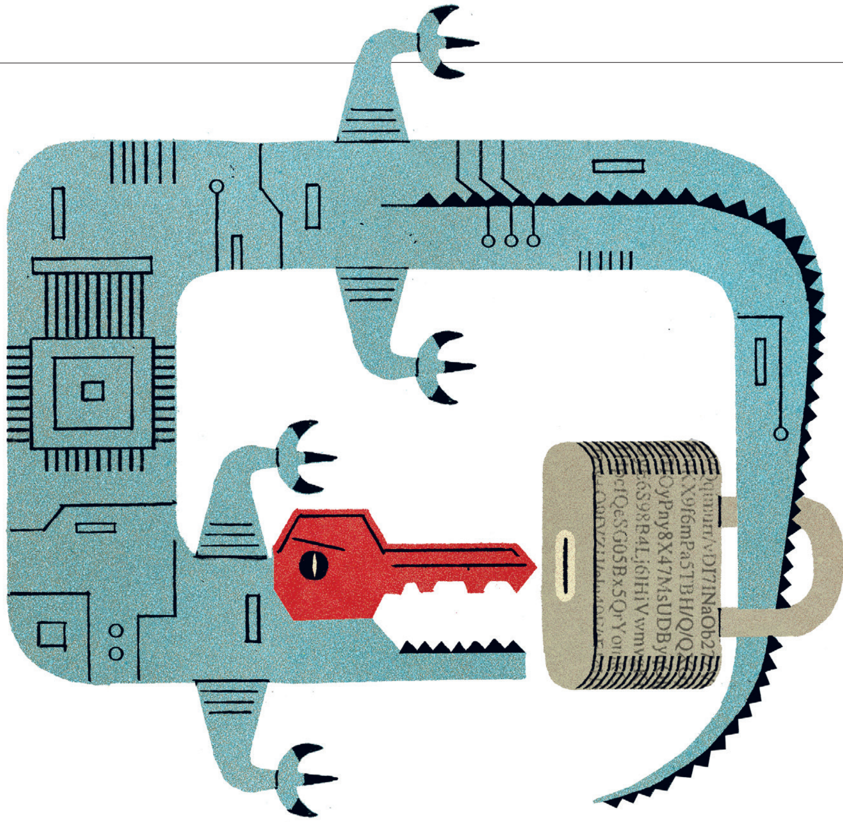
Do you see a similar trend happening among countries? Japan, the US, Europe and China all have strong interests in quantum computing. Do you foresee greater international collaboration, or do you think national and economic security concerns might create more tension instead?

By contract, we cannot hire scientists from certain countries. This is due to trade policies and regulations related to quantum computing. These restrictions are largely influenced by US government regulations, as we are accessing IBM's best quantum computers in Yorktown Heights. There are strict regulatory frameworks we must adhere to.

But we strive to maintain an international perspective as much as possible by collaborating with multiple nations.

Do you think having more people from diverse countries involved would accelerate innovation and deepen research in quantum computing?

Yes, due to COVID-19 and border closures, as well as the slow response from Japanese universities in adapting to remote hiring systems, we haven't had many participants from abroad. Factors like the weak Japanese yen have also contributed to this. But we're now seeing an increasing number of applications from overseas, and we're working to move forward with that.



HYPERSAFETY

THE QUEST for the quantum computer has been compared to efforts to generate sustainable fusion energy—possible in theory, but always seemingly just out of reach.

Similarly, recent breakthroughs have brought quantum processing to reality and closer to practical use. While still experimental, researchers say even current, relatively simple quantum computers are hundreds of millions of times faster than classical computers, literally solving in minutes what would theoretically take a classical computer longer than the age of the universe. Obstacles remain, but practical quantum computers could give areas like drug discovery or materials science an unimaginable boost—any area in fact where the fast calculation of large numbers can make a difference. In the field of artificial intelligence, it could hasten the dawn of a sentient superintelligent AI.

All of this power naturally requires new approaches to things like cybersecurity. Today's defenses, built to thwart standard computers, would be close to useless in the face of a brute force quantum computing attack, exposing the world's stores of data—including financial systems, energy grids and transport networks. Similarly, the prospect of a truly post-human intelligence lends the discussion of AI guardrails a greater urgency.

Quantum computing itself will evolve its own defensive structures, just as classical computing did. But in the meantime, preparations are under way for what is assumed will be a revolution in computing power. The European Union Agency for Cybersecurity is working on Post-Quantum Cryptography, and the International Organization for Standardization is developing a global standard for this. The World Economic Forum has partnered with the UK Financial Conduct Authority to study risks, while the Canadian Government has published a Quantum Readiness Guide. The G7 Cyber Expert Group has been advising finance ministers and central banks on cybersecurity for many years, including a "continuous learning" component, that reads in part, "cybersecurity strategies and frameworks need periodic review and update to adapt to changes in the threat and control environment, enhance user awareness, and to effectively deploy resources." And it has recently published a report on the opportunities and risks of quantum computing.

The G7 expects that working quantum processors will be available within a decade. In 2022, the Pentagon's Chief Data Officer, David Spirk, suggested that military applications could be just five years away. Human progress may be about to take another giant leap.

Is there potential for Japan, the US and other countries to collaborate on national security issues in quantum computing? For example, how could quantum cryptography or communication contribute to these efforts, and what about concerns over its impact on current cryptographic methods?
Quantum cryptography and quantum communication are certainly promising for security. Quantum communication, for instance, is theoretically secure but still faces challenges like slow throughput. It's something we need to improve.

As for cryptography, cryptographers are always working ahead of us. They know quantum computers are coming, so they're already developing more secure, unbreakable encryption methods. But the issue lies in the data we're encrypting today using current methods. If someone stores encrypted data now, quantum computers could potentially break it in the future once they become powerful enough. That's a genuine concern.

Given your role at Keio University, how is the Keio Center for Strategy addressing critical technologies and defense issues, especially since defense research is not typically popular at Japanese universities?
In Japan, universities are broadly divided into public and private institutions. Public universities like the University of Tokyo, Kyoto University and Osaka University focus predominantly on science, engineering and medicine—about 70%—with only 30% dedicated to social sciences and humanities. Keio, on the other hand, has 70% on humanities and social sciences.

This gives us greater flexibility to explore critical topics, such as national security and quantum computing, from a broader range of perspectives. It allows us to host and encourage a wide spectrum of opinions. For example, we can accommodate both critics of defense-related research and proponents of national security strategies.

This diversity fosters an environment where contrasting views are debated professionally and academically, which has helped us establish initiatives like the Keio Center for Strategy, which addresses critical issues.

This breadth of perspectives combined with our openness to dialogue is one of Keio's strengths. Universities should be places where differing viewpoints are encouraged and debated, and we take pride in upholding that balance within our academic framework.

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Why do you think it is essential for us to engage with quantum computing now, and how do you see collaboration—both across industries and with fields like AI and semiconductors—driving the future of this technology?
Quantum computing is at a pivotal stage, and it's crucial for corporations, both in Japan and globally, to start engaging with this technology now.

The world is facing a shortage of computational resources due to the rapid expansion of artificial intelligence and other technologies. Companies like Nvidia are increasing chip production, but this also increases energy use, worsening global warming.

Quantum computing, on the other hand, is not only energy-efficient, but is also capable of solving specific types of problems that are unsolvable with classical computing alone.

These challenges, if addressed, can significantly accelerate business innovation while contributing to sustainability.

Right now, we're in what I call the "open innovation stage." This collaborative approach has produced remarkable results, leveraging the diverse expertise of these teams. While we are still in the exploratory phase, this kind of open innovation allows companies to prepare for the future.

In five or 10 years, some companies may choose to work independently once certain problems are proven solvable and quantum computing demonstrates clear advantages. But there will always be a need for collaborative forums to tackle emerging challenges, discover new scientific insights and develop innovative problem-solving methods. The diversity of industries and perspectives involved in these collaborations accelerates progress and ensures a steady flow of groundbreaking ideas.

And speaking of AI and semiconductors, keep in mind that quantum computing doesn't exist by itself—it must work alongside other technologies. We are actively developing interfaces between AI and quantum systems, as well as between classical and quantum computers.

This integrative, problem-driven approach ensures that all relevant technologies are combined to address specific challenges effectively. The future of computing is hybrid, with classical computers remaining the foundation and quantum systems helping them in high-impact areas.

By taking a collaborative, forward-looking approach, corporations can not only address today's challenges, but also position themselves to lead in the era of quantum-driven innovation. ◆

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