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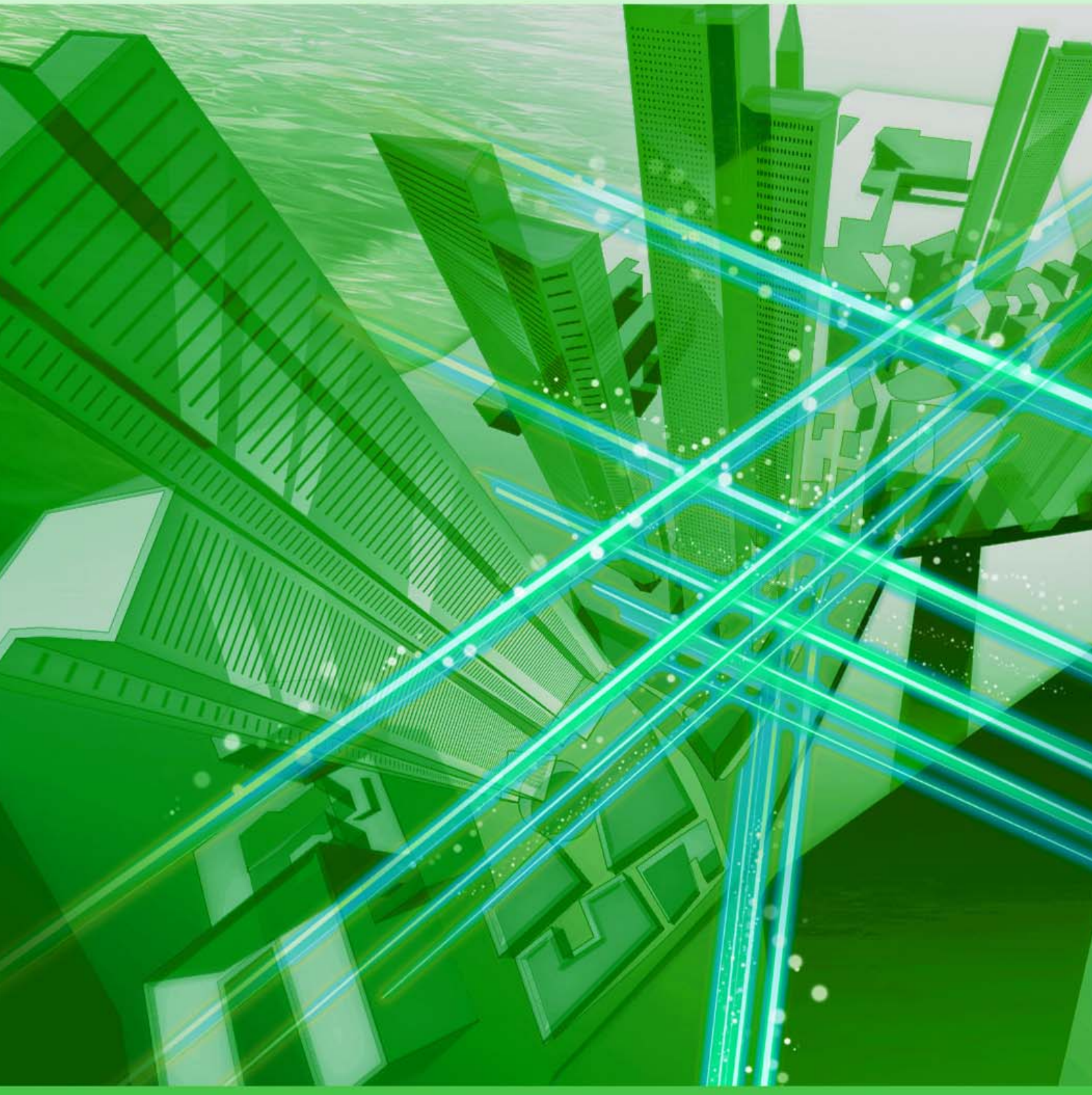

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Our Can-do Attitude Can Make the World a Better Place. Let's Open Up the Future by Believing in Ourselves

Naoki Shibutani
Senior Executive Vice President, NTT

Overview

To solve social problems, it is important to promote digital transformation using information and communication technology. The efforts of the NTT Group to solve such problems have been highly evaluated both in Japan and overseas, e.g., being selected as a "Derwent Top 100 Global Innovator" for nine consecutive years. We asked Naoki Shibutani, a senior executive vice president of NTT, about his current duties and the required attitude of the senior management regarding the ability of their employees to solving social problems in the world that has changed significantly due to the novel coronavirus pandemic.

Keywords: IOWN, technological development, remote work

The key to advanced technological development is "continuation"

—You were appointed a senior executive vice president of NTT in June 2020. Can you tell us about your current duties?

I went from being a member of senior management of an NTT operating company to now in a position of overseeing the entire NTT Group. I am carrying out my duties with the knowledge of the significant responsibility of my new role. The NTT Group is heralding a concept called the Innovative Optical and Wireless Network (IOWN), which we are aiming to implement by 2030. Many companies from all over the world participated in the IOWN Global Forum for developing and popularizing IOWN. Starting with formulating a roadmap for the next 10 years in cooperation with member companies, we are heading step by step toward deployment of IOWN.

With regard to our "Environment and Energy Vision: Zero Environmental Impact" formulated in March 2020 as an initiative of the "Promotion of ESG[*1] management" (a pillar of our medium-term management strategy "Your Value Partner 2025"), "achieving extremely low power consumption" through IOWN is the main goal, and I believe that IOWN will bring about innovation not only in information and communication technology but in all fields.

To carry out such a forward-looking initiative, I think it is important to not only look at the current situation and make decisions accordingly but also continue research and development (R&D) from a medium- to long-term perspective because the people involved in projects, the environment, and society may change over time.

*1 ESG: environmental, social, and corporate governance

—From what experience did such thinking originate?

I learned a lesson from my experience 20 years ago of being involved in global expansion of the R&D of arrayed waveguide grating (AWG) devices. At that time, an AWG device was highly regarded as the key device in the early days of the Internet because they could multiplex multiple wavelengths with a single optical fiber, greatly increasing transmission capacity of optical networks. After achieving world-leading research results, NTT laboratories have continued to refine optical microfabrication technology (e.g., planar lightwave circuits, silicon photonics, nanophotonics) and succeeded in evolving it into the key technology of IOWN, namely, photonics-electronics convergence.

NTT laboratories have evolved this technology and continued to carry out cutting-edge research for more than 20 years, and I think that "continuation" is an important part of advanced technological development. I believe that even if the person in charge changes, we must keep the technology pipeline flowing, and technological development from a long-term perspective that is not affected by the ups and downs of corporate management will produce outstanding results. Efforts to constantly circulate our products on the market are also important. In particular, it is necessary to build a so-called "ecosystem" in which our R&D results are commercialized, made profitable, and used to fund future R&D. Through open innovation with other leading companies and universities, I would like to build such an ecosystem that inherits and spreads technologies both vertically and horizontally.

For many years, I've been involved in reliability design for the digitization of switches while pursuing the construction of safe, low-cost, and efficient networks. After gaining such experience, in the early 2000s, our optical broadband and "Hikari Denwa" optical Internet Protocol (IP) telephone services became widespread. In line with that trend, areas with Internet connection rapidly expanded without sufficient reliability design and performance evaluation. Therefore, many communication failures occurred on a nationwide scale in 2007, which resulted in a crisis that shook the foundation of NTT. At that time, IP networks were cheap and flexible but involved immature methods for achieving redundancy and recovery. On top of that, the reliability of the network architecture was not fully considered because the priority was to expand services quickly, and most operations (including design, construction, and maintenance)

were outsourced. I thought that the state of affairs in which NTT could not even investigate the causes of failures and consider recovery measures led to the continuation of those large-scale failures.

Given the situation I described above, with the help of NTT laboratories, we started studying the Next Generation Network (NGN), namely, the next-generation IP integrated network, from scratch, and we worked on insourcing on-site operations (such as design, construction, and maintenance) that had been outsourced. From these efforts, we developed this NGN in two years and introduced it nationwide. Since then, the NGN has expanded to serve more than twenty-million customers over more than 10 years without facing any major failures. We have now achieved 100% insourcing of daily operations of the NGN.

From this experience, as a technology-strategy manager, I was convinced that, first, our core technology should not be simply outsourced and, second, reliability design should be given top priority no matter what. I believe that to further transform NTT into a digital company, we should give top priority to strengthening our capability by insourcing operations such as designing artificial intelligence (AI) analytical models, analyzing digital data, investigating network architectures that are resilient against cyberattacks, and implementing countermeasures against unauthorized access. However, the shortage of engineers in these technical fields is a serious problem common to all NTT Group companies. Accordingly, I want to accelerate the training of more engineers in the fields of AI, digital transformation, and cybersecurity.

Accumulate successful experiences with the "stretch method"

—You can learn from anything and use it in your work.

In a previous interview, I talked about working hard to restore equipment and support customers in the wake of the Great East Japan Earthquake as the manager of the Fukushima branch. The actual conditions of our equipment affected by the disaster were not what was expected at the head office. I learned the importance of confirming the locations, settings, and state of equipment at the actual site such as what equipment is installed in potentially submerged areas near the coast as well as in areas with a risk of landslides and bridge collapses. After witnessing the damaged equipment, I regretted that if I had confirmed the sites in advance on the basis of the knowledge that I acquired through being in charge of reliability design, we might have been able to minimize the damage. Ever since that disaster, I now ask our employees to confirm the actual location, setting, and state of equipment no matter how difficult it is. This confirmation—which I call *in-field practical ability*—should be handed down from generation to generation. I think this way of thinking applies to not only equipment sites but also sales sites. For example, if you want to do a job related to agriculture, you should go to a farm and learn farming; in other words, it is vital to understand issues from the same perspective as the customer. If we can use our experiences acquired through our five senses in our own specialized field, we will be able to make more realistic proposals. It is important to face the issues of our customers as if we were them and solve problems while keeping pace with them.

As a person in charge of technology strategy, I also think that companies that bring innovation to society develop technologies and improve them to be used in the real world. Companies that can achieve this can be said to be "technology driven." This is important for NTT as well. Now that we can no longer compete in communication alone, it is time to change the culture of the entire NTT Group.

When I took my current position in June 2020, I thought I wanted to see the upper limits of our impact on changing the world when the potential of the NTT Group is freely unleashed. Although NTT is a private company, it has a public element in light of our background, and it is unique in the sense that it is engaged in basic research while being a telecommunications carrier. I think that our technical and social-contribution capabilities are better than our employees can imagine; however, to be honest, I don't think we have

fully used these capabilities.

To overcome this problem, I ask our employees and related parties to perform difficult tasks when they try to solve various problems. Although those who are asked to do so seem surprised at first, as they are repeatedly asked to do such tasks, they feel more confident in their ability to solve problems and seem to find it interesting to take on the challenge. If you do what you can to the extent you can, cultural change is unlikely to occur, and your frame of mind will be hard to change. However, our employees can accumulate valuable experiences with the support of their supervisors in expanding their limits and helping them overcome hurdles. By repeating this process, your confidence what you can do will grow, and cultural change will happen.

—It is important for employees to be aware of their advanced abilities and for senior management to draw out their strengths.

I'm working on solving problems with the "stretch method" to gradually expand employees' limits. If you don't understand a person's limits, namely, a standard, you can't expand it or set a definite goal. On the other hand, I sometimes think it's better not to set limits at all. I say that because when adapting to changes, the limits also change according to the criteria of those limits. For example, NTT has always been particular about the quality of our services and products, so naturally the criteria of standards are also high. If the standards are met, the services can be used safely and securely; however, if we become fixated with those criteria, costs and price will increase, and the time it takes to provide services may become excessive.

However, a global trend is to launch products and services even if their functions are somewhat insufficient and improve them while they are being used. This means launching products onto the market at prototype level and polishing them up while they are on the market. In fact, young employees at NTT EAST stood up thinking that they could make social contributions during the coronavirus pandemic by using their skills. In particular, they created and launched a remote desktop service for teleworking with new security technology in just two weeks without spending money. Although we did not guarantee the quality of service, when we provided it free of charge, it became a big hit without any trouble. Since then, we have continued to improve its security and operational functions while responding to user

requests. If these young people have a place where they can take on challenges, their ideas can be put to good use and cultural change will happen. I want to review everything from the perspective of critical thinking by asking "Is this really right?" rather than continuing to protect matters like golden rules. Safety and security are important; however, I want to create an environment in which anyone can casually try something new without hesitation.

Do you know the saying "The sky is the limit"? That is the title of a book I read when I started working. It means "the possibilities are as infinite as the sky." I think it is probably us who impose limits on ourselves. Shortly after I joined NTT in 1985, the Japanese economy slumped as the economic bubble burst. I don't want to make the excuse that in addition to the "lost" 20 years due to that economic slump, another 10 years will be lost due to the novel coronavirus pandemic. I doubt the people who worked hard would say the word "lost" in regard to the results of doing their best.

Action starts from the heart, not the mind. This is why I think that having the spirit of "Let's try" is required for those in senior management. When an employee proposes a plan or project, his/her supervisors sometimes point out the issues of the proposal in view of their own experience only. In response to such attitudes of supervisors, employees hesitate to move ahead because they think all those issues must be solved before they can move forward, so I ask supervisors to hold back and say "That's a good idea!" first. Expressing your solid support and talking about how to improve, and sharing the lessons you have learned will motivate your employees. If you kill your employees' enthusiasm, they will never come to you with proposals, and in the long run, that

situation will be a loss to the company and society as a whole. I have continued my "That's a good idea!" activities from my days at NTT EAST even after coming to NTT. Even now, I hang on the office wall the three slogans "That's a good idea!", "Overcoming barriers," and "Making an impact" and continue to ask employees to put them into practice on a daily basis.

Be transparent regarding problems and develop an attitude of solving them in good faith

—What are the qualities and perspectives required of senior managers of a group with 300,000 employees worldwide?

First, I realized that it is necessary for me to think with a longer time frame and extend my areas of expertise. I think senior managers are required to look at the world 30 years from now from a global perspective, aim to make an impact on the future, focus on what to do to make it happen, and present a roadmap to that future. I think the concept of IOWN that President Sawada advocated is an easy-to-understand example.

The senior management has roles to play. The vice president devises the tactics to materialize the president's strategy and works with the senior management of group companies to execute those tactics. On the basis of those tactics, other senior managers convey enthusiasm and worthiness to 300,000 employees. I think that such steady activities are vital.

Furthermore, as the management theory *organizational ambidexterity* suggests, unless you are a company that can start new businesses while maintaining existing ones, at best, you will have no future. In reality, however, the more you visit the sites of your existing businesses, the more you stick to those businesses. Perhaps many senior managers often hear on-site that "We don't have the budget," "We can't provide more people," or "If we want to make a profit, we can only do this." To develop a future-oriented business even under such circumstances, it is necessary for employees to share convincing stories, understand and be motivated by them, and take the challenge of exploration.

In addition, it's very important for the senior management to deliver a message that resonates with universal values when presenting our guidelines to the 300,000 employees. Although building a relationship

of trust with our employees is very difficult, it can be lost in a moment. I think that the senior management must be transparent regarding problems with all employees and customers and continue to take actions and make statements to cultivate an attitude of solving such problems in good faith.

—Please say a few words to researchers and engineers inside and outside the company.

I'll say to them "The game is long." Thirty years ago, I was greatly inspired by the free society of the United States that I witnessed while studying there. After returning to Japan, I established a remote work environment using ISDN[*2] data communication and worked on Japan's first experiments on satellite offices. With a budget of 500 million yen, we set up satellite offices in Funabashi (Chiba Prefecture), Ageo (Saitama Prefecture), and Kamakura (Kanagawa Prefecture), and a "resort office" in the Yatsugatake mountains (Nagano Prefecture). At that time, the communication tools we had were telephones, fax machines, data transfer by floppy disks, and fixed-point cameras, and institutional aspects, such as communication rules and performance management, were inadequate. Unfortunately, this work style could not be widely popularized. However, through this experience, making people's work style freer and more creative became one of my life's work.

More and more people are using remote tools due to the novel coronavirus pandemic, and Japanese companies are seriously considering reforming their employment systems. Throughout my 30-year mission, I learned that social change is not just about technology; it takes a long time, and it is important not to give up. I hope that all researchers/engineers will continue to have enthusiasm without forgetting the thoughts they had when they first joined the company. By doing that, they will change the world. I believe that the accumulation of daily simple and steady steps with intent will lead to global expansion of IOWN to support the digital society and creation of a sustainable society based on renewable energy. Achieving these goals will face many barriers and take a long time; nevertheless, society can be changed for the better, and we have the power to do it. Therefore, believe in yourself, and let's move forward step by step.

Interviewee profile

■ Career highlights

Naoki Shibutani joined Nippon Telegraph and Telephone Corporation in 1985. He worked in NTT Department I, where he engaged in operations targeting corporations beginning in 1999 then served as a senior manager of the Planning Department at NTT EAST starting in 2001 (and was a guest researcher at the Center for Strategic and International Studies (CSIS), Washington, D.C.). In his career at NTT EAST, he also served as the department manager of the Plant Planning Department, Plant Section, Network Business Headquarters; manager of the Fukushima branch office; executive manager of the Medium-term Management Strategies Promotion Office of the Corporate Strategy Planning Department; senior vice president and executive manager of the Plant Planning Department, Network Business Headquarters; senior vice president and executive manager of the Tokyo Olympic & Paralympic Games Promotion Office; and senior executive vice president and senior executive manager of the New Business Development Headquarters, president & chief executive officer of NTT Vietnam Corporation, senior executive manager of the Digital Transformation Headquarters, and president & chief executive officer of NTT e-Sports Corporation. He assumed his present position in June 2020.

*2 ISDN: integrated services digital network

Think from Multiple Perspectives so that You Can Enjoy Your Work

Hiroaki Gomi
Senior Distinguished Researcher, NTT Communication Science Laboratories

Overview

Human body movements, including highly skilled movements by athletes as well as people's everyday movements, are strongly supported by unconscious sensory-motor processes, embedded in the central nervous system. NTT Communication Science Laboratories revealed, for the first time, that body-state information based on vison is involved in the adjustment of one of those processes, namely, stretch reflex. We asked Hiroaki Gomi, a senior distinguished researcher at NTT Communication Science Laboratories, about his research results and his attitude as a researcher.

Keywords: stretch reflex, vision, body-state representation

We discovered that body-state information based on vision is involved in the adjustment of the stretch reflex

—Tell us about the research you are currently conducting.

We are pursuing research to clarify the mechanism of information processing concerning human body movements that are unconsciously performed using sensory information (such as vision and somatosensory) by combining kinematics, psychophysics, electrophysiology, and computational modeling, etc., and deepen our basic knowledge about information processing in the brain.

Roughly speaking, there are two types of human body movements: voluntary, which are activated consciously, and involuntary, which are activated unconsciously. A well-known involuntary movement is the phenomenon called the *knee reflex*, by which the foot rises involuntarily when the area just below the kneecap is tapped suddenly, e.g., during a medical examination. Although this action is executed unconsciously, the body is being moved by stretch reflexes. An involuntary movement is involved in motor control, namely, the ability to coordinate various body mechanisms required for movement, and it is thought to enable a quick reaction that corresponds to, for example, the movement of an opponent in sports. Not limited to sports, everyday movements such as walking, standing up, and reaching for objects involve involuntary components that are processed unconsciously through peripheral and central nerve reflexes (**Fig. 1**).

By elucidating these mechanisms, we want to advance research on the entire information processing of the brain.

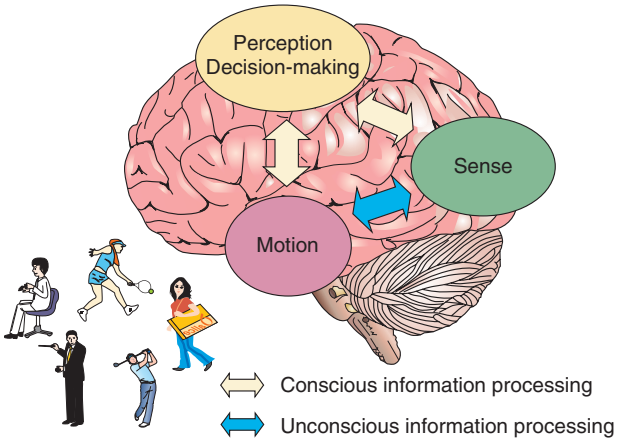

Fig. 1. Conscious and unconscious information processing of the brain that generates movement from input sensory information.

—When we hear about elucidation of our everyday movements, your research sounds very familiar to us. Please tell us more about the research you are focusing on.

We are investigating information processing concerning the stretch reflex, a nervous reflex caused by proprioceptive information sent from receptors (sensors) such as skin, muscles, tendons, and joints. The stretch reflex is caused by the passive expansion and contraction of muscles, and it is thought to play an important role in stabilizing posture (**Fig. 2**). Studies have shown that the stretch reflex response is not constantly generated; instead, it is adjusted in accordance with the ever-changing states of the body during movements. It is, however, not well understood what kind of information processing is performed in the brain for calculating the appropriate adjustment. For example, it is unclear whether the adjustment of the stretch reflex depends on proprioceptive information only or a body-state representation (i.e., the imagined body in the brain) obtained by integrating multiple sensory information, including vision.

We have shown for the first time that this stretch reflex is regulated in accordance with visual information representing the ambiguity of the body state [1]. Our experiments confirmed that the stretch reflex during the movement of the wrist to reach a visual target is smaller than normal under two conditions: (i) mismatch between the visual feedback of hand motion and the actual hand motion and (ii) elimination of the visual feedback of actual hand motion. On the basis of the knowledge we have thus far obtained, we aim to further elucidate the information processing performed in the brain for regulating the reflex system. In the future, I'd like to gain a deeper understanding of controlling mechanisms of human-body movements.

Our hypothesis that "the adjustment of stretch reflexes is regulated not only by proprioceptive information but also body-state representations obtained by integrating multiple sensory information, including vision" is currently being debated worldwide. We are going to present additional evidence that supports this hypothesis, which will help expand our understanding of brain processing for smooth and dexterous movement control when interacting with various environments.

An example of an actual application of somatosensation is a small device we developed called "Buru-Navi," which gives the user holding the device the feeling of being pulled by stimulating tactile sensation (**Fig. 3**). By considering the characteristics of the skin's tactile system, we succeeded in downsizing, increasing the number of degrees of freedom, and improving the efficiency of the previous version of Buri Navi developed by our former colleagues. It is now possible to create the sensation of being pulled in various directions, even though nothing is physically connected to it from the outside.

In addition to being able to guide the visually impaired, this technology can also be used to enhance the feeling of being immersed in a video of first-person-view motion, such as riding a motocross bike on a rough road, by stimulating synchronized haptic sensations. We hope our research can help in developing

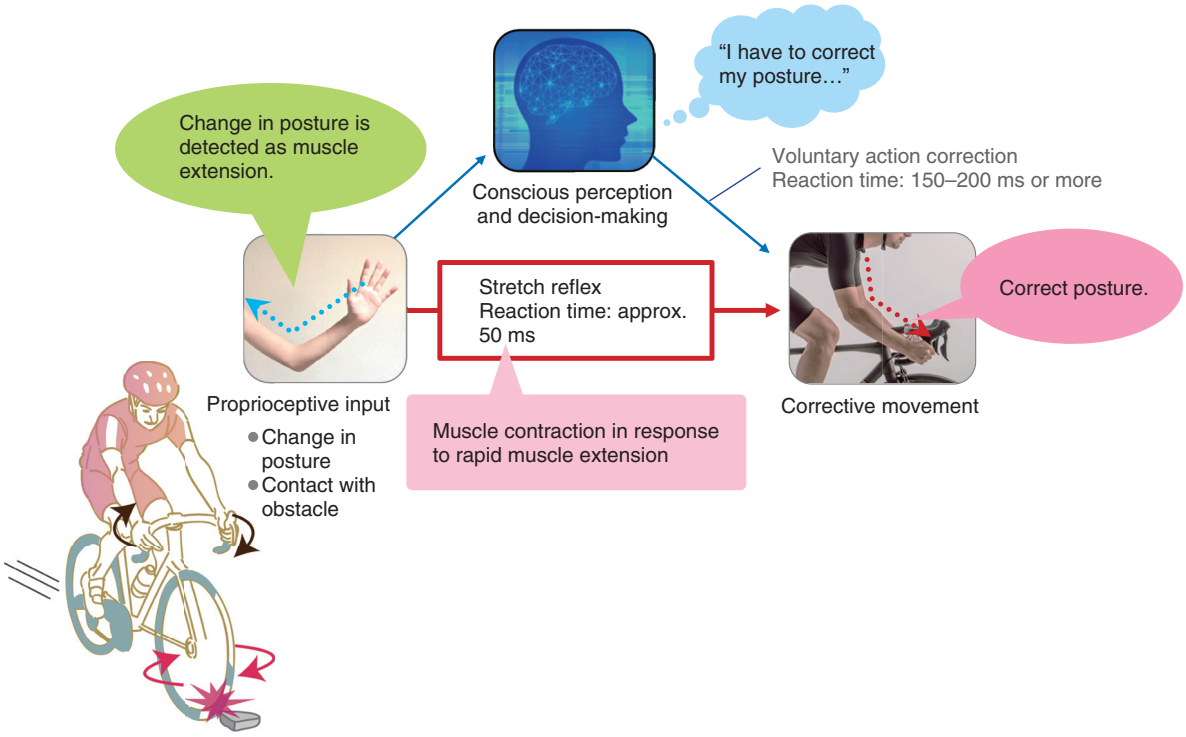

Fig. 2. The process of conscious and unconscious reactions in contact with an obstacle.

devices that exploit the ability of human information processing.

Determine what is important and make anything interesting and useful

—You said that your findings are causing worldwide debate, but do you have any idea about how to announce your research results?

I think there are various perspectives on how to evaluate research. Regarding papers, this involves publishing results that are unknown to the world and getting those results recognized and published after peer review. In this process, the degree of importance of the results will be questioned, and if they are deemed very important, they can be accepted by influential journals. Our ongoing research on the brain covers various fields, such as physiology and psychology. The current trend is not to pursue research from one perspective in a specialized field but to pursue research from a complex perspective that combines knowledge from various fields. By combining motor and sensory aspects, psychological viewpoints, and neuroscientific evidence, we will continue to obtain convincing and impactful results in understanding brain computation.

Fig. 3. Buru-Navi4.

One of my daily goals is to engage in research by taking these trends into account, explain in papers how our results are important, by introducing new perspective. Results on proprioceptive reflexes have received worldwide attention due to being announced

in the press release of a journal.

I also think it is important for researchers to communicate. NTT values dissemination of research information by researchers, and every year, NTT Communication Science Laboratories organizes an open house to present research results to the general public. Needless to say, ease of understanding is important when communicating with the public. Applying trial and error when explaining results to the general public at the open house is useful for giving lectures at universities. Therefore, explaining a research project to others improves one's communication skills. Since many departments exist within NTT, we have many opportunities to explain our research projects to researchers outside the field and non-researchers. Even for a particular research result or plan, the perspectives, background, understanding, etc. differ according to department or specialty, so it is important to explain in a manner that matches the audience. Explaining the necessity and importance of a research project, especially to managers outside the field, may be thought of as a time-consuming and non-essential job that is not directly related to research. However, this process, which is sometimes accompanied by severe criticism, has a positive aspect to extend the viewpoints that may be difficult to imagine ourselves.

—Just changing the viewpoint definitely contributes to maintaining a positive attitude.

I think it is very important to make anything interesting and useful by changing the way you look at things. Research activities require steady effort but often fail, and success stories are rare. Each activity is a repetition of revealing something unknown, failing, recovering, and doubling one's efforts. If you find this process uninteresting, you probably won't be able to move forward. However, even if you keep that positive way of thinking in mind, it may not actually be interesting. I'm conducting research while simultaneously determining what's important and what's not. No matter how much you change your perspective, if you don't think your research is important, it won't be interesting. While repeating the process I mentioned above, it is really interesting to find the essence or kernel of each research topic, and I believe it is important to strive for this.

In contrast to what I said above, some things may not be interesting but are important; therefore, I think it is necessary to make every effort to make them interesting. For example, when I was in junior high school, I wasn't very good at English and didn't like studying it until I was a high-school student, so I was mostly focused on studying science and mathematics. However, when I suddenly thought, "If I can speak English, I'll be able to communicate with various people, so I'll acquire the means to do so," my attitude toward studying English, which I was not good at, changed. If your method of studying is not interesting, I think you should make it interesting. I feel that if we are not so good at communicating in English, we should make such effort through trial and error.

Recently, the international conference of a new academic project initiated by the Ministry of Education, Culture, Sports, Science and Technology and organized by Professor Kenji Doya of OIST (Okinawa Institute of Science and Technology) was held online. It was planned to have world-class researchers related to artificial intelligence come to Japan to attend the conference. Unfortunately, due to the coronavirus pandemic, the conference was held virtually. Although I was assigned to be a session chair at that conference, I didn't expect it to be held online. I thought it would be a little difficult to hold an online meeting even in Japanese, let alone in English. It was a bit of a burden to put together an online discussion among researchers—including researchers of computational theory of cognition and behavior, the current hot-topic of deep learning, and physiology—who would give video presentations on a variety of topics. To be the chair, it was necessary to understand the details of the topics given by all speakers. Since I wanted to perform my duties as chair properly, I frantically watched presentation videos in advance. I watched 26 videos (each 30–40 minutes long and including presentations on topics other than those of the discussion I chaired) and repeatedly reviewed what I didn't understand; it was like studying for exams. I was desperate to make the discussion interesting.

I value the sense of excitement and wonder when conducting research

—We get the sense of your accomplishment from you studying hard. How do you maintain your enthusiasm?

Experimenting is sometimes really boring because of many repetitions of trials. I have talked about how people use surrounding visual information to move the hand. In that experiment, we sometimes needed to

continue an experiment on that movement (i.e., checking hand and eye movements of all subjects) all day long. Even if this task itself was not interesting at all, I was excited to imagine where the findings of the experiment will lead and what we can understand about the computational mechanism from them. Only seeing the difficult things in front of you will only discourage you; it ought to be fun to think about the results beyond those difficulties.

If a researcher thinks he or she is an authority in their field, I believe that he or she will stop being a researcher at that moment. There are many unsolved problems in each field, so focusing on one of those unknowns is what makes research interesting. For that reason, it is necessary to sincerely deal with what you do not understand. I think we can do our best as long as we have the enthusiasm to understand what we are interested in.

To maintain this enthusiasm, I value intrinsic motivation and interest. I also have frequent discussions with researchers in close but different fields. Every time I talk about sensations, behaviors, research trends and the like that I think are interesting, I realize the importance of communicating. I also value the feeling of "That's strange." When studying information processing in the brain, I sometimes find it interesting at unexpected moments in daily life. The experiment on stopped escalators that I described in my previous interview [2] is a good example. We feel an odd sensation when we get on a stationary escalator, and I started developing thoughts about what kind of information processing in the brain is involved in creating this sensation. Exploring ideas in this manner is vital to understand the human sensorimotor mechanisms.

Regarding the feeling of being pulled by BuruNavi, deeply exploring what kind of information processing in the brain generates this sensation and what kind of stimulus should be given to start will lead to an appropriate problem setting, which will develop into research results. Since the subject of our research is close to everyday life, it may be easy to find a research topic by exploring everyday phenomena.

—Please say a few words for the next generation.

The goal or sub-goal in research should be created and motivated by ourselves. I think that if you feel you are being made to work, nothing will go well. If you feel that way, I want you to make every effort to change your mindset so that you will be enthusiastic about your work. I hope that through thinking positively, the research you are conducting will be something that makes you think, for example, "I forgot to sleep and eat because I got absorbed in my work." The "making the topic interesting" that I mentioned earlier will lead to becoming engrossed in your research topic.

Of course, if you overdo it, your health will suffer, and if you try too hard, you will often become stressed, so it is better to be mindful of those risks. However, I think it's okay to have a period of frantic work, especially when you are young. All the same, if you are "on" all the time, you might be crushed, so I want you to properly switch "off." What I find difficult in my research life is separating my personal curiosity and work. I'm sure some people can separate them, but I'm one of those who is not so good at it. As researchers, we must constantly learn new things. It would be sometimes difficult to separate efforts to acquire knowledge or skill for personal intellectual curiosity from those for work if all efforts are related to the research topic. If this distinction cannot be made on an objective scale alone, I think that you need to set a boundary with your own subjective scale. This boundary setting might be quite essential in your research life, which is not common for every researcher, rather it is greatly dependent on your personality, ability, and capacity, etc. I hope that we can keep this diversity (or freedom) in our research environments.

I'd also like to touch on the changes in the environment surrounding researchers. I feel that the speed of research is increasing due to the increase in useful tools such as the Internet. Papers that had to be searched for in the library or ordered after several weeks in the past can now be read instantly via the Internet. However, I want research to proceed while thinking about the essential issues rather than searching speed. I sometimes see researchers trying to solve a problem in a superficial manner without addressing the essential issue. I'm always trying to take the time to figure out the essence of the problem. NTT Communication Science Laboratories has an environment where you can spend time on interesting and original research. I feel very fortunate to be able to research in such an environment and have excellent colleagues. I want to pursue new scientific ideas and technologies that will be interesting to my colleagues, worldwide collaborators, and society.

I really like the saying "Sokutenkyoshi (Live naturally)," which was used by the Japanese novelist Soseki Natsume. It means that you can live by

abandoning your narrow view of looking at things and living according to the principles of nature. People, including myself, are weak, and we're obsessed with our own perspectives. By thinking from many perspectives, the perspective of others, the perspective of society, and even the perspective of the universe, I think that you will be able to find enjoyment while doing so. Research is often unsuccessful and frustrating; however, I hope you will enjoy it and try not to feel too much pressure.

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■ **Interviewee profile**
Hiroaki Gomi

Senior Distinguished Researcher, Leader of Sensory and Motor Research Group, NTT Communication Science Laboratories.

He received a B.E., M.E., and Ph.D. in mechanical engineering from Waseda University, Tokyo, in 1986, 1988, and 1994. He was involved in biological motor control research at ATR (Advanced Telecommunication Research Labs., Kyoto) from 1989 to 1994, where he developed computational models of human motor control, robot learning mechanisms (demonstration learning), and a manipulandum system for investigating human arm movement. He was an adjunct lecturer at Waseda Univ. (1995–2001) and adjunct associate professor (2000–2003) and adjunct professor (2003–2004) at Tokyo Institute of Technology. He was also involved in the CREST (1996–2003, 2010–2015) and ERATO (2005–2010) projects of Japan Science and Technology Agency. He served as a committee member of the neuro-computing technical group of the Institute of Electronics, Information and Communication Engineers (IEICE) (1997–2000), its vice chair (2006), and chair (2007), committee member of the Japanese Neural Network Society (JNNS) (2012–2018, 2020), and chair of the 'Brain and Mind Mechanism workshop' (2015–2020). His current research interests include the computational and neural mechanisms of implicit human sensorimotor control and interaction among sensory, motor, and perception, and the development of tactile interfaces. He is now involved in the 'Correspondence and Fusion of Artificial Intelligence and Brain Science' Project (2016–2020). He is an IEICE fellow and member of the Society for Neuroscience, the Society for the Neural Control of Movement, the Japan Neuroscience Society, Japanese Neural Network Society, and the Society of Instrument and Control Engineers.

Road to IOWN

Jun Sawada
President and Chief Executive Officer, NTT

Abstract

The "Road to IOWN," NTT's initiatives aimed at implementing the concept known as the Innovative Optical and Wireless Network (IOWN), is introduced in this article, which is based on a lecture given by Jun Sawada, NTT President and Chief Executive Officer, at the NTT R&D Forum 2020 Connect held from November 17th to 20th, 2020.

Keywords: IOWN, remote world, Digital Twin Computing, All-Photonics Network

1. Introduction

I will introduce the "Road to IOWN," NTT's initiatives to implement the Innovative Optical and Wireless Network (IOWN). Before that, however, I'd like to mention that NTT's tender offer for shares of NTT DOCOMO, aimed at making NTT DOCOMO a wholly owned subsidiary of NTT, was successfully completed on November 16, 2020, acquiring approximately 91% of NTT DOCOMO's shares. The purpose of this tender offer is to strengthen and grow NTT DOCOMO so that it can compete with GAFA (Google, Amazon, Facebook, and Apple) and other over-the-top players amid intensifying domestic and borderless competition. However, this is a rather reactive approach. By taking a proactive approach, we want to strengthen NTT DOCOMO in a manner that leads to the growth and development of the entire NTT Group (**Fig. 1**).

1.1 History of pandemics and hegemony

Let me shift the viewpoint a little. In 1602, Matteo Ricci, an Italian Jesuit missionary, published a world map in China, called the "Kunyu Wanguo Quantu," which was introduced to Japan in the years after the Battle of Sekigahara in 1600. If we zoom in on this map, we can see four large islands drawn in the center, so we can see that Japan had already been recognized at that time. In other words, it is clear that from this era that Japan should recognize its role in the global structure.

Now, as we bear the third wave of novel-coronavirus infection, let's take a historical look at how humanity has dealt with pandemics (**Fig. 2**). The era when Japan was clearly depicted on the Jesuit map I just mentioned is debated as the time before the Spanish Empire dominated the world or was in the process of dominating. Before that era was the Islamic caliphates, which were preceded by the Mongol Empire. The Mongol and Spanish Empires had histories of taking hegemony in the wake of the plague and smallpox, respectively. During the Reformation, Holland gained prominence, and people moved from Spain in large numbers, shifting the world economic center to Holland.

In the 18th century, the technological innovation of the Industrial Revolution gave Britain hegemony. At that time, cholera spread from Asia to Europe and the United States. After that, the Spanish Flu raged for a couple of years from the end of World War I. Some people say that the Spanish Flu ended WWI; nevertheless, economic decline followed, and the United States emerged as the global power. We should bear this perspective in mind while carefully considering

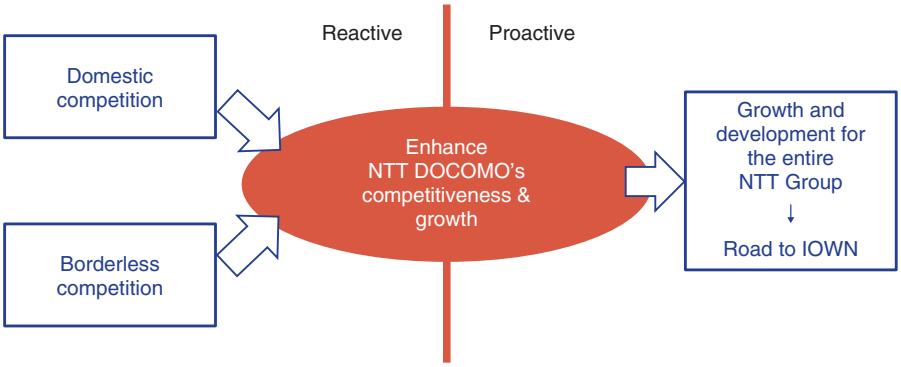


Fig. 1. Why make NTT DOCOMO a wholly owned subsidiary?

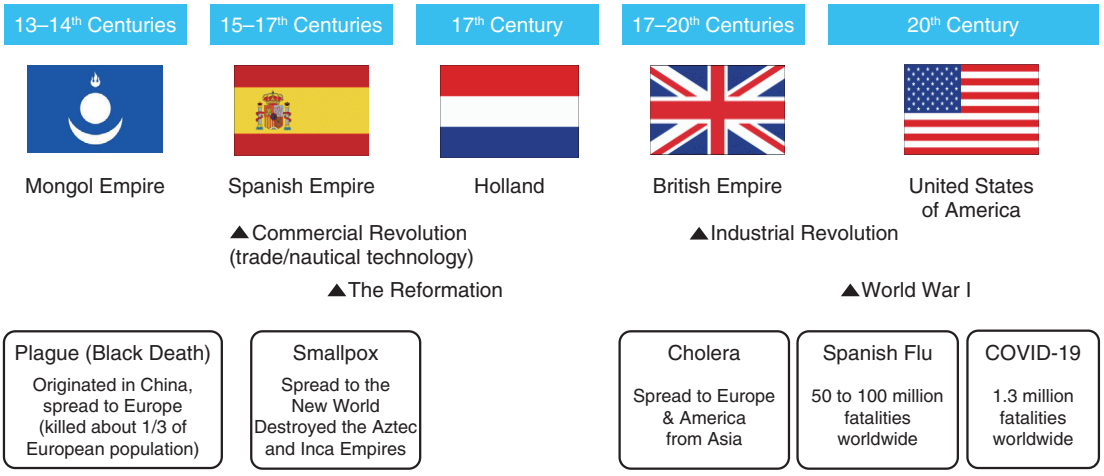


Fig. 2. History of pandemics and hegemony.

what kind of world is waiting for us beyond the current coronavirus pandemic.

1.2 Japan's technology trade balance

The Ministry of Internal Affairs and Communications of Japan has been compiling data on a technology trade balance for nearly 20 years (**Fig. 3**). The technology trade balance concerns export and import values for patents, knowledge, and other forms of technology transfers. Comparing exports and imports in this manner reveals that industry in Japan as a whole has a positive trade balance. In particular, I think that a positive trade balance is proof that Japanese technology, particularly related to automobiles and precision machinery, is used worldwide. On the contrary, Japanese technology has a negative trade balance in terms of information and communications. It might be better to say that it has always been negative. In other words, Japanese information and communication technology (ICT) companies purchase overseas technology and use it for their business in Japan. In 2014, a journalist said, "Few technologies—and products and services based on them—originate in Japan. The Japanese information technology (IT) industry, which does not contribute to the world at all, has no value as an industry; only an 'IT utilization industry' exists in Japan." Being personally shocked by that comment, I thought that we should strive to make our next technology a game changer.

1.3 Post-coronavirus social trends

Next, I'll talk about the current novel coronavirus pandemic. Although the novel coronavirus is still

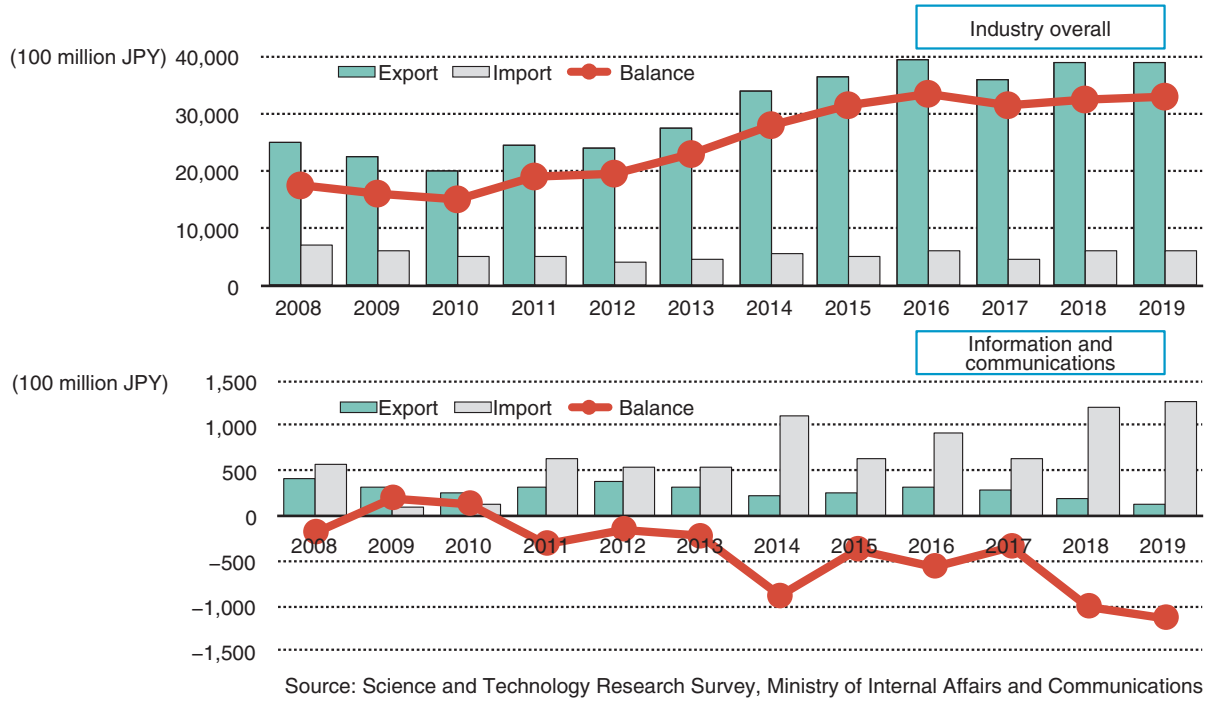


Fig. 3. Technology trade balance.

spreading rampantly, I'd like to take a look at trends in the so-called post-coronavirus society.

There are two trends, the first is the *remote world*, in other words, a decentralized society. Although various discussions will probably carry on into the future, I think that the remote world is indispensable for achieving Japan's carbon neutrality by 2050. It is necessary to ensure *social distancing* and simultaneously revitalize economic activities. In response to this need, the NTT Group has launched the new service brand called remote world. We want to provide a new environment that goes beyond face-to-face communication for remote working, medicine, and sports/entertainment viewing.

The other trend is *new glocalism*. Globalism is still a necessary element; however, I believe that we also need localism that respects the culture of Japanese people and the different cultures of each region while recognizing diversity. Therefore, new glocalism requires a paraconsistent approach.

The other day, when I was talking with the former President of Kyoto University Juichi Yamagiwa and Professor Yasuo Deguchi of Kyoto University, I was asked, "Do you know what is not included in the 17 Sustainable Development Goals (SDGs) set by the United Nations?"

The answer that I should have given is "culture" because culture is basically rooted locally and the 17 SDGs are universal global targets. I think of glocalism as a concept through which we achieve the overall goals after understanding and accepting local cultures, without excluding any. I believe we should seek a society that recognizes the quality of life of each individual, rather than trying to control everything according to one way of thinking or uniform consciousness.

Looking toward the post-coronavirus society from the perspective of economy, security, and country, I first think supply chains with reliable people must be established; second, IT must be used to accelerate digital transformation (DX) and build connected value chains. Third, energy independence must be ensured, and in accordance with that need, the NTT Group is promoting the use of *green electricity* (**Fig. 4**). We plan to increase the proportional use of renewable energy to 30% by 2030. In recognition of these actions, we have obtained certification by the Science Based Targets initiative (SBTi). However, the promotion of ICT is the base of our contribution to achieving energy independence; for example, carbon-dioxide emissions is estimated to be cut by about 70% by the adoption of teleworking. In other words,

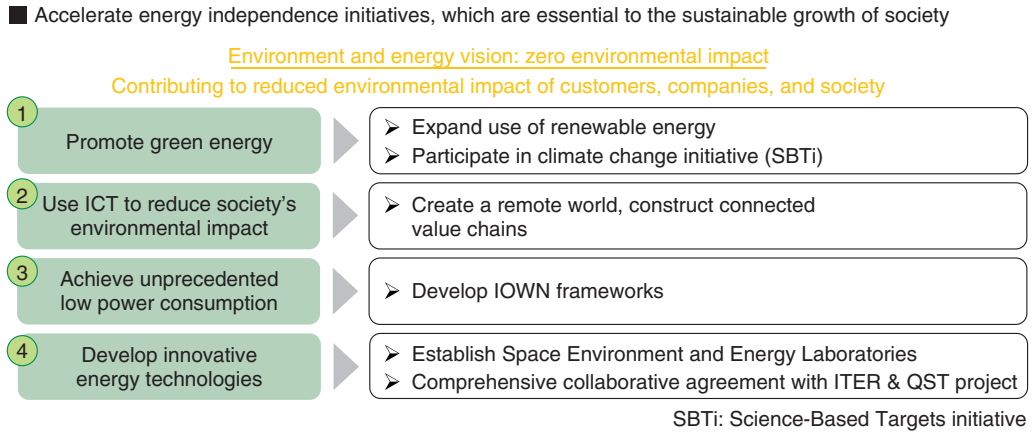


Fig. 4. Energy independence initiatives.

it is important to create a remote world and build connected value chains.

In July 2020, thinking that ICT could help create innovative energy technologies, we established NTT Space Environment and Energy Laboratories. We are also collaborating with the International Thermonuclear Experimental Reactor (ITER), which is being constructed in cooperation with seven countries and regions, and the National Institutes for Quantum and Radiological Science and Technology (QST) of Japan. To manage plasma while controlling nuclear fusion in a very short time, it is necessary to devise computing and communication methods for transmitting a massive amount (petabytes) of information to various places with ultralow delay. The ITER is scheduled for "first plasma" in 2025, and research and development (R&D) aimed at achieving that goal has begun.

2. The Road to IOWN

Today's main topic is IOWN, which is described with the keyword "game changer." I'd like to start by introducing a message from Takashi Niino, President and CEO of NEC Corporation, which announced a capital and business alliance with NTT in June 2020.

2.1 Message from Takashi Niino, President and CEO of NEC Corporation

"Hello everyone. I'm Takashi Niino from NEC. First, I'd like to congratulate NTT on holding the NTT R&D Forum. As you all know, in June of this year, NEC and NTT entered into a capital and business alliance for the purpose of R&D and global expansion of ICT products that use innovative optical wireless technology. Through this alliance, we aim to cooperate over a long period as equal partners that transcend the boundaries of operators and manufacturers.

I'll start by briefly explaining the purpose of this alliance. While promoting the spread of the Open Radio Access Network (O-RAN) Alliance specifications, we will develop base stations that are O-RAN compliant and internationally competitive and aim for the top share in the future global market. We will also develop a compact photonic integrated circuit with the world's highest performance and low power consumption and information and communication equipment incorporating it and market that equipment globally. What's more, we will strive to develop innovative optical wireless devices that contribute to implementing IOWN as well as upgrading technologies related to, for example, submarine-cable systems, space communications, and security. As one of the world's leading telecommunication operators promoting the introduction of advanced technology, NTT has industry-leading R&D and technological capabilities with regard to photonics and compact photonic integrated circuits.

In the meantime, NEC has a wealth of expertise in building communication infrastructure that ensures the quality and reliability required by operators as well as world-class advanced communication technologies and digital technologies such as artificial intelligence and security. I am convinced that by joining hands with NTT, we can contribute to strengthening Japan's industrial competitiveness and further ensuring the safety and reliability of communication

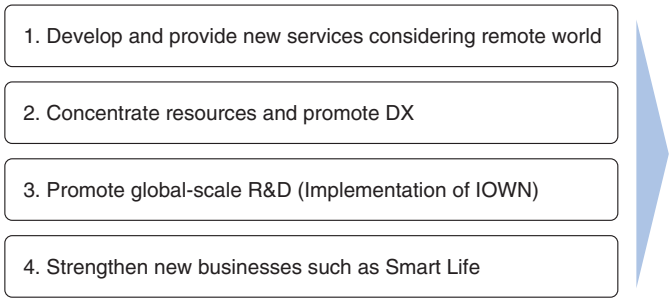


Fig. 5. Road to IOWN—NTT's intended direction.

infrastructure. So, President Sawada, let's make this happen together. Thank you for giving me your kind attention today."

Thank you, President Niino. NEC and NTT plan to jointly develop a wireless access network compatible with O-RAN-compliant multimedia while preparing for the fusion of photonics and electronics, namely, IOWN.

2.2 Directions of NTT

NTT is heading in four directions, as shown in **Fig. 5**. The first direction is the provision of new services suitable for the remote world. The second direction is how to promote DX while concentrating resources of the entire NTT Group. The starting line in that direction was the tender offer for shares of NTT DOCOMO. The third direction is the implementation of IOWN, which is today's main topic. And the fourth direction is strengthening new businesses, including our global ones.

A contribution we will make to society is strengthening the international competitiveness of the Japanese ICT industry. In particular, we'd like to lead the world in the advancement of information and communications in new areas such as space and underwater. Improving national security is also worth mentioning. Besides cybersecurity, we are also discussing business continuity plans and countermeasures against disasters. We want to further develop and expand the ICT industry as a whole.

Today, I'd like to introduce four distinctive technologies for achieving the third direction in which NTT is aiming for, namely, implementation of IOWN. Before that, I'd like to introduce a message from Akio Toyoda, President of Toyota Motor Corporation.

2.3 Message from Akio Toyoda, President of Toyota Motor Corporation

"Hello everyone. I'm Akio Toyoda. When we came up with the idea of the "Woven City," I felt that it would never be possible without the help of NTT. I announced the Woven City concept at the Consumer Electronics Show held in Las Vegas in January of this year (2020), and soon after that, I went to see President Sawada. At that meeting, Mr. Sawada and I agreed that we want to make a human-centered city where people can live with peace of mind and live happy lives without being controlled and monitored through information. Since the two of us held a press conference last March, our work to create the Woven City has started. When I talked to the Toyota side, they said that NTT is more like a teacher than a partner in creating smart cities. They said that, first, they put everything we both had on a table. They were amazed by what NTT put out: NTT came up with not just the communication, energy, and administrative relations that we had imagined but also the expertise necessary for people to live fulfilling lives, such as in medical care and entertainment. After all, we at Toyota alone cannot help people build fulfilling lives.

The phrase 'new normal,' which I had never heard before this initiative began, has become a more common word. Together with NTT, I want to continue to create a city where people can really be happy in the new normal. This cannot be accomplished by Toyota and NTT alone. It can be accomplished through the aspirations and technologies of many people. I am looking forward to our continued collaboration with NTT and thank you everyone for your kind attention."

Thank you, President Toyoda.

2.4 Digital Twin Computing

The Woven City will be built in Higashifuji in

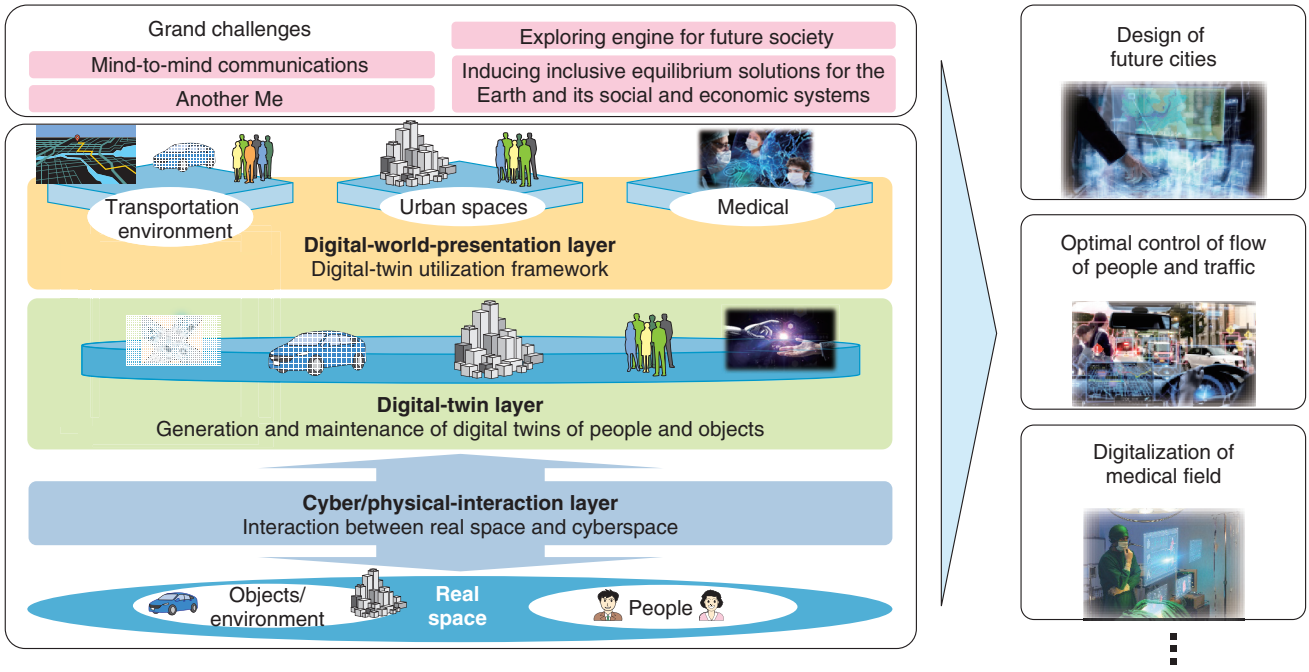


Fig. 6. Digital Twin Computing.

Susono City, Shizuoka Prefecture; after that, smart cities will be promoted in Shinagawa Ward in Tokyo and cities around the world. In addition, the main focus of the collaboration is to create a *platform of platforms* that connects those cities, and the story of that collaboration leads to the development of Digital Twin Computing (**Fig. 6**). The idea behind Digital Twin Computing is forming another city in cyberspace, making predictions and simulations for various scenarios, and using these results to improve the lives of residents or ensure smooth operation of urban facilities in real space. Creating a positional starting point is important to enable the designing of future cities, optimal controlling of people and traffic flows, and smarter medical fields through Digital Twin Computing. The current two-dimensional (2D) maps should be converted into 3D, then, by adding a time axis, into 4D. To accumulate those 4D map data and integrate sensing data of people and objects with highly accurate position and time information to be used for future prediction, it is essential to develop a cross-industry infrastructure. We call this infrastructure the "4D digital platform™" (**Fig. 7**). I'm thinking that this infrastructure will be used as the starting point for cyberspace or smart cities. We will start practical use of the 4D digital platform in 2021.

Another use case of Digital Twin Computing that I should mention is a personal medical solution (**Fig. 8**). NTT is currently researching a Bio Digital Twin. By sensing biological information about the brain and heart and combining it with a prediction simulator and personal information such as physiological and behavior information, the Bio Digital Twin will be useful for diagnosis and treatment in ultra-microscopic areas of the human body. Considering our ultimate goal should be to improve the quality of life of humankind as a whole, I'd like to discuss the development of Bio Digital Twin technology that will help humanity as a whole and social acceptability.

2.5 All-Phonics Network

Next, I'll talk about the All-Photonics Network. Global Internet protocol (IP) traffic is projected to increase 1.5 times in two years, and IT power consumption is projected to increase 1.6 times in five years. Under such circumstances, NTT aims to introduce *all-optical* technology into its communication infrastructure. Current optical access networks have a star topology, and lines are drawn from NTT buildings to customers one by one. We want to overlay multi-loop access networks over existing networks. This concept is a world first, and the key to it is a technology for freely branching optical fibers without

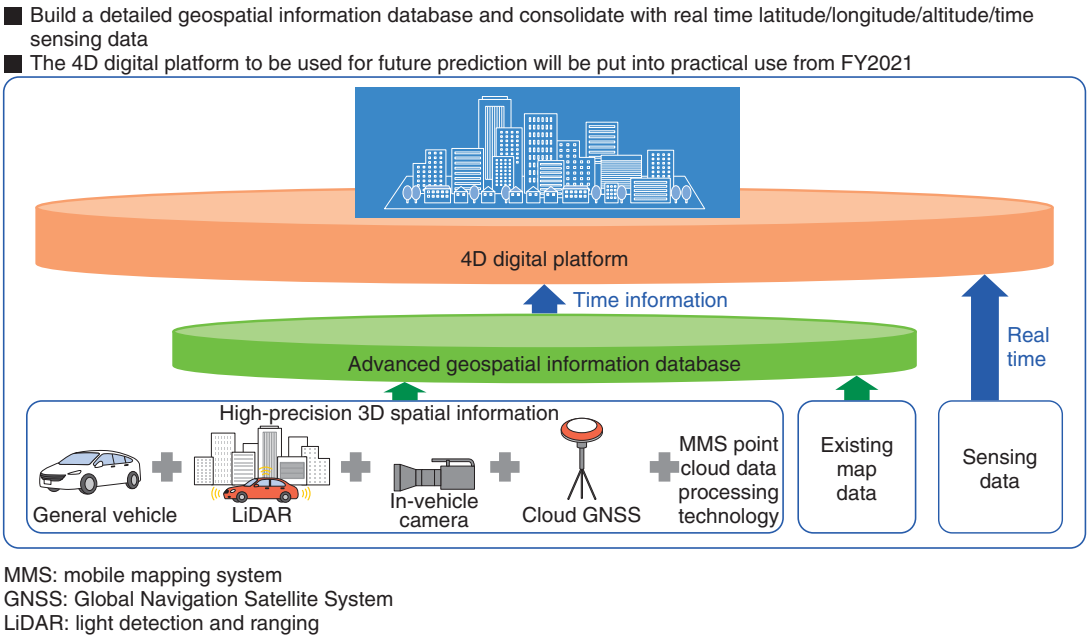


Fig. 7. 4D digital platform™.

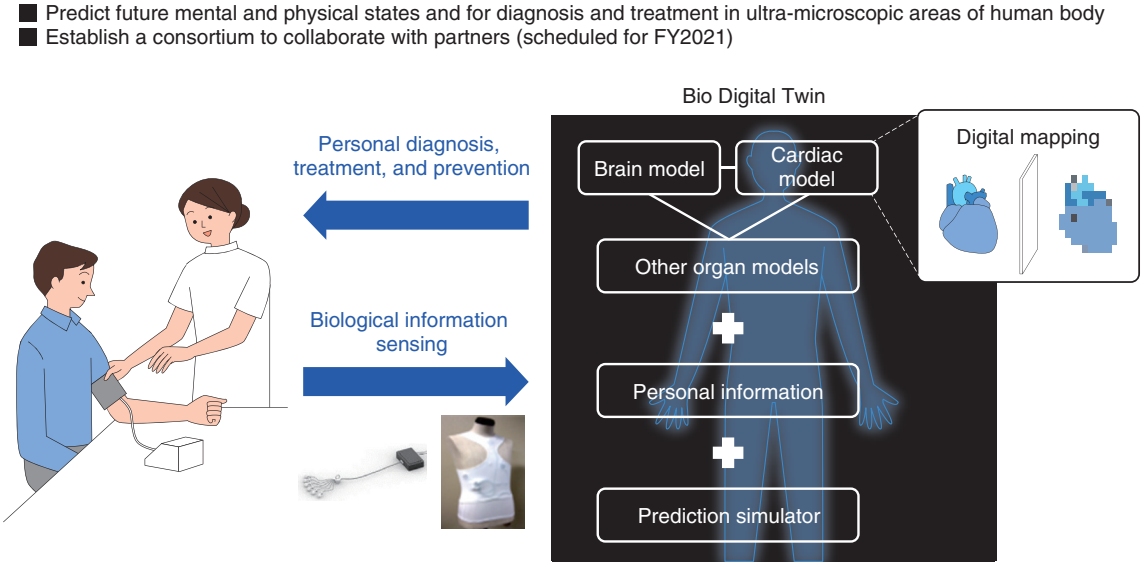


Fig. 8. Personal medical solutions.

interrupting communications. This technology is still being researched, but once we have implemented it, we will be able to create a reliable and adaptable access network (**Fig. 9**).

I'd also like to introduce *distributed ultra-reality viewing* as a use case for the All-Photonics Network (**Fig. 10**). In the post-coronavirus society, many people will watch sports from home without even entering a stadium. We want viewers to share a sense of presence with the stadium, through cheers and atmosphere, in an interactive manner while conveying the performance of athletes to those viewers without

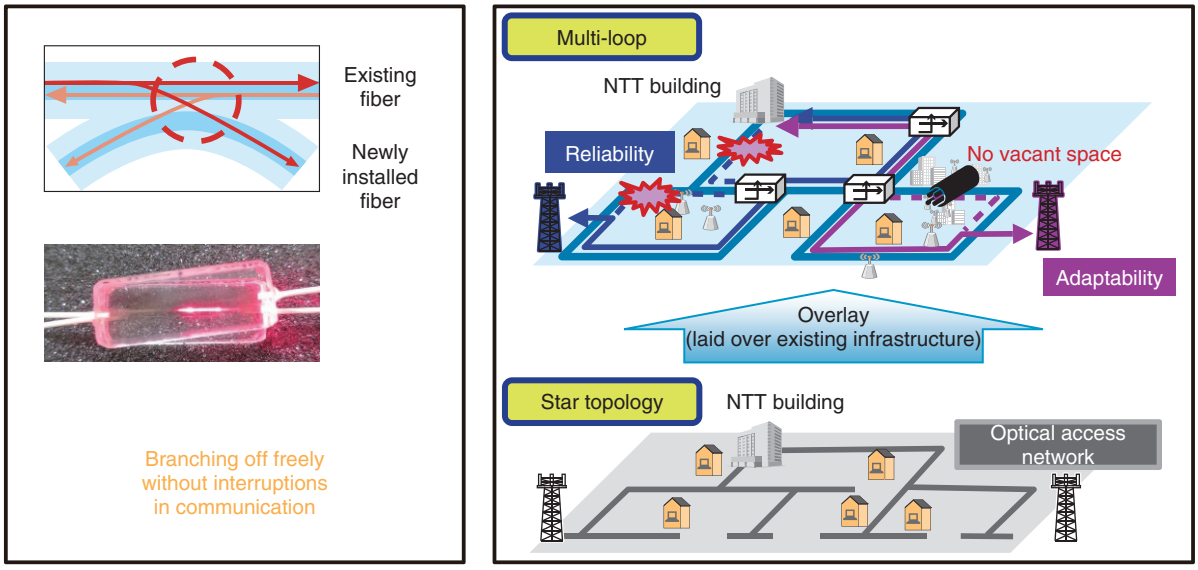


Fig. 9. Prospects for the All-Photonics Network.

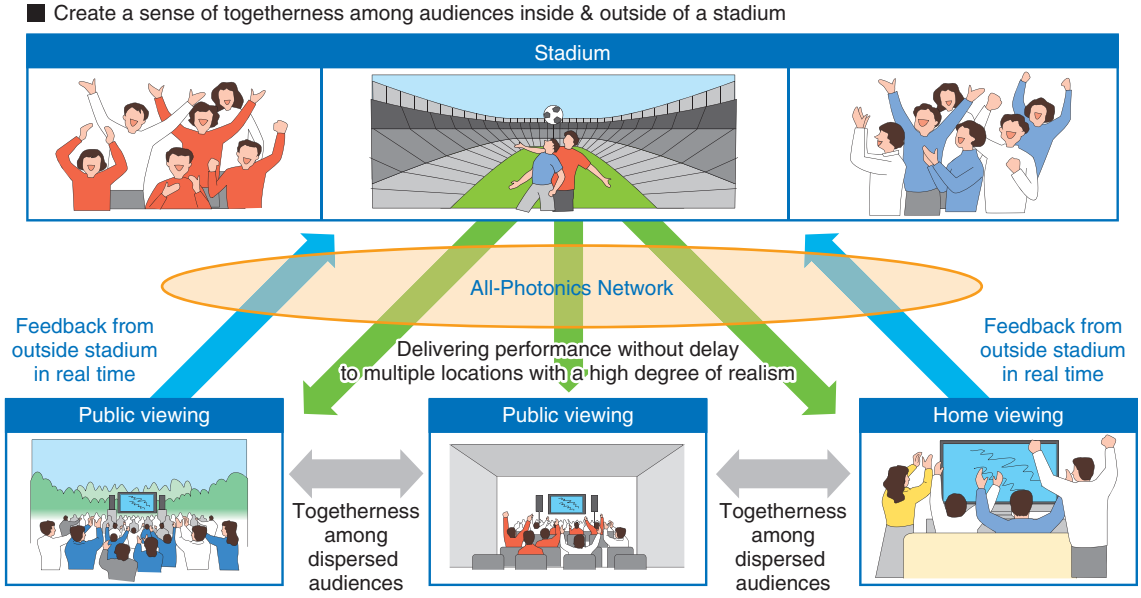


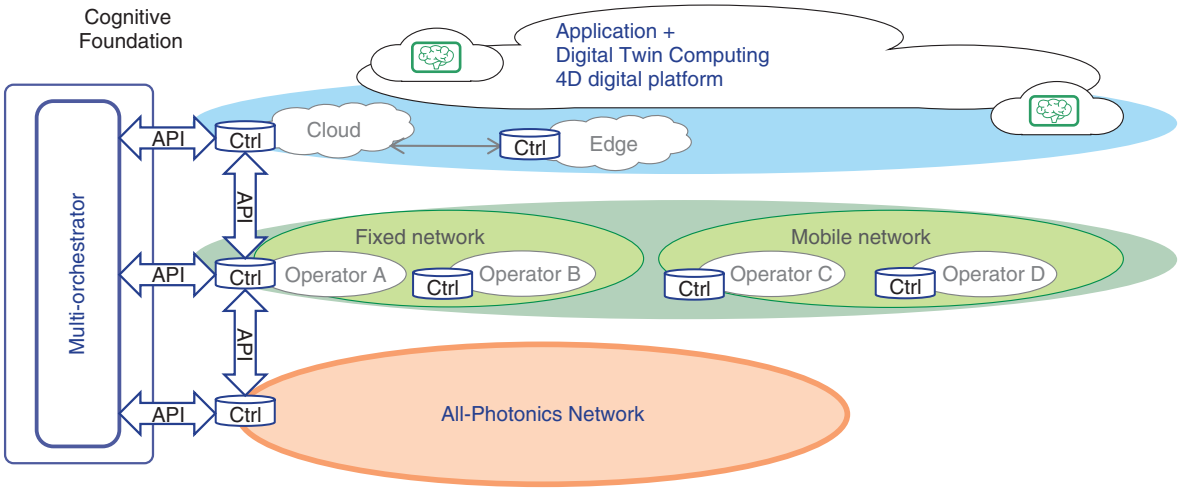
Fig. 10. All-Photonics Network case study (distributed ultra-reality viewing).

delay.

2.6 Photonics-electronics convergence device/ disaggregated computing model

We are currently working on a prototype of a photonics-electronics convergence device that will be complete it in two years. The first step of this prototyping is to adopt an optical-electronic co-packaging as an input-output device for large-scale integrated circuits, which are the core elements of silicon photonics. The next step is to achieve inter-chip transmission by optical wiring. In the following step, intra-chip transmission is achieved using optical elements. We plan to introduce a *disaggregated computing*

■ Develop IOWN framework consisting of the All-Photonics Network, Digital Twin Computing, and Cognitive Foundation®



API: application programming interface
Ctrl: controller

Fig. 11. IOWN framework.

model—in place of the conventional physical-server (box)-oriented computing model—using that photonics-electronics convergence chip to connect functional modules such as central processing units, graphics processing units, and memory via light. Implementing this model requires an ultra-powerful white box and a new operating system.

2.7 Concept of IOWN

IOWN consists of the All-Photonics Network, Digital Twin Computing, and Cognitive Foundation® (**Fig. 11**). The huge amount of data involved in Digital Twin Computing and its 4D digital platform will be supported by using the end-to-end All-Photonics Network. What's more, although core networks of mobile networks and fixed networks are currently separated, I think we will need to integrate them into one platform.

Our medical ICT strategy, including the personal medical solutions I mentioned above, is located in the domain of Digital Twin Computing. On the contrary, O-RAN/vRAN (virtualized radio access network) and associated devices are positioned on the infrastructure side. We are pushing ahead with R&D under the assumption that the disaggregated computing model will support all these domains (**Fig. 12**).

2.8 IOWN space computing

Next, I'll talk about *space computing*, namely, a space datacenter separated from the Earth's energy systems (**Fig. 13**). For example, we are considering mounting computing resources on low-earth orbit satellites and connecting the satellites to form a *distributed processing computing platform*. Raw data are transmitted to the satellites using laser transmission, and the results of calculations and analysis are returned to Earth also using laser transmission. It has been decided that multiple-input multiple-output (MIMO) technology will be installed on satellites in a year and a half, so I think such technology can also be used for space computing.

2.9 IOWN roadmap

The roadmap for the implementation of IOWN is shown in **Fig. 14**. In 2020, the IOWN Global Forum was established. In 2021, use cases of the All-Photonics Network will start to appear, so we will continue to study how to reflect the results of those use cases in our equipment. In addition, the first version of the 4D digital platform will likely be released in 2021. In 2022, we plan to announce the development of the photonics-electronics convergence digital signal processor. We will also investigate the basic concepts and reference models of disaggregated computing.

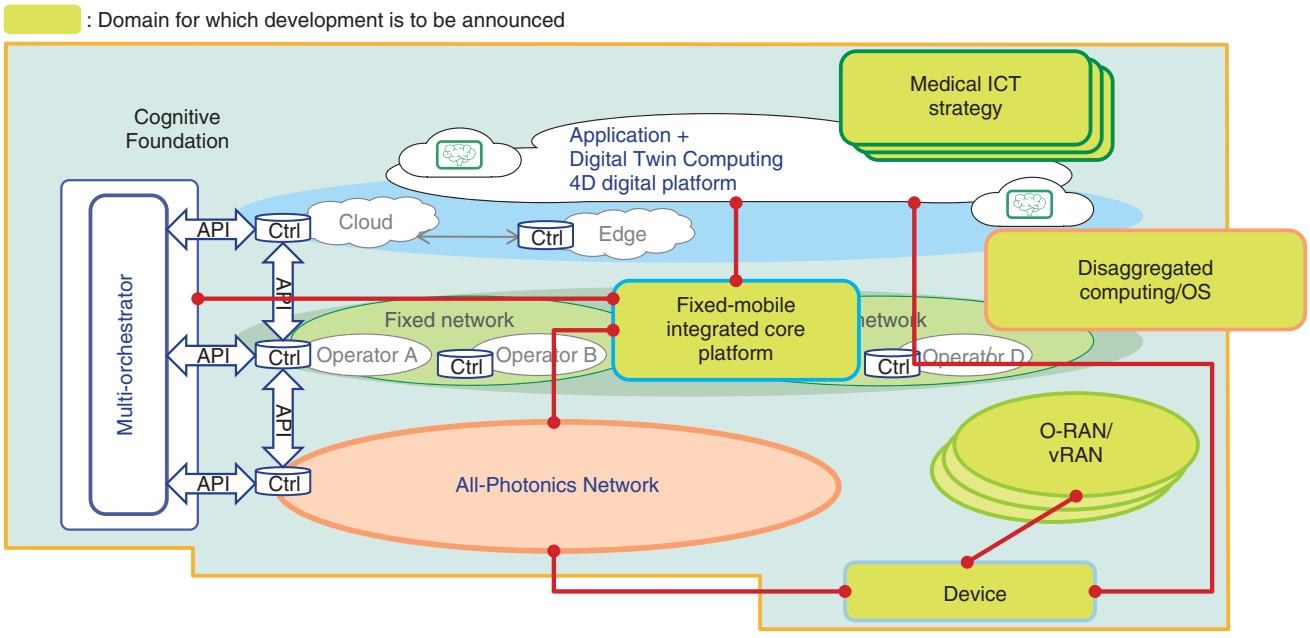


Fig. 12. Presumed information and communications structure in 2030.

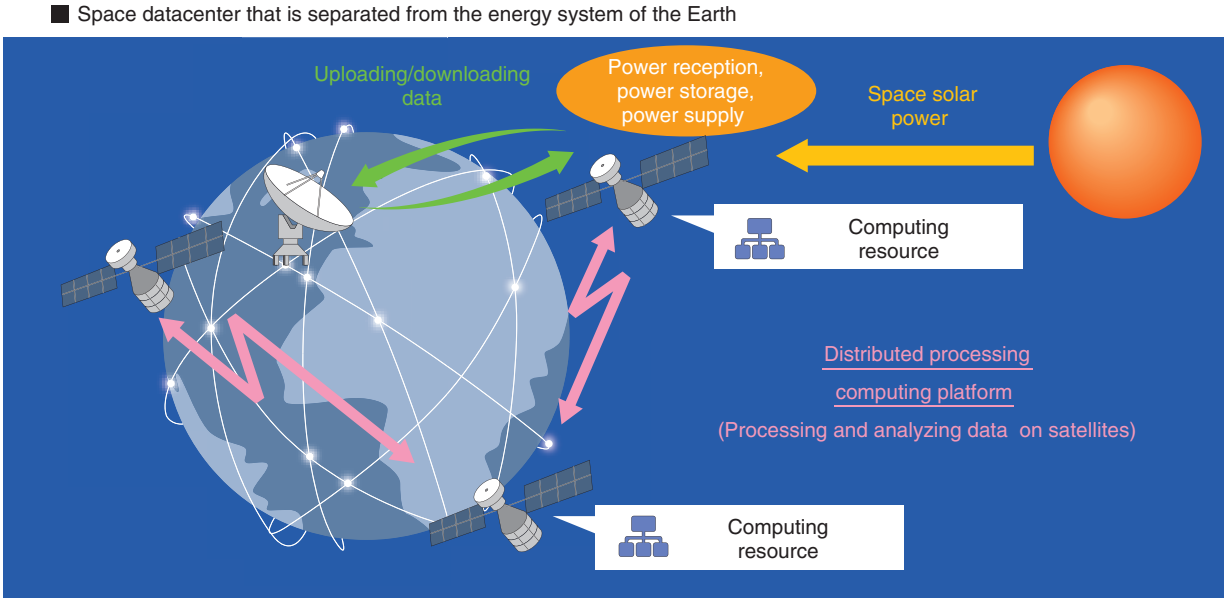


Fig. 13. IOWN space computing.

Regarding NTT DOCOMO, we are aiming for a deployment rate of the 5G infrastructure of 97% in Japan by 2023. The migration from the public switched telephone network (PSTN) to IP telephony will be complete by 2025. Also, in 2025, the first plasma of ITER nuclear fusion will be carried out, and as "grand challenges" concerning Digital Twin Computing, we are planning crowd exploration of the future society, a communication-characteristic translation engine, and a simulation coupling the water

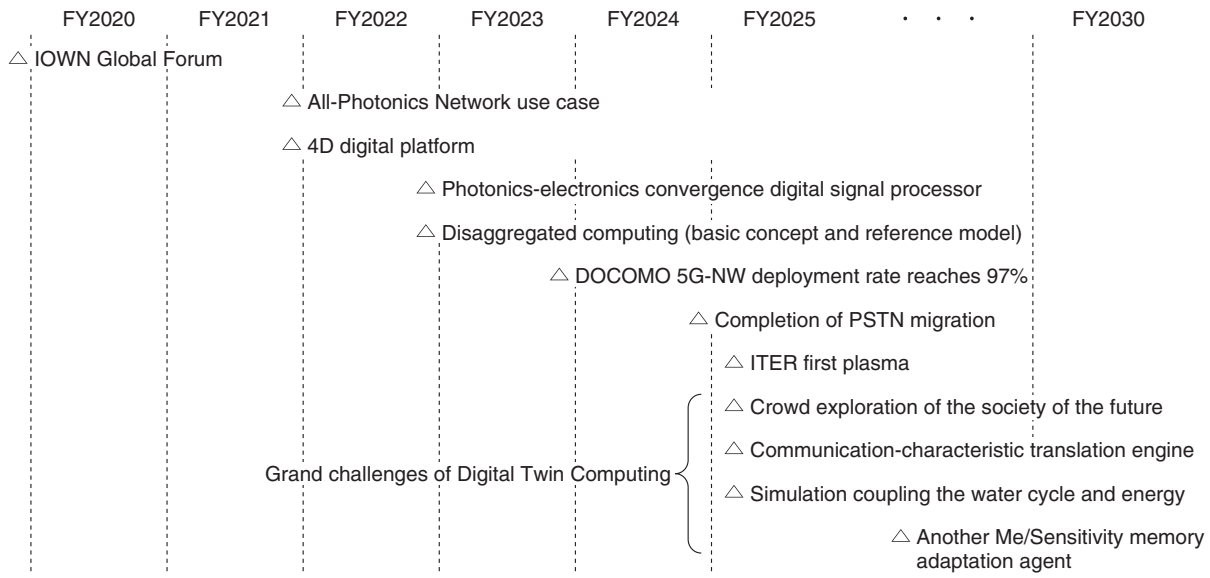


Fig. 14. IOWN roadmap.

cycle and energy. Looking further into the future, we have set the goal of R&D on "Another Me" (namely, a *coexistence alter-ego technology*) for 2035 in consideration of the considerable time it will need to develop it.

2.10 Toward further sustainable growth of society

We want to make IOWN a game changer. With the IOWN elements of photonics-electronics-conversion devices, the All-Photonics Network, disaggregated-computing model, and 4D digital platform, we want to promote various initiatives so that IOWN will bring about societal changes. We envision two major trends in the post-coronavirus society—the remote world and a new glocalism. By introducing IOWN in such a society as a game changer, we want to help make a more independent Japan while contributing to the world.

3. Concluding remarks

Many people are accessing the NTT R&D Forum via the Internet. The concept of digital events will become more common in the future. Therefore, we prepared a website for sharing ideas in 3D about NTT's vision of the world and its contribution to social issues it has targeted (**Fig. 15**). We want to make it a place for incubating technologies in a manner that enables us to share information or just go there and enjoy it. NTT will move ahead with R&D and business activities to become a game changer to change the world for the better. Thank you for your continued support.

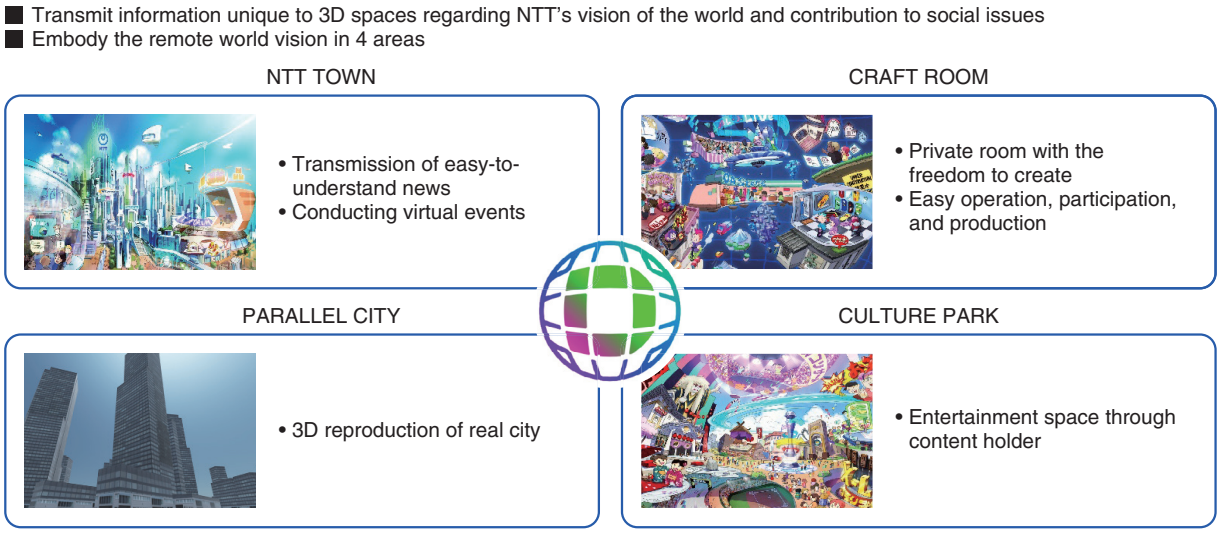


Fig. 15. 3D spatial owned media "Door".

Into the IOWN—Breakthrough Innovations—

Katsuhiko Kawazoe
Executive Vice President, Head of Research and Development Planning Department, NTT

Abstract

This article presents a lecture given by Dr. Katsuhiko Kawazoe, NTT Executive Vice President, Head of Research and Development Planning Department, at NTT R&D Forum 2020 Connect held from November 17th to 20th, 2020. The lecture introduced NTT's latest research and development activities, focusing on the Innovative Optical and Wireless Network (IOWN).

Keywords: IOWN, photonic direct communication, Extreme NaaS, data-centric computing infrastructure, photonic disaggregated computing, secure optical transport, IOWN space computing

1. Humans are burdened by unknown risks

I would like to start this speech on a bright and cheerful note, but unfortunately, this year I have to begin my talk with a serious topic. The emergence of the novel coronavirus has reminded us that humans are burdened by unknown risks. People are exposed to various risks even today in the 21st century. The report, "Global Challenges—Twelve Risks that Threatens Civilization" released in 2015 [1] lists risks such as global pandemics, extreme climate change, nuclear war, future bad global governance, and the impact of major asteroids. This is the number of asteroids that have been found to approach the Earth (**Fig. 1**). On average, about 30 new asteroids continue to be discovered every week. As you can see, there are still asteroids that haven't been discovered with today's observation technology. The asteroids shown in orange and red in the graph are dangerous because they are more than 140 meters long, capable of destroying cities. We need to further innovate and accelerate the discovery of dangerous asteroids.

Now what about the pandemic? Let's look at the response to a pandemic from a computer simulation perspective. Supercomputers take years to simulate the characteristics and behavior of a new virus. We need to wait a year or more to come up with measures to respond to a new virus. If we could simulate a new virus in a dramatically short period and predict who is likely to become severely ill and what behaviors are likely to lead to the spread of infection, we would be able to rapidly come up with measures that are far more effective. To speed up such simulations, however, we have to break through the barriers of power consumption, density, latency, and heat problems that are creating limits to the performance of today's computers. Our current technology is not yet sufficient to build a brighter future for humanity.

2. Digitalization for creating new value

So what should we do? The introduction of digital signal processing has made information and communication technologies (ICT) faster, more versatile, and more efficient. It is fair to say that it has contributed to making our lives and economy richer.

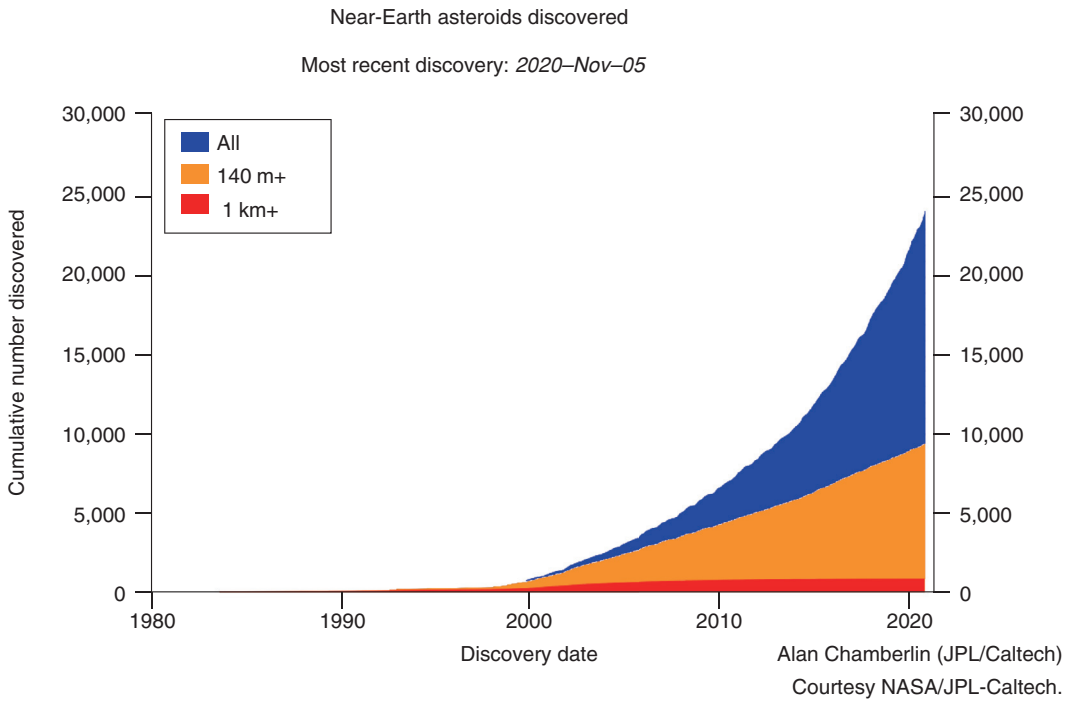


Fig. 1. Near-Earth asteroids discovered.

However, we recognized something by going through this pandemic. We are not facing just one problem. Multiple issues are intertwined, and there is no single value to address them. There are diverse ranges of value, and they will not remain the same. I believe digitalization, which will create new value that is necessary at that moment, is what we need going forward.

Last year at the R&D Forum, I introduced the concept of "umwelt" (German term for "environment") that German biologist Dr. Uexküll proposed. He said that organisms have their own information-recognition processes and the world (environment) is formed accordingly. The German philosopher Immanuel Kant's "Copernican Revolution" served as the basis of Dr. Uexküll's theory of the umwelt. Kant denied the idea that the world exists and humans recognize it, but insisted that the world is a phenomenon created by human cognitive forms, i.e., we all live in different umwelts. For example, we humans have a world in which we observe things such as beautiful flowers (**Fig. 2(a)**). In the world of insects and bees, the value is placed on flowers' nectar on which to feed (**Fig. 2(b)**), and in the world of the reptilian snake, the value is placed on mice on which to feed (**Fig. 2(c)**). I hope you have experienced the unique umwelt of different species.

Let me give you one example of how digitalization has successfully created new value. The Japanese performing art *kabuki* is facing a major challenge of its fans getting older and failing to attract younger audiences. That's why we tried to fuse the two umwelts of young and older generations who are passionate about kabuki. This is a collaboration between kabuki actor Nakamura Shido and the vocaloid* Hatsune Miku. Young people who were previously uninterested in kabuki are now watching it with great enthusiasm, sending in comments and shouting out at the performance, which is one of the traditions of kabuki viewing. Older kabuki fans also felt the benefits of a new style of stage production with Hatsune Miku and the state-of-the-art technology. We can probably say that a new value was created by fusing the two umwelts. I would say this embodies the essence of true digitalization we are aiming to achieve.

The concept of the Innovative Optical and Wireless Network (IOWN) was announced in May 2019 to address unknown risks to humanity and to promote digitalization for the creation of new value. By introducing innovative optical technology into everything

* Vocaloid: Singing synthesis software.

Fig. 2. Umwelt: unique umwelt of different species.

from networks to terminals and information processing, IOWN aims to solve the heat problem, which is putting limits on the performance of information-processing infrastructures, and to significantly improve the performance of power consumption, transmission capacity, and latency, compared to the current technology infrastructure, which is reaching its limits. This is truly a breakthrough innovation.

3. The progress in IOWN

Let me now explain the progress in IOWN. At the last NTT R&D Forum, IOWN was described as having three major elements, the All-Photonics Network, Digital Twin Computing, and Cognitive Foundation®. The origin of IOWN is the development of the optical transistor with the world's lowest energy consumption of 1.6 fJ/bit, announced in April 2019, and the development of optical devices has gone further.

In November 2019, we announced the development of the world's first all-optical switch with ultrahigh speed and low power consumption, and in March 2020, we fabricated the world's first ultrahigh speed optical logic gate that can perform arbitrary logic operations using only optical interference, which will greatly expand the possibilities of optical technology (**Fig. 3**).

In light of these optical device advancements, this year I describe three common platforms that we will build on top of IOWN, which are "photonic direct communication," "Extreme network as a service (NaaS)," and "data-centric computing infrastructure." In addition, I would like to introduce various services created from these three common platforms (**Fig. 4**).

3.1 Common platforms

(1) Photonic direct communication

Photonic direct communication achieves a high-capacity photonic path with an optical interface. By connecting the system end to end with optical paths, low latency and high-capacity communication, high-precision time synchronization, multicasting to multiple locations, and natural information communication using advanced artificial intelligence (AI) would be possible. Also, one can build function-specific dedicated networks for each wavelength of light (**Fig. 5**).

The network configuration is an optical ring configuration, which allows for high reliability and rapid area deployment. Instead of having to add more cores as new demand arises, we can add branches as demand arises and cover a (large) area with minimum fiber optics. This means that it is possible to dynamically provide high-capacity optical paths capable of accommodating a diverse protocol stack. The addition of this optical branching is made possible by the special optical fiber polishing and branch connection technology. It allows for optical branching without interrupting the network.

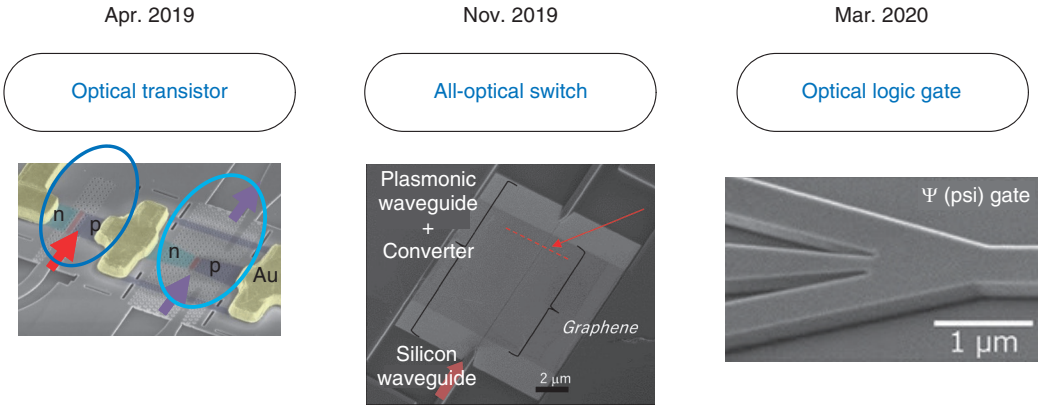


Fig. 3. Development of optical devices.

Fig. 4. The IOWN concept.

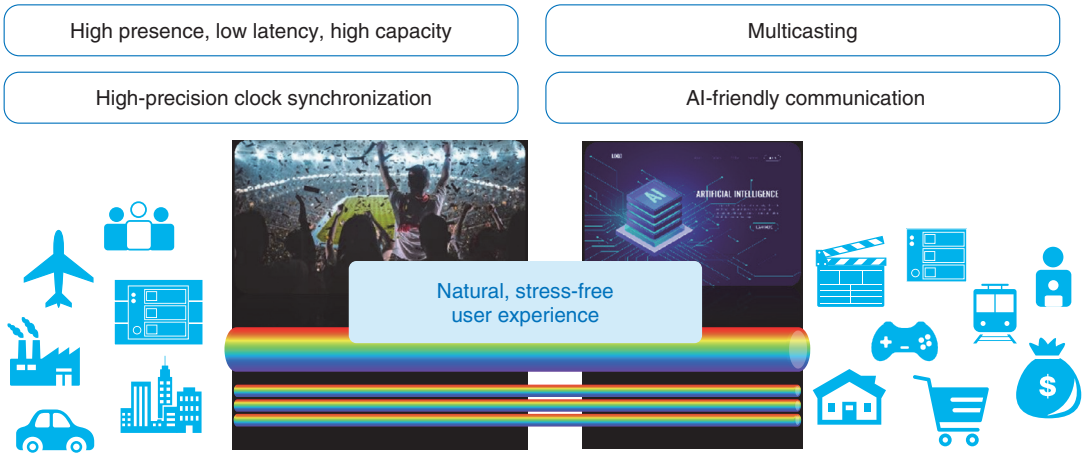


Fig. 5. Photonic direct communication.

(2) Extreme NaaS

The next common platform of IOWN is Extreme NaaS, a robust and flexible network services infrastructure. The innovative optical technology of IOWN and the multi-orchestrator of the Cognitive Foundation will allow for physical and functional

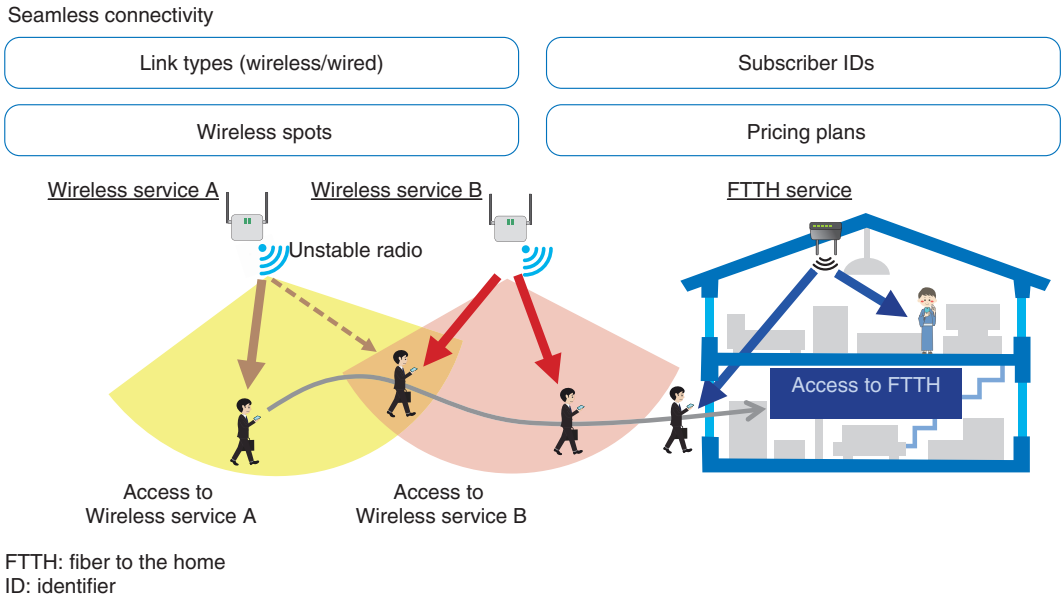


Fig. 6. Extreme NaaS.

integration of mobile and fixed networks, which means we can benefit from both mobile and fixed networks. In other words, it creates a new, robust, mobile/fixed seamless service that transcends network differences. Users are completely unaware of which network they are using and can continue to use the service stably even if their usage environment changes (**Fig. 6**).

In the demonstration experiment of the automatic operation of tractors in Iwamizawa City, Hokkaido, we implemented Extreme NaaS and achieved uninterrupted connection by anticipation prediction. Until now, handover among local fifth-generation mobile communication networks (5G), 5G, and broadband wireless access networks was not possible because networks are distinct from each other, but now they will stay connected even after a network has been switched. Since the tractors are monitored remotely via an ultralow latency network, they cannot continue to run if the network goes down. Because we are constantly monitoring the signal in the area that it is traveling, we can continue offering service by switching the network before it goes down.

Mobile and fixed networks are, because of the difference in the services they offer, built on distinct network systems. This is because functional and performance levels are different, and each system is composed of dedicated hardware and software. Since the early 2000s, network devices have become increasingly open, as demonstrated by such cases as white box switches. Hardware and software are separated using general-purpose chips instead of custom chips. The use of general-purpose devices that can accommodate a variety of applications allows for a more economical system. Currently, general-purpose devices are also being deployed in 5G radio access networks. However, because this involves using general-purpose chips, its application has been limited because the performance of such chips is inferior compared with dedicated devices using custom chips. IOWN solves this problem by improving the performance of general-purpose chips using photonics-electronics convergence technology (**Fig. 7**). Photonics-electronics convergence makes the system usable in both mobile and fixed networks.

(3) Data-centric computing infrastructure

The data-centric computing infrastructure is an ICT platform mainly composed of data or information and is an alternative to traditional Internet Protocol (IP)-centric computing (**Fig. 8**). In today's networks, information is exchanged in IP packets and the Transmission Control Protocol (TCP)/IP protocols, regardless of the type of information involved. However, each type of information has its own characteristics and uses; therefore, optimal transmission and the processing method differ depending on the type of information. We propose a new computing architecture to develop a data-centric computing infrastructure.

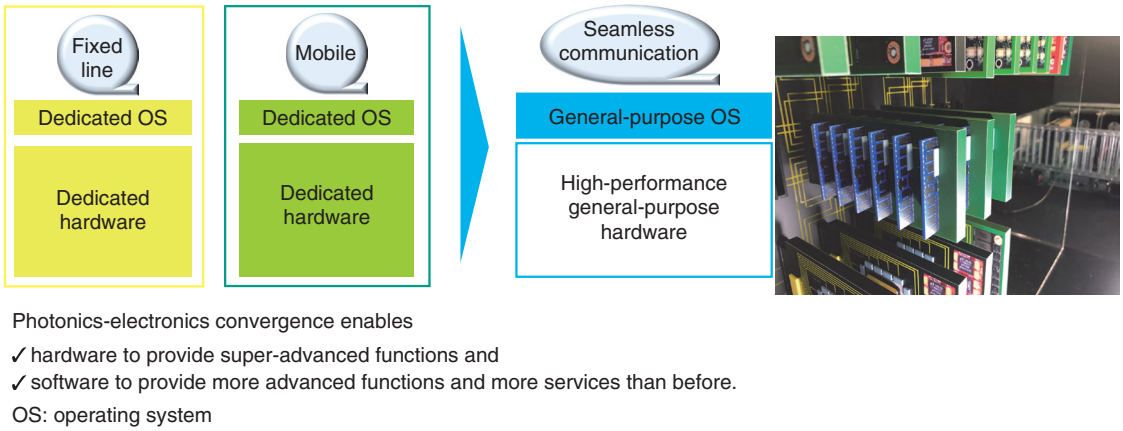
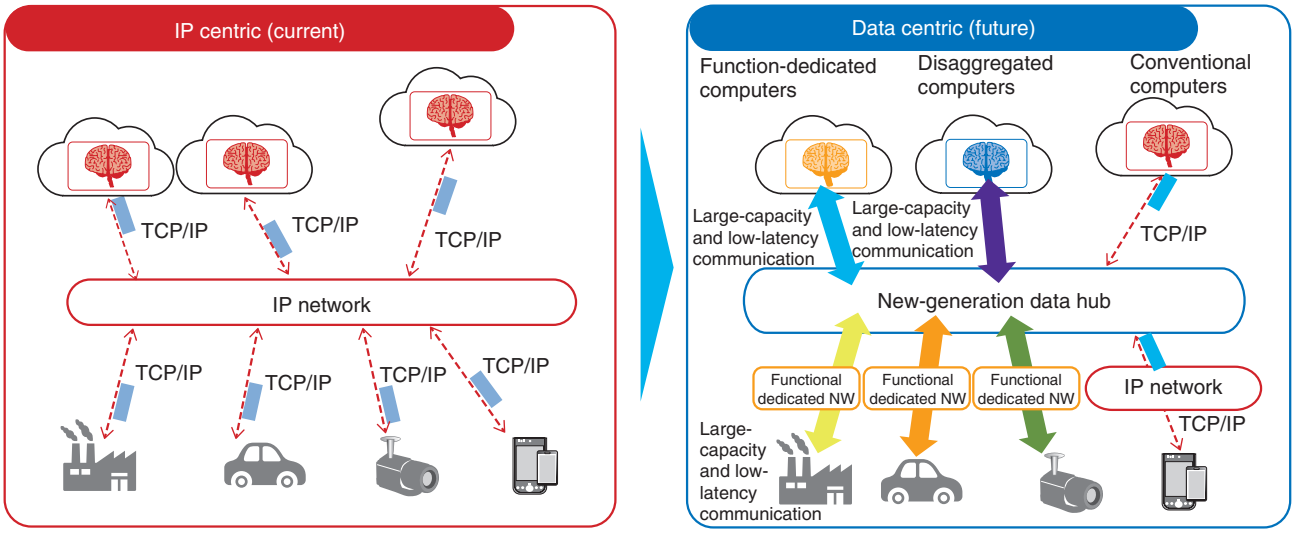


Fig. 7. New system architecture for seamless communication.



NW: network

Fig. 8. Data-centric communication and computing infrastructure.

In the current computing architecture, for large-scale information processing, each server unit is connected to a high-speed network to improve its computational processing power. However, latency becomes a major problem. In the photonic disaggregated computing that we are proposing, multiple memories and central processing units (CPUs) with optical input and output are directly connected by optical data transmission paths. To develop 800-Gbit/s-class photonics-electronics convergence devices to enable this ultrafast, high-capacity data processing, we prototyped a silicon photonics chip that performs ultrafast processing. This new computing architecture solves the heat problem and processing limitations caused by conventional power consumption and enables significant performance improvement in information-processing systems (**Fig. 9**).

3.2 Variety of services provided with IOWN

Next, I will introduce a variety of services that can be provided with IOWN.

(1) Well-being

A future prediction service that would make our lives more fulfilling is highly expected. The point is

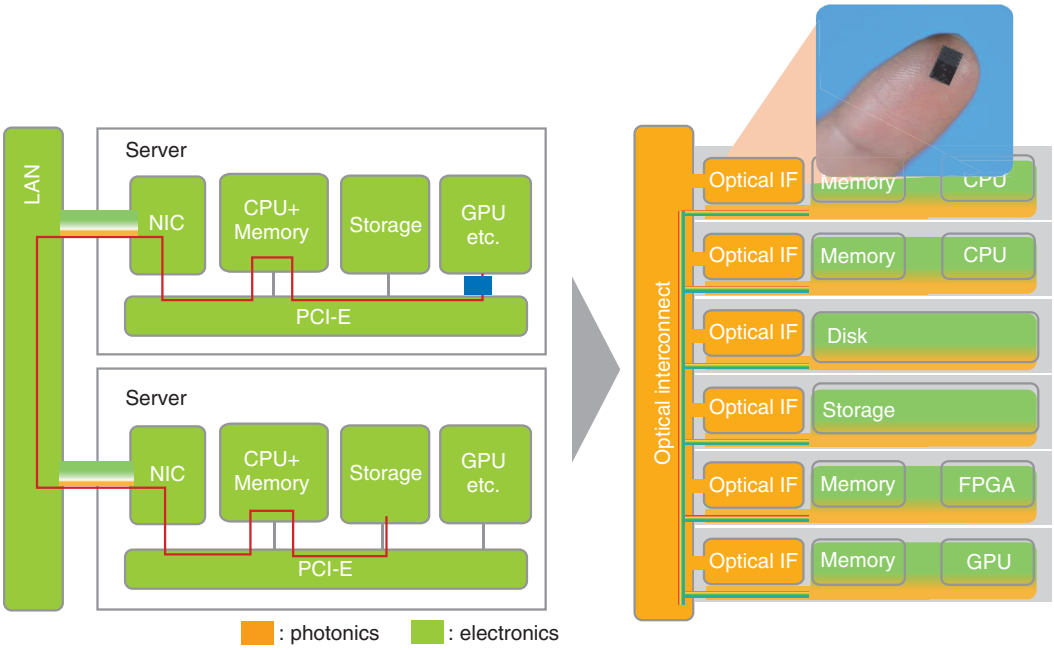


Fig. 9. Photonic disaggregated computing.

to "visualize" and "simulate" one's future changes, problems, and current physical condition. However, simulation of an individual's "body" has not yet been achieved. Therefore, we are aiming to create a human digital twin, i.e., a bio-digital twin, by incorporating biological information through a digital twin device equipped with non-invasive blood and electrocardiographic sensing technology. We will conduct simulations and future predictions on such a digital twin to help determine individual symptoms during diagnosis and treatment phases, select the appropriate drugs, prevent disease, and even contribute to the discovery of the unknown self.

To create a bio-digital twin, a digital twin device is needed that can accurately assess the body's condition. One such device is the AI tele-stethoscope, which is currently under research and development (R&D). It is capable of collecting biological sounds from various parts of the body with an 18-channel wearable acoustic sensor and transmitting them to a remote location via a network with high sound quality. This tele-stethoscope is intended to support remote auscultation but will be developed as an AI stethoscope. The AI stethoscope will learn from various information to create three-dimensional (3D) models that will estimate the shape and movement of the heart to diagnose one's heart from sound.

(2) Zero environmental impact

NTT has established a new lab, Space Environment and Energy Laboratories, to create innovative environmental energy technology in line with IOWN. This lab will contribute to achieving a sustainable and inclusive society and solving environmental problems from the space perspective. More specifically, we are working on artificial photosynthesis, lightening charge, and optimal operation control of nuclear fusion reactors.

NTT was the first private company to sign a comprehensive cooperation agreement with the International Fusion Energy Organization (ITER). This project uses IOWN's ultrahigh speed, ultralow latency network and Digital Twin Computing technology to achieve a complex and precise nuclear fusion reactor control system.

We also signed a cooperation agreement with the National Institute for Quantum and Radiological Science and Technology (QST), which is aiming to achieve nuclear fusion in Japan. We are working together to create world-pioneering innovative energy technology. Dr. Kenichi Kurihara, Director General,

Naka Fusion Institute, QST, sent us a message.
(Message from Kenichi Kurihara Dr.Eng.)

"NTT's IOWN technology, which consists of very advanced optical and information processing technologies, will play a very important role in the nuclear fusion energy development project. We would also like to promote cooperation with NTT with a view to future implementation in power generation reactors. I hope that the fusion of research from different fields—NTT and the QST—will produce a new, first-of-its-kind technology that will make a significant contribution to the actualization of humanity's dream of nuclear fusion energy."

(3) Lightning charge technology

If abnormal weather leads to more lightning strikes, damage to people and facilities will become severe. We aim to accurately forecast locations of lightning strikes using Digital Twin Computing of IOWN in weather observation. Furthermore, research on harvesting lightning energy, for charging purposes, will press ahead. We are hoping to start lightning induction and charge experiments in the natural environment in 2022.

(4) 4D digital platform™

The 4D digital platform is used to construct a digital twin in cyberspace on a real-time basis. This is made possible by using an advanced geospatial information database as the positional starting point, mapping real-world data with enhanced time accuracy, and collecting and integrating data at high speed. The 4D digital platform integrates 4D information, in other words, latitude, longitude, altitude, and time information in real time with precision. The digital twin constructed through such integration can make various future predictions and provide feedback to the real world.

By leveraging the 4D digital platform and technologies associated with it, we will provide value in areas such as road-traffic rectification, urban-asset utilization, and collaborative maintenance of social infrastructure. We aspire to develop new sensing methods through optical-fiber environmental monitoring using optical technologies including IOWN and contribute to enhancing understanding towards the Earth in the areas of environment preservation and disaster reduction by using our optical lattice clock network technologies in the future.

The 4D digital platform requires high precision/low cost object recognition technology. We applied the concept of umwelt that I introduced at the onset. What it means is that people recognize objects using visual information, whereas bats send out ultrasonic signals and use their reflected waves to perceive objects. Thus far, the NTT Group has used very high-performance and expensive LiDAR (light detection and ranging), which can capture positional relations to accurately grasp the position relation of electricity polls and other communication facilities. Therefore, we conducted experiments to see if we could combine visual information through the eyes and simple and inexpensive LiDAR to achieve better object-recognition performance than high-performance LiDAR, and the result as you see was very favorable. New value is created through the fusion of two umwelts or a compound environmental world (**Fig. 10**).

We will contribute to seaborne shipping through IOWN technology innovation. NTT and MTI Co., Ltd. signed an agreement on joint R&D for verification testing of the world's first unmanned ship navigation system.

We have a message from President Kazuo Ishizuka of MTI.
(Message from Kazuo Ishizuka)

"The biggest challenge for the NYK Group (including MTI) is to promote ESG (environmental, social, and governance) management together with our customers. What we envision for the future is to advance technological development with our industry partners on zero emission ships and autonomous ships. The common theme here is that logistics and vessels will be systematized more and more. High-speed high-capacity communication and high-precision positioning even on the ocean that IOWN aims to achieve is critical to us."

(5) Remote world

In the post-COVID society, we must balance keeping social distance and vitalizing economic activities. This will be achieved through the *remote world*. NTT launched remote world as a service brand and started providing various services to achieve the new space beyond face to face.

In R&D, we have advanced our immersive telepresence technology "Kirari!" that lets us believe as if a competition at a remote location were taking place right in front of our eyes and share the excitement of the venue. Amidst the coronavirus pandemic, various sports are being played without spectators, and our technology needs to evolve along with the change. For athletes, real-time cheers during the game gives them energy and encourages them. For spectators who are cheering for athletes, the sense of unity they feel with athletes and other spectators, through enthusiastic cheers, is the best part of the experience. To feel the sense of unity by encouraging athletes

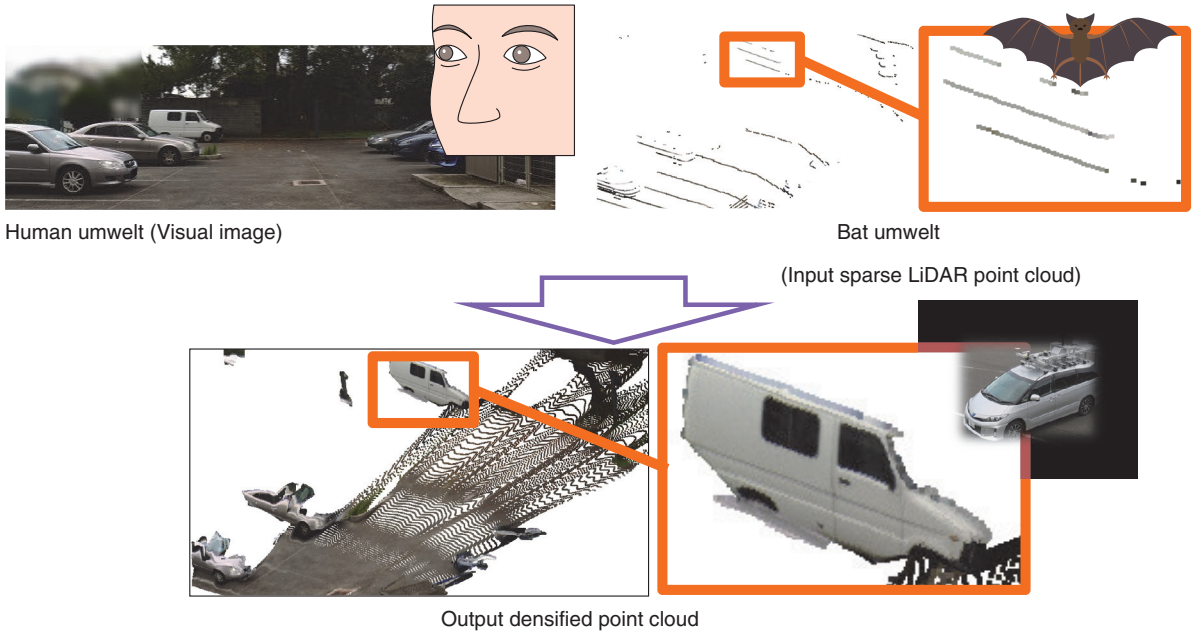


Fig. 10. Real-world digitalization technology towards the 4D digital platform™.

through passionate cheers, the most important thing is timeliness even when you are remotely viewing sports. This means that latency between the stadium and remotely participating spectators, and among spectators, has to be minimized to synchronize their emotions. This is very important.

The latency issue can be addressed using photonic direct communication technology. This technology connects all the venues on a real-time basis, which lets us cheer athletes remotely and create a sense of unity among fellow spectators. We also believe that the sense of unity can be enhanced by installing sensors to detect the amount of heat in each venue and by devising means to control the brightness of the lighting depending on the strength of cheering.

We have begun R&D on emotional perception technology that captures changes in spectators' emotions and have them interplay with one another to generate a sense of unity or interaction. We are conducting joint research with Sony Corporation who has world-class expertise in device and interaction technologies. In the post-COVID society, in the era of remote world, thanks to ultralow latency technology, one will be connected without latency from a remote location and can feel as if he/she were in the same stadium.

3.3 IOWN Global Forum

IOWN Global Forum, established in January 2020 by NTT, Intel, and Sony, has major global players who back technology innovation that IOWN aims to achieve such as Microsoft, Dell, Ericsson, and Nvidia. Membership is expanding day by day. We agreed on a plan to publish a technical core document as IOWN Global Forum Roadmap in 2021, decide specifications in 2024, and start IOWN compliant services by forum members in 2030. Having said that, NTT will not wait until 2030 but will announce new optical computing architecture in 2021. We will collaborate with various global partners for further innovation.

4. New challenges

Now, let's look at new challenges in expanding the field of R&D.

4.1 Globalization of NTT R&D

To expand and strengthen basic research further, we established NTT Research Inc. as an overseas basic research hub in April 2019, under which three labs started operation in July the same year and already produced great outcomes. For example, Cryptography & Information Security Laboratories had 12 papers accepted (15% of all accepted papers) by the top cryptography conference called CRYPTO. It is said that if you have 1 or 2 articles accepted a year, you are already a top class researcher in the

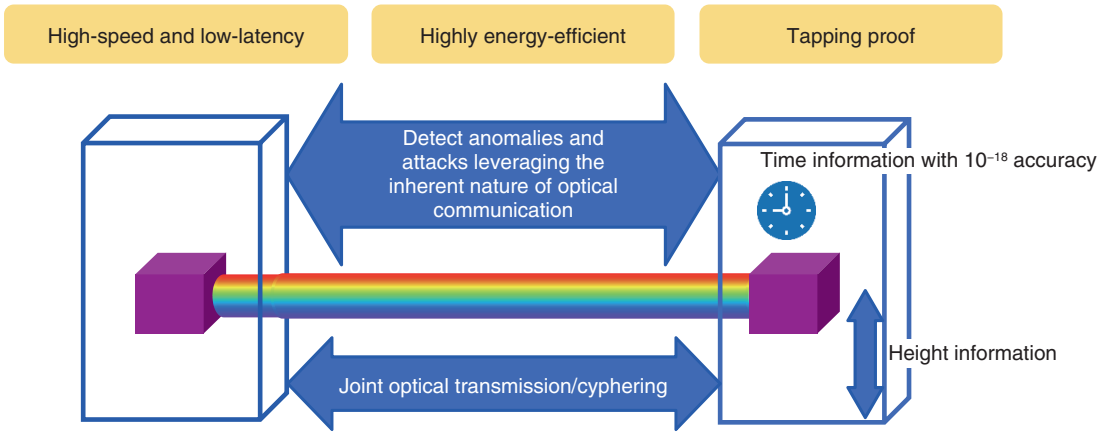


Fig. 11. IOWN secure optical transport.

cryptography field.

As a part of global R&D, we started research activities on dementia care, a common social challenge in Japan and Australia. This is research to identify true needs of patients to give them the care they need. Researchers from various disciplines are coming together to have discussions on brain science and human interface to bring back the joy of life to patients through this research. This project is highly evaluated by the Australian Government. We've received messages from the honorary Simon Birmingham, Minister for Trade, Tourism and Investment as well as the honorary Dan Tehan, Minister for Education.

(Message from Simon Birmingham)

"NTT's recent Comprehensive Partnership Agreement with Deakin University and Western Sydney University in Australia is the first of its kind outside Australia. This collaboration seeks to work together on issues of mutual interest to both our nations - across sustainable agriculture and food security, liveable cities, reliable renewal energy sources, and enhanced digital communications infrastructure. The first project is underway: to explore ways to harness technology to improve the quality of life for people living with dementia."

(Message from Dan Tehan)

"The Australian Government is fully committed to encouraging stronger collaboration between our universities and businesses to create jobs, improve productivity, and open new business opportunities. Of course, the creation of a strong, new industry-led translational research capability, focused on positive socio-economic outcomes, is also a great gain for Australia. Working together, we can shape our future."

4.2 Security

The next challenge is security. A cat and mouse chase with attackers has been continuing for a long time in security technology. In the IOWN era where everything is connected optically, we anticipate a new paradigm on security, including quantum key distribution, which is commanding attention. For example, by using an optical lattice clock, latency will be minimized to a time accuracy of 10^{-18}, which allows us to make precise measurement down to centimeters. By using an optical lattice clock, authentication technology can be developed from a completely new perspective. We call this new authentication technology using an optical lattice clock "secure optical transport," which is befitting (**Fig. 11**). Using the characteristics of light in the security field is indeed a challenge.

4.3 Space

Finally, I'll introduce our challenge in space. In November 2019, NTT and the Japan Aerospace Exploration Agency (JAXA) made an agreement to carry out joint research. We aim to achieve a seamless ground-to-space ultrahigh-speed large-capacity secure, optical and wireless communication infrastructure.

In this joint research, multiple-input multiple-output technology will be applied to a satellite for the first time to solve the capacity problem that has been a bottleneck in satellite communications. We will solve this problem by expanding the capacity

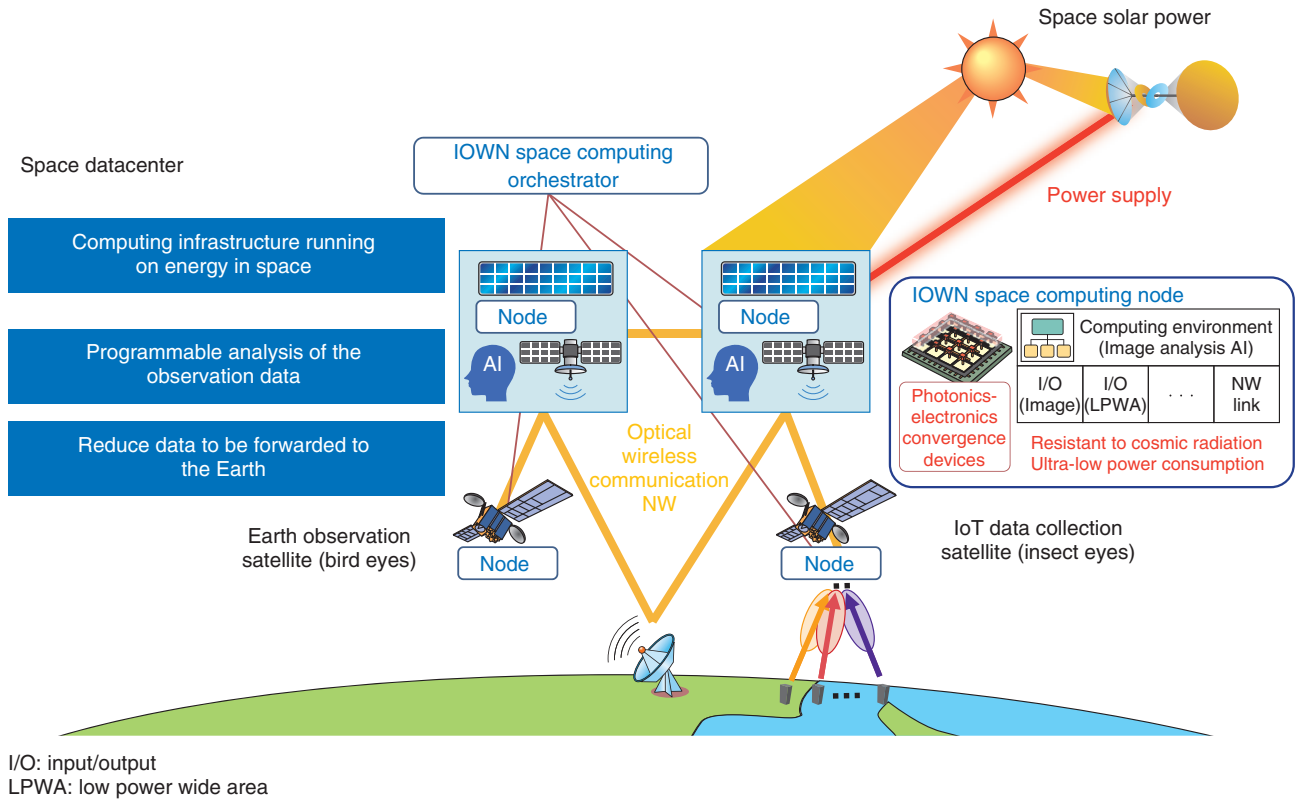


Fig. 12. IOWN space computing.

overwhelmingly and put in place low-cost Internet of Things (IoT) platforms in every corner of the world including areas without a terrestrial communication network. It has been decided to equip a communication satellite to be launched in fiscal year 2022 with this technology. We have a message from Dr. Masatoshi Harigae, Director General of Research and Development Directorate at JAXA.
(Message from Masatoshi Harigae)

"JAXA and NTT have signed a cooperation agreement to develop a large-capacity ultrahigh-speed and secure optical wireless communication infrastructure. Under this agreement, we have been conducting joint research so that outer space will be tapped into in the new information platform envisioned with IOWN."

One of our goals regarding this challenge is the IOWN space computing concept. Ultralow-energy-consumption computing capacity based on photonics-electronics convergence technology has unimaginable potential that goes beyond current technologies. We believe we can create a space datacenter that will process and analyze data on satellites. We have an eye toward a computing platform that processes and analyzes various observational data across satellites using energy only in outer space. Thanks to the various innovative technologies of IOWN that I introduced today, this will be a standalone ultra-stable permanent ICT infrastructure that will not have any impact on weather or further burden the Earth (**Fig. 12**).

5. Delivering breakthrough innovation for human happiness

Thus far, humans have come up with many innovations. Current technology lies on the accumulation of the past. We must act with a long-term vision as well as a short-term view. Happiness should not be considered momentary but temporally integrated so as to drive us to the best future possible through innovation. The infinite possibilities of technologies must be understood properly. This great challenge cannot be tackled with our knowledge alone. We must clearly face this issue with people from every sector to find a

better way forward together. Today, I introduced the progress we've made and future challenges of IOWN. The NTT Group will contribute to all people through breakthrough innovations so that humans faced with unknown risks can remain happy. Thank you very much for your attention.

Reference

[1] Global Challenges Foundation, "Global Challenges—Twelve Risks that Threatens Civilization," Feb. 2015.

Initiatives to Create Future Information-processing Infrastructure

Seiji Kihara, Hiroyuki Tanaka, and Yutaka Arakawa

Abstract

A data-centric society is coming in which real-world data will create various types of value. As the data-centric society advances, the demand for system infrastructure and software-development methods is expected to increase. This article introduces various technical issues and NTT R&D's efforts toward creating a future information-processing infrastructure that will support the data-centric society and respond to the evolution of society and technology.

Keywords: data distribution, data analysis, information-processing infrastructure

1. Circumstances surrounding information-processing infrastructure

The process of solving real-world problems using various real-world data is becoming increasingly important. There are countless examples of such processes in manufacturing, such as production management and facility-failure prediction based on plant operation data, and in retail, such as supply-and-demand prediction based on weather data, marketing, and flow-line design based on customer-behavior data. We call this process *data-value creation*. In addition to intensifying competition among companies and aggravating environmental and social problems, the shift to a remote society accelerated by the COVID-19 pandemic has prompted a digital transformation of society as a whole, and expectations for data-value creation are increasing. Against this backdrop, we believe that a data-centric society will arrive in which value will be created from data from all aspects, such as decision-making, optimization, and forecasting. The role of an information-processing infrastructure, which is the foundation of the distribution and analysis of a large and diverse amount of data, will become more important.

Looking back on technological history, the current information-processing infrastructure has continuously evolved. From the viewpoint of the system infrastructure, processor performance was first improved by speeding up the single-core central processing unit (CPU) by refinement then adopting a multi-core architecture. The whole system was initially sped up and became more sophisticated by processing using a single server and later by distributed and parallel processing using multiple servers. For software development, the waterfall-development method has long been used for developing large-scale, high-quality software such as mission-critical systems, and the agile development method has recently been widely adopted for developing web applications that require usability and rapid development. As the data-centric society progresses, the evolution of such technology is expected to continue.

On the basis of these circumstances, NTT Software Innovation Center (SIC) is working on research and development (R&D) to support a data-centric society and create a future system infrastructure and software-development methods that respond to the evolution of society and technology in cooperation with other NTT laboratories that specialize in hardware, security, and other related technologies.

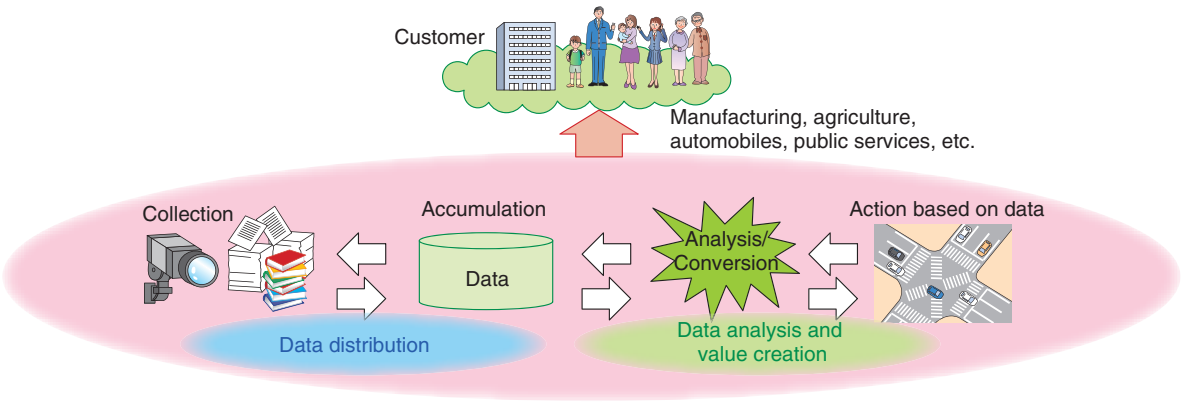


Fig. 1. Value chain of data-centric society.

2. R&D supporting a data-centric society

Figure 1 shows the general flow of data-value creation in a data-centric society. First, in various real-world places, data about real-world objects and events are generated, collected, and accumulated as sensing data and log data. Next, the data are analyzed and converted. Then, actions affecting the real world are taken to solve problems. In many cases, by repeating this flow, we can gradually mitigate problems even if the real world continues to change. By feeding data back into the real world in this manner, we can move the real world in a positive direction and provide value to customers in various domains.

To support the value chain of such a data-centric society, we are researching and developing the following basic information-processing technologies.

(1) Data analysis and value-creation technology

The application scope of data-value creation is thought to be wide, so value cannot be created in a uniform manner. What value can be created from what data by what analysis? We believe that to find a truly useful means to create value, we need to confront specific issues in each domain and take a trial-and-error approach to finding the right combination from the various available data and analytical methods. To create value from data in various situations, it is essential to improve the efficiency and sophistication of trial and error. Therefore, we are engaged in R&D to achieve this and even automating it.

Even if one finds a means to create value from one's data, it will not be a viable solution if the amount of data one needs to process is so huge that one cannot create value in the expected amount of time or at a lower cost than that one wants to create. For example, the application of artificial intelligence (AI) technology, which is expected to be used for data analysis, has been expanding as it becomes more sophisticated, while the increasing amount of processing has become a problem. In the article "An Efficient Event-driven Inference Approach to Support AI Applications in IOWN Era" [1] in this issue, we introduce technology that improves the efficiency of AI-inference processing for large amounts of video data to develop AI services that *exceed human capacity* in the Innovative Optical and Wireless Network (IOWN) era.

(2) Data-distribution technology

New technology is also needed to efficiently collect data to be analyzed. Not all real-world data are readily available. In some cases, it may not be possible to obtain all necessary data due to sensor failure, measurement timing, etc. In other cases, data may not be available due to privacy or business reasons. In addition, data are generated or accumulated in various places in the real world, which causes problems such as network and storage performance and capacity being squeezed by data collection and replication and the data owner's authority and lifecycle management of replicated data becoming out of reach. As one approach to solve such problems, we introduce the next-generation data hub technology in cooperation with other NTT laboratories, such as NTT Secure Platform Laboratories, in the article "Next-generation Data Hub Technology for a Data-centric Society through High-quality High-reliability Data Distribution" [2] in this issue. Our goal is to create a data-centric society in which vast amounts of data generated around the world are not only used within closed organizations, such as corporations, but also widely

distributed and used to create new value by combining other data and expertise never encountered before.

3. R&D of system infrastructure and software-development methods that respond to the evolution of society and technology

With the progress in the information society, the volume of data distribution and analysis will increase explosively, and the system infrastructure will require further performance improvement. In addition, new services using a wide variety of data will appear, and their individualization and customization will accelerate; thus, more efficient and high-speed software-development methods will be required.

In response to this evolution, we are engaged in the following R&D to continue and accelerate the evolution of the system infrastructure and software-development methods.

(1) System-infrastructure technology

It has been said that Moore's Law is reaching or has reached its limit. This means the end of an era when system performance was heavily dependent on CPU performance. In the new era, the effective use of application-specific hardware, such as GPUs (graphics processing units) and FPGAs (field programmable gate arrays), is considered to be a major technical problem for achieving high-speed and high-efficiency data processing. To solve this problem, we are conducting R&D in cooperation with NTT Device Technology Laboratories, which researches and develops optical interconnect technology that connects various computing resources at high speed, and NTT Basic Research Laboratories, which researches and develops Ising computers that solve problems at high speed with photonics technologies. We introduce the technology for specializing processing using application-specific hardware and the parallel processing of CPUs with many cores to create a system infrastructure that enables high-speed and high-efficiency data processing beyond the limits of Moore's Law in the article "Software Innovation for Disaggregated Computing" [3] in this issue.

(2) Software-development technology

To meet the diversifying and blurring requirements of business and keep up with the speed of business evolution, we are researching and developing technologies for AI that substitute for and transcend some of the human work required in software development. With these technologies, we aim to develop a high-speed development method with which AI and humans can work together.

As one such AI-development technology, we introduce a test automation technology that greatly improves the efficiency of the test process and ensures quality assurance by accurately and intensively testing areas of questionable quality by collecting and analyzing actual test-activity data in the test process in the article "Test Automation Technology for Analyzing Test-activity Data and Detecting Bugs" [4] in this issue.

4. Future directions

To create future information-processing infrastructure that supports a data-centric society and adapts to the evolution of society and technology, various problems described in this article need to be solved. Through collaboration with partners in various industries and experts in academic and technological fields, we aim to establish various technologies as soon as possible.

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An Efficient Event-driven Inference Approach to Support AI Applications in IOWN Era

Takeharu Eda, Ryosuke Kurebayashi, Xu Shi, Shohei Enomoto, Koji Iida, and Daisuke Hamuro

Abstract

Artificial intelligence (AI) in the Innovative Optical and Wireless Network (IOWN) era is expected to not only acquire capabilities beyond humans but also be energy-efficient, therefore contribute to the sustainability of future societies. This article describes an event-driven inference approach as a promising approach to balance AI capabilities and efficiency. This approach efficiently inspects continuous input stream data and generates events that trigger subsequent deeper inference tasks over geographically distributed computing resources only when they are truly necessary. This approach will significantly decrease energy consumption and computational and networking costs in AI inference.

Keywords: IOWN, AI, event-driven

1. Introduction

Artificial intelligence (AI) technologies such as deep learning are being applied to many commercial services worldwide and steadily progressing towards disruptive advances for real business [1]. NTT has initiated the concept of the Innovative Optical and Wireless Network (IOWN) and is developing more advanced AI-based cognitive, autonomous, and predictive systems that can recognize what humans cannot, handle much larger-scale problems than humans can do, and make decisions much quicker than humans. These systems will contribute to the establishment of a data-centric society and are expected to provide new value to society in terms of safety, accessibility, sustainability, and comfort.

2. Future AI applications in IOWN era

Figure 1 is an overview of our AI service platform. In this platform, we assume that a large number of various sensor devices (e.g., cameras, GPS (Global Positioning System), and accelerometers) are installed over a certain area (e.g., a commercial building, station, park, or even a whole city) and connected to the AI service platform. At the same time, various AI applications are deployed on the platform. The AI platform understands the physical world by analyzing data received from the sensor devices and uses the AI applications to extract intelligence from the data to meet customer needs.

Figure 2 shows a list of typical AI applications expected to be provided by the AI service platform. We focus on the two metrics described in the IOWN white paper [2], that is, cognitive capacity and response speed of the AI applications, and map them according to the metrics. Cognitive capacity indicates how precisely such applications need to capture and understand the physical world, and response speed indicates how quickly they need to give feedback to the physical world. As shown in this figure, some applications require human-level or beyond-human-level cognitive capacity and response speed (most are not possible with today's technology). This gap is what we are trying to close through IOWN.

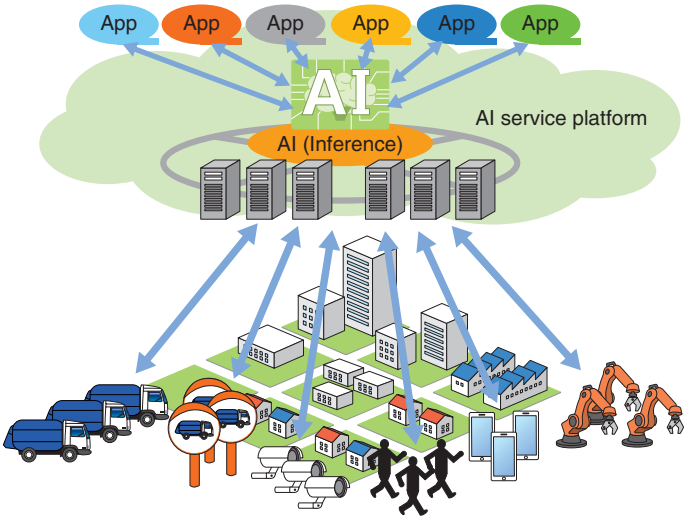

Fig. 1. Overview of our AI service platform.

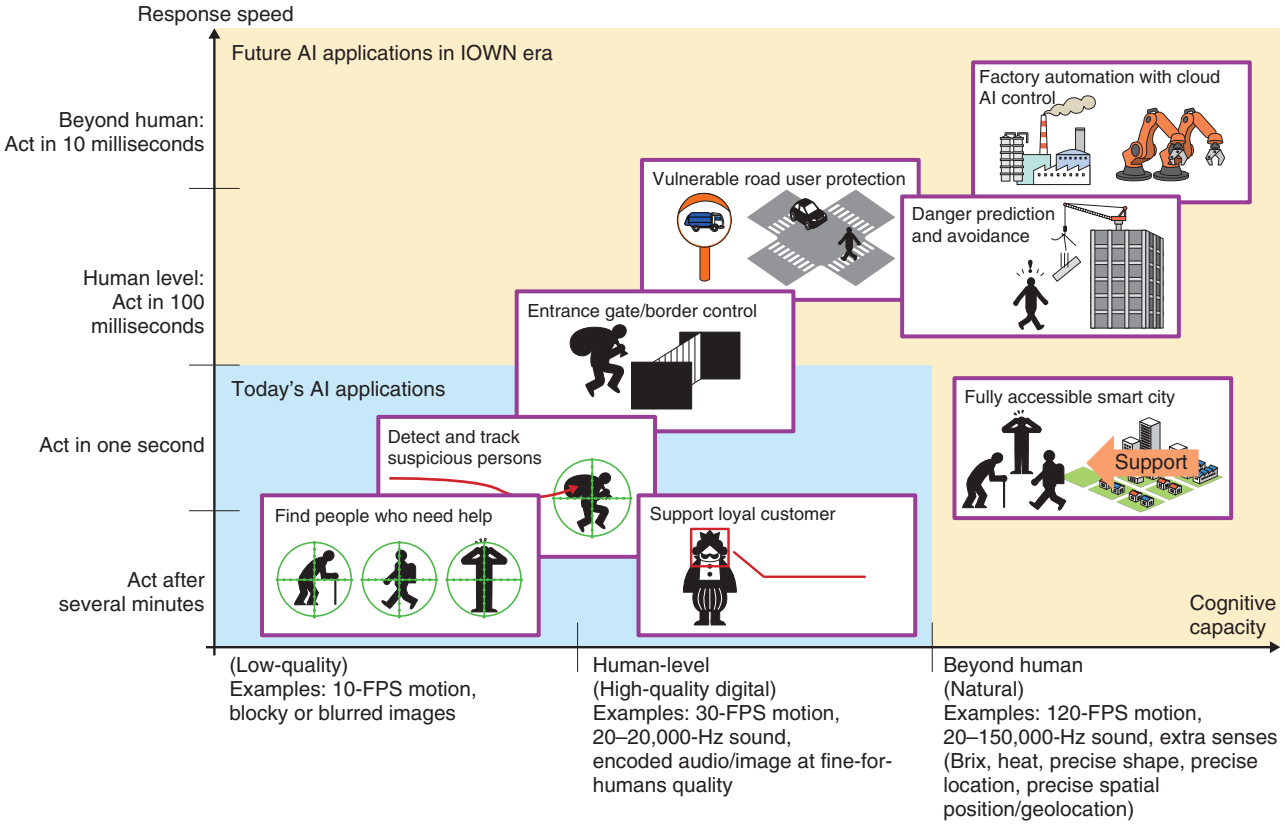

Fig. 2. List of AI applications.

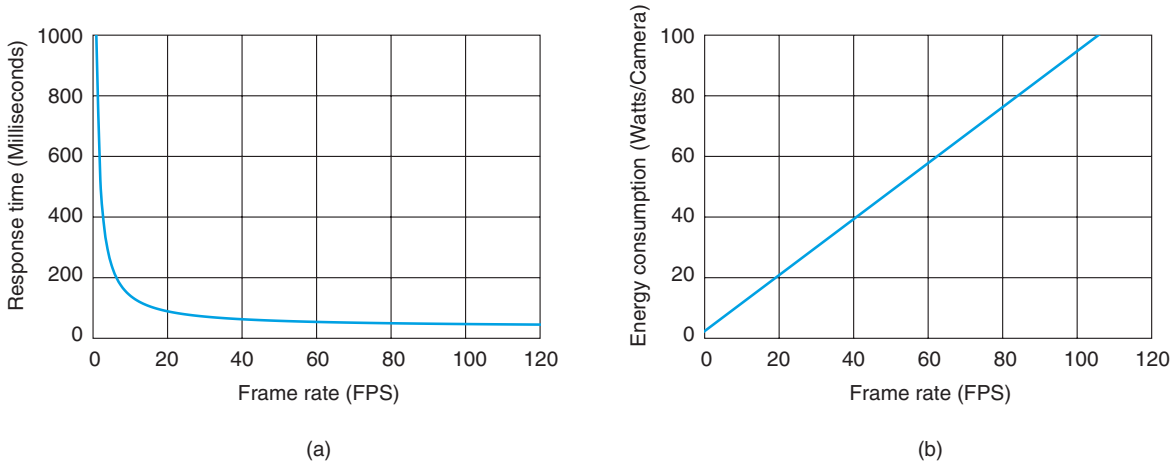

Fig. 3. Impact of frame rate on response time and energy consumption.

3. AI technologies for sustainable societies

To acquire AI capabilities beyond the human level, should we simply speed-up and scale-up AI processing? Unfortunately, while high expectations are growing given the advantages of AI, the huge energy consumption of AI is becoming a social problem [3]. In fact, improving AI capabilities often involves using more computing and networking resources, which decreases its energy efficiency. That is, there is a trade-off between AI capabilities and efficiency. Therefore, it is important to study energy-saving methods of AI in conjunction with enhancing its capabilities.

The graphs in **Fig. 3** show an example of the impact that improvements in AI capabilities may have on energy consumption. The figure shows the relationship between response time and energy consumption in AI inference processing for video images. The graphs were plotted from the results of our experiments in which we executed an inference model of Yolo v3 FP16 [4] on a server with four commercial accelerators. We also assumed a power usage effectiveness of 2. For simplicity, we focused on just inference processing and ignored network latency. Video images are generally expressed as a series of still images (or frames), and an AI inference process is applied to each frame or a set of frames. Therefore, the response time of AI inference is affected by the frame per second (FPS) of the video images as well as the processing time of AI inference. That is, a higher FPS means shorter intervals between AI inference processes, which yields better response time (see Fig. 3(a)). However, a higher FPS obviously increases the frequency of inference processing and leads to higher energy consumption per camera (see Fig. 3(b)). Let us assume that one wants to achieve 100-millisecond response time in total (i.e., human level), so one needs to keep the response time of inference processing iteration below 50 milliseconds, the energy consumption per camera will reach 45 W. This *one light bulb per camera* energy consumption is clearly not desirable from the environmental point of view. This example focuses on response time, and we can have a similar discussion with regard to the scale and complexity of AI models. Therefore, we need technical breakthroughs to break the trade-off between AI capabilities and efficiency.

4. Event-driven AI inference approach

One promising approach for breaking the trade-off is event-driven AI inference. This approach efficiently inspects continuous input stream data and generates events that trigger subsequent deeper inference tasks over geographically distributed computing resources only when they are truly necessary. This approach will significantly decrease energy consumption and computational and networking costs in AI inference.

An example of event-driven AI inference is model cascading (model splitting, early exit), where expensive but accurate AI models are split into two or more small models and the small models are properly deployed at user/edge locations to reduce computation cost, network usage, and power consumption

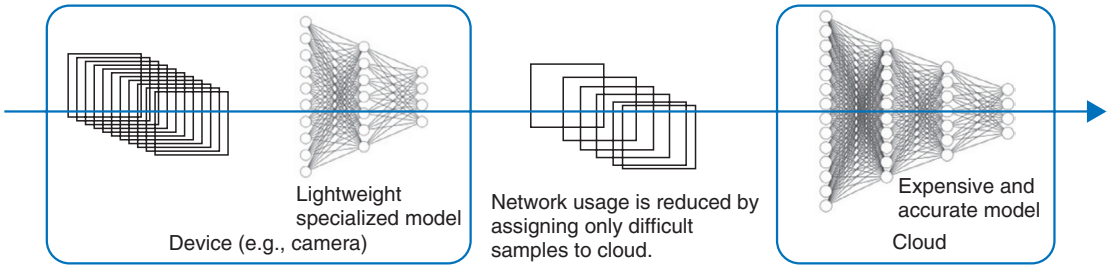

Fig. 4. Model-cascading system with camera and cloud.

without losing overall accuracy. **Figure 4** shows one example of a model-cascading system.

Since hundreds of companies have started to develop cheaper and more efficient hardware accelerators than graphics processing units, we can deploy small models on devices equipped with such AI accelerators for detecting pre-defined events and deploy the original (expensive) models on the cloud for handling difficult input samples for accurate inference provided by a large amount of computing power. AI models on devices enable security cameras to detect semantically correct events compared to naive motion detection, which is a very simple function in security cameras, and detects animals as well as humans. Such model-cascading systems reduce network usage and computation cost by using lightweight models on edge devices for efficient inference. Overall this results in both significant power savings and high capacity.

5. Learning to calibrate the confidence of lightweight models on edge devices

The role of small models on edge devices in model cascading is usually to perform the same task (i.e. detecting semantic events) with the model on the cloud, triggering decisions as to whether it sends difficult input samples to the cloud or finishes the inference within the edge devices. Since edge devices, such as cameras and home gateways, have limited computation power, they cannot afford to run powerful AI models. Thus, it is important to train lightweight and accurate models for event detection. It is desirable that the lightweight models pass only difficult input samples to the cloud. In theory, we can send such samples directly to the cloud if we know whether the lightweight model is correct, which is impossible in practice. If we send easy samples that lightweight models can correctly classify to the cloud, the network resources are wasted. The most important point in edge models is to obtain the correct confidence score of the models to input samples. Usual AI models output inference results together with confidence scores (e.g., softmax), which shows how confident the model is in its output. One recently discovered issue is that AI models tend to be overconfident, and we experimentally confirmed that the overconfidence of AI models actually negatively impacted model-cascading systems. This explains why we developed a calibration technique for model-cascading systems [5]. Our technique calibrates the confidence scores of lightweight models by taking into account the accuracy of the original AI model as well as that of the lightweight model, leading to a reduction in redundant data transfer (**Fig. 5**). Our experiments verified that this technique can reduce computation cost by 36% and data-transfer cost by 41% in model-cascading systems.

6. Model-structure sharing by early exit for further efficiency

The previously introduced calibration technique requires the model-cascading system to send the raw still images (frames) to the cloud for processing. We reduced the number of frames by using a lightweight specialized model on edge devices, but the cost incurred by edge devices in sending still images to the cloud remains significant. Thus, we implemented a more sophisticated technique based on the early exit idea where the edge and cloud models share a model structure and only compressed (quantized) feature maps are sent to the cloud to further reduce both computation and network costs (**Fig. 6**) [6]. We verified that this technique reduced network usage by 65% without losing model accuracy.

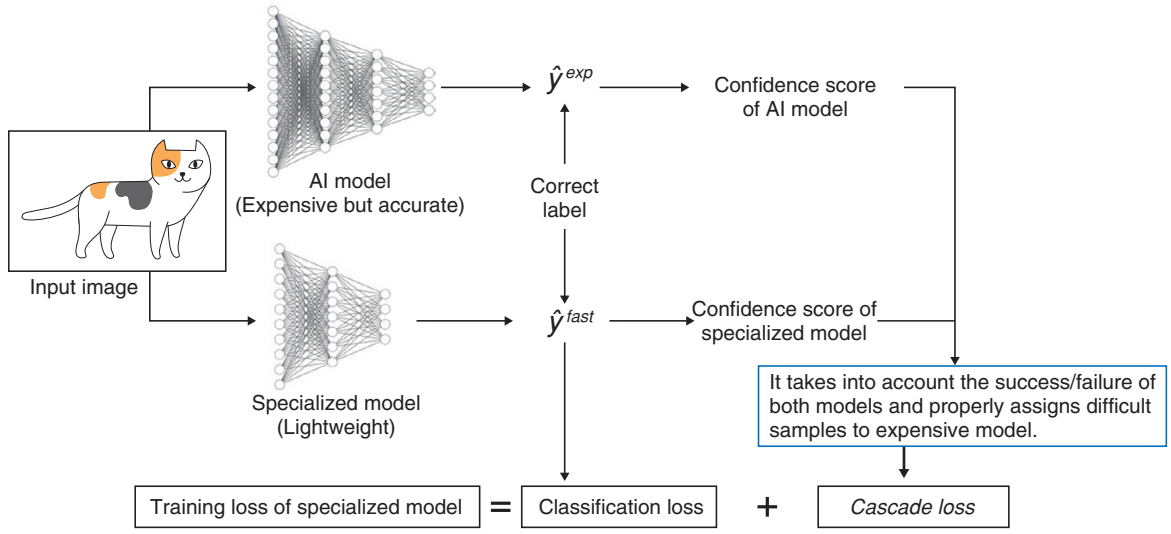

Fig. 5. Training loss of specialized models for edge devices.

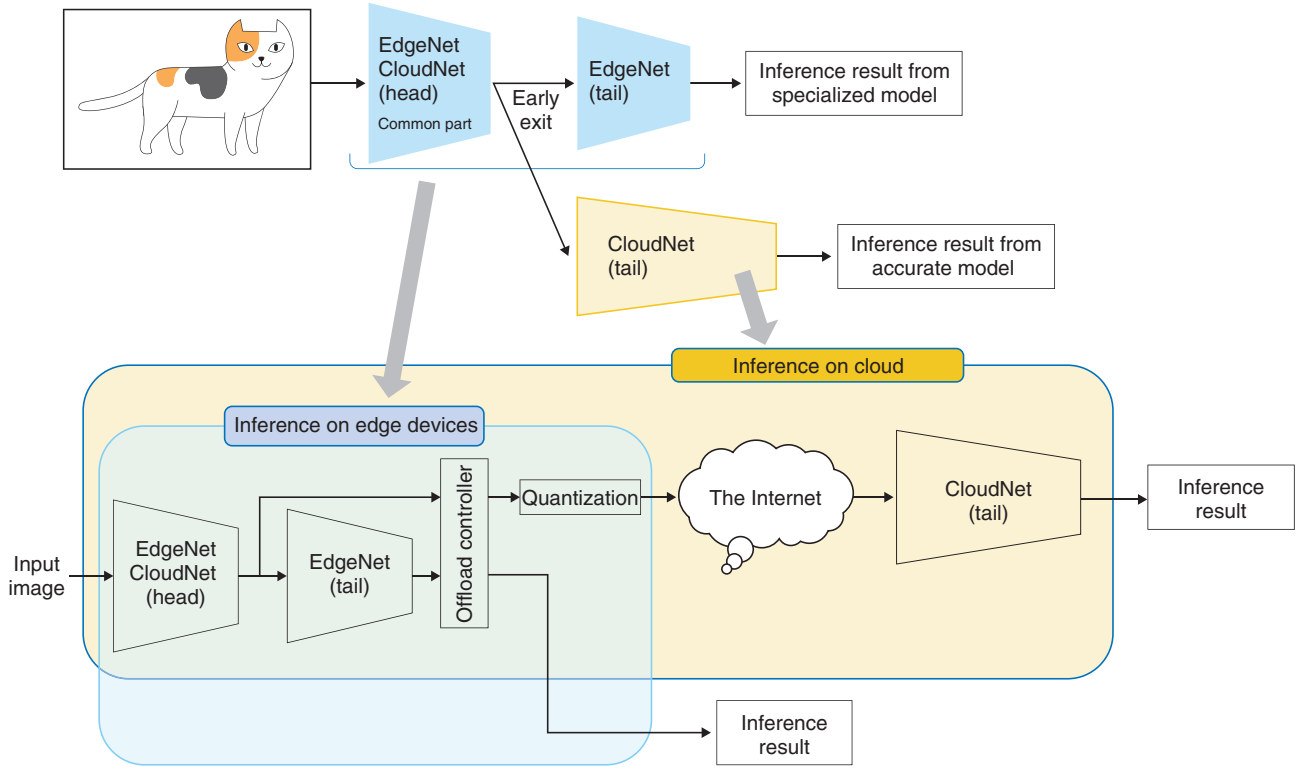

Fig. 6. Model structure sharing and feature quantization by early exit.

7. Future direction

In this article, we introduced an event-driven AI inference approach to support data analytics and provide new value to a data-centric society. By properly using the AI-based model-cascading framework, we

expect our approach will reduce computation/network costs and power consumption dramatically. By exerting continuous effort towards the research and development of IOWN, we believe our approach will yield an AI infrastructure that allows applications to perform inference and reasoning at speeds beyond human ability. Such a system will contribute to resolving many social problems associated with safety, accessibility, sustainability, and comfort.

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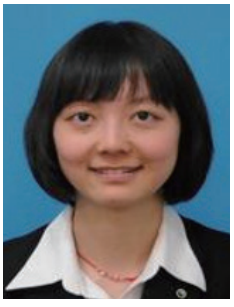

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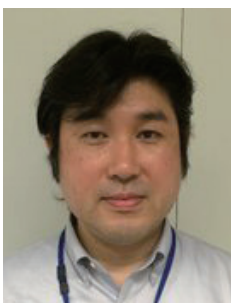

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Next-generation Data Hub Technology for a Data-centric Society through High-quality High-reliability Data Distribution

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Abstract

NTT Software Innovation Center is researching and developing next-generation data hubs as part of the Innovative Optical and Wireless Network (IOWN) proposed by NTT. These data hubs will safely distribute diverse types of data including confidential data through advanced means of data protection in an environment of high-frequency/large-capacity data traffic. This article outlines the problems involved with data distribution and introduces the technologies for configuring data governance, the main function of a data hub.

Keywords: data distribution, data-centric society, data governance

1. NTT's goal of a data-centric society

There has recently been an expansion of Internet of Things (IoT) devices thanks to advances in sensing technology and an increase in data sources having broadband connectivity through the launch of 5G (fifth-generation mobile communication) networks. In addition, advances in artificial intelligence (AI) technologies are enabling high-speed processing of data far exceeding the cognitive and processing abilities of humans. As a result, the amount of data generated throughout the world is increasing steadily in a manner that is expected to not only continue but accelerate in the years to come.

In addition to using data only within closed organizations such as companies, NTT seeks to achieve a data-centric society in which massive amounts of data will be widely distributed beyond the traditional borders of industries and fields at ultrahigh speeds between autonomously operating AI-based systems. This society will enable the creation of totally new value and development of solutions to social problems through novel combinations of data and expertise.

2. Problems in achieving a data-centric society

However, there are two main problems that must be solved to achieve this data-centric society.

2.1 Limits imposed by current data processing architecture

Data processing is currently executed by individual systems (silos) that differ in terms of purpose and processing method. This silo-oriented architecture results in many copies of the same data in those systems. In a data-centric society in which large volumes of data much greater than current levels are exchanged at ultrahigh speeds between many more entities (humans, systems, devices, etc. that distribute data) than today, this situation will only accelerate, which means that the following problems will arise if the current data-processing architecture continues to be used without modification.

- Storage and network performance/capacity will come under pressure.
- The number of data-processing flows that must be managed will increase, making data management

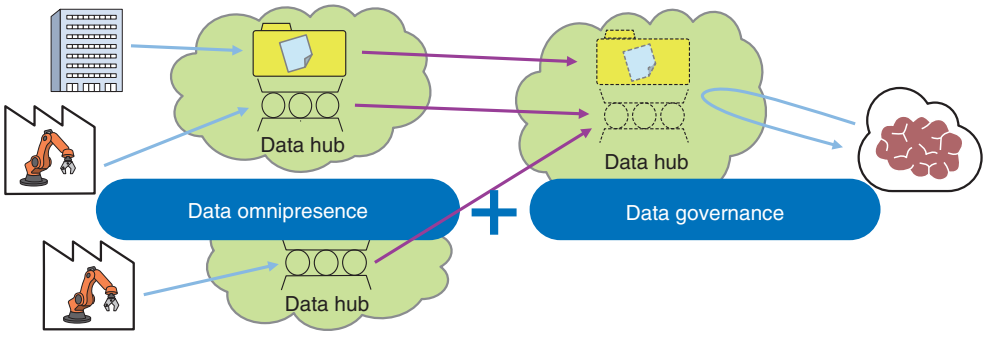


Fig. 1. Next-generation data hubs.

difficult.
- The increase in quantity and types of data items to be processed will make the management of data generation and change history difficult.
- Duplicate and derived data not covered by the rights of source-data providers or by lifecycle management will increase.

2.2 Resistance to sharing confidential information and expertise with other companies

When sharing confidential information and expertise beyond the borders of an organization such as a company, it is common to restrict secondary distribution of shared content or use of that information for purposes other than that agreed upon on the basis of a non-disclosure agreement. However, there are no effective technical mechanisms for preventing secondary distribution or unintended use, so there are limits to enforcing compliance with such an agreement. This has the possibility of hindering a surge in data distribution beyond the traditional borders of industries and fields.

3. Initiatives toward problem solutions

NTT Software Innovation Center aims to solve these problems and achieve a data-centric society by collaborating with various research laboratories including NTT Secure Platform Laboratories to develop next-generation data hubs having the following features (**Fig. 1**).

3.1 Data omnipresence

- Once a data provider creates a folder or queue within a data hub and places data in such a location, authorized users can then use those data from anywhere in the world.
- The data user can perform various types of workload processing or long-term storage with respect to data on the data hub at reasonable cost without having to worry about moving the data around.
- The data user can process data on a data hub by using diverse computing resources having a network connection to that data hub without having to worry about moving or duplicating data.
- The data user can use the application programming interfaces (APIs) of products and services of major storage systems and message broker systems to access a data hub.

3.2 Data governance

- The data provider can maintain and continue to exercise its management rights (governance) in access control, data deletion, etc. with respect to data submitted to the data hub and its duplicated and derived data.
- The data provider can prevent the use of data for purposes other than that agreed upon.
- The data provider can verify who used the provided data for what purpose and for how much.

Between these two major functions of data omnipresence and data governance to be provided by next-generation data hubs now under development, the following section mainly describes the technologies for configuring data governance, which are being developed first.

4. Technologies for configuring data governance

Among the main technologies for configuring data governance, this section mainly describes the data sandbox technology under joint development by NTT Software Innovation Center and NTT Secure Platform

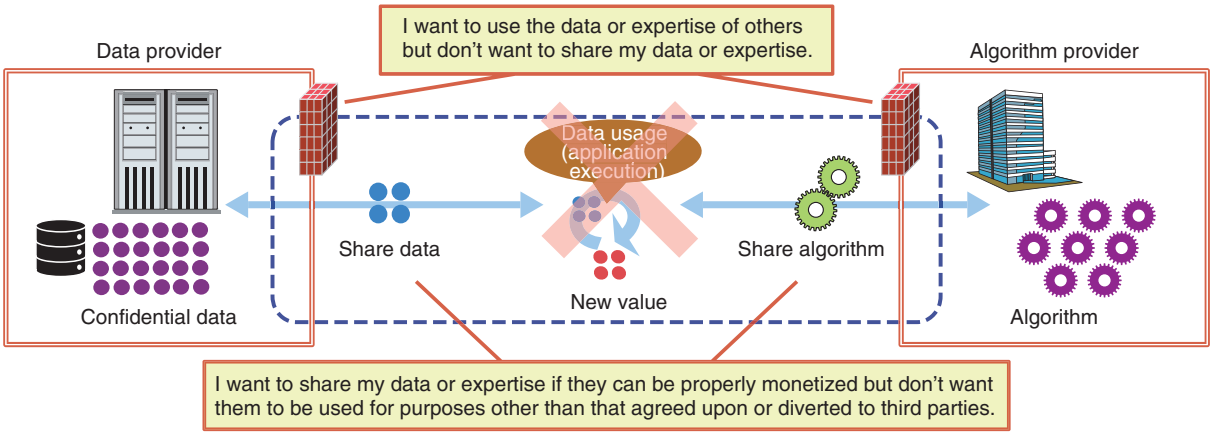


Fig. 2. Problems with data distribution between companies.

Laboratories. This is followed by brief descriptions of mutual-authentication/key-exchange technology and secure-computation AI technology now under development by NTT Secure Platform Laboratories.

4.1 Data sandbox technology

On achieving a data-centric society in which data and expertise (i.e., for creating an algorithm for giving data value) circulate beyond the borders of an organization such as a company, and new value is obtained by combining those data and expertise, the following can be envisioned in the minds of parties that distribute data and expertise.

- I want to use the data or expertise of others but don't want to share my data or expertise.
- I want to share my data or expertise if they can be properly monetized but don't want them to be used for purposes other than that agreed upon (what type and range of data to be processed by what type of algorithm) or be diverted to third parties.

The only way for individual companies to address concerns like these was to draw up and conclude a non-disclosure agreement—a time-consuming process—and place trust in each other. This type of countermeasure, however, has the potential of hindering the distribution of data beyond the organization (**Fig. 2**).

The question, then, is how to provide a systematic and technical means of defense against the above concerns instead of a defense based on agreements and mutual trust. The answer is the data sandbox technology developed by NTT Software Innovation Center.

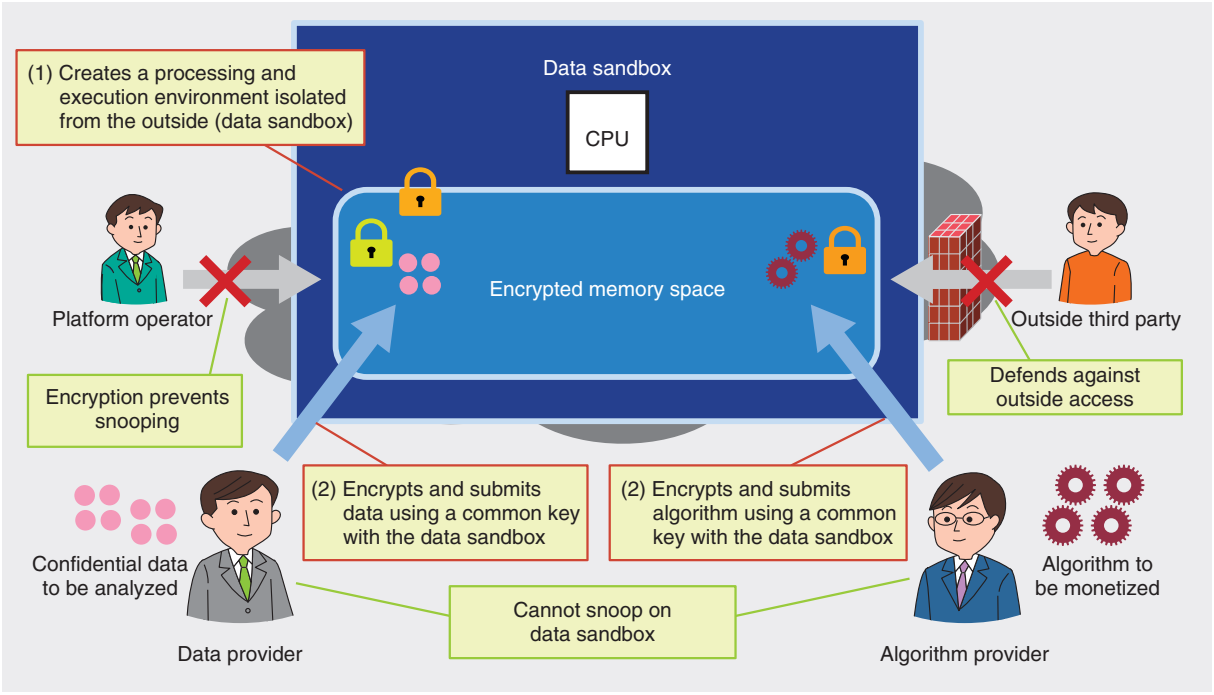
The operation of data sandbox technology can be summarized as follows.

(1) An isolated processing and execution environment called a data sandbox is created on a third-party platform such as a cloud operator that is not a party to data distribution. The data sandbox appropriately restricts communication with the outside and encrypts memory/disk space. The platform operator cannot break this encryption (**Fig. 3**).

(2) Given a data provider having data to be analyzed using another company's algorithm and an algorithm provider monetizing algorithms and providing them to another company, each of these parties generates a common key with the data sandbox and places the encrypted data or algorithm in the data sandbox using that common key. The common key used by the data provider differs from that used by the algorithm provider, thereby preventing the viewing of each other's data or algorithm. The data sandbox also restricts communication with the outside to prevent the data provider and algorithm provider from looking inside the data sandbox while allowing each to only input its data or algorithm (Fig. 3).

(3) The data sandbox decrypts the data and algorithm using common keys with the data provider and algorithm provider. Memory/disk space in the data sandbox is encrypted, which prevents the platform operator from viewing the data or algorithm (**Fig. 4**).

(4) The data sandbox performs processing using the data and algorithm. At this time, the data



CPU: central processing unit

Fig. 3. Data sandbox (operation overview 1).

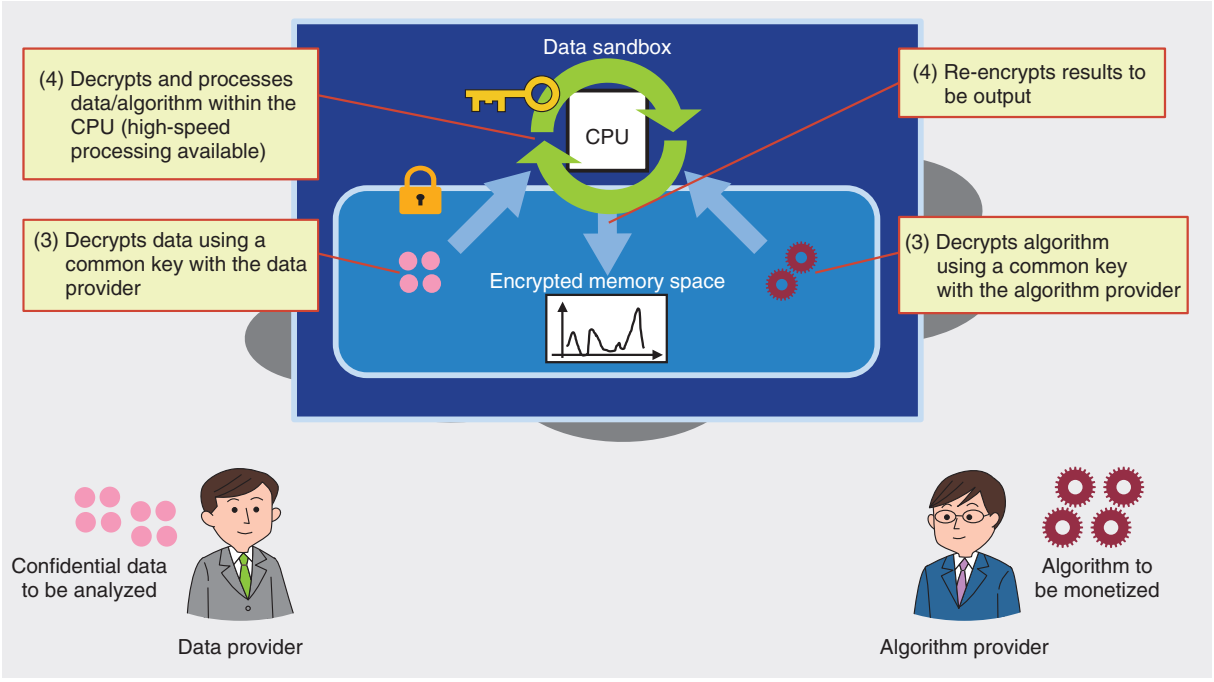


Fig. 4. Data sandbox (operation overview 2).

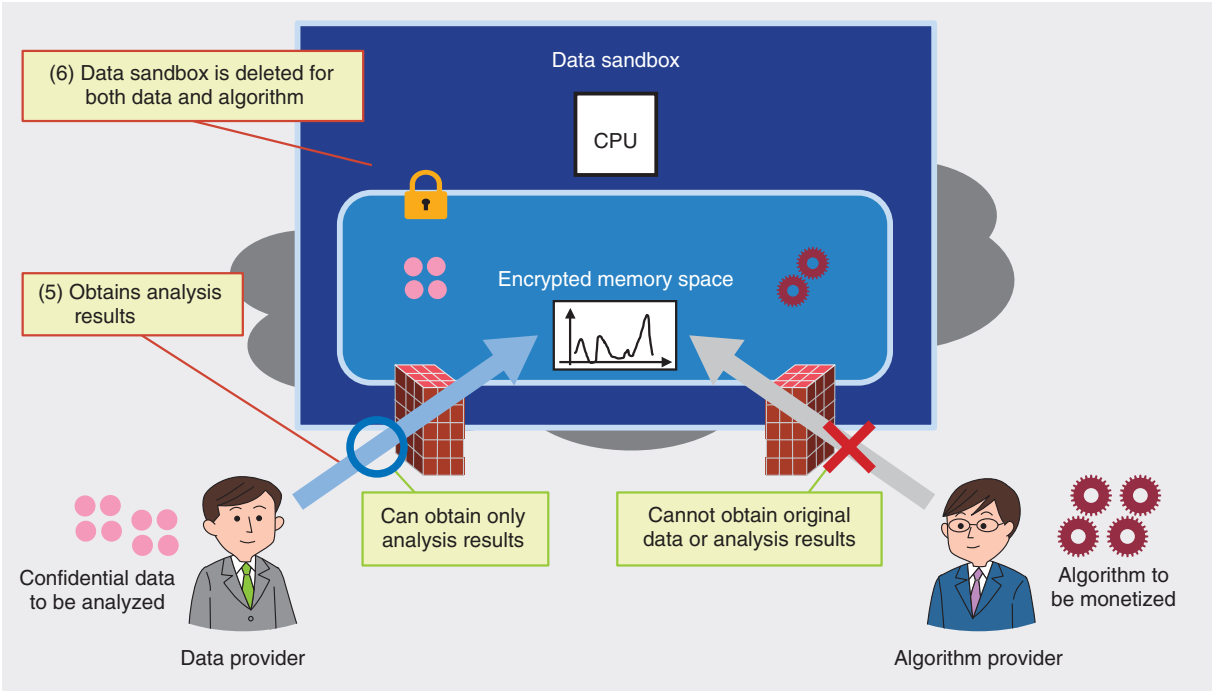


Fig. 5. Data sandbox (operation overview 3).

and algorithm in memory/disk space are decrypted only within the central processing unit (CPU) and processed in plain text to enable high-speed processing. The results of processing are again encrypted in memory/disk space when leaving the CPU (Fig. 4).

(5) The data sandbox returns only the processing results to the data provider. Since communications with the outside are appropriately restricted, the algorithm provider cannot get hold of the original data or analysis results even if it willfully or mistakenly submits a malicious algorithm (**Fig. 5**).

(6) The data sandbox is deleted with the data and algorithm after completing processing (Fig. 5).

A party with access to data distribution that uses a data sandbox operating as described above can benefit in the following ways:

- It can use data or expertise of other parties and obtain new value without having to share its data or expertise.
- It can monetize its data or expertise by systematically and technically defending against use for purposes other than that previously agreed upon or diversion to third parties.

4.2 Mutual-authentication/key-exchange technology

Next-generation data hubs will make it possible to instantly share data located anywhere in the world, but they will also require the means of encryption so that only data users approved by the data provider will be able to reference that data. Mutual-authentication/key-exchange technology enables a data provider and data user to verify each other's identity, attributes, etc. and exchange keys for encrypting and decrypting data without being observed by other parties. This enables safe data sharing only with desired parties.

We can expect next-generation data hubs to be connected to IoT devices that will exist in vastly greater numbers than today, which will make it possible to provide massive amounts of real-world data. For this reason, we are developing mutual-authentication/key-exchange technology that requires a minimal amount of computing resources and transmission bandwidth. We can also expect many parties connected to next-generation hubs to provide and use data in a mutually interactive manner. To handle this scenario, we are developing this technology to efficiently execute mutual authentication and key exchange not on a one-to-one basis but among many parties and that can

flexibly update keys in accordance with the increase or decrease in the number of parties sharing and using data.

4.3 Secure-computation AI technology

Even if a safe execution environment can be assumed, there will still be not a small amount of data for which decryption is not allowed due to data providers that are uneasy about data decryption or legal restrictions. Secure-computation AI technology enables training and prediction through machine learning with absolutely no decryption of encrypted data. It enables execution of the entire flow from data registration and storage to training and prediction without disclosing the content of that data to anyone. The end result is safe distribution and use of corporate confidential information or information restricted due to privacy concerns. This technology also makes it possible to combine and use data from multiple providers or different types of data in encrypted form. We therefore expect secure-computation AI technology to not only improve the safety of original data but to also enable new value to be uncovered due to an increase in the types and quantities of data targeted for analysis.

5. Toward the future

This article focused on the data-governance function of next-generation data hubs we are now developing. Going forward, we are looking to accelerate this development initiative toward the practical deployment of next-generation data hubs through the development of data omnipresence, which is the other major function of next-generation data hubs, seamless linking of data omnipresence and data governance, and achievement of large-capacity and low-latency capabilities by linking with the All-Photonics Network, a major component of IOWN (Innovative Optical and Wireless Network).

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Software Innovation for Disaggregated Computing

Teruaki Ishizaki, Sho Nakazono, Hiroyuki Uchiyama, and Teruyuki Komiya

Abstract

NTT Software Innovation Center researches and develops disaggregated computing technology that supports system infrastructure to respond to the evolution of society and technology. We believe that both hardware evolution and software innovation are important. In this article, we introduce technologies that use hardware specialized for specific devices, such as persistent memory and fast networks, and technologies for improving the performance of many-core central processing units by parallel processing.

Keywords: disaggregated computing, memory centric computing, post-Moore

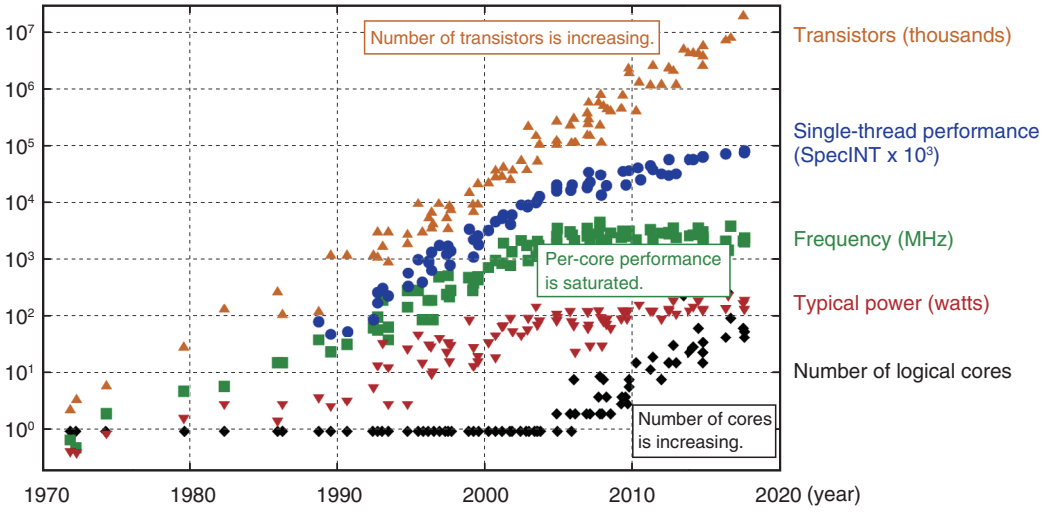
1. Post-Moore era

Moore's Law, which states that the semiconductor integration rate doubles every 18 months, has reached its limit. The single-thread performance of central processing units (CPUs) has reached a plateau (**Fig. 1**). In the post-Moore era, hardware, such as graphics processing units (GPUs) and field-programmable gate arrays (FPGAs), are evolving. Various companies are proposing next-generation hardware. However, current software that has evolved around the CPU cannot perform at its fullest because it is not optimized for specific hardware that performs certain functions very quickly. We believe that the evolution of hardware alone is not enough to develop a computing system that supports various services and applications and that it is necessary to promote software innovation for improving the performance of such advanced hardware.

We are researching and developing software that efficiently uses the coherent Ising machine called LASOLV™ (with NTT Basic Research Laboratories) [1] and optical interconnect technology (with NTT Device Technology Laboratories). We aim to solve combinatorial optimization problems that were difficult to calculate and further improve the performance of computing systems.

NTT's Innovative Optical and Wireless Network (IOWN) aims to promote a network and information-processing infrastructure with ultralarge capacity, ultralow latency, and ultralow power consumption. We must not only speed up the network but also reduce the processing delay required for high processing efficiency. To achieve this, it is necessary to flexibly combine and use various hardware with software in accordance with the application. We need to drastically review the current computing architecture, which has limitations in speed and power saving, and develop a disaggregated computing architecture that performs high-speed and highly efficient data processing. This new computing architecture will not only provide value-creating services by securely connecting a wide variety of real-world data but also create new value for a sustainable society by maximizing power efficiency.

NTT Software Innovation Center is researching and developing (a) memory-centric computing, a CPU-independent technology, and (b) technologies for improving the performance of many-core CPUs of disaggregated computing by parallel processing. In this article, we explain a programming model for persistent memory and fast network devices for (a) and LineairDB, an open-sourced high-speed transactional storage library, for (b).



Original data up to 2010 collected and plotted by M. Horowitz, F. Labonte, O. Shacham, K. Olukotun, L. Hammond, and C. Batten.
New plot and data collected for 2010-2017 by K. Rupp.
This chart is provided under the permissive 'Creative Commons Attribution 4.0 International Public License'.
Adjusting points are adding comments.
Original data: https://github.com/karlrupp/microprocessor-trend-data

Fig. 1. 42-year trend in microprocessor data.

2. Programming model for persistent memory

A new storage-tier device called storage class memory (SCM) is drawing attention. SCM is a persistent memory device that is accessible at speeds close to dynamic random access memory (DRAM) and can have as large a capacity as that of NAND Flash solid state drives (SSDs). Intel Optane Persistent Memory (PMEM), which is SCM, was commercialized as a dual in-line memory module in 2019. It requires current software running moderately fast because SCM is fast, but it cannot make full use a persistent memory device's performance. To achieve this, it must adapt the software design to SCM.

A legacy storage device, such as a hard disk drive (HDD) and SSD, is slow and not good at random accesses. Therefore, they have a general software design in which data are buffered on DRAM and the buffered data are written sequentially to legacy storage. Such a design consumes a large amount of CPU resources to move data to DRAM and storage.

The current software design is effective when the performance difference between DRAM and storage is large but is not effective because SCM performance is close to that of DRAM and the advantage of buffering on DRAM is limited.

We are researching an SCM-aware program model to replace a disk input/output (I/O) layer consisting of DRAM and a persistent memory device with a layer of only SCM with PostgreSQL's Write Ahead Logging (WAL). The architecture of WAL is illustrated in **Fig. 2**.

In conventional PostgreSQL, log data are buffered using a unique buffer mechanism (shared buffer) on DRAM, then the log data are written to the storage. The non-volatile WAL buffer reviews the log mechanism of this two-layer structure and writes data directly to PMEM without buffering to DRAM. The advantages of this method are reduction in the lock wait time of the WAL buffer area due to storage writing of log data, reduction in CPU/memory resources by reducing the number of data copies, and improvement in the performance of insert operation by about 20% [2]. This study is still ongoing as a software implementation study to reduce CPU processing by integrating storage and memory functions [3].

3. Programming model for fast network device

The storage I/O bottleneck should be eliminated by examining the SCM-aware program model described above, but the next bottleneck factor is network I/O. In particular, the latency of network I/O is fatal in distributed data processing software that exchanges data between multiple nodes.

In high performance computing (HPC), this is

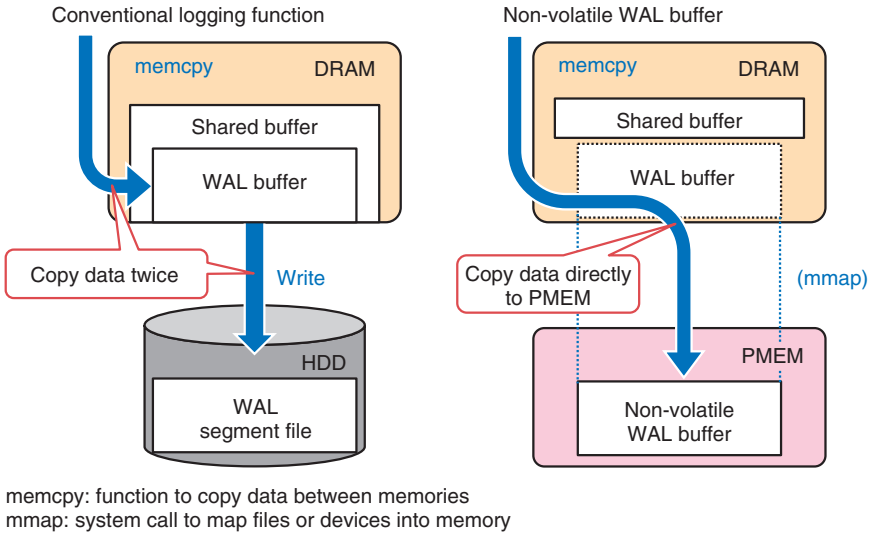


Fig. 2. Application example of non-volatile WAL buffer to PostgreSQL logging function.

solved using a high-speed interconnect device such as Infiniband and remote direct memory access (RDMA), which is a low-latency transfer technology for memory (**Fig. 3**). RDMA is a technology that both ends of network devices execute data copy by bypassing the CPU from the memory of the source server to the memory of the destination server. With no CPU intervention and no TCP/IP (Transmission Control Protocol/Internet Protocol) protocol processing, RDMA is capable of low-latency data transfer.

We are aiming to apply RDMA, which has been used mainly in HPC, to software for enterprises. We have conducted a basic evaluation of RDMA and applied it to MXNet, which is a distributed learning framework [4]. Low-latency transfer processing with RDMA is becoming possible even for memory on hardware such as FPGAs and GPUs, and we consider it an important technology to reduce CPU processing related to network processing.

4. LineairDB: open-sourced high-speed transactional storage library

From our research on disaggregated computing, we proposed a method for high-speed transaction processing on a many-core CPU. The method has high scalability of processing throughput on CPUs that have a total of 144 cores [5]. On the basis of this method, we developed and open-sourced a transactional storage library called LineairDB in April 2020 [6].

The number of transistors in CPUs has increased by increasing the number of CPU cores (Fig. 1). However, the current database design, the architecture of which was developed in the 1970s and 1980s, does not take into account many-core CPU machines because the design depends on single-core CPU machines. It is well known that the processing speed of a database decreases in many-core CPU environments [7].

Database researchers proposed various methods for solving this problem for read-heavy workloads but not write-heavy workloads. Therefore, we must use one of the current methods for write-heavy workloads. LineairDB has high-speed transaction processing technology that provides scalability for write-heavy workloads in many-core CPU environments and can improve the performance of many-core CPUs. For instance, on a server with a 144-core CPU, the method using LineairDB is three times faster than the current method for the popular benchmark YCSB (Yahoo! Cloud System Benchmark); read operation ratio 50%, write operation ratio 50%. The processing throughput is over 10 million transactions per second [6]. Since LineairDB has a simple key-value store interface, one can use it in various situations. The license of LineairDB is Apache License, version 2.0, which is highly compatible with several other licenses. We are always participating in the LineairDB community and use slack to communicate among users and developers. If one has questions and requirements, please join the LineairDB community.

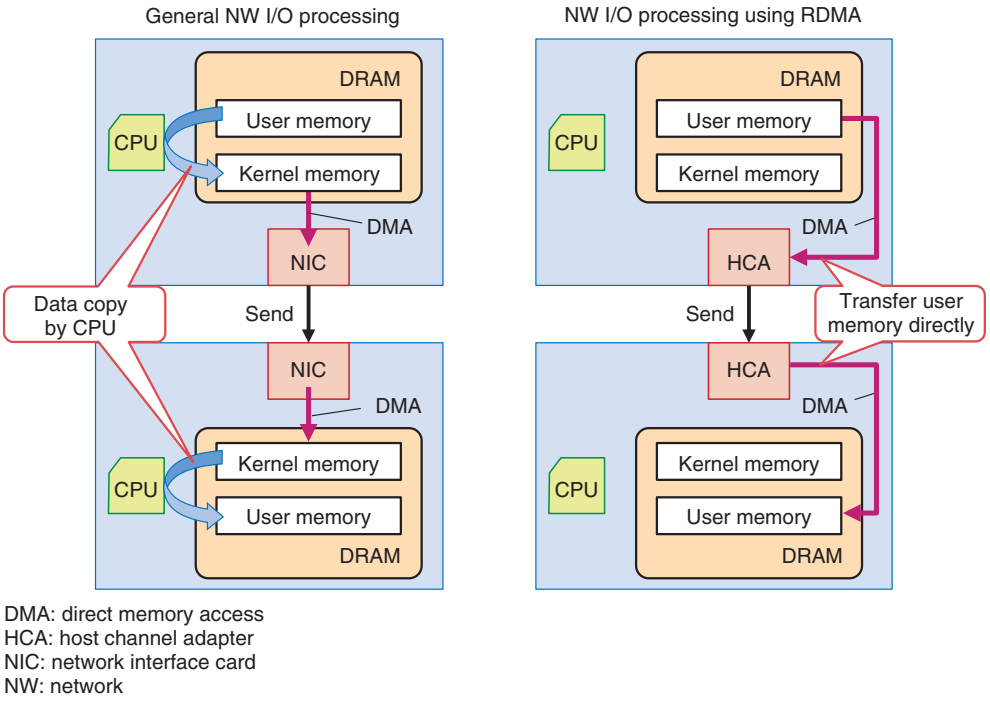


Fig. 3. General network processing and network processing using RDMA.

Developers are also always welcome to the community. We will extend LineairDB to be used in various use-cases by developing useful interfaces and range queries.

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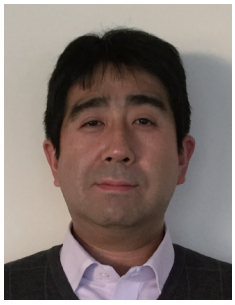

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Test Automation Technology for Analyzing Test-activity Data and Detecting Bugs

Haruto Tanno, Hiroyuki Kirinuki, Yu Adachi, Morihide Oinuma, and Tatsuya Muramoto

Abstract

There is a growing demand for the early release of software while holding down costs. Software testing, which makes up a large portion of overall development costs and is essential to ensuring a certain level of quality in software, can be viewed as the cornerstone of quality, cost, and delivery in the development process. This article describes technology undertaken by NTT Software Innovation Center for achieving a dramatic leap in testing efficiency and discusses the future outlook for this technology.

Keywords: software testing, exploratory testing, test script

1. Importance of software testing

The software-development process is summarized in **Fig. 1**. In this process, software defects that could not be removed during testing are released in that state to the user, so testing is a critical process essential to software quality assurance. Yet, attempting to do all testing manually is extremely costly. Users' needs have been changing rapidly, and software and hardware that constitute the operating environment have likewise been evolving at a rapid pace. This makes it necessary to revise software quickly as the need arises and release software updates frequently at short intervals. However, to conduct software releases frequently while maintaining a certain level of quality, testing cannot be limited to just the new additions even in a small-scale update. It is also necessary to conduct regression testing with respect to all existing features at every release to check whether they have been adversely affected by new features or a new operating environment. This need can also incur high costs. NTT Software Innovation Center seeks to revolutionize testing—the cornerstone of quality, cost, and delivery in software development—and achieve a quantum leap in productivity in the software-development process.

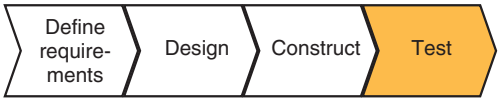


Fig. 1. Software-development process.

2. Current state of software testing

The purpose of software testing includes checking that the software is behaving normally and reducing the number of software defects. As shown in **Fig. 2**, the testing process can be broadly divided into five tasks: test planning, test design, test execution, test management, and test reporting. Test planning involves decisions on test period, resource allocation, etc. based on an overall development plan. Test design involves identifying test variations that should be carried out, exhaustively designing test cases, and for each test case, refining a specific procedure for executing the test and creating a script for automatic execution. Next, test execution involves providing

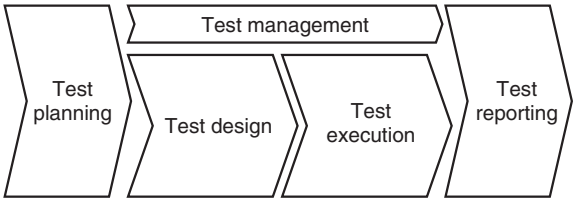


Fig. 2. Testing process.

input data for each test case, running the software, and checking whether the software is behaving as expected. Test management involves managing test-execution conditions as needed and revising the plan if conditions warrant. Then, once all tests have been completed, the final task is to compile test results and issue a test report, thereby completing overall testing. Among these tasks, test design and test execution play major roles in the testing process.

The first issue in traditional exhaustive testing is the high costs incurred in both design and execution. Pursuing completeness in testing with the aim of improving quality can take a massive amount of time while extending the period until release. Moreover, evaluating completeness is inherently difficult. For example, using specifications as a standard for completeness depends heavily on the quality of those specifications, and the content of the test itself cannot be evaluated on the basis of code coverage. In addition, simply clearing certain index values does not mean that the degree of quality improvement is well understood.

The second issue is the costs incurred in automating regression testing, which is required when issuing releases frequently in short cycles. Although many frameworks and libraries, such as JUnit and Selenium, are currently available for automatically executing tests, scripts must be created for such automatic execution, which can be very time consuming. To make it worse, a completed script does not mean that no more work is needed since it must be revised together with any revisions made to the software targeted for testing. This type of maintenance work is also labor intensive.

3. World we aim for

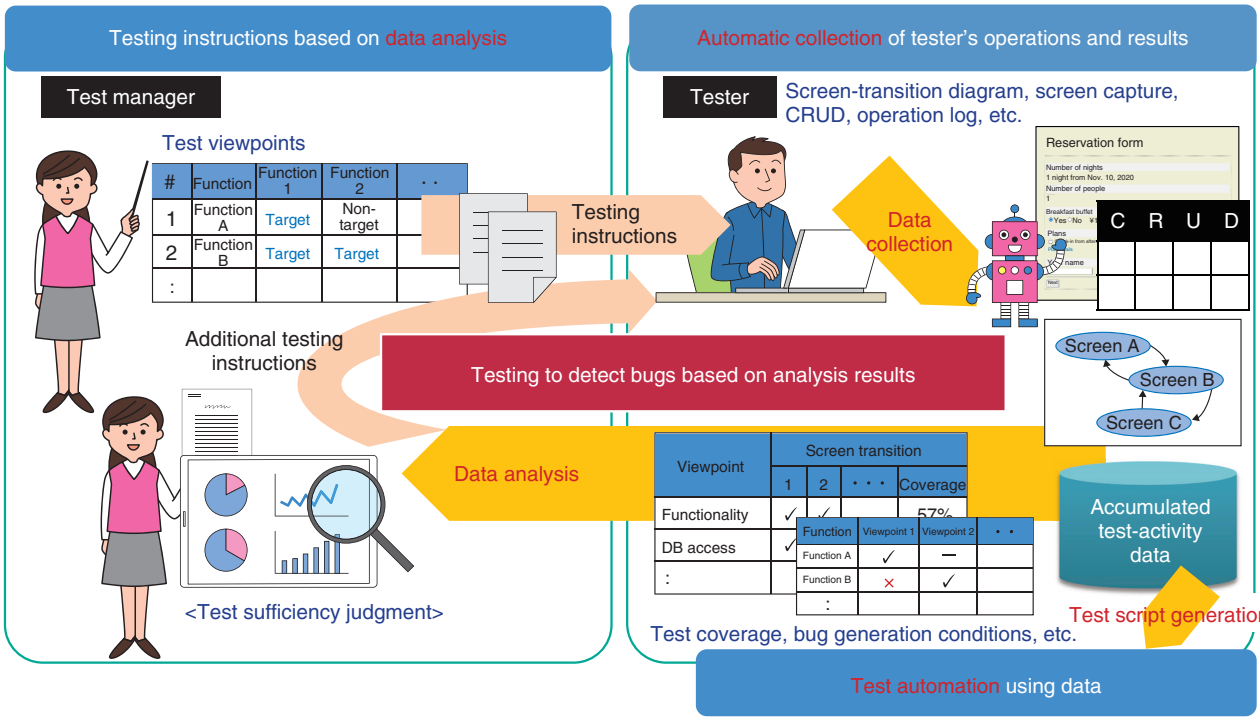
To achieve ultra-high-speed development that can handle increasingly diverse and vague business requirements and rapidly evolving businesses, the approach taken by NTT Software Innovation Center is to establish artificial intelligence (AI) development technology that can substitute or even excel in some human work and to develop software through human-AI cooperation. The world we aim for to achieve such ultra-high-speed development is shown in **Fig. 3**. In our approach, instead of haphazardly pursuing completeness, we select the locations that should be tested and concentrate our efforts there. In addition, we make successive judgments as to what locations to select and concentrate on by collecting and analyzing test-execution conditions and results. This approach solves the problems surrounding traditional exhaustive testing and achieves a quantum leap in testing efficiency. Furthermore, by using test-activity data accumulated over time and automatically generating easy-to-maintain test scripts, it has become relatively easy to automate regression testing, which makes for prompt releases after making software updates.

The NTT Group develops many business applications that use web applications as front ends and tests these applications through integration testing. In this article, we describe LatteArt as a technology targeting integration testing, which has a great need for efficiency improvements.

4. LatteArt: Technology for analyzing test-activity data and detecting bugs

A business application has many use-case scenarios, features, and screens, and each screen may have many combinations of input patterns. This incurs high costs in traditional exhaustive testing. While there are tools that support test design through automatic design of exhaustive testing on the basis of some type of model (e.g., software design model), executing all required tests is still labor intensive, thereby placing a limit on the degree to which overall testing can be made more efficient. In addition, automating the testing of web applications requires the creation of test scripts for executing screen operations automatically. In addition to the fact that the manual creation of such test scripts drives up costs, a test script must be revised whenever the associated web application is updated, which is also costly from a maintenance point of view. In this regard, there are capture & replay tools (e.g., SeleniumIDE) that can be used to create scripts even without advanced skills, but creating scripts in this manner still requires work. Moreover, because test scripts recorded by capture & replay are not modularized, they suffer from low maintainability.

To solve these problems, we developed a technology



CRUD: create, read, update, delete
DB: database

Fig. 3. World we aim for.

called LatteArt for analyzing test-activity data and detecting bugs. LatteArt has the following features.

(1) Collection of test-activity data

This step involves automatically collecting test-activity data consisting of the tester's operation log and web-application screenshots as well as test objectives input by the tester while executing tests, discovered bugs, findings, etc.

(2) Analysis of test-activity data

In this step, the test manager gives instructions on test content at a general level in the manner of combining the test viewpoint and test-target feature without creating a detailed test [1, 2, 3]. The tester then conducts tests based on those instructions. In addition, test-activity data that have been automatically collected are analyzed and visualized using a variety of data models, enabling the test manager to determine if the test is sufficient or give instructions for additional tests. For example, the models shown in the sequence diagram and screen-transition diagram in **Figs. 4** and **5**, respectively, can visualize test-activity data. Furthermore, as shown in **Fig. 6**, the test manager can focus on a specific screen transition using the screen-transition diagram to check a list of input patterns that occur when making that screen transition. Selecting locations that should be tested and concentrating on those locations in this manner facilitates testing that can detect bugs with good efficiency.

(3) Application of test-activity data

Test-activity data can be used to automatically generate test scripts that modularize screen-element locators based on the concept of page-object patterns. This approach simplifies the maintenance of test scripts even when revising an application and enables regression testing to be automated, eliminating the labor that would otherwise be required.

5. Achievements and future outlook

We aim to become a leader in test technology based on the analysis of test-activity data and change the conventional way of doing testing in the system integration industry. We are currently evaluating the application of LatteArt through joint experiments with NTT operating companies and are receiving

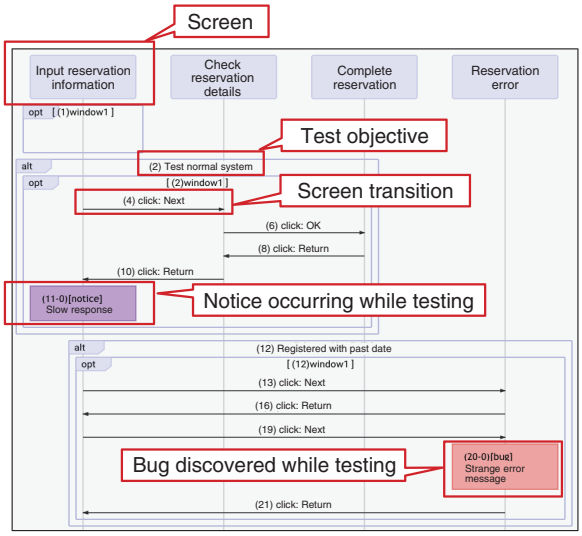


Fig. 4. Sequence diagram.

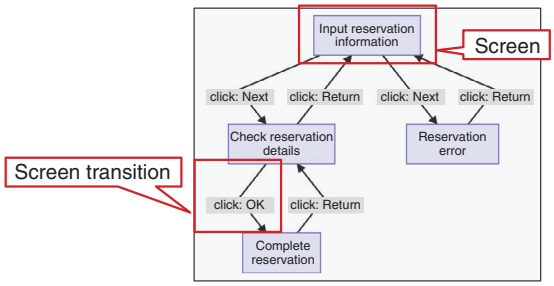


Fig. 5. Screen-transition diagram.

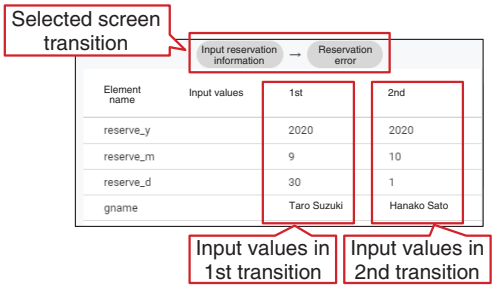


Fig. 6. Input patterns during screen transition.

positive responses from development sites. We have also received high evaluations for LatteArt through presentations at academic societies in Japan and have received a number of awards for LatteArt.

In addition to the analysis and visualization of test-activity data and the automatic generation of test scripts, as introduced in this article, we can consider a variety of research directions in the use of test-activity data automatically collected and stored using LatteArt. The following are examples of these directions.

- Test recommendations: A test with a high probability of discovering bugs can be automatically recommended by analyzing which type of test was conducted by a tester when he/she discovered bugs.
- Test education: Test-activity data of experienced testers can be used as educational material. In addition, analyzing and comparing test-activity data of multiple testers should make it possible to measure testing skills.
- Application to areas other than testing: Test-activity data could be used to restore the specifications of software targeted for testing, automatically generate manuals, etc.

Going forward, our goal is to create an ecosystem for revolutionizing testing and software development centered around LatteArt. We will achieve this by collaborating with companies and universities outside the NTT Group to incorporate various types of industrial and academic knowledge in our research. For this reason, we plan to study the conversion of LatteArt to open-source software and work on widely disseminating this technology. We are committed to making steady progress in researching and developing this technology based on feedback from development sites. Our ultimate goal is to create a world in which AI can conduct testing automatically by collecting massive amounts of test-activity data.

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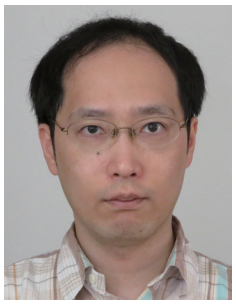

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Standardization of Next-generation Wireless LANs in the IEEE 802.11 Working Group

Yasuhiko Inoue and Akira Kishida

Abstract

The market of wireless local area networks (LANs) has extended from the original personal computer peripherals to various segments such as information appliances, Internet-of-Things devices, and automobiles. The Institute of Electrical and Electronics Engineers (IEEE) 802.11 working group, which develops the standard of wireless LANs, is working on new projects for next-generation wireless LANs. This article introduces current activities in the IEEE 802.11 working group focusing on the next mainstream wireless LANs such as the IEEE 802.11ax and 802.11be following the 802.11ax. Related activity in the Wi-Fi Alliance for providing interoperability test services of wireless LAN devices based on the IEEE 802.11 standards is also covered in this article.

Keywords: IEEE 802.11, wireless LAN, standardization

1. Standardization activity in the IEEE 802.11 working group

The Institute of Electrical and Electronics Engineers (IEEE) 802.11 [1] is a working group (WG) within the IEEE 802 LAN/MAN Standards Committee [2] that develops various standards related to local area networks (LANs) and metropolitan area networks (MANs) and is responsible for standardization of physical layer and medium access control (MAC) layer technologies of wireless LANs.

1.1 Subgroups within the IEEE 802.11 WG

There are several types of subgroups within the IEEE 802.11 WG. A task group (TG) is a subgroup responsible for developing a technical standard or recommended practice. A study group is a preparatory group to create a TG to discuss use cases, technologies, and feasibilities. As a result of discussion, a study group creates documents called Project Authorization Request and Criteria for Standards Development. There are also a group to discuss a specific topic called a topic interest group (TIG), standing committees, and ad hoc groups. **Table 1** lists the current subgroups in the 802.11 WG.

2. Standardization of the IEEE 802.11ax

The latest wireless LAN products with the brand name “Wi-Fi 6” that can be found in home-electronics retail stores are based on the IEEE 802.11ax standard. Although this standard defines data-transmission speed up to 9.6 Gbit/s, the maximum speed supported by actual products varies from about 1 to 5 Gbit/s depending on the price. The standardization of the IEEE 802.11ax will be completed shortly. The Wi-Fi Alliance [3], which provides interoperability test services, has started certification of 802.11ax devices under the brand name Wi-Fi 6.

2.1 New technologies of the IEEE 802.11ax

For better frequency utilization, the IEEE 802.11ax specified a new multi-user transmission technique called orthogonal frequency-division multiplexing (OFDMA), which has been adopted for LTE (Long Term Evolution) and WiMax (Worldwide Interoperability for Microwave Access) systems for both downlink and uplink. In the 802.11ax, a maximum of

Table 1. Subgroups in the IEEE 802.11 WG.

Subgroup	Mission
TGax	Next-Generation High Efficiency Wireless LAN
TGay	Next-Generation 60-GHz Wireless LAN
TGaz	Next-Generation Positioning
TGba	Wake Up Radio
TGbb	Light Communications
TGbc	Enhanced Broadcast Service
TGbd	Enhancements for Next-Generation V2X
TGbe	Extremely High Throughput
TGbf	Wireless LAN Sensing
TGbh	Randomly Changing MAC address
TGbi	Enhanced Service with Data Privacy Protection
Tgme	IEEE 802.11 Standard Maintenance and Roll Up
AANI SC	Advanced Access Network Interface (Interworking with 5G)
COEX SC	Coexistence (with cellular based systems)
WNG SC	Wireless LAN Next Generation

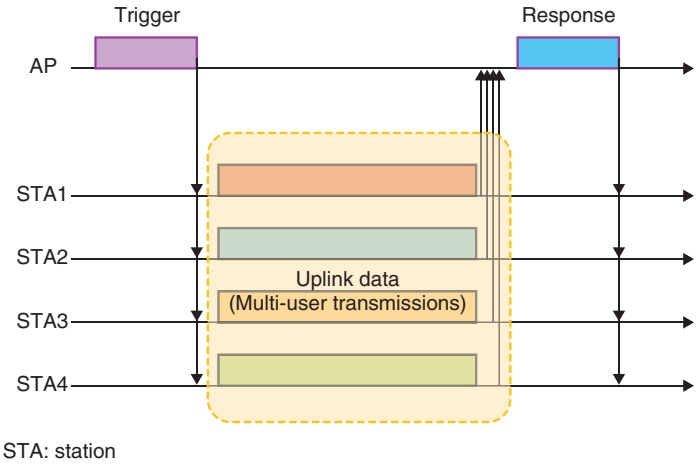


Fig. 1. Uplink multi-user transmission sequence initiated by a trigger frame.

nine users can be allocated in a 20-MHz channel and can transmit or receive data to and from an access point (AP), respectively. OFDMA is extremely useful for transmitting short packets such as voice and TCP ACK (Transmission Control Protocol acknowledgment). The 802.11ax also extended the multi-user multiple-input multiple-output (MIMO) technique, which was originally specified by the IEEE 802.11ac standard for downlink, to both downlink and uplink.

The IEEE 802.11ax defined the uplink multi-user transmission data transmission protocol sequence using a *trigger frame*, as shown in **Fig. 1**. The trigger frame enables client devices to adjust parameters, such as transmission timing and transmit power, for the following uplink transmissions by the designated clients.

The 802.11ax also defined another mechanism, called spatial reuse, to enhance frequency utilization by mitigating the effect of transmissions from other devices [4].

2.2 Support of the 6-GHz band

In the United States, the 6-GHz band (from 5.925 to 7.125 GHz) was allocated for unlicensed wireless

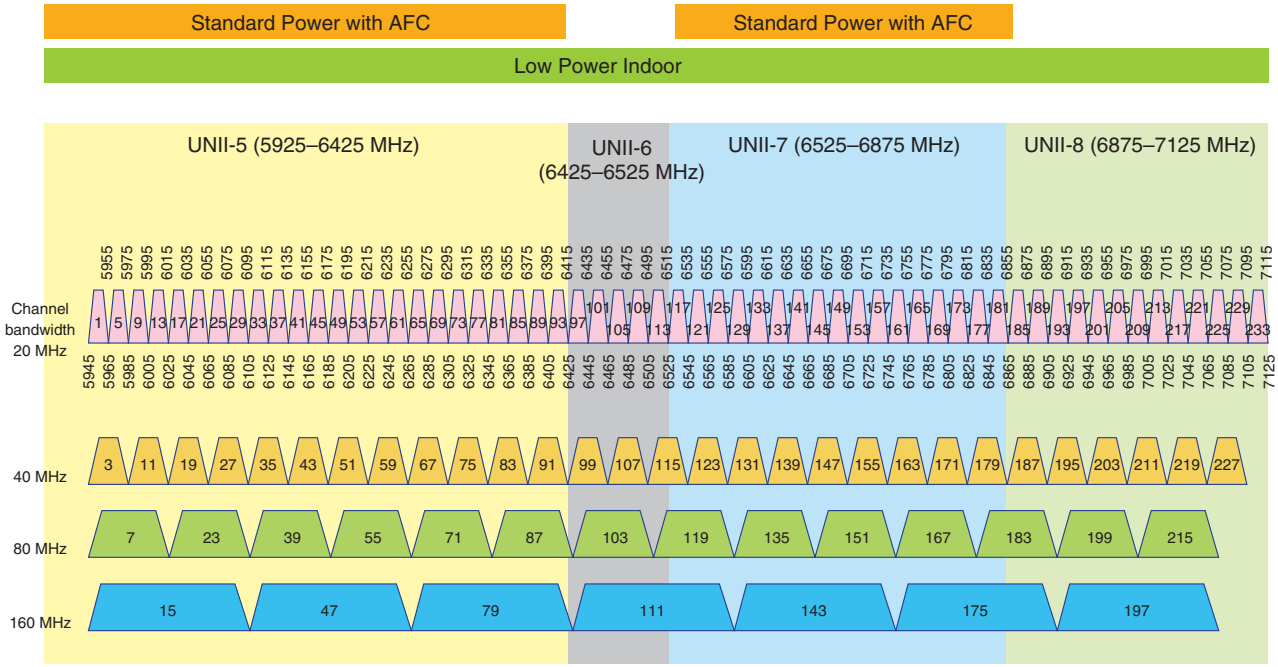


Fig. 2. Channelization in the 6-GHz band agreed in the IEEE 802.11ax.

communication systems, including wireless LANs, in the spring of 2020 (see **Fig. 2**). By this allocation of a large frequency band, it is anticipated that interference among wireless LAN devices will be reduced. Therefore, better throughput and latency performance can be expected, which enables the accommodation of new applications requiring more bandwidth such as augmented reality and virtual reality.

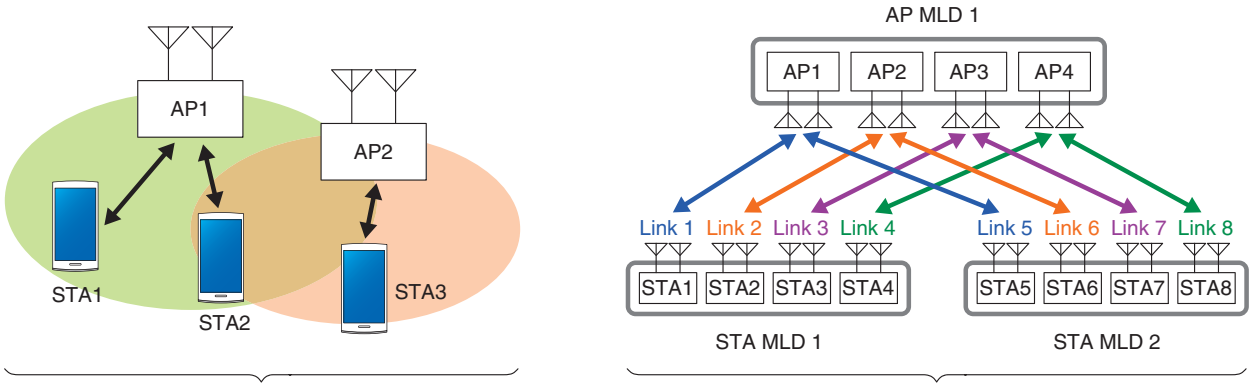
In the 6-GHz band, however, there are several incumbent wireless communication systems, and the wireless LAN system needs to satisfy specific requirements to coexist with those systems. In the United States, the 6-GHz band is divided into four segments, and the technical requirements are defined for each one. There are two categories of wireless LAN devices, Low Power Indoor (LPI) and Standard Power (SP). LPI devices are allowed to use any frequency segment of the 6-GHz band but are only allowed for indoor environments. SP devices, on the other hand, are allowed to emit higher power, but are allowed to operate in only specific frequency segments, and the use of automated frequency coordination (AFC) is mandated to protect existing wireless systems. There is another category called Very Low Power (VLP) under discussion. In Japan, discussion on the unlicensed use of the 6-GHz band has not begun; however, there is strong demand from industries, and it is very likely that discussion will begin shortly.

3. The IEEE 802.11be—the extremely high throughput wireless LAN

To achieve more than 30 Gbit/s for maximum throughput at the MAC service access point (SAP), the TGbe was created in May 2019. The IEEE 802.11be standard will be published in May 2024 in accordance with the results of the discussions in the TGbe. The IEEE 802.11be will succeed the 802.11ax as the mainstream wireless LAN standard. In addition to technical topics, the TGbe is currently discussing the framework of the draft standard called Specification Framework Document. The TGbe plans to continue this discussion until May 2021 and plans to release draft version 1.0. The following features are currently being discussed for the IEEE 802.11be standard.

3.1 Improvement in frequency-utilization efficiency and utilization of wider bandwidth

The IEEE 802.11ax adopted modulation schemes up to 1024 quadrature amplitude modulation (QAM), maximum of 8 spatial streams for MIMO, and channel bandwidth of a maximum of 160 MHz. The TGbe is considering a maximum of 4096 QAM, 16 spatial



Each STA transmits data over a single link between it and the associated AP.

(a) Conventional configuration of the IEEE 802.11 wireless LAN systems

Data are transmitted over multiple links between MLDs that consist of multiple APs or STAs.

(b) Configuration of the IEEE 802.11be wireless LAN systems using multi-link transmissions

Fig. 3. Multi-link transmission.

streams, and 320 MHz. Hybrid automatic repeat request will also be adopted to improve the efficiency of data retransmission.

3.2 Multi-link transmission

The TGbe will define multi-link transmission as a new feature. In legacy wireless LANs including the 802.11ax, each station (STA)* transmits/receives data over a single link between it and the associated AP. In multi-link transmission, it is assumed that wireless LAN devices (multi-link devices: MLDs) consisting of multiple APs or STAs and multiple links between MLDs, which operate on different channels, can be used for data transmission and reception (**Fig. 3**). Multiple links are established between MLDs that consist of multiple APs and those that consist of multiple STAs. This enables faster and more reliable transmission. For example, high-speed transmission will be possible by transmitting different data frames on multiple different links in parallel. Reliability can be improved by using multiple links for transmitting duplicated identical frames. Choosing the highest quality link for priority traffic or control frames also enables highly reliable data transmission.

3.3 Multi-AP coordination

The TGbe will define multi-AP coordination as another new feature. The following functions are being discussed in the TGbe for this feature. Coordinated spatial reuse (Co-SR) optimizes parameters such as the transmit power of each AP; coordinated beamforming (Co-BF) enables simultaneous transmission from multiple APs to avoid generating interference in the same frequency band and time; joint transmission (JT) enables receiver STAs to combine data from multiple APs; and coordinated orthogonal frequency-division multiple access (Co-OFDMA) assigns resource units flexibly between multiple APs.

3.4 Low-latency features

Features for achieving low latency and low jitter communications, even if there are many competing STAs or in interference environments, will be defined in the TGbe. Features for notifying the latency of a specified link; mechanisms that can ensure transmission time for periodic latency-sensitive traffic; and the combination of IEEE 802.1 Time Sensitive Networking and the access control mechanism of IEEE 802.11 are being discussed in the TGbe.

3.5 Other features

National security and emergency preparedness that enables the prioritization of emergency communications and a mechanism for direct communication between STAs with assistance from APs are also being proposed in the TGbe.

4. Interoperability test in the Wi-Fi Alliance

The Wi-Fi Alliance is an organization to promote

* Station (STA) is a client device of wireless LAN.

the adoption of wireless LAN devices and services into various market segments. It provides interoperability test services for wireless LAN products based on the IEEE 802.11 standards. A wireless LAN device that passed the interoperability test of the Wi-Fi Alliance is allowed to use the Wi-Fi certified logo.

The Wi-Fi Alliance has started interoperability testing for 802.11ax products under the brand name Wi-Fi 6 based on the draft version of the IEEE 802.11ax standard. As mentioned previously, Wi-Fi 6 certified products are currently available on the market. There are two more interoperability test services for 802.11ax products under development. One is called "Wi-Fi 6E" to test features for operations in the 6-GHz band in addition to the current Wi-Fi 6 interoperability test. The Wi-Fi 6E certification program will be launched shortly. The other one is "Wi-Fi 6 R2," which is based on the official standard of the IEEE 802.11ax.

5. Summary

In this article, standardization activities of the IEEE 802.11ax and 802.11be wireless LANs were briefly introduced. The IEEE 802.11ax standardization is close to completion, and products based on the draft standard are currently available. The IEEE 802.11be is the next mainstream wireless LAN standard succeeding the 802.11ax. The standardization is still in the early phase, and the TGbe in the IEEE 802.11 WG is actively discussing the features and technologies for it.

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Approach to Solving the Problems with IP-based Telephone Systems in the Field

Technical Assistance and Support Center, NTT EAST

Abstract

This article introduces a protocol analysis-support tool for Internet protocol (IP) based key telephone systems called the α-Command Analysis Support Tool developed by the Technical Assistance and Support Center, NTT EAST, to solve problems with such systems in the field. This is the sixty-second article in a series on telecommunication technologies.

Keywords: packet capture, key telephone system, command analysis

1. Introduction

The Network Interface Engineering Group at the Technical Assistance and Support Center (TASC), NTT EAST, provides technical support to identify the cause of problems in the field not only plain old telephone services provided by the public switched telephone network, but also related to Internet protocol (IP) services, such as FLET'S Hikari fiber-optic broadband service. By carrying out on-site investigation, we will be able to determine the causes of problems and provide appropriate countermeasures. Recently, problems in the field have become more diversified because the telephone systems have shifted to IP, and more valuable services using wireless terminals and cloud resources have been introduced. This article introduces our efforts concerning problems related to IP services and, in particular, proposes a tool for handling problems with key telephone systems.

2. Efforts concerning problems with IP services

Capturing and analyzing IP packets are effective for investigating the causes of problems with IP services. TASC has developed packet capture devices, as shown in **Fig. 1**. We also developed various tools for analyzing communication protocols and commands, measuring the amount of traffic and bandwidth, analyzing unauthorized accesses, or decoding voice data. These tools can be easily used by service personnel in the field and support their investigation for determining the causes of problems.

3. Development of analysis-support tool for key telephone systems

3.1 Background

Problems that occur in the field are diversifying because of the widespread use of cloud services and multi-functional equipment. Customer networks have also become complex due to the integration of several services, such as telephony and Internet. Thus, it is sometimes difficult to determine the causes of problems that occur only occasionally. In such cases, investigation is mainly conducted by interviewing customers, and only preventive measures, such as replacing equipment and/or wiring, are carried out by service personnel.

Regarding problems with key telephone systems,

“Cap-two” (multi-port large-capacity recording)

“Toy Cap” (inexpensive, simplified version)

Fig. 1. Packet-capture tools developed by TASC.

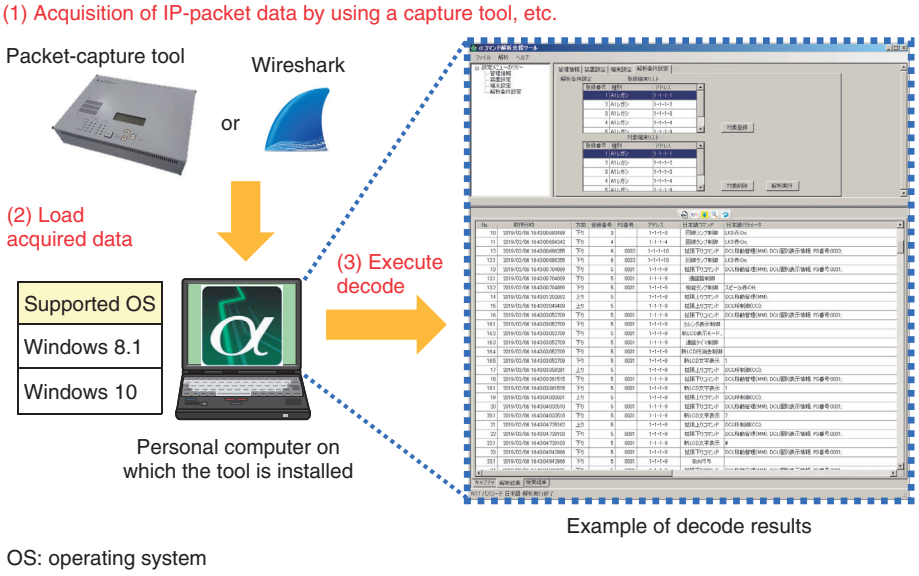

Fig. 2. Using α-Command Analysis Support Tool.

factors related to such problems exist not only in the system but also in usage (such as incorrect telephone operations), and such combined factors may lead to a longer investigation. Given these circumstances, we developed the α-Command Analysis Support Tool for monitoring exchange commands between the master equipment unit of the key telephone system and telephones.

3.2 Overview of functions

This tool can decode various information, such as communication commands (α-command), from IP packets sent between the master equipment unit and telephones of the “α series” key telephone system sold by NTT EAST and NTT WEST. By inputting the IP-packet information acquired by packet-capture devices or other software to this tool, the α-command sequence, parameters, telephone operations executed by the user, content of the telephone displays shown at those times, and operation details of the master equipment unit are outputted as analyzed results. Based on this output, it is possible to understand the system status when a problem occurred. The usage of this tool is illustrated in **Fig. 2**.

This tool also has the following functions for supporting detailed data analysis.

- “Save as CSV”: Save the analysis result displayed in the tool as a comma-separated value (CSV) file. Depending on the user’s preference, other tools that can handle the CSV data can be used to edit the analysis results.
- “Jump to”: Specify a date and time in minutes and seconds within a large amount of data and spot the data at the time the problem occurred.

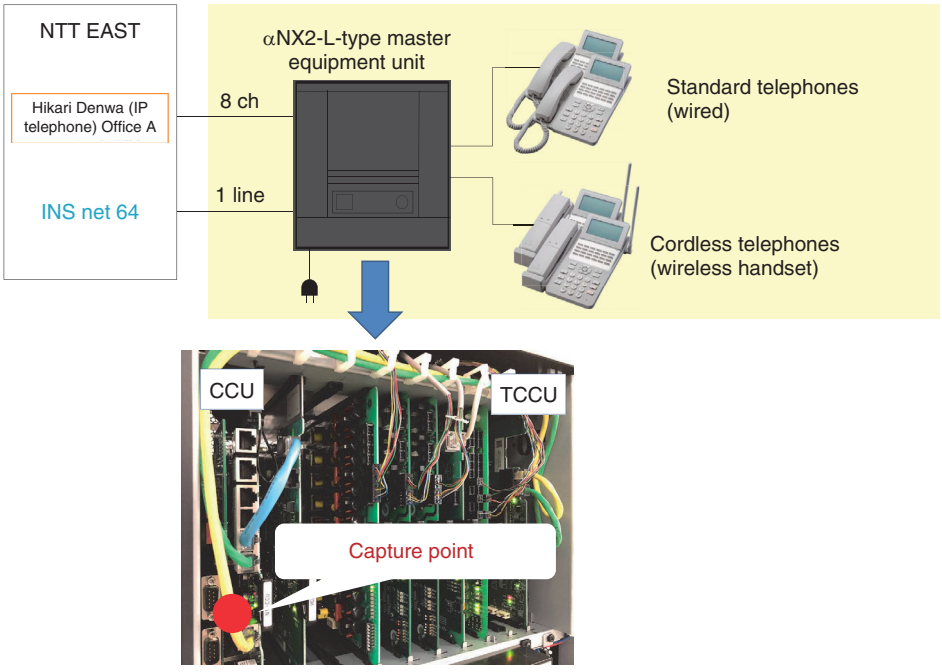

Fig. 3. Capture point.

- "Search": Search by specifying the telephone equipment (by extension number or process identifier (PS) number) or a specific α command.

4. Example cases of our analysis-support tool

4.1 Summary of problem and capture points

A customer who uses cordless telephones (NX2-<24> CCLBTEL-<1>) with an αNX2-L-type master equipment unit reported that a telephone rebooted when making outgoing calls. Although the on-site service personnel replaced the master equipment unit and a telephone, the problem persisted; therefore, TASC investigated the cause of the problem by capturing IP packets in cooperation with the service personnel. During that investigation, to detect the problem reported by the customer, IP packets were captured at the point shown in **Fig. 3** (TCCU port of communication control unit (CCU)) with the packet capture device Cap-two (see Fig. 1).

4.2 Occurrence status of problem and analysis results

During the capture period (about one month), we received five notifications of the problem from the customer, and the captured IP packets were analyzed using the α-Command Analysis Support Tool focusing on the times that the problem occurred. The operation details of a certain telephone (extension number 203) when the problem occurred are listed in **Table 1**. From the analysis results, the problem reported by the customer occurred when the *kana* (Japanese syllabary)-search function of the phonebook was used. With this in mind, we executed the same number-search operation to reproduce the same problem with the same model telephone at our laboratory. This clarified the conditions under which the problem occurred.

(1) Press the "Phonebook" button and start kana-search operation in the phonebook.
(2) Press the "Dial" button three times or more and pinpoint the call destination by kana search.
(3) Press the down-scroll button in the phonebook and select the call destination.
(4) Perform operations (1) to (3) in less than one second.

4.3 Causes and countermeasures

The reported problem was caused by internal processing in the telephone, as explained below. The mechanism that caused the problem is illustrated in **Fig. 4**.

- The amount of data processed by the telephone

Table 1. Occurrence status of problem.

Date and time of customer notification (year/month/day/time)	Extension number	Telephone-operation details
20xx / x / 22 16:52	203	Phone book →3→3→*→ Phone book
20xx / x / 27 11:22		Phone book →7→7→7→7→ Phone book
20xx / x / 27 11:24		Phone book →7→7→7→7→ Phone book
20xx / x / 28 9:42		Phone book →8→6→9→ Phone book
20xx / x / 31 18:47		Phone book →7→7→7→7→ Phone book

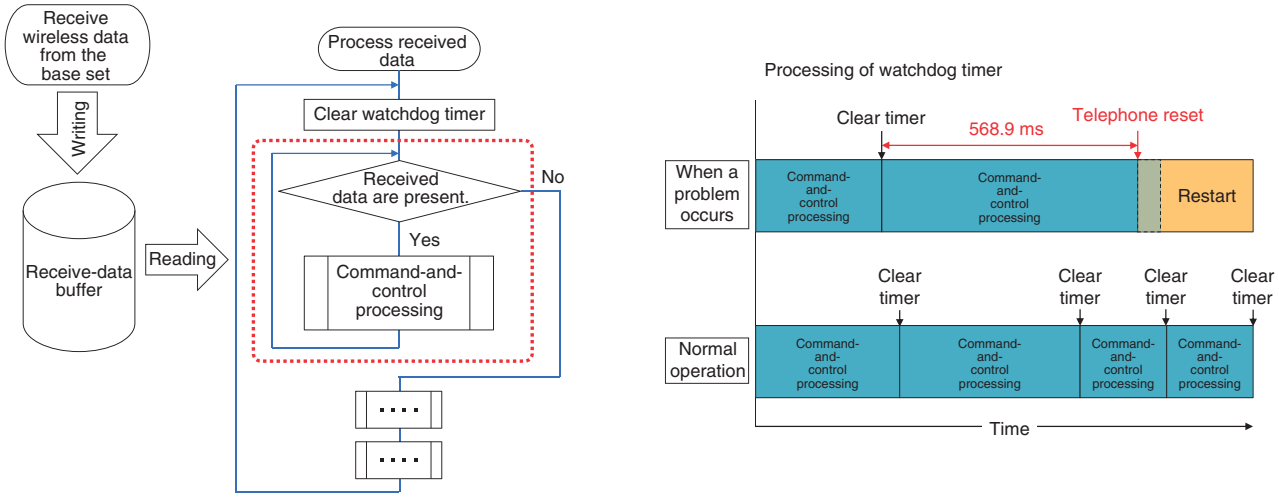

Fig. 4. Mechanism of problem occurrence (data processing in the telephone).

increased compared to that processed with previous models.

- During the kana-search operation in the phonebook, a large amount of data to be displayed on the telephone accumulated in the receive-data buffer. Although the buffered data are sequentially processed, the receive-data buffer was not emptied.
- While the telephone was processing such a large amount of data, the *watchdog timer* (568.9 ms), which detects a *terminal stack* and resets (restarts) the telephone, was activated.

Since the specifications of the telephones caused this problem, and it was impossible to change the telephone software, we took measures to change the manner in which the telephones are used. After explaining the cause of the problem to the customer, we asked the customer to take more than one second when operating the kana search to avoid this problem.

When problems occurred because a customer operated telephones in the manner described above, the only way to identify the problem had been by service personnel visually checking the operation of the telephones in question or by monitoring telephone operation with a camera or other means. However, by using the α-Command Analysis Support Tool, we can reliably identify the cause without visual inspection or monitoring with cameras.

4.4 How to obtain the α-Command Analysis Support Tool

Since September 2019, the α-Command Analysis Support Tool has been downloadable from the website of TASC* (in Japanese only). We believe that using this tool will make it possible to easily investigate

* Currently, the tool is provided only to the NTT Group, but we are preparing to enable our partner companies to use it as well.

causes of problems and prevent unnecessary replacement of equipment, devices, and/or wiring.

5. Concluding remarks

In this article, the α-Command Analysis Support Tool—which was developed as one of our technical-cooperation efforts targeting problems with on-site IP services—was introduced. The Network Interface Engineering Group in TASC supports early resolution of problems with equipment and terminals as well as networks by using various tools to acquire and analyze data. Going forward, TASC will continue to actively engage in technical cooperation, tool development, and technology dissemination through activities such as technical seminars.

Report on NTT R&D Forum 2020 Connect

Tomohisa Hosoda, Takayoshi Mochizuki, Takayuki Onzuka, Shunsuke Mori, Tomota Ieyasu, Takafumi Mukochi, Kentaro Hotta, and Kenichi Hitachi

Abstract

NTT R&D Forum 2020 Connect was held online for four days from November 17–20, 2020. This article overviews the forum and gives examples of the technologies presented under the eight main set themes.

Keywords: R&D forum, IOWN, Digital Twin Computing

1. Overview of forum

The NTT Group is striving to resolve social issues and to be a *value partner* that continues to be selected by customers. To actualize the concept of the Innovative Optical and Wireless Network (IOWN) announced in May 2019, we have been working to create an information-communication infrastructure that supports sustainable growth by achieving large-capacity, low-latency, and low-power-consumption networks using photonics technology. The forum, which was held online for the first time in November 2020, presented the latest research results in an easy-to-understand manner through lectures, special sessions, technical seminars, and exhibitions under the theme of "Into the IOWN – Change the Future."

2. Keynote lectures and special sessions

On November 17th, Jun Sawada, President and CEO of NTT, gave a keynote lecture entitled the "Road to IOWN" (**Photo 1**). At the beginning, President Sawada explained that the purpose of making NTT DOCOMO a wholly owned subsidiary of NTT is to strengthen NTT DOCOMO so that it can compete with platformers and other over-the-top service providers. He also stated that this change should lead to the growth and development of the entire NTT Group.

Next, he described the history of pandemics and hegemony and pointed out that we should bear the historical perspective in mind when considering what kind of world is waiting for us in the post-coronavirus society. He then discussed the issues facing the Japanese information technology (IT) industry from the viewpoint of the technology trade balance and went on to talk about the *Remote World*, i.e., decentralized society and *new glocalism* as trends in the post-coronavirus society.

After introducing messages from President Takashi Niino of NEC Corporation and President Akio Toyoda of Toyota Motor Corporation, he explained the roadmap to the implementation of IOWN and his intension of making IOWN a game changer in the post-coronavirus society. He also talked about Digital Twin Computing, All-Photonics Network, and photonics-electronics convergence devices. He concluded the lecture by declaring that NTT will move ahead with research and development (R&D) and business activities to change the world for the better in the future.

On November 18th, Katsuhiko Kawazoe, Executive

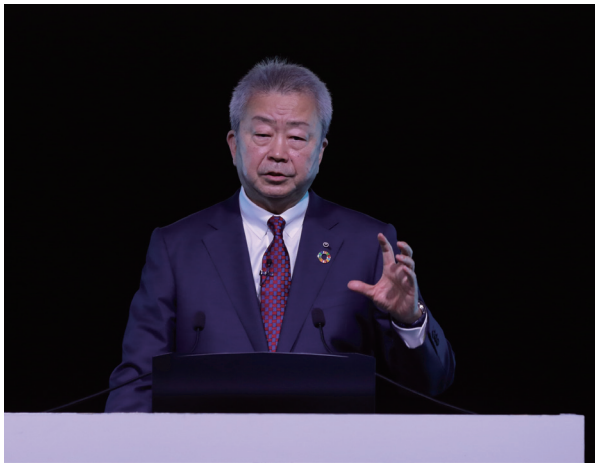

Photo 1. Keynote lecture: Jun Sawada.

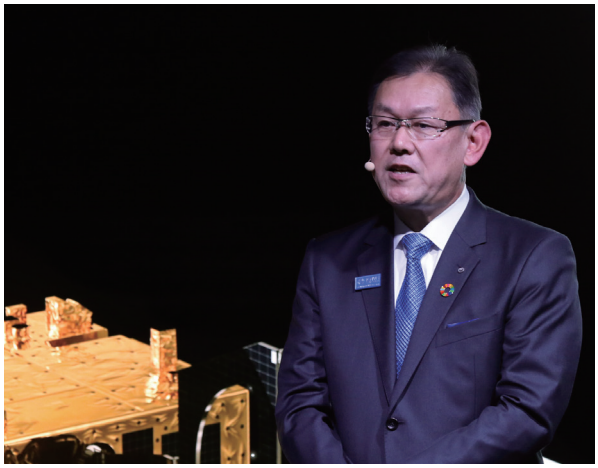

Photo 2. Keynote lecture: Katsuhiko Kawazoe.

Vice President and head of Research and Development Planning Department, NTT, presented a keynote lecture introducing the latest R&D trends and prospects under the title of "Into the IOWN – Breakthrough Innovations –" (**Photo 2**). He talked about the unknown risks that humankind bears, overcoming the power-consumption issue that confronts computers today, heat problems that limit their performance, and importance of digitalization to create new value that is needed at a particular time. After describing the progress made in regard to IOWN, he introduced the development of ultrahigh-speed optical logic gates, photonic direct communication technology, Extreme NaaS (Network as a Service), and data-centric computing infrastructure.

He also presented various services provided by IOWN, such as future prediction that will make our lives more fulfilling, lightning-charging technology, and the 4D digital platform™. While introducing messages from Kenichi Kurihara, Director General, Naka Fusion Institute, the National Institutes for Quantum and Radiological Science and Technology (QST), Kazuo Ishizuka, President of MTI Co., Ltd., and Masatoshi Harigae, Director General of Research and Development Directorate at the Japan Aerospace Exploration Agency (JAXA), he enthusiastically talked about globalization of R&D activities and space-related initiatives as new challenges for further expanding the field of R&D.

Special session 1, delivered on November 19th, welcomed guests Yuki Ota, President of the Japan Fencing Federation and Vice President of the International Fencing Federation and Haruyuki Moroishi, CEO and CCO of IMAGICA EEX Inc. and General Producer of IMAGICA GROUP. The session was moderated by Shingo Kinoshita, Executive Research Engineer, NTT Service Evolution Laboratories, on the theme "Sports & Live Entertainment Viewing Reimagined in the Post-corona Era." During the session, he and the guests discussed the current conditions and future of sports and live entertainment during the novel coronavirus pandemic (**Photo 3**).

Special session 2, delivered on November 20th, welcomed novelist Yuya Takashima, the science fiction consultant for "Mobile Suit Gundam: THE ORIGIN" and the multitalented entertainer Kaori Manabe as guests. Yuji Maeda, Vice President of NTT Space Environment and Energy Research Laboratories, moderated the session on the theme "Challenges of NTT Space Environment and Energy Laboratories in the Coming Space Millennium" (**Photo 4**). This session introduced various research challenges tackled by the Laboratories, such as optimal operation technology for fusion reactors, while referring to the world in which the science-fiction work Gundam is set.

3. Technology seminars

The technical seminars were held every day for four days from November 17th to 20th. As well as introducing the cutting-edge research results that NTT has been obtaining, the purpose of the seminars was to give a sense of what NTT is working on, the future we are envisioning, and the efforts we are making toward the future (**Photo 5**).

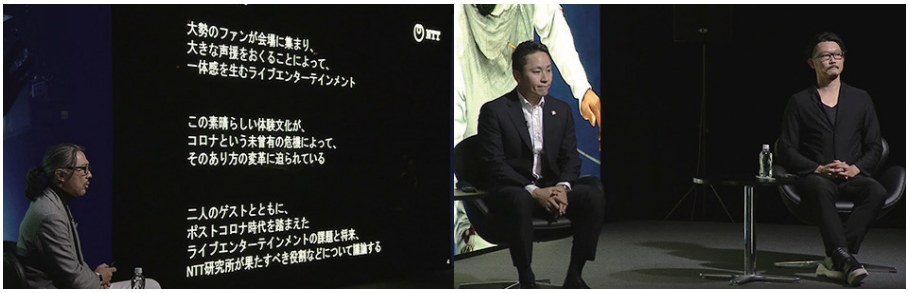

Photo 3. Special session 1: Shingo Kinoshita (left), Yuki Ota (center), and Haruyuki Moroishi (right).

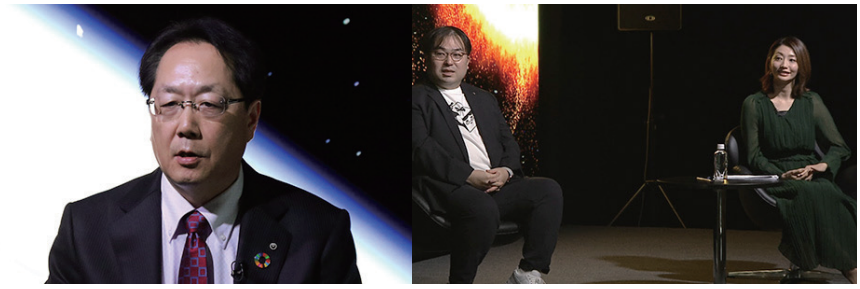

Photo 4. Special session 2: Yuji Maeda (left), Yuya Takashima (center), and Kaori Manabe (right).

Photo 5. Technology seminars 1–4.

On November 17th, a seminar was held on the theme "Into the IOWN – Beyond Human" by Masahisa Kawashima, Vice President and head of the IOWN Promotion Office, Research and Development Planning Department, NTT, and Katsutoshi Ito, General Manager and head of Connectivity Technologies, R&D Center, Sony Corporation. "Beyond humans" is one concept of IOWN for advancing artificial intelligence (AI) capabilities closer to those of humans and further beyond. They introduced a technology of the "next-generation data hub," which extracts and delivers only the necessary parts from information captured with sensors to keep the AI-processing time within 0.1 seconds, the speed of human response. In relation to another concept of IOWN, namely, the "Remote World," they introduced a "remote spectator assistance system," which was developed from joint research between Sony and NTT, and the technology that supports it. Using ultralow-latency IOWN, the system creates a virtual space in which remote spectators can share a sense of enthusiasm beyond the barrier of distance. On the theme "Into the IOWN," "photonic disaggregated computing," which ensures high efficiency and low power consumption, and "Extreme NaaS," which keeps people connected to the network comfortably, were introduced as technologies that embody IOWN.

On November 18th, a seminar entitled "Beyond

Digital Twin—Digital Twin Computing" was held by Takao Nakamura, Director of NTT Digital Twin Computing Research Center, and Michiaki Matsushima, Editor-in-Chief of "WIRED" Japan. Digital twins, which are mappings of things and people posted to the digital world, are currently being developed separately in each industrial domain. In this seminar, they explained the concept of Digital Twin Computing, which is a computing paradigm that creates a variety of virtual societies by integrating various types of digital twins. They also introduced high-precision and real-time vehicle-position data collection technology that reduces traffic congestion and five themes concerning R&D initiatives toward development of human digital twins, namely, "technology for modeling outer and inner surfaces," "technology for understanding," "technology for thinking," "technology for expressing," and "technology for reproducing a group of people." It was mentioned that more multi-faceted approaches, such as brain science, psychology, and behavioral economics, will be needed in the future. In the latter half of the seminar, four *grand challenges* were announced, namely, "Mind-to-Mind Communication," "Another Me," "An Exploring Engine for the Future Society," and "Inducing Inclusive Equilibrium Solutions for the Earth and its Social and Economic Systems." Takao Nakamura declared that he and his co-researchers will continue to carry out cutting-edge research with a wide range of variations.

On November 19th, a seminar was held by Yoshiaki Nakajima, Senior Research Engineer, NTT Secure Platform Laboratories, Takafumi Hamano, Senior Research Engineer, NTT Network Technology Laboratories, and Tatsuya Hayashi, Researcher at KMD Research Institute, Keio University, and board member and Chief Technology Officer of the security company Parongo, on the theme of "Safe and Secure Social Infrastructure for Smart World."

It is expected that an unprecedented smart world in which both the physical space and cyberspace are fused will be created by analyzing data about not only things but also humans in cyberspace and feeding those analysis results back to the physical space. In such a world, however, since various equipment and systems are connected to the network, the number of attacks will increase and the damage from such attacks will be amplified. Therefore, a new proactive approach of cybersecurity technology is required instead of the conventional reactive approach. To meet this need, NTT has developed a technology—which was introduced in the seminar—that captures the composition and state of things and people in cyberspace and analyzes them spatially and temporally. This analysis makes it possible to detect the spread of infection across domains and to identify the signs and causes of infection. Using smart agriculture as an example, the hosts then introduced certificate-based authentication technology for Internet of Things (IoT) devices, to prevent leakage of valuable cultivated expertise and obstruction of that cultivation due to unauthorized distribution of control information.

They also introduced the idea of a "dedicated core network," which enables ultralow-latency communication even when the number of connected devices and communication volume are expected to increase due to the popularization of 5th-generation mobile communication system (5G) services.

On November 20th, a seminar entitled "Contributing to a Healthy and Hopeful 'Medical and Healthcare Future' – ICT and Well-being, Human Co-being –" was held by Katsuyoshi Hayashi, Chief Producer, Research and Development Planning Department, NTT, and Professor Hiroaki Miyata of the Faculty of Medicine, Keio University.

Immediately before the seminar, NTT announced "Medical and Health Vision: Realization of a Bio Digital Twin." This seminar explained the content of this vision and introduced research from the following three perspectives: (i) "obtaining data," a technology that visualizes trends in blood glucose by irradiating radio waves acquired from a wearable sensor device, (ii) "behavior feedback," a technology that analyzes myoelectric signals and feeds analysis results back to the user; and (iii) "predicting the future," a technology for creating an image of one's future in the digital world, reviewing one's current behavior, and helping one to reach a better future.

These technical seminars demonstrated the initiatives of NTT R&D and the NTT Group, which received favorable reviews from online audiences.

4. Exhibition of R&D results

The Forum set up eight exhibition themes, "[Special Category] IOWN Key Technologies," "Networks," "AI," "Security," "Data Utilization and Management," "Media and Devices/Robotics," "Environment and Energy," and "Basic Research," and the latest R&D results (83 in total) concerning those themes were showcased in a virtual exhibition space. The exhibition presented the technologies that the NTT Group is working on, the results of collaborations

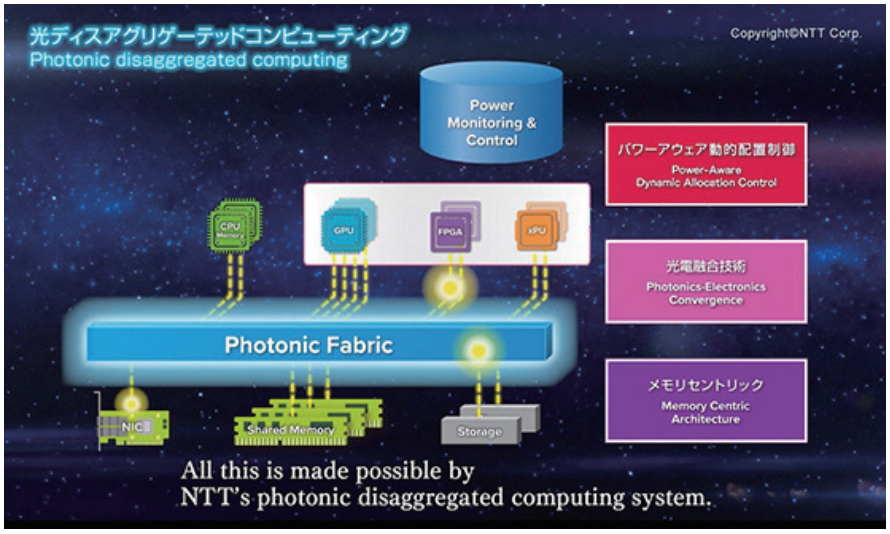

Fig. 1. IOWN Key Technologies: photonic disaggregated computing.

with partner companies, and a wide range of technologies—from technologies developed in basic research fields to commercialized technologies.

4.1 IOWN Key Technologies

The key technologies in the technology-development roadmap formulated to implement IOWN were exhibited along with expected new user experiences (**Fig. 1**). "All-Photonics Network with High Scalability and Flexibility (I01)" introduced the latest technology for creating new customer experiences, such as remote production and infrastructure sharing, by dynamically providing a large-capacity optical path that can accommodate various protocol stacks. This technology presents the possibilities of a new world created by optical interfaces and large-capacity optical paths. "Photonic Disaggregated Computing (I05)" explained the latest technology for efficiently using computing resources (such as central processing units, graphics processing units, and field-programmable gate arrays) to improve power efficiency of datacenters by closely connecting such resources with photonics-electronics convergence.

4.2 Networks

Innovative optical/wireless network technologies and advanced control/operation technologies that will create a *smart* social infrastructure were exhibited. "OAM-MIMO Multiplexing Transmission Technology (N04)" introduced a terabit-class wireless transmission technology for handling increasing wireless traffic in the era beyond 5G (**Fig. 2**). "Unified Technologies for Driverless Robotic Farm Machines (N06)" featured technology for safe and efficient autonomous driving of robotic farm machines by remote monitoring and control as well as IOWN elemental technologies, such as prediction of wireless quality, overlay networking, video streaming, image analysis, and network-cooperative device actuation.

4.3 AI

The NTT Group's AI-related technology called "corevo®"—which makes people's lives more fulfilling and creates new value by supporting the activities of people and society—was exhibited (**Fig. 3**). "Digital Twin Computing Technology (A01)" explained Digital Twin Computing, an element of IOWN, and an envisioned world in which the real world is fused with the highly interactive virtual societies through human digital twins. "Media Processing Device Technology in the Remote World Era (A15)" presented a technology for precisely controlling the sound space around the user to create a "personalized sound zone" that delivers only the sounds that the user wants to know and hear. "Asynchronous Distributed Deep Learning for Edge Computing (A20)" introduced a method for securely training a machine-learning model by using distributed storage (edge-computing environment) in contrast to the current deep learning method that involves training a model from data aggregated in one location.

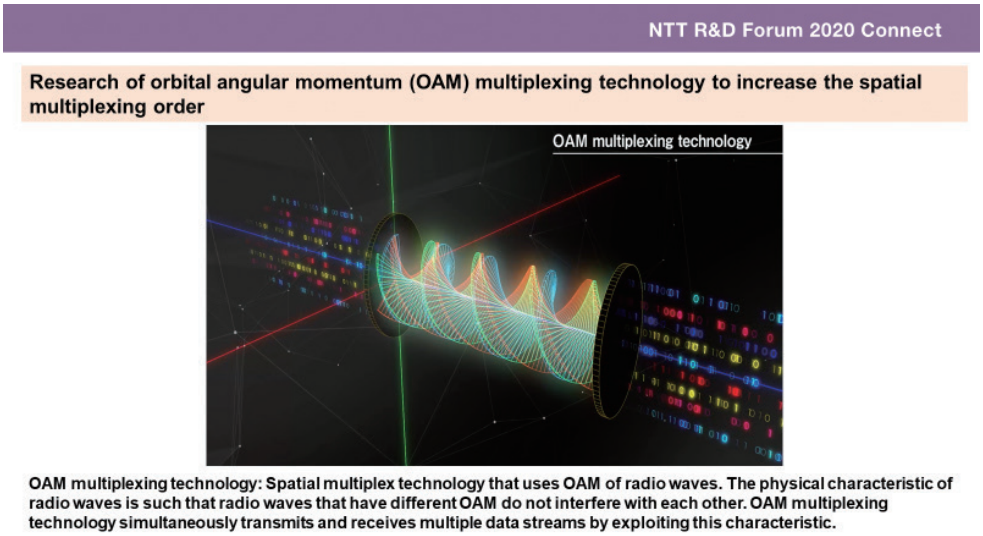

Fig. 2. Networks: OAM multiplexing technology.

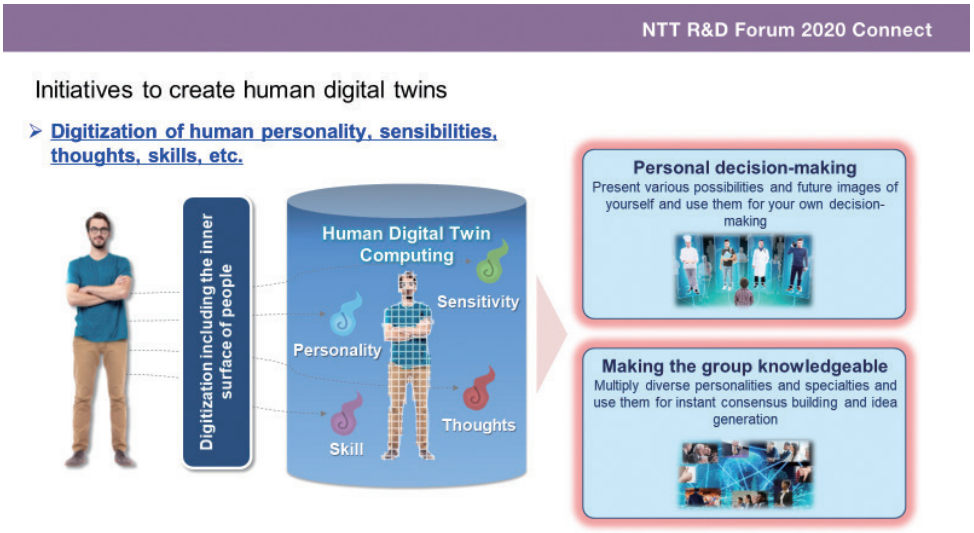

Fig. 3. AI: human Digital Twin Computing technology.

4.4 Security

Security technology that appropriately protects the smart world from complicated cyberattacks and supports secure data distribution and utilization and future cryptographic technology (**Fig. 4**) were exhibited. "NTT Post-quantum Cryptography (S05)" introduced NTT's next-generation cryptography, which is in the final selection stage of the international standardization contest. It is a basic public-key encryption technology that cannot be broken even with quantum computers.

4.5 Data Utilization and Management

A technology for processing huge and complex data at high speed and enabling multiple parties to freely use the data across industry and regional barriers was exhibited (**Fig. 5**). "Data Analysis Technology for Digital Transformation (DX) (D02)" explained a technology for implementing DX of customer contact operations during the novel coronavirus pandemic.

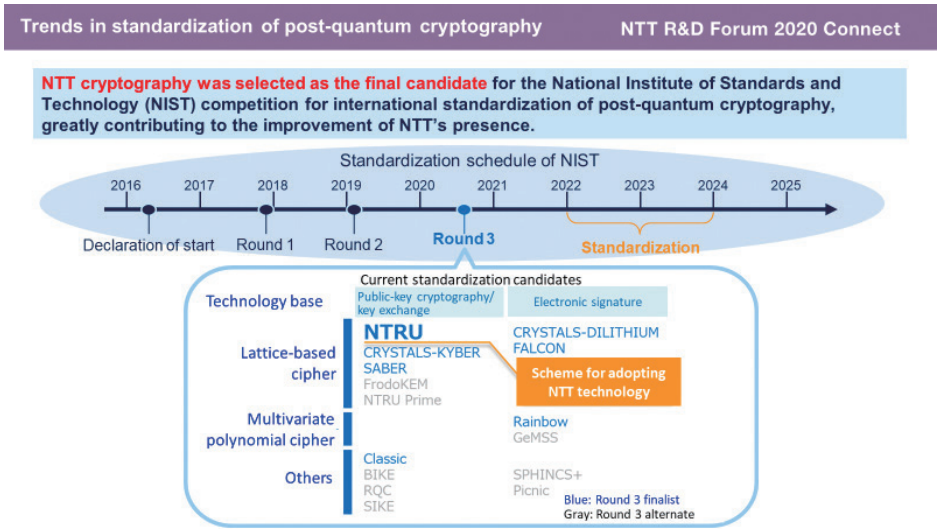

Fig. 4. Security: post-quantum cryptography.

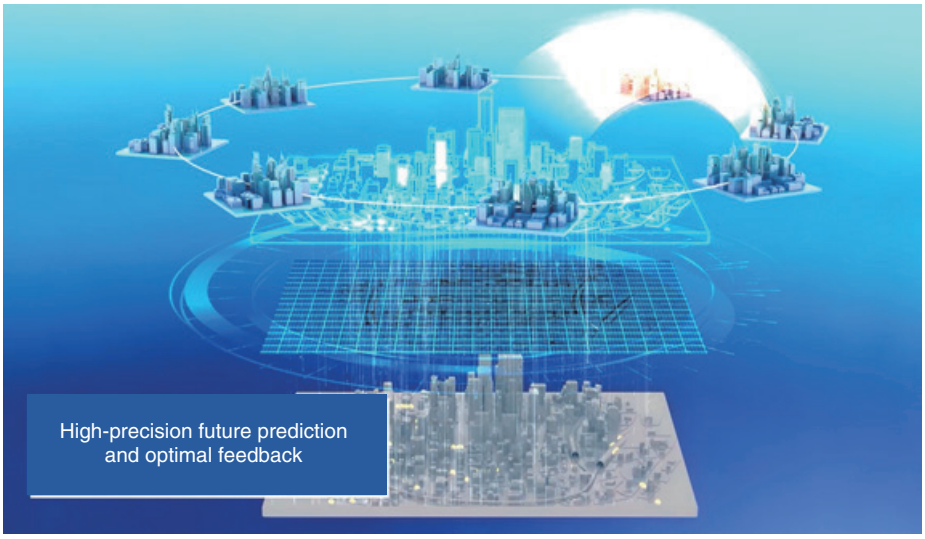

Fig. 5. Data Utilization and Management: integrated data utilization and analysis technology.

This technology enables integrated data utilization and analysis that improves productivity of workers and customer convenience in customer contact points at government offices, financial institutions, etc. "Overview of 4D Digital Platform (D06)" displayed an overall picture of the 4D digital platform™, which integrates various sensing data in real time on the "advanced geospatial information database," which is highly accurate and has abundant semantic information.

4.6 Media and Devices/Robotics

Two technologies were introduced: (i) a virtual-reality/augmented-reality technology that creates a new *life environment* for creating a society that makes the most of the abilities of a person by using data from cyberspace and (ii) a human-machine-interface technology that seamlessly connects everything (**Photo 6**). "Cybernetics Technology to Augment Human Capabilities (M01)" presented a technology for augmenting human motor skills by acquiring and

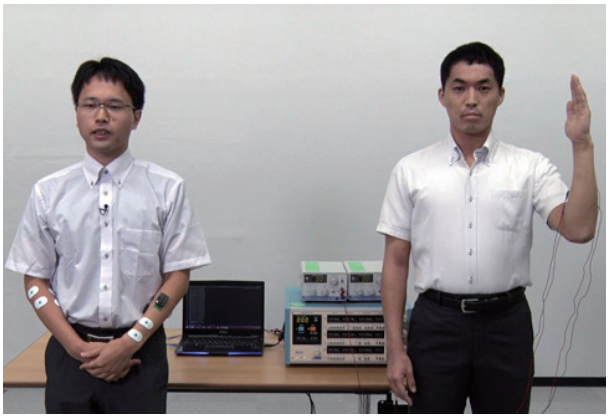

Photo 6. Media and Devices/Robotics: cybernetics technology.

Fig. 6. Environment and Energy: optimal operation technology for fusion reactors.

analyzing biological signals and providing feedback to help people improve their motor skills and become who they want to be. "Remote Spectator Assistance System (M02)" showcased a technology for enhancing the sense of excitement and unity and stimulating interaction between spectators during remote viewing of sports and concerts and a technology for creating a space where remote spectators can share their enthusiasm beyond distance.

4.7 Environment and Energy

Environmental and energy technologies that will revolutionize the future of the global environment with the aim of regenerating the global environment and creating a sustainable and inclusive society was exhibited (**Fig. 6**). "Optimal Operation Technology for Fusion Reactors (E02)" introduced a technology that will help the International Fusion Experimental Reactor (ITER) project achieve stable operation of nuclear fusion by enabling the construction of a network that can transmit various sensor data from a fusion reactor to the control center at ultrahigh speed and low delay and feed that data back to actuators by using IOWN technology (i.e., All-Photonics Network and Digital Twin Computing). In the future, we plan to use Digital Twin Computing to reproduce fusion reactors in cyberspace through advanced simulations. "Lightning Control and Charging Technology (E03)"

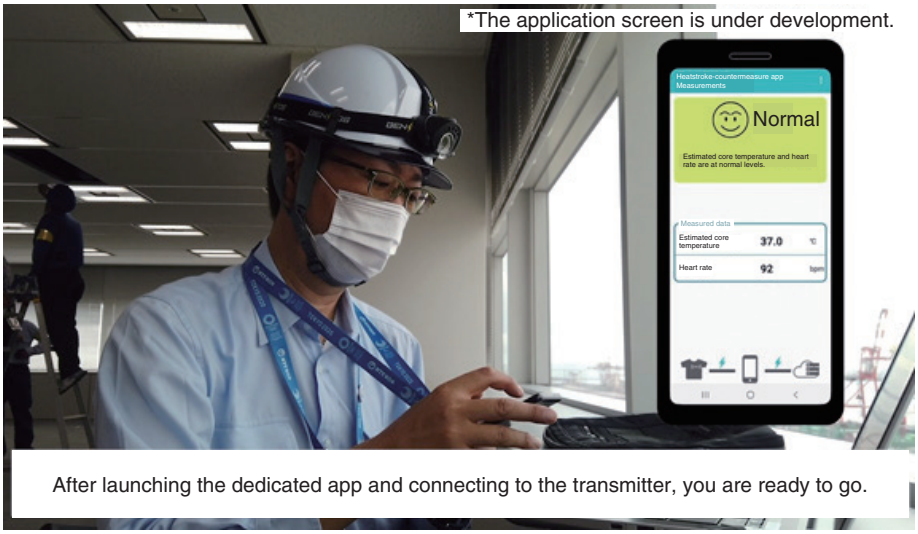

Fig. 7. Basic Research: heat-related-health-hazards prevention system.

described study of a technology that controls lightning to protect people and equipment from lightning strikes and utilization of lightning energy in anticipation of an era of heavy lightning.

4.8 Basic Research

Basic research that will bring about change in society was exhibited. It included R&D of innovative information-processing technology, advanced device technology, materials technology, and medical and biotechnology. "Wearable Stethoscope for Remote Auscultation (B01)" introduced a technology for supporting online medical care and self-care. By embedding a large number of acoustic sensors into an examination gown, multi-faceted high-quality sounds associated with biological activities of the wearer can be simultaneously transmitted to a receiving terminal in a remote location, and it is possible to convert (visualize) information, such as generation of videos showing the movement of the heart from sounds and creation of sentences about findings. "Heat-related-health-hazards Prevention System (B02)" featured a technology for remotely monitoring workers equipped with wearable biological and environmental sensors and estimating and alerting each individual to the risk of heatstroke (**Fig. 7**).

5. After the forum

This was the first time that the forum was open to the public online, and it was viewed by more than 20,000 people. Since this event was an online forum, a large number of the general public participated, in addition to the group employees who were invited to attend. We found that people had expectations concerning NTT's R&D from questionnaires and inquiries after the forum was held. To meet these expectations, we will make even greater efforts regarding basic research and R&D of new technologies.

Authors (from left): Shunsuke Mori, Director, R&D Planning, NTT Research and Development Planning Department; Tomota Ieyasu, Manager, R&D Planning, NTT Research and Development Planning Department; Tomohisa Hosoda, Vice President, R&D Planning, NTT Research and Development Planning Department; Takayuki Onzuka, Senior Manager, R&D Planning, NTT Research and Development Planning Department; Takayoshi Mochizuki, Senior Manager, R&D Planning, NTT Research and Development Planning Department; Kenichi Hitachi, Senior Manager, Research Planning Department, NTT Science and Core Technology Laboratory Group; Takafumi Mukochi, Director, Research Planning Department, NTT Service Innovation Laboratory Group; and Kentaro Hotta, Senior Manager, Research Planning Department, NTT Information Network Laboratory Group

External Awards

42th CHEMINAS Poster Award
Winners: Koji Sakai, Tetsuhiko Teshima, Yuko Ueno, Hiroshi Nakashima, and Masumi Yamaguchi, NTT Basic Research Laboratories
Date: October 28, 2020
Organization: Society for Chemistry and Micro-Nano Systems (CHEMINAS)

For "Three-dimensional Extracellular Recording by Self-folding Graphene Electrode Array."
Published as: K. Sakai, T. Teshima, Y. Ueno, H. Nakashima, and M. Yamaguchi, "Three-dimensional Extracellular Recording by Self-folding Graphene Electrode Array," 42th CHEMINAS, Oct. 2020.

Spotlight on Optics
Winners: Yoko Yamashita, Takashi Matsui, Taiji Sakamoto, Shinichi Aozasa, Masaki Wada, Takayoshi Mori, and Kazuhide Nakajima, NTT Access Network Service Systems Laboratories
Date: November 24, 2020
Organization: The Optical Society (OSA)

For "Reduction of Differential Modal Gain in a Two-mode Amplifier Using a Void-inscribed EDF."
Published as: Y. Yamashita, T. Matsui, T. Sakamoto, S. Aozasa, M. Wada, T. Mori, and K. Nakajima, "Reduction of Differential Modal Gain in a Two-mode Amplifier Using a Void-inscribed EDF," Applied Optics, Vol. 59, No. 30, pp. 9574–9580, Oct. 2020.

The Minister of Internal Affairs and Communications Award, the Fourth Infrastructure Maintenance Awards
Winner: NTT (NTT Access Network Service Systems Laboratories)
Date: November 27, 2020
Organization: The Ministry of Land, Infrastructure and Transport, the Ministry of Internal Affairs and Communications, the Ministry of Education, Culture, Sports, Science and Technology, the Ministry of Health, Labour and Welfare, the Ministry of Agriculture, Forestry and Fisheries, the Ministry of Economy, Trade and Industry, and the Ministry of Defense

For the development of technology for visualizing the uneven load applied to utility poles and other facilities.

Outstanding Paper Award
Winners: Zubair Md. Fadlullah, Fengxiao Tang, Bomin Mao, and Nei Kato, Tohoku University; Osamu Akashi, Takeru Inoue, and Kimihiro Mizutani, NTT Network Innovation Laboratories
Date: December 8, 2020
Organization: IEEE Asia-Pacific Region Paper Award Committee

For "State-of-the-art Deep Learning: Evolving Machine Intelligence Toward Tomorrow's Intelligent Network Traffic Control Systems."
Published as: Z. Md. Fadlullah, F. Tang, B. Mao, N. Kato, O. Akashi, T. Inoue, and K. Mizutani, "State-of-the-art Deep Learning: Evolving Machine Intelligence Toward Tomorrow's Intelligent Network Traffic Control Systems," IEEE Communications Surveys & Tutorials, Vol. 19, No. 4, pp. 2432–2455, May 2017.

Papers Published in Technical Journals and Conference Proceedings

Behavioral and Physiological Correlates of Kinetically Tracking a Chaotic Target
A. Takagi, R. Furuta, S. Saetia, N. Yoshimura, Y. Koike, and L. Minati
PLOS ONE, Vol. 15, No. 9, e0239471, September 2020.

Humans can innately track a moving target by anticipating its future position from a brief history of observations. While ballistic trajectories can be readily extrapolated, many natural and artificial systems are governed by more general nonlinear dynamics and, therefore, can produce highly irregular motion. Yet, relatively little is known regarding the behavioral and physiological underpinnings of prediction and tracking in the presence of chaos. Here, we investigated in lab settings whether participants could manually follow the orbit of a paradigmatic chaotic system, the Rössler equations, on the (x,y) plane under different settings of a control parameter, which determined the prominence of transients in the target position. Tracking accuracy was negatively related to the level of unpredictability and folding. Nevertheless, while participants initially reacted to the transients, they gradually learned to anticipate it. This was accompanied by a decrease in muscular co-contraction, alongside enhanced activity in the theta and beta electroencephalographic bands for the highest levels of chaoticity. Furthermore, greater phase synchronization of breathing was observed. Taken together, these findings point to the possible ability of the nervous system to implicitly learn topological regularities even in the context of highly irregular motion, reflecting in multiple observables at the physiological level.

Receiver Integration with Arrayed Waveguide Gratings toward Multi-wavelength Data-centric Communications and Computing

Y. Doi, T. Yoshimatsu, Y. Nakanishi, S. Tsunashima, M. Nada, S. Kamei, K. Sano, and Y. Ishii

Applied Science, Vol. 10, No. 22, 8205, November 2020.

This paper reviews receivers that feature low-loss multimode-output arrayed waveguide gratings for wavelength division multiplexing (WDM) as well as hybrid integration techniques with high-speed throughput of up to 100 Gb/s and beyond. A design of optical coupling between higher-order multimode beams and a photodiode for a flat-top spectral shape is described in detail. The WDM photoreceivers were fabricated with different approaches. A 10-Gb/s photoreceiver was developed for a 1.25-Gb/s baud rate and assembled for eight-channel WDM by mechanical alignment. A receiver with 40-Gb/s throughput was built by using visual alignment for a 10-Gb/s baud rate and four-channel WDM. A 100-Gb/s receiver assembled by active alignment with a four-channel by 25-Gb/s baud rate is the basis for beyond-100 Gb/s and future multi-wavelength integrated devices toward data-centric communications and computing.

Independent Control of Cocontraction and Reciprocal Activity during Goal-directed Reaching in Muscle Space

A. Takagi, H. Kambara, and Y. Koike

Scientific Reports, Vol. 10, 22333, December 2020.

The movement in a joint is facilitated by a pair of muscles that pull in opposite directions. The difference in the pair's muscle force or reciprocal activity results in joint torque, while the overlapping muscle force or the cocontraction is related to the joint's stiffness. Cocontraction knowingly adapts implicitly over a number of movements, but it is unclear whether the central nervous system can actively regulate cocontraction in a goal-directed manner in a short span of time. We developed a muscle interface where a cursor's horizontal position was determined by the reciprocal activity of the shoulder flexion–extension muscle pair, while the vertical position was controlled by its cocontraction. Participants made goal-directed movements to single and via-point targets in the two-dimensional muscle space, learning to move the cursor along the shortest path. Simulations using an optimal control framework suggest that the reciprocal activity and the cocontraction may be controlled independently by the central nervous system, albeit at a rate orders of magnitude slower than the muscle's maximal activation speed.

Analogous Adaptations in Speed, Impulse, and Endpoint Stiffness When Learning a Real and Virtual Insertion Task with Haptic Feedback

A. Takagi, G. De Magistris, G. Xiong, A. Micaelli, H. Kambara, Y. Koike, J. Savin, J. Marsot, and E. Burdet

Scientific Reports, Vol. 10, 22342, December 2020.

Humans have the ability to use a diverse range of handheld tools. Owing to its versatility, a virtual environment with haptic feedback of the force is ideally suited to investigating motor learning during tool use. However, few simulators exist to recreate the dynamic interactions during real tool use, and no study has compared the correlates of motor learning between a real and virtual tooling task. To this end, we compared two groups of participants who either learned to insert a real or virtual tool into a fixture. The trial duration, the movement speed, the force impulse after insertion and the endpoint stiffness magnitude decreased as a function of trials, but they changed at comparable rates in both environments. A ballistic insertion strategy observed in both environments suggests some interdependence when controlling motion and controlling interaction, contradicting a prominent theory of these two control modalities being independent of one another. Our results suggest that the brain learns real and virtual insertion in a comparable manner, thereby supporting the use of a virtual tooling task with haptic feedback to investigate motor learning during tool use.

Seeing the World through Text: Evaluating Image Descriptions for Commonsense Reasoning in Machine Reading Comprehension

D. Galvan-Sosa, J. Suzuki, K. Nishida, K. Matsuda, and K. Inui

Proc. of the Second Workshop on Beyond Vision and Language: Integrating Real-world Knowledge (LANTERN), pp. 23–29, Barcelona, Spain (Online), December 2020.

Despite recent achievements in natural language understanding, reasoning over commonsense knowledge still represents a big challenge to artificial intelligence systems. As the name suggests, common sense is related to perception and as such, humans derive it from experience rather than from literary education. Recent works in the natural language processing and the computer vision field have made the effort of making such knowledge explicit using written language and visual inputs, respectively. Our premise is that the latter source fits better with the characteristics of commonsense acquisition. In this work, we explore to what extent the descriptions of real-world scenes are sufficient to learn common sense about different daily situations, drawing upon visual information to answer script knowledge questions.