NTT Technical Review

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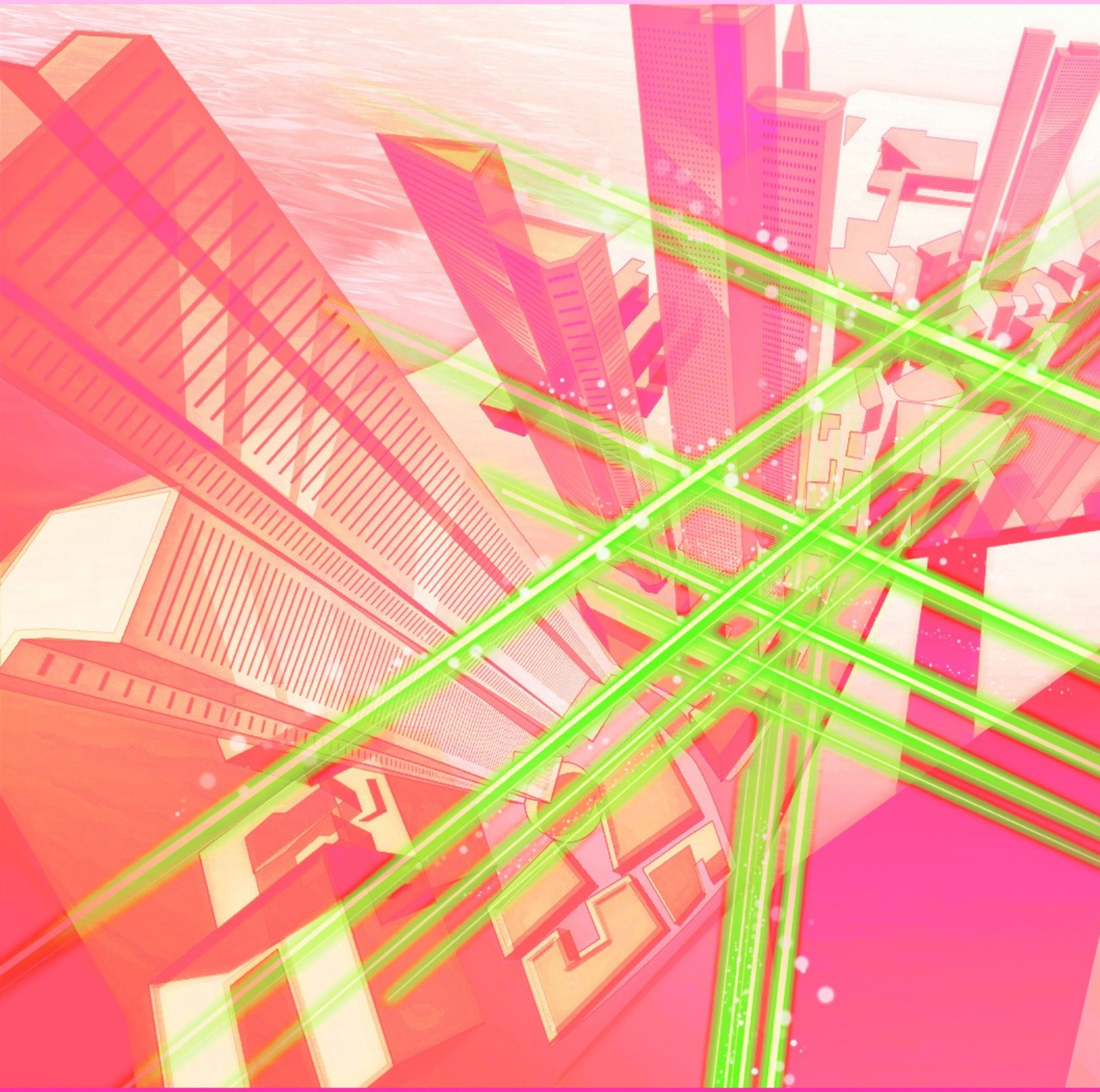
2020



March 2020 Vol. 18 No. 3

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Promoting Communication with Digital Transformation and Applying Mutually Exclusive and Collectively Exhaustive Principle

Atsuko Oka
Senior Vice President, Head of Technology Planning, NTT

Overview

The NTT Group is committed to solving social issues, and its initiatives and responsiveness have been highly evaluated. The Group joined the international environmental protection initiatives EP100 and EV100 as their first telecommunications carrier member. It has also been selected as a global top innovator for the eighth consecutive year. We asked Atsuko Oka, NTT senior vice president, head of Technology Planning, for her 2020 outlook for the NTT Group, which strives to provide high-quality, highly reliable services for safe and secure operation of information and communication technology infrastructure.

Keywords: digital transformation, IOWN, MECE

Providing reliable communication infrastructure as *Your Value Partner*

—What kind of year was 2019?

In 2019, typhoons Faxai and Hagibis hit the Japanese archipelago in quick succession and caused severe damage in many areas due to strong winds and river flooding. I'd like to express my deepest sympathies to all those affected.

About 80,000 communication lines were affected. While NTT was working to restore telecommunications services, which is a social infrastructure, I strongly felt that we need to consider strengthening our resilience (namely, ability to recover from disasters and failures)—starting with quick recovery—and further strengthen dissemination of information. We have thus begun efforts to (i) predict the impact on communication facilities from the path and intensity of a typhoon and (ii) prepare in advance people and materials necessary for restoration near areas where damage is expected. Since those efforts are based on prediction, they may end up in vain. Even so, from the standpoint of a telecommunications carrier, quick recovery is our top priority, and I think it is too late to start responding after a disaster. To make it possible to quickly restore the infrastructure, we are making full use of artificial intelligence and other technologies developed by NTT laboratories to predict the occurrence of disasters and respond proactively to them.

I thought it was necessary to disseminate not just information about disasters affecting our communication facilities but also information about what kind

of services NTT provides, what kind of equipment is used for those services, what state the equipment is in, and what recovery activities are ongoing. Major international events are increasingly being held in Japan, so many visitors come to participate in and watch these events. Web services and social networking services are not only supported in Japanese but also in English and many other languages. Since such events are becoming ever more regular, it is important to ensure stable communication and tight security so that they run smoothly and companies operate normally. The Security Strategy Section of the NTT Technology Planning Department is carrying out early detection, analysis, and response and investigating technology for early defense regarding cyber threats. As the saying goes, "Being prepared means peace of mind;" thus, for stable provision of communication, we want to proactively respond to anything by paying attention to details.

—It is encouraging just to hear that. How will you tackle this challenge in 2020?

NTT announced a medium-term management strategy called *Your Value Partner* in November 2018. The pillars of this strategy are twofold: promoting our own digital transformation (DX) and supporting our customers' DX. This strategy is a major mission for us. Although DX sounds like pursuing cost reduction and efficiency, by freeing up more time for people through DX, it will help to reform work styles such as reducing overtime work, enhance communication, and promote open innovation. For example, in the case of a business that conventionally uses paper, digitizing the entire business process and distributing digitized information will accelerate the entire process. This digitization will speed up the provision of services to customers, thereby improving customer satisfaction and customer experience. Moreover, we are aiming to increase profits by providing customers—as a future solution service—with actual examples of us promoting DX and making things more convenient.

We are already conducting activities in each field. We have launched a cloud-based billing platform called Smart Billing™ and are proposing a cloud-based contract-management platform called Smart Fulfillment to corporate customers.

With customers seeming to be actively working on DX, we are often asked to tell them about what we are promoting at NTT. As customer DX proceeds, companies and individuals will change their work styles,

and communication with people they haven't spoken to before will increase further. As a result, open innovation will progress.

—It seems that a new world can be opened up by changing the way we use time.

Looking to the future, we are promoting the Innovative Optical and Wireless Network (IOWN), a next-generation communication infrastructure that is being targeted for practical use around 2030. The IOWN Global Forum, a new industry forum for achieving IOWN, has already been registered as a corporation, and NTT, Sony, and Intel have been appointed as initial board members. More than 100 companies in Japan and around the world, including Microsoft, Verizon, Orange, and China Telecom, have shown interest in joining. The response to setting up the forum was faster from outside Japan. Until recently, the concepts that NTT has launched have often been disseminated only within Japan. However, the positive reaction from global companies to IOWN can be attributed to the establishment of new global bases including NTT Research, Inc. in the United States, strong interest in the All-Photonics Network, the key element of IOWN that introduces optical technology end-to-end from the network to the terminal, and the expectation of IOWN as a solution to issues such as limitations of semiconductor devices concerning low-power consumption and high-speed transmission.

The NTT Technology Planning Department will continue introducing, operating, and maintaining new technologies developed in our research laboratories as well as outside ones while formulating and implementing measures related to disaster countermeasures,

security, and efficient procurement of equipment. When the technologies, new services, and businesses that make up IOWN become concrete, we will also consider the grand design of a network suitable for IOWN as well as a migration plan for gradually migrating from existing networks to the All-Photonics Network.

"Practice makes perfect"

—Please tell us what you value in carrying out your mission.

"Practice makes perfect" is my favorite phrase. I believe that we will be able to handle almost anything if we do things seriously and steadily. Also, my maxim is be timely; I am often the first to arrive at meetings. Other attendees arrange their schedules to fit meetings into their busy schedules; in other words, they reserve their precious time for meetings. Many, however, can barely fit meetings into their schedules. Time is lost when time is not kept. Today, time can be bought with money, such as when we use electrical appliances to cut down on time consumed by household chores; however, I don't think face-to-face communication and getting involved with challenging tasks can be bought. I feel that precious time should not be wasted.

I take notes at work and keep a personal diary. I don't write much and it's not well organized, but sometimes I notice things when I look back. I don't think we can rely on memory alone. The beginning of this habit dates back to my college days. Attending a combined junior and high school, the people around me were all old friends, but when I entered university, the people around me were all new. At first, in an environment where I had nobody to rely on, I realized I could rely on only myself and started taking copious notes for my classes. When I lent my notes to classmates before tests, those notes kept circulating among the students; thus, I contributed in some way to the student community. This continued into my professional life. After joining NTT, I went to work at an affiliated organization, and I kept taking notes, even though my team didn't have the habit of doing so, and they eventually used my notes. Therefore, it can be said that the notes and memos I took for myself contributed to my work.

I also maintain a conscious attitude based on the MECE (mutually exclusive, collectively exhaustive) principle. If you focus too much on your task, you won't see the whole picture, and you will be worried that you are missing something. However, if you take a step back and look at the whole picture again from a slightly higher viewpoint, you may notice an omission, so I work while being aware of MECE. It is important to categorize each task by creating a framework to understand the whole picture. This will help reduce unnecessary meetings and redundancy in my work. I only got into this habit after starting my professional life. I may have picked it up when I was working at the Corporate Planning Department of NTT Communications. I felt guilty if I had to ask for something again because of my narrow or lack of vision.

—You can learn from anything and apply what you learned to future tasks! Please tell us about any turning points you encountered.

When I joined NTT, I was assigned to Software Research Laboratories, where I was engaged in research related to the Internet. The sudden transfer to the International Business Department changed my mindset, and it seems to me now that it was a turning point.

In the 1990s, the Prime Minister of Malaysia, Mahathir bin Mohamad, gave his vision for a full-fledged information society arriving in the 21st century, which he called the multimedia super corridor (MSC), which would be achieved while competing against developed countries around the world. After the MSC project was launched, NTT received a request for cooperation, and I was transferred to the

International Business Department to participate in that project.

At that time, I was very worried because I could not speak adequate English. Although I had some experience in presenting my research at conferences, I had no experience in promoting NTT technologies outside Japan or working with people from different countries to create concepts, so I asked myself "what should I do?"

When I started working on the MSC project, however, I realized that NTT's technologies were outstanding and was driven by the desire to promote those technologies, so I felt I was moving forward. I also thought that if I did not present such technologies effectively, other people would not understand them, and communication was the key to that understanding. On top of that, I realized that it is necessary to have a marketing mindset like that taught in business schools. Unexpectedly, this challenging time turned into an opportunity.

I faced another turning point in 1999. I studied abroad and learned business basics and skills to develop business from technology. Through my experiences studying abroad and in Malaysia and working with multinational team members on projects, I cultivated diverse perspectives and communication skills and recognized the importance of the spirit of contribution.

"A feeling of being worthwhile" gained by working hard

—What does "work" mean to you?

To me, work naturally means working hard and getting paid, but at the same time, it means changing the world through the results of our work and satisfying our customers with the services we provide. As I said, my work hasn't always gone smoothly. For example, moving to the International Business Department and participating in the Malaysian project may have been a setback in some ways, including a language barrier. However, there is always a way; we are not working alone. One of the great things about joining NTT is that someone always helped me, and I am very grateful for that help.

I tried to find a role model. However, it is not easy to find people with similar backgrounds or in similar situations. Therefore, I've been trying to find a good role model by "cherry picking" when interacting with various people. Sometimes I wonder if my activities will be helpful to younger women. In fact, the number of women in managerial positions is increasing, so I want to observe their work style and performance and "pick" the best of them and take on further challenges.

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

I originally got involved in technology as a researcher. Technology does not always take shape immediately and lead to business. Sometimes it takes shape after some time, maybe even after 20 years. The first thing I did after returning from studying abroad was help launch a video-distribution service. At that time, said to be the first year of broadband, most video distribution was 64-kbit/s quality. However, various technologies have been combined, and now we have reached 5G (fifth-generation mobile communications), which allows us to enjoy stunning images on smartphones. Some technological developments produce results immediately, while others blossom with time. Accordingly, it is important to make the research and technology that we are working on *open* through communication with the rest of the world. Unlike in the past, information can now be transmitted in many ways, such as via the web, and the importance of open innovation and co-working is increasing. That's why integrity is fundamental when it comes to making things open as well as communicating and connecting with people.

Interviewee profile

■ Career highlights

Atsuko Oka joined Nippon Telegraph and Telephone Public Corporation (now NTT) in 1988. After serving as the director of the IP Services Department of the Net Business Division of NTT Communications from 2006 to 2010, she became the president and CEO of NTT NaviSpace in 2010 and served as a board member and general manager of the Solution Business Division of NTT Resonant from 2017 to 2019. She assumed her current position in June 2019.

In Life, Nothing Is Wasted. Let's Build a Society in which Everyone Can Live an Active Life

Tessei Kobayashi
Senior Distinguished Researcher, NTT Communication Science Laboratories

Overview

A report published in August 2015 by the World Literacy Foundation estimates that economic and social loss due to illiteracy in Japan is about 95.1 billion yen annually [1]. Thanks to compulsory education, Japan is said to have achieved a literacy rate of 99.8%. However, according to a survey by the National Institute of Informatics conducted in 2016 [2], many junior- and senior-high-school students do not understand the structure of basic sentences, such as the relationship between subjects and predicates. We interviewed Tessei Kobayashi, a senior distinguished researcher at NTT Communication Science Laboratories, who is researching the development of the linguistic ability, which plays an important role in social participation, about his current research and attitude as a researcher.

Keywords: child language development, early education, picture book

Toward educational support based on evidence

—Would you like to start by telling us about your current research?

I'm researching the mechanism of child language acquisition and evidence-based educational support. Children generally learn the basics of their mother tongue during their first 3 years of childhood. I'm researching the mechanisms of speech perception, utterance, and learning of vocabulary, grammar, and letters involved in that learning process. English as a second language has recently been included in elementary schools in Japan, and this area has also been my research target.

I'm also studying social cognition. Children are able to judge the feelings and emotions of others from around 3–5 years old, and I'm investigating the development of that ability in relation to language skills. The focus has been on both language acquisition and cognitive skills of typically developing children; however, I think that if the feeling/emotion-judgement mechanism is understood, it will be possible to understand the stumbling points concerning language acquisition in atypically developing children. My goal is to continue researching these topics in collaboration with medical institutions such as hospitals and provide evidence-based educational support.

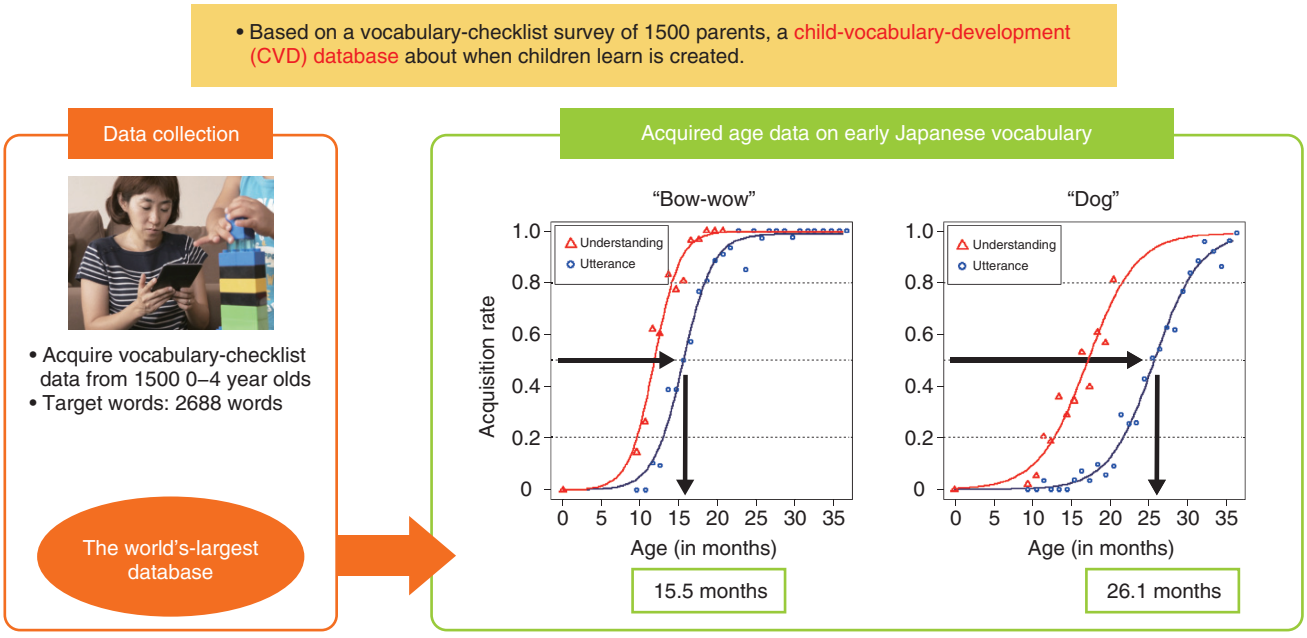

Fig. 1. Child-vocabulary-development database.

—It's a combination of your wisdom and affection for children. Your research might help many parents in raising their children. So, specifically, what kind of research do you conduct?

In one of my studies, namely, the mechanism by which Japanese vocabulary is acquired, not much basic data are available. Accordingly, we asked mothers of children aged up to 4 years to check what words their children can say at that stage. We then created statistical models to understand the initial development of language acquisition. Looking at the relationship between age and language acquisition from the collected data revealed that about 50% of infants at 15.5 months can say the word "*wanwan*" (Japanese "bow-wow") when they see a dog, whereas they can say "*inu*" ("dog") at 26.1 months. Moreover, the first word that infants can understand is their own name, and about 50% of infants can understand their name at about 7 months. We confirmed that in the next step of language acquisition infants understand words used for social communication such as "peekaboo" and "bye-bye" and by their first birthday, they can speak by understanding about 15 words on average. We thought that it would be useful if we could create a database of such data and use it to search for words according to age (in months and years) of infants and create content according to their age (**Fig. 1**). Based on such scientific findings, I've been supervising an educational television program for over 10 years. Evidence-based guidelines can now be added to the program production, which was conventionally based on years of experience and know-how.

We have also created picture books based on this database. A total of about 300,000 copies have been published in a series of five books. Although we created a picture book based only on words learnt at the earlier stages of language acquisition, the rate of language acquisition differs from child to child. Given that fact, we have been conducting field experiments with the aim of creating picture books personalized for individual children. That is, mothers are asked to check the vocabulary status of their children, and a picture book incorporating words learnt is created that is suitable for that child. Since this picture book was very popular among test participants, we started commercializing it in collaboration with NTT Printing in December 2019 and began test sales as four personalized educational picture books. Picture books significantly contribute to language acquisition, so this picture book represents an effort to support language acquisition. In general, as part of programs such as Bookstart, local governments distribute one picture book to parents when infant medical checkups start; however, it is difficult to get children into the habit of reading picture books by distributing

Fig. 2. A child using Pitarie.

*Sota is a legal trademark registered by Vstone Co., Ltd.

Fig. 3. Demonstration of Pitarie-Touch at the Picture Book Museum.

only one book.

To encourage parents and children to learn languages by making it a habit to read picture books, I thought it was important to motivate them to go to the library. In January 2020, in cooperation with the village of Onna in Okinawa, Japan, we began creating a personalized educational picture book for parents and their children who received a medical checkup to give children opportunities to go to the library. The personalized educational picture book is completed in about 10 days, so it is a mechanism for getting children to go back to the library to receive their books in an attempt to make it a habit to read picture books through repeated behavior, that is, if children are encouraged to return to the library many times, they can choose suitable picture books from the collection.

We have also developed a system of searching for picture books—called *Pitarie*—that searches for picture books that match the interest and the developmental stage of individual children [3] (**Fig. 2**). Although a target age group is indicated on each picture book, the range is quite wide. Therefore, by (i) analyzing the target age presented on the picture book and the word and sentence data appearing in the picture book and (ii) estimating the complexity of the sentences by using academic data and natural language-processing technology, picture books can be retrieved based on a narrower range of age and readability. As well as the title, the words used in the picture book are sorted; however, in picture books, fonts are not in a fixed form and characters may overlap the pictures; thus, picture books cannot be read mechanically using optical character recognition, etc. Accordingly, 6000 picture books were manually input to this system. Note that there can be an error between the target age and actual vocabulary status of the child depending on the status of the child's development. Therefore, the target age represents a guideline only. Nevertheless, I think that using Pitarie makes it possible to select suitable picture books for an individual child, and get children into the habit of going to libraries and reading picture books.

Pitarie has been commercialized by NTT DATA Kyushu, and in April 2019, it was officially introduced at the Fukui Prefectural Library. It was then officially installed at a nursery school in Shinagawa ward, Tokyo, and was very popular among the childcare staff. At an event called "Picture Book Museum" held during the summer break in Fukuoka City, a demonstration of recommending favorite picture books while interacting with a robot was held, and it was experienced by 20,000 people over almost two years (2018–2019) (**Fig. 3**). It was an experience that differed slightly from everyday life, so it was fun for the children. During the experience, the process of developing preferences for colors and patterns was analyzed. For example, in the case of a picture of a person on a book's cover, it turned out that children like faces with big cartoon eyes, which differs from more artistic faces on books that adults want to read.

In the future, I'm thinking of analyzing child-growth records. With the cooperation of a nursery school and growth records regarding the vocabulary that children learned will be input by the staff into a special app, which could then recommend picture books suitable for a particular stage of a child's

growth. Although we already have the know-how, we are investigating ways to implement this without putting a burden on childcare staff. More recent studies in developmental psychology have shown that as the frequency that parents read picture books aloud to their children at the age of one or two increases, the reading comprehension and mathematical skills of third and fourth graders in elementary school (8–9 year olds) improves. With the hope that our research will help support this learning base, we have presenting our results throughout Japan.

Ultimately, enthusiasm and motivation pave the way forward

—How did this research get started?

I think science is about explaining natural phenomena, and engineering is about creating things that we can use by referring to the explained phenomena. Humans speak in words, but animals do not. I wanted to find out why we can start to speak naturally after birth; that is, science was the trigger for my research. At university, I majored in psychology and became interested in human beings. In graduate school, I expanded my research to include the psychology of chimpanzees, elephants, and rats and investigated the mechanism of thinking and cognition in humans before they acquire language (a unique human characteristic) by comparing it with that in mammals. From that experience, I learned that humans are special among mammals because of traits such as our language ability, and I have come to explore our existence from an evolutionary and developmental perspective. Approaches to researching language vary widely. Even so, research on infants enables us to follow the process from knowing nothing up to learning a language; therefore, I thought it was important to be able to see the transitions of development and evolution.

Many scientists find it interesting to take up the challenge of solving what has not been solved. I have the same feeling. When I faced an unsolvable problem, could not explain the analytical data as hypothesized, or could not understand the clues, I still thought that it was worthwhile and pushed on with my research.

In general, basic research in science attempts to explain natural phenomena and presents results in papers. However, my current work has been expanded to the point at which such research results can be put to practical use after engaging in much discussion with various people. I've recently become very excited to handle the entirety of this process even though it is a small part of the NTT Group. I think this is not possible at research institutions such as universities. Originally, I was a scientist specializing in psychology and biology, so I was conducting research without being fully conscious of my contribution to society. However, because I'm working in a company, I think it is very rewarding to transition research accomplishments into businesses in collaboration with many colleagues and partners such as with Pitarie.

—What is the motivation that supports your research activities?

My motivation is twofold. The first is the feeling I get from the moment that I can understand the small things that I didn't understand before, that is, the joy of understanding. The second is the joy of having someone apply my research results and realizing I made a contribution. It is up to researchers to decide what approach to take when they begin research, and I think it depends on their sense of determining which problem to solve. In my case, I took the problem of human language acquisition, and how to solve that problem also depends on the sense of the researcher. I want to—I need to—brush up this skill, so it is important to take on such challenges.

However, there are times when we are asked questions such as "Does this mean anything?" Throughout the various stages of research and commercialization, people in various positions express differing opinions and concerns. In my experience, many of these opinions and concerns have been valid, which sometimes stopped me from doing what I tried to do. As you work on new research topics, getting people to understand them requires a great deal of effort. However, in any situation, it is important to push ahead with enthusiasm and confidence in what one really thinks is right. Rather than expecting someone to do something for you, it is necessary to take responsibility and have the willingness to do it all yourself until the very end, and this mindset is a source of motivation.

Nothing is useless in life. Get involved with those around you and push ahead

—Please say a few words to our researchers.

After joining NTT, I was ordered to research a subject different from the specialized field that I was

involved in as a student. Being able to stick to your specialty is very fortunate, but when you are not able to do that, which is often the case, turn what you are currently working on into something you like. Although my current research is completely different from that when I joined the company, I feel that my new specialty is interesting. Also, by stepping into engineering and business areas, I can realize that my research results are useful in society.

When I wasn't able to do what I wanted, I struggled through every day. I remember the head of the laboratory at that time saying, "There is nothing wasted in your life." At that time, I thought it was just words of comfort, but now I realize it is true. Something seems to be useless at first glance, but by working on it and gaining experience, it can be very useful regarding my current research.

As I mentioned earlier, it is important to have those who support you and get people around you to understand the significance of your research. Research and development is about creation and revealing new ideas; therefore, it can be difficult for others to understand. However, by patiently repeating explanations, you can gradually increase the number of people who understand your work and support you. By working with such people, you can produce concrete results.

—How will you proceed in the future?

I think it is my research style to set specific goals, go one step at a time, and achieve those goals. My team is currently conducting research on emotional development. I believe that knowledge of emotions, that is, thinking about and reading what others are feeling, is a very important ability in regard to children's social life, so we are measuring this ability and investigating how to use it to support emotional development.

In the near future, we plan to conduct a survey at several elementary schools. For example, if emotion is added to the word "Hello?", the expression will vary in meaning. We will measure how well children understand such words. Mainly outside Japan, information on children having difficulty understanding speech is being gathered. With that in mind, I want to understand the actual situation in Japan and consider how to improve the capacity to understand speech.

We still do not fully understand the learning process of writing and reading Japanese *hiragana*. Since the only large-scale study on this was conducted 50 years ago, we want to collect the latest data. In a previous study, we got children to write *hiragana* on paper, video-recorded it, and analyzed it; however, we can now measure writing order and speed by having children write *hiragana* on a tablet device that can automatically record and analyze such data. Analyzing typically developing children is more likely to lead to support for children with dyslexia. Studying child development revealed that a small stumble in the middle stages of development may reverberate later in life. I believe that if we find this stumble early on and provide support and training to address it, even if doing so does not lead to a fundamental solution, the child in question will be able to lead a fulfilling social life. I hope to continue supporting children so that they can have such a life.

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■ **Interviewee profile**

Tessei Kobayashi

Senior Distinguished Researcher, Interaction Research Group, Innovative Communication Laboratory, NTT Communication Science Laboratories.

He received a Ph.D. in psychology from the University of Tokyo in 2004. He is currently researching child language development, specifically vocabulary spurts and syntactic bootstrapping.

A Digital World of Humans and Society—Digital Twin Computing

Ryutaro Kawamura
Senior Vice President, Head of NTT Service Innovation Laboratory Group

Abstract

This article introduces a lecture presented by Ryutaro Kawamura, senior vice president and head of NTT Service Innovation Laboratory Group, at a special session of NTT R&D Forum 2019 held on November 14 and 15, 2019. The lecture described the latest research activities at the laboratory group, focusing on NTT's vision of Innovative Optical and Wireless Network or IOWN.

Keywords: IOWN, Digital Twin Computing, digital representation of humans

1. How will humans use the power of digital technology in the future?

Looking forward 10 and 20 years into the future, to what end will we, humanity, use the power of ever-advancing digital technology? As you know, predictions are being made about the coming of a major turning point in social systems, and Japan's Society 5.0 initiative reflects such ideas. Discussions are also raising the possibility that the long-lived capitalistic society is coming to an end. Let's look back at the history of digitalization in relation to humans and things over the past 30–40 years. To begin with, email appeared around 1985. This development can be seen as a step forward in digitalization centered around humans. Then, around 1995, the Internet appeared, and at the same time, the digitalization of information accelerated in relation to things, which improved daily life and services such as for providing products, timetables, and maps. Next, a new era in human communication appeared around 2005 in the form of social networking services (SNSs), and since 2015, we have been in an era marked by the digitalization of things driven by a combination of Internet of Things (IoT) and artificial intelligence (AI). Looking back at this recent history of digitalization, the digitalization of humans and things has been progressing in a mutually repeating cycle. Taking this cycle into account and viewing the recent development of IoT, we consider that it is time for human digitalization to take another turn. Of importance here is that value in this new era will increase not in a linear and proportional manner but rather in an explosive and discontinuous manner, and I predict that the time for this to occur is imminent (**Fig. 1**). In this regard, the expression *digital twin* has recently come into use in the sense that the digital representation of humans and things can enable replication, fusion, and exchange as well as saving and recording, all of which are strong points of digitalization. However, in much the same way that so-called *silos* have appeared in industry, the fact is that the digital twin concept has progressed in separate industries with no mutual compatibility.

2. Digital Twin Computing initiative

The digital twin framework up to now has been to map individual targets in the real world represented

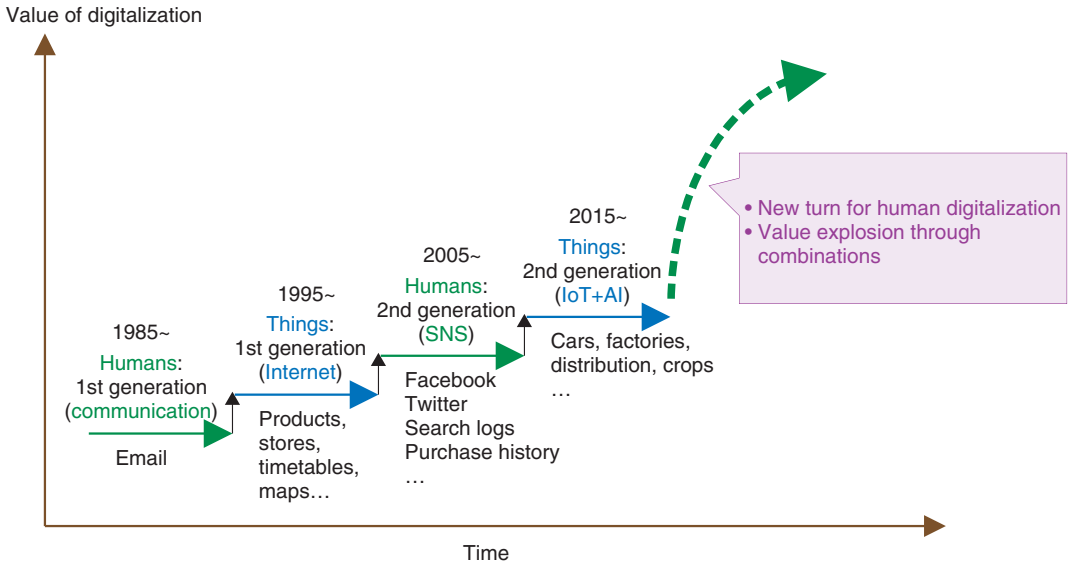

Fig. 1. Progress in digitalization in relation to humans and things.

by automobiles, robots, etc. in cyberspace and to analyze those targets and make predictions. The results of such analysis and predictions are then remapped to the real world and put to use.

As an extension of this conventional digital twin framework, we proposed Digital Twin Computing and began an initiative to make it a reality (**Fig. 2**) [1]. Digital Twin Computing takes digital twins of things and humans in diverse industries and performs computations on them in any desired combination. This makes it possible to accurately reproduce combinations that could not be comprehensively handled up to now, such as humans and automobiles in a city, and to make predictions about the future. In addition, Digital Twin Computing represents a new computing paradigm that goes beyond physical reproduction of the real world by achieving interactive effects among digital twins including the inner state (e.g., consciousness and thought) of humans in cyberspace. This initiative will endeavor to configure a virtual society composed of a variety of digital twins, replicate in cyberspace digital twins of single entities in the real world, and exchange or fuse some of the elements constituting different digital twins to generate new digital twins that do not exist in the real world.

This initiative will take up the challenge of achieving a digital representation of the inner state of individuals. By representing not just the outward appearance of humans but their inner state as well, it should be possible to achieve advanced interactivity even from a social perspective such as human mobility and communication. Moreover, representing the personality of every person should make it possible to achieve interactivity based on diversity and individual features as opposed to interactivity between individual digital twins without personality that are statistically rounded out as average values.

We argue that these features will enable the creation of a virtual society in which a variety of things and humans interact with each other in advanced and sophisticated ways beyond the limitations of the real world.

3. Digital representation of humans

It is important to note that a human digital twin in Digital Twin Computing can provide not only a digital representation of anatomical and physiological features but also a digital representation of a person's inner state. There are two main approaches to achieving such a difficult objective. The first approach is to emulate human abilities using computers and to repeat that process to "get continuously closer to human qualities." Technologies for recognizing sounds and voices and for communicating via conversation are good examples of how progress can be made with this approach. The second approach, which might be called the ultimate approach, is to physiologically clarify the human brain and body and transcribe the results to a computer. This field, which

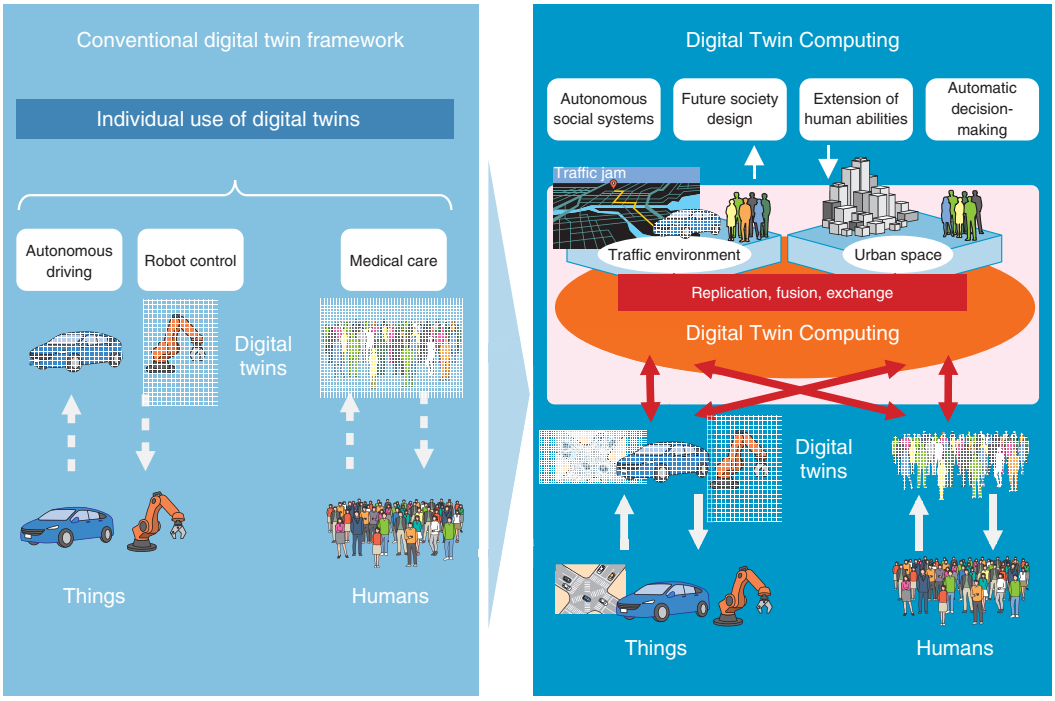

Fig. 2. Digital Twin Computing initiative.

is representative of brain and neuroscience, has been making much progress and has already been producing research results that can be used for engineering purposes. Our plan is to work toward this digital representation of humans by using the best elements of these two approaches (**Fig. 3**).

The following introduces several key technologies that NTT laboratories have so far taken up with respect to the first approach (**Fig. 4**).

3.1 Speech recognition

NTT laboratories have been researching for half a century how to accurately recognize the human voice as a technology for listening [2]. This research began with the recognition of words and clearly spoken sentences, but from around 2010, the technology was able to accurately recognize natural human utterances and be used at customer-contact centers. With the introduction of the latest neural networks, the technology is finally approaching the abilities of human speech recognition.

3.2 Speech synthesis

The question here is how and to what extent textual information can be converted to natural, humanlike speech. This technology includes text analysis processing to determine the reading of *kanji* (Chinese characters) in the Japanese language according to context and processing for synthesizing speech signals with appropriate pitch and speed. From around 1990, the technology has been used for making automatic replies to calls as well as synthesizing speech of animated characters, robots, etc. Deep learning based on speaker voice data is driving the synthesis of natural and diverse voices that have the feel of a real voice.

3.3 Understanding emotions and intent

Various approaches are being undertaken to develop technology for understanding the other party in a conversation to the point of identifying a person's gender, emotions, and degree of urgency. This can be accomplished, for example, by detecting whether a customer is dissatisfied or angry from a call between that customer and a contact-center operator. This technology is capable of detecting *cold anger* (calm and cool expression of anger), which is usually difficult to infer, from not only the loudness and pitch of voices but also from conversation rhythm, choice of words, etc. It is also able to achieve high-accuracy recognition of satisfaction, which is a feature that does not appear as easily as dissatisfaction.

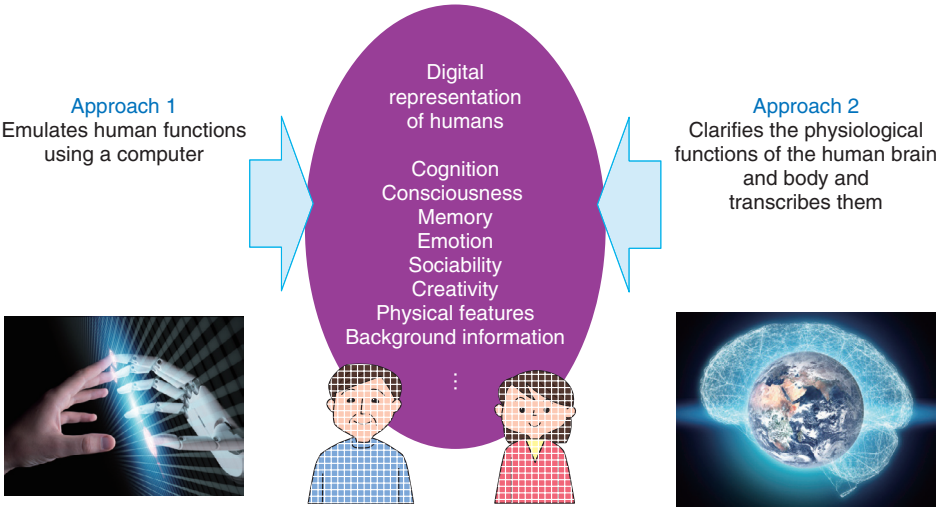

Fig. 3. Two main approaches to digital representation of humans.

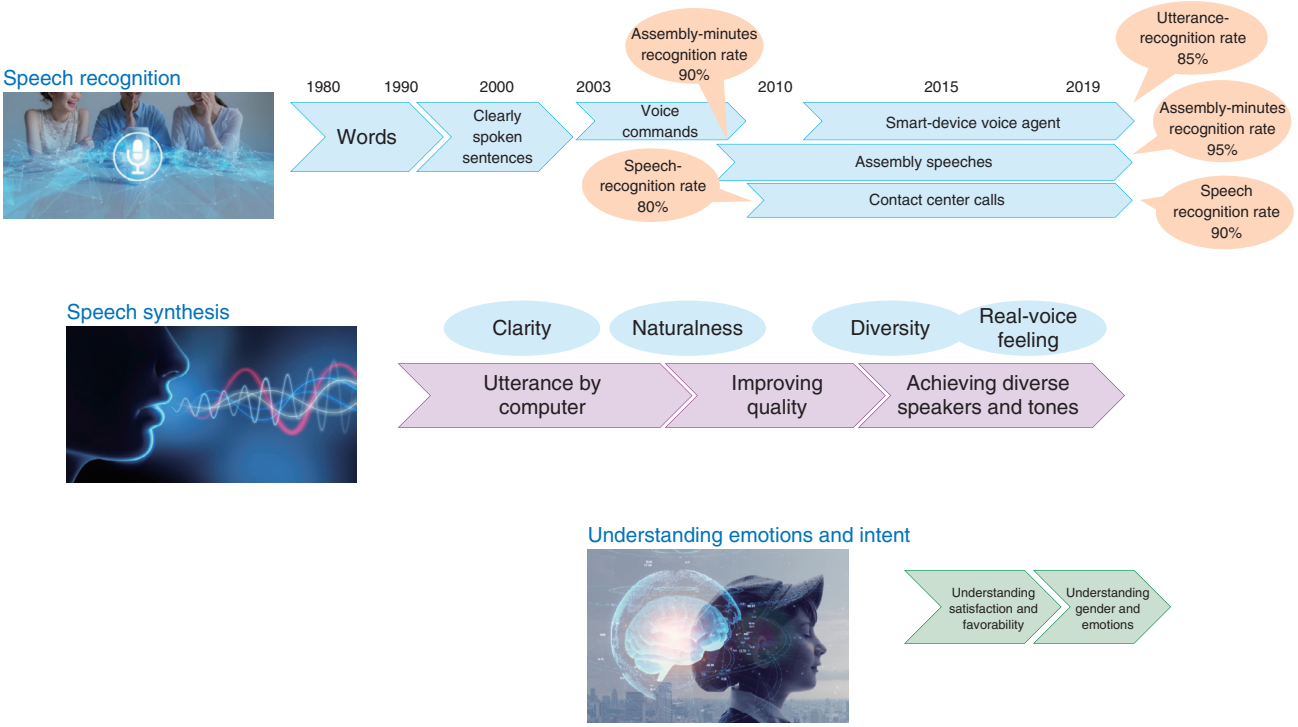

Fig. 4. Human digitalization—progress in approach using speech technology.

4. Layered structure and hourglass structure

Of importance when studying Digital Twin Computing technology and architecture is whether an hourglass structure can be added to a layered structure (**Fig. 5**). This is because the creation of a *common layer* in the middle of a structured layer can drive innovation. The Internet is a good example of this concept since the positioning of the IP (Internet protocol) layer as a common layer makes for smooth

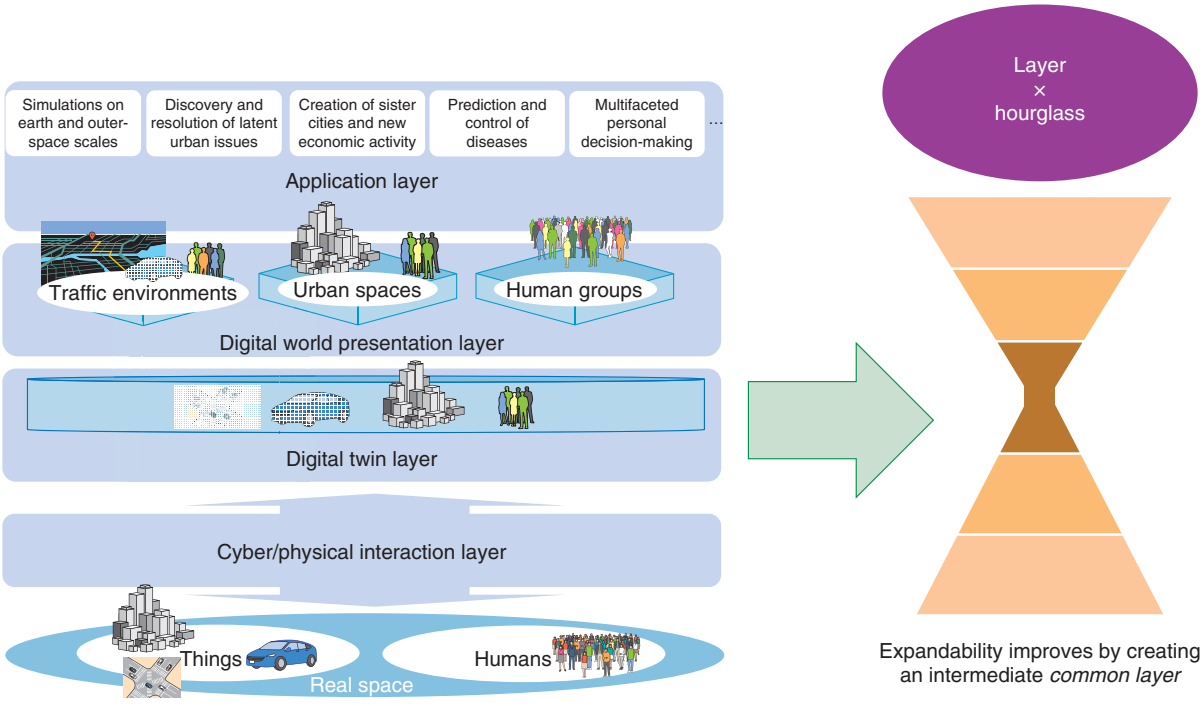

Fig. 5. Key to expansion: layered structure × hourglass structure.

interaction between the lower network and upper application layers. In Digital Twin Computing, as well, we consider that a narrow section—this common layer—is necessary and that the digital twin layer in Digital Twin Computing architecture will serve as this section. The digital twin layer maintains digital twins generated from various types of sensor data in real space and derivative digital twins generated from computations on digital twins. These digital twins maintained in the digital twin layer serve as basic constituent elements for constructing diverse virtual societies.

5. Technology supporting large-scale computation

It is preferred that the results of discussions among many human digital twins in cyberspace be fed back to real space and reflected in decision-making. This will require computing technology that far exceeds current computer performance. One example of technology supporting such large-scale computation is the LASOLV™ coherent Ising machine now being researched and developed at NTT laboratories. LASOLV is used to find solutions to combinatorial optimization problems by using special optical pulses to reach a physically stable state through mutual interaction. We can expect this technology to enable high-speed processing on an order of magnitude different from that of current computers. We are also developing middleware that simplifies the use of LASOLV in the Python language [3].

6. Use cases of Digital Twin Computing

Digital Twin Computing can be used on a variety of scales, as shown in **Fig. 6**. Specifically, the following uses can be expected.

- High-speed and parallel debate and decision-making by human digital twins
- Development of solutions to difficult national problems based on the actions of past leaders who have experience in overcoming crises
- Extensive and detailed urban digitalization through the integration of digital twins and social infrastructures such as the transportation system

7. Toward explosion in value through computations on digital twins

Our goal is to make Digital Twin Computing a truly useful concept together with a wide range of

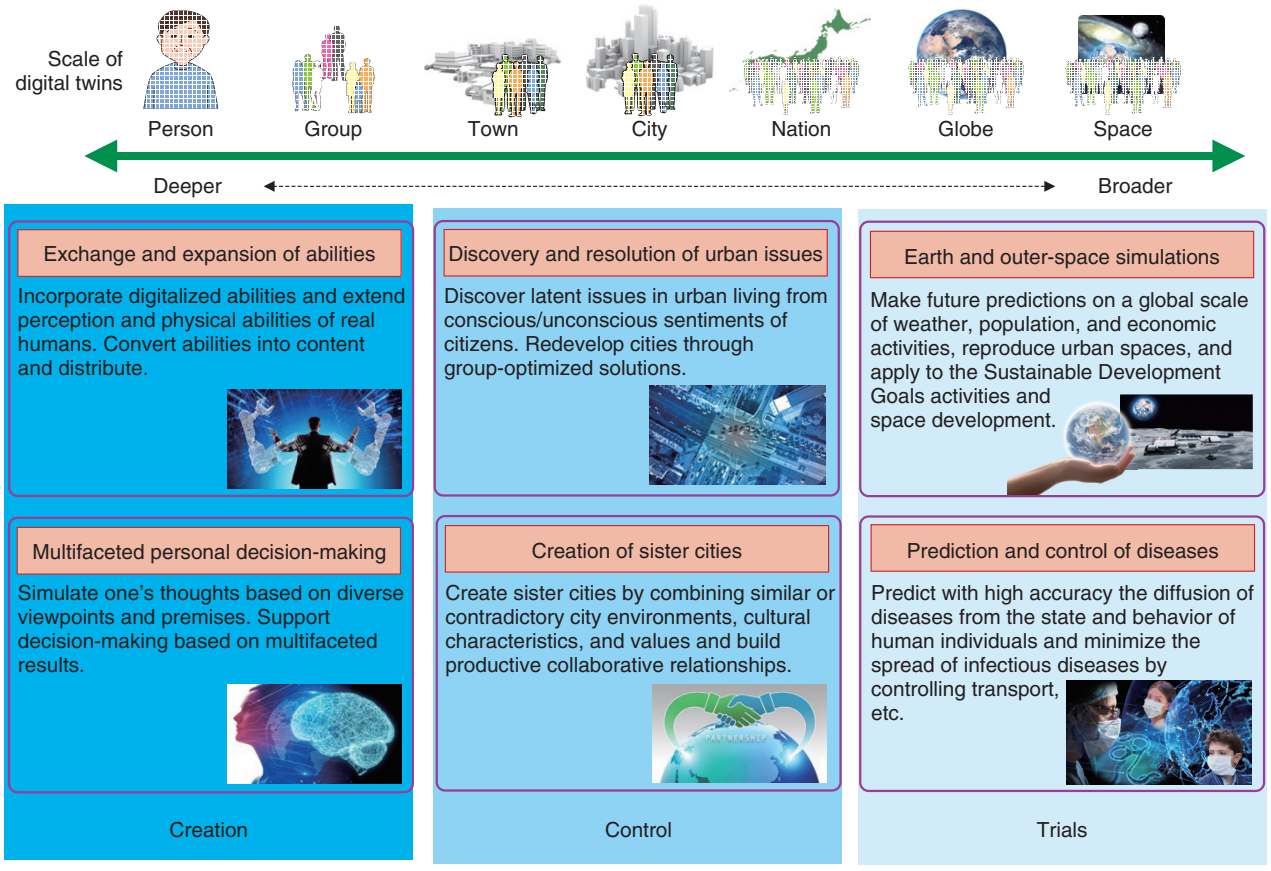

Fig. 6. Use cases.

interdisciplinary partners including those in the social sciences, humanities, etc. We also believe collaboration with a variety of industries is essential to making Digital Twin Computing a reality. Going forward, we plan to cultivate productive partnerships and promote research and development in this unexplored field while collecting much knowledge to forge a path to a digital society of the future.

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Innovative Network for 2030 (Beyond 2020)

Arata Itoh
Senior Vice President, Head of NTT Information Network Laboratory Group

Abstract

As part of NTT's Innovative Optical and Wireless Network (IOWN), we are focusing our research and development efforts on converting the transport network to be all-photonics based and maximizing its potential. We are also working on rapidly providing services and optimizing value chains. This article introduces IOWN initiatives at NTT Information Network Laboratory Group and recent research examples. It is based on a special session presented by Arata Itoh, senior vice president and head of NTT Information Network Laboratory Group, at NTT R&D Forum 2019 held on November 14 and 15, 2019.

Keywords: IOWN, All-Photonics Network, Cognitive Foundation

1. Issues and solutions toward a smart world

The NTT Group aims to achieve a *smart world* to solve social issues in collaboration with business partners. We have begun to clarify technical issues and drawn up solutions through trials and verification experiments with a variety of partners.

Through these efforts, issues in achieving sustainable growth have come to light. The current network infrastructure is not necessarily equipped to deploy low-latency services, such as genuinely connected cars, video delivery, and remote medicine, on a nationwide scale, so there is a need to significantly increase the potential of the future network.

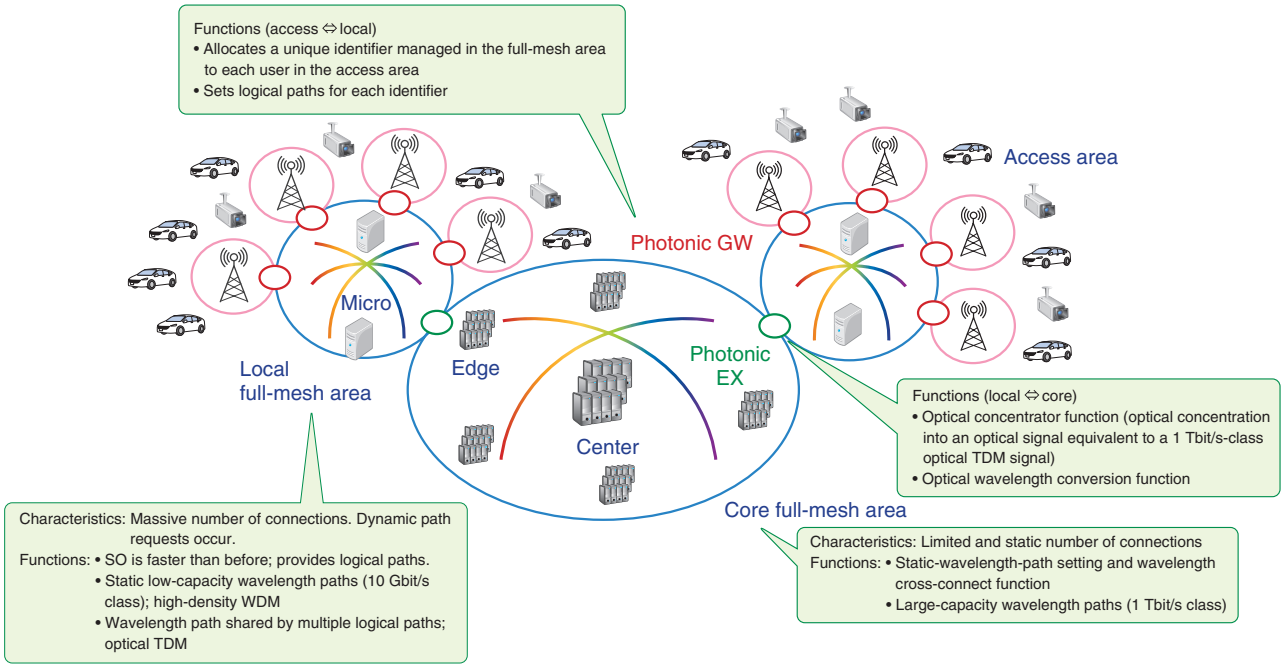
One direction being taken toward solving these issues is the development of a breakthrough network that can transfer inter-terminal Internet protocol (IP)/non-IP traffic without optical-to-electronical signal conversion. Based on photonics technology, Innovative Optical and Wireless Network (IOWN) will be a major key technology to solving these issues as it is a large-capacity, low-latency, flexible, and low-power-consumption network.

The following sections introduce the main initiatives in relation to the All-Photonics Network and Cognitive Foundation®, which are the fundamental elements of IOWN.

2. Main elemental technologies in the All-Photonics Network

Using the wide-band properties and flexibility of optical communication, a major feature of the All-Photonics Network is its ability to achieve an optimized function-specific network by providing a full-mesh connection of optical paths in wavelength units among many locations for each terminal, user, or service. We established the following four basic functions making up the All-Photonics Network.

(1) A network transport configuration function for achieving optical full-mesh networks and wireless access networks to provide high-speed and high-quality end-to-end data transfer (Function 1).



SO: service order
TDM: time division multiplexing
WDN: wavelength division multiplexing

Fig. 1. Optical full-mesh network-configuration technologies.

(2) A network design and control function for efficiently accommodating the massive number of wavelengths and frequencies needed for constructing and operating the above networks (Function 2).
(3) A function-specific network function for optimally combining information and communication technology (ICT) resources, such as network and computing, and meeting diverse service requirements (Function 3).
(4) A terminal function applying photonics-electronics convergence device technology for achieving low power consumption and low latency per unit amount of data (Function 4).

From these basic functions, we introduce elemental technologies representative of functions 1–3 (see the article "Basic Technologies toward the All-Photonics Network" in this issue for technologies of Function 4).

2.1 Optical full-mesh network-configuration technologies (for Function 1)

Two key technologies for achieving an end-to-end optical full-mesh network are petabit-class large-capacity wavelength-path technology and photonic exchange (EX)/gateway (GW) configuration technology (**Fig. 1**).

In terms of petabit-class large-capacity wavelength-path technology, we plan to establish ultra-high-speed optical signal transmission technologies (ultra-high-speed digital signal processing technology and ultra-high-speed optical frontend circuit technology) for achieving a maximum bit rate of 1 Tbit/s per wavelength. We will also undertake research and development of multicore/multimode technology and technology for expanding the transmission capacity per single fiber called transmission-wavelength-range expansion technology (transmission over the C- and L-bands).

To maintain scalability, we will also research and develop photonic EX, a function for directly replacing small-capacity optical paths in the domain-divided local full-mesh area with a large-capacity optical path in the core full-mesh area, and photonic GW, a function for turning back signals from the access area to the local full-mesh area directly in optical form. These functions achieve low latency and low power consumption by allocating wavelength paths dynamically instead of performing packet processing.

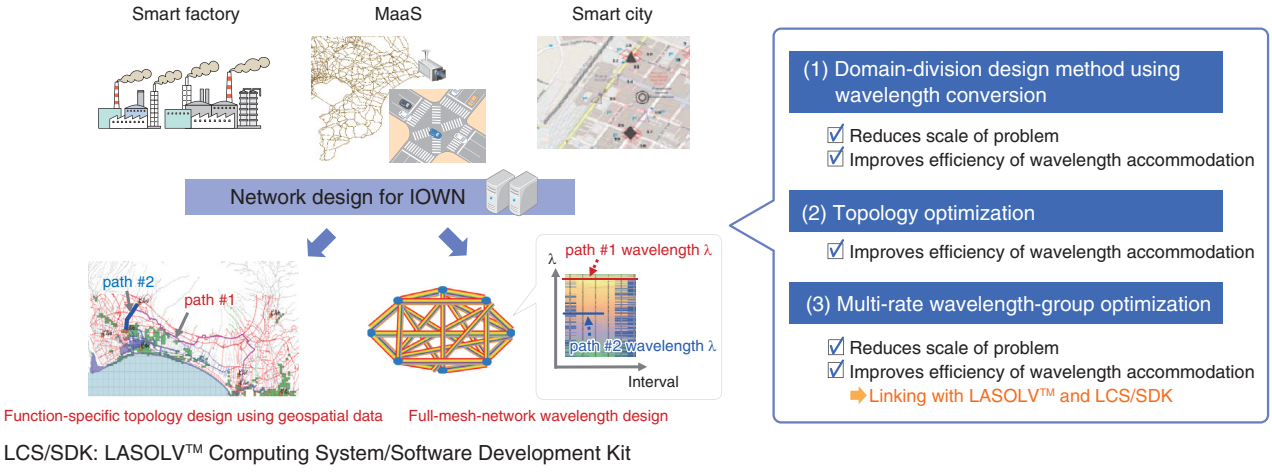


Fig. 2. Accommodation-design technology based on spatial data science.

2.2 Accommodation-design technology based on spatial data science (for Function 2)

As described above, the All-Photonics Network allocates wavelengths for each terminal, user, or service and enables end-to-end wavelength path connections. In this regard, the explosive increase in the number of communication terminals due to the spread of the Internet of Things, mobility as a service (MaaS), etc. and the resulting combinations of communicating parties means that a massive number of optical paths will be needed. This need underscores the importance of accommodation-design technology for efficiently allocating a limited number of wavelengths (**Fig. 2**).

There are three key points in accommodation-design technology.

(1) **Domain division that uses wavelength conversion technology via the photonic EX/GW functions described above**. That is, the division of the local area into multiple domains and performing wavelength conversion at domain boundaries enables the reuse of the same wavelength by different domains. This makes for more efficient use of wavelength resources. Domain division also reduces the number of wavelengths that should be allocated to optical paths. The key to domain division lies in the method of division and optimization of the unit of division such as by making divisions centered about hubs having high demand for originating and terminating calls.

(2) **Topology optimization**. The idea is to derive optimal paths and topology within a domain and improve the efficiency of wavelength accommodation while enabling effective provisioning for new or additional installing of optical fibers.

(3) **Multi-rate wavelength-group optimization**. Grouping optical paths having the same route within a domain and allocating and managing wavelengths as a wavelength group make it possible to increase the efficiency of wavelength accommodation and reduce the scale of the wavelength-allocation problem. Achieving an appropriate scale for this problem enables optimal wavelength allocation using the LASOLV™ coherent Ising machine and LASOLV™ Computing System/Software Development Kit (LCS/SDK)*.

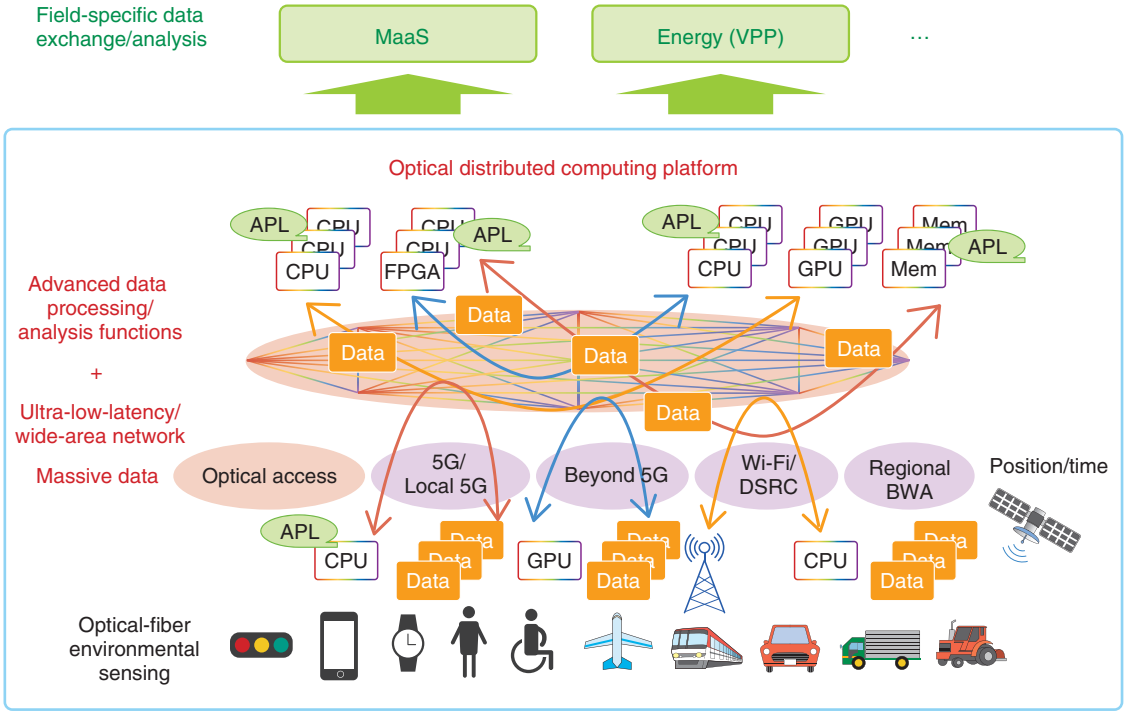
Combining these technologies makes it possible to reduce the number of wavelengths required per fiber to about 1000, which means that the system is feasible assuming the use of multicore fiber.

2.3 Optical distributed-computing-platform technology (for Function 3)

We are studying optical distributed processing technology for achieving advanced processing of large volumes of data from various devices connected to an optical full-mesh network according to diverse service requirements (**Fig. 3**).

The key point is the use of the large-capacity and low-latency properties of an optical full-mesh network

* LCS/SDK: Middleware for solving combinatorial optimization problems with the LASOLV™ coherent Ising machine.



APL: application
BWA: broadband wireless access
CPU: central processing unit
DSRC: dedicated short-range communications
5G: fifth-generation mobile communications
FPGA: field-programmable gate array
GPU: graphics processing unit
Mem: memory
VPP: virtual power plant

Fig. 3. Optical distributed-computing-platform technology.

to drive dynamic and high-density cooperative operation of computing resources distributed over a wide area. Therefore, computing resources located far from each other can be operated on as if they were located at the same location, and ever-changing resource requests can be flexibly handled. This technology can achieve both highly efficient use of computing resources and advanced data processing.

3. Main elemental technologies in Cognitive Foundation®

Cognitive Foundation is a mechanism for carrying out integrated deployment, configuring, and linking as well as management and operation of ICT resources on different layers such as the cloud, network services, and user facilities. In addition to making business more efficient for service providers and driving their digital transformation, Cognitive Foundation will enable even higher levels of user convenience such as the rapid provision of services to end users. Essential technologies for achieving Cognitive Foundation include user-friendly operation technology for automatically designing and autonomously operating diverse resources and technologies for enhancing and optimizing the entire system including the wired and wireless systems.

In this area, we are researching and developing *natural* wireless-access platform technology as an optimization technology for wireless resources. The goal is to achieve optimized wireless areas tailored to usage conditions and to link multiple wireless areas to enable the provision of seamless wireless connections regardless of the type of wireless connection. We call such wireless control technology *Cradio* including the quality-prediction technology for achieving optimal use of multiple types of wireless access (**Fig. 4**).

This technology aims to provide comfortable services for users' various demands by using artificial intelligence (AI) to predict beforehand dynamic changes in wireless communications quality accompanying the movement of drones, autonomous driving vehicles, smartphone terminals, etc. and automatically selecting and configuring an optimal wireless environment.

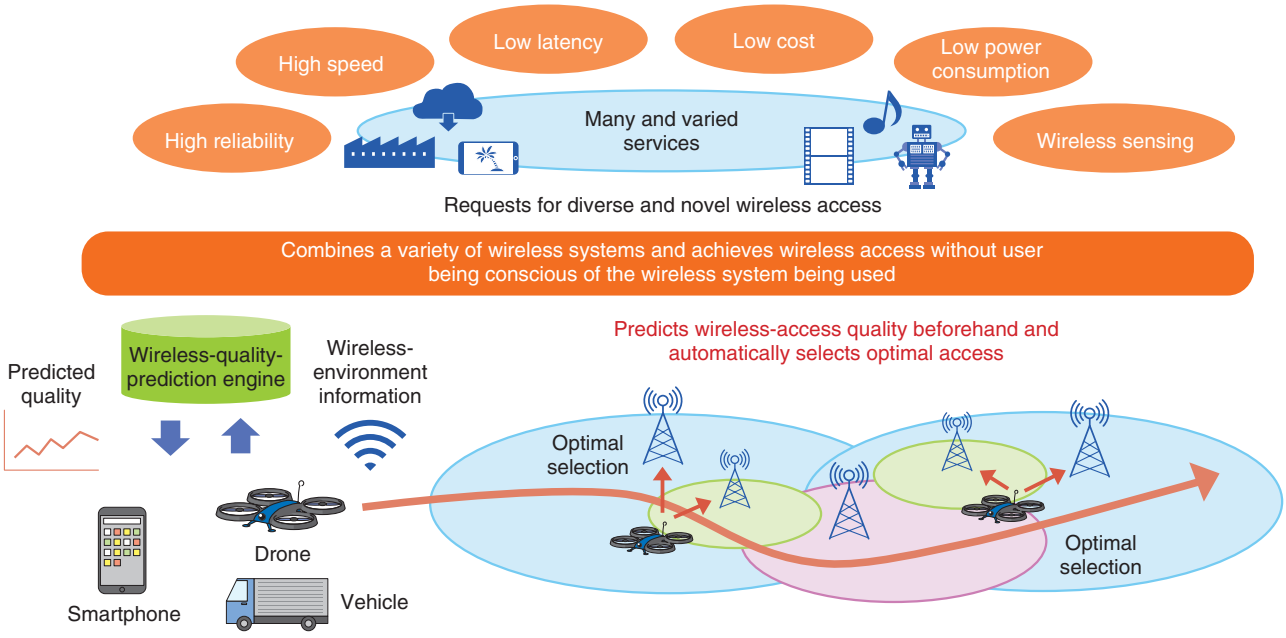


Fig. 4. Quality-prediction technology for optimal use of multiple types of wireless access.

4. Toward the creation of new value

To enhance the value of optical fiber laid throughout Japan, we are also researching and developing the extensive use of optical fiber beyond communication fields to non-communication fields.

We can consider, for example, high-efficiency optical-energy usage technology for maintaining communications during a disaster by effectively using infinitesimal amounts of energy in optical fiber transmissions. We can also consider rolling out services by using the optical-fiber environment-monitoring technology that obtains and visualizes environmental data through optical fiber sensing as a regional environmental data platform (**Fig. 5**).

Our plan is to pursue research and development toward the creation of new value including non-communication fields while collaborating with a variety of partners through the IOWN Global Forum and other settings.

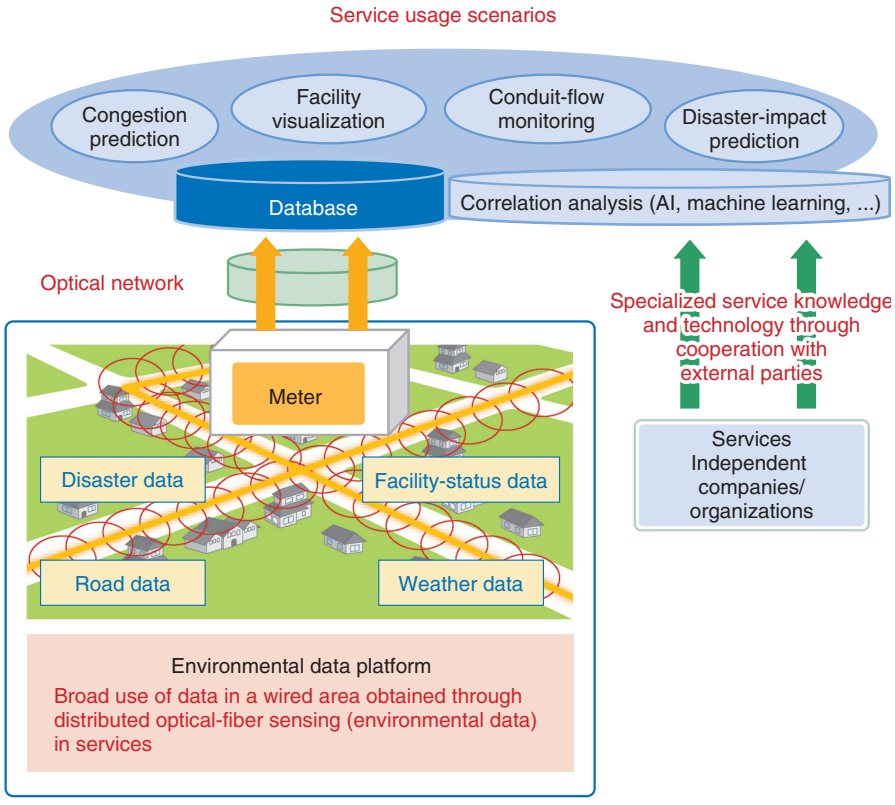


Fig. 5. Optical-fiber environment-monitoring technology.

Arata Itoh
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He received a B.E. and M.E. from Tokyo Institute of Technology in 1986 and 1988. Since joining NTT in 1988, he has conducted research and development of asynchronous transfer mode-based multimedia switching architecture and the Next Generation Network. He has also been involved with the NTT EAST/WEST R&D Center and the R&D vision group of the NTT Research and Development Planning Department.

Basic Technologies toward the All-Photonics Network

Tetsuomi Sogawa
Senior Vice President, Head of NTT Science and Core Technology Laboratory Group

Abstract

Optical technology is important for achieving the All-Photonics Network, a key element of NTT's Innovative Optical and Wireless Network (IOWN). This article introduces basic research on optical technologies, including large-capacity optical transmission system/device technology, photonics-electronics convergence technology, the LASOLV™ coherent Ising machine, and optical lattice clock network. It is based on a special session presented by Tetsuomi Sogawa, senior vice president and head of NTT Science and Core Technology Laboratory Group, at NTT R&D Forum 2019 held on November 14 and 15, 2019.

Keywords: IOWN, All-Photonics Network, photonics-electronics convergence

1. Introduction

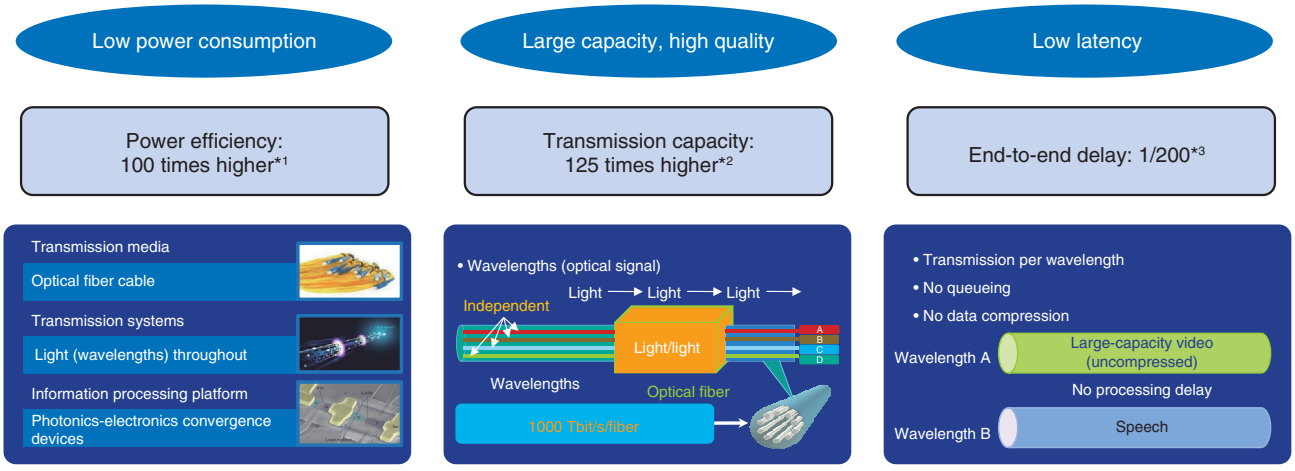
Internet traffic continues to dramatically increase, resulting in more power consumed by information technology equipment called upon to process huge amounts of data. At the same time, Moore's Law, the scaling law involving the evolution of large-scale integrated circuits, is approaching its limit. The miniaturization of semiconductor devices generates leakage currents and heat, thus, degrades performance. Though the amount of data that must be processed continues to increase, the inability of scaling up computing power at its traditional pace is becoming a fundamental problem.

2. What is the All-Photonics Network?

One target for the All-Photonics Network, a key element of Innovative Optical and Wireless Network (IOWN), is a 100-fold increase in power efficiency (**Fig. 1**). To this end, we are studying technology for transmitting signals using light from the network to terminals and studying new devices such as photonic-electronics convergence devices. We also aim to increase transmission capacity 125 fold, so we are studying large-capacity optical transmission system/device technology using, for example, new optical fibers such as multicore fiber. Furthermore, to reduce end-to-end delay by 1/200, we are researching various technologies to, for example, transmit information with no compression when communications do not allow for delay.

3. Role of increasingly important optical technology

Easy-to-use electronic technology has been used for chips that perform a variety of operations in computers. However, the recent trend toward high-density integration has been accompanied by an increase in



*1 Target power efficiency for the photonics part

*2 Target communication capacity per fiber

*3 Target delay for uncompressed video traffic within the same prefecture in Japan

Fig. 1. Target performance of All-Photonics Network.

the heat generated by wiring within a chip and the resultant constraint on performance. For this reason, we set as a target a new chip that integrates optics and electronics with lower power consumption by introducing optical communications technology in the chip's wiring section that incorporates high-speed computing technology characteristics of optical technology. Therefore, the use of optical technology in an end-to-end manner in conjunction with network opticalization plays an important role in making IOWN a reality.

This article focuses on four research themes toward achieving the All-Photonics Network.

4. Large-capacity optical transmission system/device technology

Compared with the 1980s when optical communications first got underway, communication speeds using optical fiber have increased by as much as six orders of magnitude over the last forty years (**Fig. 2**). This has been enabled by key inventions such as semiconductor lasers, planar lightwave circuits, and fiber amplifiers, and transmission capacity has recently dramatically increased through the development of digital signal processors for digital coherent communications.

NTT reported in 2019 on a successful experiment to transmit 1 Tbit/s-per-wavelength optical signals in 35-wavelength division multiplexing at the laboratory level [1]. We also reported on the successful transmission of 1 Tbit/s-per-wavelength optical signals at a practical level for over 1000 km under a commercial environment using laid optical fiber [2]. The current outlook is for transmission on the level of 1 Pbit/s per fiber using, for example, a new fiber structure called *multicore fiber* that, as the name implies, incorporates many cores in a single fiber.

Devices applied to the core, metro, and access networks must evolve steadily, and devices that interconnect datacenters, the demand for which is growing dramatically, will become increasingly important. Therefore, there is a need for making as many end-to-end connections, including those between datacenters, as possible by optical means, and that is exactly what we want to achieve with IOWN.

5. Photonics-electronics convergence technology

Although it was very difficult to handle light in the past, a structure called a photonic crystal (**Fig. 3**), in which the refractive index is changed periodically, has made it possible to confine light to a small area and improve the interaction between light and material. Basic low-power operation of a variety of devices based on photonic crystals, such as optical switches, optical lasers, optical memory, and optical random-access memory, has been demonstrated experimentally.

The roadmap for photonics-electronics convergence technology is shown in **Fig. 4**. In Step 1, the plan is to achieve a structure that integrates circuits

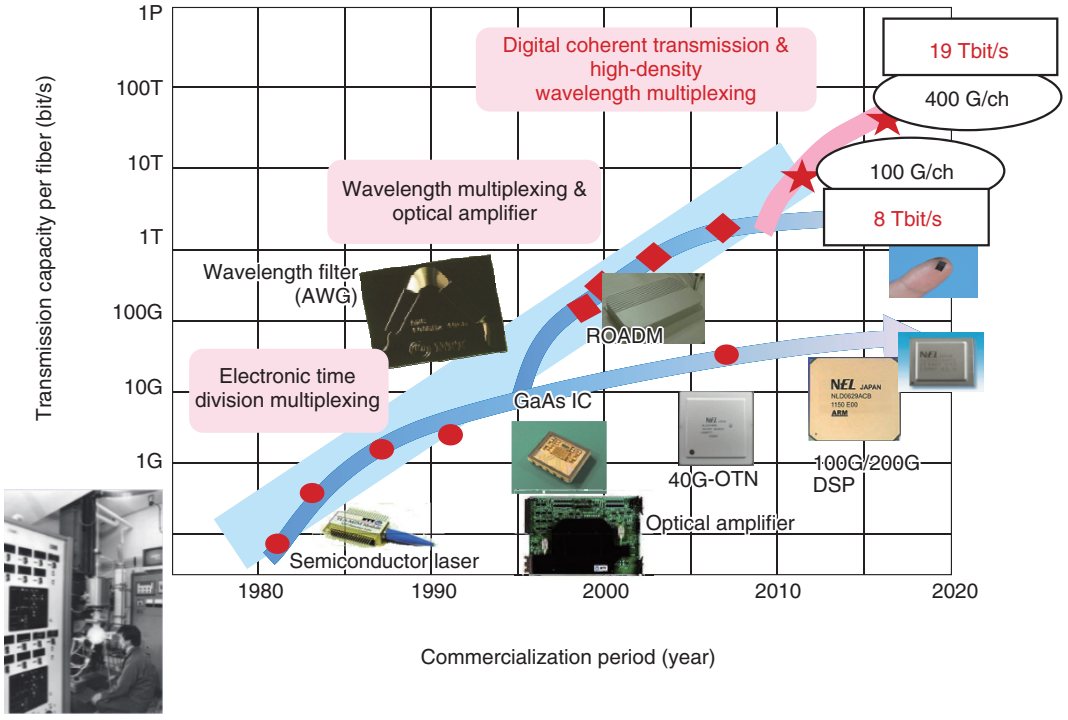


Fig. 2. Progress in photonics technology enabling traffic growth.

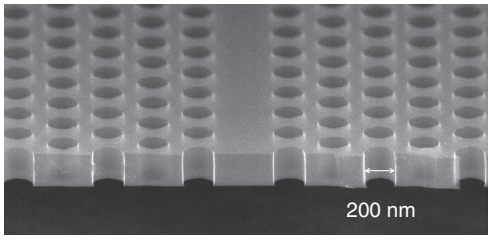


Fig. 3. Photonic crystal.

mounted using silicon photonics with fibers, analog integrated circuits (ICs), etc. and achieve high connection speeds with elements outside the chip. In Step 2, the plan is to directly interconnect chips by short-range optical wiring, and in Step 3, the plan is to make inter-core connections within a chip by optical wiring to achieve ultra-low-power consumption.

Step 3 will further improve the performance of chips by taking advantage of the arithmetic processing that is characteristic of light. While passing through a typical *n*-step logic gate would generate *n*-step worth of delay, the form of optical switches and optical circuit as a logic circuit, which we call an *optical pass gate*, can obtain a calculation result instantaneously with just the time taken to pass through the optical circuit [3]. Although we are at the basic evaluation stage with just a small number of bits, we are also studying the application of optical pass gates and optical transistors [4].

6. LASOLV™ coherent Ising machine

Next-generation computers, many of which have been announced in recent years, are expected to solve complex problems requiring a huge amount of computational resources that have been difficult with conventional computers [5, 6]. Against this background, we are researching solutions to combinatorial optimization problems—one type of complex problem—through the use of our coherent Ising machine called LASOLV™ that uses optical technology, one of NTT's main focus areas. There are many combinatorial optimization problems in the real world. They involve a massive number of combinations

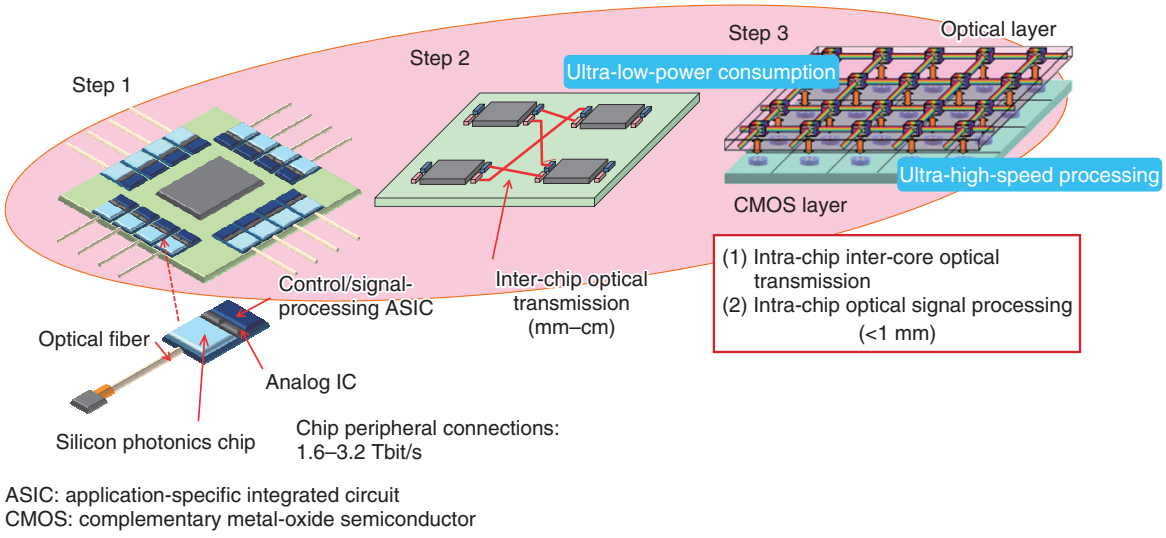


Fig. 4. Roadmap for photonics-electronics convergence technology.

that are generated when the number of options increases, a situation that has been difficult with current computers.

Combinatorial optimization problems can be converted to graph problems, and an Ising machine is a computer based on the new concept of conducting physical experiments to derive solutions to such graph problems. For example, if we were to arrange a magnet oriented to either the S-pole or N-pole at each node of a graph according to certain constraints then release our hold on those magnets, the total energy of the system would take on its smallest value as the magnets orientate themselves to their most stable configurations. This would, in effect, derive an answer to that graph problem.

LASOLV uses optical technology to create a situation equivalent to this magnet experiment. Specifically, it inputs 2000 optical pulses into an optical fiber 1 km in length and passes them any number of times through a special optical amplifier to amplify them repeatedly. The system eventually settles into a state whereby the phase of each optical pulse is either 0 or π. If we compare the oscillation of an optical wave to that of a playground swing, we can say that it settles into a state whereby *the swing is either ahead or behind*. In addition, the machine takes some of the optical pulses from the optical fiber and measures their phase states, sets constraints in the graph problem in terms of optical interactions, and returns these pulses to the optical fiber overlaying them on the original pulses. Repeating this process while circulating the optical pulses about 1000 times through the optical fiber provides a solution to the problem (**Fig. 5**).

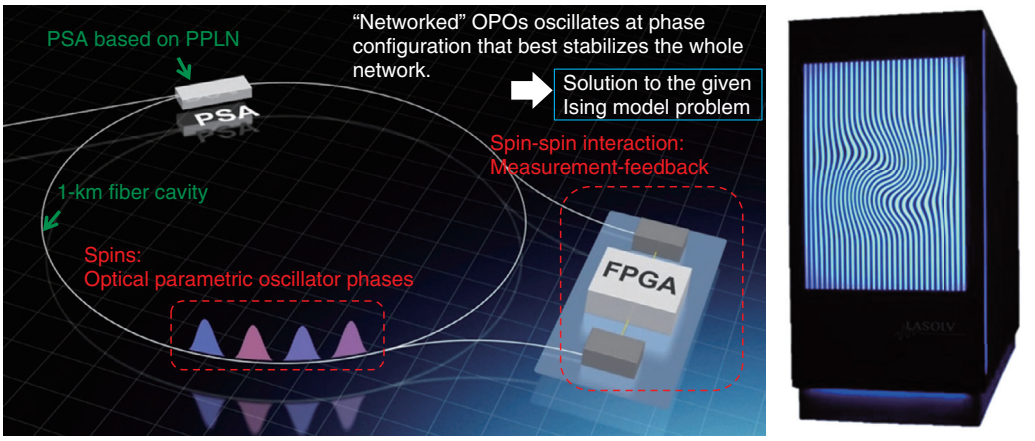
On comparing LASOLV with quantum annealing developed by another company, it was found that LASOLV exhibited superior performance the more complex the graph structure became, even when solving relatively small problems. It has also been recently found that LASOLV can even be useful in solving larger-size problems [7].

LASOLV can be applied to complex wavelength-allocation problems in the All-Photonics Network of IOWN and perform high-load processing in machine learning.

7. Optical lattice clock network

The optical lattice clock invented by Professor Hidetoshi Katori of the University of Tokyo loses only one second every 30 billion years, which is more accurate than the advanced cesium atomic clock by three orders of magnitude. The optical lattice clock can also be read out by laser, which opens up the possibility of clock transmission over optical fiber. We are studying what this feature has to offer by constructing a network of optical lattice clocks installed in many of NTT's central offices.

As suggested by the general theory of relativity, clocks run faster at higher altitudes, so optical lattice clocks that have achieved 10^{-18} of total accuracy of clock frequency allow us to compare remote locations



(a) LASOLV operation concept (b) LASOLV external view

FPGA: field-programmable gate away
OPO: optical parametric oscillator
PPLN: periodically poled lithium niobate
PSA: phase sensitive amplifier

Fig. 5. LASOLV™.

and measure differences in altitude as small as 1 cm. In Japan, an earthquake-prone country, this means that minute crustal movements and massive gravitational movements can be detected, which points to the possibility of constructing a very effective, safe, and secure infrastructures.

However, when carrying such ultra-high-accuracy signals by optical fiber, it is necessary to control drops in accuracy caused by optical fiber fluctuations. We are currently conducting a trial of an optical lattice clock network that connects various bases by NTT EAST optical fiber and includes relay equipment installed in NTT central offices (relay stations) to cancel such optical fiber fluctuations while maintaining high accuracy (**Fig. 6**). In the future, we would like to see an optical lattice clock network introduced into IOWN for developing new types of time-related business.

8. Toward Achieving the All-Photonics Network

Going forward, we will promote research and development efforts to achieve *world-best, world-first, and impressive technology*. We will promote further research and development of photonics-electronics convergence technology, the key to achieving the All-Photonics Network.

We also plan to make IOWN a reality in collaboration with experts in a wide array of research and technology fields while holding discussions with various companies and universities via the IOWN Global Forum [8]. To all parties involved in this effort, we look forward to your support and cooperation.

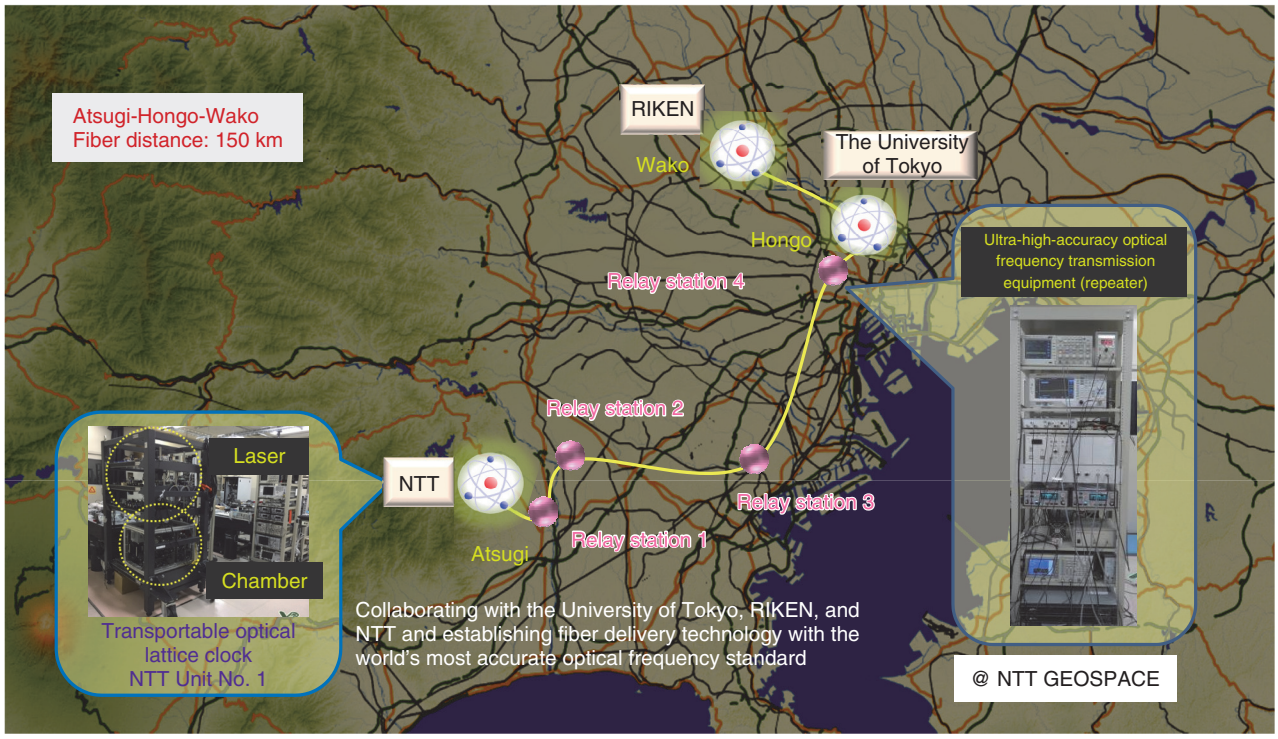


Fig. 6. Optical lattice clock network trial.

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Trademark notes

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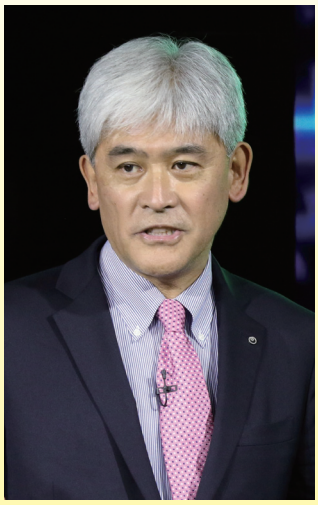
Upgrade Reality—Reality in IOWN Concept

Kazuhiro Gomi
President & CEO, NTT Research, Inc.



Abstract

This article introduces the vision of NTT Research, Inc., which began its operations in July 2019 with the three laboratories. This article is based on the special session for NTT Research, Inc. at the NTT R&D Forum 2019, which was held on November 14 and 15, 2019.

Keywords: advanced basic research, IOWN, Upgrade Reality

1. The current situation of ICT sector and launch of NTT Research, Inc.

Looking at the recent trends in the information and communication technology (ICT) market, we see new innovations making good progress in the areas of Internet of Things (IoT), big data, artificial intelligence (AI), and automation. Many technologies to support such trends are now affordably available, which triggered digital transformation (DX) in many business sectors, which has created tremendous positive impact on the way we do business and live our lives. However, there are several limiting factors on the horizon that could impede this evolution. These factors are ICT energy consumption, saturated Moore's Law, and security (or privacy) (**Fig. 1**).

To sustain DX for over a long period, we see the need of having some kind of "game changer," rather than incremental improvements. That is exactly how NTT research and development (R&D) laboratories view the Innovative Optical and Wireless Network (IOWN) initiative. IOWN is a reflection of NTT R&D's focus on long-term solutions.

NTT Research, Inc. was founded in July 2019 to conduct basic research activities related to the key components of the IOWN initiative. This company is based in the area outside of San Francisco, California, in the United States known as Silicon Valley. The key advantage of this setting is this is where many of the major global talent and global research partners are located; therefore, collaborations with them are easily facilitated. Also, by having this footprint in Silicon Valley, NTT R&D as a whole becomes a part of such communities. The vision of NTT Research, Inc. is to further enhance the research activities that NTT has been engaged in for a long time through such collaborations (**Fig. 2**).

2. The activities of each laboratory

NTT Research, Inc. is currently organized into three research areas, as shown in **Fig. 3**. These are the Physics & Informatics Laboratories (NTT PHI Labs), the Cryptography & Information Security Laboratories (NTT CIS Labs), and the Medical & Health Informatics Laboratories (NTT MEI Labs).

2.1 NTT PHI Labs

PHI Labs studies completely novel optical computers called coherent Ising machines (CIMs), which are designed to solve combinatorial optimization problems efficiently. An example of a combinatorial optimization problem is the traveling salesman problem, which is to find the shortest overall route covering all

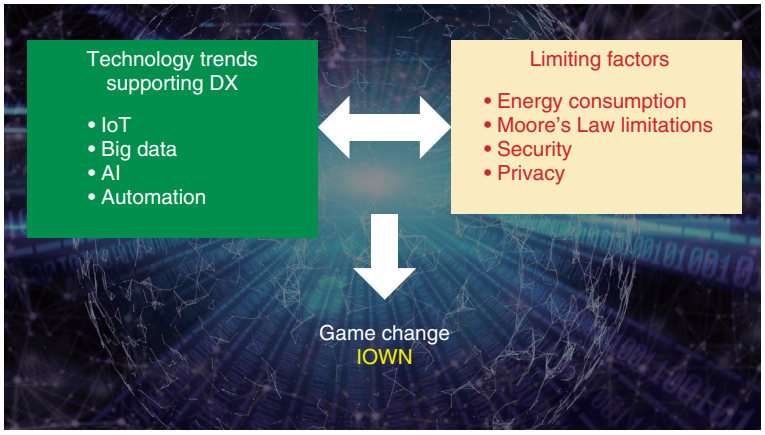


Fig. 1. Technology trends and limiting factors.

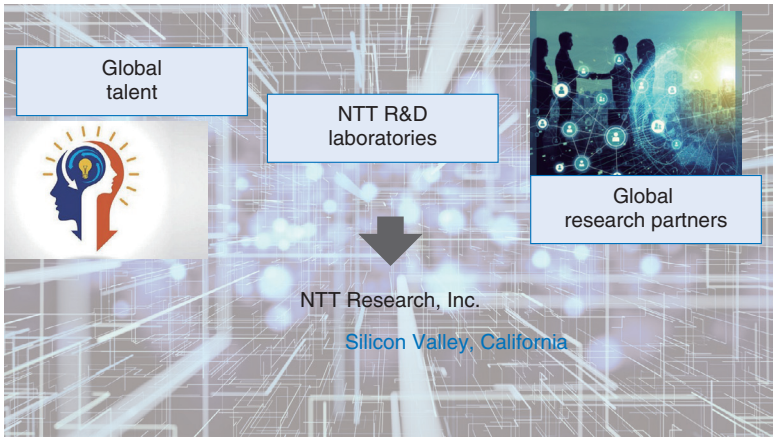


Fig. 2. Why NTT Research, Inc. was established in Silicon Valley.

Physics and Informatics (PHI Labs)

Cryptography and Information Security (CIS Labs)

Medical and Health Informatics (MEI Labs)

Fig. 3. Laboratories in NTT Research, Inc.

the customers. The number of possible routes increases exponentially as the numbers of customers and possible paths increase. This problem can take years to solve on conventional computers when dealing with practical cases. The concept of the traveling salesman problem can be applied in many similar real-life problems such as optimal traffic control to minimize congestion in a large city and wavelength allocation in mobile phone services.

Over the years, NTT R&D has been working on optical versions of the CIM, which combine the principles of quantum information processing with those of brain information processing. NTT Research, Inc. announced in November the start of a research collaboration with eight external partners in the United States, Canada, and Australia (five US-based universities, one Australian university, NASA, and one software startup) to enhance the research activities around CIMs. Together with these partners, PHI Labs studies the theoretical aspects of these machines, conducts related experiments, and explores applications for which these machines would solve their

issues effectively and efficiently.

2.2 NTT CIS Labs

CIS Labs conducts research on cryptography. To build a smart world and connected society, we need to be ever-more attentive on the issues around privacy and security. Crypto systems are developed to protect security and privacy; however, the implementation of such systems tends to make information sharing more difficult. In other words, easy information sharing and protection of privacy/security are trade-offs in many cases. CIS Labs is researching new cryptographic techniques that enhance the flexibility in information exchange while maintaining security and privacy. Another topic that this group is tackling is post-quantum cryptography, addressing the concern that most current crypto systems would be broken when quantum computers are in place.

CIS Labs is also working on the topic of blockchain security. Blockchain has been implemented in several applications such as crypto currencies and fintech applications. However, there has not been much research into its security implications and scalability issues. One of CIS Labs' focus areas is the proofs of blockchain security, for example, to answer the question, "under what conditions can a blockchain be broken."

We will continue to assemble a dream team of top experts and talent. Currently, the team consists of researchers and scientists who came from the faculties of top level universities in this field such as the University of Texas, Northeastern University, Princeton University, and Cornell University.

2.3 NTT MEI Labs

MEI Labs' field of research is medical and health sciences. This is closely related to Digital Twin Computing (DTC), an important component of the IOWN initiative. Medical practice is always looking for the best solution *along with* the next best. With this in mind, to have your digital twin (alter ego) in the cyber world and administer treatments to it would create a huge advantage for medical care in the future. If a particular treatment, tested on the digital twin, does not work, we can try another approach without risking the patient's health. Furthermore, if you have a precisely simulated model of your body or part of your body (i.e. organs), it would create a revolution in the world of medical practice. Today, with significant progress in bio-sensing technologies, a vast amount of medical information is becoming available. Together with the innovations in AI, big data, and robotics, precise human-body simulation and medical treatment based on it will be the next step we need to pursue. In the past, medical records, and even test and imaging results, existed solely within the handwritten analog world, but now these data are all digitally stored. We envision that, by leveraging the output from advanced crypto technologies, such data will be effectively exchanged among bio-medical/data-analytic experts to study and create simulated human-body models while maintaining patients' privacy.

Many experts have been pointing out that medical and health sciences need to collaborate in a more robust manner with math, science, and engineering disciplines. In this new era where information technologies are progressing rapidly, we can expect medical and health sciences to leverage a variety of these innovations. However, such an approach should be ethically sound. The fundamentals of human community needs to be preserved while developing cutting edge medical and life-science technologies. One of the conditions for achieving this is the integrity of the members engaged in the research activities.

In Silicon Valley, such collaborations are normal between industries, academia, medical facilities, and startups, each of which brings its own strengths. We see many young people in their 20s and 30s proving their mettle in the competitive environment of Silicon Valley. MEI Labs offers an attractive workplace for highly motivated researchers in the fields of medicine, data science, and material science.

3. Researchers at NTT Research, Inc.

We have recruited over 20 researchers and scientists thus far, all of whom have doctorates and 10 hold professorships. They have variety of backgrounds in terms of where they are from. Just under ten are from North America, one is from Europe, and just under ten are from Asia.

We also formalized numerous research collaborations, mostly with universities in the United States (**Fig. 4**). These partnerships effectively enhance the talent and resources engaged in our research activates, expand the horizon of our thinking process, and strengthen our ties to research networks. We are envisioning to further enhance these partnerships moving forward.

These basic research NTT Research, Inc. is engaged in is in line with the IOWN initiative. Our activities are also to support further development of NTT's global businesses from innovation perspectives along with two other companies, NTT Disruption and

Universities

- California Institute of Technology
- Cornell University
- Massachusetts Institute of Technology
- Princeton University
- Rutgers University
- Stanford University
- Swinburne University of Technology (Australia)
- Technical University of Munich (Germany)
- University of California, Berkeley
- University of California, Los Angeles

Other research institutions

- NASA Ames Research Center in Silicon Valley
- 1Qbit (Canada)

Fig. 4. Research partners.

NTT Venture Capital. NTT Disruption will be showcasing what can be done in the near future using the latest DX technologies. It will unearth concrete solutions tailored to various verticals such as healthcare, financial, autonomous driving, sports, and entertainment. NTT Venture Capital will take responsibility for the medium term by identifying and investing in promising startups. NTT Research, Inc. is ideally placed to take charge in addressing longer-term innovation by envisioning "beyond Internet," which the IOWN initiative is targeting.

4. Conclusion

The motto of NTT Research, Inc. is *Upgrade Reality*. By "reality" we mean so-called accepted norms that define what we think of as the real world. Our focus will always be on fundamental improvements to the status quo.

Kazuhiro Gomi
President & CEO, NTT Research, Inc.
He joined NTT in 1985. Before taking up his current post in April 2019, he served as vice president (VP) of the Global Business Department of NTT Communications from 2001 to 2004, after which he served as VP of the Global IP Network Business Unit of NTT America (2004 to 2009), chief operating officer of NTT America (2009 to 2010), and president and chief executive officer of NTT America (2010 to 2019).

R&D Initiatives to Make the Most of Human Abilities by Amplifying Human Intelligence to Achieve a Smart World that Harmonizes People and Environments

Akihito Akutsu, Kenichi Minami, Hiroaki Kawata, and Shigekuni Kondo

Abstract

Information and communication technology (ICT) will soon be necessary to make the most of and supplement people's abilities and support their activities by harmonizing people and environments through natural interactions that seamlessly blend with their activities. This article introduces the ICT research and development initiatives at NTT Service Evolution Laboratories to achieve a smart world that harmonizes people and environments.

Keywords: Point of Atmosphere (PoA), ambient, activity support

1. Introduction

Thanks to the remarkable progress in information and communication technology (ICT), it is now possible to access the information one needs from a smartphone or personal computer anytime and anywhere, and Internet services, such as social networking services, online shops, and navigation services, such as maps and route guidance, have become indispensable. Current Internet services are mainly provided via web browsers, and many more users can take advantage of these benefits not only through improved content attractiveness but also by improving ease-of-use (usability, web accessibility, findability) and operation (interoperability). However, services currently provided on the Internet are based on the premise that users access information with the required knowledge and a specific purpose. Therefore, a corresponding level of ICT literacy is required to take advantage of the benefits of such services. Achieving a world in which everyone can benefit from ICT services regardless of their literacy or situation will entail not only users actively accessing information but also require the environments surrounding users to 'understand' them and provide information in a form that people can recognize within the scope of their abilities without being burdened. One approach to this challenge is *ambient computing* [1]. Ambient means "peripheral," "environmental," or "surrounding." Thus, ambient computing is a concept of a world in which computers gather required information on behalf of people without anyone needing to perform operations or commands. With the recent developments in the Internet of Things and artificial intelligence, it has become possible to collect a large amount of information about people and the environment, enabling presentation of necessary information based on the results of predictions made by recognizing people's activity patterns up to the present. We believe that the advent

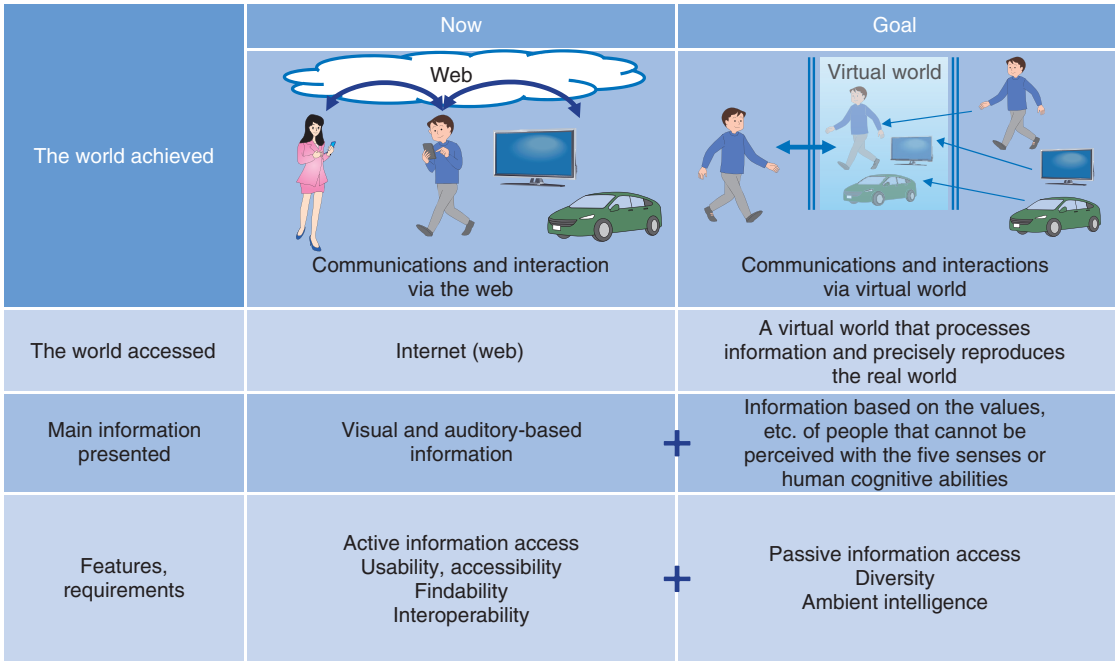


Fig. 1. The target world of PoA.

of a smart society where the environment can 'understand' people and provide them with the information they need and make proposals to them will be possible in the near future. However, the presentation of information and proposals should not impede human activities or cause stress. We believe ICT will be necessary to make the most of and supplement people's abilities and support their activities through natural interactions that seamlessly blend with their activities. These Feature Articles introduce the ICT research and development (R&D) initiatives of NTT Service Evolution Laboratories to achieve a smart world that harmonizes people and environments [2–5].

2. Point of Atmosphere (PoA)

NTT announced the establishment of the Point of Atmosphere (PoA) project at the NTT R&D Forum held in autumn 2018 [6]. This project aims to achieve a smart world that enables natural interactions by harmonizing people and environments. The surrounding environment can support people in making decisions by enabling the environments to 'understand' people's actions, intentions, and feelings in various situations without them being aware of the individual devices around them. For example, various ICT devices around the house could be linked with information obtained from people and the environment to create an illusion of a raincoat hanging on the wall or a wet floor to naturally convey the fact that it is going to rain today. To achieve this world, NTT Service Evolution Laboratories has defined PoA as any interface that seamlessly connects the real and virtual worlds and meets the following requirements:

- It must collect real-world information about people and environments in such a way that the sensing target is not burdened.
- It must process the collected information to accurately reproduce real-world people and environments in the virtual world.
- It must provide people with new perspective in a natural manner.

PoA is not limited to just being a user interface but is also an interface with a wider meaning that includes information processing for people and environments. To date, information presented via the Internet has been mainly based on audiovisual information and accessed purposely by people. PoA also uses information that cannot be obtained with the five senses, such as values, and enables people to naturally recognize information from the surrounding environment (**Fig. 1**).

The aim of PoA is to use various information

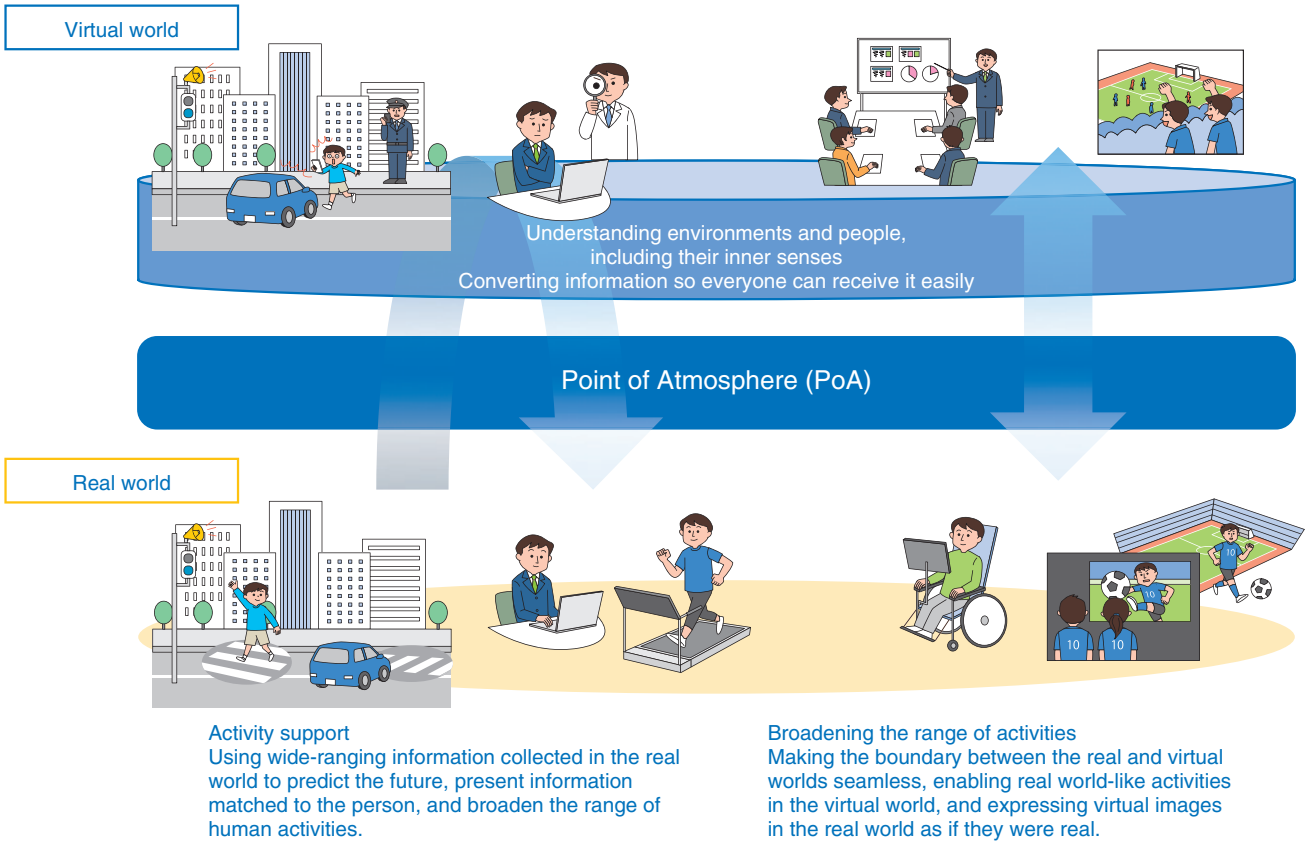


Fig. 2. Linking virtual and real worlds via PoA.

collected from the real world for virtual-world processing to predict the future or enable people to naturally recognize the information that they need and feed the information back to them. Enabling real-world-like behaviors in the virtual world in this way makes it possible to make the most of and supplement human abilities and support voluntary improvement in behavior, thus, expanding the range of human activities (**Fig. 2**).

3. Use cases

3.1 Activity support by predicting the future

In healthcare, PoA could be used to prompt seemingly healthy people to pay more attention to their health by projecting a haggard future version of themselves. Conveying such useful information from various surrounding objects (e.g. display devices, phones, speakers, and lights) will enable people to lead healthier lives. In transportation, this technology could enable people to obtain train departure times without the need to look at a timetable or prevent being hit by a car by being provided a sense of a car approaching. Collecting large amounts of information from the real world will make it possible to use the virtual world to predict the occurrence of unforeseeable circumstances such as catastrophic disasters, thus, minimizing the damage in the real world.

3.2 Supporting activities that transcend time and space

When someone cannot attend a sporting event at an actual venue due to physical limitations, it will be possible through PoA for that person to watch the event from home but still be able to engage in real communications with the spectators as if he/she were actually there at the event. One could also have the experience of viewing a sporting event and feeling the hardships and joys of the players as if one were a player or manager. In addition, by transcending time and space, one could enjoy games between famous players of the past and present.

4. Supporting technologies

Enabling PoA will require technologies to sense both people and environments, transmit and process information obtained by sensing, and feed information back to people and the environment. As well as information about the five senses, physiological information, behaviors, and surrounding environments, technology for sensing people and environments will also collect information that cannot be perceived either directly or from the surrounding environment without burdening people to naturally supplement and support human activities. The technology for processing and transmitting information obtained by sensing will process the information collected in the virtual world, achieve zero latency media transmission to present the information to people so that they would not feel transmission and processing delays, and achieve structuring of people's inner senses such as their emotions, values, and thoughts by elucidating mechanisms of their behavior and thoughts. This will make it possible to communicate and interact in ways that transcend time and space or to guide people to live a better life by appealing to their instincts. Technology to provide feedback to environments and people will detect information that makes the most of the five senses and provide information that cannot normally be sensed in a form that is recognizable in order to expand the range of human activities. As the environments surrounding people become smarter, they will 'understand' people's abilities and situations and interact with them as necessary or enable communication in which the boundaries between real space and virtual space are imperceptible, thus, helping people obtain abilities they did not originally have or lost. These technologies will process the collected human and environmental information in virtual space to precisely reproduce and expand the real world, offer support for real-world human activity, and make the most of and supplement abilities.

5. Conclusion

This article described initiatives to achieve a smart world where people and the environment are in harmony. For more people to benefit from ICT and to expand the range of their activities by making the most of their abilities, it is necessary for such technology to 'understand' how people perceive information, how it should be fed back to them, and how they can naturally recognize information as they need it at certain times and in certain situations, but not from a conventional viewpoint of how to present information. NTT Service Evolution Laboratories is promoting R&D of technologies that will contribute to such human-centered communication and interaction services.

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Natural Communication Technologies Providing Information through Natural Exchanges that Do Not Interfere with Human Activities

Atsushi Sagata, Takashi Sano, Kota Hidaka, Takashi Satou, Shinji Fukatsu, Takafumi Mukouchi, and Hidenobu Nagata

Abstract

NTT Service Evolution Laboratories is conducting research on providing high-presence viewing experiences involving virtual people and objects as if they have been brought to life right in front of the viewers. This article introduces natural communication technologies providing natural and valuable user experiences by creating people, objects, and space that emulate an incredibly realistic presence and seamlessly linking them to the real world through natural interactions without any sense of latency.

Keywords: natural experience, space and object creation, zero latency

1. Towards creating *natural* experiences through the intersection of real and virtual space

We have been focusing on transmitting information of people and objects from remote locations to fully reproduce them in other remote locations to make it feel as if they are right in front of us [1, 2]. Now that highly intelligent applications and services have permeated people's lives and virtual reality (VR) and augmented reality (AR) have become more accessible, we would like to further expand the range of experiences offered to users and offer and have them be more natural. Our aim is not only to faithfully reproduce information of people and objects at a location but also create objects through video projection and audio that give the feeling that they have been brought to life, thus create valuable experiences that transcend reality. We are studying what aspects are important for providing such experiences. While accurately expressing objects is valuable in terms of higher reality, transforming or exaggerating them may result in expressions with more impact. For example, in the "Great Wave off Kanagawa" from the "Thirty-six Views of Mount Fuji," Katsushika Hokusai was able to express the wave as a still image but as if it were moving. Perhaps some people feel the power of this wave more than objects in realist paintings or photographs due to Hokusai's unique expression that gives it movement. Thus, if someone's understandings of a large wave is much more powerful than that of a wave seen in a photograph, Hokusai's painting can be said to have created a real experience for him or her that transcends reality.

1.1 Society 5.0

The advent of the information society has made it possible to digitize various objects in real space and enable complex re-construction and expression in cyberspace. Continuing from the hunting/gathering society (Society 1.0), agricultural society (Society 2.0), industrial society (Society 3.0) and information society (Society 4.0), the Cabinet Office of Japan

defines Society 5.0 as "a human-centered society that balances economic advancement with the resolution of social problems by a system that highly integrates cyberspace and physical space" [3]. In other words, in addition to accurately imitating real objects that exist in real space, there is an expectation that reality will be transcended through the fusion of the real and virtual.

1.2 Generative adversarial networks

Generative adversarial networks (GANs) are key for creating video that allows viewers to perceive an object that looks real or expressing objects that transcend the original [4]. Through this technology, computer graphics (CG) images with the quality of real photos is becoming a reality. It is also becoming possible using GANs to create completely different images but with the same characteristics of the reference images. GANs enable processing of tasks, such as sensing the actors on stage, then generating images of animals having the same characteristics of the actors' movements. For example, in the *kabuki* dance performance "Renjishi" (Two Lions), there is a scene where the affection between the parent and child is expressed through the performance of a lion watching over its cub as it runs up the side of a valley. Using GANs, we even can entertain audiences by generating realistic images of the lions as having the same characteristics as the actors. It would be effective to realistically express the kabuki lion as a "lion," but if it were possible to create an experience of Utagawa Hiroshige's woodblock print "shishi no kootoshi" (a lion drops its cub) that seemed real in front of viewer's eyes, it could be considered as an experience that surpassed reality. When presenting an object generated with image-processing technology, to make viewers feel as if life has been breathed into it, it is important for the viewers to feel that the generated object is not just a mere imitation. If it is recognized as a mere imitation, it will be difficult to stir people's emotions. Although it is a major challenge, technology is required to achieve a viewer experience in which generated objects appear to move autonomously. Research on predicting human postures based on the skeleton has begun, and it is somewhat possible to predict future postures based on prelearned motions and reproducible motions that have some form. We aim to achieve natural exchanges in which the object/person that is sensed moves naturally and autonomously, so that in its interactions with, for example, actual people, there are no distractions due to processing latency, etc.

1.3 Natural communication technologies

To achieve these objectives, we have been researching and developing natural communication technologies. Such technologies consist of the following five elements; (1) space and object creation technology to freely create seemingly real space and objects of the human imagination that transcend reality, (2) zero latency media technology that both reduces physical delays in transmission and processing, thus eliminating sensory delays such as the discomfort people feel due to latency, (3) 2D/3D video display technology that enables both two-dimensional (2D) and three-dimensional (3D) displays to be viewed naturally, (4) information-presentation technology to enable natural interactions between reality and virtual space, and (5) new approaches collectively called "five senses + X transmission technology" for transmitting and presenting not only our five senses but also one's psychological feelings directly and naturally.

2. Space and object creation technology

Space and object creation technology estimates data beyond the obtained sensing data by taking into account the past forms of the same scene or person. We have thus far developed a technology to generate 3D spatial information (CG model) from 2D video in real time using deep learning (**Fig. 1**). This technology was actually used in a kabuki performance called "Cho Kabuki," which is a new type of kabuki performance using information and communication technology. It was held during the Niconico Chokaigi 2019 festival organized by video streaming company Dwango Co., Ltd [5]. Although 3D information is not included in 2D video, this technology creates 3D information based on similar past scenes in real time and *transforms* the characters that appear in Cho Kabuki into other CG characters, enabling a new yet characteristically Cho Kabuki production. In the future, we plan to apply *transformation* to other live-action video by combining 3D spatial information (CG models) and object-extraction technology.

3. Zero latency media technology

Physical delays in transmission and processing is a major issue in achieving natural interaction at remote locations by VR/AR. Although efforts have been made to reduce these physical delays and commercialization has advanced to some extent, it is physically impossible to reduce delay to zero, even at light speed. Thus, to achieve natural interaction, we

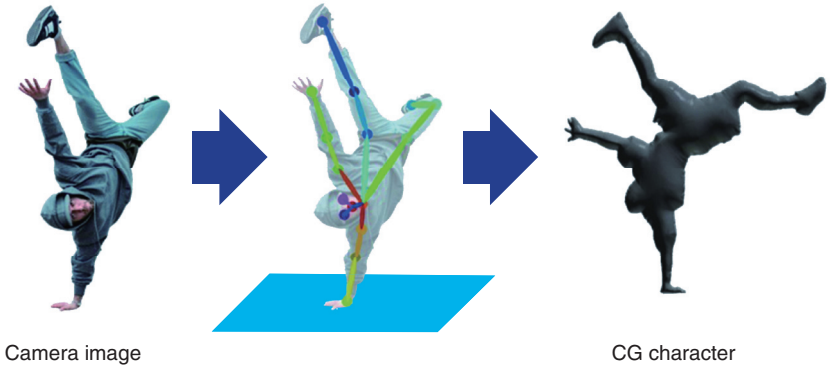

Fig. 1. Real-time 3D information synthesis.

believe that technology is needed that not only eliminates physical delays but also eliminates the discomfort that humans feel from delays as well as eliminating sensory delay. Thus, we are researching zero latency media technology. Specifically, this ongoing research involves clarifying the mechanisms of sensory delay from various information such as peripheral situations and behavior patterns, creating more natural prediction technology that does not cause discomfort due to delay, and clarifying the prediction mechanisms in the brain to eliminate sensory delay due to the world predicted in the brain.

4. 2D/3D video display technology

NTT has developed "HiddenStereo"—a stereo-video-generation technology that uses the characteristics of human vision to enable users to enjoy 3D images when wearing stereo glasses and clear 2D images without stereo glasses [6]. This technology generates left and right images by adding and subtracting a *disparity inducer* to a 2D image to generate left and right parallax. When the disparity-inducer components are combined, they cancel each other out so that only the original 2D image is visible when viewed with the naked eye. Depth information of the 2D image is required to generate the disparity-inducer components. In the case of stereo images, depth information can be obtained using epipolar geometry, etc., but a great deal of operations and ingenuity are required to capture the precise depth information. With normal 2D images taken with a monocular camera, however, the depth information of each pixel cannot be obtained. We are engaged in automatic generation and systemization of "HiddenStereo" that entails depth estimation using deep learning models, extraction of objects through frame and background differences, and instance segmentation using deep learning models for 2D images taken with monocular cameras.

5. Information-presentation technology for natural interactions

To enable natural and realistic information-presentation technologies, we are conducting research and development on 360-degree glasses-free tabletop 3D display technology (360° autostereoscopic 3D) (**Fig. 2**) and sound field synthesis technology. This technology enables viewing of 3D objects with binocular disparity on a screen on a table without using 3D glasses by combining multiple projectors arranged in a circle and a special screen called a *spatially imaged iris plane screen* [7]. A large 120 cm-diameter screen and optical linear blending enable smooth movement of the point of view (smooth motion parallax), even though the number of projectors is 1/4 to 1/10 that of conventional technology. Sound field synthesis is a technology that can reproduce a sound field using a linear loudspeaker array of multiple loudspeakers in a line. This technology can control the distance between a sound source and audience member as well as its direction. In past events and installations, we used this technology to produce virtual sound sources that come close to audience members to reproduce kabuki performances [8] and goalball matches, a team sport played by visually impaired athletes. We have been investigating an extension of this technology to reproduce sound in a limited area. We have succeeded in reproducing a sound field using a multipole-loudspeaker array consisting of multiple small speakers closely arranged in

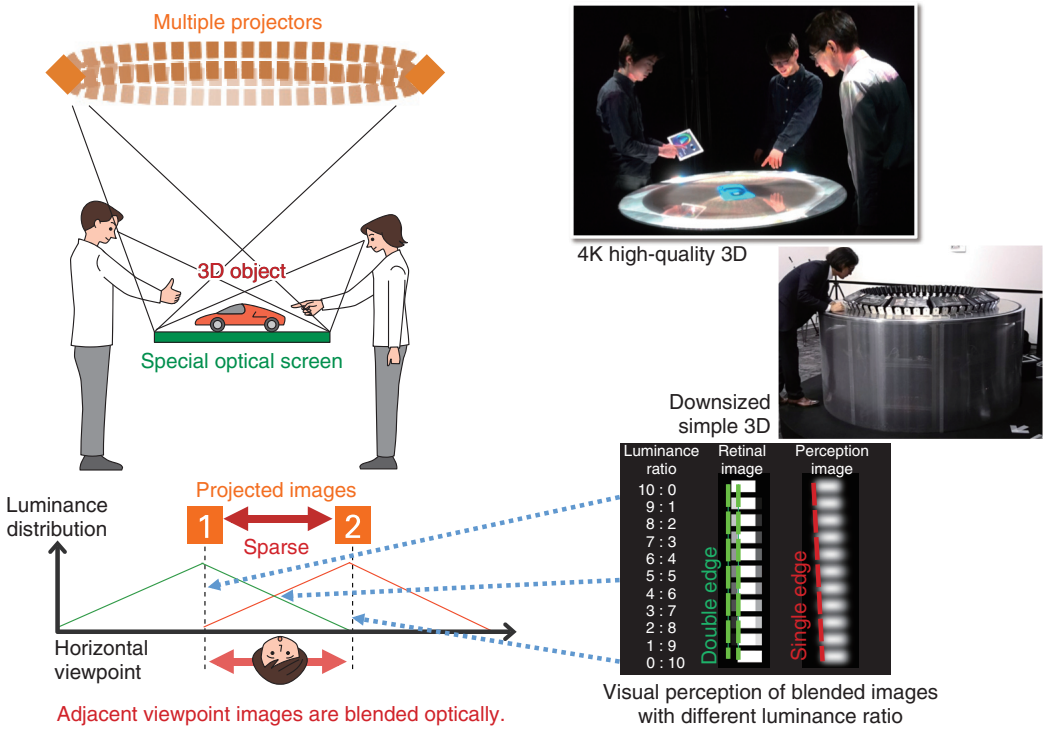

Fig. 2. 360-degree glasses-free tabletop 3D display technology (360˚ autostereoscopic 3D).

a Cartesian grid. This array enables control of the directivity pattern of an arbitrary sound source while being smaller than current speaker arrays [9, 10]. These technologies place importance on achieving natural communications to enable users to enjoy a sense of reality without having to wear special devices such as head mounted displays, 3D glasses, or headphones. In other words, the sophistication of environments surrounding users will make it possible to reproduce natural and realistic presence without burdening them. Such technologies could be applied in the field of entertainment to create more realistic experiences of sporting events or concerts. In business, these technologies should help teleconferencing evolve from screen and audio sharing to space sharing. It may no longer be just a dream to have a remote participant projected by a digital twin next to oneself at a conference and whisper to that person or share written communications. Even in the home, a television (TV) that plays back sound with volume and frequency characteristics optimized only in areas where there are elderly people could become a reality. In other words, rooms and TVs present sounds properly controlled according to each listening area so one would not have to increase the volume to suit the elderly when watching TV with the whole family. It may enable the elderly to enjoy sounds without hearing aids. It would also be possible to control the sound so that it would not leak in the direction of children's bedrooms so that one could watch TV without the need of using headphones.

6. New approaches to transmit and present the five senses + X directly and naturally

The evolution of sound and video as means of presenting information has been remarkable and has made it possible to experience not only improvements in definition but also 3D effects. However, utilization of the other senses has not progressed. Achieving natural user experience and presentation of various information requires utilization of vision and hearing as well as the other senses. Services that create highly realistic experiences will have to appeal not only to sight and hearing but also touch, smell, and even taste. In terms of information presentation, methods that occupy the important sensory organs for sight and hearing are not always the natural means of conveying information. This means that if information can be transmitted using methods other than

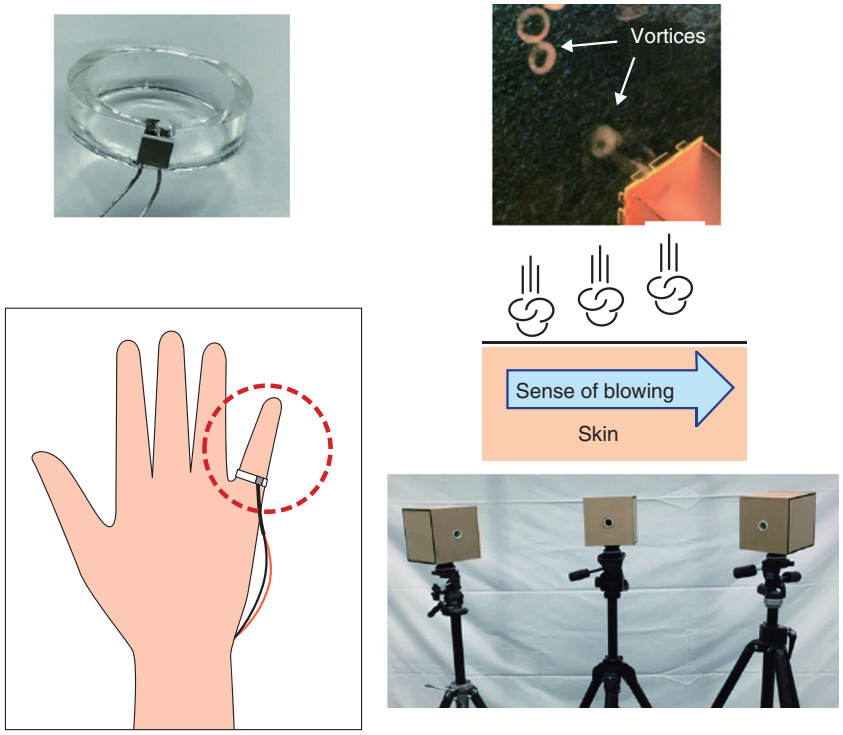

Fig. 3. "ThermalBitDisplay" presents information to the skin.

visual or auditory, or a combination of these, it will be possible to receive information naturally anytime and anywhere. We are currently working on presenting information to the skin (**Fig. 3**). "ThermalBitDisplay" is an information-presentation device that uses temperature without disturbing the senses of sight and hearing and consists of a ring with an embedded thermoelectric element used to obtain information only when pressed against the lips. Unlike push-type notifications, this device enables one to check information only when he/she wants to, and enables one to check information casually because one does not need to use sight or hearing. We are also working on the expression of new reality through stimulation using vortex rings (air movements that can be generated using a so-called air cannon). By controlling the time difference between stimuli, we are also researching technology to create pseudo-sensations as if something is passing close to oneself. By creating sensations other than that of something passing through controls that include stimulation in certain locations, for example presentations combining sounds, we believe it will be possible to further improve the realism of moving sound sources. Going forward, we will continue researching and developing technologies to enable more natural experiences or reception of information by conveying sensations other than through the senses of sight and hearing.

7. Conclusion

This article described the research and development of natural communication technology to achieve free interaction and intersection between real and virtual spaces including information exchange. The virtual space is sometimes described as a *mirrorworld* [11], and we believe it is not just simply an electronic cyber world but also a *parallel world* by *intersecting* with real space. Ideally, we believe that as well as enabling users to experience what they want to be good at, such as singing or dancing, in the parallel world, it is desirable to feed this back to the real world. We will make such intersection between virtual and real world one of our themes and proceed with our research and development of natural communication technology.

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Ambient Assistance Technology Supporting Human Behavior by Understanding the Relationship between People and Environments

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Abstract

Many of the actions we take are not only based on our own abilities, thoughts, and emotions, but are also broadly influenced by the real-world environment that surrounds us. Focusing on the environments that surround people engaged in activities, we aim to establish ambient assistance technology to help people choose the most optimal behavior by natural interaction with the environment based on models that combine environments with human perceptive and physical states.

Keywords: human/environment sensing and modeling, behavior simulation, action support

1. Introduction

Our "Point of Atmosphere" world, where natural interactions that harmonize people and environments are possible, is composed of information and communication technologies (ICTs) that help people choose the best behavior. These ICTs can determine the situations people are in, objects surrounding people, and their relationships with others as well as their behaviors, intent, and feelings in a wide range of daily activities. This suggests that ICT will go beyond online services and evolve to provide value by directly influencing various human behaviors in the real world (**Fig. 1**).

Based on the trends in this ICT evolution, we are investigating ambient assistance technology, which models real-world environments (spaces, objects, and other people) that surround people engaged in various activities. The constructed models are combined with the models of perceptional, psychological, physiological, and physical states of people. Then, the choice of the best action is naturally supported through the devices that are human-environment interfaces (**Fig. 2**).

2. A new world born of ambient assistance technology

What new conveniences will come about in our lives through the development and use of ambient assistance technology? In a city, for example, the possibility of colliding with a dangerously driven car when that car is in the pedestrian's blind spot can be determined using models of the person and those around him or her as well as environmental models for roads and traffic flows to instantly derive a simulation to enable the person to take advanced precautions, such as evacuating to a nearby building,

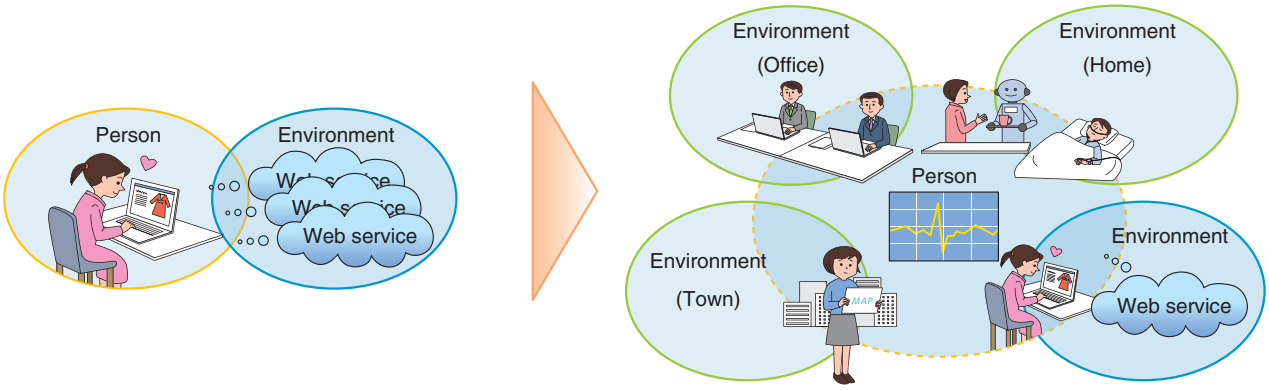

Fig. 1. Evolution of ICT.

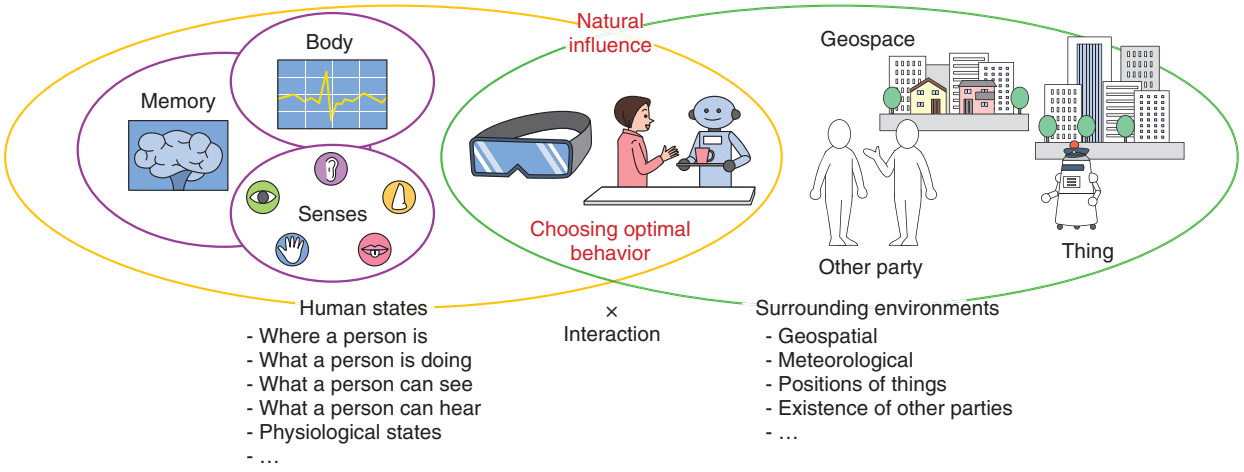

Fig. 2. A world enabled by ambient assistance technology.

through digital signage around the person or wearable devices. For those who want to lose weight, a map app will guide them on a route with a slight detour to appropriately increase their activities without affecting the arrival time at their destinations, and an artificial intelligence agent could present easy-to-accept and optimized exercises to a person with the right timing to spark motivation and help exercising become a habit. In the office, these technologies enable environmental measurements to, e.g., increase productivity and encourage creative collaboration by adjusting temperature for comfort, adjusting lighting (brightness, color) to encourage concentration or relaxation, and creating sound fields to raise confidentiality or conversely to encourage information exchange, based on the modes of behavior in which people work (at their desks, in meetings, brainstorming, presentations, etc.) and surrounding situations (room layouts, desk alignments, gatherings of people, office equipment arrangements, etc.). This will naturally guide people towards the best actions to enable them to casually notice things that they would not normally notice, enable them to change their behaviors to achieve their goals, naturally change the way they work with influence from the environment, and increase their productivity and promote creative

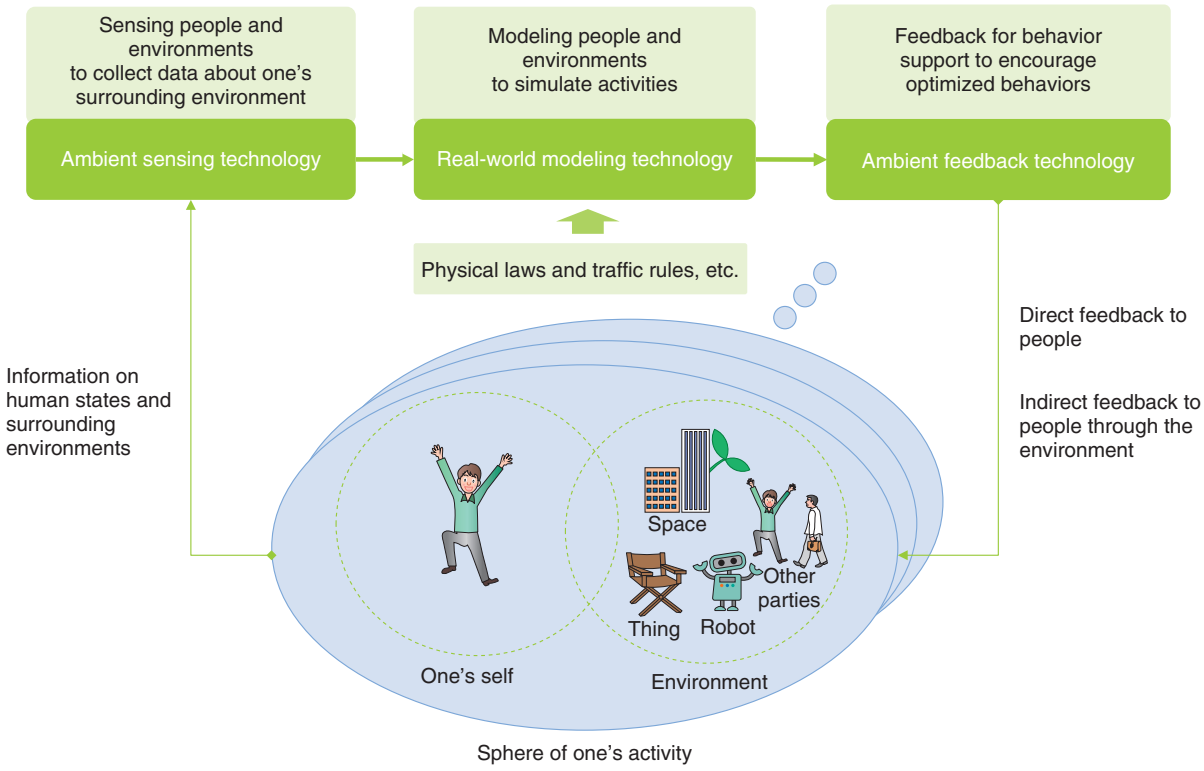

Fig. 3. Elements of ambient assistance technology.

collaboration.

3. Towards ambient assistance technology

To make the aforementioned world a reality, we are developing ambient assistance technology to support optimized human behaviors. To do this, the following technical elements are required (**Fig. 3**). The first element is ambient sensing technology. Human behavior is based on various abilities, such as physical and psychological, that mutually influence each other. Additionally, environments in which people are partaking in various activities and their relationships with others are also considered to affect the demonstration of their abilities. Ambient sensing technology enables the generation of models for people and their surrounding environments by continually collecting and digitizing status information of the activity areas centered on active people without interfering with their original activities. The second element is real-world modeling technology. Ambient sensing technology collects information on the states of active people and their surrounding environments to reveal the mechanisms (models) of the changing states of people's abilities or physical spaces. Real-world modeling technology integrates such digital models of people and the environment to enable reproduction (simulation) of real-world situations in the past, present, and future. The third element is ambient feedback technology. Real-world modeling technology can simulate human behavior and psychological abilities in certain environments and situations. Ambient feedback technology supports user behaviors by extracting optimal behaviors in a situation such as specific training methods and influencing the user through wearable devices and devices embedded in the surrounding environment.

4. Ambient sensing technology

Ambient sensing technology focuses on human behaviors and the states of their surrounding environments in the real world and digitizes them immediately. Specifically, while defining targets of human and environmental sensing, we are studying the following technologies: personal space life log collection technology that continuously collects and digitizes state information of the activity area (personal

space) in which the person is without causing them stress; personal space life modeling (twin modeling) technology to generate personal modeling (behavior, body movement, perception, emotions, physiology and ecology, etc.) and surrounding environment modeling (physical space, environmental state, surrounding object recognition, communications, etc.). For example, for human sensing and modeling, we have been working on state estimation (central fatigue estimation [1, 2] and state transition estimation of muscle activity patterns [3]) based on the collection and analysis of biometric data including heart rate and myoelectric data collected from wearable devices worn on the body in the form of shirts, socks, hats, etc. For sensing and modeling the environment, we have been working on technologies that estimate road conditions a user is currently walking on (inclinations, steps, stairs, etc.) obtained from body movements through the smartphone the user is carrying [4] and technology that maps sensing information from many people to physical space and detects changes in environmental conditions over a wide area [5]. Starting with devices to simultaneously record personal and environmental information acquired to date, we plan to study new sensing and modeling approaches combining environments and people that take into account the abilities of a person appearing in an environment, changes in the states of the environments appearing with a person's behavior, etc.; thus, encouraging further research and development of ambient sensing technology.

5. Real-world modeling technology

Real-world modeling technology accumulates personal and environmental twin models obtained from ambient sensing technology and lays over high-precision spatial information and environmental monitoring, which is a bird's-eye-view real-world model contrasting personal space, and incorporates physical laws, traffic rules, etc to achieve an autonomous real-world model that is constantly updated. In the real-world model, it can be expected that higher-order situations (contexts) will become clear from the reproduced relationships between people and between people and the environment. For example, a "cognitive map" that shows how a person perceives his or her place in geospatial space is dependent on his/her spatial cognitive ability, sense of direction, and spatial knowledge, which vary from person to person. It is also said that a place can be felt to be relatively closer than the actual geographical distance depending on the familiarity with it and attractiveness [6, 7]. Thus, reproducing real-world maps that look different and are distorted for each person from their spatial cognitive models and high-precision spatial information will reveal what a person who gets lost easily is actually looking at and in what kind of situations and what intentions caused them to lose their way, which can then be used to naturally help the person avoid such situations. Also, it could be possible to reproduce human memory models for changes in time by reproducing how information is transferred between people and environments in the real world by simulating past-present-future time lines from accumulated real-world models. With real-world modeling technology, therefore, we plan to investigate the digitizing of things that cannot be directly measured with individual sensors and models.

6. Ambient feedback technology

Ambient feedback technology supports people to engage in optimal behaviors calculated using real-world modeling technology. This technology will require methods to simulate human behavior and select optimal behaviors based on those simulation results. Therefore, we are considering using real-world models not only of oneself but also of other people. We aim to calculate optimal behaviors by comparing other people's behaviors calculated from the models of others. This other person behavior is simulated by applying the same situation and purpose of behavior as oneself to the model of the other person. For example, by comparing the behaviors of sports professionals with one's own behavior it might be possible to calculate more specific training methods. People will require support in performing behaviors after calculating optimal behaviors. Smartphone event notifications are often used for this purpose. In the future, we will consider more natural and casual methods so that anyone can benefit regardless of ICT literacy. For example, if the digital signage now widely in use advances further, anything in a city could become a signage device. If so, it might be possible to provide timely messages that are easy for people to perceive not only through the visual and auditory senses but also through any or all five senses. In addition, if wearable devices evolve, it might be possible for people to engage in optimal behaviors by just wearing such a device.

We conducted research on comparing human behavior by extracting the characteristics of professional and amateur movements [3]. In terms of

wearable devices, we conducted research on inducing changes in muscle activity and walking without any user intention by applying contact stimulation to the sole of the foot from the insoles of shoes that change in hardness and shape [8]. To encourage people to engage in optimal behaviors, we have been researching message-generation methods that are easy for people to accept, based on behavioral change models [9]. We will keep expanding these techniques to enable the implementation of ambient feedback technology.

7. Conclusion

Although efforts to develop ambient assistance technology have only just begun, we are aiming for a world in which anybody can enjoy its benefits regardless of their ICT literacy. We will work quickly and steadily towards achieving the challenging goals of deeply understanding people and environments in the real world and modeling them to extract optimized behaviors of people from simulations and support people in engaging in those behaviors naturally.

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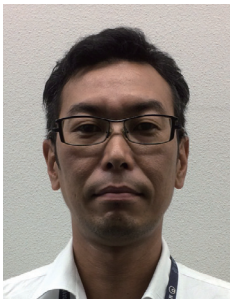

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User Experience Method for Deeper Understanding People's Values to Design and Change Their Behavior

Yumiko Matsuura, Hiroyuki Toda, Momoko Nakatani, Takeshi Kurashima, and Harumi Saito

Abstract

Advances in technology has expanded the scope of people's lives even though the behavior of people living comfortable lives has become complicated along with various personal values systems. This article introduces methods with which people can naturally achieve a state of well-being faster by enabling them to adopt technology to change their behavior for the better. There are two methods, one for analyzing people's daily behaviors or Internet usage for understanding people and the other for providing technology to promote awareness and a sense of achievement by clarifying mechanisms of change regarding people's minds and behaviors.

Keywords: behavior design, understanding human behavior, well-being

1. Behavior design to achieve a state of well-being

The recent spread of the Internet of things (IoT), in which all things are connected through the Internet, has brought closer a world in which it is possible to determine what is happening now, what will happen in the future, and how objects, e.g., devices, should move towards obtaining desirable results, based on multi-dimensional, large-scale data obtained from IoT that far exceeds the processing capabilities of humans. If ambiguous and complicated human behaviors can be understood using artificial intelligence (AI), it will likely become possible to plan not only how objects but also people should move. AI can study what is positive behavior from their behaviors to provide feedback for them to change their behavior for the better. If this cycle can be sustained, people can achieve a state of well-being [1] (**Fig. 1**).

Therefore, with findings from our previous studies on (for example) service-design-process research and analysis and modeling of spatio-temporal behaviors, we aim to develop *interaction* technology that will influence human cognition to enable people to achieve a state of well-being so they can continue in a more positive direction. This technology will be achieved by scaling various ambiguous and diverse values such as prioritizing objects—not only economic values, understanding ideals that people pursue, observing what behaviors people engage in to reach their ideals and modeling them, and enabling the prediction and measurement of success levels from those models. If data from various people can be acquired through IoT devices, through those observed data and interviews regarding people's ideals and daily activities, the values they have, and how those levels are expressed can be handled in models of user values. It will also be possible to deepen understanding of the behavioral models that explain why a person takes a certain action and what principle led to that action from the actual behavioral data. Once modeled, the current situation can be fit to the model, what will happen from the fitted model can be predicted, and how results will change with what actions can be understood so that results of action towards an ideal can be predicted. Then, by understanding how

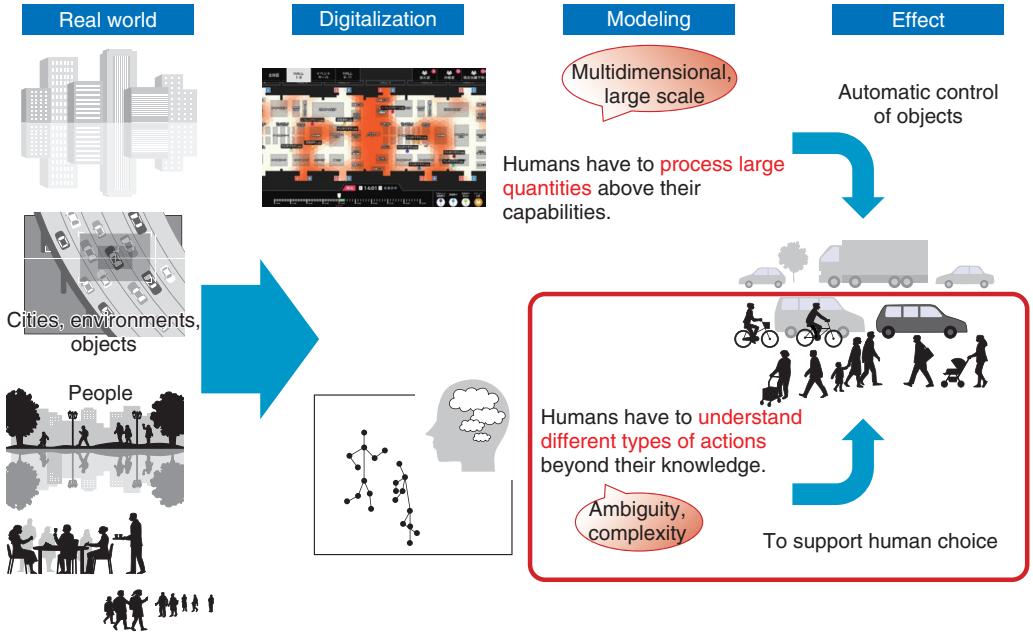

Fig. 1. Changing behavior to achieve a state of well-being.

people accept information and feel about conversation and communication with other people, etc. and by providing a means to give them awareness, behaviors can be designed that will lead people to predicted results that approach overall and individual ideals so that environments to assist people in reaching a state of well-being can be created (**Fig. 2**).

These environments could work in concert daily to encourage behaviors under various conditions where there is a need for individual or group optimized behavior, such as finding the shortest time when moving, avoiding congestion, or wanting to visit various places. This could lead to a less crowded society as a whole. Also, through dialogue between people and staff at helpdesks, shops, or neighbors, this could lead people in a direction that satisfies not only the individual but also stakeholders. To induce positive behaviors without one's (people's) awareness, similar to if one was moving by one's own will, we aim to support people's natural behavior to smoothly and comfortably improve themselves by providing necessary information if they become confused and supporting those with diminished physical capabilities.

When conducting daily activities will be possible in both the real and virtual worlds, it might be possible to have personalities in both. Even if a person uses different personalities in both, has several living spaces including virtual space, and their values become more diversified, we will be able to promote research and development for assisting people towards positive behavior more naturally. We hope this interaction technology will improve people's lives.

2. Technology to achieve behavioral design

2.1 Understanding human behaviors for achieving a state of well-being

To lead a person to a state of well-being, it is important to understand the behaviors (e.g. moving from A to B, staying at A, eating, etc.) and states (e.g. physical and mental conditions, etc.) of that person and the surrounding environment. As mentioned above, data collection has been rapidly progressing due to the wide spread of IoT. Thus, we are pursuing research and development based on the framework shown in **Fig. 3**, aiming at a world that uses data to bring people into a state of well-being. The most important point is not only to understand the behavior recorded in observation data but also construct a behavior model based on those data. Since this understanding and modeling make it possible to understand the behavior of people in situations in which there are no observational data and predict future behaviors, we believe it will be easier to decide on strategies to change the future for the better.

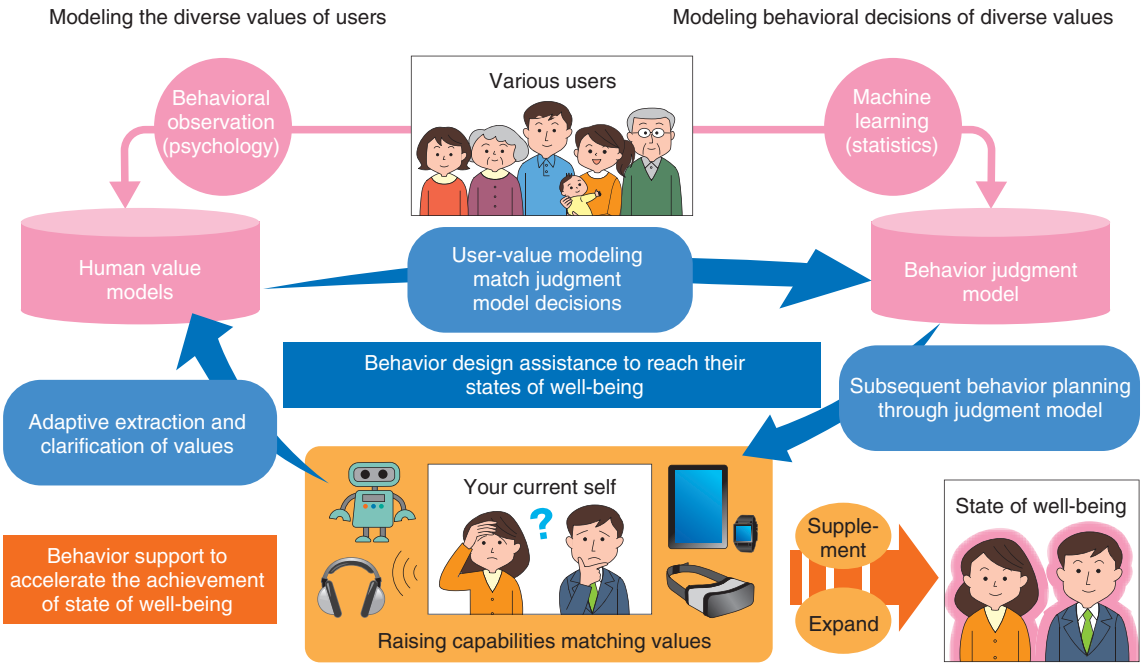

Fig. 2. Behavior-change support to reach a state of well-being.

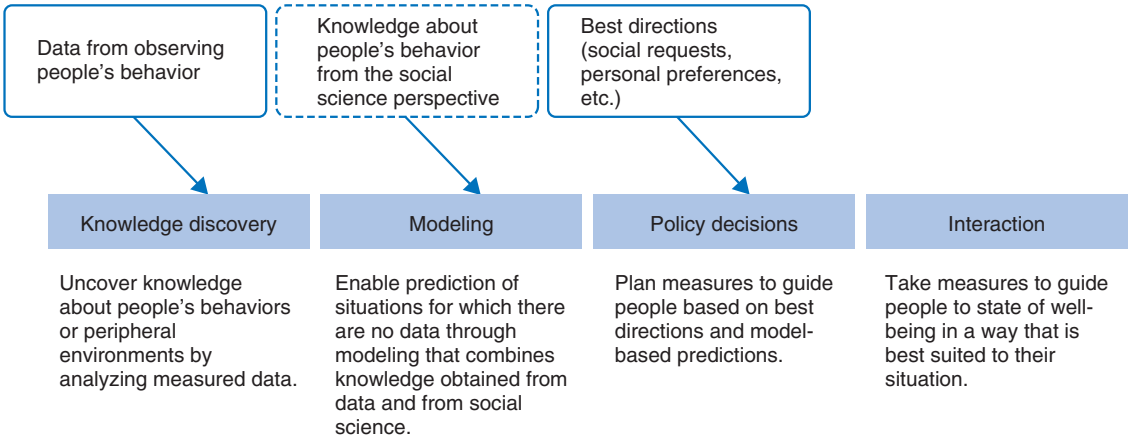

Fig. 3. A framework that uses data for people to achieve a state of well-being.

To achieve this, people flow estimation (PFE) [2] makes it possible to understand the people flow not explicitly included in data by using the characteristics of human behavior obtained from data analysis as knowledge.

As shown in **Fig. 4**, from population information of each area at each time step, PFE estimates the people flow between cells over time. The point with this method is that it estimates the people flow between areas from only the population information of each area at each time step, which does not explicitly represent crowd movement. When the number of areas where people are moving is N, this method solves the problem of estimating people flow between areas (number of unknown values (transition in population between each area pair) is N^2) from population information for two time steps (number of known values (population of each area) is $N \times 2$). If this problem is

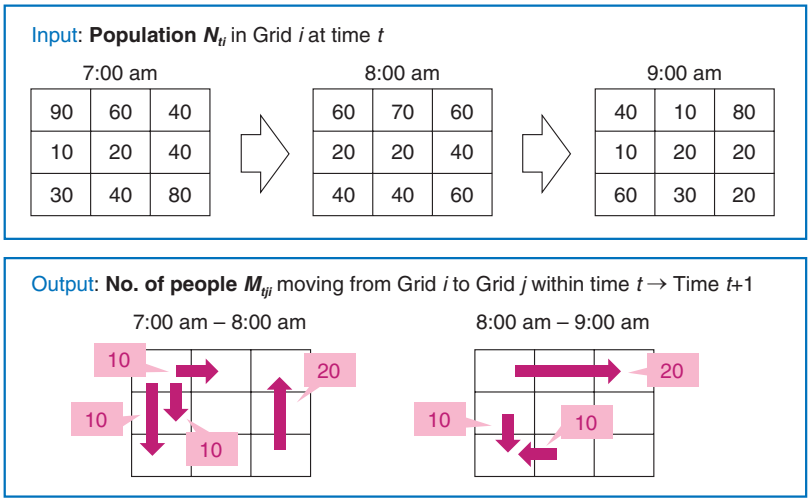

Fig. 4. Estimating people flow from spatio-temporal population data.

considered, there will be too many solutions that are consistent with the observed population data. Since there will be multiple movement patterns that can explain the change in population for each observed area of the input data, it will be difficult to accurately estimate the correct people flow.

In response to this problem, we first clarified the characteristics of human behavior in cities by analyzing real data. We then introduced the characteristics of human behavior obtained from data analysis as a constraint to the problem of estimating people flow between areas to narrow down the solutions.

Specifically, we used the following findings, which were obtained based on people-moving data in cities.

- Human movement is affected by the distance between areas (Saitama → Tokyo > Saitama → Yokohama)
- People's departure probabilities vary from area to area (weekday mornings: residential district> business district)
- The ease with which people gather depends on the area (weekday mornings: business district >residential district).

Based on the above findings, instead of directly estimating the population between areas (number of unknown values is about N^2), we estimate scores that reflect the characteristics of each area (e.g. score of how easily people gather in each area, score of how likely people depart from each area; number of unknown values is about $N \times 2$) that affect the movement of people (**Fig. 5**). PFE uses the following formula to understand the flow of people.

(Ease of moving from area i to area j) ≈ (probability of departure from i) × (ease of people gathering at j) × (ease of movement based on the distance between i and j).

This model makes it possible to select a solution that seems to move people. It is also possible to drastically reduce the unknown values that need to be calculated, resulting in much lighter computation cost.

The above is an example of incorporating the knowledge obtained from data analysis into a model to more accurately estimate human behavior without explicit observed data of the behavior. In addition to the knowledge gained from data analysis, we will also try to model human behavior using social science knowledge. We believe that this modeling will enable us to understand various human behaviors to effectively change them for the better.

2.2 Research of understanding human values and interaction for achieving a state of well-being

Clarifying the mechanism of well-being is obviously not something that can be done overnight. A state of well-being is very different for each person and changes depending on the surrounding environment and circumstances. Moreover, it is well known that people's thoughts and judgments are often irrational. To achieve our goal of clarifying the mechanism of well-being, we are conducting research to both deeply understand the diverse values of people and develop support methods (interaction technology) by using knowledge from a wide range of fields such

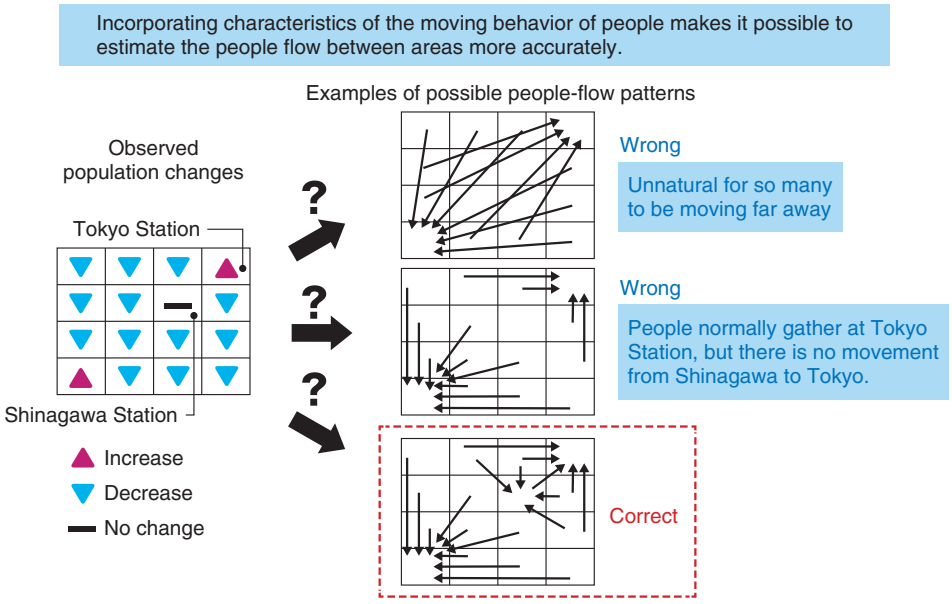

Fig. 5. Observed population changes and examples of possible people-flow patterns.

as psychology, engineering, and design (research to understand values).

To understand people's values related to well-being, our approach is to clearly define targets and study people's values both quantitatively and qualitatively. For example, when we previously focused on parents who are raising small children, we conducted both web surveys and interviews to understand their values and child-rearing behaviors [3]. The results indicated that parents have both short-term and long-term goals. There are six long-term goals regarding their children's futures. **Figure 6** illustrates the general results. Some parents wanted to entertain or calm their children ("To make the kids feel calm and happy" in the diagram). These factors can be explained as short-term goals. The same parents may also whish their children "To be a person who can do what s/he wants (goal 1)" or "to be a person who is independent-minded in his/her life or choices (goal 2)", which can be explained as long-term goals. Having both long and short-term goals, items that are given priority differ depending on the state of the parent's mind, environments, and the state of the child, which may lead to disparate child-rearing behavior.

As shown in Fig. 6, parents' long-term goals for their children's future can be categorized into six types with the degree of emphasis depending on the parent. There are also multiple types of "good life goals" positioned above the long-term goals. The various factors make it difficult to understand the reason of behavior. However, our approach of using both qualitative methods, such as interviews, and quantitative methods, such as large-scale questionnaires, enable us to deeply understand human values. In the case of understanding parents, after modeling values, we developed scales to enable easy measurement of value types, which would lead to developing support services that match parents' values.

The reason we focus on interaction research is because people are social creatures, and interactions with others have a significant impact on the state of well-being. Therefore, we are focusing on the effects of interactions among diverse people and developing methods for achieving a state of well-being. Since it is important to understand the interactions among people and what changes the motives and thoughts of people, we are conducting research in the real world on limited targets and situations to observe them as naturally as possible. We are mostly designing and developing tools/programs to support dialogue in *living labs*. Living labs is an approach that involve users as co-creators in the service-design process. It is attracting attention not only for service design but also as a methodology useful for community development including local revitalization. It also contributes to a state of well-being. Incorporating living lab activities in the community enables people to live with better awareness. Hence, we are implementing

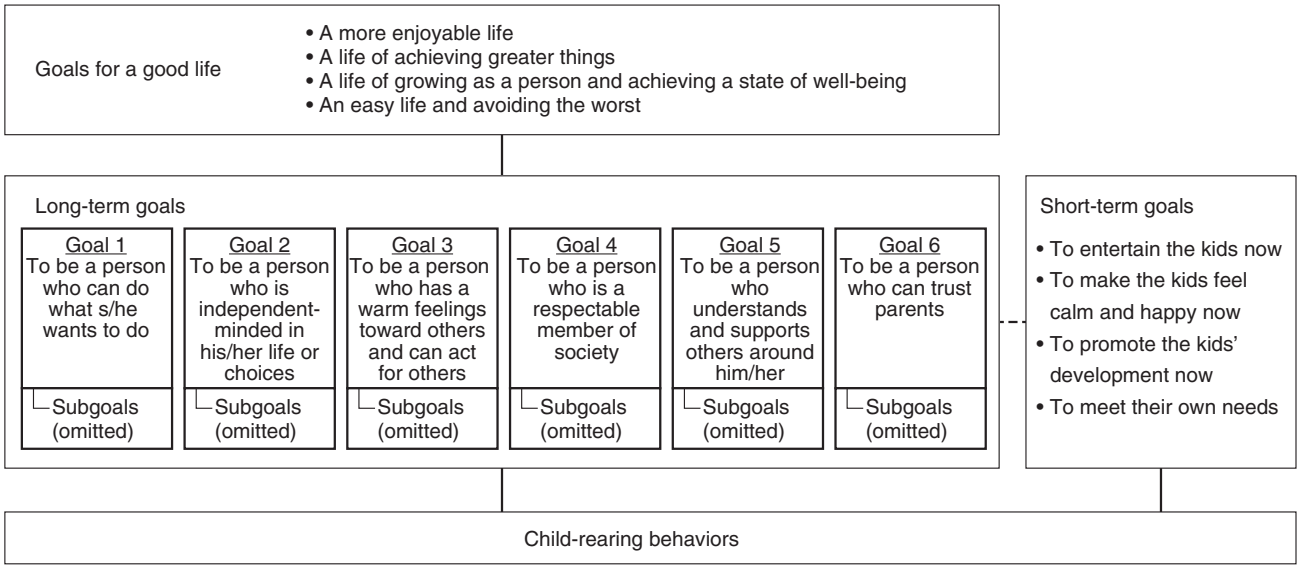

Fig. 6. Values of parents that affect their child-rearing behavior.

living labs in multiple locations, such as in the Japanese cities of Omuta, Sendai, and Yokohama, while engaging in dialogue with partners with differing values such as residents, companies, local governments, and universities. For example, at Tama-Plaza in Yokohama, we are studying how to support and accelerate the efforts of the local residents, companies, and government by developing frameworks and tools to communicate with one another to solve various problems the town has. We are also conducting research in Omuta, a city that places importance on a person-centered view of people that integrates the idea of "living true to oneself" while remaining connected with surrounding people, in collaboration with the local government, organizations, and companies to understand what is required to improve the town so that people can live in it with this view. Through this field research, we are painstakingly clarifying important viewpoints and developing frameworks and tools to support people in interacting with one another to achieve states of well-being.

3. Future developments

People's values and behaviors are diverse and sometimes irrational. Understanding, modeling, and transforming them into a better state is certainly a very difficult challenge. We will continue to engage in research and development with the aim of improving the well-being of people and solving social issues by using knowledge from a wide range of fields such as psychology, data analysis, and design.

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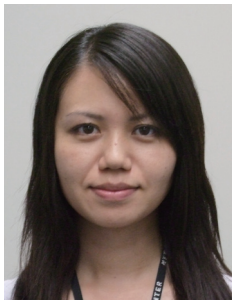

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Sports Social View—Method of Inclusive Sports Appreciation Extracting and Sharing the Essence of Sports through the Sense of Touch

Akiko Hayashi, Junji Watanabe, and Kentaro Shimizu

Abstract

NTT Service Evolution Laboratories is collaborating with the Tokyo Institute of Technology to enable people with various physicalities, including those with disabilities, to enjoy sports together. This article introduces a new method of enjoying sports that not only uses the audiovisual senses but also the sense of touch.

Keywords: tactile information, inclusive design, translation of sports

1. For inclusive sports viewing

What can be done so that people with various physicalities, including people with disabilities, can enjoy watching sports together? Understanding diversity has become increasingly important as reflected in the vision "diversity and harmony" of the international sports event to be held in Tokyo in 2020. NTT Service Evolution Laboratories is collaborating with Associate Professor Asa Ito of the Tokyo Institute of Technology on research into sports viewing for the visually impaired. We started with the aim to support people with disabilities to enjoy sports, but as the joint research progressed, rather than support, we arrived at the awareness of accepting differences and co-creating new experiences.

2. The limitations of describing things with words

The most common way for the visually impaired to enjoy sporting events is through audio commentary. There are people who enjoy audio commentary of baseball or soccer. However, some visually impaired people who once were able to see before have said, "We were able to enjoy exciting scenes as we saw them," but after their sight deteriorated they described their sports enjoyment as only a contextual overview of the flow of matches through audio commentary. In other words, they became unable to enjoy the raw skills of the players. There are also limitations to audio commentary for some competitions. Although competitions, in which offense and defense take turns, such as baseball, can be understood through audio commentary, it is difficult to convey the fine details, such as the force of movements and rhythm, in competitions such as tennis with its dizzying rallies or judo in which offense and defense are deployed at the same time.

A sense of unity is also an important factor affecting satisfaction when watching sports [1]. This means getting excited at the same time as a spectator nearby. However, it is difficult for the visually impaired to feel a sense of unity with the surrounding spectators. Therefore, current audio commentary is problematic in that it cannot express movements in sports very well, and the visually impaired are left out of the surrounding excitement.

Fig. 1. Translation of tennis match.

3. Physical translation of sports

To enable sharing of sport-viewing experiences with the visually impaired, we developed a method of viewing sports that physically re-expresses (translates) what is happening instead of using language. With this method, we attempted to express the force and rhythm of movements during a tennis match and judo match, which are difficult to verbalize.

3.1 Tennis match

The translation of the tennis match involved a translator (a sighted person) and visually impaired person (with total late-onset blindness) sitting face-to-face with the translator tapping a circular board laid across both their knees (**Fig. 1**) to reflect the position and strength of the ball as it was hit while the translator watched the tennis match. During a rally, the board was struck rhythmically on the visually impaired person's left and right, and he moved his head left and right as if he were following the movement of the ball to watch the rally. When a ball was hit and had a long flight, the visually impaired person could be heard uttering "this is a big one," indicating that he was enjoying the spatial nature of the rally. The translator also conveyed not only the physical action of hitting serves but also the rhythm of the players before serves by tapping the board. Although such rhythm does not appear as actual movement, the translation of tension and rhythm helps the visually impaired understand the situation more deeply. This can be consistent with the notion that the processes of generating a sense of being deeply moved ("Kandoh" in Japanese) are tension and release [2].

3.2 Judo

The translation of the judo match involved two translators (sighted persons) and a visually impaired person, and used a towel to express force interactions. Two translators held both ends of a towel, and the visually impaired person (with total late-onset blindness) grabbed the middle of it (**Fig. 2**). Translators played the roles of the judo players by pulling the towel up and down and left and right to express movements, pulling against each other, falling backwards to destabilize the opponent's center of gravity, etc. The visually impaired person described his impression of it as like "another judo match was being held on the towel. It felt more judo-like that watching it on television." The translations enabled some kind of transformation or interpretation to occur, which gave rise to other *events* while imitating the competition. This is because the translators were able to reflect the anxiety, tension, surprise, and joy that they felt in their translations. In other words, the visually impaired persons were able to experience another's *events* through the translators' interpretations, rather than just simply being conveyed visual information that had been converted into haptic information. This could be what led to the impression that "another judo match was being held on the towel" described above.

This research project was inspired by "museum

Fig. 2. Translation of judo match.

social view" in the field of art appreciation. In art appreciation, people with visual disabilities and sighted people interact through dialogue in front of art works to deepen their understanding of them. Although art appreciation and sports watching may seem different, both are similar in that they entail deep understanding of the subject through the physicality and interpretation of others. Thus, we call our project "Sports Social View."

4. *Essence* and *description* in translation

Having translated sports for several competitions, we realized that there are two factors in the expression of a translation. One is the sense of the *essence* of movements that express the rhythm and impact of a tennis rally or the destabilizing of the center of gravity in judo. The other factor is *description*. This is information that conveys the state of a competition such as the position of the ball and winning and losing. The translation is generally structured to put the essence on the description element. In tennis, the description element is expressed by tapping positions to represent the ball being hit in a rally, while the intensity and way of tapping express the impact of the player hitting the ball as the essence. In tennis or badminton, although the description elements that express the space in rallies are similar, the essences of the ball bouncing in tennis and the shuttlecock cutting through the air in badminton are different.

If we review sports from the perspective of essence and description elements, we can reclassify them from different perspectives. Hence, we are currently working on further deepening translations by asking researchers specializing in sports and sports players about the essence of competitions. Activities of this project have been published on the "Invisible Sports Picture Book" [3] website, which currently introduces various sports such as rugby, table tennis, and sailing. In the case of table tennis, although the speed and force of hitting seems important from the viewpoint of an amateur, we found "reading the rotation of the ball" is rather important, so rotation is expressed by hitting a disk (**Fig. 3**). Soccer and rugby are also competitions that develop around the ball in a similar

Fig. 3. Translation of table tennis (Photo by K. Nishida).

Fig. 4. Tennis match experienced in darkness.

wide-open space, but what is different is that soccer gets its attraction from the development of tactics, whereas rugby is highlighted by a battle of players trying to steal the ball from each other as they collide and the forcefulness of that activity. Thus, pursuing the essences of sports that involve fighting for balls entails significant differences. Even if someone is a sighted person, one could say that he/she could not "see" the sport. Thus, watching sports with translated expressions of essences such as those above may be effective not only for the visually impaired but also for sighted people.

5. Technology for sharing inclusive sports viewing experiences

Through this kind of sports translation, we wanted to share the experience of sports translation with even more people across time and space as the principle that the visually impaired and sighted can enjoy watching sports together became more or less established. We used tactile recording and presentation technologies to accomplish this aim. Focusing on the sports translation of tennis in particular, we produced exhibitions of "tennis match experienced in darkness" and "tennis match felt through the palm" through which one can experience sports translation anywhere and anytime via recording and playback of vibrations.

5.1 Tennis match experienced in darkness

"Tennis match experienced in darkness" involves a 1800 x 900 mm table that mimics a tennis court. Sports translations are carried out on the table, then participants experience a tennis match by touching the table (**Fig. 4**). The translator taps the table in sync with the tennis rally, and microphones are attached to the underside of the table at four locations to record the vibrations. Vibration speakers are attached at the same positions as the microphones, and the recorded vibrations are replayed with the video. Participants in this exhibit place their palms on the table and feel the vibration of the table being tapped. The experience consists of the above table and a large screen in a small room, and a tennis match is viewed under the following conditions. (1) Watching tennis with all information; video, ambient sound, and vibrations (sighted-people situation); (2) enjoying tennis with the video subtracted and only ambient sound and vibrations (vision subtracted); and (3) enjoying tennis with video and sound subtracted, with only vibrations (vision and hearing subtracted). This makes it possible to create different physical situations and enjoy sports through physical translation.

In interviews after the experience, the visually impaired described their understanding of the match as "it was the first time I could tell where the ball hit in a tennis match" and described their feeling of unity as "I felt like I was watching with someone." Some of the sighted people described the essence of tennis as having their "senses sharpened and feeling more the rhythm of rallies," which indicates that physical translations are also an effective way for sighted people to enjoy sports.

5.2 Tennis match felt through the palm

"Tennis match felt through the palm" involves a 450 x 300 mm table that mimics a tennis court. In the

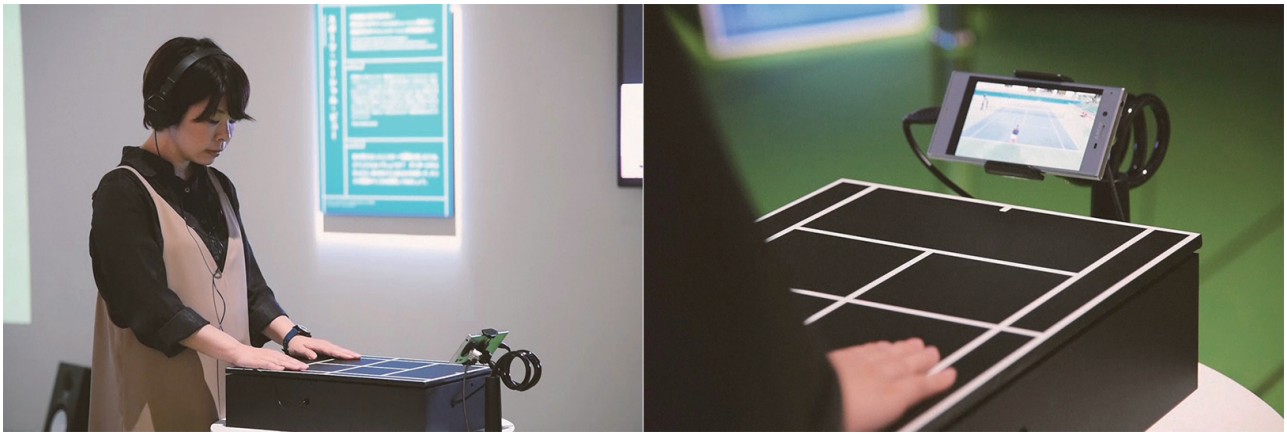

Fig. 5. Tennis match felt through the palm.

same way as "Tennis match experienced in darkness," tennis video and sound are replayed with a smartphone and headphones, and tapping vibration is replayed with vibrating speakers attached to the underside of a table at four locations (**Fig. 5**). Participants watch a tennis video on their smartphone screens while listening to the sound through headphones and feel the player hitting the ball by placing their palms on the table. The smartphone provides video and audio playback as well as power. This is a miniature version of "Tennis match experienced in darkness" that enables sports translation in stadiums and public viewing sites where an external power source is not available. As described above, exploring the spectator experience with the visually impaired also made it possible to create new ways for sighted people to enjoy sports, thus opening up the possibility of an inclusive spectator experience.

6. Future developments

Our project is based on the idea of translating the essence of sports and sharing it with the visually impaired. Although there are people with many types of physical conditions, changing the modalities of sensation might enable many people to enjoy sports viewing together. In the near future, we would also like to apply this method to actual situations such as in stadiums and public viewing spaces.

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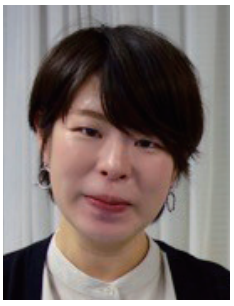

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Field Trials of Open and Disaggregated Transponder in Optical and IP Networking

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Abstract

An open and disaggregated optical transmission system is a candidate enabler for future high-capacity, low-latency, and flexible optical networks. The open software architecture is key to developing an open transponder for this transmission system. In this article, we propose the new optical transponder architecture. We conducted field trials of low-latency optical transmission using an open and disaggregated transponder with the open software architecture in a datacenter interconnect network to confirm the feasibility and usefulness of this transponder.

Keywords: whitebox, datacenter interconnect, TIP

1. Introduction

NTT proposed and is working on the Innovative Optical and Wireless Network (IOWN), which is composed of the All-Photonics Network, Cognitive Foundation®, and Digital Twin Computing [1], resulting in an innovative network with excellent capacity, low latency, flexibility, and energy efficiency to create a smart world. Focusing on the physical layer, in addition to time-of-flight of light in an optical fiber and signal processing time at transmission ends, one of the bottlenecks for achieving ultimate low latency might be a hierarchical tree-type network topology with vertically integrated optical transmission equipment. There have recently been serious discussions on an open and disaggregated optical transmission system, which can add more flexibility to the network topology. This activity is expected to drive the development of a wide range of services by providing openness and multi-vendor implementation at the component level and enabling the addition of user's own applications and autonomous operation. It will also enable us to tailor network topology for each application, such as high-speed storage backup via a wide area network or transmission of multi-channel uncompressed ultra-high-definition images captured at a sporting event via a network to a broadcast station. It is therefore important to create a platform for accelerating flexibility and technical innovation in this optical transport network.

2. Activities towards open and disaggregated optical transmission systems

In the traditional optical transport network, optical transmission equipment is locked into specific vendors in a vertical integration model and fixed from the transceiver to the operating system. This approach results in high implementation and maintenance costs, makes decentralization of supply sources difficult, and usually forces network interoperability on the user. It also makes it difficult to tailor network topology for applications. NTT laboratories have been developing flexible control technology for optical transport networks that facilitates the virtualization of ICT (information and communication technology) resources and started collaboration with its

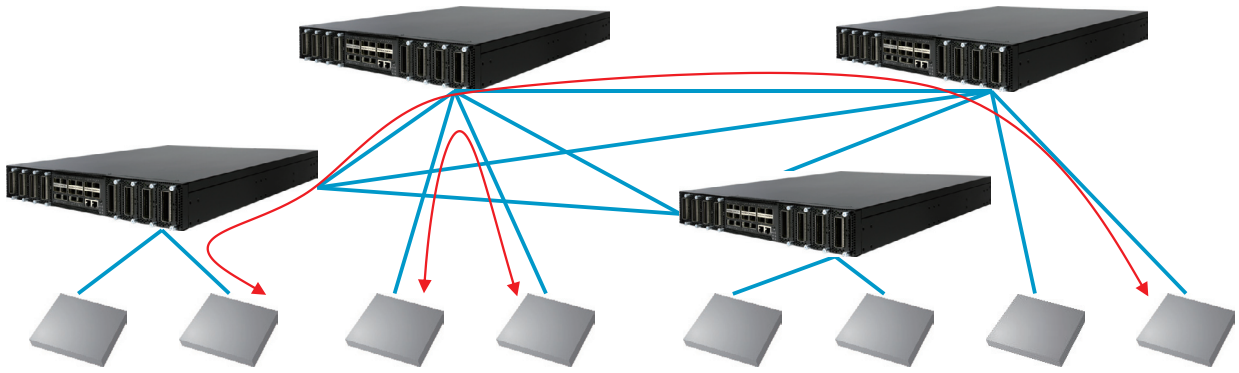

Fig. 1. Full mesh network topology with whitebox packet transponder.

global partners including network operating system (NOS) vendors, original design manufacturing vendors, optical component vendors, and other partners to define the open interface of an optical transponder through activities in the Telecom Infra Project (TIP). In December 2017, the first interface specification and architecture of the Transponder Abstraction Interface (TAI) [2], which facilitates disaggregation between software and hardware of an optical transponder, was proposed to TIP. Its working model was then exhibited at TIP Summit 2018 and the Optical Networking and Communication Conference & Exhibition (OFC) 2019 with open hardware [3]. This section describes an optical network adaptable to cloud-native systems that we have been studying and software architecture for an open optical transponder.

2.1 Optical network with open and disaggregated optical transmission systems

Conventional networks feature a hierarchical tree-type topology based on the telephone network and Internet access. One key advantage of this topology is user-manageability; it allows operators to handle and maintain a huge number of calls or services to each of their users simply with a hierarchical structure. On the other hand, an optical transport network that handles cloud services, Internet of Things, and edge computing used to be required to support ultra-low-latency communication machine to machine (M2M). An issue with tree-type topology is the high latency for M2M because communications between edges when they are under different branches need to pass up and down the tree through many optical fiber paths and equipment units. The full-mesh network with a whitebox packet transponder shown in **Fig. 1** enables lower latency at low cost because of capital expenditure reduction with multi-vendor coherent module capability, transponder-switch converged architecture, open hardware, and rich network function implementation capability at the carrier edge with cloud-native and micro-service architecture.

2.2 Transponder architecture for open optical transponder

Achieving an optical network adaptable to cloud-native systems, as described above, will require a reduction in the cost of implementing and operating an optical transport network as well as flexible network control. In datacenters, the evolution of open source software (OSS) accelerates automation of operations such as zero-touch provisioning and streaming telemetry. When the disaggregation of hardware and software technology developed for datacenter servers and switches spreads to the optical transport network field, operators can also use automatic operation technologies with OSS for optical transport networks. We propose the optical transponder architecture shown in **Fig. 2** that adopts a Linux-based NOS and enables the disaggregating of optical transmission equipment into hardware and software in a whitebox format. This architecture provides Ethernet-based optical and Internet Protocol (IP) networking capable of simple operation while adopting packet switching integrated architecture.

It also hides the proprietary specifications for the coherent components loaded on the optical transmission equipment and adopts the TAI [4], which is an application programming interface for vendor/generation-independent coherent module control. The use of the TAI reduces NOS development and maintenance costs and enables NOS and optical transmission equipment to be combined in diverse ways. In

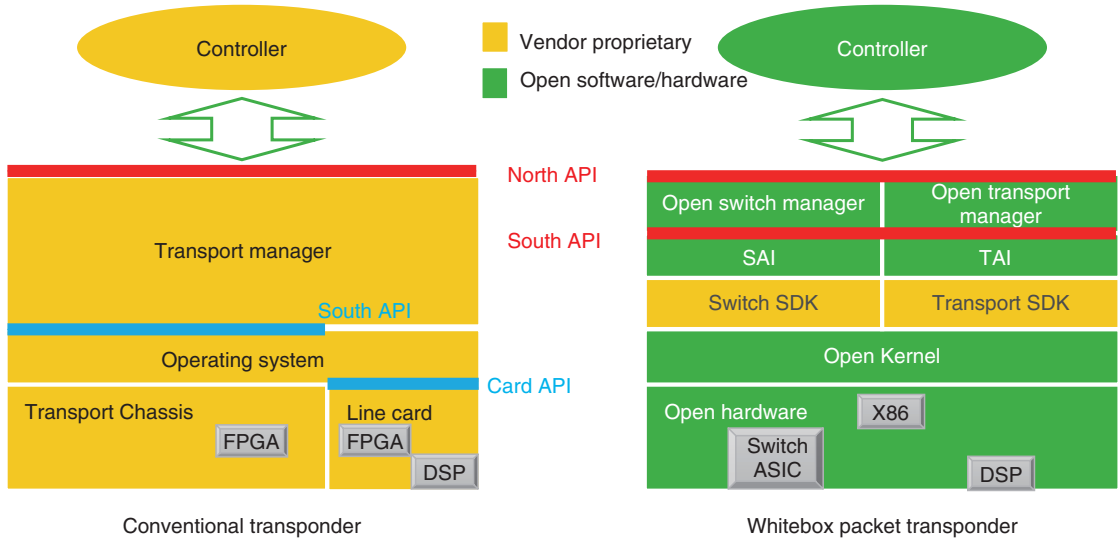

Fig. 2. Conventional and proposed transponder architectures.

(a) Cassini (b) Galileo

Fig. 3. Whitebox packet transponders.

addition, hardware in this architecture takes on a modular configuration, which means that it can be used for small starts and easily exchanged as needed. The whitebox packet transponders Cassini and Galileo shown in **Fig. 3** are being proposed at TIP for an open optical transport network [5].

3. Field trials of uncompressed video transmission in commercial datacenter interconnect

There is currently a major move toward the use of IP for transmitting video and audio in broadcast facilities. This transition is expected to enable uncompressed video/audio transmission, making full use of the large-capacity, low-latency, and bidirectional communication characteristics. Interest is also growing in developing a remote production system that interconnects a relay site and broadcast station over an IP network and sends the video and audio acquired in the field to a broadcast station without prior editing (**Fig. 4**). Since the editing process takes place at the broadcast station, fully equipped production vans are no longer required and editing crews are allowed to stay at the broadcast station. However, multiple Ethernet switches are required for long-distance transmission, which can affect the Precision Time Protocol used for synchronization among video devices. Long-distance and large-capacity capabilities in the transmission of such video and audio are therefore important. Taking this into account, we conducted field trials of 4K/60P video using commercial dark fiber between datacenters to assess the effectiveness of our proposed optical transponder architecture (**Fig. 5**). In these field trials, we used Cassini whitebox packet transponders to directly connect two

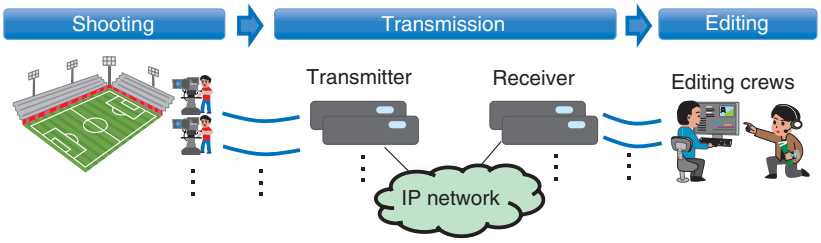

Fig. 4. Remote production workflow.

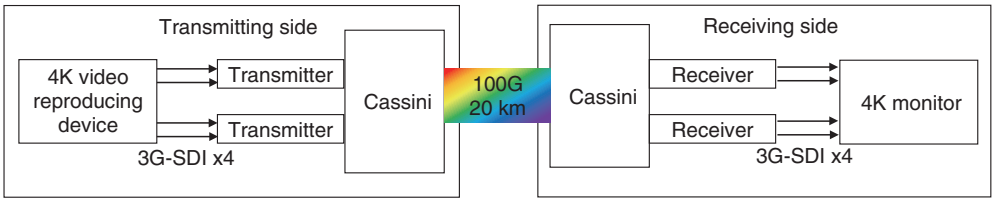

Fig. 5. Experimental setup of large-capacity transmission of uncompressed 4K video.

points over approximately 20 km of dark fiber. For optical transmission, we used an analog coherent optics transceiver for carrying out digital coherent processing on the digital signal processor mounted on a Cassini plug-in unit. This pair of Cassini transponders is equipped with different NOSs, uses quadrature phase-shift keying as the modulation system, and interconnects by 100-Gbit/s Ethernet.

The 4K/60P video to be transmitted is output from a 4K video-reproducing device using four 3 Gbps Serial Digital Interface (3G-SDIs). These video streams are then input to two transmitters—two 3G-SDIs per transmitter—and the outputs from these transmitters are finally output as separate SMPTE ST 2110* flows. These transmitters connect directly to a Cassini transponder. The receivers used in this trial likewise connect to a Cassini transponder and the received IP flows are output by the four 3G-SDIs. Using this system, we conducted the field trials from July to September 2019 (**Fig. 6**). These trials confirmed that the video could be correctly reproduced on the receiver side and that 4K/60P uncompressed video could be transmitted using Cassini transponders.

Fig. 6. Transmission of 4K video to receiver side.

4. Conclusion

The optical transponder architecture we proposed is adaptable to cloud-native systems and enables flexible control of the optical network and easy addition of services. Going forward, we plan to develop technology for autonomously controlling and stabilizing the optical network in response to changes in the environment, application operations, etc.

* SMPTE ST 2110: A standard developed by the society of motion picture and television engineers (SMPTE) for transmitting video over IP networks for the professional media industries.

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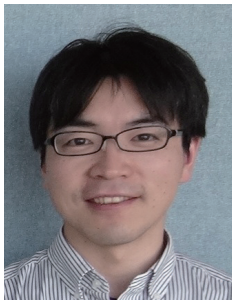

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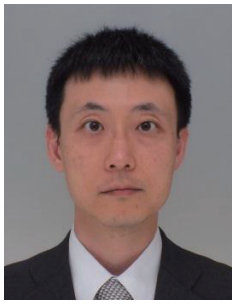

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Does Exploratory Hand Movement Provide Information on Tactile Sensations?

Takumi Yokosaka

Abstract

People move their hands in a variety of ways, such as tracing a finger on a material to feel its roughness or pushing a materials' surface to feel its hardness, to judge the feel of materials around them. Many studies on human tactile sensation did not focus on such hand movements. This article introduces my studies on investigating whether hand movements—and even eye movements—can be used to provide information for estimating the tactile sensation felt by a person. These studies are expected to provide not only important information for clarifying the mechanism of tactile perception but also help in designing guidelines for tactile-information display devices attached to arms and hands.

Keywords: human perception, tactile perception, exploratory hand movement

1. Introduction

People can feel a variety of tactile sensations (e.g., hardness and roughness) by actively exploring the surface of an object with their hands and fingers. While haptic-display technology and product-surface design technology, which are applied to induce such a predetermined tactile sensation, have been attracting attention, how these technologies actually create an end-user tactile sensation has received little attention. In fact, even if many people touch the same object, they will not all feel the same tactile sensation. For example, how surface roughness is perceived varies from person to person [1], and the perceived roughness can change as the force of the fingers pushing the surface changes [2, 3]. Accordingly, even if people are using the same haptic display or touching the surface of the same object, the tactile sensation felt by each person is likely to change from person to person. One way to determine what type of tactile sensation a person actually felt is to actually ask them; however, from the viewpoint of an end user, having the person report their tactile sensation every time they touch something is inconvenient. It would therefore be useful if it were possible to estimate externally—by using an objective measurement index—how a person felt when touching an object.

This article focuses on exploratory movement of a hand while touching an object as a source of information (i.e., a measurement index) about a tactile sensation. In many previous tactile studies, such hand movements were treated as something that should be controlled, and the tactile ability of a stationary hand and a hand performing simple movements (such as linear ones) were investigated. However, they overlooked the role of hand movements. It is known that how hands move on objects changes according to what type of tactile sensation is to be determined [4], and it is suggested that the movement of the hand plays the role of a *window* that reflects the tactile sensation. This article introduces my efforts to investigate how exploratory hand movements provide information about tactile sensation.

2. People know the relationship between exploratory hand movements and tactile sensation

Do exploratory hand movements actually contain tactile information? If so, we might be able to use that information. In other words, by looking at the

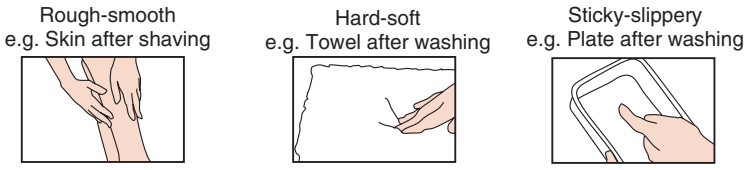

Fig.1. TV commercials use hand movements to convey a rich sensation of touch to viewers.

hand movements of someone else touching an object, we might be able to imagine how that object feels when touched. Although this situation may seem strange, we are already familiar with it through television (TV) commercials (**Fig. 1**). For example, we have seen scenes in which skin is stroked by a hand, a towel is pushed by a hand, or a plate is rubbed with a finger. Watching such scenes, we can imagine the smoothness of the skin after shaving, the softness of a towel washed using softener, and the frictional squeak of greasy plates that have been washed using detergent. This imaginative ability of people was previously investigated through psychophysical experiments [5].

First, six participants (each called a *toucher*) touched an object (such as wood or glass) and evaluated the tactile sensation they felt. The hand movements of each toucher were recorded while he/she was touching his/her target object. Ten other participants (each called an *observer*) were asked to observe the touchers' hand movements and guess how the touchers felt when they touched the target object. To investigate whether hand movement is actually used as an information source, a toucher's hand movement was reproduced with moving light points that exclude information other than hand movement (e.g., skin deformation and nail color) (**Fig. 2**). The experimental results indicated that all ten observers responded in a similar manner. That is, when the observers watched the light-point hand movements of a toucher touching an object that the toucher felt was sticky, they tended to judge that the toucher was touching a sticky object. When the observers watched the light-point hand movements of a toucher touching an object that the toucher felt was fluffy, they tended to judge that the toucher was touching a fluffy object. The results indicated that people can use a common strategy—based on hand movements—for estimating tactile sensations. It is thought that people possess such a common strategy because the movement of hands touching objects contains information on the tactile sensation felt by the toucher.

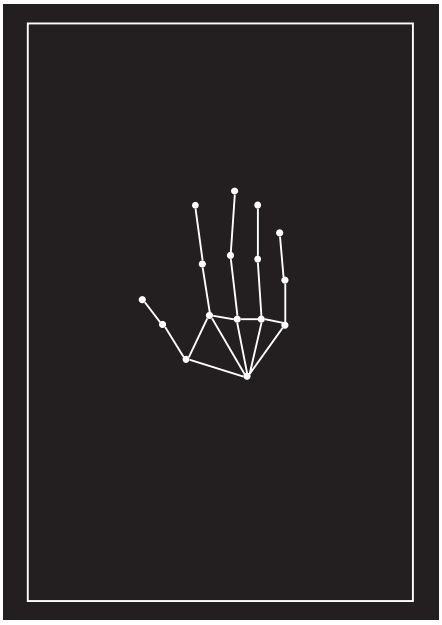

Fig. 2. A scene from a video of hand movements of a toucher in a previous experiment [5]. The hand movements were drawn as moving light points and observed by observers.

3. Analysis of exploratory hand movements

What exploratory hand movements actually contain certain tactile information? An experiment was conducted in which participants were asked to touch various objects that they encounter on a daily basis and report their tactile sensations [6]. By analyzing the measured hand movements, what movements can explain these tactile sensations were determined. The experimental results revealed that the speed of a stroking hand and the magnitude of the hand's pushing force contained information on the hardness, roughness, stickiness, and warmth felt by the participants. Two trends were identified: (i) the evaluations of hardness and temperature (related to pushing and static contact) are related to the magnitude of the

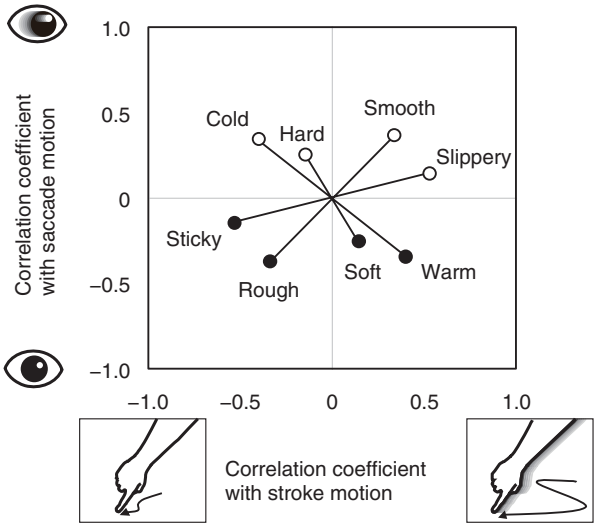

Fig. 3. Correlation between active movements of the eyes and hands and evaluation of tactile sensation. For example, active eye movements (saccade motion) have a positive correlation with coldness, which indicates that the eyes move more actively when someone is touching an object judged as cold. On the contrary, the stroking motion of the hand has a negative correlation with coldness, which means that the hand moves more actively when someone is touching an object judged as warm.

pushing force and (ii) the evaluation of roughness and stickiness (related to surface friction) is related to the speed of the stroking hand. Even more interesting is that active eye movements also contain tactile information. The reason for this is still open to question, but exploratory eye movements might be related to the physical properties of the object surface.

To estimate tactile sensations, it may be useful to combine measurements of hand speed and active eye movements. As shown in **Fig. 3**, active eye movements contain information on hardness, warmth, and roughness, and the speed of the hand contains information on stickiness, roughness, and warmth. From these results, it might be possible to specify which of the four main touch sensations—hardness-softness, roughness-smoothness, stickiness-slipperiness, and warmth-cold—are felt. For example, when a person moves his/her eyes and hands, he/she is feeling a smooth sensation (first quadrant in Fig. 3), and when a person is not moving his/her eyes but moving his/her hands, he/she is feeling a warm sensation (fourth quadrant in Fig. 3).

4. From perceived physical properties to evaluated preference

Hardness, roughness, stickiness, and warmth are tactile sensations that are closely related to the physical properties of an object. For example, perceived hardness is strongly affected by compliance [7, 8], and perceived roughness is strongly affected by friction [9–11]. Perception of these sensations is necessary for properly adjusting movements, such as when a person is gripping an object. However, tactile sensation has not only this function but also a function that determines how favorable the touched object is to the person touching it. Differing from sight and hearing, tactile sensation is a perception that occurs when the body is directly in contact with an object, so this evaluation of tactile preference is important. I also investigated whether movements of a hand touching an object also contain this perception of preference [12]. First, I showed that the evaluation of preference can change if the manner of touching changes. For example, woody materials were evaluated as preferable when being stroked but evaluated as less preferable when being pressed. This means that there is a close relationship between how an object is touched and tactile sensation (preference evaluation). Next, I discussed the analysis of the movement of a hand touching an object and that the features related to stroking motion (such as hand speed) contained information on the evaluation of preference. On the contrary, the features related to pushing did not contain such information. These results suggest that measuring stroking motion will allow us to estimate

evaluated preference.

5. Benefits of measuring hand movements and applying the measurement results

According to the results presented thus far, it may be possible to estimate how a person feels by measuring his/her hand movements. Therefore, what are the benefits of measuring and analyzing hand movements and how does this differ from measuring and analyzing physical properties (such as compliance and friction)? One benefit of measuring hand movements is making it possible to consider the effects of individual differences and manner of touching, as described in the introduction. For example, individual differences due to differences in search strategies of end users cannot be determined by measuring the physical properties of touched objects; however, they might be determinable by measuring hand movements. In fact, which information is used preferentially, spatial information or temporal information regarding the perception of roughness, depends on the person [1]. Since it is also known that hand movements differ according to the manner in which such spatiotemporal information is used [13], measuring such movements might allow us to consider individual differences. As stated above, the tactile sensation (evaluation of roughness or evaluation of preference) can change when the manner of touching an object changes even if the same person touches the object. This fact cannot be understood from measuring the physical properties of the object; instead, it could be understood by measuring hand movements. To analyze the physical properties of objects, we must measure the physical properties of all objects end users might touch. To analyze hand movements, however, all we need to do is attach a motion sensor to the hand. This approach has a high affinity with a haptic display worn on the arm; that is, attaching such a device to measure the movement of the arm makes it possible to continuously monitor the tactile sensation felt by the wearer.

6. Conclusion

Studies on whether hand movements contain information on tactile sensation were introduced. The results of these studies are expected to contribute to not only establishing an objective method for estimating tactile sensation but also revealing human-tactile mechanisms that are still unknown.

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Activities at W3C Technical Plenary and Advisory Committee Meetings Week (TPAC) 2019 in Fukuoka

Yumiko Matsuura, Kiyoshi Tanaka, Shigeru Fujimura, and Koichi Moriyama

Abstract

The W3C (World Wide Web Consortium) Technical Plenary and Advisory Committee Meetings Week (TPAC) 2019 was held from September 16 to 20 in Fukuoka, and this meeting was the second time held in Japan. The activities of the NTT Group related to development of web technology in TPAC are described in this article.

Keywords: W3C TPAC, web authentication, digital signage

1. Overview of W3C TPAC 2019 in Fukuoka

The Technical Plenary and Advisory Committee Meetings Week (TPAC) is an annual general meeting held by the World Wide Web Consortium (W3C), which is a membership-based international consortium of industrial and academic organizations involved in standardizing and promoting web technology. The days before and after the plenary session held on that Wednesday were filled with various activities related to standardization, including face-to-face technical discussions in the Working Group (WG) and discussions on the use of technology from a business perspective and technology that has been adopted in the Business Group (BG). TPAC 2019 was held at the Hilton Fukuoka Sea Hawk and was the largest ever, with over 640 participants and over 100 meetings and sessions.

The key topics of the plenary session included an announcement regarding Sir Tim Berners-Lee, inventor of the World Wide Web as well as the founder and centripetal force within the W3C, of his intention to step down as director. There was also a report on the proposal for the W3C to obtain legal entity status in January 2021, which has been discussed in various meetings as a means to achieve stable operation of the W3C, and members were asked to make preparations within their own organizations. Concerning the handling of intellectual property in the standardization process, a proposal for a policy of early confirmation of royalty-free implementation by each organization, which is currently required at the time of recommendation, was promptly confirmed to prevent reworking in WG discussions.

2. NTT Group activities

The NTT Group provided stable Internet connection service during the conference via NTT Communications and NTT WEST. Meeting participants included many individuals from many countries, and communication between members via the Internet for web conferencing, GitHub, etc. required a very fast and robust network environment. By continuously and reliably performing daily tasks such as monitoring during meetings and equipment inspection after meetings, the NTT Group contributed to the high evaluation of the meetings by participants.

3. FIDO authentication and the WebAuthn WG

The Web Authentication (WebAuthn) WG has been

standardizing a JavaScript application programming interface (API) for web browser implementation of simple and strong web authentication based on the FIDO™*1 model [1, 2].

The standardization of web authentication in the W3C began with the contribution of the basic specifications of the web part (draft) by the FIDO Alliance in November 2015. The FIDO certification model was made compatible with operating systems and browser platforms and officially recommended as Level 1 in March 2019. Level 2 is currently being formulated.

NTT DOCOMO and NTT laboratories joined the FIDO Alliance as a board member and a sponsor member, respectively. NTT DOCOMO has chaired the Consumer Deployment WG and FIDO Japan WG and is contributing to the formulation and popularization of FIDO certification specifications by providing summaries of issues and feedback regarding commercial introduction and improvement of the FIDO specifications.

Seizing the opportunity of getting together with key persons involved in web security and authentication at TPAC 2019, three initiatives from Japan were taken up to promote even more widespread application of the simple and robust FIDO authentication model in commercial services, including web authentication.

3.1 Demonstration booths

The NTT Group took the initiative to set up web authentication demonstration booths during the week of the meeting. The FIDO Japan WG and the Japan FIDO Alliance member companies also participated by demonstrating web authentication on smartphones, web authentication using personal computers and security keys, and the operation of an authentication device that uses the veins in users' palms. By popularizing FIDO certification and introducing new first-in-the-world initiatives in Japan, we were able to demonstrate the appeal of password-less authentication.

3.2 Luncheon speech

On the second day, we conducted a 30-minute presentation entitled "Contributions from NTT and Japan Teams for Simpler, Stronger Authentication." The presentation covered how NTT DOCOMO was an early adopter by using the FIDO specifications for d ACCOUNT™*2 log-in biometric authentication since May 2015 [3] and initiatives of the NTT Group and Japanese companies regarding web authentication. Knowledge gained from world-first commercial applications and feedback for improving specifications were also presented along with ideas for moving forward. At TPAC 2019, which was held in Japan for the first time in a long while, a luncheon speech (a first for TPAC) describing valuable Japanese initiatives generated strong interest and lively discussion among several audience members (**Photo 1**).

3.3 WebAuthn WG

In the WebAuthn WG, more specific feedback was offered, and there was discussion on formulating Level 2. The three main points were 1) current differences in browser implementations, 2) problems with the specifications for providing a frictionless authentication experience, and 3) best practices for effective use of the many options for implementing password-less authentication. We believe these efforts have increased the momentum of standardization activities for reducing the risk of unauthorized access originating in the online use of passwords.

4. Web-based Signage BG

Web-based signage [4] is digital signage that uses web technology and features the implementation of services by simple installation of a web browser on a terminal. In the W3C, the Web-based Signage BG (co-chaired by NTT) began studies on the implementation of web-based signage in April 2012, starting with analysis of use cases, and has been discussing the implementation of the browser API required by services. The Web-based Signage BG meeting was held at TPAC 2019 for the first time in about two years. The history of the activities was reviewed, and it was confirmed that web-based signage has already been commercialized and is in use worldwide. Having achieved the initial goal of widespread use of web-based signage, the members agreed at the meeting to terminate activities of this BG.

5. Breakout session topics

One of the features of TPAC is "unconference-style" breakout sessions held on the day of the plenary session. Volunteer participants deal with all matters from setting the discussion topics to managing the sessions. The discussion topics can be very diverse, such as seeking broad audience perspectives

*1 FIDO stands for First IDentity Online. FIDO is a trademark of FIDO Alliance.
*2 d ACCOUNT is a trademark of NTT DOCOMO, INC.

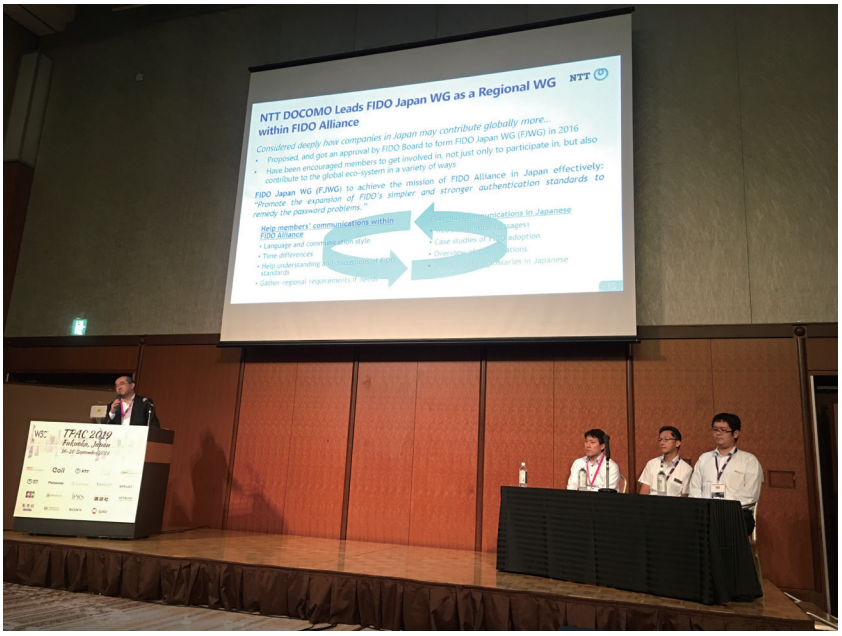

Photo 1. Luncheon speech at the TPAC.

on divided opinions within the WG, or proposing new topics for future discussion in the W3C. This time, 59 sessions were held with lively discussion, and up to 12 sessions were conducted simultaneously.

Of particular interest was the six related sessions presented by Google and Apple regarding browser privacy, including increased security risks and proposals for new browser security models. Behind this, IP (Internet protocol) addresses and cookies used for personalization in web advertising are considered personal information under the General Data Protection Regulation (GDPR)*3 and require careful handling. Another background issue is the considerable progress in browser fingerprinting [5] as a method of tracking users that does not use cookies and is more difficult to prevent.

It goes without saying that the protection of privacy is an important issue, and browser vendors are expected to propose new specifications based on the discussions held in these sessions in the near future.

References

[1] FIDO Alliance, https://fidoalliance.org/
[2] WebAuthn WG, https://www.w3.org/TR/webauthn/
[3] K. Moriyama, "Toward a Password-free World: NTT DOCOMO Efforts on d ACCOUNT Biometric Authentication Using the FIDO Standard and Future Prospects," *Denkitsushin* (Telecommunications), Vol. 80, No. 840, pp. 13–19, 2017 (in Japanese).
[4] K. Tanaka, M. Nakamura, K. Suzuki, and K. Takegami, "Trends in Web-based Signage Standardization," NTT Technical Review, Vol. 15, No. 8, 2017.
[5] N. Nikiforakis, A. Kapravelos, W. Joosen, C. Kruegel, F. Piessens, and G. Vigna, "Cookieless Monster: Exploring the Ecosystem of Web-based Device Fingerprinting," Proc. of the 2013 IEEE Symposium on Security and Privacy, pp. 541–555, Berkeley, USA, May 2013.

Trademark notes

*3 GDPR: European Union (EU) regulation for general data protection formulated by the European Parliament, European Council, and European Commission intended to strengthen and integrate data protection for all individuals in the EU.

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She received a B.S. and M.S. in computer science from Keio University, Kanagawa, in 1991 and 1993. She joined NTT Human Interface Laboratories as an engineer in 1993 and engaged in the development of multimedia systems and a content delivery platform. She was in the Research and Development Strategy Department twice, most recently she started collaboration with leading companies in industries such as automotive and manufacturing. As a result of organizational changes in July 2017, she is now at NTT Service Evolution Laboratories and is involved in research management on human understanding and interface design.

Kiyoshi Tanaka
Senior Research Engineer, Supervisor, Co-innovation Promotion Project, NTT Service Evolution Laboratories.

He received a B.E., M.E., and Ph.D. in communication engineering from Osaka University, in 1992, 1994, and 2005. He joined NTT in 1994 and since then has been engaged in researching video-on-demand systems and metadata-related interactive video systems and services, especially those related to IPTV and digital signage services. His current interests include standardization of digital signage. He is one of the co-chairs of the W3C Web-based Signage Business Group. He is also a member of the Institute of Electronics, Information and Communication Engineers (IEICE), the Human Interface Society in Japan, and the Institute of Image Electronics Engineers of Japan (IIEEJ).

Shigeru Fujimura
Senior Research Engineer, NTT Service Evolution Laboratories.

He received an M.S. in information science and technology from the University of Tokyo in 2005 and joined NTT the same year. Since then, he has been engaged in research on web mining and web engineering, especially on effective methods of implementing web applications. His research interest is data management systems using blockchain and smart contract technology.

Koichi Moriyama
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He received a B.E. in electrical engineering and an M.E. in computer science from Keio University, Kanagawa, in 1992 and 1994. He is responsible for the innovation of NTT DOCOMO's devices and platform software and for the partnerships that support NTT DOCOMO's innovation goals, including those related to FIDO standards. Mr. Moriyama has previously held positions with Sony Ericsson Mobile Communications, Inc. and Sony Corporation. He was also a visiting research scholar at Georgia Institute of Technology, USA, while he was at Sony Corporation.

NTT and Telefónica Start PoC on Open Optical and Packet Transport Technologies within Telecom Infra Project

1. Introduction

NTT and Telefónica announced that they have conducted a successful proof of concept (PoC) on open optical and packet transport technologies at the TIP Summit'19 held in November 2019 in Amsterdam, the Netherlands. A whitepaper of the PoC was published on the website of the Telecom Infra Project (TIP) in January 2020 [1].

The goal of the PoC is to implement open and commoditized networks to achieve wide scale economy for some components of the Converged Architectures for Network Disaggregation & Integration (CANDI) architecture and create an open market for disaggregated elements, both Internet protocol (IP) and optical.

To achieve this goal, NTT and Telefónica created the CANDI sub-group under the framework of TIP's Open Optical and Packet Transport (OOPT) project group in October 2018. In 2019, Orange, Telia Company, and the pan-European research network operator GÉANT joined CANDI. Only one year after the creation of the working group, the first collaboration PoC was completed in Madrid, Spain.

With this PoC, the team succeeded in building a converged network with a packet technology controlling telecommunication traffic and an optical technology transmitting data long distance, following the required architecture, open technology and open interface promoted by CANDI.

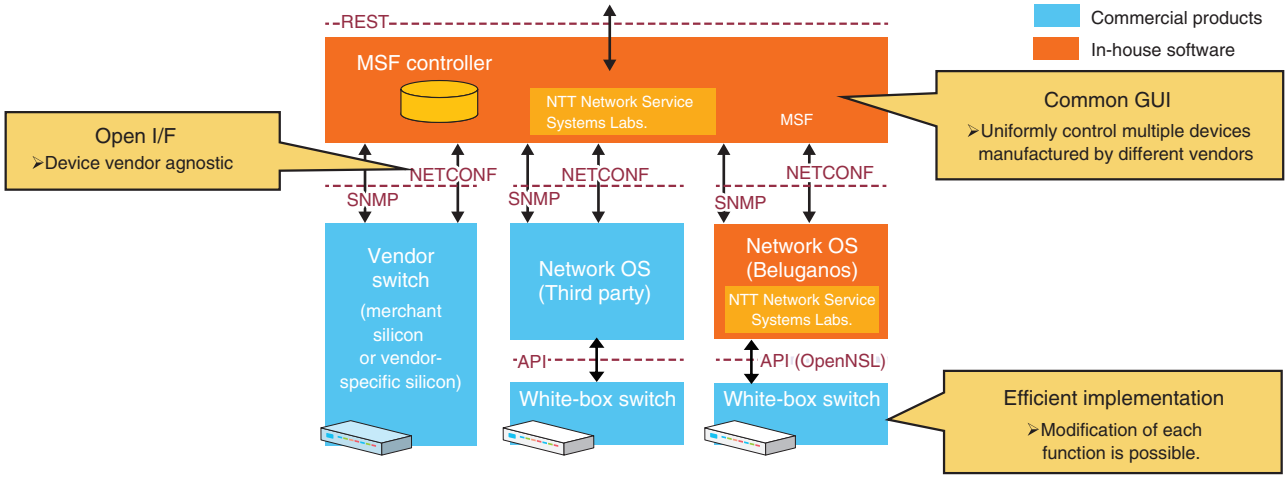
2. NTT's MSF and Beluganos development history

NTT has been engaged in the Multi-Service Fabric (MSF) project since 2014 to promote the use of open hardware provided by such communities as the Open Compute Project (OCP), leading to disaggregation between software and hardware in packet transport equipment and the network architecture and developing its system. This project is enhancing service reliability and flexibility of service development, as required by telecom operators. Since 2016, NTT has also started developing in-house software, *Beluganos*, which is a network operating system (OS) using an open interface controlling packet transmission chip in a white-box switch to activate the functions that are implemented by vendors (**Fig. 1**).

NTT has been disclosing both MSF and Beluganos as open source software (OSS) respectively to accelerate the development of open technology in the packet transport field and implementation of carrier-required features by multiple vendors to avoid vendor lock-in since 2017. In 2019, NTT contributed to and succeeded in a PoC through collaboration with Taiwan's largest carrier Chunghwa Telecom by using these OSS.

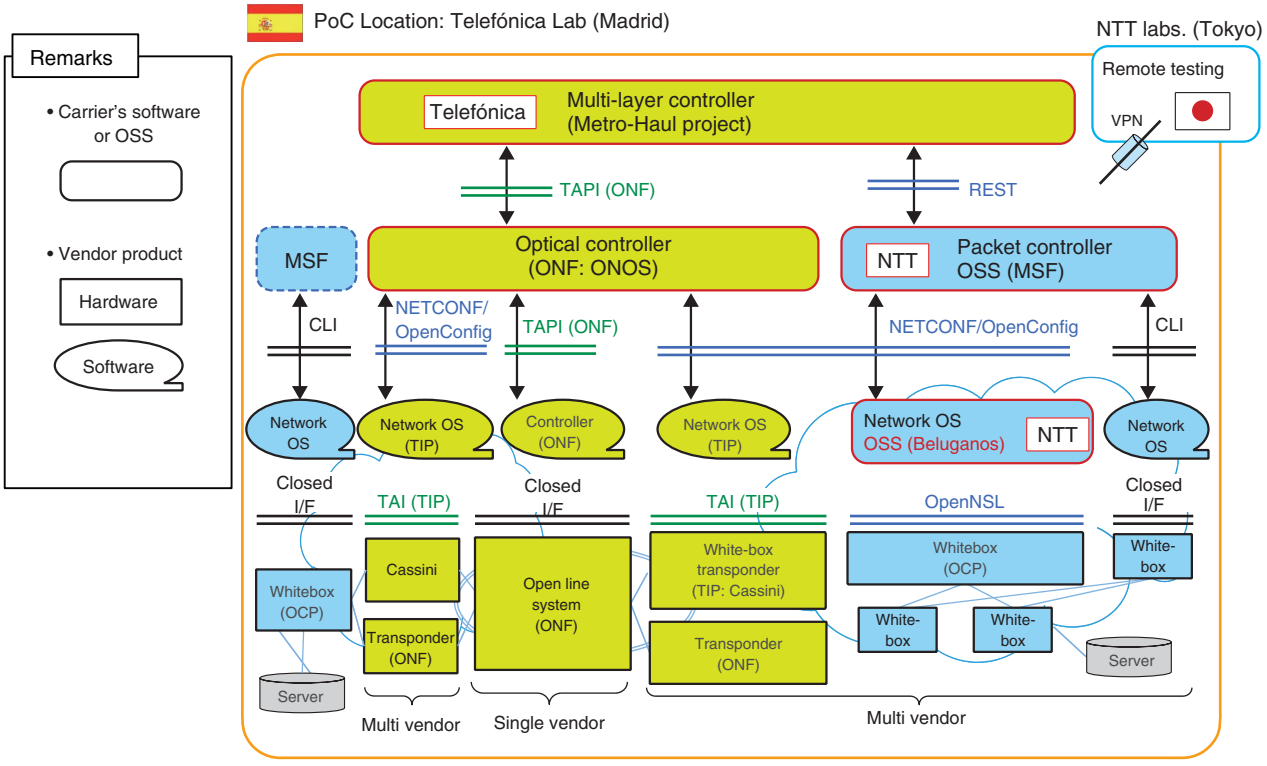
3. Roles of Telefónica and NTT

To develop the PoC, Telefónica provided a multi-layer controller based on open standard interfaces with both the packet controller and optical controllers, and NTT provided an IP software-defined networking (SDN) controller (MSF) and network OS Beluganos as the reference model of the architecture and open interface (**Fig. 2**). Beluganos controls the OpenNSL (Open Network Switch Library) as an open interface of the packet transform chip of a white-box switch and also provides Netconf/Openconfig, which is becoming the de-facto open interface for remote-controlling packet devices. MSF succeeded



API: application programming interface
GUI: graphical user interface
I/F: interface
NETCONF: Network Configuration Protocol
OpenNSL: Open Network Switch Library
REST: Representational State Transfer
SNMP: Simple Network Management Protocol

Fig. 1. MSF and Beluganos.



CLI: command line interface
ONF: Open Networking Foundation
ONOS: Open Network Operating System
TAI: Transponder Abstraction Interface
TAPI: Telephony Application Programming Interface
VPN: virtual private network

Fig. 2. Architecture of first PoC.

in controlling three different network OSs on white-box switches and controlling the open interface that is Netconf/Openconfig for Beluganos.

This PoC is supported by Edgecore Networks, ADVA, IP Infusion, and Infinera, as TIP members. Open community, Open and Disaggregated Transport Network (ODTN) in Open Networking Foundation (ONF), and the Metro-Haul project funded by European Union provided implementation and support in the field of optical disaggregation.

4. Future prospects

Through this PoC, NTT and Telefónica have started providing the feasibility of use cases required by the operators in CANDI. At the same time, they started a community to clarify the issues to be addressed for obtaining all the functions required by the use cases including scalability and operational issues.

NTT and Telefónica will continue to contribute to conducting enhanced PoCs twice a year in CANDI to prove such feasibility and find issues with developing the technology required to confirm the feasibility of operators' use cases. By maximizing the advantage of disaggregation technology and introducing the latest technology much earlier, NTT and Telefónica will contribute to avoiding vendor lock-in and enabling telecommunication networks with which people can use much more varied services faster.

Reference

[1] Website of NTT, "Telecom Infra Project has published the white-paper of the collaboration PoC among NTT, Telefónica and other operators,"
https://www.ntt.co.jp/topics_e/tip2019/index.html

Telefónica executive's comment

Endeavor to Develop Open and Intelligent Cloud-native Transport Networks

Óscar González de Dios
Telefónica I+D global CTO

In the past years, Telefónica has been upgrading its IP and optical transport networks in a series of transformation projects, internally named "FUSION", in order to deliver the transport requirements of the customers. However, the approach on fully relying on vendors' proprietary solutions has led to delays in introducing new functions and innovations. Moreover the interfaces among the Operational support systems have been proprietary, non-programmable and closed interfaces that prevent new applications from a rapid and automated introduction.

Telefónica is currently working on the full definition of Software Defined Transport Network model, named "iFUSION", as main pillar of the network transformations, which covers the SDN-based control for core, metro and backhaul network segments including IP/MPLS, optics and microwave technologies. In order to introduce the network softwarization principles effectively, Telefónica chooses the standard technologies, especially those that are more mature in the industry, for interfaces and service models.

On the other hand, while the fully aggregated model in optical networks is perfectly valid regarding its operation, it has prevented from quickly incorporating new transmission technologies from other vendors. In packet transport, hardware and software are currently coupled, so the capacity, features, and operation of the routers are tightly coupled. In that sense, Telefónica has an internal program, "openFUSION", to foster the partial disaggregation of optical networks and commoditizing IP routers into white boxes.

Telefónica has joined NTT to lead the CANDI initiative in an effort to foster openness in the Telco industry. The CANDI initiative in which NTT and Telefónica collaborate together with other operators is the perfect place to develop the solutions for an operator open network and drive the industry. With the PoCs, the CANDI initiative will continue to demonstrate the telco use cases with open standard interfaces, coordinated IP/Optical control and disaggregation.

NTT researcher's comment

Towards Flexible and Reliable Networks with Open Technologies

Minoru Yamaguchi
Transport Network Innovation Project,
NTT Network Service Systems Laboratories

NTT Network Service Systems Laboratories is researching and developing MSF and Beluganos and discloses them to achieve networks in which free choice and operation that meet operator requirements are possible as with server virtualization technology. These activities promote a highly flexible and reliable network. NTT's activities received approval from TIP, and a subgroup in which operators discuss use cases and architectures was established to drive disaggregation and open innovation. This was the first time we managed a community and conducted a PoC with carry-in equipment outside Japan. We conducted technical discussions with five operators and ran the secretariat in parallel. We also constructed an environment to conduct this PoC. We went to Telefónica Lab in Spain and built the environment in cooperation with Óscar and other participants. The PoC sometimes did not progress as expected because of time differences and language barriers as well as the circumstances of each company, but we could share common requirements and issues by organizing discussion items and roadmaps. We can interest many operators, vendors, and system integrators by spreading the results of this PoC as common requirements of operators, and we felt that our activities have great appeal. We would like to do our best for achieving flexible and reliable networks with open technologies by involving many people and working together.

For inquiries:
Public Relations Office, Planning Department,
NTT Information Network Laboratory Group
https://www.ntt.co.jp/news2019/1910e/191016b.html

External Awards

SG13 Fellow
Winner: Yoshinori Goto, NTT Network Technology Laboratories
Date: October 25, 2019
Organization: International Telecommunication Union - Telecommunication Standardization Sector (ITU-T) Study Group (SG) 13

Mr. Goto has served ITU-T SG13 for many years. He has been vice chairman of SG13 since he was elected at the World Telecommunication Standardization Assembly (WTSA) in 2012. Through his extraordinary commitment and expertise, he has been successfully managing Working Party 2 of SG13, which includes all activities of the SG related to cloud computing and big data. Furthermore, he has significantly supported the SG13 chairman in managing the SG by leading important ad hoc groups related to the preparation of SG13 for the next study period as well as in creating ITU-T Focus Groups under the partnership of SG13. He demonstrated his high managerial and negotiation skills when leading activities in SG13.

Certificate of Service
Winner: Seishi Takamura, NTT Media Intelligence Laboratories
Date: November 14, 2019
Organization: Picture Coding Symposium

For his contributions as an organizing committee member and session chair.

Network Slicing Implementation 2019 Award
Winner: Takuya Tojo, Hiroki Baba, Shiku Hirai, NTT Network Technology Laboratories; Soushirou Abe, Mitsuo Amasaka, Tomohiro Okada, Kazuto Toyozumi, Takayuki Nakamura, Masaya Nakouji, Aki Fukuda, Masashi Funada, Akira Matsuda, NTT Network Service Systems Laboratories, Yuuki Sakaue, Tatsuya Fukui, NTT Access Network Service Systems Laboratories
Date: November 21, 2019
Organization: MEF (Metro Ethernet Forum)

For "5G xHaul Sharing as Slices with LSO Orchestration."

Best Paper
Winner: Xiaoxi Zhang, Machiko Shinozuka, Yuriko Tanaka, NTT Network Technology Laboratories; Yuko Kanamori, Toshihiko Masui, National Institute for Environmental Studies
Date: November 27, 2019
Organization: The 11th International Symposium on Environmentally Conscious Design and Inverse Manufacturing (EcoDesign 2019)

For "Forecast of Future Impacts of Using ICT Services on GHG Emissions Reduction and GDP Growth in Japan."
Published as: X. Zhang, M. Shinozuka, Y. Tanaka, Y. Kanamori, and T. Masui, "Forecast of Future Impacts of Using ICT Services on GHG Emissions Reduction and GDP Growth in Japan," Proc. of EcoDesign 2019, pp. 88–95, Yokohama, Japan, Nov. 2019.

Best Paper Runner Up
Winner: Seishi Takamura, Media Intelligence Laboratories; Atsushi Shimizu, NTT TechnoCross Corporation
Date: November 27, 2019
Organization: 2019 IEEE International Conference on Visual Communications and Image Processing (VCIP 2019)

For "Water-bottom Video Coding Based on Coding-oriented Reference Frame Generation."
Published as: S. Takamura and A. Shimizu, "Water-bottom Video Coding Based on Coding-oriented Reference Frame Generation," Proc. of VCIP 2019, Sydney, Australia, Dec. 2019.

Best Research Paper Award
Winner: Ryo Ishizuka, Hironori Washizaki, Yoshiaki Fukazawa, Waseda University; Shinobu Saito, Saori Ouji, NTT Software Innovation Center
Date: December 14, 2019
Organization: The 10th International Workshop on Empirical Software Engineering in Practice (IWESEP 2019)

For "Categorizing and Visualizing Issue Tickets to Better Understand the Features Implemented in Existing Software Systems."
Published as: R. Ishizuka, H. Washizaki, Y. Fukazawa, S. Saito, and S. Ouji, "Categorizing and Visualizing Issue Tickets to Better Understand the Features Implemented in Existing Software Systems," Proc. of IWESEP 2019, Tokyo, Japan, Dec. 2019.

2019 IEICE Communications Society OCS Young Researchers Award
Winner: Hiroki Taniguchi, NTT Network Innovation Laboratories
Date: December 17, 2019
Organization: The Institute of Electronics, Information and Communication Engineers (IEICE) Communications Society Technical Committee on Optical Communication Systems (OCS)

For "255-Gb/s PAM-8 O-band Transmission Using MLSE Based on Nonlinear Channel Estimation with 20-GHz Bandwidth Limitation."
Published as: H. Taniguchi, S. Yamamoto, M. Nakamura, and Y. Kisaka, "255-Gb/s PAM-8 O-band Transmission Using MLSE Based on Nonlinear Channel Estimation with 20-GHz Bandwidth Limitation," IEICE Tech. Rep., Vol. 119, No. 93, OCS2019-18, pp. 43–46, June 2019.

IDW '19 Best Paper Award
Winner: Munekazu Date, Shinya Shimizu, Hideaki Kimata, NTT Media Intelligence Laboratories
Date: December 24, 2019
Organization: The 26th International Display Workshops (IDW '19)

For "Depth Range Control in Visually Equivalent Light Field 3D (VELF3D)."
Published as: M. Date, S. Shimizu, and H. Kimata, "Depth Range Control in Visually Equivalent Light Field 3D (VELF3D)," Proc. of IDW '19, Vol. 26, pp. 65–68, 3DSA3/3D3-1, Sapporo, Japan, Dec. 2019.

Papers Published in Technical Journals and Conference Proceedings

Maximum Entropy Method without False Peaks with Exact Numerical Equation

F. Ishiyama

Journal of Physics: Conference Series, Vol. 1438 (Proc. of CCISP 2019, Phuket, Thailand, Nov. 2019), 012031, January 2020.

The standard numerical maximum entropy method (MEM) still uses the Yule-Walker equation, which contains rough approximation by Walker. The commonly used numerical equation contains additional modifications to reduce calculation cost. We now have powerful computers, so there is no reason to use this modified equation. We argue that the drawbacks of MEM, such as false peaks and peak splitting, are from these modifications. They do not appear when using the exact numerical equation, even a given time series is fractional.

Verifying Commuting Quantum Computations via Fidelity Estimation of Weighted Graph States

M. Hayashi and Y. Takeuchi

Proc. of Quantum Information Processing Conference 2020, Shenzhen, China, January 2020.

We proposed methods for verifying whether a weighted graph state, which is a useful resource state for quantum computing, can be faithfully prepared. We also applied our methods to verify quantum supremacy demonstrations.