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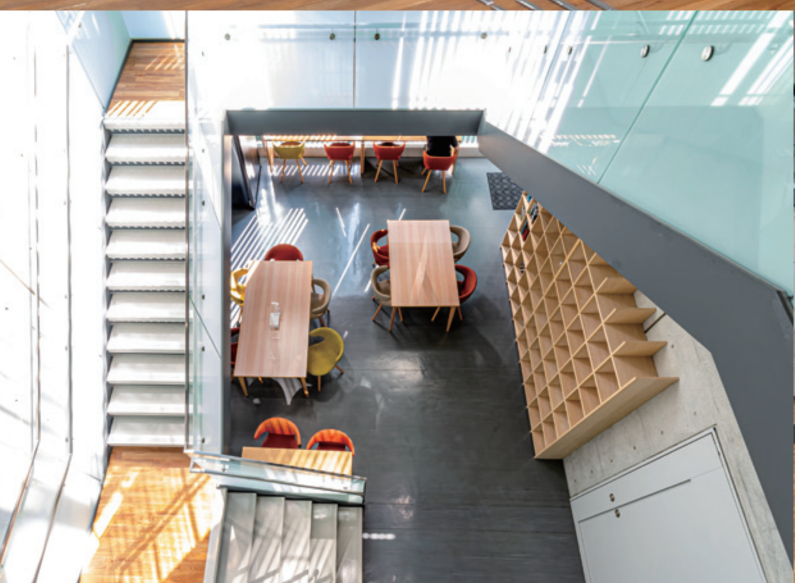
FEATURE

Toward the Development of the CiNet Brain

Interview

Realizing the Whole Brain in a Computer!



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Cover Photo:
(Top) CiNet's motto displayed in the first-floor hall
CiNet's first Director General, Prof. YANAGIDA Toshio, proposed CiNet's motto as "omoroi kenkyu" (unique and interesting research), urging researchers to advance "research that is not merely 'interesting,' but that inspires deep emotions." Current Director General Prof. KITAZAWA Shigeru is carrying on the spirit of his predecessor, under the slogan "more omoroi research from Osaka."

(Bottom Left) Open working space
This spacious and open multi-purpose working space with its high ceilings is located on the basement floor. Researchers are free to use this space in addition to their own labs for such purposes as studying materials and writing papers.

(Bottom Right) Discussion room

Upper left Photo:
Discussion room located next to the first floor lobby
The discussion room is available for CiNet members to engage in discussions together at any time. It is the venue for various interactions, including during daily coffee breaks or after special lectures. It is also used regularly for internal CiNet receptions and gatherings, where all people, regardless of rank, position or job can come together to exchange information.

Greetings for 2023

Message from the President

President of the National Institute of Information and Communications Technology
Dr. TOKUDA Hideyuki

The pandemic of COVID-19 continues beyond 2020 with no end in sight, and last year Russia's invasion of Ukraine led to global food and energy shortages and soaring prices. Also, the Ukrainian mobile phone base stations were destroyed, but many people were able to continue information transmission and administrative services via Starlink satellites. If we imagine a world where information from Ukraine was cut off and only one-sided information (fake news, etc.) was sent from Russia, the world would have been misunderstood. It was a year in which we once again recognized, the importance of the robustness and resilience of our country's information infrastructure, non-terrestrial networks, and national security.

Thus, the importance of ICT is becoming increasingly significant. Telework and hybrid communication using web conferencing, accelerated by the COVID-19 pandemic, are expected to realize a richer communication environment by utilizing metaverse, cybernetic avatars and digital twins. In addition to the communication field, environmental sensing and forecasting techniques such as the prediction of torrential rain, space weather forecasting technology that observes and predicts environmental changes in space, and increasingly applicable and sophisticated machine learning and AI technologies, the evolution of new ICT will expand our living space.

It is important to realize a society in which everyone can play an active role freely, free from temporal, spatial, and physical constraints, and in which social issues can be solved and economic development can be sustained.

As Japan's sole national research and development institution specializing in the field of ICT, NICT aims to promote the research and development of ICT through an integrated approach ranging from fundamental to applied research. At the same time, we will pursue collaborations with universities, industry, local governments, and domestic and overseas research institutions to return R&D results throughout society and foster innovation.

NICT's 5th Mid-to-Long Term Plan, which is now in progress, calls for a system that deals flexibly with social problems on a global scale and merges cyberspace and physical space. Our aim here is to create a human-centered sustainable and inclusive society known as safe and secure Society 5.0.

To this end, we are making steady progress in the four strategic research fields of Beyond 5G, AI, quantum ICT, and cybersecurity. In Beyond 5G, we are taking the lead in international activities toward technology development and standardization in such areas as terahertz communications, non-terrestrial networks, and space-time synchronization technology. We are also supporting more than 60 R&D projects in our Beyond 5G R&D Promotion Project. In AI, we are advancing steadily in a variety of fields including AI simultaneous interpretation as targeted by the Japanese government's Global Communication Plan 2025 (GCP 2025), the use of big data, and the merging of AI with the research of brain information communication. In quantum ICT, we are making great strides from joint field experiments with domestic and overseas collaborating institutions to actual applications. Finally, in cybersecurity, Cybersecurity Nexus activities are gaining momentum as an industry-government-academia hub for improving cybersecurity abilities within Japan based on data accumulated over many years and knowledge of human resource development.

At NICT, we are committed to promoting industry-government-academia collaborative activities and continuously expanding ICT while listening to the opinions of a wide range of citizens and cooperating or even competing on a friendly basis with domestic and overseas stakeholders. In this endeavor, I look forward to your continued support and cooperation.

In closing, I pray that this year will be a wonderful and enriching time for everyone. Please accept my heartfelt New Year's greetings.

Interview

Realizing the Whole Brain in a Computer!

Aiming to create a CiNet Brain with a "conscious mind" through the fusion of different fields

The Center for Information and Neural Networks (CiNet), operated jointly by NICT and Osaka University, is at the center of R&D efforts to create an artificial brain capable of seeing, hearing, and feeling, one that is possessed with empathy and able to understand humor. Researchers from almost every brain-related field, including brain science, information and communications technology (ICT), brain-machine interface (BMI), brain function measurement, and robotics, are all working together on this initiative. The ultimate aim is to create an artificial CiNet Brain with the same depth of feeling and empathy, or mind, as a human brain.

In this article, we talked to KITAZAWA Shigeru, Director General of CiNet, a leading institution in "whole brain science" research.

KITAZAWA Shigeru
Director General,
Center for Information and Neural Network (CiNet),
Advanced ICT Research Institute

After receiving his doctoral degree, he worked for National Institute of Advanced Industrial Science and Technology, and Juntendo University. Then he became professor at Graduate School of Frontier Biosciences, Osaka University in 2011. Current position from April 2022. Ph.D. (Medicine).

——You were appointed director general of CiNet in April this year. What was your motivation to start research in this field?

KITAZAWA In my student days, I studied physiology at medical school under Prof. ITO Masao, who was famous for his cerebellar research. At that time, working in the Faculty of Engineering of the same university was Prof. AMARI Shunichi, who had formulated a methodology known as backpropagation that is widely used in neural networks. In the Faculty of Pharmaceutical Sciences, Prof. SHIMIZU Hiroshi had proposed the concept of bioholonics, which posits that structure is self-organized in the field of life.

It being a time when tremendous advances were being made in brain science and AI, I became interested in the mechanism by which the brain understands language and why consciousness emerges. I began my brain science research with the idea of trying to see if it was possible to model the entire function of the brain in a simple way.

In 1991, I became an assistant professor at the Faculty of Medicine of the University of Tokyo and from 1994, I joined the Electrotechnical Laboratory (currently the National Institute of Advanced Industrial Science and Technology). The research I started then was on "optimization of reaching movements with the hand." When we examined acceleration of hand movements, we found that these movements were actually optimized in terms of physics-based principles.

Next, I began research on perception of time and space, which is still ongoing. One of the problems relating to spatial awareness is known as the saccadic problem. The eyeballs are always moving rapidly at a rate of about three times per second, but somehow the image that the eye sees always appears to be stationary without any shakiness. This problem had already been addressed in the 10th century by Arabian philosopher Ibn al-Haytham, and was subsequently also observed by Descartes and Helmholtz.

We don't pay any attention to the problem in our daily lives, but I thought that there must be something deeper behind the phenomenon. These problems led me to pursue a career in brain science research.

A Researcher-first Research Environment

——Having joined CiNet, do you find any difference from universities?

KITAZAWA What makes CiNet different from universities is its finances. For example, CiNet has a total of four functional magnetic resonance imaging (fMRI) machines for research purposes and magnetoencephalography (MEG) equipment, and it is rare for universities in Japan to have such equipment. In addition to the outstanding research facilities, CiNet also has dedicated technicians who can operate and maintain the highly specialized equipment, enabling researchers to concentrate purely on their research. At universities, maintenance work is usually left to young assistant professors, who have to sacrifice their research time to do it.

Another key point, which may seem to be not directly related to research, is the inclusion of a discussion room next to the first-floor lobby area. It's a great place for researchers from different fields to come together and interact with one another when they are temporarily able to step away from their experiments. I believe that such a space can inspire many different ideas and insights.

At CiNet, there are researchers from various brain science-related fields. In addition to researchers in neuroscience, ICT, BMI, sensing, imaging, and robotics, there are also psychology and philosophy researchers involved, meaning that we are truly a diverse collection of researchers from various fields.

My predecessor, Prof. YANAGIDA Toshio, proposed the concept of "omoroi" (meaning "unique and interesting") research, and my aim is to add just one word to that concept: "motto" (meaning "more") "omoroi" research. To borrow Prof. Yanagida's words, "omoroi" research is something profound that "seems to well up from the bottom of your heart and shake you to your core." It is very important for each and every researcher to continue with research they believe to be "omoroi." If it is truly "omoroi," the research will continue to grow and expand.

——What is CiNet aiming to achieve?

KITAZAWA American mathematician and "father of information theory" Claude Shannon wrote in A Mathematical Theory of Communication, his famous paper published in 1948, that "…semantic aspects of communication are irrelevant to the engineering problem." As soon as you turn information into a digital quantity, it loses its meaning. Feelings and emotions such as pain, sadness, and happiness can only be expressed in the form of a numeric symbol.

The conversion of information into symbols has greatly improved computing technologies and made our lives more convenient, but in order to realize an AI with a conscious and empathetic mind, we must restore the "meaning" of information. It is only after the original meaning is restored that information can make any emotional connection with people.

CiNet Brain, an AGI with a Human Mind

——It is said that artificial intelligence (AI) might exceed the capacity of the human brain. What are your thoughts on this?

KITAZAWA There is a great deal of attention being focused on when AI will surpass human capabilities. In some specific areas, like shogi and go, AI has already exceeded human capabilities, and even professional shogi players cannot beat AI. Many professionals refer to the moves of AI to improve their abilities. In the field of medicine too, AI is far more accurate and quicker at finding anomalies than doctors.

So, what makes AI different to humans? Even though AI is now better than humans at shogi and go, it finds no enjoyment in playing these games. Neither is it the case that AI performs diagnostic imaging out of a noble sense of mission to cure disease.

This is where CiNet Brain comes in, which is the research project that we are working on. CiNet Brain is an artificial general intelligence (AGI) that possesses the ability to think for itself and have emotions or, in other words, to have a human mind. It is an AI that is capable of thinking not just about itself, but about the entire environment around it, and possesses a social consciousness.

In order to realize such intelligence with a conscious mind, AI also needs to have a body. A newborn baby without any knowledge of the world starts exploration first by crawling, and remembers physical experiences, such as the sensation of pain when bumping into things, or the warmth of its mother's skin.

However, even though AI might be able to list many types and examples of pain, it cannot sense pain itself. I want to create an AI with qualia (subjective, conscious experiences) that can physically experience the world. That is CiNet Brain.

Challenges beyond Technical issues

——Might people not fear an intelligence that surpasses human capabilities?

KITAZAWA It is important for CiNet Brain to be friendly enough and trustworthy enough not to cause fear. We want to be open and considerate when explaining to society what we do.

ELSI is an acronym that stands for ethical, legal, and social issues. It refers to the non-technical challenges that we must strive to overcome when introducing new science and technology in society.

In that sense, insights from philosophy are vitally important in developing AI. How the mind resides in the brain has been a major issue for philosophy since the time of Descartes. Regarding ELSI, we believe that not only consideration of ethical aspects, but also research that integrates philosophy will be necessary.

—— What do you expect from CiNet researchers?

KITAZAWA Each of us must find an "omoroi" research theme and research it deeply. This is the key. If you continue to conduct "omoroi" research that shakes you to your core, it will surely be accepted around the world. If you do good research, you will attract young people. To achieve this, I think it is important to continue to conduct and disseminate research that moves young people.

CiNet Brain combines all functions of the human brain. Since the brain develops with all of the elements that humans possess, including motor skills, social skills, cognition, and ethics, any research that is related to the brain will help to realize CiNet Brain. That is why we need the cooperation of researchers from many different fields and disciplines.

——What are your ambitions for the future.

KITAZAWA My goal is to realize an AI, CiNet Brain with a mind. If our mind resides in our brains, I believe that CiNet Brain should also have a mind. It is a difficult task, but I hope to realize CiNet Brain within ten years.

Roundtable Talk among Young CiNet Researchers

Our Visions for the CiNet Brain

What is the research life for CiNet researchers, who lead the brain science in Japan? We interviewed three young researchers.

PROFILE

Moderator

KASHIOKA Hideki, Managing Director, Knows CiNet from past to present

KAIJU Taro, Researcher, Develops BMI system

SHIBUSAWA Shuka, Researcher, Measures brain activities using MEG

OKUMURA Toshiki, Researcher, Studies brain functions related to smells

KASHIOKA We are holding this roundtable discussion to ask young researchers who are actively engaged in their research about their image and impressions of CiNet. Let's kick off by hearing from each of you about your own research.

KAIJU I'm studying the brain-machine interface (BMI), which extracts brain activity in the form of signals and uses these to operate assistive devices such as a robotic hand just by thinking. Brain activity is basically the electrical activity of the neurons, but as the signals are very weak, it is extremely difficult to precisely measure them externally. We are working to develop very high-definition electrodes for stable and reliable recording of these weak activities. We are also developing more effective signal decoding methods in order to better understand the intentions of a user from their brain activity.

SHIBUSAWA I'm doing researches using an MEG (Magnetoencephalography). MEG is a device which measures weak brain magnetic fields generated by neuronal electrical activities. However, the magnetic field is extremely weak, less than one 100 millionth of geomagnetism (which is 46 microtesla in the vicinity of Tokyo), so MEG is required to measure in a magnetically-shielded room. MEG is a non-invasive method that can be measured on the scalp and features high temporal resolution in the millisecond level.

I am investigating how visual, auditory, and other stimuli affect brain rhythms, such as alpha oscillations, and developing the method for expanding human brain functions.

OKUMURA I'm studying the relationship between the sense of smell and brain function using functional magnetic resonance imaging (fMRI). One of the advantages of fMRI is that it has higher spatial resolution than other non-invasive neuroimaging techniques. In particular, using ultra-high fields (UHF) fMRI, it is possible to measure the brain activity and structure in fine detail.

UHF fMRI can detect differences even among the six layers of the cerebral cortex. Even so, measuring the activity in olfactory areas is challenging due to the poor signal-to-noise (SN) ratio.

Through my research, I aim to measure in detail what areas of the brain are activated when we smell something, and to examine cross-modal processing (related to different sensory information being mutually influenced and recognized).

Appeal of CiNet

KASHIOKA You are all using fMRI and MEG in your research. What do you consider to be the advantages of the research environment at CiNet?

SHIBUSAWA MEG is used mainly in the medical field and limited in research field due to difficulties in maintenance and management. However, in CiNet, as the research technical staffs who has advanced knowledge about operation and maintenance supports us even no previous experience about MEG, we can use it with confidence.

OKUMURA I feel completely the same. Besides that, at CiNet, since there is one 7-tesla fMRI machine and three 3-tesla fMRI machines, I feel that there are few scheduling conflicts among researchers. I think having such research environment is one of CiNet's appealing points.

KAIJU I particularly appreciate the fact that there are so many researchers with a wealth of experience so close by. One of the appeals for me is that in open spaces like the cafeteria, I can engage in communication with researchers from diverse fields. I believe that this open and refreshing environment, coupled with the stimulation of encountering novel ideas that I have not considered before, will lead to new advances in my own research.

What led you to study brain science?

KASHIOKA What was it that led each of you to want to study brain science?

SHIBUSAWA When I was in high school, I chose a university where I could major in brain science. However, there was just one lab involved in brain science. At CiNet, everyone is working on brain science, which is why I like it so much.

OKUMURA Previously I was in the faculty of agriculture at university to study human brain function. Around that time, I came to CiNet to do joint research. It made me realize I could devote myself to brain research if I stayed at CiNet.

KAIJU Another good point is that CiNet is on the campus of Osaka University, meaning that it is easy to interact with the teaching staff of the university. I had determined that if I was going to study brain science, CiNet would be the best place to do it.

How does your research link to the CiNet Brain project?

KASHIOKA What are your thoughts on the realization of CiNet Brain, the modelling of the entire human brain that CiNet hopes to achieve?

SHIBUSAWA I currently research how we can approach individual differences in human brain activity. I am interested in how such individual differences could be reflected in CiNet Brain.

OKUMURA I also think that investigating individual differences is a challenge. Olfactory perception varies from person to person, and different people would feel the same odor differently. This difference among individuals seems to be greater for olfaction than for sight and hearing, so one of my future research themes will be how to consider such individual differences into the model of the entire human brain.

KAIJU My aim is to create a neural sensor that will measure the brain in fine detail, so that we can read out everything about the brain, including individual differences. My understanding of CiNet Brain's approach is to first thoroughly examine the entire brain, and then create a brain simulator on a computer in the second step. Is that interpretation right?

KASHIOKA Yes, that's right. Firstly, we aim to take a detailed look at the various functions of individual parts of the brain and then, as a second step, connect these detailed functions at a more advanced level. Next, we will look at what activities are going on at the whole-brain level. Our image for the completed CiNet Brain could be likened to a flood disaster, where rather than just accurately reading information about how many houses have been washed away by watching a video of the damage, it is possible to monitor the entire situation and how it unfolds, and combine this with common sense in making a decision to "go and help."

I hope that in about ten years from now, all the knowledge gained from your research will have been integrated to realize CiNet Brain.

Challenges of research life at CiNet

KASHIOKA Until now, we've focused on the positive aspects of CiNet, but are there any areas that you think could be improved?

OKUMURA There are too many administrative procedures relating to research. I understand the need for checks of course, but even when purchasing something small that is needed for research purposes, we have to do so much admin.

SHIBUSAWA I am a first-year researcher, and I feel that there are very few senior female researchers who can act as role models for my career. I expect that by encouraging current young and mid-career female researchers to play an active role, we can create a better environment for the next generation.

KASHIOKA Yes, the proportion of female researchers at CiNet is not very large, is it?

SHIBUSAWA Only a few of the principal investigators (PIs) are women. In order to enable women to continue their research with peace of mind as they have life events such as marriage and childbirth, CiNet needs to create systems that make it easier for women to build their careers.

KAIJU For researchers, if there are any gaps in their cycle of producing research papers, it can affect career advancement, and this also makes it difficult for male researchers to take childcare leave. We need to make it easier for male researchers to get involved in caring for their children.

Dreams and outlook for the future

KASHIOKA What are your expectations of CiNet and your dreams for the future?

SHIBUSAWA When developing new technologies, it is imperative to consider safety aspects. There are professionals for safety assessment at NICT, and I hope that we can realize even more advanced research, while continuing to fulfil various safety requirements.

KAIJU In invasive BMI research, researchers need to be extremely careful about assessing safety aspects. At the same time, Osaka university has a wide range of research departments, so one of CiNet's strengths is that it can draw on the advice of many such experts in various fields. I hope to continue my research with the guidance and support of Osaka University faculty members.

OKUMURA With physical phenomena, it is possible to make the margin of error smaller and smaller and ultimately create a mathematical formula. With life phenomena, however, although they can be understood statistically and probabilistically, it is no simple matter to convert them into a mathematical formula like physical phenomena. My research dream is to describe life phenomena mathematically without any errors.

KASHIOKA That's a dream very close to the vision for CiNet Brain. I would like to thank all of you for joining in this discussion today. Let's all work together towards our common goal of realizing CiNet Brain.

Human Performance Improvement Project

Improving Brain Function in Older Adults to Enhance Their Motor and Cognitive Functions

NAITO Eiichi

Director of Brain Networks and Communication Laboratory, Center for Information and Neural Networks (CiNet), Advanced ICT Research Institute

After finishing graduate school, he worked as an assistant professor at Kyoto University and a senior researcher at Advanced Telecommunications Research Institute International before joining NICT in 2011. 2021-present, he is engaged in research on human sensory and motor functions using MRI. He is an invited professor at the Graduate School of Frontier Biosciences, Osaka University. PhD (Human and Environmental Studies).

In Japan, the population is aging at a rate unparalleled in other countries. The desire to enjoy an active life with a healthy brain and body is common to all people, but it is inevitable that brain and body functions deteriorate as we age. However, these functions can be improved through training. Here, we show that training can improve the decline in the inhibitory function of the nervous system typically seen in the brains of older adults and improve their motor function.

■Background

Currently, in Japan, the percentage of the total population aged 65 and over is approaching 30%, the highest in the world, and this percentage is expected to continue to increase in the future. While the desire to remain healthy and enjoy life as we age is common to many people, it is also true that brain and body functions decline with age. However, this phenomenon is by no means irreversible, and these functions can be improved through training. Understanding the exact causes of the decline in brain and body functions of older adults and improving these functions is an important issue in our super-aging society. Our group at the Center for Information and Neural Networks is developing a human performance improvement project that focuses on motor and cognitive functions, clarifies the causes of these functional declines, and aims to improve these functions.

■Functional Decline in Inhibitory Systems in the Brains of Older Adults

For the brain to function properly, the balance between excitation and inhibition in the nervous system is extremely important. Inhibition is essential for the brain system to operate in an orderly and rule-based manner. When we measure brain activity with functional magnetic resonance imaging (MRI) while a person is performing a task, in addition to brain activity called the positive blood oxygenation-level dependent (BOLD) signal, we can also measure the inhibition of brain activity called the negative BOLD signal. For example, when a person is processing visual information, the brain inhibits the auditory cortex, which is not needed for this, and likewise inhibits the visual cortex during auditory information processing. This type of inhibition is called cross-modal inhibition and is thought to be a mechanism by which a person inhibits other sensory areas in order to concentrate on processing information for one sense.

Such an inhibitory mechanism also exists in the motor cortex, which is located in the left and right cerebral hemispheres. This is an interhemispheric inhibitory mechanism mediated by nerve fibers called the corpus callosum, which connects the left and right motor cortices. In general, hand movements are "primarily" controlled by the contralateral motor cortex. Interhemispheric inhibition is a neural mechanism that inhibits the right motor cortex to prevent unintended movements of the left hand while the right hand is moving, for example.

Functional MRI of young adults during a simple right-hand sensory-motor task shows increased activity in the contralateral (left) motor cortex and decreased activity (inhibition) in the ipsilateral (right) motor cortex. This inhibition is thought to be due to interhemispheric inhibition from the left motor cortex to the right motor cortex. On the other hand, when brain activity was measured in older adults of over 65 years in age, it was found that this inhibition disappeared in approximately 60% of these older adults (Figure 1). It has also been found that the cross-modal inhibition described above also is reduced or has disappeared in many older people. Although there are other inhibitory mechanisms in the brain besides the cross-modal and interhemispheric inhibitions, it seems that the inhibitory function in the aging brain has generally deteriorated.

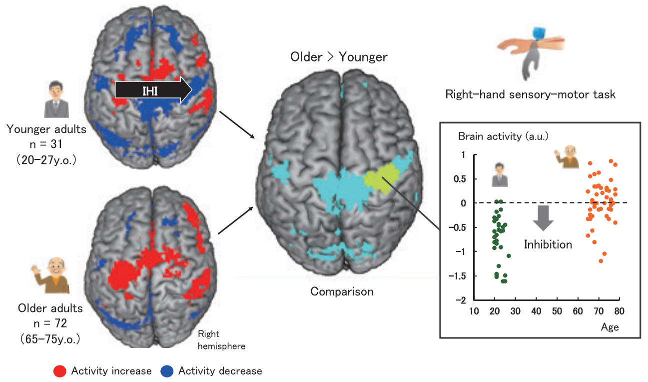


Figure 1 Deterioration of interhemispheric inhibition (IHI) in older adults

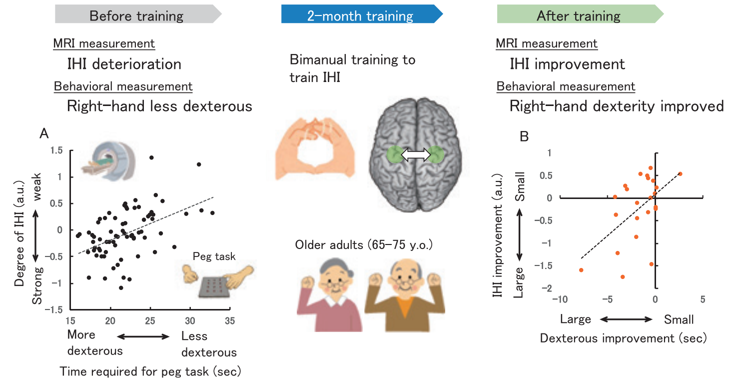


Figure 2 Bimanual training improves interhemispheric inhibition (IHI) and hand dexterity

■Bimanual Coordination Training Reactivates Inter-hemispheric Inhibition and Improves Hand Dexterity

Using the abovementioned right-hand sensory-motor task (Figure 1), further investigation of interhemispheric inhibition in older adults revealed that older individuals with reduced or lost interhemispheric inhibition from the left motor cortex to the right motor cortex were less dexterous with their right-hand fingers (Figure 2A). In this study, hand dexterity was assessed by a test called the peg task. The task involved removing one peg at a time from a board with pegs stuck in it, rotating it, and returning it to its original hole. Dexterity was assessed by the time it took to complete this for all 12 pegs (time required for peg task). It is said that the dexterity of a hand is mainly achieved through control by the contralateral motor cortex. If the ipsilateral motor cortex becomes involved in the control of movements as a result of reduced interhemispheric inhibition, this activity interferes with the precise control by the contralateral motor cortex, and this may be the cause of the reduced dexterity. If the decline of interhemispheric inhibition is one of the causes of deterioration of hand dexterity, then if interhemispheric inhibition can be reactivated by training, hand dexterity can be expected to improve as well.

Therefore, we examined this effect by dividing right-handed healthy older participants aged 65-75 into two groups and training them for two months. In the 2-month training, one group was designated as the bimanual group and the other group as the right-hand group. Before the training, there were no differences in hand dexterity or interhemispheric inhibition between the two groups. The bimanual group underwent coordination training in which different movements were performed simultaneously with the left and right fingers (Figure 2 middle panel). This training required the left and right motor cortices to control each hand independently and was expected to train interhemispheric inhibition effectively. The right-hand group trained only the right hand.

During the training, both groups did not receive any training on the peg task itself. However, after the training, the bimanual group showed improved hand dexterity. On the other hand, no such improvement was observed in the right-hand group. Further analysis revealed that in the bimanual group only, hand dexterity was more improved in older participants who showed better improvement in interhemispheric inhibition assessed in the right-hand sensory-motor task after training compared to before training (Figure 2B). In other words, bilateral hand-finger coordination training effectively improved ipsilateral motor cortex inhibition (interhemispheric inhibition) in older adults with reduced inhibitory function, and improved their right-hand finger dexterity. This research was conducted in collaboration with a sporting goods manufacturer, and the results are currently being applied to an exercise program that the company is developing in society for improving the motor function of older people.

■Future Prospects

The results presented here show that the age-related decline in inhibitory function is not irreversible and can be improved through training, and that improvement of this inhibitory mechanism can also lead to improved behavior. While conventional brain training has focused on activating the brain, we have shown for the first time that brain function can be improved by improving the inhibitory mechanisms of the brain. In the future, we intend to develop training programs that target the declined inhibition found in other brain regions, and while verifying their effectiveness, we aim to propose training programs that can improve interlimb (hand and foot) coordination and the ability to perform cognitive and motor tasks simultaneously, which are required in situations such as driving a car.

7T-MRI Scanner that Measures Brain Activity with High Resolution

KIDA Ikuhiro

Associate Director of Brain Function Analysis and Imaging Laboratory, Center for Information and Neural Networks (CiNet), Advanced ICT Research Institute

After completing his doctoral course, he worked at Yale University for 6 and half years. He moved to Hokkaido University ,then worked at Tokyo Metropolitan Institute of Medical Science. He joined NICT in 2012. Ph.D.(Science)

WADA Atsushi

Senior Researcher, Brain Function Analysis and Imaging Laboratory, Center for Information and Neural Networks (CiNet), Advanced ICT Research Institute

After completing master course, he worked as a researcher in ATR. He joined NICT in 2009. He has been engaging in AI, neuroimaging, visual neuroscience, etc. Ph.D.(Informatics)

KASHIOKA Hideki

Managing Director, Center for Information and Neural Networks (CiNet), Advanced ICT Research Institute

After completing his doctoral course, he worked at ATR. He joined NICT in 2006. He engaged in research of Machine translation. Ph.D.(Engineering).

The Center for Information and Neural Networks (CiNet) is measuring brain activity in high resolution, storing the vast quantities of data that are generated, and analyzing these data with the aim of realizing next-generation artificial intelligence technologies utilizing brain information. Such research activities require the installation of 7T-MRI systems for high-resolution measurement of brain activity, as well as the construction of brain-information data storage and processing infrastructure for storing and analyzing brain-activity data. It is now 10 years since research facilities were first opened in the central research building in 2013, and work is underway to update the existing devices and machines in order to achieve further breakthroughs. This article introduces the features and utilization methods of the various devices and machines that are being updated.

7T-MRI Equipment Measures Brain Activity in High Resolution

In recent years, the ultra-high field MRI landscape has changed significantly. Some 7T-MRI scanners for human use (the MAGNETOM Terra by Siemens Healthcare in 2017, and the SIGNA 7.0T MRI by GE Healthcare in 2020) have been granted a CE mark in Europe and certification by the U.S. Food and Drug Administration. Although examinations are currently limited to the head and limbs only, these scanners are becoming more actively utilized in clinical testing in Europe and the U.S. The new MR scanner that will be introduced at CiNet is the MAGNETOM Terra (Figure 1) by Siemens Healthcare, which received approval in 2017. As it has yet to be approved under the Pharmaceutical and Medical Devices Act in Japan, initially, it will be used solely for research. There are 37 of these scanners globally, with confirmed plans for 10 new scanners (as of October 2022). CiNet will be the first institution in Japan to introduce such a scanner. The information contained in this article is therefore not based on actual experience of using the scanner, but on information provided by Siemens Healthcare.

MR Scanner

The new 7T-MRI system is more compact than earlier models, with a length of 3 m (magnet: 2.8 m), compared to 3.8 m (magnet: 3.3 m) for the old equipment. The old system was large enough to fit the entire human body into the magnet for head imaging, but the new system fits up to the subject's knees. In comparison, the 3T-MRI system is even smaller, with the subject's entire lower body protruding from the magnet. Besides the size, the new system is also much lighter, weighing in at less than 20 tons compared to the previous system's weight of more than 40 tons. This reduced weight allows for the system to be transported via temperature-controlled air freight in less than 24 hours, rather than being shipped by sea, which used to take several months. This significantly shortens installation time, including setting up the magnet. Despite its smaller size and weight, the new system features various new technologies. The magnet features an active shield that reduces magnetic field leakage through the placement of a coil in the opposite direction to the coil that generates the static magnetic field. Combined with the existing iron magnetic shield, this will narrow the 5-gauss leakage field that used to extend almost up to the door of the operations room (approx. 11 m). However, as in the past, caution still needs to be taken over bringing in magnetized items. The system also features "zero helium boil-off technology," which eliminates the need for liquid helium to cool the superconducting magnet, in turn reducing operating costs.

MRI Coil

The head coil is engineered for 8-channel parallel transmission of RF pulses in the research imaging mode, as well as single transmission in the normal imaging mode, in conjunction with the 32-channel receiver coil. On the old system, switching between imaging modes would take at least 10 minutes, but with the new system, switching now takes just a few minutes. A multiple-array

Figure 1 New 7T-MRI machine to be Installed *Provided by Siemens Healthcare*

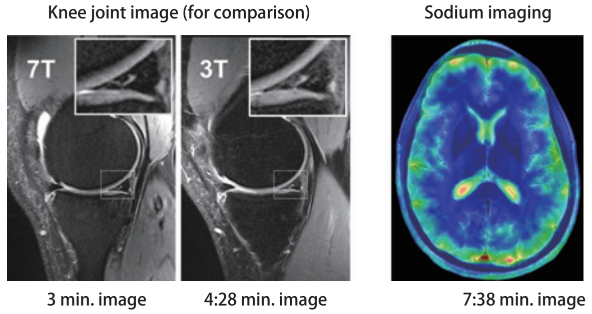


Figure 2 7T MR imaging *Provided by Siemens Healthcare*

coil on the receiving side is important for parallel imaging techniques and can reduce scan time, while parallel transmission techniques are effective against uneven image intensity due to shortened transmission pulses arising from increased strength in the magnetic field. The new system can handle up to 16-ch transmission / 64-ch receiving coils. In addition to the head coil, the new system also features a 1-ch transmission / 28-ch receiving coil capable of imaging knee joints and limbs. As limbs are not as large as the head, even with a single transmission, an even image equivalent to 3T-MRI can be obtained, and the increased magnetic field strength makes high-resolution imaging possible (Figure 2 (left)). The two coils target protons, a commonly-used MR imaging technique, and a loop coil (1-ch transmission / 1-ch receiving) targeting phosphorus (^{31}P) and a head-coil with 1-ch transmission / 32-ch receiving for sodium imaging (^{23}Na) are also being introduced on the new system. The ^{31}P coil can obtain information on cellular metabolism, while the ^{23}Na coil enables images of sodium to be captured, which is present in extracellular fluid and plays a role in maintaining homeostasis (Figure 2 (right)).

Peripheral Equipment

A clip-on-camera (by Skope) capable of measuring fluctuations in the magnetic field will also be installed. The magnetic field fluctuates due to body movements such as the subject's breathing and pulse, as well as system operations (eddy currents, mechanical vibrations). When conducting measurements over a long period of time, fluctuations in the magnetic field can degrade image quality and result in artifacts during measurement. The clip-on-camera makes it possible to directly measure both long-term and short-term magnetic field fluctuations directly. By using that information in image reconstruction processing, it is possible to reduce image distortion and ghosting, and improve signal-to-noise ratio. In addition, the new system will also include a 32-ch electroencephalograph compatible with ultra-high field MRI and video display goggles, and headphones set with eye movement measurement for stimulation.

Construction of Brain-Information Data Storage and Processing Infrastructure

CiNet is constantly amassing vast quantities of brain-measurement data, using high-performance, large-scale brain measurement devices (4 MRI and 1 MEG). By accumulating this vast amount of brain data and applying large-scale data analysis, we are investigating brain mechanisms, including perception, cognition, emotion, decision-making, motor control, social behavior, and language. Based on these understandings, we accelerate the development of novel neurotechnologies such as brain-information decoding and brain-based artificial intelligence (AI). For this aim, we will introduce a new petabyte-scale storage system for massive brain-measurement data and a high-performance computing cluster for large-scale brain data analysis. The features of these systems are detailed below.

Brain-data storage

Aiming to accumulate the vast quantities of MRI and MEG data collected at CiNet, we are introducing a large-scale storage system with an effective capacity of 20 petabytes. We have adopted decentralized storage architecture, which enables both effective data protection of valuable brain-measurement data and the high access performance required for large-scale data analysis. The use of Lustre, a parallel file system with a proven track record in high-performance computing, realizes high-speed connectivity between storage systems and computer servers (up to 200 Gbps between each node) via dedicated interconnects. This configuration enables multiple computation processes running simultaneously across different computing nodes to access large-scale data. We have additionally introduced an all-flash storage (effective capacity of 470 terabytes) consisting solely of solid-state drives (SSDs), which allows for data processing with high-frequency access (high input/output operations per second (IOPS)). The introduction of these two types of storage for brain-measurement data realizes a distinct data storage environment capable of performing, in parallel, multiple brain-data analyses with different data sizes and access patterns.

Brain-data analysis computing cluster

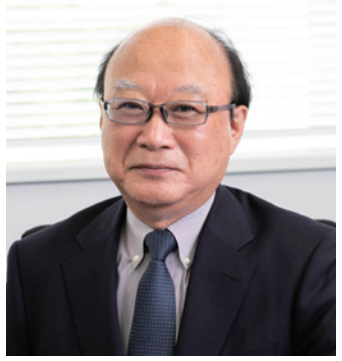
We are constructing a high-performance computing cluster capable of large-scale brain data analysis. We have introduced 16 general-purpose computing servers equipped with large memory capacity (4TB/unit) and 10 GPU servers (8 with 1 GPU and 2 with 8 GPUs) equipped with the latest high-performance GPGPU (NVIDIA A100). They are connected to the brain-data storage system via the abovementioned dedicated interconnects to achieve high-speed node-to-node data access. This configuration provides a high-performance computing environment that meets the computational requirements for brain-ICT research on a larger scale, including functional and structure analyses of the brain using large volumes of brain-measurement data, AI model construction that requires high-load GPGPU computation, and modeling of brain-information representation with large-scale matrix calculations that require large volumes of memory.

Future Prospects

In the new 7T-MRI system, the multi-transmission technologies and clip-on-camera technology will enable improvements in ultra-high field MRI performance. In addition, in the brain-information data storage and processing infrastructure that will be constructed, we will prepare an environment that enables the efficient storage and processing of such data. By taking full advantage of these various systems, we aim to further advance human brain function research from high-resolution brain-activity measurement.

ELSI Studies of CiNet Brain Social Implementation

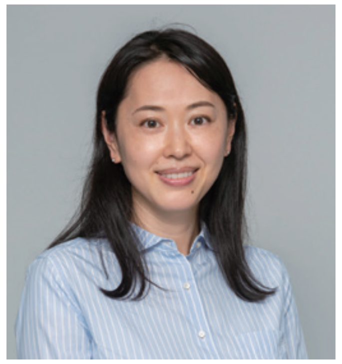
Towards Increased Social Acceptance of Brain Information and Communication Technology



TAGUCHI Takahisa

Associate Director General, Center for Information and Neural Network (CiNet), Advanced ICT Research Institute

He joined NICT in 2013. Before coming to NICT, he worked at Institut Pasteur, Osaka University, AIST as a researcher in neuroscience. In CiNet, he is working as associate director general. Ph.D. (Engineering).



NISHITSUTSUMI Yu

Researcher, Center for Information and Neural Network (CiNet), Advanced ICT Research Institute

She joined NICT in 2022. Before coming to NICT, she worked at University of Tokyo as a project assistant professor. Her research concerns ethical aspects of neuroscience. Ph.D. (Philosophy).

During the 10 years since its establishment, the Center for Information and Neural Networks (CiNet) has achieved a diverse range of research outcomes, in all fields from basic to applied research, which are helping to link research on human brain functions to innovative ICT applications.*1 NICT's Medium-to-Long-term Plan (FY2021-2025) sets out targets to advance research that will lead to the construction of CiNet Brain (Figure 1), a model that comprises the entire information-processing capabilities of the human brain, and also to promote industry-academia-government collaboration that will help to boost social acceptance of R&D outcomes, and promote social implementation.

CiNet's Goal of Open Innovation

At CiNet, we have been working actively to promote understanding of our research outcomes, not only in the specialist researcher community, but also more broadly within society. In so doing, our aim is to attract the interest of people in various industries, which will lead to a diversity of joint research initiatives. We do not limit ourselves to a linear approach that starts with basic research before moving on to applied and practical research. Rather, by disclosing and sharing information at various levels, we work to create a structure capable of responding to corporate needs at different stages. This is how open innovation at CiNet works. Moreover, our collaborations are not limited to universities and research institutions. Instead, we focus on broad social needs and issues, with the aim of ensuring that our research outcomes can be rapidly implemented in society.

Among our various research initiatives, the development of human perceptual information estimation technology, which combines internal brain information processing and AI, is one advanced initiative that has reached the practical application phase. As shown in Figure 2, we show a video of nature to a subject in a functional magnetic resonance imaging (fMRI) machine, collect vast amounts of information on their brain activity as they watch the video, and construct a decoding model from that information. We also construct an encoding model capable of predicting brain activity from the information input into a subject. Using these two models, we have created a system capable of predicting, to some extent, what the subject sees and feels in response to audiovisual input information. This technology has already been used in commercial services, and shows great promise for future development, which is why it was featured in the Cabinet Office's Public/Private R&D Investment Strategic Expansion Program (PRISM), which aims to accelerate social implementation.

ELSI Considerations in PRISM

Under the PRISM Program, various perceptual information estimation models based on human brain activity information are being created, and work is being advanced in both the public and private sectors to develop an environment where it is possible to utilize brain activity data in a broad range of business scenarios (Figure 3). We are considering the ethical, legal, and social implications (ELSI) of these estimation models, so that they can be used with peace of mind by companies, and also by the consumers who are their customers. Within PRISM, we have organized a study group and invited not only experts in this field, but also researchers in the humanities, as well as representatives of government and business, to participate in and deepen discussions. In FY2023, we plan to compile guidelines for the industrial applications of these estimation models.

At the same time as we started to consider ELSI under PRISM, we also formed a group in CiNet to study ELSI in the context of brain ICT research. This group has started philosophical and ethical investigations not only about the brain AI models being advanced by PRISM, but also about research into CiNet Brain in general, and is promoting research to make CiNet Brain a comprehensive model. These considerations are, out of necessity, broad in nature and are being conducted in collaboration with external researchers (in particular those from the Osaka University Research Center on ELSI).

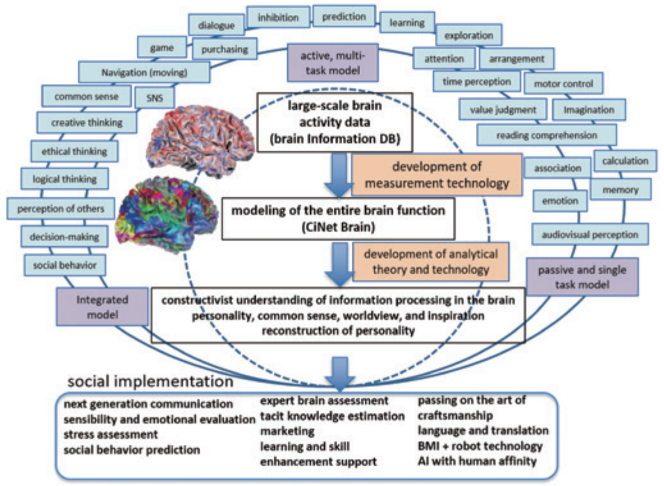


Figure 1 CiNet Brain Model of the entire brain

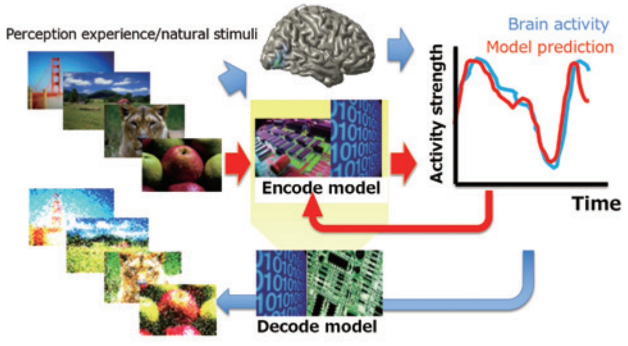


Figure 2 Conceptual diagram for construction of an encoding model for audiovisual information processing by natural audiovisual stimuli and reconstruction of input information using a decoding model

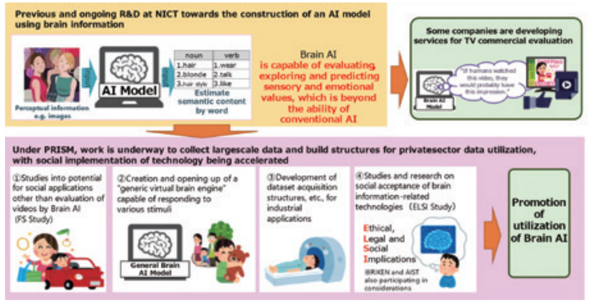


Figure 3 Overview of PRISM Project

Brain Information Research from a Philosophical Perspective

Neuroethics*2 is the study of ELSI in neuroscience. It focuses particularly on the ethical aspects of ELSI and explores ways to resolve various issues related to what it is that makes humans "human," including personality, identity, agency, authenticity, and autonomy. The various questions that neuroscience is helping to clarify have the potential to profoundly impact such matters relating to human nature.

As noted above, at CiNet, we are implementing a wide variety of research projects with a view to constructing CiNet Brain. These projects cover many areas, including systems neuroscience and brain-machine interface (BMI) research, and the fusion of brain science and ICT. All of these research fields have various ELSI. From an ethical standpoint, the issues with brain measurement by devices such as fMRI and electroencephalography (EEG) relate mainly to mindreading and privacy, whereas with BMI, they include human enhancement and manipulation by others. These issues are directly linked to matters relating to our human nature, such as autonomy and agency, which leads us to the question, "Is there some sort of fundamental ethical principle that we must absolutely uphold when working on such issues?"

In fact, there are still no clearly defined basic ethical principles in neuroethics. For example, in biomedical ethics, there are the "four principles of biomedical ethics,"*3 which is intended to form the basis for all ethical codes and guidelines in medical care settings and situations where medical research is carried out on humans. In neuroethics too, it is likely that we may also be able to identify basic principles that justify various ethical norms. Although it would be possible to simply apply the already existing four principles of biomedical ethics, we ought to consider the possibility that neuroethics involves issues such as those that relate to the very nature of humanity itself and thus require their own separate consideration. CiNet has also begun research on the ethical foundations of such brain science research.

Future Prospects

Even if the establishment of basic principles could not immediately solve various existing (or conceivable) ethical issues, they can be expected to provide rough criteria for the practical implementation of neuroscience research and the social implementation of its outcomes. Work has already begun to compare and combine existing ethical guidelines, and to organize them theoretically and conceptually. We believe that not only people involved in research, but also every member of society should explore what such norms mean, and work to advance them based on a mutual exchange of information and understanding.

Footnote

*1 For details, see Journal of NICT, Vol. 68, No. 1, 2022.

*2 The purpose of neuroethics is to resolve various issues relating to neuroscience, and is comprised of two sub-fields: "neuroscience of ethics," and "ethics of neuroscience." Neuroethics specialist Dr. Judy Illes takes the approach that these sub-fields should be independent of each other, with a third sub-field "interactions of neuroscience and society" added to the above two sub-fields [1][2].

*3 The four principles of biomedical ethics are: (1) respect for persons, (2) nonmaleficence, (3) beneficence, and (4) justice. The Belmont Report only describes three principles, as (2) is incorporated into (2) is incorporated into (3) [3][4].

Reference

[1] Illes, J. Neuroethics defining the issues in theory, practice, and policy. Oxford: Oxford University Press, 2006.

[2] KAGAWAChiaki, "Brainuero science and ethics," Perspective of Brainneuro Ethics," Keiso Shobo, 2008 (in Japanese).

[3] MARUYAMA Eiji, "Four principle of life ethics and medical research," Journal of Japanese Society of Prosthetics and Orthotics, vol.27, no.1, pp58-64 (in Japanese).

[4] National Commission for the Protection of Human Subjects of Biomedical and Behavioral Research: The Belmont Report: Ethical Principles and Guidelines for the Protection of Human Subjects of Research, OPPR Reports, April 18, 1979.

Report on the 12th CiNet Symposium and Announcement of CiNet Conference 2023

HARUNO Masahiko
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HAGURA Nobuhiro
Senior Researcher, Brain Networks and Communication Laboratory, CiNet, Advanced ICT Research Institute

The 12th CiNet Symposium took place on November 8 (Tue) at Knowledge Capital Congrès Convention Center (Osaka) on the theme of "Brain ICT in virtual spaces." Featuring presentations and discussion sessions examining issues from various angles, the symposium looked at the relationship between humans and the ICT environment, which continues to develop rapidly, including virtual spaces and avatars. More than 300 participants joined the hybrid event, both on-site and online, demonstrating the depth of interest in this theme in society and among the research community.

To kick off the symposium, Assistant Professor. NARITA Yusuke of Yale University gave a keynote lecture titled "Body, mind and soul: A perspective from an economist." Professor. Narita stated that out of the Eight Consciousnesses of Buddhism, digitalization of the first five consciousnesses, which relate to sensory information, is already advancing, and that in the future, it is likely that even "manas consciousness" and "ālaya consciousness," which are deeply related to brain science and represent a more spiritual outlook on the world, will also become digitalized. He also raised the question of what is likely to happen in a highly digitalized society of the future. He explained that money is a one-dimensional means of measuring the value of past and future human activities, and that in an advanced digitalized society, such an appraisal may change into something more local and more dynamic through AI, resulting in money holding less significance. It was a stimulating lecture that raised questions about digital transformation and a highly decentralized society.

Next, Professor ANDO Hideyuki of Osaka University of Arts, Dr. SUMIOKA Hidenobu of Advanced Telecommunications Research Institute International (ATR), and Professor INAMURA Tetsunari of the National Institute of Informatics (NII) gave invited lectures about their research into how avatar and virtual reality technologies can influence human behavior and emotions. All three researchers have their own different approaches and it was impressive to see how the virtual world has already become a part of everyday human life.

Next, four CiNet researchers introduced their research on virtual spaces and brain ICT. Dr. HIRASHIMA Masaya (Senior Researcher) spoke about his work on mobility support systems using virtual space and avatars, and Dr. TANAKA Toshiko (Researcher) spoke about how using an avatar changes people's social behavior and brain activity.

To close the symposium, Mr. KAWAMOTO Kenta of SONY AI gave a keynote lecture titled, "Deep reinforcement learning outperforms top Gran Turismo drivers." It was fascinating to hear that the level of driving achieved through the deep reinforcement learning algorithms not only outperforms top professional drivers, but also realizes the fairness that the competitive sporting world implicitly demands. This also suggests a direction that human-centric brain ICT research could take in the future.

Overall, the symposium gave the strong impression that virtual spaces and virtual reality technologies are already starting to change human life and society, and that they are become a main theme for brain ICT research, alongside AI and BMI. We would like to express our appreciation to all the departments involved in making the symposium a success.

Figure 1 Keynote lecture by Assistant Professor . NARITA Yusuke, Yale University

Figure 2 Keynote lecture by Mr. KAWAMOTO Kenta, Sony AI Inc.

CiNet Conference 2023

The 8th CiNet Conference is scheduled to be held from **March 7 to 9, 2023,** under the title of "Beyond Motor Control: Bridging the gap between action and perception." The theme to be explored in the conference this time is the boundary region of brain information processing relating to "cognition and sociality" and "motor control."

The conference will bring together up-and-coming young researchers from various countries and host discussions on the differences and interactions among various fields, with the aim of contributing to the development of research on the fusion of information and neural networks at NICT and enhance its international presence. We look forward to welcoming on-site and online participants.

For further details, see the link below.

▼**Information about the CiNet Conference**

https://cinet.jp/english/

Elucidating How the Brain Represents Temporal Information and Developing Technologies to Manipulate the Subjective Experience of Time

HAYASHI Masamichi

Researcher (tenure-track), Brain Networks and Communication Laboratory, Center for Information and Neural Networks (CiNet), Advanced ICT Research Institute, Ph. D.（Science）.

Biography

1982 Born in Osaka Prefecture
2006 Graduated from University of Fukui
2011 ～ 2019 After receiving a doctorate from Graduate University for Advanced Studies, engaged in research relating to perception of time and numbers at University College London, University of Helsinki, University of Sussex, University of California, and Osaka University.
2019 Joined NICT
2021 Appointed to current position

Awards, etc.

2018 Young Investigator Award, 2nd Japanese Meeting for Human Brain Imaging
2015 Best Presentation Award for Young Scientists, Comprehensive Brain Science Network

Q&As

Q What is good things to be a researcher?

A Being the first to discover things that no-one else knew before, being able to leave living proof in the form of written papers for future generations and being able to study overseas and participate in academic meetings around the world.

Q What are you currently interested in outside of your research?

A Watching overseas TV dramas. Recently, I have been watching s.w.a.t, NCIS, Hawaii Five-O and Chicago Fire, learning about the meaning of teamwork and leadership!

Q What advice would you like to pass on to people aspiring to be a researchers?

A My hope is for students to enjoy the process of taking time to explore ideas fully and pursue the truth, without being overly preoccupied with getting immediate results or fearing failure.

Just as we often hear words and phrases such as "time flies" or "good timing," time is ever-present and intrinsically intertwoven into our daily lives. It is believed that, in order to adapt our actions to a dynamically changing environment, we consciously or unconsciously estimate and learn the timing and duration of various events, putting such information to use to predict what may happen in the future.

However, despite it being incredibly important to accurately recognize the passage of time, our perceptions of time can very easily be distorted, depending on such factors as our environment, degree of alertness, or emotional state. As the situation currently stands, all we can do is to surrender ourselves to these perceived ups and downs in the flow of time. If we could understand the mechanisms in our brains that govern perceptions of time, and control these perceptions freely, I believe it would unlock the potential to transform our lives in the future.

In my research to date, I have identified the areas of the brain that are thought to represent temporal information, and clarified how those regions are related to both the ability to estimate time and biases in our perceptions of time. We are currently working to further deepen our understanding of the brain's time perception mechanisms and seeking to manipulate time perceptions artificially. Specifically, this involves such methods as transcranial magnetic stimulation, which enables modulation of neural activities for a short period of time non-invasively, and tactile stimulation through wearable devices. Using these methods, we are looking into ways in which it may be possible to control subjective perceptions of the flow of time. If we could successfully manipulate perceptions of time through our research, I believe it could have various technology applications, such as the development of an artificial brain model that mimics temporal information processing mechanisms, or the promotion of learning complex motor skills through manipulation of human time perceptions, as well as improved ability to recognize signs when driving.

Figure Brain stimulation via transcranial magnetic stimulation (TMS)
TMS can induce a transient, small electrical current in the brain by producing a rapid change in the electromagnetic field via a coil placed on the scalp. This photo shows an example of experiments that can manipulate the functional connectivity between two brain regions using two TMS coils.

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