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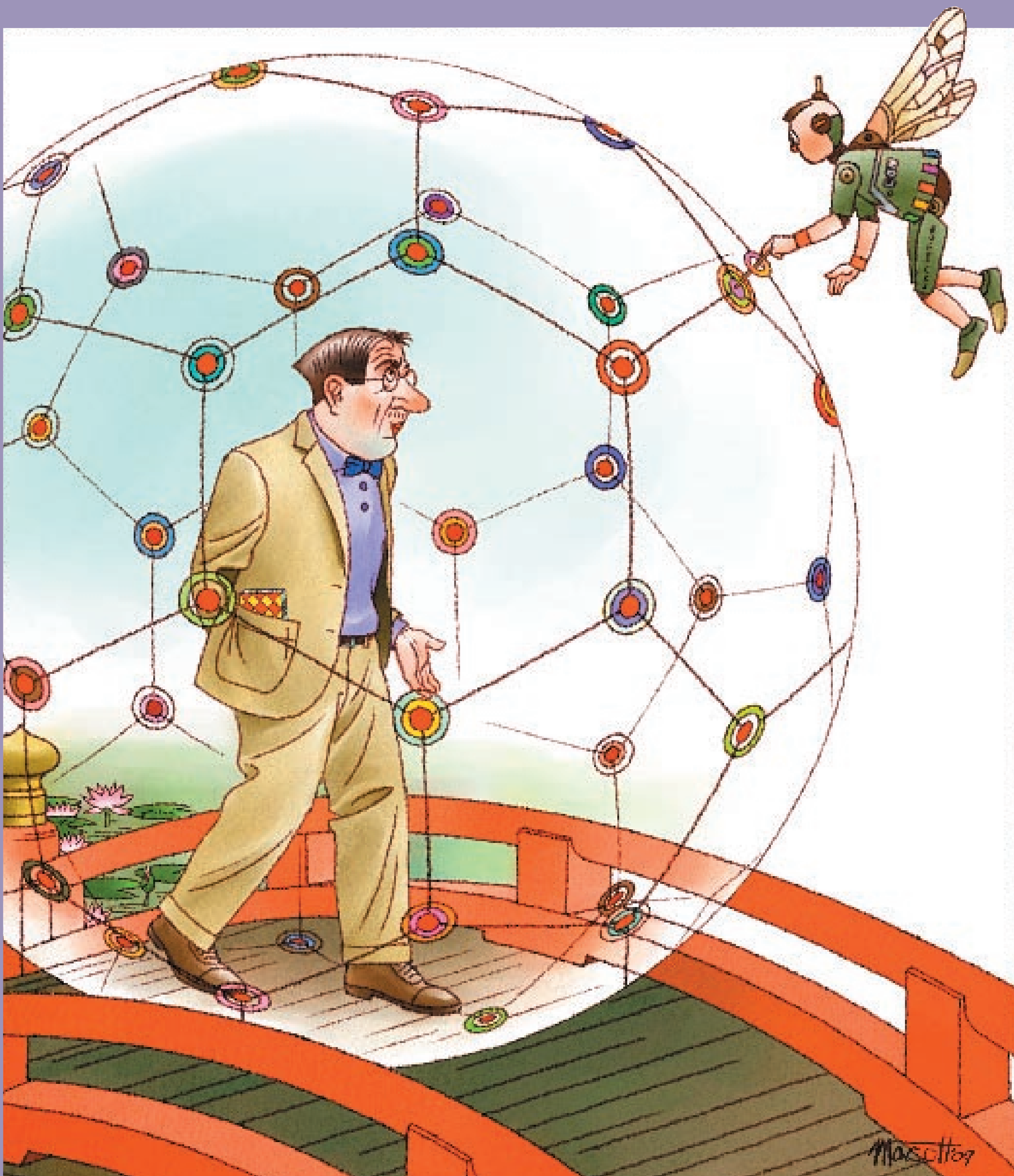


Seiji Yamada
Professor, Digital Content and Media Sciences Research Division, NII

NII Interview: Seiji Yamada+Madoka Tainaka

Human-Agent Interaction: Leading the Way to the Future

The Approach to Agent Design

NII SPECIAL
INTERACTION DESIGN

Tainaka: Mr. Yamada, you are studying the interaction between human beings on the one hand and robots and anthropomorphic agents(*1) on the other — in other words, "human-agent interaction" or HAI for short. First of all, what do you mean by "interaction?"

Yamada: Interaction refers to the various types of data produced during interchange with human beings. It covers all of the information generated in the process of interaction: dialogue in natural language (*2) as well as the appearance, shape, facial expressions, sensations, body language, gestures, induced behavior, emotions and so on of the interacting parties. My research focuses in particular on not the information provided through language but on non-verbal information, information that is not verbalized. For purposes of study, I classify this into three categories by relationship: ① human being and robot ② human being and anthropomorphic agent, and ③ human being and human being (through agents). By comparing these three types of interaction and identifying the similarities and differences, I hope to arrive at a methodology for the design of agents.

Tainaka: With regard to the robots in category ①, these days robot pets and cleaning robots and so on are becoming a part of daily life. What type of robots do you think will be needed in the future?

Yamada: Apart from specialized situations such as the exploration of Mars, I don't think it will be necessary for robots to function autonomously in daily living environments. It will be more important for them to be easy to operate and capable of working on tasks together with humans. Moreover, I think it would be desirable for them to provide information that is not dependant on language and culture and can be intuitively understood by human beings – for example, facial expressions and gestures and so on.

Particularly important for the design is that there be little disparity between the appearance of the robot and its function. We call this the "adaptation gap." If a robot is similar in appearance to human beings, people will naturally expect to be able to talk to that robot. If this proves not to be the case, they will be disappointed and lose interest. Conversely, if the appearance of the robot makes people think it will not be of much use but it proves to have useful functions, things will go well. There should be as little gap as possible.

This is true of human-to-human interaction as well. Social psychologists have shown that if you have a good first impression of someone but your expectations are betrayed, you have an even worse impression of them than would otherwise be the case. Moreover, if the appearance of

(*1) Agent : An entity that executes functions by making autonomous judgments in accordance with user intentions. Expected to become a next-generation user interface.

(*2) Natural language : The language customarily used by human beings for communication (as opposed to a programming language, etc.).

(*3) Masahiro Mori : A pioneer in the field of automated control and robot engineering in Japan. Professor Emeritus of the Tokyo Institute of Technology.

(*4) Second Life : An internet-based virtual world that has been operated since 2003 by Linden Lab in the United States. In Second Life, people use avatars to experience a virtual life that includes conversing with other avatars, shopping, working and so on (see article on pages 6-7).

Madoka Tainaka

Science and Technology Editor/Writer
Expert member, Council for Science and Technology
Ministry of Education, Culture, Sports, Science and Technology

a robot is too close to that of a human being, people feel discomfort or displeasure. Dr. Masahiro Mori (*3) calls this the “uncanny valley.”

Tainaka: So you’re saying that currently human beings are vastly superior to robots, so their appearance should be in keeping with this reality. In that sense, cleaning robots are a success. They do a good job, and some people are so attached to them that they give the robot a name.

Yamada: Anthropomorphism is the key, as evidenced by the fact that people usually give robots names. For example, if you put eyes and arms on a refrigerator and had it say “Open my belly!” people would naturally open the door. Research conducted at the Michita Imai Laboratory (at Keio University) has also shown that if a robot has two eyes, one on the right and one on the left, people feel affection for that agent.

Tainaka: Next, could you talk about Category ②, a human being and an anthropomorphic agent?

Yamada: This refers to an agent created in software, one that does not have a physical body like a robot. One example of this type of agent is the dolphin that provides help to users of Microsoft Office. The avatars in Second Life (*4) are also anthropomorphic agents. In modern-day society, we spend a lot of time using computers and mobile phones, and these agents can be created at a much lower cost than a robot, so they will play a larger and larger role as time goes on. However, the Microsoft dolphin is not highly regarded, and it has been eliminated from the more recent versions of the program. The reason is that it doesn’t appear when users want it to.

For anthropomorphic agents to become more user-friendly, they must be able to analyze user patterns of behavior from the user’s gaze, mouse movements and GPS and other location information, so they can determine what type of information users want and when they want it and provide this information with precision. If we can resolve these kinds of problems, someday anthropomorphic agents may function like personal secretaries. They’ll handle our schedules for us, and when we leave the house, they’ll move to a mobile phone and give us street-level information and so on.

Agents have the potential to connect human beings with one another in ways that provide greater benefit.

Tainaka: Will advances in this type of research enable Category ③ interaction: human to human through agents? In other words, will interaction between human beings also be facilitated by robots and anthropomorphic agents?

Yamada: Yes. Already robots and anthropomorphic agents are helping to achieve progress in communicating with autistic children, and we are gradually gaining knowledge about how to use them to facilitate human-to-human interaction. Human beings are much smarter than robots and anthropomorphic agents, so rather than expecting perfection from machines, I think we should focus on creating interactive artificial agents that are skillful in helping human beings perform at their best.

A Word from the Interviewer

Watching the TV commercial that shows the Asimo functioning, I thought for a moment that, even though it could not fly through the sky, a robot like Astro Boy had already been achieved. But in reality this is a long way off. Mr. Yamada’s idea is that, this being the case, we should design robots and anthropomorphic agents that can be useful to humans by making skillful use of human capabilities. As research into AI and human-like robots seems to have stalled, this approach definitely seems more realistic. It also seems like it might provide a more flexible and comfortable approach to the interaction between humans and human-made agents.

NII SPECIAL

INTERACTION DESIGN

Robots that Interact with and Imitate Human Beings

Recently, an impression of robots has been shifted from machines to natural human-wise agent. There are high hopes for the development of robots that can communicate naturally with human beings, with facing the day that humanoid robots will come to our homes.

Tetsunari Inamura
Associate Professor,
Principles of Informatics
Research Division, NII

"They'll do the cooking!" "They'll do the cleaning!" There are increasingly high hopes for the achievement of humanoid robots designed to assist human beings by imitating human behavior. But behind such scenes, software engineers have to write mountains of code with prediction for a variety of situations: do this in this situation, if that doesn't work try it again that way, and so on. Moreover, the unfortunate truth is that currently they can only operate robots using a limited set of experimental environments.

Creating Robots that can Improvise

"Almost recent robots are not good at improvising" says Tetsunari Inamura, Associate Professor at Principles of Informatics Research Division, NII. "When they faced novel locations, tools or tasks that have not been predicted by robot developers, they would completely stuck. We want to create robot systems that can adapt quickly to diverse environments in response to only simple commands."

Robots are very good at doing some things and very poor at doing others. They excel at things like precision control, storing and reproducing large amounts of information accurately, and acting in accordance with predetermine rules without making mistakes. On the other hand, they are not suited to things like interpreting vague instructions, dealing with unfamiliar environments, or behaving naturally when dealing with human beings. It is simply not possible to program robots to deal with every possible circumstance. Even when human beings provide them in advance with evaluation functions and use reinforcement learning to enable them to achieve appropriate behavior toward given goals, they still require enormous amounts of time and a number of trials, and this method might need a considerable burden on the user. A different approach will be required when we design robots that can engage in housework with general purpose.

"Watch & Imitate" Approach to "Ask the Right Questions" Approach

With consideration a way to make robots to learn through interaction with human beings, without any programming by humans, Associate Professor Inamura decided to use two methods based on mechanisms of the human brain. One was "Watch & Imitate" approach in which the human being perform a certain behavior and the robot would watch and learn the behavior. The other method was to explain the objective and the action to the robot using natural language.

If robots simply copied human movement exactly as though recording them on a videotape, improvisation would never achieved. For example, for a behavior of casting away trash in a wastebasket, they should not simply imitate the movements of arms and legs. Rather, it would be best if they understood that the goal to be achieved is the movement of trash to the wastebasket. But this is very difficult for robots.

Accordingly, Inamura decided to try to embed an interactive dialogue capability into robots that would enable the robots to ask questions, to which the human being would respond with simple answers. The robots would interpret these replies and then act. "For human beings as well, if you're a novice at something, it's perfectly natural for you to be taught by experts and learn how to do it," explains Inamura. "So robots also need to have a process through which they can learn from human beings. But there would be no sense in having them ask every little detail. So it is only when they are able to ask appropriate questions that robots will become usable intelligent machines."

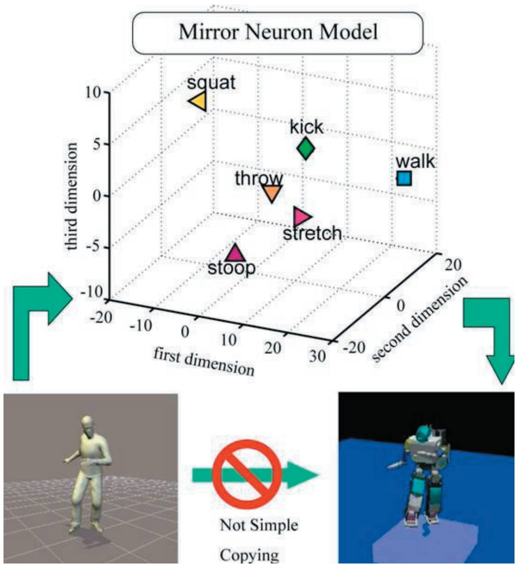


Fig. 1


Fig. 2 "Cooking *Okonomiyaki*" Collaborative Task in the SIGVerse
Left: An avatar operated by a user moves the *okonomiyaki* to a plate. During this process, the robot observes the behaviors of the avatar and decides a suitable support behavior that can be done parallel. Right: The user hardly operated the avatar at all, so the robot is cooking the *okonomiyaki* by itself. In this way, it is possible to create a program that determines behaviors of the intelligent robot by confirming how the robot behaves in response to user behavior.

Mirror Neurons and Mimesis Theory

Accordingly, Associate Professor Inamura focused on the mirror neurons(*1) in neurophysiology and the mimesis theory(*2) inanthropology and archaeology. The mirror neurons are thought to convert a behavior of the others into an one's own behavior pattern. The goal is to design a model of the mirror neurons in order to achieve the "Watch & Imitate" functions of the human brain.

Next, Inamura conducted an integrated review of the mimesis theory and the functions of the mirror neurons. This integration leads to a deep connection between the "Watch & Imitate" function and the process of abstracting the behavior of the others and expressing it linguistically to communicate with others.

Associate Professor Inamura has proposed mathematical models to realize these functions from a viewpoint of engineering. First, using a method called Hidden Markov model, he extracted parameters that constitute a time series motion pattern. He calls these extracted parameters proto-symbols. Inamura proposes a method in which each proto-symbol is assigned a position in a phase space, that is called a proto-symbol space, with evaluating the relationships (similarity) between proto-symbols. Even if the robot encounters an unknown motion, it can be imitated as a combination of known basic motions by referring to this proto-symbol space(Fig. 1).

Creating a Virtual Experimentation Space

Although it would be best to conduct robot research using actual size robots, the construction of these robots would require an enormous budget. Even if such a robot were acquired, it would require a great deal of personnel resources for maintenance. For this reason, virtual environments in which research can be completed by computer simulation are needed. As one of the projects in the Grand Challenge(*3), NII is promoting the construction of the SIGVerse(*4), a multidisciplinary platform to enable researchers in various fields to pursue research on human social intelligence in a computer-based virtual environment(Fig. 2).

Agents (robots) with near-human level perceptions, intelligence, motor skills and communication skills are modeled in this virtual space and manipulated in complex environments with sensor simulation for sight, sound and touch. User also embed one's own intelligent agents in the virtual environments. For example, make robots in this virtual environment communicate each other, then society's response to this conversation can be simulated. In addition, the system can simulate and calculate plausibility of conversation from robot agents according to each situation. In this way, the connection to the real world has been emphasized in the design of this platform.

Associate Professor Inamura has been involved in this project, especially on the development of robot applications. His goal is to create an environment in which physical laws, sensor information and communication can be accurately simulated. "It is the fate of robots to be expected to do everything in daily life environments," says Inamura. "To response to these expectations, I want to provide such a platform as an experimental tools and develop a robot that can, imitates and acquires behaviors with making communication between human beings interactively."

Many people will expect novel wave of the future created by this project.

(Written by Asako Tsukasaki)

(*1) Mirror neurons were discovered by accident in a section of the frontal lobe of monkey's brain. These nerve cells act like a mirror, firing both when a subject act or intend to act a specific type of action and when the subject observes the same action performed by the other.

(*2) Mimesis is a Greek word meaning copying or imitation. Mimesis theory suggests that the ability to imitate the others' behavior is the beginning of an ability to communicate.

(*3) The name of a project being promoted by NII to support research on difficult problems in information science and technology that will be faced in the next generation.

(*4) SIGVerse is a virtual environment in which an enormous number of agents interact each other in parallel. These agents are also connected to actual robots and user/operators in the real world. This system configuration makes us possible to evaluate and develop real-world interactions efficiently.

Using 3D Internet to Create an Infrastructure for Participatory Scientific Research

Researchers have begun the construction of a new platform that will enable 3D Internet users to use an avatar (an anthropomorphic agent) to converse, exchange information and conduct joint experimentation and research with other users. This is expected to form an infrastructure for participatory science and help create an environmentally friendly society.

Helmut Prendinger
Associate Professor,
Digital Content and Media Sciences Research Division, NII

The Global Lab Project initiated in June 2008 is one of NII's Grand Challenge projects and is headed by Helmut Prendinger, Associate Professor at the Digital Content and Media Sciences Research Division. Global Lab is a convenient platform that enables anyone to participate at any time from any location, simply by connecting to the Internet. The aim of the project is to create a next-generation Internet that is not a simple web-based environment but a three-dimensional virtual world that more faithfully simulates the real world.

The Prendinger Lab, currently the only world-scale laboratory in this field is conducting comprehensive research and development of 3D Internet (Second Life and its open source version, Open Simulator). An indication of the importance of this area is the fact that 3D Internet was selected as a "thrust area" for the Supercomputing 2009 conference (*1) that is expected to attract some 11,000 attendees.

Global Lab is a platform for communication and participation in Second Life, the online 3-dimensional virtual reality that can simulate the real world. Employing characters known as avatars as their alter egos, users can converse and share information with other users around the world. They can also conduct various experiments and engage in collaborative work operations. Moreover, using virtual mobility technology, users can participate in activities without actually moving from their location, making the reduced global environmental load another major advantage of the system.

Development of a Dedicated Language and Technology for Second Life

To develop Global Lab, Associate Professor Prendinger first developed a unique language called Multimodal Presentation Markup Language 3D (MPML3D). MPML is a markup language (*2) based on XML, which was developed to enable the use of multiple input and output methods utilizing characters (agents). MPML3D is a further evolution of MPML and comprises the world's first agent authoring language (*3) for Second Life. Associate Professor Prendinger is also developing the Environment Markup Language 3D (EML3D) that enables authoring of Second Life environments in the same manner. These tools will improve the efficiency of research, as they are easy to use for even people who are not programming language experts.

To the state-of-the-art technologies of Second Life, the Prendinger Lab has also succeeded in adding EmoHeart, a technology for automatically expressing the emotions of avatars, and Automatic Gesture (AuGe), a technology for generating gestures. These were developed jointly with the Ishizuka Lab of Mitsuru Ishizuka at the University of Tokyo. When the user enters a chat message while conversing through avatars in EmoHeart, the message is automatically analyzed and a heart-shaped object expressing an emotion appears automatically on the user avatar's chest (Fig. 1). In addition, AuGe selects gestures automatically for chat messages. These technologies enable avatars to exchange information in a more natural manner.

Experimentation Using Sensor Networks

Various scientific experiments can also be conducted through simulations. For example, in an actual ubiquitous network, it is costly to conduct experiments using radio IC tags known as Radio Frequency Identification (RFID) to identify individuals using sensor networks. Moreover, miniature models lack flexibility and two-dimensional soft-

(*1) http://sc09.supercomputing.org/

(*2) A language used to embed information on sentence structure and modification in the text.

(*3) A programming language used for multimedia content authoring that combines various types of data (text, images, video, audio and so on).

Fig. 1 EmoHeart displays objects that express emotion.

Fig. 2 Enables real-time monitoring even in remote locations.

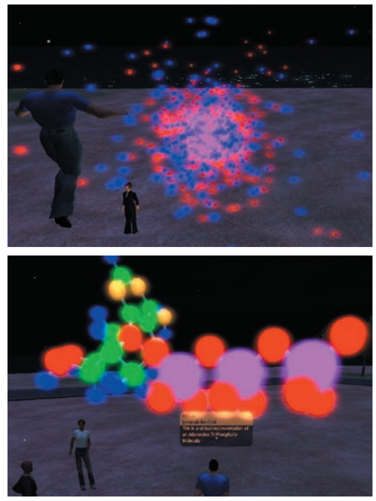


Fig. 3 This research is also expected to find applications in the fields of astronomy (top) and molecular biology (bottom).

ware solutions are imprecise. But Global Lab can be used as a testing platform for this kind of technology. RFID tags in a test environment can also be used to locate the position of avatars. This has the advantage of making it possible to conduct evaluations before actual deployment, as well as the fact that the test can be conducted remotely. Associate Professor Prendinger says that rather than conducting the actual test, conducting verification in Global Lab makes it easy to determine where problems lie and what should be done to resolve them.

In addition, the sounds produced by daily life activities such as cooking and cleaning can be recorded in advance and avatars made to simulate the movements of these activities in accordance with the sounds produced by real people.

Support for Agriculture in Remote Locations

Virtual reality also enables real-time remote monitoring of rice paddies and the like in remote locations. Accordingly, participatory agricultural systems equipped with controllable servers are currently in operation. Through the cooperation of Shinshu University and Niigata University, such systems have been collected in cyberspace to help cultivate rice and monitor vineyards and so on (Fig. 2). Another system receives images and data on climate soil and the like that are delivered in real time from the National Agricultural Research Center of the National Agriculture and Food Research Organization (NARO), and uses them to create virtual spaces in which the images and data can be shared in order to support online decision-making.

Moreover, NII has also worked with the National Astronomical Observatory of Japan to develop a platform for experiments aimed at visualizing the evolution of star clusters and so on. Work is also progressing on a system that will enable general users to conduct joint research on the molecular structure of chemical substances and verify climate change models (Fig. 3). NII is linked with the National Astronomical Observatory of Japan by the world's fastest scientific information network, the SINET3 operated by NII.

Achieving Participatory Science and an Eco-friendly Society

Global Lab has the potential to enable anyone to connect to the sensor network and participate in experiments in agriculture, astronomy and molecular biology. Associate Professor Prendinger said that his goal is to create a 3D Internet-based infrastructure for advanced communication and participatory science. Although he and his colleagues are not specialists in the scientific fields with which they are dealing, he said, they are able to provide a platform for research. "Participatory science means that everyone, not only experts but also common users and interested individuals, can engage in scientific exploration and discovery," he said. "So some people call it the 'democratization of e-Science.'"

He also speaks enthusiastically about the future potential for this research. Once this infrastructure is in place, he said, the movement of people and objects can occur virtually rather than in the real world, without sacrificing the quality of social communication. This will help achieve an environmentally friendly society as well. It will also be possible to verify environmental hypotheses in a form close to that of reality, and this will help to increase environmental awareness. Associate Professor Prendinger said that he wants to expand the scale of his research even further from this point on.

(Written by Asako Tsukasaki)

Ultrasonic Positioning Method Developed Through Collaboration

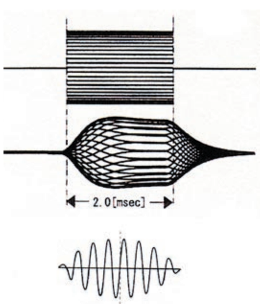
Collaboration (joint research) between individuals and organizations has produced many significant achievements. It was only after the new century had arrived that there was a lot of talk about "collaboration." However, the joint NII-university collaborative research described here dates back to the 1990s.

"Interactive Tokyo," an exhibition held in September 2008 at the National Museum of Emerging Science and Innovation in Odaiba, Tokyo, was designed to introduce interactive technologies to the general public. An ultrasonic positioning system designed by Hiromichi Hashizume, Professor at the Information Systems Architecture Research Division, and others was exhibited at the exhibition (see photo on next page). This technology transmits ultrasonic waves in the direction of a target object and determines the location of the object by means of the time it takes the ultrasound to reach that object.

Professor Hashizume (left), Mr. Maeda (center) and Associate Professor Sugimoto (right) discuss the performance of a new prototype circuit board.

Determining a location without using a measuring rule is not particularly unique. In the global positioning system (GPS), radio waves are transmitted from satellites and the location is determined by the time it takes these radio waves to arrive. However, GPS radio waves cannot reach indoor locations. Moreover, there is an error of several meters in the positional measurements, so they are not precise enough for use in cramped indoor locations.

In contrast, the positional measurements made using the ultrasonic wave system developed by Professor Hashizume and his colleagues are much more precise. The error for a surveyed distance of three meters is no more than 0.3 mm. Up to now, an error of several centimeters was thought to be unavoidable when measuring with ultrasonic waves. Using a new approach, Professor Hashizume and his colleagues were able to the error to 1/100 of that produced using existing methods.



The shape of an ultrasonic wave that is sharp when transmitted (top) becomes rounded (middle) by the time it is received. This is a peculiarity of narrow-band communication elements.
This distortion does not occur with beat waveforms (bottom). (Reprinted from Hashizume, Kaneko and Sugimoto 2008.)

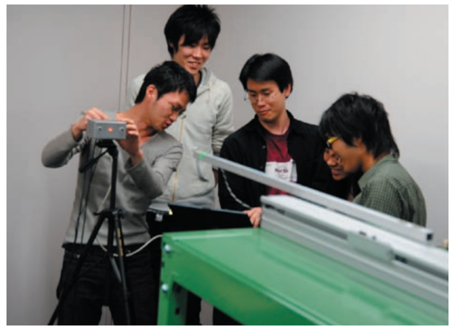
Reducing Error using "Beats"

Ultrasound is used in daily life in a variety of ways. People use ultrasound to clean eyeglass lenses. Doctors conduct ultrasound tests. Ultrasound is also used in automatic doors, to measure the distance between vehicles, in parking meters and so on. Powerful ultrasonic waves can also be used to fuse plastics. Nevertheless, the market for equipment that simply transmits and receives ultrasonic waves through the air is not large. Measurement using ultrasonic waves has the potential to increase the demand for such equipment.

Ultrasonic waves are acoustic waves of a frequency that is inaudible to the human ear. The audible range of the human ear is said to be approximately 20 Hz to 20 kHz. In general, sounds that exceed 20 kHz are so high as to be inaudible to the human ear, and these are referred to as ultrasound. The sounds used by Professor Hashizume were ultrasonic waves with a frequency of 40 kHz, which is commonly used in automatic door sensors and the like. Unlike ocean waves that move up and down, an acoustic wave is generated as fluctuations in the pressure of the air, water etc., so these waves are also referred to as pressure waves or dilatational waves. In air, ultrasonic waves attenuate quickly, reaching a distance of only several dozen meters.

How was Professor Hashizume able to improve the error of ultrasonic wave measurements? The truth is that, in principle, the error of several centimeters produced when ultrasonic waves are simply transmitted through the air is unavoidable (see figure at left). This is because the waveform has been rounded by the time it is received. For this reason, Professor Hashizume decided to introduce a different principle: that of phase matching. This method involves extracting the phase data characterizing waveforms from the "beat" produced by two ultrasonic waves, one

Demonstration of ultrasonic positional recognition (at Interactive Tokyo 2008).



Students use ultrasonic waves to measure the distance and angle of a moving object.

with a frequency of 39.75 kHz and another with a frequency of 40.25 kHz. This method enables the error produced for a surveying distance of three meters to within 0.3 mm and the angle error to within 0.2 degree. The result is the achievement of positional measurement performance that is more than adequate for use in indoor locations.

Applications Currently Being Solicited

In what situations can this technology be used? "This is a basic research achievement," says Associate Professor Masashi Sugimoto of the Tokyo University Graduate School of Engineering, who has been working with Professor Hashizume on the joint research project. "So we have no intention of limiting its applications. We want it to be widely used, so we're open to any offers for applications."

Associate Professor Sugimoto also spoke about the process through which this research was begun. "As more and more compact mobile information devices come into widespread use, ideas such as tossing information the way you would toss a ball become possible. You could point the device in your hand this way and that toward a person to send an e-mail, print documents and so on. In order to make this possible, it was necessary to estimate the precise position of the target object and appropriately assess the situation. And for this reason, accuracy on the millimeter level was needed."

Research into ultrasonic positioning is already moving to the next stage. Up to now, researchers have succeeded in making two-dimensional measurements of the angle and distance to an object. The current goals are to make three-dimensional measurements of the location of a moving object and capture video images of such objects using ultrasound.

Collaboration Began Naturally

After Associate Professor Sugimoto finished his Ph.D. studies, he began working at the National Center for Science Information Systems, the predecessor of NII, as a teaching assistant in the software engineering research division. This was where he first met Professor (then Assistant Professor) Hashizume. At that time, Associate Professor Sugimoto thought of Hashizume as "my teacher," but after Sugimoto moved to the University of Tokyo in 1999, their relationship changed to one of collaborative researchers. The two naturally began a collaboration that extended beyond the boundaries of NII and the University of Tokyo.

Professor Hashizume feels that the biggest difference between conducting research at universities and at a research institute like NII is the presence of students. "The power of students is amazing," he says while discussing the advantages of collaboration. "They're young, so sometimes they make big mistakes. But even these mistakes will occasionally provide new hints for research." Associate Professor Sugimoto also welcomes the current situation. "Professor Hashizume participates in the weekly meetings at the laboratory, and he also provides guidance to students. So the current situation is also beneficial to students."

In October 2008, students from the Graduate University for Advanced Studies also joined the project. Yasunari Maeda, a Ph.D. candidate, first met Professor Hashizume four years ago. At the time, Hashizume was a part-time instructor at Sophia University, and Maeda asked him a question about microprocessors. "He's really good at designing electronic circuits, and that has broadened our research," says Hashizume. "It's been a big help." These three researchers appear to have complete confidence in one another. Undoubtedly they will continue to involve others as well, giving birth to new collaborations and producing new research achievements.

(Written by Tomoaki Yoshito)

Looking into what intelligence is.

"Even a Pill bug Can Think?!"

For the past three years, NII has been engaged in a study comparing the behaviors of human beings and pill bugs. This study, begun originally as a collaborative effort with Shinshu University and other institutions, is interesting, because it may overturn the commonly held assumption that intellectual behavior is a product of the highly developed brain. We discussed many things with Nobuhiro Furuyama, associate professor of the Information and Society Research Division, about the most recent developments in this collaborative project.

Nobuhiro Furuyama
Associate Professor,
Information and Society Research Division, NII

Are pill bugs intelligent? Few people would answer in the affirmative. But what makes people so reluctant to say, "yes"? When we do something, we make a plan, and, during and/or after executing the plan, verify the performance to see whether the plan was appropriate, whether the action was performed as planned, etc. If there were unexpected troubles with any of the processes, we attempted to revise the plan to make the behavior better suited to the requirement. The ability to adapt to the environment is a hallmark of intelligence, and it is the brain that plays the central role in the process, or so it was assumed for a long time (Fig. 1). In contrast, the behavior of the pill bug has been considered to be mechanical because the creature does not have the brain or its equivalent. For example, if a pill bug initially turns right when it encounters an obstacle, it would turn left when it encounters the next obstacle. This behavioral pattern, known as the "turn alternation," has been considered "mechanical," not intelligent; that is, the pill bugs simply follow their instinct, which happens to be the simplest, yet one of the most efficient ways to escape from enemies.

Breaking the Spell: Intelligence as a product of the brain.

"We strongly believe that human beings are always intellectual," says Furuyama. With psychology as his background, he has conducted research on the human body. He has examined whether it is correct to think that the brain alone controls all human behavior. Meanwhile, in ethology, certain species of animals have long been thought to act only mechanically even though there has not been much basis for this conclusion. The two assumptions, one for humans and the other for pill bugs, are actually two sides of the same coin. This realization opened up the possibility to conduct collaborative research to compare the behaviors of humans and pill bugs. Mr. Furuyama, Hiroyuki Mishima, Associate Professor of Waseda University, and Shin Maruyama, Project Researcher at NII, are in charge of the human behavioral side, and Tohru Moriyama, Assistant Professor of the Young Researcher Empowerment Project at Shinshu University, and Masao Migita, Associate Professor at Shiga University are in charge of the behaviors of pill bugs.

To determine their latent capabilities, Moriyama and Migita put the pill bugs in a specially designed circular corridor. Since both sides of the corridor were filled with water, the pill bugs had to escape from the water so they did not drown in it. As they move along the corridor, however, they come across projections like stepping stones. Since the pill bugs do not like dry environments either, and usually do not turn upward and climb onto projections, they also had to escape the projections. In an environment like this, the pill bugs initially exhibited turn alternation to avoid both obstacles (the water and the projections) (Fig. 2). However, as they kept avoiding the obstacles endlessly for nothing in the circular corridor, some of them started climbing up onto the projections, and swung their antennae to and fro, apparently exploring upward to see if there was a place to escape. Moriyama and Migita found this behavior very intriguing, and thought, "Maybe, pill bugs can think!"

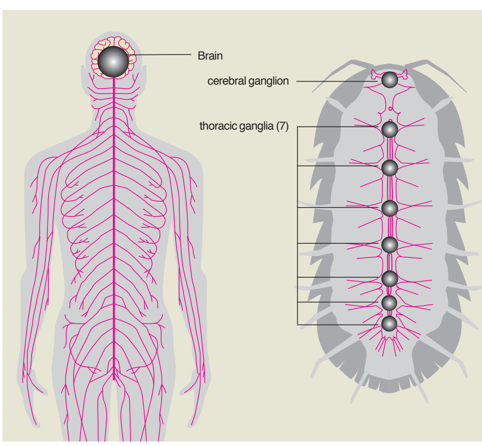


Fig. 1 Nervous System of Human Beings and Pill bugs
A highly-developed brain serves as the center of the nervous system in a human being. Conversely, in a pill bug, the neural ganglia in each section of the thorax (which is divided into seven parts) exerts independent control over the different body parts. The ganglion in the head is not the center, but merely serves to regulate overall balancing.

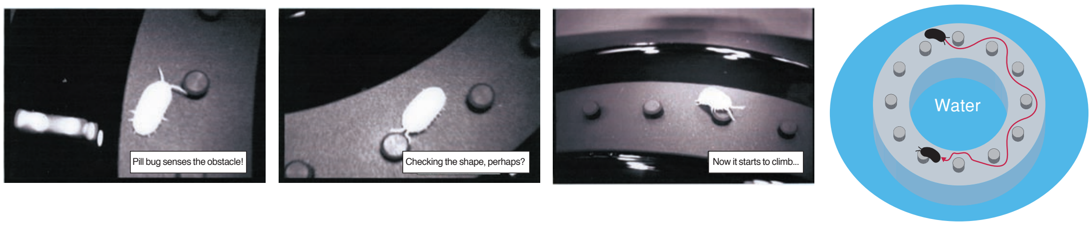


Fig. 2 Changes in Behavior of Pill bugs Walking Along a Circular Corridor
The pill bugs avoid obstacles by means of endlessly alternating their turning responses, but as time goes by, some of them start exhibiting unique behaviors such as climbing up a projection (top). This is the first step in adapting to the environment. (Due to the lighting, the pill bug in the figure appears white.)

Do Pill bugs Use Tools, Too?

In another attempt to induce an idiosyncratic behavior from the pill bugs, Moriyama and Migita covered their antennae with tephlon tubes (Fig. 3). Including the attached tubes, the lengths of the antennae were approximately 1.5 times longer than the bare antennae. As expected, the pill bugs walked clumsily with the tubes. Moriyama and Migita then put the pill bugs with tubes in a stair case and let them climb down the stairs (Fig. 4). The height of the steps increased by 1 mm as the pill bug goes one step down from top to bottom. With tubes attached to their antennae, the pill bugs went down further than the control group without tubes. However, if the pill bugs with tubes were allowed to explore in the environment for 10 minutes before being put in the stair case, their responses were more like the control groups. What implications can we obtain from this?

The behavior of pill bugs is, in general, considered mechanical. If the antennae can reach the bottom of a stair, it means that the stair is safe to descend for the pill bugs. When the tubes were attached and, immediately after, the pill bug was put in the stair case, they recklessly tried to descend a greater distance for they sensed the mechanical vibration at the tip of their extended antenna. However, with exposed to the environment for only about ten minutes, the pill bugs seemed to find out that the attempt was indeed reckless, changed the way they interpreted (or use the information of) the vibration from the tip of their antenna, and changed the way they acted in the environment. “An attempt to do something different than before is the first step toward adaptation to the environment,” says Furuyama. Crucially, their attempts of new behavior seem to be guided by their robust ability to perceive the environment, even when the sensors were experimentally manipulated.

Human Adaptive Behavior

What about human beings? Is human behavior always controlled by the brain? Mr. Furuyama and his group asked people in their 20s and 30s to discriminate between pieces of sandpaper of different roughness by touch. The subjects were each tested under four different conditions: (1) with their bare hands, (2) with Scotch tape on their fingers, (3) with sandpaper wrapped around their fingers, and (4) again with their bare hands. The results showed that the accuracy rate was about the same for all conditions. When the sense of touch was impaired due to attachments to their fingers, their confidence rates greatly decreased. In such cases, however, the subjects would put forth much more effort, instead trying different ways to touch the surface. For example, many subjects pressed harder against the sandpaper when their finger was wrapped with Scotch tape and softer when the finger was wrapped with sandpaper. Human subjects try more different methods of exploration than ever before, but their choice of new methods does not seem to be random, but rather guided by perceptual information.

A Species-independent Knowledge Acquisition Mechanism

The aim of this research group is not only to find out how pill bugs behave. All living things act based on information that they sense about the environment in which they live. A comparison of the behaviors of human beings and pill bugs that have completely different nervous systems may reveal a common, species-independent principle about the mechanism through which living things obtain information from their environment. There certainly seems to be some similarities in how a pill bug with tubes on its antennae moves around in an attempt to obtain information from its environment and how human being furiously move their fingers in an attempt to discriminate the roughness of sandpaper. Mr. Furuyama thinks that this type of behavior does not originate from thoughts in the brain but from the environment.

Research on what the invariants are in perception of the environment has only recently begun, but Furuyama and his colleagues believe that their research will provide new points of view with regard to “perceptually-based information” and “intelligence.” NII’s pill bug research may provide a completely new and unexpected answer to the question, “What is intelligence?”

(Written by Akiko Ikeda)

Fig. 3 Pill bug with a Straw-like Teflon Tube on its Antennae
The antennae are extended by attaching a tube to them that was 1.5 times longer than a bare antenna. (One may wonder whether the pill bug is annoyed...)

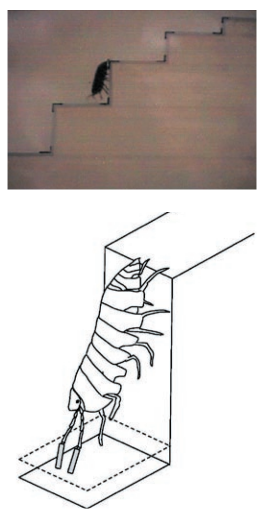


Fig. 4 Pill bug Limit Descent Distance
Normally, a pill bug that is 11 mm in length can only descend up to 12 mm. With the tubes attached to its antennae, it can descend up to 15 mm. This is only temporary, however. An exposure to the environment for ten minutes before the start of the test allowed the pill bugs to revert to the 12 mm limit.

NII ESSAY

This is Not the Age of the Three Kingdoms

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The setting for the Tale of Three Kingdoms is the China of approximately 200 A. D.. In the story, heroes in each of the three kingdoms fight to build their respective nations. One of the reasons for the appeal of this tale can be found in the interactions of several unique individuals. Liu Bei had many strong military commanders, but initially he suffered defeat after defeat. After obtaining the services of military strategist Zhuge Liang, however, he was able to achieve victory based on Zhuge Liang's strategic planning. This encounter enabled Liu Bei to make up for his own lack of knowledge and make his mark on history.

Amalgamation of Knowledge Creates More Powerful Knowledge

To some people, the word "researcher" may conjure up images of a person sitting alone in a room, silently thinking about things. With the increasing compartmentalization of science in recent years, however, there are limits to what can be accomplished by one person. The field of informatics in particular is an interdisciplinary one and requires the amalgamation of various types of knowledge possessed by many different people. This knowledge can be complemented with that of other people to arrive at new solutions to problems that formerly could not be resolved with the knowledge possessed by a single person.

The encounter between Liu Bei and Zhuge Liang took place as a result of a private introduction by someone. Naturally in those days personal relationships were the only way to discover people who possessed the knowledge that one needed.

These days, however, researchers live in a very different world. The knowledge obtained by researchers is made available in the form of academic papers that are distributed throughout the world. These papers also list the names of other researchers that contributed to that study, so simply by sitting in front of a computer one can use data mining technologies to easily discover individuals and groups throughout the world who possess the knowledge that one needs. It is even becoming possible to determine what connections between people will produce new knowledge in the future.

An Informatics That Can Help Resolve Humanity's Problems

In recent years, information about individuals has come to extend to various venues, including not only information in academic papers that concerns researchers but even social networking services used by the general public. This information can be used to learn what type of people possess the knowledge one needs and even what type of connections between people will produce new knowledge. I believe that informatics technologies can link knowledge on a worldwide scale and can go beyond the limitations of human knowledge to find solutions to the problems that currently face humanity.

Weaving Information into Knowledge

NII

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