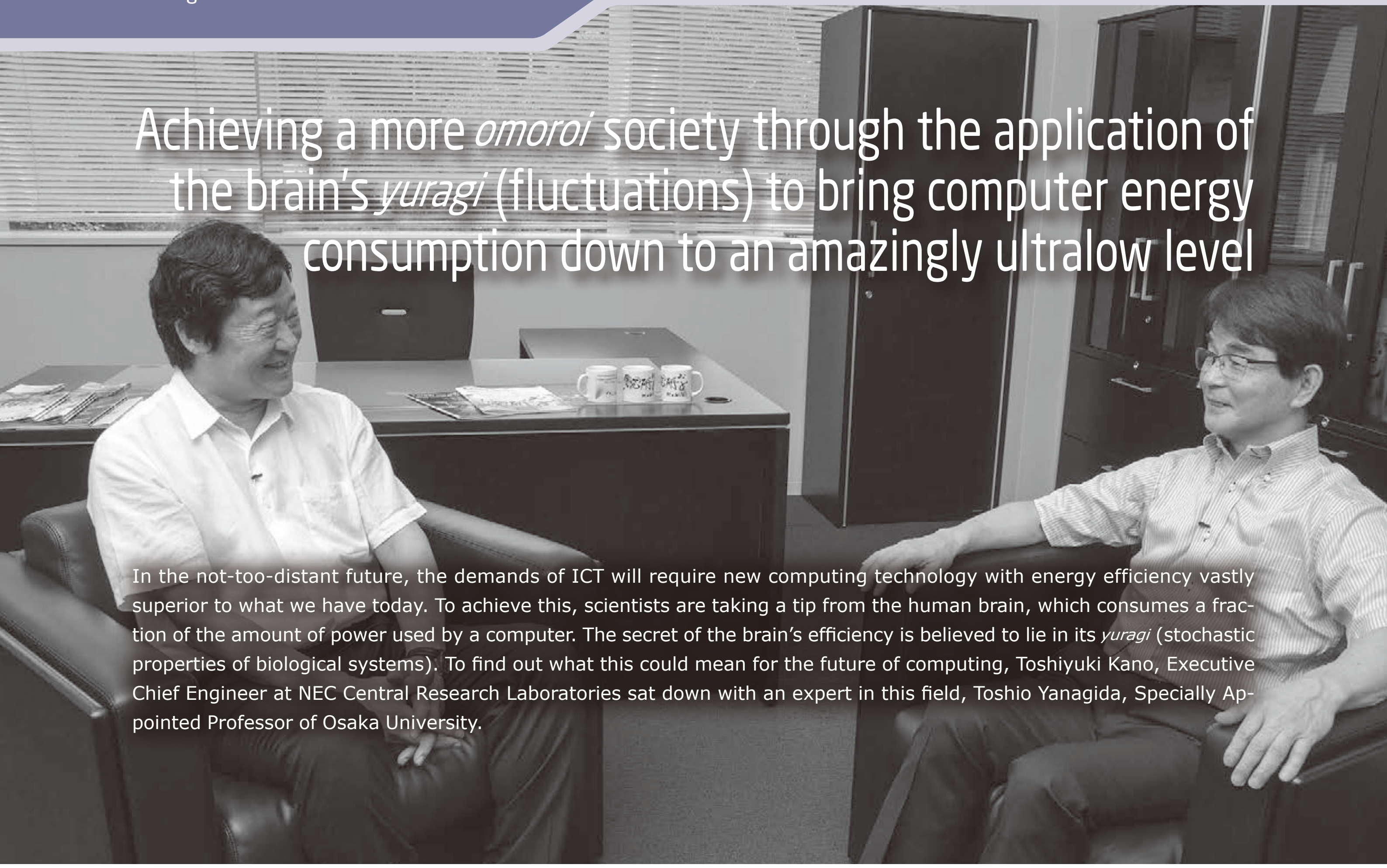

Achieving a more *omoroi* society through the application of the brain's *yuragi* (fluctuations) to bring computer energy consumption down to an amazingly ultralow level

In the not-too-distant future, the demands of ICT will require new computing technology with energy efficiency vastly superior to what we have today. To achieve this, scientists are taking a tip from the human brain, which consumes a fraction of the amount of power used by a computer. The secret of the brain's efficiency is believed to lie in its *yuragi* (stochastic properties of biological systems). To find out what this could mean for the future of computing, Toshiyuki Kano, Executive Chief Engineer at NEC Central Research Laboratories sat down with an expert in this field, Toshio Yanagida, Specially Appointed Professor of Osaka University.

Toshio Yanagida

PhD in Engineering
Specially Appointed Professors of Graduate Schools of Information Science and Technology and of Frontier Biosciences, Osaka University
Director, NEC Brain-Inspired Computing Research Alliance Laboratories

Pioneer in single-molecule measurement using fluorescence microscopy and nano-manipulation by laser trap. Serves as directors at RIKEN's Quantitative Biology Center and NICT/Osaka University's Center for Information and Neural Networks. Also heads the NEC Brain-Inspired Computing Research Alliance Laboratory, jointly established by Osaka University and NEC in April 2016.

Toshiyuki Kano

Executive Chief Engineer, NEC Central Research Laboratories

Specializes in information networking and cloud computing. Serves as deputy director of the NEC Brain-Inspired Computing Research Alliance Laboratories where he is currently engaged in planning technological strategy.

Powerful synergy created by researchers from many different fields working together

Kano: You head the Center for Information and Neural Networks - or CiNet. Can you start by explaining exactly what it is and what it does?

Yanagida: CiNet started in 2011 at research centers belonging to the National Institute of Information and Communication Technology, or NICT, and to Osaka University. Our objective was to develop leading-edge technology with intelligent functions, while at the same time improving our understanding of how the human brain works.

CiNet was formally established with the opening of the CiNet research building in 2013. Since then, we have been conducting basic research into brain functionality and applied research in areas such as information and communications technology, brain-machine interface, brain function measurement, and robot engineering. We have over 200 researchers and graduate students working here.

Kano: Back in the winter of 2013, Professor Masayuki Murata of the Graduate School of Information Science and Technology at Osaka University told me that you wanted to make "brain chips" so I should go and talk to you. That was the first time we met. In April 2016, Osaka University and NEC opened the NEC Brain-Inspired Computing Research Alliance Laboratories in the CiNet research building. That was the beginning of our joint research into brain-inspired computing technology.Anyway, what was it that got you thinking about making brain chips?

Yanagida: I belonged to the electrical engineering department at college and was studying semiconductor physics. Then I got a job at an electronics component manufacturer and subsequently decided to switch the focus of my research to biology. The reason I did that was because the basic concept of semiconductor physics was well understood by that time and was transitioning to practical applications, and I thought I would like to do research in a different undeveloped area. So I started thinking about making brain chips that would work like a living organism.

Kano: Why did you choose NEC as a partner to make brain chips?

Yanagida: As a matter of fact, when I was a senior at college, I did an internship at the NEC Central Research Laboratories. So I already was quite familiar with NEC.

Kano: But you didn't join NEC after your internship, did you?

Yanagida: No, I didn't. There were many very competent people at the Central Research Laboratories. But it seemed kind of too clever so I was reluctant to join them because - if you don't mind me saying - it just didn't look like *omoroi* in the Osaka dialect (laughs). To tell you the truth, I just wasn't capable of keeping up with them. But when I look back now, it was what triggered me to change my subject to biology.

Kano: When you proposed this joint research project to us, I was just about at the end of one stage of the research I was involved in at the time and I was wondering what my next challenge would be. So when I heard about the idea of brain chips, I thought maybe we could apply the mechanism of the brain to computers. And when I talked to you, I thought, hey, it would be interesting.

By the way, you are also the director of RIKEN's QBiC and it's also doing joint research with NEC. So there are actually four entities - CiNet, QBiC, Osaka University, and NEC - conducting joint research. What do you think?

Yanagida: The significance of using living organisms as a model is not to break everything down into its constituent components such as the brain and molecules, but rather to find out what basic principles they all have in common. The real significance of this research is that researchers from different research areas are working together - for example, the human brain for CiNet, molecules and cells for QBiC, information systems for Osaka University, and semiconductors and IT for NEC.

Developing a computer with ultra-low power consumption by applying the concept of brain *yuragi*

Kano: You are researching biological systems focusing on brain *yuragi*. What do you think we can learn from living organisms that's applicable to semiconductor technology?

Yanagida: What really distinguishes biological systems from semiconductor-based digital systems is that the former is incredibly more energy-efficient than the latter. For example, AlphaGo, a specialized computer program designed to play the board game *go*, was in the news recently when it beat a human opponent. To do that, it had to use 250 kilowatts of electricity. The human brain, on the other hand, only consumes about 20 watts. This includes the energy to keep neurons alive. So we developed technology that measures the brain temperature using MRI and MRS at high resolution and tried to find the difference in energy consumption between when the brain is at rest and when it is thinking. The difference was just 1 watt. When you look at it on a cellular level, the cell uses a mere 1 picowatt, although it is a complex system and processes massive information. If we can figure out how such complex systems can be controlled using such a small amount of energy, we might be able to apply the same principles to the creation of an ultra-low power consumption computer.

Kano: And the secret to that is in the *yuragi*. Am I right?

Yanagida: Exactly. One of the reasons the computer needs so much energy is that it has to shut off noise. That's not the case with the brain - running at 1-20 watts - and the cell - running at 1 picowatt. Rather than shutting off noise, we think they actually take advantage of it. Noise may be something that we humans consider a nuisance, but that's not necessarily the case for other living organisms. So we developed single-molecular nano measurement technology that can directly observe the activity of a single protein molecule. Then we observed a motor protein molecule called myosin that's responsible for muscle contraction. What we found is that myosin uses a form of group-based autonomous cooperation by taking advantage of the *yuragi* of thermal motion.

Kano: Is that what you mean by "shaky state"?

Yanagida: What I mean by "shaky" is that a transition is taking place. In terms of engineering, you could see it as performing attractor selection using *yuragi*. Today's computers derive answers by processing all data correctly - which means an outrageous amount of computation when things get complicated and *that* means it has to use an equally outrageous amount of energy.

In the meantime, chemical reactions in the brain and cells are extremely complex. If you tried to accurately control all of these reactions using computers, you'd need an unbelievable amount of computation.

For example, the number of synapses that connect the cerebral neurons is about 100 trillion. Even if this is controlled simply with 0 and 1, the number of combinations would be at least two to the power of 100 trillion. If these combinations are calculated with supercomputers, even a few dozen billion nuclear power generators wouldn't be enough. But look at our brain. It only uses 1-20 watts. And it's hard to believe that it controls all the chemical reactions. How does it do it? Chemical reactions do not occur independently. Because the energy they use is almost indistinguishable from thermal noise, they can autonomously achieve metastable states, known as attractors, while interfering with each other using *yuragi*. In other words, reduction with a high degree of freedom takes place spontaneously. The idea is that a limited number of states are selected by the *yuragi*. When brain activity is actually measured, you find that it undergoes spontaneous fluctuation (*yuragi*) around various states from the unconscious state. That is to say, the brain prepares attractors that have the potential to take the next action even when it's in an idle state and it chooses the appropriate attractor while fluctuating back and forth.

Kano: You also conduct applied studies in networks and robots that use *yuragi* in a similar way to living organisms, right?

Yanagida: Right. Professor Masayuki Murata is working on networks, and Professor Hiroshi Ishiguro is developing robots that are more like humans. If we tried to control these networks and robots with digital systems, calculations on the order of 10 to the power of a few dozens would be required to control a vast amount of different elements and reactions, resulting in an explosion of combinations. However, if they can figure out which alternative is correct while fluctuating back and forth between different states, rather than between individual elements, then it should be possible to control those networks and systems with very little energy, even if they are complicated.

Kano: It's been a few months since Osaka University and NEC launched the NEC Brain-Inspired Computing Research Alliance Laboratories and we asked you to head it. We look forward to building new computer systems using the *yuragi* mechanism while learning many things from you. We'd love it if you could give us some advice on how to expand our perspective.

Yanagida: As I said, you can't help but end up having a combination explosion when you try to control everything at the element level. So it wouldn't work. The secret lies in the mechanism in which you insert noise into each element to make it free while activating interaction between the elements to limit the number of possibilities or conditions that come up to the surface. So you can choose a possibility instead of having an explosion of combinations. Let's take a familiar phenomenon as an example. If you leave a bowl of *miso* soup on the table for a while, a pattern is generated in the soup due to the convection phenomenon. What we are trying to do is control this pattern using macro parameters such as the boundary condition and temperature rather than correctly describing everything on the molecular level. You could say that control is possible as long as you use macro thermodynamic parameters to design engines even if you know nothing about details on the molecular level.

Kano: If we try to simulate *miso* soup using existing technology, the only way would be like allocating a 64-bit-or-so address to each grain of *miso* and theoretically calculating the collision of every single molecule. That's not the way you do it. Is it like a new order is created through a formation of things moving autonomously into groups?

Yanagida: Yes. If I elaborate on it further, the process of creation of new value is also *yuragi*. Just like the pattern in the *miso* soup changes when the temperature changes by 0.1°C, we have to take account of human behavior in which we derive answers while taking action and making decisions according to various environmental changes. But the brain doesn't seem to have such a beautiful algorithm, so I think there is a possibility we can achieve that using an unexpectedly simple mechanism such as deep learning.

How should we interpret singularity?

Kano: Changing the subject, the singularity or the so-called 2045 problem is getting some attention lately. What do you think about this?

Yanagida: In a sense, unraveling the principles of the brain is more terrifying and carries a heavier burden of responsibility than developing nuclear energy. I'm sure there would be more than a few researchers who would quit if we got close to the point of being able to elucidate everything about the brain. If AI were to surpass humans and it looked like there could be serious consequences, it'd be necessary bring social scientists, politicians, and people from all walks of life into the discussion, not just AI researchers. Yet I'm optimistic about it. I don't think the so-called singularity or the 2045 problem will happen. And I have a feeling that even many brain researchers don't buy that either. I mean, not in terms of technology but rather of mentality, so to speak.

Kano: At NEC, we want to be the world's top player in the AI field. For that reason, we are actually seeking to generate the singularity. We think it's important to have an attitude where everything that can be imagined or anticipated we try to achieve, so we want to create technology that will accelerate the singularity. The era in which semiconductors continue evolving according to Moore's law has come to an end. The evolution of ICT will stall unless we ignite new innovation.

People are predicting that 10 billion "things" will be connected by IoT, but conventional technology cannot cope with this. We need a paradigm shift of the computer itself. Until we achieve that, we can't stop the evolution of AI technology whether it is called the singularity or otherwise.

As you said, we have to do something if things start to look serious. But by that point, if a human-surpassing AI has come into existence, it may be able to overcome any rules we try to impose on it. So I think we should get together with experts from a wide variety of fields and draft a roadmap now that prevents runaway AI.

Yanagida: As to the question of what creates the singularity, AI is one of the most effective ways to solve the issue you are talking - such as what to do when 10 billion things are connected by IoT. The total amount of digital information today is 1.8 zettabytes, and that's expected to increase twentyfold in the next ten years. So if the energy used by computer-related equipment today accounts for just a few percent of total power consumption, that means that it will account for a few dozen percent ten years from now. The key to solving this grave problem lies in the principles of life. If we succeed in turning them into actual applications, we'll be able to dramatically reduce the energy used by computers. The significance of our joint research is precisely in responding to such qualitative changes.

Kano: I think you are right. We will knuckle down and work even harder.

"*Omoroi* research" will create an "*omoroi* society."

Kano: Which brings me back to "*omoroi* research" ("fun research") that you are always talking about. When did you start saying "*omoroi* research"?

Yanagida: Maybe it was in 2001 when I became the research director at Osaka University's Graduate School of Frontier Biosciences. What triggered me to start saying that was when I started questioning the way that science and technology were developing. In the 20th century, everything was focused on convenience. Now in the 21st century, qualitative and spiritual wealth has become important. When we think about what quality and wealth are, we Osakans would say "*omoroi* society."

Kano: What nuance does "*omoroi*" have?

Yanagida: It's an idea that arises from the question of how exactly do we benefit society by avidly improving scientific and technological levels, increasing productivity, promoting energy saving, and making new drugs. Do people really want science and technology to keep progressing? Maybe there are more people who feel uncomfortable about it.

"Stop the research. There is no point in making things even more convenient and making people's life spans even longer." That's what my wife says to me all the time (laughs). So maybe we should change our way of thinking. It's not that what we should do without science and technology. Rather we should create an "*omoroi* society" in a backcasting manner, so to speak. And that will make everyone happy. With this hope in our mind, we call our research "*omoroi* research." Maybe it's hard to understand for non-Osakans. It's something that wells up from the bottom of your body and mind.

Kano: Like trembling with joy?

Yanagida: Yes, fun to the point of carrying us away. It's neither "interesting" nor "smart." It's like every drop of our blood tingles with excitement. I think from now on we should think about society, science, and technology that will make everyone unconsciously feel, "Isn't it fun?"

Kano: I myself have had a chance to work with and talk with scholars in different specialties in the joint research with Osaka University. And I get carried away by every single thing that comes up in the conversation. I just find it all incredibly exciting. Maybe that aspect supports your "*omoroi* research."

Yanagida: Unless you conduct "*omoroi* research," you can't help create an "*omoroi* society." I look forward to continuing to conduct "*omoroi* research" with NEC.

Kano: I know you think we're all really serious at NEC, but I hope we can learn from you and become more innovative by introducing a little *omoroi* into our corporate culture and help you create an "*omoroi* society." Thank you very much.

- This article is edited based on an interview conducted in July 2016.

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