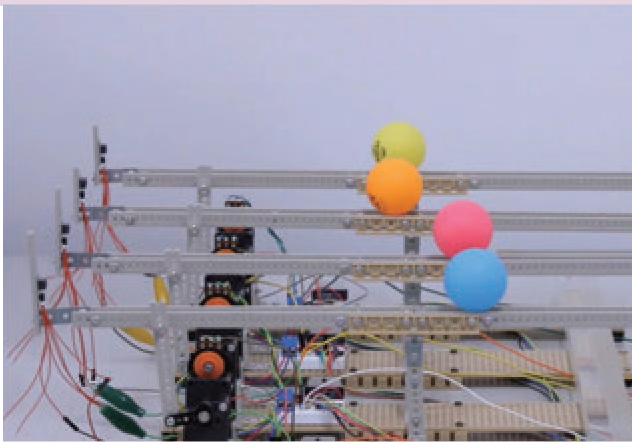
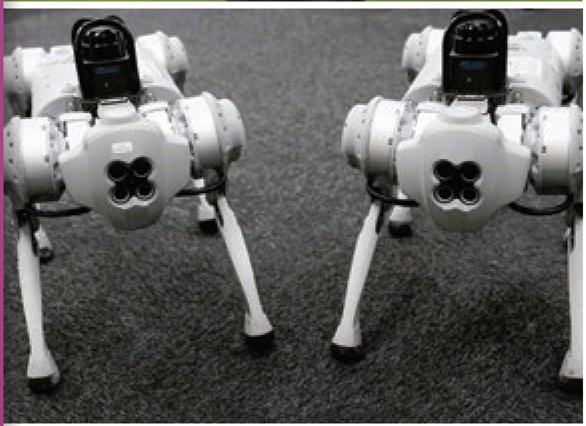
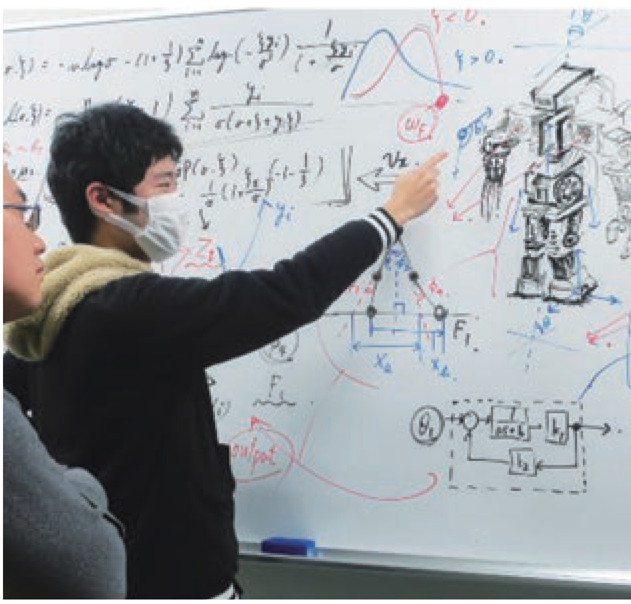
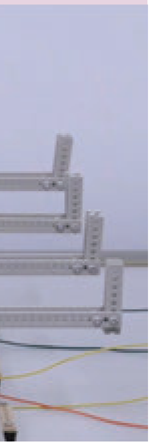
New Frontier in Informatics and Systems

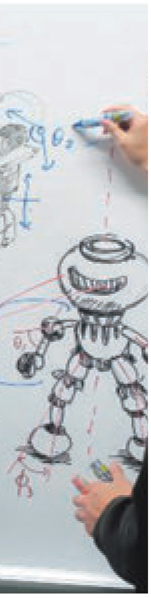
Research and education in the Course of Systems Science are concerned with a new and unified approach to a variety of technological problems arising in computer communication networks, mechatronics systems, cyber-physical systems, medical information systems, and biological systems.
In particular, we are seeking theoretical methodologies applicable to these complex systems of large scales.
Emphasis is also placed upon understanding of complicated mutual interactions among human-beings, systems and environments.











Putting Information into Action

The Systems Science Course is focused on mathematically grasping common dynamic pictures of systems consisting of multiple objects, both for understanding such systems more deeply and for studying methodologies for controlling these pictures. Advances in machine learning technology and growing computational power have made it possible to use AI to generate data analysis results that include some interpretation of static data, or even to generate new data. Nevertheless, it is still a significant challenge to develop methodologies to understand and control dynamic systems in the real world from data. For example, for decision-making problems in video games or other kinds of virtual reality systems, a machine learning technique known as reinforcement learning has attracted attention by showing that it can learn from experience and acquire strategies better than humans. However, robots and other machines are still not capable of flexibly judging situations and taking responsive action like humans do in the real world. These kinds of technologies are commonly required in a wide range of other fields (aside from robots), including economics, energy, and autonomous vehicles. Students in the Systems Science Course study how information should be used for making behavioral choices and how the human brain uses the data it obtains for making decisions, and they can learn useful methodologies for understanding and applying such knowledge. The course offers a learning environment for cultivating essential insights for pursuing this kind research.

Jun Morimoto

Professor, Systems Science Course

March 2001: Received a doctoral degree from Nara Institute of Science and Technology (NAIST). April 2001: Postdoctoral Fellow, The Robotics Institute, Carnegie Mellon University. April 2008: Head of Department (concurrent position), Department of brain-robot interface, Computational Neuroscience Laboratories, Advanced Telecommunications Research Institute International (ATR), December 2019: Team Leader, Man-Machine Collaboration Research Team, Guardian Robotics Project, RIKEN. April 2021: Professor, Systems Science Course, Graduate School of Informatics, Kyoto University.

Learning“How”to Address Unknown Issues

In the Course of Systems Science, we are working on scientific research across a variety of fields. For instance, we use sensors to measure information from biological and mechanical systems in order to infer their internal states, project their future behavior, and control them. Also, by elucidating how the brain’ s neural circuits process information, we are working to create a system that is capable of not only learning and making inferences but also adjusting itself to an uncertain and changing environment. Furthermore, we are studying algorithms and theory for making inferences and discoveries from the vast amount of image and document data available online and elsewhere, together with the high-performance parallel computing that makes such systems possible.

Not only are these research fields related to systems but, in many cases, research projects conducted in these fields share a common approach - researchers conduct their studies through mathematical models, constantly aware of the flow of information. Using mathematical models, researchers can treat different objects as if they were the same, thereby gaining broad perspectives.

For example, by using a “graph” that consists of vertexes and edges, researchers can express not only networks (neural networks, website link structures, railway systems, etc.) but also structures of relevant data, such as tagged images on social media. Because the objects thus modeled can be treated mathematically, scientists can advance their research even further. In the field of machine learning, significant research is being carried out into a technique called graph embedding for efficient information search. One drawback of this technique was that a graph with a hierarchical structure is not expressed very well in Euclidean space. This problem has been solved by a mathematical idea of using a curved space called “hyperbolic space.”

Another characteristic of students/researchers in the Course of Systems Science is strongly conscious of systems in the real world, in addition to conducting mathematical study at an abstract level. Issues in the real world can be often solved with established methods, but very new methods occasionally arise out of addressing the challenges posed by difficulties. In the study of methodology of statistics, for instance, we are constantly exploring new ways to make inferences and predictions from data. What is important for such a situation is again knowledge in mathematical fields such as probability theory and optimization.

Thus, mathematical foundations and applications interact with each other in the Course of Systems Science. Students are invited to learn an aspect of this scientific discipline, broaden their perspectives, and acquire universal approaches and attitudes; that is, “how” to address unknown issues, through research activities and lectures at Graduate School of Informatics. We would be delighted if their experience here motivates them to address unknown issues and find clues to developing new techniques or academic disciplines.

Hidetoshi Shimodaira

Systems Science Course

March 1990: Received a bachelor’s degree from the Department of Mathematical Engineering and Information Physics, School of Engineering, The University of Tokyo. March 1995: Received a doctoral degree from the Department of Mathematical Engineering and Information Physics, Graduate School of Engineering, The University of Tokyo. April 1995: Received a Research Fellowship for Young Scientists from the Japan Society for the Promotion of Science. July 1996: Assistant Professor, Department of Prediction and Control, Institute of Statistical Mathematics. June 2002: Lecturer, Department of Mathematical and Computing Sciences, Graduate School of Information Science and Engineering, Tokyo Institute of Technology. May 2005: Associate Professor, Department of Mathematical and Computing Sciences, Graduate School of Information Science and Engineering, Tokyo Institute of Technology. April 2012: Professor, Division of Mathematical Science, Graduate School of Engineering Science, Osaka University. September 2016-present: Team Leader (concurrent position), Mathematical Statistics Team, RIKEN Center for Advanced Intelligence Project (AIP). April 2017-present: Professor, Department of Systems Science, Graduate School of Informatics, Kyoto University.

Outline

Group and Teaching Staff

Group	Teaching Staff
Mechanical Systems Control	Shun-ichi Azuma/Professor Ikumi Itano/Assistant Professor
Human Systems	Manabu Kano/Professor Kana Eguchi/Senior Lecturer Shota Kato/Assistant Professor
Integrated Dynamical Systems	Toshiyuki Ohtsuka/Professor Kenta Hoshino/Assistant Professor
Mobility Research	Osamu Nishihara/Associate Professor
Mathematical Information Systems	Toshiyuki Tanaka/Professor Tomoyuki Obuchi/Associate Professor
Statistical Intelligence	Hidetoshi Shimodaira/Professor Junya Honda/Associate Professor
Learning Machines	Jun Morimoto/Professor Satoshi Yagi/Assistant Professor
Integrated Systems Biology	Shin Ishii/Professor Hideaki Shimazaki/Associate Professor Jaepyung Hwang/Program-Specific Assistant Professor
Biomedical Engineering	Hirohiko Imai/Assistant Professor
Computational Neuroscience (Adjunct Unit)	Mitsuo Kawato /Adjunct Professor (Advanced Telecommunications Research Institute International) Takuya Isomura/Adjunct Professor Louis Kang/Adjunct Associate Professor (RIKEN) Kenji Doya/Adjunct Professor (Okinawa Institute of Science and Technology)

Curriculum of Systems Science Course

Doctoral Program (Informatics)

3rd — Doctoral Thesis

2nd, 1st — **Subjects provided by the Course (total 6 credits including 4 credits from seminars)**
Seminar on Systems Science, Adv. *E* (2 credits)
Seminar on Human Machine Symbiosis, Advanced A, B *E*, Seminar on Systems Synthesis, Advanced A, B *E*
Seminar on Systems Informatics, Advanced A, B *E* (2 credits each)

Research Guidance

Master's Program (Informatics)

2nd — Master's Thesis

2nd, 1st — **Subjects provided by the Course (optional 8 credits or more)**

Advanced Subjects
Systems Sciences, Advanced II, Control Theory for Mechanical Systems, Theory of Human - Machine Systems, Theory of Integrated Dynamical Systems, Theory of Learning Machines, Integrated Systems Biology, Medical Information Systems, Modeling and Problem-Solving of Complex Systems, Systems Biology E (2 credits each)
Computational Neuroscience, Computational Intelligence (1 credit each)

Recommended Subjects by Other Courses
Information-Theoretic Systems Theory (DS)
Statistical Systems Theory (DS)
(2 credits each)

Basic Subjects
Systems Sciences, Adv. I (2 credits)

Seminars and exercises for Master's thesis (Mandatory 10 credits)
Advanced Study in System Science 2*E*
(Assigned to M2, 5 credits)
Advanced Study in System Science 1*E*
(Assigned to M1, 5 credits)

General Subjects provided by the School

Interdisciplinary subjects of the Perspectives in Informatics (Mandatory 2 credits)
Perspectives in Informatics 1 Perspectives in Informatics 2
Perspectives in Informatics 3*E* Perspectives in Informatics 4*E*
Perspectives in Informatics 5*E* (2 credits each)

Perspectives in Platform Studies (2 credits), Computational Science, Introduction (2 credits), Computational Science, Exercise A (1 credit), Information and Intellectual Property (2 credits), Innovation and Information (2 credits), Information Analysis and Management (2 credit), Information Analysis and Management, Exercise (1 credit), Social Contributions through Informatics *E* (1 credit), Internship in the Field of Informatics *E* (1 credit)

Specific subjects provided by the school

Prior to admission: Differential and Integral Calculus | Linear algebra | Fundamental background of the subjects provided by the Course, etc.

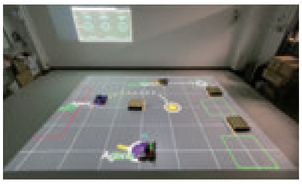
Note: Subjects marked with the letter "E" will be provided in English.

Mechanical Systems Control

Control Theory and Applications

Control theory is the academic foundation for designing the motion of dynamic systems. In this lab, we develop innovative control theory and deploy the results to leading-edge scientific and industrial applications. We also challenge ourselves to create dynamic systems that open up new possibilities for the future. Through their research activities, students cultivate the research skills needed to become a systems control leader in academia and industry.

[Shun-ichi Azuma , Ikumi Itano]



Control of conveyor robots

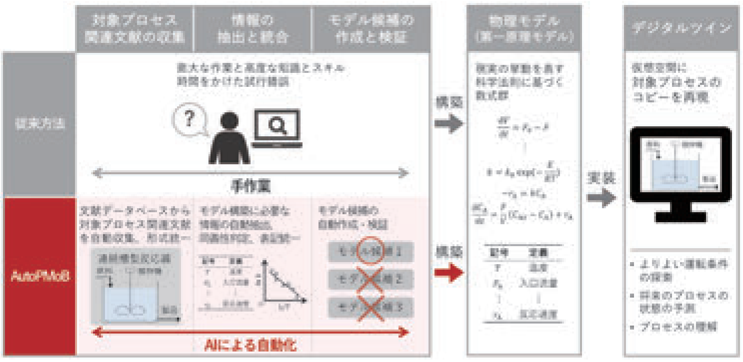
Control of a swarm robot system

Human Systems

Aiming to develop human-centered system design methodology

The society that values humankind is called for now. The situation is similar in the latest industrial science and technology, thus novel system design methodology is required from various positions such as those who develop technology and those who use technology. We perform basic research on developing human-centered system design methodology through understanding the mechanism of human recognition and action. In order to contribute our results to our society, we also perform applied research in various industries such as semiconductor, pharmaceutical, steel, chemical, and automobile. Furthermore, through these studies, we conduct the education that aims at training talented people to take a broad view of things and have high aims.

[Manabu Kano , Kana Eguchi , Shota Kato]



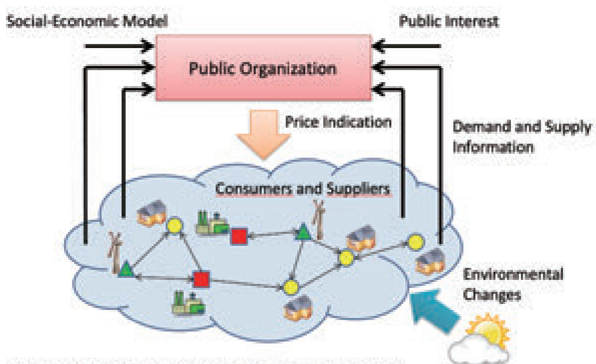
Development of AI for automatically developing physical models from literature information

Integrated Dynamical Systems

Toward harmonious coexistence of a diversity of systems

For analysis and design of novel systems to realize symbiosis and synergy of various objects including humans, machines, societies, and environments, it is essential to find out universal principles in modeling, analysis, design, and control of dynamical systems. To this end, we conduct researches on novel methodologies to deal with nonlinearities, uncertainties, and dynamic optimization , which are often fundamental difficulties in various problems. We also apply our methodologies to a wide range of fields, aiming practical as well as theoretical education and research.

[Toshiyuki Ohtsuka , Kenta Hoshino]



Example of System Consisting of Humans, Machines, Society, and Environment

Outline

Mobility Research

Optimizations for design and operation

The research interest of this group mostly lies in mobility technologies, such as vehicle stability controls, which have found practical applications in active safety systems for reducing car accidents, energy efficiency improvements, and collision avoidance systems. These research topics are being investigated with a view toward precise optimization within the constraints of their dynamical properties.

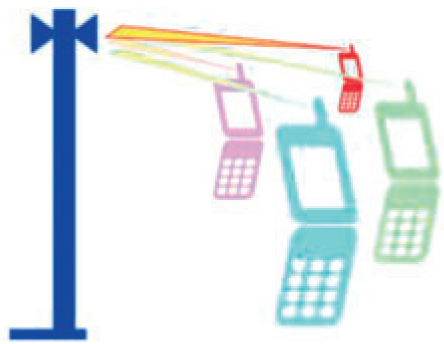
[Osamu Nishihara]

Mathematical Information Systems

The mathematics of large-scale probability models

We aim to develop a mathematical, cross-disciplinary understanding of a diversity of problems related to information processing under environments with uncertainty. Many problems in information processing today can be formulated with large-scale probability modeling, and using the regularities that arise thanks to the scale of these probability models is the key to achieving advanced information processing. We are working on topics in areas including statistical mechanics of information, which addresses information mathematics of large-scale probability models through analogy with statistical mechanics, and theoretical problems related to statistical machine learning, deep learning, and data science.

[Toshiyuki Tanaka , Tomoyuki Obuchi]



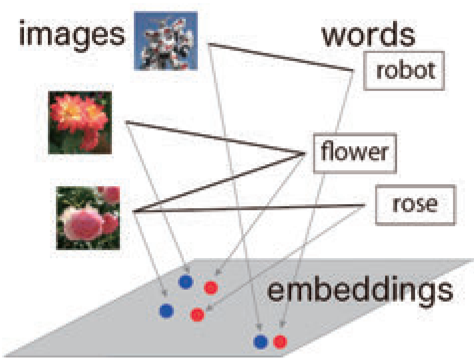
Digital communications as data science: the key to realizing high-performance digital communications lies in extracting the required information from "data" in which numerous signals interfere.

Statistical Intelligence

Statistics and machine learning: Theory and applications

Statistics is playing important roles as a theoretical framework for fast-moving fields such as big data, data mining, and artificial intelligence. Statistics provide methodologies for inductive inference from data with consideration of randomness. Recent years have seen rapid progress in machine learning, from information extraction from a massive quantity of data to decision-making with a small quantity of data, on the basis of this approach. Through addressing real-world data, we are developing new statistical methods with emphasis on mathematics and programming skills.

[Hidetoshi Shimodaira , Junya Honda]



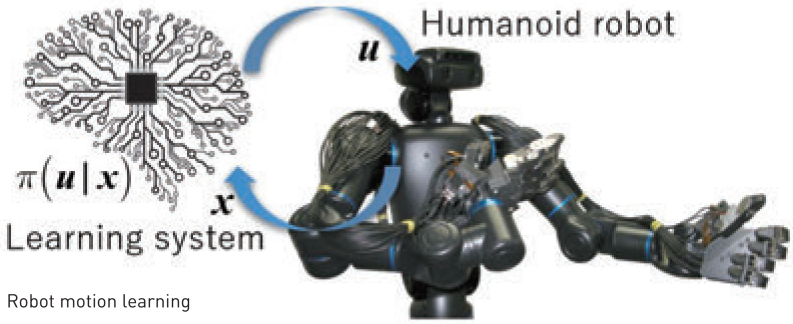
Multiveriate analysis of multiple domains.
Dimensionality reduction via graph-embeddings and bidirectional search between images and tags.

Learning Machines

Toward the realization of learning machines with bodies

The fusion field of artificial intelligence and robotics is expected to be a field that will produce the basic industrial technologies of the future. We will explore methodologies to enable machines with bodies to learn skillfully and produce desired behaviors from limited experience and data, just like humans. In order to realize learning machines that can operate in a dynamically changing open environment, we conduct education and research on basic technologies for robot motion learning methods, mathematical models of multi-degree-of-freedom robots, and human motion intention estimation.

[Jun Morimoto , Satoshi Yagi]



Robot motion learning

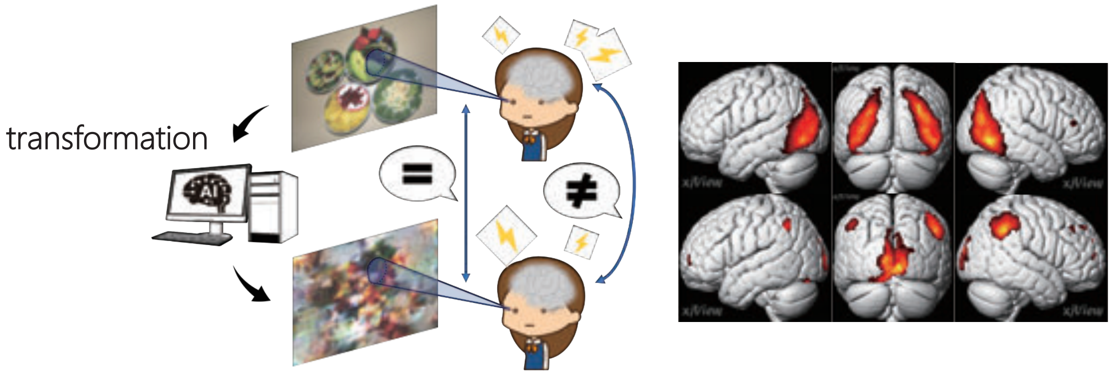
Integrated Systems Biology

Constructing models of information processing in life and intelligent systems

Intelligence (the brain) and life are complex systems that adapt to uncertain and changing environments. Aiming at elucidating the principles of information processing in those complicated systems, we are focusing on researches in the areas of computational neuroscience, systems biology, and bioinformatics, while conducting applied research, such as the application of these principles in the building of robots that have adaptive information processing mechanisms that we have learned about through our studies of living organisms.

We conduct interdisciplinary education and research on life systems.

[Shin Ishii , Hideaki Shimazaki , Jaepyung Hwang]



(Left) A deep learning-based image conversion technology, GAN-SID, converts "natural" images into "non-natural" images, preserving the parts that draw a person's attention (gaze)
(Right) Brain activity when viewing "natural" and "non-natural" images differs

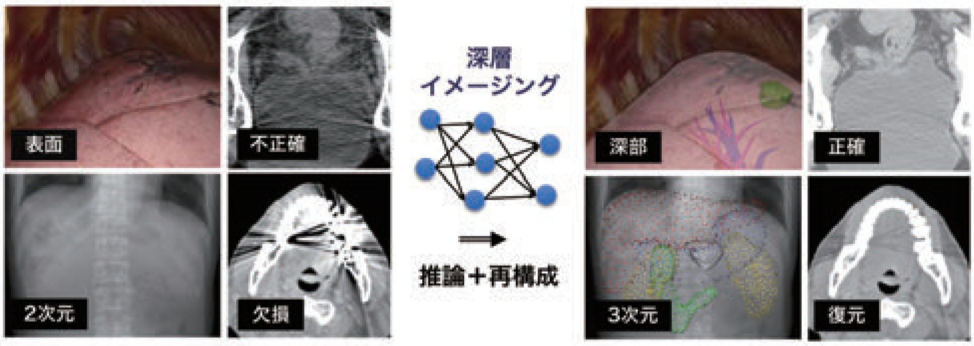
Outline

Biomedical Engineering

Learning bout the functions and physical characteristics of human bodies

Information systems such as data processing systems used in genetic analysis, diagnostic imaging systems are key technologies of modern medicine. Interdisciplinary collaboration is essential to further progress of medical systems' research that combines the two keywords of "bio" and "information." We carry out joint research projects with other research organizations in different fields including the Faculty of Medicine to develop surgical navigation systems, medical imaging techniques, and innovative methods to measure biological characteristics of human bodies.

[Hirohiko Imai]



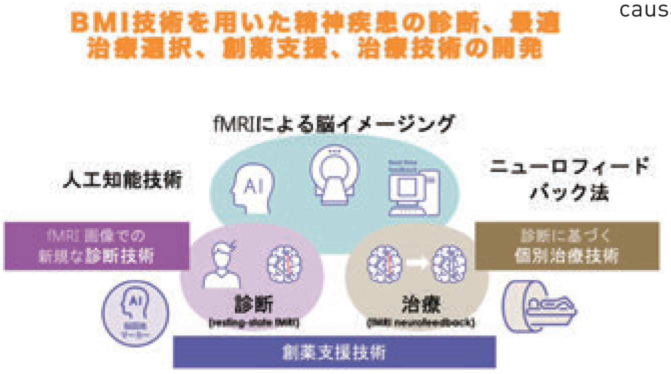
Medical image processing and modeling for diagnosis and treatment

Computational Neuroscience Adjunct Unit (In collaboration with Advanced Telecommunications Research Institute International)

■Knowing the brain by building the brain

(a) Connecting the brain and artificial intelligence

Humans and other animals are known to be capable of learning from a small sample. On the other hand, deep neural networks and other forms of current artificial intelligence today require learning samples around the same size as that of the parameters. Metacognition, multilayered generative and analytical models, and synchronization of neural activity are thought to be some of the secrets the brain holds. We aim to comprehend these and other characteristics of the brain and apply them in the development of the next generation of artificial intelligence.



(b) Brain-machine interface

Brain-machine interface technology that directly connects the human brain with machines is attracting attention as a type of "brain tech" that can improve the capabilities not only of people with impaired sensory, mobility, and central nervous functions, but also the ablebodied. Specifically, it involves a process of applying decoding techniques to non-invasively measured brain activity data, and in return providing the subject with decoded neuro-feedback that induces activity patterns in specific parts of the brain in response to certain information. The goal is to utilize this method in the treatment of psychiatric disorders and establishment of a causal approach to neuroscience.

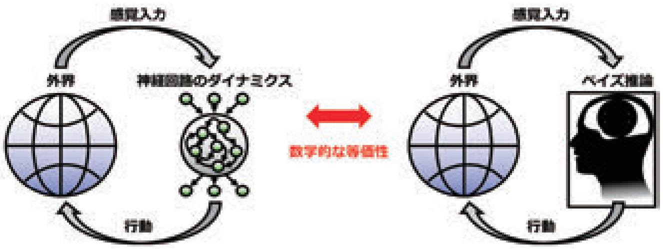
[Advanced Telecommunications Research Institute International : Mitsuo Kawato]

Computational Neuroscience Adjunct Unit (In collaboration with RIKEN)

■Exploring the mechanism for emergence of intelligence from neural circuits

How do the neural cells and synaptic couplings that constitute the brain achieve the kind of superior intelligence we find in living creatures? With a view to solving this mystery, we apply mathematical approaches such as dynamic theory, Bayesian statistics, machine learning, and the free energy principle to construct a universal theory of the brain. We focus particularly on topics such as internal model learning in the cerebral cortex and the mechanisms of memory and spatial awareness in the hippocampus. We aim to apply our findings in the development of new artificial intelligence algorithms, psychiatric disorder models and the like.

[RIKEN: Takuya Isomura, Louis Kang]



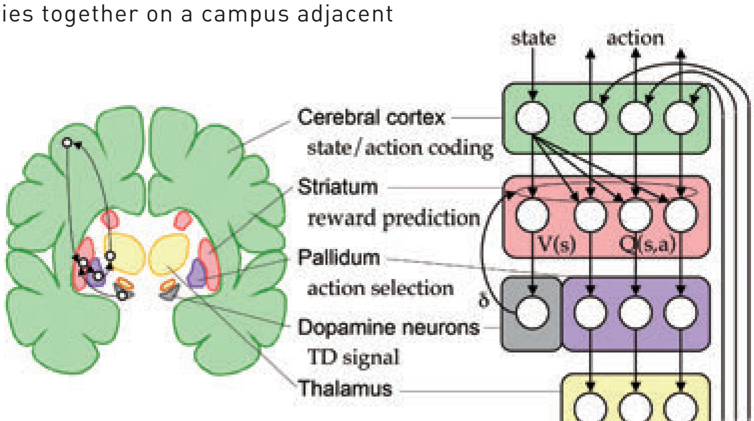
Neural circuit dynamics and plasticity potentially apply Bayesian inference

Computational Neuroscience Adjunct Unit (In collaboration with Okinawa Institute of Science and Technology)

■Shedding light on the computational theories of action learning and the learning systems of the brain

Humans and other animals can acquire new behaviors in line with various environments. What workings of the brain enable such acquisition? Answering this question requires a complementary approach to developing computational theories and algorithms on action learning in diverse environments and explicating the mechanisms of neural cells and molecular networks in the brain. Our lab brings researchers from a variety of different fields and countries together on a campus adjacent to the ocean in Okinawa to pursue research on topics including development of new algorithms for reinforcement learning and Bayesian inference, using those algorithms in action learning by robots and applications to bioinformatics, experiments in measurement and control of activity in the cerebral cortex, basal ganglia, and serotonin neurons of rats and mice, explication of human action learning and brain activity, and evolution of group behavior objectives and learning processes in robots.

[Okinawa Institute of Science and Technology: Kenji Doya]



The neural circuit of the basal ganglia and its functions in reinforcement learning