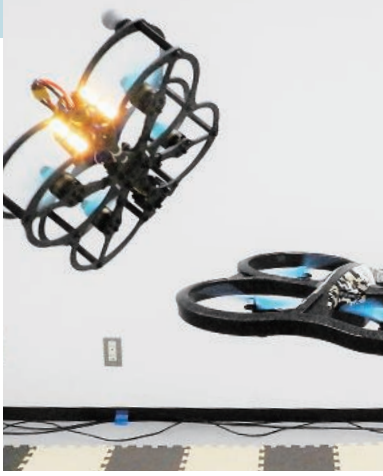
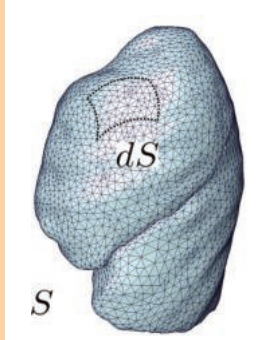
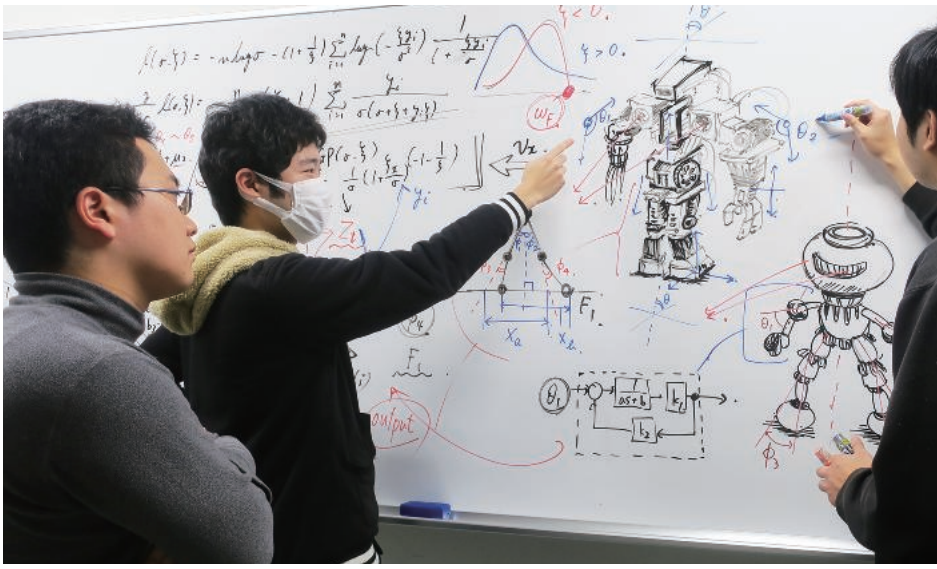
Department of Systems Science

New Frontier in Informatics and Systems

Research and education in the Department 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.







Capturing the Essence of "Motion" for Broad Application

Systems science is an academic approach that attempts to understand the world by abstracting all objects and viewing them as "systems." I specialize in dynamical systems theory and control engineering, which use mathematical expressions to shed light on general properties of "motion" and formulate principles for realizing desirable "motion." Different kinds of "motion" within events occurring around us, such as mechanical motion and natural phenomena, may have underlying commonality, no matter how unrelated to each other they may seem. Hence, dynamical systems theory and theories and algorithms of control engineering may be universally applicable in various fields, including vehicles, robots, aircraft, environment and energy, and society and economics. Students and researchers of such an academic discipline not only learn things that are practical in the real world but also enjoy the satisfaction of identifying essences without being misled by superficial differences among individual objects. I believe that there is beauty in the concept and methodology of systems science because it deals with the essential qualities of things. If you have an interest in principles common to various events that take place around us and wish to acquir knowled of systems science while cultivating the capability to penetrate to what is essential, then the Department of Systems Science is the place for you!

OHTSUKA Toshiyuki
Department of Systems Science

1990: Received a bachelor's degree from the Department of Aerospace Engineering, Faculty of Engineering, Tokyo Metropolitan Institute of Technology. 1995: Received a doctoral degree in engineering from the Graduate School of Engineering, Tokyo Metropolitan Institute of Technology. Previously Assistant Professor in the Institute of Engineering Mechanics, University of Tsukuba, Assistant Professor then Associate Professor in the Graduate School of Engineering, Osaka University, and Professor in the Graduate School of Engineering Science, Osaka University. 2013-present: Professor in the Department of Systems Science, Graduate School of Informatics, Kyoto University. Member of the Society of Instrument and Control Engineers, Institute of Systems, Control and Information Engineers, and IEEE. Engaged in research into nonlinear systems theory and theory and applications of optimal control.

Learning "How" to Address Unknown Issues

In the Department 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 Department 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 Department 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 the 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.

SHIMODAIRA Hidetoshi
Department of Systems Science

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

Divisions and Groups

Division	Group	Research and Education Topics	Professor (Associate Professor)
Human Machine Symbiosis	Mechanical Systems Control	Advanced Control Theories and Their Application to Mechanical Systems	
	Human Systems	Human-Centered System Design, Modeling, Virtual Sensing and Control	KANO Manabu
	Integrated Dynamical Systems	Optimal Control, Nonlinear Systems Theory, Distributed Control Theory	OHTSUKA Toshiyuki
	Mobility Research	Advanced Safety Vehicle, Active Safety, Collision Avoidance	(NISHIHARA Osamu)
Systems Synthesis	Adaptive Systems Theory	Learning, and Inference Theories and Their Applications	TANAKA Toshiyuki
	Mathematical System Theory	Statistics, Machine Learning	SHIMODAIRA Hidetoshi
	Computational Intelligence Systems (Adjunct Unit)	Data Mining and Pattern Recognition Based on Statistical Machine Learning	UEDA Naonori
Systems Informatics	Information Systems	Stochastic Modeling and Performance Analysis of Information and Service Systems	(MASUYAMA Hiroyuki)
	Integrated Systems Biology	Modeling of Intelligence (Brain) and Life, and Its Application	ISHII Shin
	Biomedical Engineering	Information Systems for the Medical Field	MATSUDA Tetsuya
	Computational Neuroscience (Adjunct Unit)	Computational Neuroscience, Brain Network Interface	KAWATO Mitsuo
		Neural Circuit Information Processing, Neural Information Code	FUKAI Tomoki
		Basal Ganglia, Neuromodulators, Evolutionary Robotics	DOYA Kenji
Applied Informatics (Affiliated)		Supercomputers and High-Performance Parallel Processing	NAKASHIMA Hiroshi

Graduate Curriculum

Courses for the Master's Program

Control Theory for Mechanical Systems
Theory of Human-Machine Systems
Modeling and Problem-Solving of Complex Systems
Theory of Integrated Dynamical Systems
Adaptive Systems Theory
Statistical Systems Theory
Theory of Information Systems
Theoretical Life-Science
Medical Information Systems
Supercomputing (Advanced)
Advanced Study in Systems Science 1
Industrial Mathematics and Design
Advanced Study in Systems Science 2
Systems Sciences 1 (Advanced)
Systems Sciences 2 (Advanced)

Courses for the Doctoral Program

Seminar on Systems Science (Advanced)
Seminar on Human Machine Symbiosis (Advanced)
Seminar on Systems Synthesis (Advanced)
Seminar on Systems Informatics (Advanced)
Seminar on Applied Informatics (Advanced)

Teaching Staff

(M) : Academic Center for Computing and Media Studies

Professors

KANO Manabu; OHTSUKA Toshiyuki; TANAKA Toshiyuki; SHIMODAIRA Hidetoshi; UEDA Naonori (NTT, Adjunct); ISHII Shin; MATSUDA Tetsuya; KAWATO Mitsuo (ATR, Adjunct); FUKAI Tomoki (RIKEN, Adjunct); DOYA Kenji (OIST, Adjunct); NAKASHIMA Hiroshi (M)

Associate Professors

NISHIHARA Osamu; SAKURAMA Kazunori; MASUYAMA Hiroyuki; NAKAO Megumi; FUKAZAWA Keiichiro (M)

Senior Lecturers

OBA Shigeyuki

Assistant Professors

HOSHINO Kenta; UEDA Yoshihiko; LIU Yan; HIGASHI Hiroshi; IMAI Hirohiko; HIRAISHI Tasuku (M)

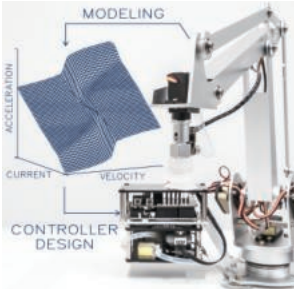
Human Machine Symbiosis

As computer networks spread and information systems become more sophisticated, the interrelationship between manmade systems (typified by machines) and humankind and the environment (including the natural environment and our social environment) is becoming ever more complicated and diverse. So we aim at making the relationships between machines, humankind, and nature harmonious and stable, while being able to cope with complexity and diversity. To this aim, we clarify both the principles and the methodologies of relationship building theoretically, by taking a wide range of approaches that encompass systems theory, control engineering, artificial intelligence, cognitive science, human interface technology, robotic engineering, and reliability engineering. Based on these studies, we build various types of concrete systems.

Mechanical Systems Control

Aiming to design robust and flexible mechanical systems

Advanced control methods that can operate mechanical systems properly under adverse conditions are necessary in order to built systems that have the flexibility to adapt to, and the robustness to withstand, environmental change. Our group focuses on developing this kind of advanced control theory. We also conduct education and research regarding the application of such theory in mechatronics and robotic engineering. More concretely, our theoretical research topics include robust control, system modeling, saturated systems, nonlinear systems, and hybrid systems. Application examples of our research include magnetic levitation systems, crane systems, inverted pendulums, airship control, snake-like robots, and biological systems.



A robot arm with 7 degrees of freedom

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.

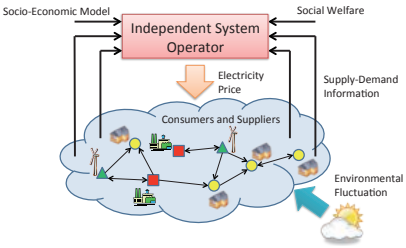
[Professor: KANO Manabu]

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, dynamic optimization, and distributed control, 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.

[Professor: OHTSUKA Toshiyuki, Associate Professor: SAKURAMA Kazunori, Assistant Professor: HOSHINO Kenta]



A system consisting of humans, machines, societies, and environments

Mobility Research

Optimizations for design and operation

The research interest of this group mostly lies in technologies for automobiles, such as electronic stability controls, energy efficiency improvements, and collision avoidance systems. In some cases, similar systems have begun to be applied in stock cars. These subjects are investigated in the light of the precise optimizations considering the constraints of their dynamical properties.

[Associate Professor: NISHIHARA Osamu]

Outline

System Synthesis

For intelligent systems, acquisition of information about themselves and their surroundings is prerequisite to attainment of their self-stabilization and enhancement of their own functions. The division performs education and research from the standpoint of applied mathematics for solving a variety of problems in Systems Synthesis: artificial realization of adaptive and learning abilities in humans and the living things as well, and modeling and information processing for exploring systems' advanced functions.

Adaptive Systems Theory

Theoretical approaches to systems that learn and adapt

We aim to create artificial systems that have the ability to learn, infer, and adapt — like animals and humans do — and are involved in education and research that focuses on various theoretical problems that will have to be overcome for this to happen. Specifically, with interests in the application to artificial intelligence, pattern recognition, data mining, digital information communication, we conduct research into theories of probability-based inference and learning, which explains the efficient acquisition of useful information in an uncertain environment, and the statistical mechanics of information processing, which can be discussed by drawing an analogy between the information mathematics of large-scale probability models and statistical mechanics.

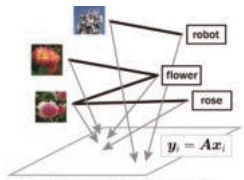
[Professor: TANAKA Toshiyuki, Assistant Professor: UEDA Yoshihiko]

Digital communications as data mining: How one extracts the desired information from many intermixed signals is the key to high-performance digital communications.

Mathematical System Theory

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 provides methodologies for inductive inference from data with consideration of randomness. Large amounts of data can now be easily obtained via high-throughput systems, and the field of machine learning, in particular, is growing rapidly. Through addressing real-world data, we are developing new statistical methods with emphasis on mathematics and programming skills. [Professor: SHIMODAIRA Hidetoshi, Assistant Professor: LIU Yan]



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

Computational Intelligence Systems Adjunct Unit

Data mining & pattern recognition based on statistical machine learning

Data mining is the technology which discovers significant latent relationships, rule, patterns from huge amount of data like Web contents. It has been widely used in many recommendation systems for products already. We are pursuing statistical machine learning approach to provide highly sophisticated data mining technologies to extract, classify, organize, visualize, and predict latent information hidden in the data. We will offer education and research opportunities in this field.

[Professors: UEDA Naonori and TANAKA Toshiyuki]

Latent information extraction, classification, organization, visualization, and prediction from huge amount of data

Systems Informatics

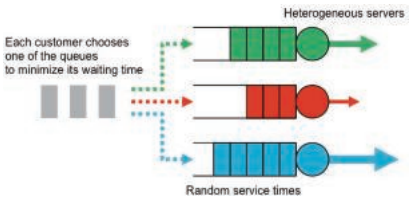
The division performs the education and research from the standpoints of systems science and information science for solving a variety of problems in various kinds of practical systems. Current education and research program is concerned with communication systems, brain and neural systems, and systems in biomedical engineering. We have concerns about practical systems but also theoretical approaches.

Information Systems

For optimal decision-making under uncertainty

There are various information and service systems in which an unspecified number of users compete against each other. In respect of these systems, users and service providers are frequently forced to make decisions based on unverified information. For optimal decision-making under such uncertain circumstances, we develop methods of system modeling and simulation using stochastic processes, and we also study analysis and performance evaluation of mathematical models through applied probability, queueing, statistics, optimization, game theory, etc.

[Associate Professor: MASUYAMA Hiroyuki]



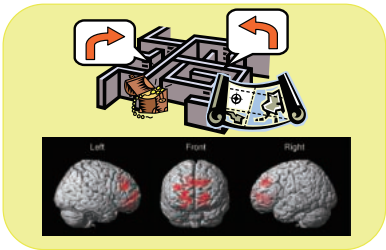
Strategic multiple queueing model

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.

[Professor: ISHII Shin, Senior Lecturer: OBA Shigeyuki,
Assistant Professor: HIGASHI Hiroshi]



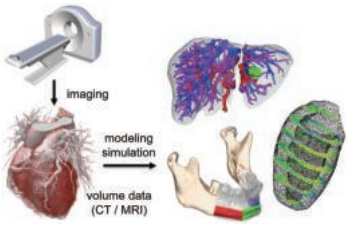
A model of the decision-making process in an uncertain environment, and images of information processing within the brain

Biomedical Engineering

Learning about 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.

[Professor: MATSUDA Tetsuya, Associate Professor: NAKAO Megumi,
Assistant Professor: IMAI Hirohiko]



Medical image processing and modeling for diagnosis and treatment

Outline

Computational Neuroscience Adjunct Unit

Create a brain in order to understand the brain

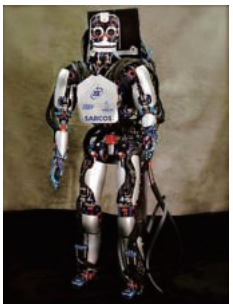
(a) Humanoid Robot

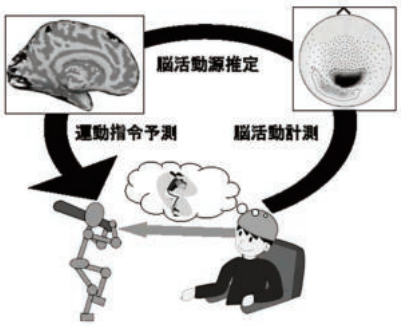
The goal of our study is to control robots by thoughts in the brain. This study is expected to contribute to the connection of humans and robots as a future telecommunication device and to the development of an assistive device for the recovery of motor functions in humans. We aim to understand brain mechanisms especially those of motor control.

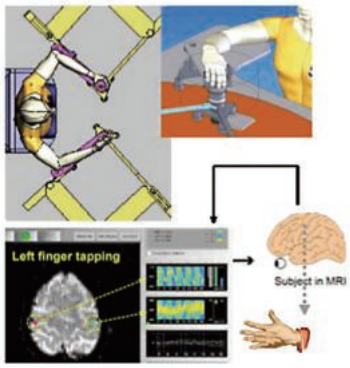
(b) Brain Machine Interface

We aim to understand the brain function through computational neuroscience and to develop a Brain Machine Interface (BMI) for recovery of motor functions in humans as technology for IT and clinical applications.

[Professors: KAWATO Mitsuo and ISHII Shin]



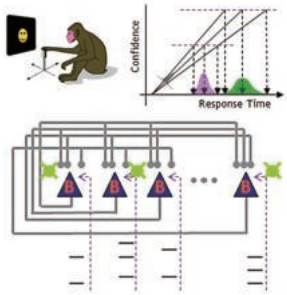




Neural circuit information processing

Neuronal networks play a central role in information processing by the brain. To uncover the principles governing the computation by the brain, we perform theoretical analysis of neural network models, construction of microcircuit models of the brain, and development of mathematical tools for deciphering neural code. Moreover, we will develop and use methods in non-linear dynamical systems, stochastic process, probabilistic inference and machine learning. Furthermore, we give motivated students an interdisciplinary research opportunity to learn theories and applications of brain information processing.

[Professors: FUKAI Tomoki and ISHII Shin]

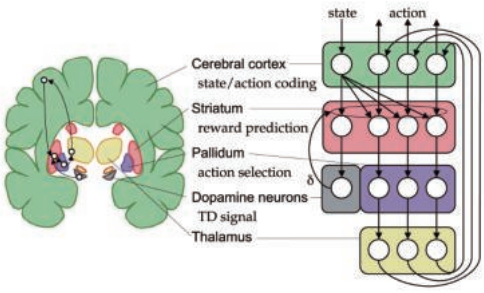


A neuronal network model for perceptual decision making inferred from activity of the monkey brain

Computational theory of action learning and the brain's mechanisms for learning

Humans and animals can learn varieties of behaviors under novel, uncertain environments. What is the brain's mechanism for such flexible learning? Its understanding requires integration of the computational theory of action learning and the dynamics of the networks of the neurons, molecules, and genes in the brain. Our laboratory works on the algorithms of reinforcement learning and Bayesian inference, their implementation to robotics and bioinformatics, neural recording from rats' basal ganglia and the brain stem, human brain imaging, and evolution of learning capabilities in a robot colony. We welcome members from a variety of countries and disciplines to enjoy research in the campus overlooking the ocean of Okinawa.

[Professors: DOYA Kenji and ISHII Shin]



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

Applied Informatics (Affiliated)

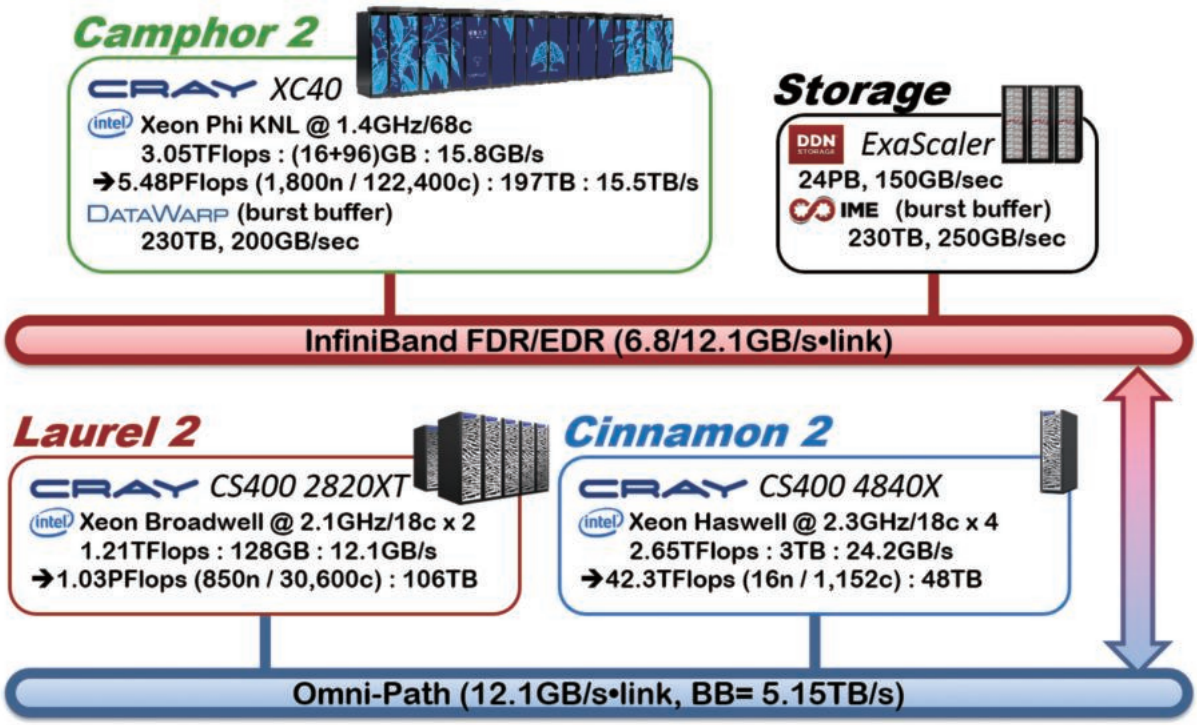
(Academic Center for Computing and Media Studies)

We carry out fundamental and applied research regarding parallelization and high-performance computing technologies that hold great promise for supercomputing at the frontiers of science. We also look at ways to put this research into practical use. We work on research projects with researchers from various scientific fields that need large-scale simulations and scientific computation, as well as with researchers involved in supercomputer technology within the university and in the wider scientific community. Our students are learning a wide range of high-performance computing technologies, from the design of software for parallelized applications to high-performance hardware.

[Professor: NAKASHIMA Hiroshi, Associate Professor: FUKAZAWA Keiichiro
Assistant Professor: HIRAISHI Tasuku]

Aiming to be at the forefront of computing performance

We are involved in research into supercomputers, their software, and systems that are thousands or tens of thousands of times more powerful than ordinary personal computers. We are studying the basic technologies for high-performance parallel processing, such as parallel systems that link together many computers, languages that simplify parallel processing, and software libraries that can be widely used in a range of fields. Much of this research is in the form of joint research projects that extend beyond the field of computer science to involve researchers in the fields of medicine, physics, engineering, and other areas.



Supercomputer System in ACCMS