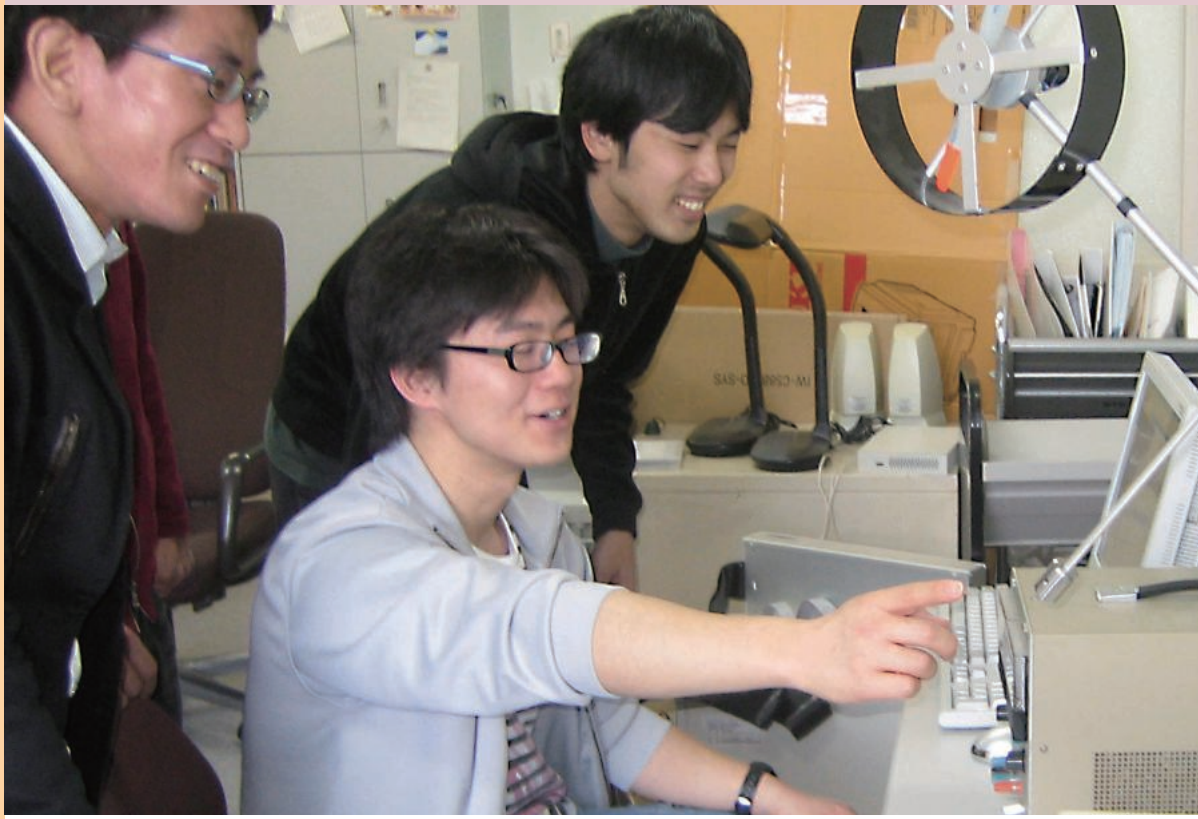
Department of Applied Mathematics and Physics

Engineering/Natural Systems: Modeling, Analysis, Operation, Design and Solution

In the highly advanced information society today, we encounter various situations that entail modeling, analysis, planning, control and operation of complex and large-scale systems. In these situations, it is extremely important to uncover common mathematical structures shared by those problems which are seemingly unrelated, and to develop mathematical methods to solve them, in addition to acquiring specialized knowledge of individual disciplines such as information technology, electricity, mechanics and chemistry.
From this viewpoint, the eight laboratories of the Department of Applied Mathematics and Physics undertake leading-edge researches on applied mathematical analysis, discrete mathematics, system optimization, control systems theory, applied mathematical modeling (adjunct unit), physical statistics, dynamical system theory, and mathematical finance (affiliated division).



Modeling and Control: Describing and Manipulating Systems

The science of control is the study of trying to manipulate the movement of various things, from mobile vehicles such as automobiles and aircraft to production systems for the steel production process. For example, preventing vibration on robot manipulators is also a control task. We need to extract characteristics that are important to control from a control object that displays complex movements, create a model, and use that model to come up with a control rule to produce the desired movement. We invite you to expand the field of application for the science of control and have a go at developing new modeling methods and control rules.

OHTA Yoshito
Department of Applied Mathematics and Physics

Professor Ohta graduated from the Department of Electronic Engineering, School of Engineering, Osaka University in 1980. He was appointed as a Research Associate in Osaka University in 1983, and obtained his Doctorate Degree in Engineering from Osaka University in 1986. He was promoted to a Lecturer in 1991, to an Associate Professor in 1994, and to a Professor in 1999 at Osaka University. Since 2006, he is a Professor at the Department of Applied Mathematics and Physics at Kyoto University.

Optimization of Discrete Structures

The objective of applied mathematics and physics is to create a model to explain phenomena that are seemingly intangible and to formulate "theories for actual use" that can produce optimum answers to problems. In this regard, my laboratory deals with problems that have discrete structures. For instance, it would take an enormous amount of time to check all possible routes between two points on a map. However, we can produce a solution for instantly identifying the shortest route between those two points if we were to use a theory known as dynamic programming. We invite you to take up the challenge of creating your own solution to unsolved problems.

NAGAMOCHI Hiroshi
Department of Applied Mathematics and Physics

Professor Nagamochi received his Doctorate degree in March 1988 from the Graduate School of Engineering, Kyoto University. In April 1988 he was appointed a Research Associate at the Informatics Division, Toyohashi Institute of Technology. In April 1990 he became a Research Associate at the Section of Applied Mathematics and Physics, School of Engineering, Kyoto University, and in April 1993 promoted to Associate Professor. In April 2000 he returned to the Informatics Division of Toyohashi's Institute of Technology as a Professor. As of July 2004 he is a Professor at the Graduate School of Informatics, Kyoto University. His research specialty is discrete optimization, covering a broad range of fields which include, among others, graph algorithms, scheduling, and enumeration algorithms.

Outline

Divisions and Groups

Division	Group	Research and Education Topics	Professor
Applied Mathematics	Applied Mathematical Analysis	Applied Integrable Systems and Numerical Algorithms	NAKAMURA Yoshimasa
Applied Mathematical Systems	Discrete Mathematics	Theory and Application of Discrete Optimization, Graph Theory, and Discrete Algorithms	NAGAMOCHI Hiroshi
	System Optimization	Optimization Theory & Algorithms and Operations Research	YAMASHITA Nobuo
	Control Systems Theory	Systems Control Theory, System Identification, and Large-scale and Stochastic Dynamical Systems	OHTA Yoshito
	Applied Mathematical Modeling (Adjunct Unit)	Applied Mathematical Modeling and Social Information Systems Modeling	NONAKA Yoichi
Mathematical Physics	Physical Statistics	Physical Statistics, Basic Theory of Nonlinear and Complex Systems, and Stochastic Process Fundamentals and Applications	UMENO Ken
	Dynamical Systems	Dynamical Systems, Ordinary and Partial Differential Equations, and Mathematical Physics	YAGASAKI Kazuyuki
Mathematical Finance (Affiliated)		The Science of the Functional Efficiency of Finance	

Graduate Curriculum

Courses for the Master's Program

Operations Research (Advanced)
Mathematical Physics (Advanced)
Systems Analysis (Advanced)
Topics in Applied Mathematics and Physics A, B
Mathematical Analysis (Advanced)
Discrete Mathematics (Advanced)
Control Systems Theory (Advanced)
Optimization Theory (Advanced)
Physical Statistics (Advanced)
Introduction to Mathematical Finance
Financial Engineering
Dynamical Systems (Advanced)
Advanced Study in Applied Mathematics and Physics I
Advanced Study in Applied Mathematics and Physics II

Courses for the Doctoral Program

Seminar on Applied Mathematics (Advanced)
Seminar on Applied Mathematical Systems (Advanced)
Seminar on Mathematical Physics (Advanced)
Seminar on Applied Mathematics and Physics (Advanced)
Seminar on Mathematical Finance (Advanced)

Teaching Staff

Professors

NAKAMURA Yoshimasa; NAGAMOCHI Hiroshi; YAMASHITA Nobuo; OHTA Yoshito;
NONAKA Yoichi (Hitachi, Ltd.,Adjunct); UMENO Ken; YAGASAKI Kazuyuki

Associate Professors

TSUJIMOTO Satoshi; FUKUDA Ellen Hidemi; SATO Hiroyuki (Program-Specific Associate Professor); KASHIMA Kenji;
TAKAHASHI Yoshiyasu (Hitachi, Ltd., Adjunct); SHIBAYAMA Mitsuru

Senior Lecturers

SEKIDO Hiroto (Program-Specific Senior Lecturer)

Assistant Professors

KAMIOKA Shuhei; SHURBEVSKI Aleksandar; OHKI Kentaro; IWASAKI Atsushi; YAMAGUCHI Yoshiyuki

Applied Mathematics

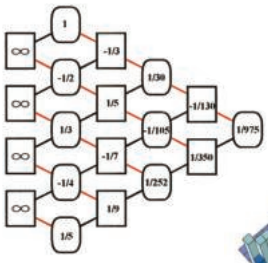
This Division consists of two Groups: first, the Applied Mathematical Analysis Group, which carries out research into the applied analysis of the tremendous range of functions and the mathematics of algorithms and other integrable and discrete integrable systems; and second, the Discrete Mathematics Group, which studies combinatorial problems, graph and network problems, logical functions, discrete optimization, and other topics. The Applied Mathematics Division conducts research and education in many topics, including the creation of new mathematical models, the development of algorithms, the understanding of the complexity of mathematical computation, and system modeling.

Applied Mathematical Analysis

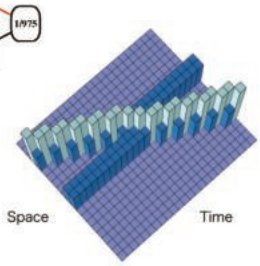
Developing algorithms from integrable systems

We carry out research in the areas of contemporary soliton research and integrable system research, not only regarding the applied analysis of orthogonal polynomials and special functions that are closely associated with integrable systems, but also regarding the application of the mathematical methods developed by integrable system studies to the solution of various problems hitherto thought to be unrelated to integrable systems (such as numerical calculation and algorithm development). Our Group is a pioneer in this research field, and conducts studies into the applied analysis of integrable systems in the development of algorithms and other new branches of mathematics from the perspective of computer science.

[Professor: NAKAMURA Yoshimasa,
Associate Professor: TSUJIMOTO Satoshi,
Program-Specific Senior Lecturer: SEKIDO Hiroto,
Assistant Professor: KAMIOKA Shuhei]



η-algorithm
(discrete KdV equation)



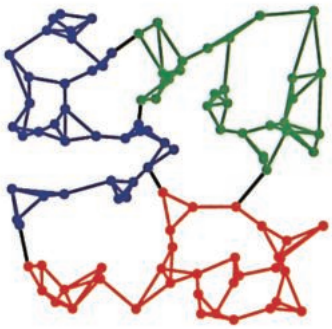
Ultra-discrete soliton

Discrete Mathematics

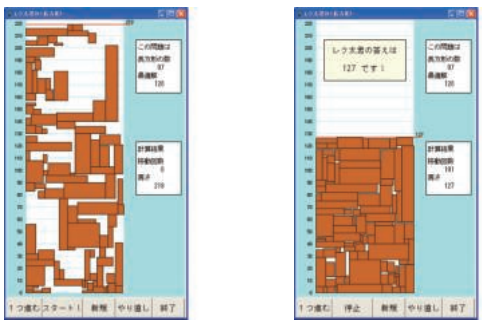
Exploring the complexity of discrete mathematics problems and developing algorithms

Topics in discrete mathematics, such as the graphs and networks used to represent systems, schedules to enhance the efficiency of production, and the logical analysis of large volumes of data, are closely related to applications of research results. We explore the complexity of the calculations used to solve these problems; design logical approximation algorithms; develop taboo search algorithms, genetic algorithms and other metaheuristic algorithms; and apply them to solving actual problems.

[Professor: NAGAMOCHI Hiroshi,
Assistant Professor: SHURBEVSKI Aleksandar]



Computation of a minimum cut that separates a network into three components with the same number of vertices



A puzzle in which you have to fit the pieces into a box of fixed width without any of the rectangular pieces overlapping and try to make the height of the packed pieces as low as possible (left).
Illustrations of the calculations performed by "Rekuta-kun," a packing solution developed at the Applied Mathematics and Physics Laboratory: start (middle) and final result (right).

Outline

Applied Mathematical Systems

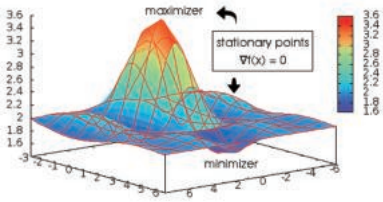
We carry out education and research regarding mathematical theories that are used in the analysis, planning, management and evaluation of a wide range of complex systems that occur in a computer-networked society and in modern production systems. Examples of these theories include mathematical programming, applied probability theory, network theory, modern feedback control theory, estimation and identification of probability systems, and robust control theory. We also apply these theories in the development of problem-solving algorithms. In an adjunct unit, we also engage in education and research for applying various methodologies in real-world systems.

System Optimization

Optimization is the keyword for solving problems

We conduct education and research regarding the theory and methodology of system optimization, which plays an important role as a mathematical approach that is used to resolve many different kinds of practical problems. In particular, we develop efficient mathematical optimization approaches to actual large-scale systems, complex nonlinear systems, and systems with uncertainty, as well as basic research regarding mathematical programming.

[Professor: YAMASHITA Nobuo,
Associate Professor: FUKUDA Ellen Hidemi,
Program-Specific Associate Professor: SATO Hiroyuki]



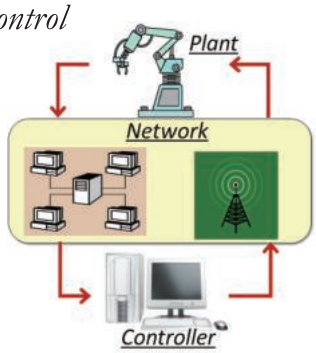
Optimal solutions of an unconstrained problem

Control Systems Theory

Mathematical approaches to modeling and control

We carry out teaching and research regarding the mathematical methodologies of modeling, analysis and design of control systems, and their application with the aim of developing practical and expansive control theories. Our main research themes are robust control, control systems with input/output constraints, networked control systems, algebraic system theory, mathematical optimization in control, stochastic realization, system identification and quantum control theory.

[Professor: OHTA Yoshito, Associate Professor: KASHIMA Kenji,
Assistant Professor: OHKI Kentaro]



A sketch of networked control systems

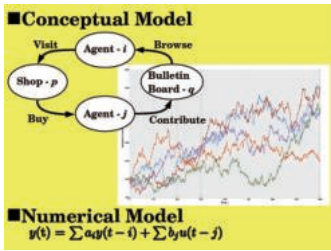
Applied Mathematical Modeling Adjunct Unit

(In collaboration with Hitachi, Ltd.)

Infusing information systems with intelligence

To make information systems useful to our day-to-day lives and industry at large, we need to be able to mathematically model both the behavior of people and the movements of objects that these systems deal with. The form of these models ranges from the conceptual to the numerically precise. We will examine case studies from industry in our research of modeling technology, including methods of using human knowledge (structural modeling) and methods using actual data (multivariate analysis).

[Professor: NONAKA Yoichi, Associate Professor: TAKAHASHI Yoshiyasu]

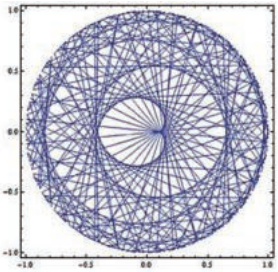


A conceptual and its numerical model

Mathematical Physics

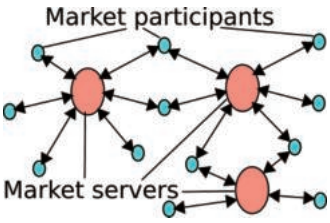
We look into mathematical models in physics, chemistry and biology that form the foundations of engineering and investigate those models from a dynamic system perspective by applying methods developed in statistical physics, dynamical systems theory, differential equations, probability theory, stochastic process theory, and computer simulation; and we conduct applied research with the goal of gaining a better understanding of their mathematical structure and building fundamental theories.

Various coupled multi-element systems



Chaos code for signal analysis and multiuser communications system

A conceptual diagram of a complex network



A model of the financial market and the market participants

Physical Statistics

The mathematical studies on dynamics of coupled multi-element network systems and design theory of complex engineering systems

We aim to gain a mathematical and unified understanding of the complex and diverse phenomena that arise out of the intense mutual interactions of multiple elements (units) in a system and apply this understanding to information processing and design of complex engineering systems. For example, we will use stochastic process theory, ergodic theory, statistical physics, dynamical system theory, computer simulations, and large-scale data processing techniques to analyze information processing and performance evaluation in neural networks; the structure of the Internet and other complex networks such as social media systems, and the propagation of information within them; and the dynamical properties of price change, stock markets and other economic phenomena.

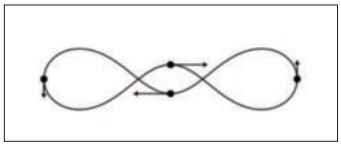
[Professor: UMENO Ken,
Assistant Professor: IWASAKI Atsushi]

Dynamical Systems

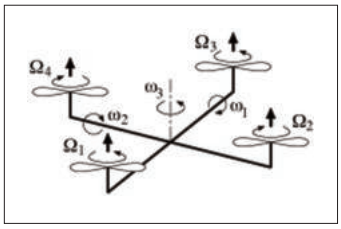
Looking into the world through dynamical systems theory

Our research purpose is to analyze complicated phenomena such as chaos and bifurcations in various systems appearing in science, engineering and other disciplines using dynamical systems approaches, and apply them to develop novel engineering technologies. For this purpose, we not only use standard approaches but also establish new innovative theories in dynamical systems. Moreover, we utilize numerical approaches such as verifiable computation and large-scale numerical simulation, and study the nonintegrability of dynamical systems and differential equations, nonlinear waves in partial differential equations, periodic motions in the n-body problem of classical mechanics and kinetic theory of many-body systems, design of spacecraft transfer trajectories and dynamics and control of flying objects such as quadcopters.

[Professor: YAGASAKI Kazuyuki, Associate Professor: SHIBAYAMA Mitsuru,
Assistant Professor: YAMAGUCHI Yoshiyuki]



4-body super-eight solution which is proven to exist by using variational methods



Mathematical model of quadrocopters