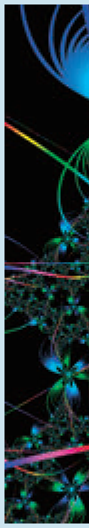
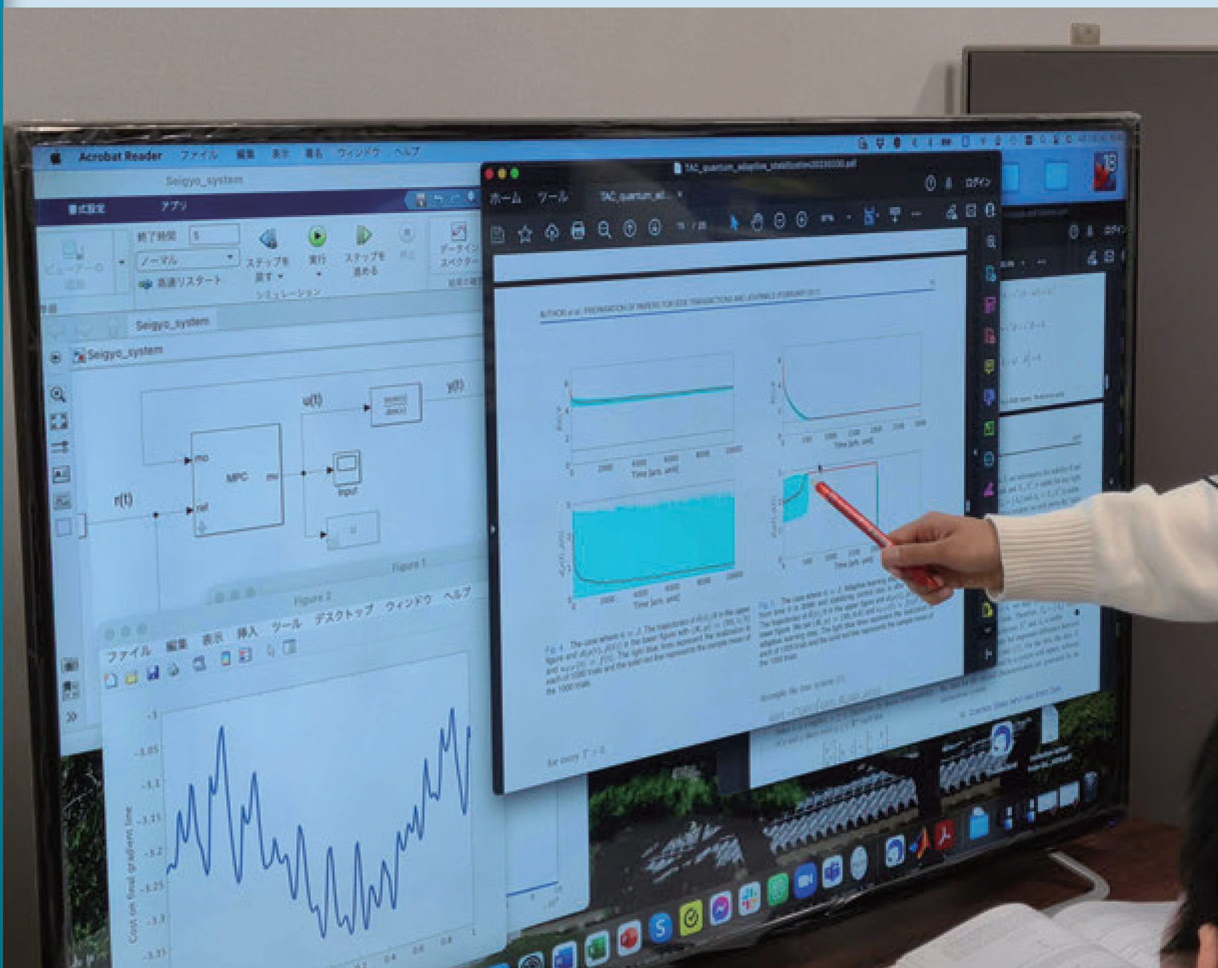
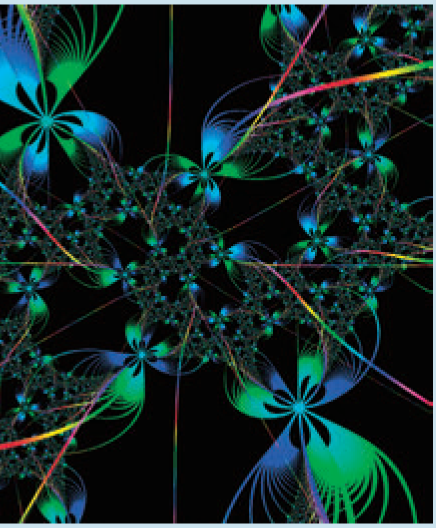
Using Applied Mathematics and Physics to Seek Solutions to Problems in Engineering/ Natural Systems

In the highly advanced information society of today, we encounter various situations that involve modeling and analysis of complex and large-scale systems, their control, design, and operation.
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 seven laboratories of the Course of Applied Mathematics and Physics undertake leading-edge research on applied mathematical analysis, discrete mathematics, system optimization, control systems theory, applied mathematical modeling (adjunct unit), physical statistics, and dynamical system theory.







Universality of the Power law and Establishing Risk Indicators

The discovery and application of a super generalized central limit theorem

Why are power laws so prevalent in nature and the universe? That is the mathematical question that sparked this journey. Power laws, which are different to Gaussian distributions, can be asymmetric and remarkably diverse. The mathematical basis for such power laws can be traced back to a generalization of the central limit theorem, stating that the sum of random variables converges to a Gaussian distribution. While examining this mathematical basis, we constructed an algorithm to accurately estimate power laws from the massive amounts of data about the world that we now have access to. This has led us to develop new data analysis methodology for identifying real-time risk indicators for financial markets. As well as in financial markets, power laws also appear in many aspects, including physical phenomena in the universe. A power law is a common mathematical concept that sheds light in fields as wide-ranging as statistical physics, probability theory, chaos theory, cosmology, financial markets, neuroscience, and number theory (Riemann zeta function). Join us on this voyage of discovery! It has only just begun.

Ken Umeno

Professor, Applied Mathematics and Physics Course

Professor Umeno received his Doctoral Degree March 1995 from the University of Tokyo. In April 1995, he was a special postdoctoral researcher at the Institute of Physical and Chemical Research (RIKEN). From 1998 until he joined Kyoto University in 2012, he worked for Japan's Ministry of Posts and Telecommunications (currently the National Institute of Information and Communications Technology). From 2005 to 2010, he was the Laboratory Head of the Next Generation Mobile Laboratory of RIKEN. He has been a Professor with Graduate School of Informatics, Kyoto University, since 2012. His research specialty is chaos theory, complex systems, and statistical mechanics. His recent invention is correlation analysis of GNSS data for detecting ionospheric Precursors before large earthquakes and is currently investigating in uncovering the physical mechanism to generate electro-magnetic anomalies. Together earthquake, he is also interested in physically inspired model of Financial Crisis as critical phenomena of phase transition in statistical mechanics.

Mathematics and Computers for Solving Problems through Optimization

As the concept of "optimization" has become increasingly familiar to people, technical terms such as "optimization" and "optimal solution" have made their way into everyday language. In the field of applied mathematics, we first describe "everyday optimization" as an "mathematical optimization model" that enables computers to deal with. Then we develop algorithms to find optimal solutions of such optimization models with large-scale and complex real-world applications.

Our laboratory deals mainly with continuous optimization, in which the candidate optimal solutions are expressed as continuous variables. Continuous optimization is an essential tool for deep learning and financial engineering. Why not come along and take advantage of the power of applied mathematics to help us shape a more optimal societyfor the benefit of many people?

Nobuo Yamashita

Professor, Applied Mathematics and Physics Course

Professor Yamashita received his Doctorate degree in March 1996 from Nara Institute of Science and Technology. In April 1996 he was a research fellow at Japan Society for the Promotion of Science. In August 1997 he was appointed an assistant professor at the Section of Applied Mathematics and Physics, School of Engineering, Kyoto University. In April 2005 he became an associate professor at the department of Applied Mathematics and Physics, Graduate School of Informatics, and In July 2014 he was promoted to professor. His research specialty is continuous optimization, covering a broad range of fields which include, among others, large-scale optimization, equilibrium problems, and nonlinear equations.

Outline

Group and Teaching Staff

Group	Teaching Staff
Applied Mathematical Analysis	Satoshi Tsujimoto/Professor
Discrete Mathematics	Kazuya Haraguchi/Associate Professor
System Optimization	Nobuo Yamashita/Professor Ellen Hidemi Fukuda/Associate Professor Yuya Yamakawa/Assistant Professor
Control Systems Theory	Kenji Kashima/Associate Professor Kentaro Ohki/Assistant Professor
Physical Statistics	Ken Umeno/Professor Erica Uehara/Senior Lecturer
Dynamical Systems	Kazuyuki Yagasaki/Professor Mitsuru Shibayama/Associate Professor Yoshiyuki Yamaguchi/Assistant Professor
Applied Mathematical Modeling (Adjunct Unit)	Yoichi Nonaka/Adjunct Professor Yoshiyasu Takahashi/Adjunct Associate Professor (Hitachi Ltd.)

Curriculum of Applied Mathematics and Physics Course

Doctoral Program (Informatics)

3rd / 2nd / 1st

Doctoral Thesis

Subjects provided by the Course (total 6 credits including 4 credits from seminars)
Seminar on Applied Mathematics and Physics, Advanced A, B, *E* (2 credits)
Seminar on Applied Mathematics, Advanced, *E*   Seminar on Applied Mathematical Systems, Advanced, *E*
Seminar on Mathematical Physics, Advanced, *E* (2 credits each)

Research Guidance

Master's Program (Informatics)

Master's Thesis

2nd

Subjects provided by the Course
(Optional 12 credits or more from the recommended subjects provided by the other Course. 8 or more credits are required from the subjects provided by the Course and "Computational Science, Introduction" of the general subject provided by the School.)

Advanced Subjects
Mathematical Analysis, Adv., Discrete Mathematics, Adv., Control Systems Theory, Adv., Optimization Theory, Adv., Physical Statistics, Adv., Dynamical Systems, Adv.
Introduction to Mathematical Finance (2 credits each)
Financial Engineering, Topics in Applied Mathematics and Physics A
Topics in Applied Mathematics and Physics B (1 credit each)

Basic Subjects (2 credits each)
Operations Research Adv., Mathematical Physics, Adv., Systems Analysis, Adv.

Seminar Subjects
Seminar in Mathematical Analysis, Seminar in Discrete Mathematics, Seminar in System Optimization, Seminar in Control Systems Theory
Seminar in Physical Statistics, Seminar in Dynamical Systems

Recommended Subjects provided by other Courses
Pattern Recognition Adv. *E* (IST), other 11 subjects

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

1st

General Subjects provided by the School (2 credits each)

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 credits), 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

Basic Mathematics
Calculus, Linear algebra, etc.

Preferred to understand the subjects on the right

Applied Mathematics
Complex functions, Fourier analysis, Numerical analysis, Graph theory, etc.

Mathematical Systems
Linear programming, Optimization, Control theory, etc.

Mathematical Physics
Classical dynamics, Differential equation, Statistical mechanics, etc.

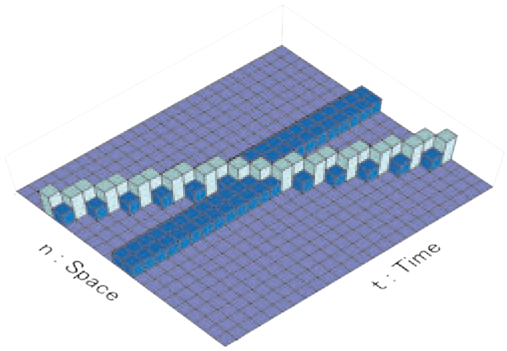
Note: Subjects marked with the letter "E" will be provided in English.

Applied Mathematical Analysis

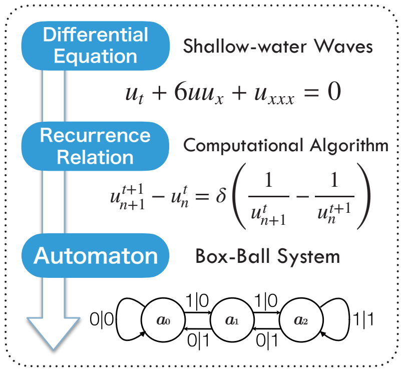
Developing algorithms from integrable systems

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.

[Satoshi Tsujimoto]



Ultra-discrete soliton



Theory linking continuous and discrete systems, and automata

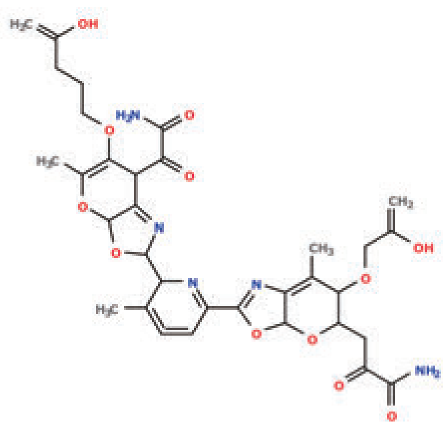
Discrete Mathematics

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 computation used to solve these problems; design exact and approximation algorithms; develop tabu search algorithms, genetic algorithms and other metaheuristic algorithms; and apply them to solving actual problems.

[Kazuya Haraguchi]


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 pie ces as low as possible.


The structural formula of a compound expected to have a certain target value of heat of combustion. It was constructed by formulating and solving an inverse problem of a prediction model learned from a database of compounds in the form of a mixed-integer optimization problem.

Applied Mathematics and Physics Course

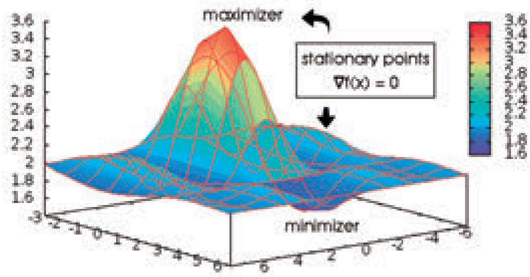
Outline

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.

[Nobuo Yamashita , Ellen Hidemi Fukuda , Yuya Yamakawa]



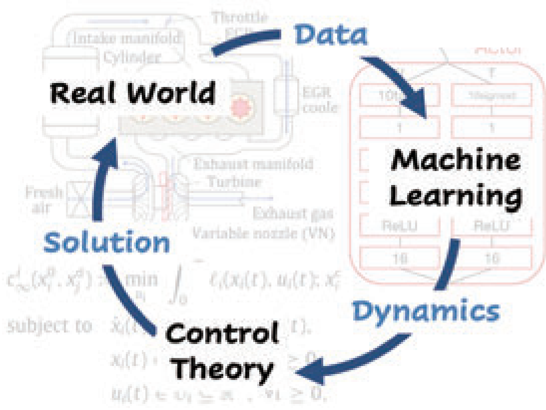
Optimal solutions of an unconstrained problem

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.

[Kenji Kashima , Kentaro Ohki]



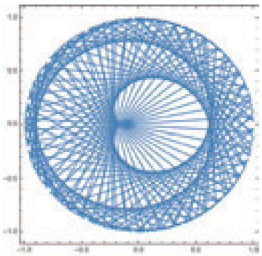
Conceptual diagram of a control system design

Physical Statistics

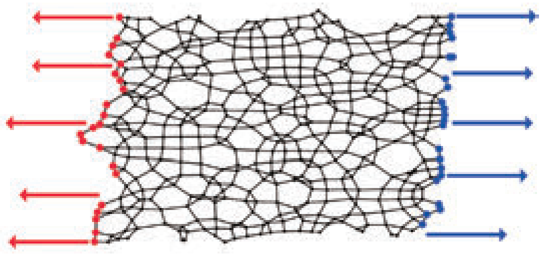
The mathematical studies on dynamics of coupled multi-element network systems and design theory of complex engineering systems

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.

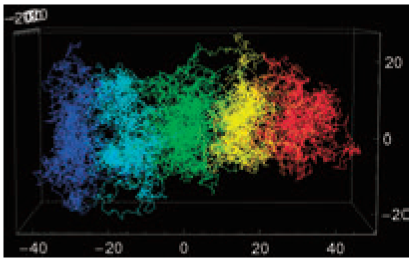
[Ken Umeno , Erica Uehara]



Chaos code for signal analysis and multiuser communications system



The distribution of vertices when a random network is extended by applying an external field to the vertices in the boundaries of the network is computed from the graph Laplacian.



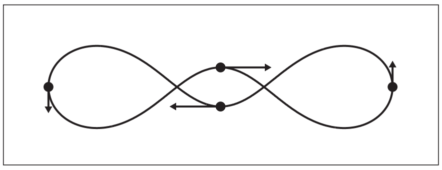
Polymer physics

Dynamical Systems

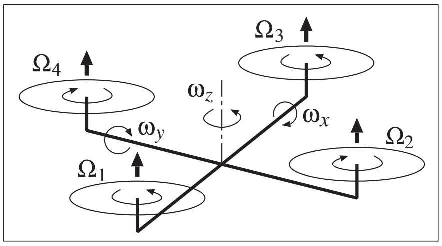
Looking into the world through dynamical systems theory

Our research purpose is to analyze complicated phenomena such as chaos and bifurcations in various systems appearing in natural 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 groundbreaking theories in dynamical systems. Moreover, we utilize numerical approaches such as verifiable computation rigorous numerics 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, several problems in the kinetic theory of many-body systems, design of spacecraft transfer trajectories, and dynamics and control of flying objects such as quadcopters.

[Kazuyuki Yagasaki , Mitsuru Shibayama , Yoshiyuki Yamaguchi]



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



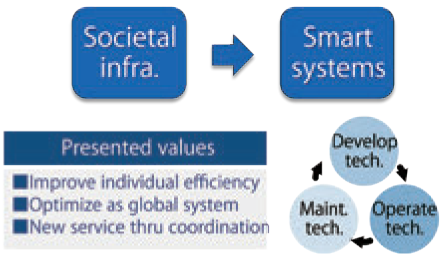
Mathematical model of a quadcopter

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).

[Hitachi Ltd.: Yoichi Nonaka , Yoshiyasu Takahashi]



Modeling of a social infrastructure system

Applied Mathematics and Physics Course