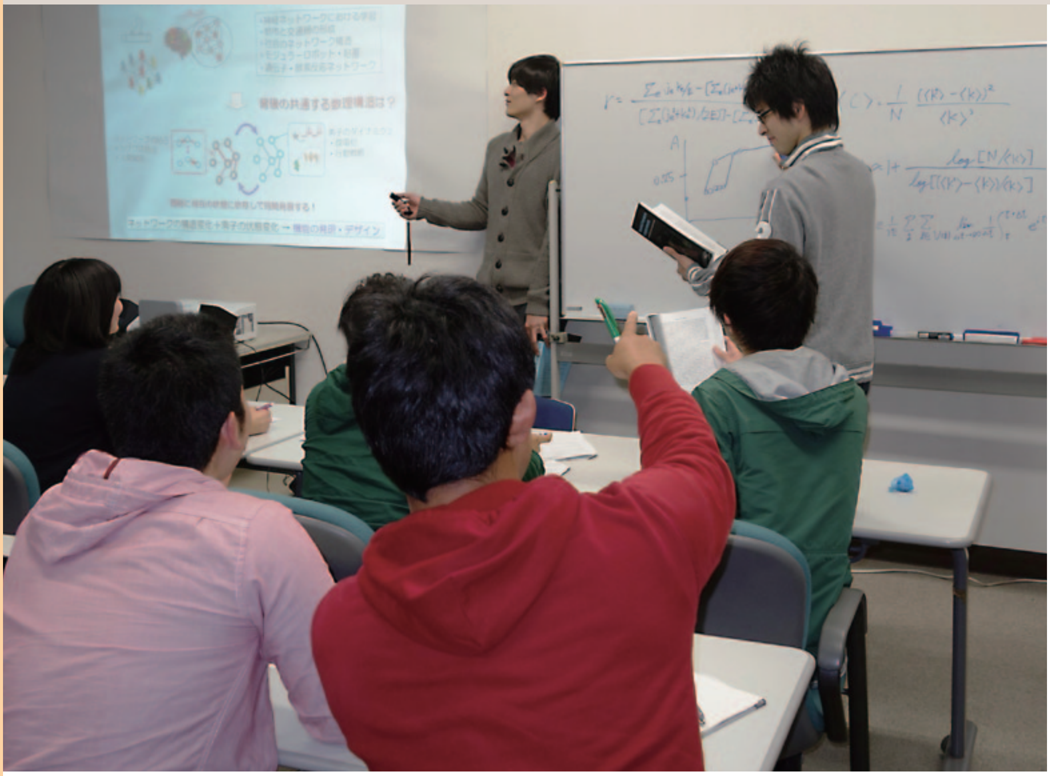
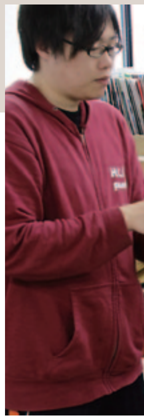
Department of Applied Analysis and Complex Dynamical Systems

Toward the Analysis and Synthesis of Varied Behavior of Complex Systems

Toward the Analysis and Synthesis of Varied Behavior of Complex Systems
Complex systems refer to systems that exhibit, as a whole, a variety of behavior and functions such as self-organization, chaos with a large degree of freedom, and learning and associative memories through nonlinear large-scale interactions among those elements.
This department aims to clarify the fundamental principles and structures of these complex systems, analyze and extract useful information from this huge mass of information, and design suitable systems. We undertake education and research related to the clarification of solution structures for complex mathematical models by way of mathematical and numerical analysis, development of models and solution algorithms for chaos in complex dynamics, nonlinear phenomena such as pattern formation, and complex systems, as well as inverse problems .

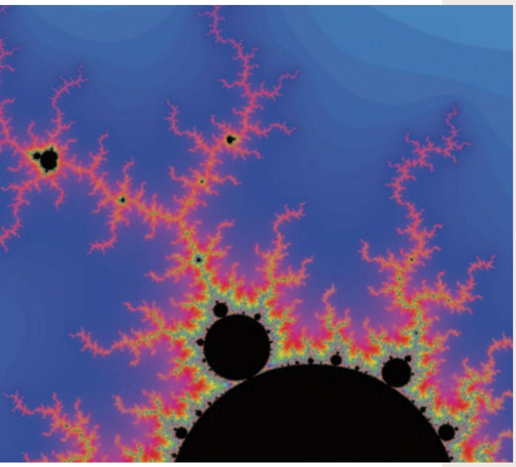


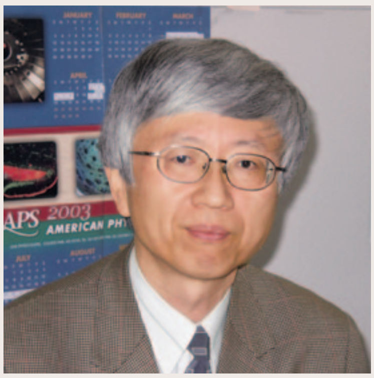


An Invitation to the Department of Applied Analysis and Complex Dynamical Systems

Applied Analysis and Complex Dynamical Systems Science is a discipline which strives to explain complex phenomena that could not be understood or utilized fully on simplified mathematical models in the past by using various computers and analysis based on new concepts such as chaos and fractals. In particular, our department focuses on systems that are sensitive to strong nonlinearity, a high degree of freedom, large scales, and errors in order to fuse together engineering perspectives with scientific perspectives based on mathematics, numerical calculations, nonlinear physics, computational mechanics, etc. In other words, we hold in esteem the respective values of both science, which represents the pursuit of "reason", and engineering, which represents the art of "craftsmanship". Both in terms of our research and education, effort is made to mutually compensate for the drawbacks of each of these aspects to truly combine science and engineering.

With faculty members who are also comprised of graduates from both science and engineering fields, the department has three divisions: Applied Analysis, Nonlinear Physics, and Applied Mathematical Sciences. Each of these divisions operates under the keywords "applied analysis," "nonlinear physics," and "engineering" in their educational and research activities. More specifically, both basic and applied education and research is conducted primarily on fluids, elastic bodies, and neural systems that display strong large-scale or nonlinear characteristics, separating these into fields such as differential equation, numerical analysis, probability theory, fractal analysis, nonlinear dynamics, fluid dynamics, statistical mechanics, computational dynamics and computational mechanics.





FUNAKOSHI Mitsuaki
Department of Applied Analysis and Complex Dynamical Systems

1976 Master of Department of Applied Mathematics and Physics, Graduate School of Engineering, Kyoto University. 1983 Doctor of Engineering, Kyoto University. 1976-1995 Research Institute for Applied Mechanics, Kyushu University. 1998- Department of Applied Analysis and Complex Dynamical Systems, Graduate School of Informatics, Kyoto University. 2004-2006 Dean of Graduate School of Informatics, Kyoto University. 2014-2015 President of Japan Society of Fluid Mechanics. 2009-2014 Editor-in-Chief of Fluid Dynamics Research. Research subjects are nonlinear aspects of fluid motions and nonlinear mechanics.

Department of Applied Analysis and Complex Dynamical Systems

Outline

Divisions and Groups

Division	Group	Research and Education Topics	Professor
Applied Analysis	Applied Analysis	Inverse and Ill-Posed Problems, Fractal Theory, Nonlinear Differential Equations, Numerical Analysis, Probability	ISO Yuusuke KIGAMI Jun
Nonlinear Physics	Nonlinear Dynamics Nonequilibrium Dynamics	Fluid Dynamics, Elasticity	FUNAKOSHI Mitsuaki
Applied Mathematical Sciences		Theoretical Neuroscience, Network Science, Nonequilibrium or Nonlinear Physics, and Network Dynamical Systems	AOYAGI Toshio
	Computational Mechanics	Computational Mechanics	NISHIMURA Naoshi
	Industrial Mathematics	Computational Physics and Monte Carlo Simulation	

Graduate Curriculum

Courses for the Master's Program

Applied Analysis A
Applied Analysis B
Complex Dynamics A
Complex Dynamics B
Applied Mathematical Sciences A
Applied Mathematical Sciences B
Topics in Differential Equations A
Topics in Differential Equations B
Topics in Nonlinear Analysis A
Topics in Nonlinear Analysis B
Seminar on Applied Analysis I
Seminar on Applied Analysis II
Topics in Applied Analysis I
Topics in Applied Analysis II
Topics in Nonlinear Dynamics A
Topics in Nonlinear Dynamics B
Topics in Nonequilibrium Dynamics A
Topics in Nonequilibrium Dynamics B
Seminar in Complex Dynamics I
Seminar in Complex Dynamics II
Topics in Complex Dynamics I
Topics in Complex Dynamics II
Topics in Computational Mechanics A
Topics in Computational Mechanics B
Topics in Control Theory A
Topics in Control Theory B
Seminar in Applied Mathematical Sciences I
Seminar in Applied Mathematical Sciences II
Topics in Applied Mathematical Sciences I
Topics in Applied Mathematical Sciences II
Advanced Study in Applied Analysis and Complex Dynamical Systems I
Advanced Study in Applied Analysis and Complex Dynamical Systems II

Courses for the Doctoral Program

Seminar on Applied Analysis and Complex Dynamical Systems (Advanced)
Seminar on Applied Analysis (Advanced A & B)
Seminar on Complex Dynamics (Advanced A & B)
Seminar on Applied Mathematical Sciences (Advanced A & B)

Teaching Staff

Professors
ISO Yuusuke; KIGAMI Jun; FUNAKOSHI Mitsuaki; NISHIMURA Naoshi; AOYAGI Toshio

Associate Professors
FUJIWARA Hiroshi; YOSHIKAWA Hitoshi

Senior Lecturers
KUBO Masayoshi; MIYAZAKI Syuji; CHEN I-kun; SHIRAISHI Daisuke

Assistant Professors
TUTU Hiroki; HARADA Kenji; NIINO Kazuki

Departmental Activities

The Department of Applied Analysis and Complex Dynamical Systems deals with studies including development of novel analytical techniques for the new academic filed of complex systems science, investigation of order-forming characteristics in complex systems, modeling and control of complex dynamical systems, and function design for complex mechanical systems. In particular, in cooperation with the Department of Mechanical Engineering and Science, the Department of Micro Engineering, and the Department of Aeronautics and Astronautics of the Graduate School of Engineering, as well as the International Innovation Center, we promoted education and research in the field of mechanical engineering at the "Research and Education on Complex Functional Mechanical Systems New Developments in Mechanical Engineering Inspired by Complex Systems Science" Center for research and education (FY2003-2007) as part of the 21st Century Center of Excellence (COE) Program. Following this program, we have been promoting education and research for expansive relationship between science and engineering. Recently, we organized a symposium entitled "New Frontier in Complex Systems Science From theory to practice" at Kyoto University in June, 2012. In this symposium, we had an opportunity to have lectures that give a broad understanding of our researches to general public as well as applicants for admission to doctoral course. Also, we organized the 14th Informatics Symposium (February 2013) entitled "Numerical Simulation and Informatics," in which two staffs of the department gave talks on numerical simulation.

Applied Analysis

Applied mathematics seeks to go far beyond mere application of pure mathematics to solution of physical and mechanical problems. Through research into mathematical models of phenomena, applied mathematics creates new mathematics. Our Division teaches and carries out research in applied analysis where there is particular emphasis on analysis in fields of applied mathematics. We seek to improve our understanding of existing analytics and create new analytics for the 21st Century. To give specific examples of the kinds of research we do, we analyze mathematical models of physical and mechanical phenomena by applying mathematical and numerical analysis and stochastic theory to get a better understanding of both the analytical methods and the mathematical structure of the model, and to establish new analytical techniques. In this Division, the key words are “nonlinear analysis” and “inverse problem analysis,” and our staff constantly interacts with one another while they teach and conduct research.

Nonlinear Analysis and Inverse Problem Analysis

Analysis in the 21st Century

Faculty Members and Their Research Interests

■**Numerical Analysis of (Partial) Differential Equations, Numerical and Mathematical Analyses**
I am interested in both mathematical and numerical analyses in research regarding the determination of unknown coefficients and other inverse problems, as well as boundary value problems and other forward problems with respect to partial differential equations that describe mechanical and physical phenomena.
[Professor: ISO Yuusuke]

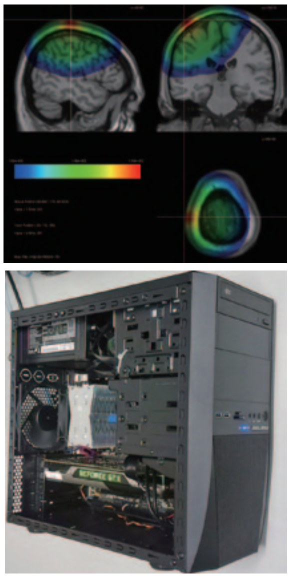
■**Fractal Analysis, Fractal Geometry**
I am interested in the mathematical theory of problems concerning heat and wave propagation in fractal concept models —new models for the natural world.
[Professor: KIGAMI Jun]

■**Numerical Analysis of Ill-posed Problems, Design and Implementation of Multi-precision Arithmetic Environments**
I am interested in research concerning regularization methods and numerical analysis of multiple-precision calculations with the aim of solving inverse problems that occur in mechanics and geophysics and reconstructing
[Associate Professors: FUJIWARA Hiroshi]

■**Inverse Problem Analysis, Numerical Analysis of (Partial) Differential Equations, Partial Differential Equations, Brain Model Mathematical Research**
I mathematically analyze partial differential equations that appear in mathematical physics and mathematically and numerically analyze the inverse problems found in these partial differential equations, where the unknown coefficients of these inverse problems are determined by observed data.
[Senior Lecturer: KUBO Masayoshi]

■**Boltzmann Equations, Kinetic Models**
I am interested in the Boltzmann equations, kinetic models, and related inverse problems.
[Senior Lecturer: CHEN I-kun]

■**Structure of Brownian Motion and Random Walk**
How does the trace of Brownian motion look like? What can we say about the structure of random walk trace? Such questions have fascinated probabilists and mathematical physicists for a long time, and they continue to be an unending source of challenging problems. I am interested in the nature of sample paths of these fundamental processes.
[Senior Lecturer: SHIRAISHI Daisuke]



Numerical Simulation of Light Propagation in a Human Brain (top) and Hardware used in Simulation (bottom).

Department of Applied Analysis and Complex Dynamical Systems

Outline

Nonlinear Physics

The dynamic behavior of systems that have a high degree of freedom and engage in nonlinear mutual interactions is both complex and richly diverse, and yet, many of these systems possess qualities in common with each other, such as a regular structure, and are fascinating subjects for research. In this Division, we use logical analysis and computer simulations to gain a better understanding of the complex behavior and control of these kinds of dynamic systems, as well as to clarify their common principles.

Fluid Dynamics and Computational Physics

Studies of the complex behavior of fluids and other nonlinear dynamic systems

We aim to understand and control the various patterns of complicated behavior of nonlinear dynamical systems such as fluid systems, many-particle systems, and structural systems. In particular, we are trying to clarify, control and utilize in fluid systems and coupled dynamic systems the nonlinear behavior of chaos, synchronization, pattern formation, generation and interaction of nonlinear waves, interaction of vortices, and thermal convection. To achieve this aim, we conduct logical analysis based on the theory of nonlinear dynamic systems, reduction theory, and singular perturbation methods, and apply simulation techniques such as differential calculation, spectral methods, Monte Carlo techniques, and molecular dynamic methods.

[Professor: FUNAKOSHI Mitsuaki]

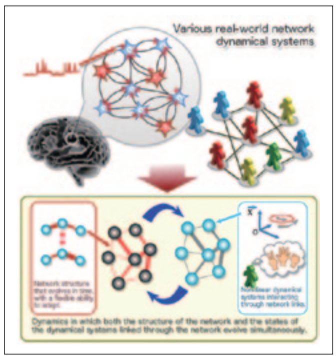
An efficient mixture of fluids is attained if two cylinders, one inside the other, are rotated slowly in opposite directions so that each fluid particle moves chaotically. This is called chaotic mixing.

Nonequilibrium Physics and Theoretical Neuroscience

From nonlinear and non-equilibrium physics to theories on networks as well as living and neural systems

Physical systems like fluids and chemical reactions are not the only cooperative phenomena that are made up of comparatively simple elements, and yet exhibit complex behavior and advanced functions that are impossible to predict from the individual elements alone. This same characteristic is also found in neural systems and social phenomena. For example, in neural systems, the mutual interaction between the basic elements called neurons all grouped together allows the neural system to acquire the advanced information processing functions of learning, memory and decision-making, or from a more ordinary perspective, they form the dynamic elements in a network (neurons, cities, people, etc.). The network structure and dynamic activity of the elements are simultaneously changing, and the network exhibits the ability to organize itself. Our research looks at these kinds of cooperative phenomena that have multiple elements, and focuses on reduction theory, rhythmic phenomena, and chaos theory from the perspective of nonlinear dynamics and non-equilibrium physics.

[Professor: AOYAGI Toshio,
Senior Lecturer: MIYAZAKI Syuji,
Assistant Professor: TUTU Hiroki]



Neural systems and social networks are nonlinear dynamic systems that have a high degree of freedom and develop as their dynamic elements change the structure of their interconnections. At first glance, these systems might appear to be completely different, but the invariant structure that they both have may be hidden. Mathematical models are useful tools to help us understand these systems.

Applied Mathematical Sciences

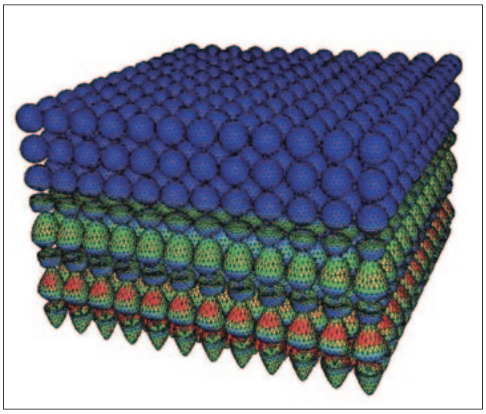
Many of the objects that we study in mechanics are large and complex, and often exhibit behavior that is uncertain and difficult to predict. Although the most important issue for us is to be able to accurately predict this behavior and control it, this is generally not easy to do. High-speed simulation techniques are essential to the prediction and analysis of large, complex systems; and in order for us to be able to control complex systems, the control method we use has to take into account the indefinite nature of the system and the uncertainty of its behavior — i.e., the method of control has to be robust. In our Division, we develop and apply these techniques from the standpoint of applied mathematical science.

Computational Mechanics

Computer simulations: development of fast BIEMs and their applications to engineering problems

Numerical simulations provide powerful tools for solving various problems in science and engineering. Computational mechanics, together with theoretical and experimental mechanics, is an effective method of investigating mechanical phenomena in engineering based on numerical simulations. Our group specializes is Boundary Integral Equation Methods (BIEM) which are among major techniques in computational mechanics. BIEMs are particularly effective in wave and fracture problems. We focus on fast BIEMs and their applications to large-scale problems with special interest in electromagnetic wave propagations in periodic structures, which have many applications in optics. Other topics of interest include shape optimization problems, eigenvalue problems and inverse problems.

[Professor: NISHIMURA Naoshi,
Associate Professor: YOSHIKAWA Hitoshi,
Assistant Professor: NIINO Kazuki]



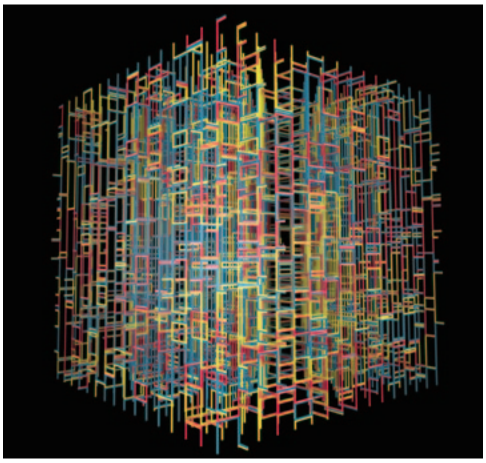
Example of analysis using a time domain fast multipole boundary integral equation method

Industrial Mathematics

Exploring quantum matter by computational approach

Based on theoretical approach and large-scale numerical simulations, we investigate and control physical phenomena in physics and engineering. For example, we focus on macroscopic phenomena driven by quantum mechanics. It is a challenging problem to predict the behavior of quantum matter numerically. We also develop numerical algorithms of quantum simulators.

[Assistant Professor: HARADA Kenji]



The horizontal direction represents two-dimensional space for electrons, and the vertical direction indicates imaginary time which is used to express quantum fluctuations numerically. Colored lines represent the path of electrons in spacetime, which called "world lines." To predict the behavior of quantum matter, we need to make many samples of world lines by quantum simulators.