Math Clinic

One of the critical obstacles to the development of interdisciplinary research collaborations between mathematical sciences and other disciplines is the difficulty of converting the needs of the scientific discipline into new seeds of mathematical studies, and vice versa: it is also difficult to recognize what kind of scientific problems can be solved mathematically, and what kind of mathematical ideas are effectively applicable to solving those problems.

In this group, we hold regular office hours, called "math clinic", where researchers and graduate students from our graduate school can bring their problems related to mathematical ideas. Through an intensive consultation with members of the group including graduate students, we aim at fostering new interdisciplinary studies by trying to find out what is the problem to be solved and what mathematical methods and ideas can be used to attack it.

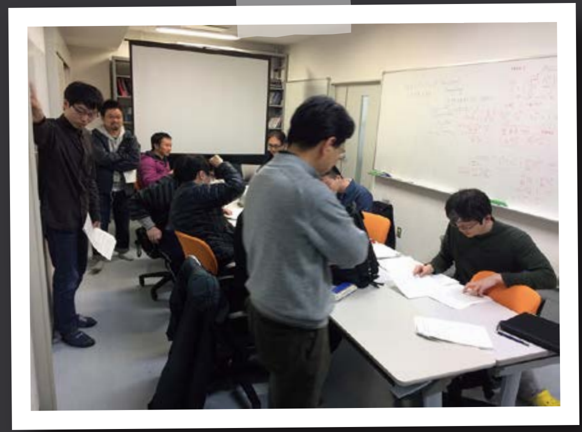
Faculty Members in MACS

The list is in the alphabet order. Each number indicates the study group (SG) in which the member joins, and * corresponds to SG-organizer.

- **Takeaki Araki**, Physics **8**
- **Shigehiko Hayashi**, Chemistry **7**
- **Tomoo Hirano**, Biological Science **6***
- **Masatoshi Ichikawa**, Physics **5**
- **Yasuhiro Ishitsuka**, Mathematics **1, 3, 4**
- **Tsuyoshi Kato**, Mathematics **6**
- **Daisuke Kishimoto**, Mathematics **3**
- **Hiroshi Kokubu**, Mathematics **6, 8**
- **Mikio Kurita**, Physics **4***
- **Takeshi Matsumoto**, Physics **5**
- **Takemasa Miyoshi**, RIKEN AICS **1**
- **Tetsuya Nagata**, Physics **2, 4**
- **Hiroki Ohta**, Physics **3, 6, 7**
- **Tokitaka Oyama**, Biological Science **5**
- **Takashi Sakajo**, Mathematics **1***
- **Shin-ichi Sasa**, Physics **3*, 7**
- **Yoshinori Shichida**, Biological Science **7**
- **Shigeru Shinomoto**, Physics **6**
- **Hiroshi Sugiyama**, Chemistry **7**
- **Karel Svadlenka**, Mathematics **4**
- **Yoshiko Takahashi**, Biological Science **2, 8***
- **Yuta Takase**, Biological Science **2, 5, 8**
- **Shoji Takada**, Biological Science **3, 7***
- **Koichiro Tanaka**, Physics **2***
- **Sadayoshi Toh**, Physics **5***
- **Michio Yamada**, Research Institute for Mathematical Sciences **5**
- **Jun Yamamoto**, Physics **2**
- **Shigeo Yoden**, Geology **1**

Past Seminars / Activities (2016-2017)

- **MACS Kick off Symposium** (May 15, 2016)
- **1st MACS Colloquium** (October 26, 2016)
- **[SG8] Observation of gut development in the chicken embryos** (November 4, 2016)
- **[SG7] MACS Seminar "Sampling in machine learning"** (December 7, 2016)
- **2nd MACS** Colloquium (December 19, 2016)
- **[SG8] MACS Seminar "The mystery of skin protecting our bodies"** (January 10, 2017)
- **[SG7] MACS Seminar "The state of the art in Monte Carlo sampling with skew detailed balance conditions"** (January 25, 2017)
- **[SG8] MACS Seminar "The revival of D'Arcy Thompson's spirit: The force law determining the form of living organisms"** (February 9, 2017)
- **[SG5] Observation of flocks of white-fronted geese** (February 10-12, 2017)
- **MACS 2016 project report meeting** (February 17, 2017)
- **[SG7] MACS Seminar "Analysis of the structures and dynamics in gene regulation on the basis of experimental data"** (February 22, 2017)



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This leaflet was produced by the staff of the Graduate School of Science, Kyoto University.
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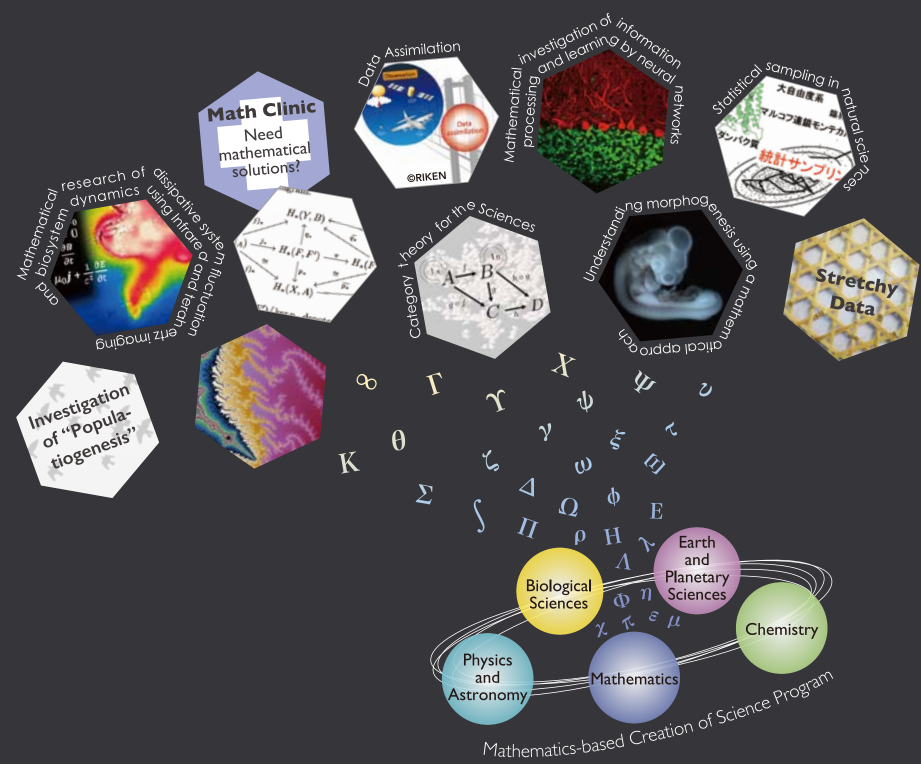
designed by: Knorico Arisawa, and **special thanks to:** Benoit Collins, Ivan Ip, and Karel Svadlenka.

Graduate School of Science Kyoto University

MACS



March, 2017

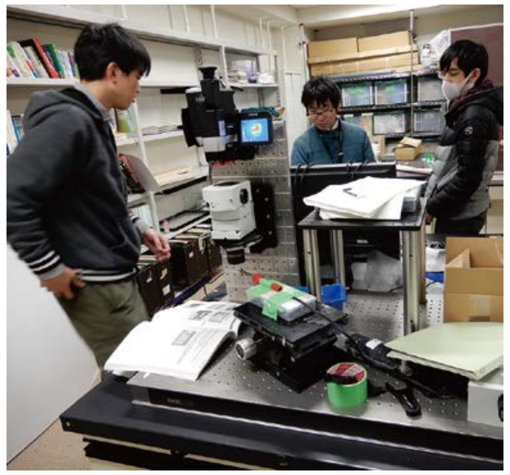
京都大学 理学研究科・理学部
GRADUATE SCHOOL OF / FACULTY OF SCIENCE
KYOTO UNIVERSITY

Toward the emergence of unexpected new research fields

MACS

Fundamental research in science is the principal component of the elaboration of knowledge that is then used in order to promote all academic activities, including those in natural science and engineering. As such, fundamental research facilitates the expansion of the range of our viewpoints and the development of creative research; therefore, it is of paramount importance towards the development of science and technology. As the newly announced mission at Graduate School of Science in Kyoto University states: "we aim at developing new research fields on the basis of trans-disciplinary collaboration through seeking for universal principles".

Nowadays, our society tends to put a strong emphasis on applied research, sometimes followed by an increasing disinterest for fundamental research. Furthermore, while academic knowledge itself has continued to develop, it has been segmented into highly specialized fields with little cross-interaction. If this trend continues, there is a risk that problems arising from our society end up being solved without the necessary hindsight and awareness of other issues, despite the fact that our society itself is getting more and more diverse and complicated. Therefore, it is urgent for natural science to **foster new international scientists with a flexible and wide range of points of view and generate new integrated research fields,** in order to deal with such a diversity of problems arising from our society.



Mathematics is one of the disciplines of science which have played an essential role in the development of fundamental scientific research at Kyoto University for a long time. In our educational program, we focus on the universality of mathematics, and, building up on this key feature of this discipline, we **aim to design education and research in order to facilitate emergence of unexpected new research fields through integrating the five divisions in natural science at Kyoto University.** Specifically, we have launched "study groups (SG)". They cover various trans-disciplinary themes and their approaches are endowed with a high level of freedom. At the same time, we encourage students to pursue unexplored directions that would not appear inside a traditionally established research discipline. Thus, through the activities in these SG, we aim at making it possible to achieve education and research which spontaneously give rise to unexpected new research fields in natural science, and also international research leaders taking on a lead on such new fields.

The following two statements describe the characteristics of the educational program MACS:

- ❑ We aim at finding new formation of education and research in natural science by taking advantage of a potential in universal aspects of mathematics. We believe that **this program is truly unique in the world in the sense that we facilitate emergence of unexpected new research fields by keeping a high level of freedom to the activities in this program.**
- ❑ We aim at removing the boundaries between different divisions in natural science and at looking at natural science from the overall viewpoint of science and technology. Through this approach, we aim at **fostering researchers with both deeply specialized knowledge and a wide range of viewpoints, i.e. highly original scientists reflecting the unique characteristic of this program.**

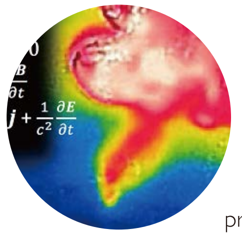
MACS is the abbreviation of MAthematics-based Creation of Science program.

MACS 2016 Study Groups (SG)

Data Assimilation

Data assimilation (DA) is a rapidly developing subject spanning the fields of statistical and mathematical sciences. It proposes a new style of scientific analysis, which assimilates large-scale observation data into a theoretical model of the studied phenomenon, yielding more reliable predictions. For example, DA is successfully applied to weather forecasting, where its effectiveness has already been verified. In this SG, in collaboration with the data-assimilation research team led by Dr. Miyoshi team leader from RIKEN AICS, we organize a two-semester course on DA including exercises and discussion seminars with graduate students. The aim of this SG is to create new research directions and open ways for new applications in a wide range of disciplines.

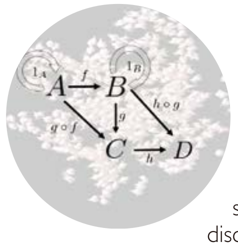
[Organizer: Takashi Sakajo, Mathematics]



Mathematical research of dissipative system fluctuation and biosystem dynamics using Infrared and terahertz imaging

In this SG, we use infrared and terahertz imaging to visualize objects in non-equilibrium state and biosystem dynamics that have not been made visible yet. We try to create a novel scientific field based on mathematical processing of thus obtained data. In particular, we will learn what can be visualized using the infrared camera (which can sensitively measure black body radiation) and the terahertz microscope (which can visualize the states of water and giant molecules). At the same time, we will photograph samples selected by the participants. We expect that, as they learn about infrared and terahertz imaging through simple experiments, the participants will become able to formulate new research proposals of their own interest.

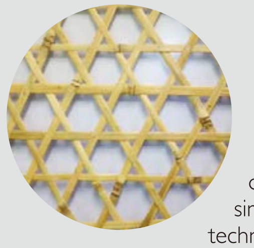
[Organizer: Koichiro Tanaka, Physics]



Category theory for the Sciences

We learn the category theory with the view of using it as the basis for the construction of an abstract framework to unify diverse ways of scientific understanding, such as models and theories. Through considering various examples appearing in the sciences, we aim at producing a unique environment where researchers from different backgrounds and also students, who desire to become researchers in their future, could freely discuss topics beyond their own research fields. In particular, we begin with reading the paper "Category theoretic analysis of hierarchical protein materials and social networks, D.I. Spivak et al, PLoS ONE 6(9) (2011)" in order to get the feel of category theory. Then we continue with the textbook "Category Theory for the Sciences, D.I. Spivak, MIT Press (2014)".

[Organizer: Shin-ichi Sasa, Physics]



Stretchy Data

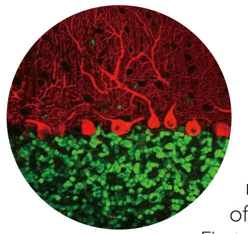
Appropriate linking of data obtained on several overlapping domains is a common problem appearing not only in natural sciences but also in various other fields (e.g., "gluing together" partial digital archive images of a cultural asset). Data on overlapping regions usually have different values due to measurement errors and trying to overcome this inconsistency by simply taking the arithmetic mean results in unnatural jumps. Existing techniques focus on the smoothness aspect of data connection, which is not satisfactory from the scientific point of view. In this SG, we discuss the possibilities of a new data-stitching algorithm which assumes that the data represent a stretchy elastic body. By this assumption, the evaluation of the data can be viewed as an energy minimization problem, which corresponds to an extension of the classical arithmetic mean theory. Although the algorithm has been successfully tested on several data sets, its theoretical justification is still missing. We are going to investigate the potential of this new idea based on mathematical theory.

[Organizer: Mikio Kurita, Physics]

Investigation of "Populatiogenesis": seeking mathematical principles behind cooperative phenomena on various scales

Mathematical clarification of cooperative phenomena realized by populations of cells or organisms is an important issue. For example, while the formation processes on the level of cell population are essential for further investigation of organ morphogenesis and development, these processes have not yet been entirely understood. The scale of cooperative phenomena in populations is very broad, ranging from the micro-scale (e.g., bacterial floras) to the macro-scale (e.g., bird flocks), and each scale contains unresolved problems. For example, the phenomenon of bird flocking seems simple at first glance but nobody has yet succeeded in giving a precise explanation of the aerodynamic advantages of forming flocks based on the theory of fluid dynamics. Therefore, in this SG we aim at educating students who possess deep knowledge both in biological science and in mathematics.

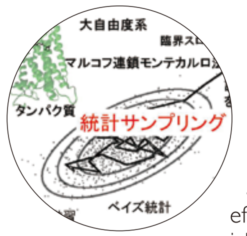
[Organizer: Sadayoshi Toh, Physics]



Mathematical investigation of information processing and learning by neural networks

Neural networks in a brain hold memory through various kinds of information processing and learning. We aim at launching a trans-disciplinary collaboration that would be based on the knowledge of neuroscience and use the ideas of mathematical science, with the purpose of comprehensively understanding the brain's mechanism of efficient learning. First, by focusing on learning of motions in a cerebellum consisting of a simple and regular neural network, we study such a cerebellar neural network and the modeling methods of information processing and learning in neural networks. Then, in order to deepen our understanding of learning mechanisms by neural networks, we try to extract essential questions to be clarified and attempt to synthesize experimental observations and mathematical ideas around this subject. We begin with reading "A theory of cerebellar cortex, D. Marr, J. Physiology 202 (1969)".

[Organizer: Tomoo Hirano, Biological Science]



Statistical sampling in natural science: from mathematics to applications

Statistical sampling is a universal computational method applicable to a wide area of science, from material sciences appearing extensively in physics, earth science, chemistry, and biology, to information science such as data-based machine learning. A common problem among these is to efficiently sample from a very large state space and evaluate the state variables of interest. For this purpose, a countless number of algorithms have been developed. In this SG, we aim at understanding the mathematical structures of the cutting edge algorithms for statistical sampling and their background from the viewpoint of physics. Furthermore, we try to apply these algorithms to modeling problems such as those arising from proteins and nucleic acids. It would be wonderful if new sampling algorithms are discovered through this activity. We begin with reading "Basics of Markov chain Monte Carlo methods, Yukito Iba, Computational StatisticsII chapter1 (in Japanese), Iwanami press (2005)".

[Organizer: Shoji Takada, Biological Science]

Understanding morphogenesis using a mathematical approach

In this SG, we aim at understanding the morphogenesis and organogenesis of creatures mathematically. We adopt our material from the article "On the growth and form of the gut, C. Tabin et al., Nature (2011)". This is an interesting article which tried to solve the morphogenetic mechanisms of vertebrate gut looping using a combination of multiple interdisciplinary approaches, including developmental biological analysis, physical simulacrum using rubbers, measurement of tissue mechanical properties, and the devising of mathematical theory and computational simulation. Thus, this article is regarded as a monumental interdisciplinary research for understanding the morphogenesis of creatures. Through reading and fully understanding this article, we discuss the possibility of applying interdisciplinary approaches to the understanding of morphogenesis and organogenesis.

[Organizer: Yoshiko Takahashi, Biological Science]