# Methods and Applications in Mathematical Life Sciences

## 変革 A: 3G+∞(無限) Fusion Meeting

**Date:** 17th February 2023

**Place:** ASHBi, B1F, Main conference room
Faculty of Medicine Building B,
Yoshida campus, Kyoto University
`https://ashbi.kyoto-u.ac.jp/`

**Networking place:** From 18:00 –
がんこお屋敷・高瀬川二条苑,
〒 604-0922 京都府京都市中京区木屋町通二条下ル東生洲町 484-6

*Organizers:* Antoine Diez (ASHBi), Hiroshi Ishii (ASHBi), Clément Moreau (RIMS)

*This joint meeting is organized by the following groups*

PI: S. Seirin-Lee – KAKENHI, Grant-in-Aid for Transformative Research Areas (A) 22H05110

PI: K. Ishimoto – KAKENHI, Grant-in-Aid for Transformative Research Areas (A) 21H05309

PI: M. Akiyama – KAKENHI, Grant-in-Aid for Transformative Research Areas (A) 20H05948

# Program

09:55 – 10:00 **Opening remarks**

*Chair: Antoine DIEZ*

10:00 – 10:40 **Yoshiki HIRUTA (蛭田 佳樹)**, *Research Institute for Mathematical Sciences, Kyoto University (京都大学 数理解析研究所)*

Reversal symmetry breaking of model microswimmers in noisy and bounded environments.

10:50 –11:30 **Kento YASUDA (安田 健人)**, *Research Institute for Mathematical Sciences, Kyoto University (京都大学 数理解析研究所)*

Most probable path of an active Brownian particle

*Lunch time*

*Chair: Clément MOREAU*

13:30 – 14:10 **Antoine DIEZ**, *Kyoto University Institute for the Advanced Study of Human Biology (ヒト生物学高等研究拠点)*

Kinetic theory for active particle systems with geometrical constraints

14:20 – 15:00 **Hiroshi ISHII (石井 宙志)**, *Kyoto University Institute for the Advanced Study of Human Biology (ヒト生物学高等研究拠点)*

Dynamics of localized patterns in nonlocal evolution equations

*Break*

*Chair: Hiroshi ISHII*

15:30 – 16:10 **Tomohiro MIMURA (三村 知広)**, *Graduate School of Engineering, Kyoto University (京都大学大学院工学研究科)*

A simulation model based on cell centers for representing three-dimensional tissue deformation

16:20 – 17:00 **Kentaro MORIKAWA (森川 健太郎)**, *Graduate School of Engineering, Kyoto University (京都大学大学院工学研究科)*

Method of infering the distribution of area expansion in differential growth-driven morphogenesis using harmonic map

17:00 – 17:10 **Closing remarks**

18:00 – **Free discussion and networking**

# Book of Abstracts

### Reversal symmetry breaking of model microswimmers in noisy and bounded environments.

**Yoshiki HIRUTA (蛭田 佳樹)**

*Research Institute for Mathematical Sciences, Kyoto University (京都大学 数理解析研究所)*

The motility of microswimmers is strongly restricted by their surrounding environments because of their small inertia. Due to the restriction, microswimmers with a reciprocal deformation cannot achieve any net velocities. This work addresses microswimmers in noisy and bounded environments. In such environments, microswimmer can achieve net velocity as an expected value even with a reciprocal deformation and under a spatially uniform noise. In this talk, I will introduce a minimal two-sphere swimmer which can swim with noise but cannot swim without noise.

### Most probable path of an active Brownian particle

**Kento YASUDA (安田 健人)**

*Research Institute for Mathematical Sciences, Kyoto University (京都大学 数理解析研究所)*

In this study, we investigate the transition path of a free active Brownian particle (ABP) on a two-dimensional plane between two given states. The extremum conditions for the most probable path connecting the two states are derived using the Onsager-Machlup integral and its variational principle. We provide explicit solutions to these extremum conditions and demonstrate their nonuniqueness through an analogy with the pendulum equation indicating possible multiple paths. The pendulum analogy is also employed to characterize the shape of the globally most probable path obtained by explicitly calculating the path probability for multiple solutions. We comprehensively examine a translation process of an ABP to the front as a prototypical example. Interestingly, the numerical and theoretical analyses reveal that the shape of the most probable path changes from an I to a U shape and to the $\ell$ shape with an increase in the transition process time. The Langevin simulation also confirms this shape transition. We also discuss further method applications for evaluating a transition path in rare events in active matter.

## Kinetic theory for active particle systems with geometrical constraints

**Antoine DIEZ**

*Kyoto University Institute for the Advanced Study of Human Biology (ヒト生物学高等研究拠点)*

During the last decades, there has been a growing effort to understand how complex self-organized patterns (or structures) can emerge from active particle systems when the number of particles becomes very large. Typical examples in biology include the flock of birds or the swarm of bacteria and other active cells. More recently, this modelling framework has also been applied in socio-economical contexts (opinion dynamics, wealth distribution...) or in data science and optimization with the development of so-called particle methods. Sensible modelling attempts have been based on classical tools developed in statistical physics to study inert systems and in particular on the kinetic theory of gas. The core idea is the (rigorous) derivation of PDE models from many-particle systems: this is a long-standing mathematical question tracing back to Boltzmann, but which has recently enjoyed some kind of a renaissance. In this talk I will briefly review and discuss some recent trends in the study of collective dynamics and self-organization phenomena and discuss how the behavior of many-particle systems can be inferred by looking at appropriate scaling limits. Then, I will illustrate these ideas with a system of so-called "body-oriented" particles which, in particular, demonstrates the influence of stochasticity and geometry on self-organization.

## Dynamics of localized patterns in nonlocal evolution equations

**Hiroshi ISHII (石井 宙志)**

*Kyoto University Institute for the Advanced Study of Human Biology (ヒト生物学高等研究拠点)*

In this talk, we deal with time evolution equations with nonlocal effects described by spatially convolution with appropriate integral kernels. Such nonlocal effects are used to describe cell-cell interactions and population diffusion processes. Recently, nonlocal evolution equations have been widely used as mathematical models in fields related to biological phenomena such as neuroscience and ecology. From the viewpoint of pattern formation, it is known that even a single equation can form various patterns due to nonlocal effects. In this lecture, I will give an overview of mathematical models with nonlocal effects and introduce the results of analysis on the dynamics of localized patterns.

## A simulation model based on cell centers for representing three-dimensional tissue deformation

**Tomohiro MIMURA (三村 知広)**

*Graduate School of Engineering, Kyoto University (京都大学大学院工学研究科)*

The dynamics of cells play a crucial role in regulating the three-dimensional morphogenesis of tissues and organs in living organisms. Numerous mathematical modeling and simulation studies have been performed to comprehend this phenomenon. Among these, the cell-center model, which accounts for cellular discreteness, holds promising potential. Although the cell nucleus, commonly considered to be the cell center, can be easily observed experimentally, methods such as Delaunay triangulation and Voronoi tessellation have only been established for two-dimensional tissues. This study presents the development of a mathematical model based on the cell-center approach to address three-dimensional tissue deformation.

## Method of infering the distribution of area expansion in differential growth-driven morphogenesis using harmonic map

**Kentaro MORIKAWA**

*Graduate School of Engineering, Kyoto University (京都大学大学院工学研究科)*

The three-dimensional (3D) morphologies of many organs in organisms, such as the curved shapes of leaves and flowers, the branching structure of lungs, and the exoskeletal shape of insects, are formed through surface growth. Although differential growth, a mode of surface growth, has been qualitatively known to be a factor in 3D morphogenesis, quantitative understanding of the mechanical contribution of differential growth has not been achieved. In this study, we developed an inference method of area expansion rate distribution that governs the growth of surface into the 3D morphology to enable this quantitative understanding. To test the validity of this method, we applied it to a simple 3D morphology for which the area expansion rate distribution could be theoretically derived, and evaluated the error between the predicted and the theoretical solution. We also applied this method to complex 3D shapes for which the theoretical solution could not be obtained, and evaluated its accuracy through numerical experiments. The results indicated that the error decreased linearly in log-log scale with the number of meshes in both evaluations, and this confirmed the validity of the prediction for sufficiently fine meshes. Furthermore, we applied this method to the actual developmental system, the Japanese rhinoceros beetle horn primordium formation process, where differential growth is considered to govern the 3D morphogenesis. The results showed that the left and right edges of the horn primordium were predicted to have particularly high area expansion rates. This result is consistent with the experimental observation of higher cell division rates in those regions. This confirms the validity of the method in actual biological systems.