ICMMA 2026

International Conference on Mathematical Modeling and Applications

International Conference on

"Interfacial phenomena:
bridging theory, computation, and experiments"

Poster Presentation

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ICMMA 2026 Poster Presentation Abstracts

1. “Two Formulations of Weak Acceleration for Evolving Interfaces”

Syota Koide (National Institute of Technology, Matsue College)

Acceleration plays a fundamental role in hyperbolic interface evolution, yet its weak formulation has not been fully established within the framework of geometric measure theory. In this work, based on our recent paper published in Note di Matematica, we propose two weak formulations of acceleration for evolving interfaces.

The first formulation is based on varifolds, which provide a measure-theoretic description of generalized hypersurfaces. The second formulation is formulated in terms of Caccioppoli sets (sets of locally finite perimeter), another fundamental framework in geometric measure theory. Both formulations are derived from the time derivative of an integral quantity corresponding to a weighted momentum of the evolving interface.

We further prove that, under suitable assumptions, these two notions of weak acceleration coincide. This equivalence establishes a unified framework connecting the varifold and Caccioppoli-set approaches to interface evolution.

The proposed formulations provide a mathematical foundation for the study of weak solutions to hyperbolic mean curvature flow and related geometric evolution equations. They are expected to be useful in future investigations of existence theory and variational formulations for hyperbolic geometric flows.

This work is based on joint research with Professor Seiro Omata (Professor Emeritus, Kanazawa University).

2. “Effect of Interfacial-Energy Heterogeneity on Drying-Induced Crack Pattern Formation”

Shin-ichi Ito (The University of Tokyo)

Drying-induced fracture in particle–liquid mixtures, such as mud cracking, is strongly influenced by interfacial effects associated with the loss of liquid from the particle network. As drying proceeds, liquid is locally depleted from an initially saturated particulate structure, leading to the nucleation of microscopic cracks. Whether these nuclei grow or disappear is governed by the energetic competition between elastic deformation of the particle network and spatially heterogeneous interfacial energy. Nuclei that continue to grow act as precursors to macroscopic cracks. The spatial distribution of interfacial energy can therefore play a central role in the formation and evolution of crack patterns. Direct experimental characterization of this distribution, however, remains challenging.

Motivated by this difficulty, we develop a continuum framework for quantitatively investigating the relationship between spatial variations in interfacial energy and the resulting fracture patterns. Drying-induced cracking is modeled as shrinkage-induced fracture of a thin elastic layer adhered to a rigid substrate. Within a two-dimensional continuum description, spatially heterogeneous interfacial energy is explicitly incorporated into the fracture energetics.

A difficulty in studying such heterogeneity numerically is that crack trajectories in discrete fracture models can be influenced by the underlying mesh geometry, particularly when irregular or random meshes are used. Numerical randomness associated with discretization can then become difficult to distinguish from the physical randomness introduced through the interfacial-energy field. To separate these effects, we employ a phase-field formulation in which fracture-pattern formation is represented by the evolution of continuous fields governed by the competition among elastic deformation, substrate adhesion, and interfacial energy. This formulation reduces artificial sensitivity to mesh geometry and enables us to examine systematically how statistical properties of the prescribed interfacial-energy field affect crack-pattern formation.

Numerical simulations show that both the temporal evolution and morphology of the fracture patterns vary markedly with the statistical properties of the interfacial-energy field. In this presentation, we focus particularly on geometrical descriptors of the resulting fragments and examine their quantitative relationships with the statistics of the underlying interfacial-energy field. These results provide a basis for relating observable fracture morphology to otherwise inaccessible spatial heterogeneity in interfacial energy.

3. “A Linearized Ordinary Differential Equation Model for Formose Reaction Network Kinetics”

Taisei Fujimoto (The University of Osaka.), Taisei Fujimoto(Univ. of Osaka), Yoko Hase(Toyota Central R&D Labs., Inc.), Yoshiharu Mukouyama(Univ. of Osaka, Univ. of Tokyo Denki), Shuji Nakanishi(Univ. of Osaka), Hiro Tabata(Univ. of Osaka)

The formose reaction produces sugars from formaldehyde through a non-enzymatic process. Because formaldehyde can be obtained by the reduction of CO2, the formose reaction has attracted considerable interest in the contexts of the origin of life and CO2 utilization. However, this reaction system involves a complex chemical reaction network (CRN), in which numerous elementary reactions are interconnected, leading to an increasingly complex product distribution as the reaction proceeds. This complexity makes it difficult to elucidate the structure of the CRN and, consequently, to predict product formation quantitatively. To address this challenge, we focused on the initial stage of the reaction, before the CRN becomes highly complex, and elucidated its structure through quantitative analysis of the reaction products. On the basis of the identified CRN, we further developed a linearized ordinary differential equation model to describe the dynamic behavior of the formose reaction network.

4. “From Invariants to Commuting Observables: Quantum Argument Shifts and a Taylor Formula for Integrable Systems”

Yasushi Ikeda (Meiji University)

Many mathematical models become more tractable when their symmetries produce conserved quantities or mutually commuting observables. In classical Hamiltonian systems, the Mishchenko--Fomenko argument-shift method constructs such quantities by differentiating invariant functions along a fixed direction. This poster develops a quantized version of this principle for the matrix Lie algebra gl_d and compares two different constructions of the resulting commuting operators.

The first construction uses quantum partial derivatives on the universal enveloping algebra U(gl_d). These derivatives satisfy a modified Leibniz rule adapted to noncommutative multiplication. When iterated on central elements, they generate a commuting family whose principal symbols recover the classical argument-shift algebra. The second construction begins with the Feigin--Frenkel center at the critical level and applies shifted evaluation. For the antisymmetric Segal--Sugawara vectors, the shifted-evaluation coefficients coincide exactly with the iterated quantum derivatives. This identity gives an exact quantum Taylor formula and identifies the two constructions coefficient by coefficient.

The result provides a bridge between classical invariants, noncommutative algebra, and quantum integrability. It also connects structural theory with symbolic computation.

5. “Nonlinear Forecast Reconciliation of Cause-of-Death Mortality”

Tsuchiya Yuki (Graduate School of Advanced Mathematical Sciences, Meiji University), Naoki Matsuyama (Meiji Univ.)

Long-term mortality forecasting has become increasingly important for the insurers’ economic solvency assessments under the regulation launched in 2026, as well as for longevity risk management. It must account for long-term changes in the cause-of-death mortality because the effects of medical and public health developments vary by cause of death. However, cause-of-death mortality forecasting models tend to perform poorly when aggregated to predict all-cause mortality. To address this problem, forecast reconciliation methods provide a framework for adjusting independently generated base forecasts of all-cause and cause-of-death mortalities to improve their predictive performance, ensuring the aggregate coherence of them. Minimum Trace (MinT) is a representative forecast reconciliation method that uses the covariance structure of base-forecast errors to determine a reconciliation matrix that minimizes the total variance of reconciled forecast errors. While MinT has previously been used for cause-of-death mortality forecasting, a recent study has proposed a data-driven method in which a neural network is used to estimate the forecast-error covariance matrix used in MinT from base forecasts. However, this network mainly relies on fully connected layers and is not designed to capture relationships within the age dimension of mortality forecasts in tensor form. We therefore propose a MinT-CNN framework, which introduces a Convolutional Neural Network (CNN). The MinT-CNN applies convolution only along the age dimension to independent Lee-Carter (LC) forecasts of all-cause and cause-of-death mortalities. The resulting features are then used to estimate the covariance matrix for the MinT and determine the adjustments to each base forecast. Compared with the previous method, the MinT-CNN also improves how the covariance matrix is constructed, ensuring that it is symmetric and positive definite. This improvement reduces the number of parameters and stabilizes training while maintaining the MinT projection structure used in the previous method. Using Japanese male mortality data from the World Health Organization (WHO) Mortality Database, we compare the MinT-CNN forecasts with independent LC forecasts, bottom-up forecasts and traditional MinT forecasts with shrinkage covariance estimation. The results show that the MinT-CNN improves predictive accuracy for both all-cause and cause-of-death mortality. These findings suggest that CNN-based forecast reconciliation can improve the predictive accuracy of mortality forecasts in tensor form while maintaining the MinT projection structure.

6. “Nonlinear Dynamics of Hinokitiol-Fueled Disks on Aqueous Surfaces”

Lara R. Holstein (NIMS)

In the field of active matter, chemically fueled self-propelled objects displaying nonlinear behaviors represent a promising means to emulate sophisticated biological functions in synthetic systems. However, designing such systems remains a challenge because motion from a molecular viewpoint remains underexplored. Herein, we present the functional molecule, hinokitiol (HT), as a novel fuel species toward synthetic active matter capable of complex, autonomous behaviors. Upon release of HT, onto the aqueous surface, self-propelled motion was induced via the emergence of a surface tension gradient surrounding the disk, termed Marangoni flow. Spontaneous transition from continuous to oscillatory motion was achieved by blending HT within an elastomer scaffold; furthermore, disk behavior could be modulated by altering either the molecular arrangement of the fuel species or the mesoscale structure of the elastomer scaffold. In the presence of Fe(III) ion, HT rapidly forms the complex, FeHT3, which functions as a chemo-repulsive signal that guides disks away from iron-rich regions and establishes exclusionary zones for subsequent disks. These results demonstrate the systematic engineering of life-like nonlinear dynamics shaped by molecular-level design.

7. “Nonreciprocal pattern selection organized by an O(2)-symmetric critical exceptional point”

Yuta Tateyama (Chiba University), Yuta Tateyama (Chiba Univ.), Daniel Greve (Univ. of Münster), Hiroaki Ito (Chiba Univ.), Shigeyuki Komura (WIUCAS), Hiroyuki Kitahata (Chiba Univ.), Uwe Thiele (Univ. of Münster)

We investigate the bifurcation mechanisms governing nonequilibrium pattern transitions in a two-field nonreciprocal Swift-Hohenberg model. Direct numerical simulations reveal a variety of spatiotemporal states, including stationary patterns, traveling waves, standing waves, and modulated waves. By deriving a reduced dynamical system through a single-mode approximation and performing a normal form analysis near the O(2)-symmetric Takens-Bogdanov bifurcation point, we demonstrate how this higher-codimension point serves as an organizing center for the global phase diagram. Our results clarify the correspondence between the critical exceptional point and the universal bifurcation scenarios observed in nonreciprocal continuum systems.

8. “Critical Fractional Heat Flows: Long-Time Dynamicsand a Local-to-Nonlocal Perspective”

Yi Yang (Meiji University)

We extend the study of energy-critical heat flows from the local Laplacian to the fractional Laplacian in $\mathbb{R}^N$. For $4s < N < 6s$, positive global solutions exhibit tail-dependent asymptotic regimes. At $N = 6s$, we construct global solutions and sign-changing infinite-time bubble towers with exponentially separated scales via a nonlocal inner–outer gluing.

9. “A Mathematical Approach to Origami Hat Production”

Toshie Sasaki (Meiji University), *Ichiro Hagiwara (Meiji Univ.)*

In recent years, against the backdrop of growing disaster-prevention awareness and the need to accommodate diverse usage environments, there is a growing demand for lightweight, portable, and easy-to-use helmets. In particular, during disasters and factory tours, there is a need for the development of protective gear that provides compact storage, comfort, and an appealing design. We developed a safety hat that was the lightest and met helmet safety standards based on that idea. The safety hat consists of the wing-folding hat and the crash energy-absorber honeycomb. This has been well received by users, but we want to deliver something even more aesthetically pleasing to them with accordion folding hats.

The fold lines of the wing fold are perpendicular to the direction of the load placed on work helmet. On the other hand, as far as the fold lines of the accordion folding hat developed here form a truss structure. Accordion folding hats carry lower impact loads than wing-folding hats. Traditional hats tend to cause sweating because the hat makes direct contact with the head. When the hat is made of origami with fold lines, the contact between the head and the hat is more linear. Therefore, we choose a regular n-sided shape instead of a curved folding.

By adding angles to a straight accordion fold, not straight shapes can be created. Here, the relationship

between the fold angle and the angle in the development diagram was derived. To create a hat silhouette that fits the shape of the head, a rounded shape was designed based on a quarter of a regular n-sided shape. Using this method, the origami hat with a rounded top was completed, and a design approach was proposed to realize a practical three-dimensional shape as a hat. Regarding hat size, the relationship between each parameter on the development view and head circumference was derived. And for head circumference, it became possible to design hats that meet the S, M, and L size specifications.

Based on this, when the desired silhouette is given, we get automatically the development formula of n-sided accordion folding hats that conform to the shape of the head. We also have developed lighter and safety accordion folding hats than the wing-folding hats. At the venue, we will also discuss this.

10. “Propagation and blocking of driven curvature flow in a strip domain with periodic obstacles”

Ryunosuke Mori (Meiji University)

We study the long-time behavior of driven curvature flow in a strip domain with periodic obstacles. We introduce the notions of left and right opening angles and use them to characterize propagation, blocking, and propagation speeds. This characterization also reveals that, unlike in previously studied strip domains without obstacles, the propagation speeds on the left and right sides of the obstacles can be different.

11. “Morphological Transition and Interfacial Growth Dynamics Change in Metal Dendrites Induced by Surfactants”

Tomoya Nakamura (Chiba Univ.), *Hiroaki Ito (Chiba Univ.), Hiroyuki Kitahata (Chiba Univ.)*

Dendritic structures are ubiquitous non-equilibrium patterns observed across scales, from biological tissues to geophysical phenomena. In particular, metal dendrites formed via electrodeposition exhibit a rich variety of morphologies depending on experimental conditions.

During electrodeposition, additives significantly modify the growth dynamics of the metal surface. Because interfacial surface dynamics govern fundamental dendritic growth characteristics, including branching frequency and growth speed, understanding how surface dynamics dictate macroscopic pattern formation is an important challenge in the physics of pattern formation.

In this study, we investigated the relationship between surface growth dynamics in the presence of a nonionic surfactant and centimeter-scale metal dendrite pattern formation. To clarify the correlation between surfactant concentration and dendrite patterns, we characterized dendrite growth dynamics through electric current, maximum radial growth speed, and pattern thickness.

We found that at lower surfactant concentrations of less than 0.3 uM, the dendritic patterns were more branched and denser. In contrast, at higher concentrations of more than 0.5 uM, the patterns became less branched and sparser.

In addition, at intermediate surfactant concentrations of 0.3 to 0.5 uM, which correspond to the transition point between the dense and sparse patterns, radial dendrite growth was arrested. Notably, during this growth arrest, the electric current remained non-zero, indicating that ion deposition shifted from lateral to vertical growth and that the dendrite thickness significantly increased to more than 200 um. These results suggest that the surfactant blocked lateral metal ion deposition around 0.4 uM and that the interaction between the deposition surface and metal ions below and above approximately 0.4 uM changed drastically.

12. “Bifurcation and initial-condition dependence of coupling patterns in two-dimensional bilayer thermal convection with an undeformable interface”

Mizuki Nakamura (Graduate School of Science and Engineering, Chiba University), Hiroaki Ito (Chiba University), Hiroyuki Kitahata (Chiba University)

Rayleigh-Bénard convection is one of the most famous systems exhibiting pattern formation under nonequilibrium conditions, which occurs in systems with a temperature difference between the upper and lower boundaries and is driven by thermal buoyancy. In bilayer systems with an undeformable horizontal interface, thermal convection in these layers can be coupled in two manners: mechanical coupling (MC) and thermal coupling (TC). The vertical flow directions in the two layers are opposite in MC, whereas they are the same in TC.

In the present study, we investigated the selection mechanism of thermal convection patterns in a symmetric bilayer system with an undeformable horizontal interface by systematically changing the initial conditions in a two-dimensional hydrodynamic simulation. In this system, MC and TC are bistable in a certain parameter region. Based on the simulation results with varying initial conditions, we investigated the selection mechanism of the coupling patterns. Furthermore, we quantitatively discuss the specific factors determining the coupling pattern from the perspective of heat transport.

13. “Numerical Analysis on Curved Surfaces Using the Minimizing Movement Method”

Rin Tosaya (Meiji Univ.)

1. Research Background and Objective

Many real-world physical phenomena, such as liquid coatings on free-form industrial surfaces and global meteorological fluctuations, occur on complex curved surfaces. Simulating these phenomena with traditional methods, like the finite element method, requires generating surface-conforming meshes. This introduces significant challenges: laborious geometric mesh creation and high computational costs. Furthermore, standard time-evolution methods overcomplicate governing equations when dealing with global physical constraints, such as volume preservation, which often leads to computational instability. To overcome these challenges, this research aims to establish a novel simulation methodology that eliminates complex mesh generation while strictly satisfying physical conservation laws, including total volume and surface area.

2. Proposed Hybrid Methodology

To successfully address the dual challenges of complex geometries and physical constraints, this study proposes a hybrid methodology.

・Closest Point Method (CPM): The CPM embeds a given surface into a 3D space, mapping spatial points to their closest point on the surface. This allows partial differential equations on curved surfaces to be solved using standard Cartesian grids in the surrounding space. Consequently, this circumvents complex mesh generation and enables stable differential computations free from coordinate singularities.

・Minimizing Movement Method: For time evolution, this method formulates the process as an energy functional minimization problem rather than solving differential equations directly. Complex constraints, like volume preservation, are easily introduced by appending penalty terms to the energy functional. The L-BFGS quasi-Newton method was selected to solve the minimization problem due to its proven superiority in computational speed and memory efficiency.

3. Current Achievements and Future Work

Using the constructed numerical solver, verification experiments were conducted. First, a CPM-based solver successfully simulated the wave equation on a sphere. Results demonstrated that waves propagated naturally along the surface curvature, verifying that the proposed Cartesian grid method reliably approximates differential operations on curved surfaces.

Additionally, simulations of the heat equation were performed incorporating explicit volume conservation conditions and wetting energy. While interfacial tension causes droplets to continuously shrink and disappear in standard heat equations, this proposed method accurately tracks morphological changes while strictly preserving the droplet's volume. The framework also operated perfectly on complex topologies like a torus. Future work will focus on expanding the model by introducing gravitational potential.

14. **"Effects of spatial structures on gelation-induced flow patterns"**

Kojiro Otoguro (Meiji University), Shunsuke Tanaka(Tokyo Univ. Sci.), Miyuki Kunihiro(Tokyo Univ. Sci.), Hiroki Ishikawa(Tokyo Univ. Sci.), Yutaka Sumino(Tokyo Univ. Sci.)

Dynamical patterns formed by interfacial instabilities are important in engineering and geoscientific contexts, such as fluid migration processes in soils. Rheological changes due to chemical reactions are among the significant factors generating such patterns. Here, we focus on laboratory experiments that mimic fluid migration in soil accompanied by solidification of the migrating fluid. We performed injection experiments using aqueous solutions of sodium salicylate (NaSal) and cetyltrimethylammonium bromide (CTAB) in a structured Hele-Shaw cell. These solutions form wormlike micelles with a single relaxation time upon mixing. Without spatial structures, we observed meandering motion of the filamentous pattern formed by the injected fluid (NaSal aq.). We then introduced a square lattice structure into the cell and found that the meandering motion was suppressed when the lattice constant was sufficiently small. Furthermore, we performed numerical simulations and analytical investigations based on a moving-interface model incorporating a reduction in interface mobility due to gelation. Our numerical simulations reproduced the overall behavior observed in the experiments, including the meandering motion and its suppression by the spatial structure. The numerical results indicated that the meandering motion is caused by splitting of the filament tip into two branches followed by suppression of the motion of one branch. Our analytical investigation revealed that modification of the filament width leads to stable filament propagation, thereby suppressing the meandering motion.

15. **"Barchan movement by sand supply using crest line model"**

Sofia Navarro Yabe (Meiji University), Masashi Shiraishi(MIMS, Meiji Univ.), Hiraku Nishimori(MIMS, Meiji Univ.)

To mathematically explain the basic movement mechanism of the barchan dune, we are constructing a minimal mathematical model that describes each dune using 2 variables. It was confirmed that the central axis of the downstream barchan was shifting due to the sand influx from the upstream barchan.

16. "Continuous generation of confined bubbles: viscous effect on the gravito-capillary pinch off"

Haruka Hitomi (Ochanomizu University), Ko Okumura (Ochanomizu Univ.)

We investigate the continuous generation of bubbles from a bath of air in viscous liquid in a confined geometry (Hele-Shaw cell). In our original setup, bubbles are spontaneously generated by virtue of buoyancy and a gate placed in the cell: the gate acts like an inverted funnel trapping air beneath it before continuously generating bubbles at the tip. The dynamics is characterized by the bubble-formation period and the bubble size as a function of the amount of air under the gate. By analyzing the data obtained for various parameters, we clearly identified that the dynamics of the bubble formation is governed by dissipation in the viscous fluid beneath the trapped air balanced by a gravitational energy change due to buoyancy, after examining numerous possibilities of dissipation, which demonstrates the potential of scaling analysis in significantly complex cases. Furthermore, we uncover a general mechanism of pinching-o! at low Reynolds numbers, which convincingly explains the bubble size: in the present case viscosity plays a vital role, different from the conventional mechanism of Tate proposed in 1864, in which gravity competes with capillarity. Accordingly, the present study significantly and fundamentally advances our knowledge of the generation and pinch-o! of bubbles, with the results relevant for a wide variety of applications in many fields. In particular, the present study demonstrates a promising avenue in microfluidics for understanding physical principles by scaling up the system, without losing the characteristics of the flow at low Reynolds numbers. (Adapted from Hitomi & Okumura, Phys. Rev. Research 2025; CC BY 4.0)