Interdisciplinary Approaches to Inverse Problems via Quantum Sciences and Machine-learning-based Methods
– IMI Grant for General Research-Workshop (I) –

Date : September 12th (Sat.) – 14th (Mon.), 2026.

Venue : IMI W1-D-414, West Zone 1, Ito campus, Kyushu University

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Web : https://joint.imi.kyushu-u.ac.jp/post-20976/

September 12th (Sat.)

13:45-14:25 Hiroyuki Miyoshi (The University of Tokyo)
Impulse-induced liquid jets from bubbles with arbitrary contact angles: coupling analytical and experimental results

This research investigates the relationship between the contact angle of a spherical bubble attached to a tube submerged in a container and the jet speed induced by an impulsive acceleration at its base. While it has been well established that bubble geometry strongly influences the ejection speeds of liquid jets, mathematical studies of liquid jets with arbitrary bubble shapes remain limited. In this work, we derive a pressure impulse in the small-cavity limit as a tractable integral of classical Legendre functions. It is shown that the jet speed can be divided into two components: (i) the velocity induced by the hydrostatic pressure impulse distribution created by the curvature of the bubble, and (ii) the velocity induced by the distribution of the submersion of the tube in a container. This decomposition reveals that an optimal bubble curvature emerges only when the tube is submerged: the optimality is absent for non-submerged configurations, where the jet speed increases monotonically with bubble depth. Experiments confirm this non-monotonicity and quantitatively support the predicted shift of the optimal geometry with submersion depth. This work was carried out in collaboration with H. Watanabe, I. Kikuchi, and Y. Tagawa at Tokyo University of Agriculture and Technology, and has recently been accepted in Journal of Fluid Mechanics.

14:25-15:05 Xinchi Huang (Quemix Inc.)

Quantum computing for partial differential equations: fundamentals, results, problems, and prospects

To derive the solution to inverse problems governed by some partial differential equations (PDEs) appeared in mathematical physics, the numerical solutions to the corresponding forward problems are usually necessary. As an interdisciplinary branch of computer science, intersecting with physics and mathematics, quantum computing has been expected to accelerate the matrix operations in the part of numerically solving PDEs.

In this talk, we focus on the forward stage and explain some fundamental non-variational quantum algorithms (that is, without optimizations on classical computers) for PDEs. Next, we demonstrate some results with circuit simulations on classical computers and explain the possible speedup with respect to the grid number. Finally, we discuss the current limitations, problems, as well as the prospects, for quantum computing as a PDE solver.

15:25-16:05 Yong-Gwan Ji (Korea Institute for Advanced Study)

Ellipsoidal characterization of neutral inclusions for imperfect bonding of high-conductivity type

In this talk, we discuss neutral inclusions with the imperfect bonding properties of high-conductivity type. An inclusion, which is a bounded domain, is said to be of imperfect bonding of high-conductivity type if the flux is discontinuous along its boundary while the potential is continuous. The inclusion is neutral to a uniform field if the presence of the inclusion does not perturb the field outside the inclusion. It is known that ellipses and ellipsoids can be neutral to all uniform fields by introducing a proper imperfect bonding parameter on boundaries. The purpose of this paper is to prove the converse. We prove that if an inclusion of imperfect bonding of high-conductivity type is neutral to all uniform fields, then it is an ellipse or an ellipsoid. The neutrality condition is given by existence of the solution to a certain differential equation on the boundary surface and the main result is proved by converting the neutrality condition into an algebraic boundary identity characterizing ellipses and ellipsoids. To do so, we construct a suitable (0,2)-tensor on the boundary which is symmetric, trace-free, and Codazzi. This is joint work with Junyong Eom, Shota

Fukushima, Hyeonbae Kang, Xiaofei Li, and Shigeru Sakaguchi.

16:05-16:45 Lorenzo Cavallina (Tohoku University)

Can you hear the shape of a triangle?

In this talk, we address the problem of identifying the shape of a triangular domain from three of its Dirichlet eigenvalues $\{\lambda_i, \lambda_j, \lambda_k\}$. It is conjectured that the knowledge of the first three Dirichlet eigenvalues $\{\lambda_1, \lambda_2, \lambda_3\}$ is enough to determine a triangular domain up to rigid motions. On the other hand, not all triples $\{\lambda_i, \lambda_j, \lambda_k\}$ uniquely determine the shape of a triangular domain (a known example of such an "unhearable triple"" is given by $\{\lambda_1, \lambda_2, \lambda_4\}$). In this talk, we describe a few processes that force unhearability and, as a byproduct, we provide an infinite family of unhearable triples. This is based on a joint work with Ryoki Endo (Niigata University) and Xuefeng Liu (Tokyo Woman's Christian University).

September 13th (Sun.)

10:00-10:40 Hiroshi Takase (Okayama University)

Functional analysis and PDE in spectral Barron spaces

The spectral Barron space, an infinite-dimensional Banach space consisting of functions that can be well approximated by two-layer neural networks, has recently attracted considerable attention. In this talk, I will present several functional analytic results on the spectral Barron space, including the characterization of its dual space and its (compact) embedding properties, as well as the well-posedness of the Schrödinger equation in this space. These results suggest that the forward problem considered in this talk is well suited to approximation by (deep) neural networks. This talk is based on joint work with Mourad Choulli (Université de Lorraine) and Shuai Lu (Fudan University).

10:40-11:20 Tomoyuki Oka (Fukuoka Institute of Technology)

Two-material optimal design problem governed by the heat equation

In this talk, we consider a two-material optimal design problem for the time-averaged duality pairing between a heat source and the weak solution of an initial-boundary value problem for the heat equation with a two-material diffusion coefficient, under a volume constraint. In the elliptic case, this problem can be relaxed through homogenization, and the resulting relaxed problem possesses a self-adjoint structure. On the other hand, in the parabolic case, such a structure is generally not available, since the adjoint variable is characterized by a terminal value problem. We discuss the direct relaxability of the parabolic problem and its long-time behavior under several specific assumptions.

11:35-12:15 Naotaka Shoji (TDSE Ltd.)

数理科学と機械学習による産業課題の解決 – TDSE における社会実装事例の紹介

Solving Industrial Challenges through Mathematical Sciences and Machine Learning: Case Studies of Social Implementation at TDSE

TDSE 株式会社は、「データに基づいて意思決定を高度化する」をミッションに掲げ、創業以来 200 社を超える企業・組織に対し、AI・データサイエンスを活用した課題解決を支援してきました。統計解析、機械学習、数理最適化、数理モデリングなどの先端技術を実社会の課題へ適用し、企業の競争力向上や新たな価値創出に取り組んでいます。本講演では、まず TDSE の事業概要を紹介するとともに、データサイエンティストおよびエンジニアが担う役割や業務内容についてご説明します。さらに、当社がこれまで手掛けてきたプロジェクト事例を通じて、AI・機械学習や数理科学が産業界においてどのように活用され、どのような価値を生み出しているのかを具体的にご紹介します。本講演が、産学連携のさらなる発展や、数理科学・データサイエンスの社会的価値について議論を深める契機となれば幸いです。

TDSE Corporation is a specialized AI and data science company whose mission is to “Enhance decision-making through data.” Since its establishment, TDSE has supported more than 200 companies and organizations in solving business challenges through the application of AI and data science. By applying advanced technologies such as statistical analysis, machine learning, mathematical optimization, and mathematical modeling to real-world problems, we help organizations improve their competitiveness and create new value. In this talk, we will first provide an overview of TDSE’s business and introduce the roles and responsibilities of data scientists and engineers. We will then present several case studies from projects we have undertaken, illustrating how AI, machine learning, and mathematical sciences are applied in industry and what kinds of value they generate. We hope that this presentation will serve as an opportunity to foster further discussion on industry–academia collaboration and the societal value of mathematical sciences and data science.

13:45-14:25 Kei Matsushima (Hiroshima University)

A boundary integral-based numerical method for diffraction grating and application to inverse design

In this talk, we present a novel boundary integral formulation for two-dimensional scalar wave scattering by periodic diffraction gratings. Such scattering problems play an important role in the analysis and design of optical devices, including laser systems and metasurfaces. We first establish the equivalence between the proposed boundary integral equation and the original diffraction problem. Using a Rellich-type uniqueness argument, we then prove that the boundary integral equation is uniquely solvable under suitable geometric assumptions. We also propose a Nyström discretization of the integral equation and derive an error estimate for the resulting numerical scheme. Finally, we demonstrate the applicability of the proposed method to inverse design problems, including the design of wave-motion converters, absorbing layers, and metalenses.

14:25-15:05 Keigo Morishita (Tohoku University / JSPS DC2)

A rigorous computational proof of large-radius non-existence of the Dirichlet trapped mode

This talk studies localized waves in a two-dimensional channel containing a semicircular obstacle. The wave satisfies a Dirichlet condition on the channel walls and a Neumann condition on the obstacle boundary, and it decays along the channel. Such a non-radiating solution is called a Dirichlet trapped mode. We prove that no such mode exists below the cut-off frequency (i.e. the bottom of the essential spectrum) when the obstacle radius is sufficiently large. The proof combines variational analysis with certified interval-arithmetic computations using Arb.

15:25-16:05 Siiri Rautio (Josai University)

Quantum Variational Regularization for Linear Inverse Problems

We present a framework for solving regularized linear inverse problems using quantum optimization methods. By discretizing the solution space and encoding data fidelity and regularization terms into quadratic unconstrained binary optimization (QUBO) models, we formulate both Tikhonov- and sparsity-promoting regularized inverse problems within a unified quantum optimization framework. We further introduce a notion of quantum sensitivity that characterizes the effect of perturbations arising from approximate quantum evolution and discretization. We derive bounds relating these perturbations to stability properties of the underlying inverse problem, thereby establishing a theoretical connection between quantum solution variability and classical notions of ill-posedness. The framework is extended to variational inverse problems through wavelet-based representations and complemented by reduced-order modeling strategies in both parameter and Hamiltonian spaces to mitigate current hardware limitations. Numerical experiments on simulated and physical quantum hardware indicate that the resulting low-energy solution distributions retain information about the underlying inverse problem, while also revealing the limitations imposed by finite-time evolution, discretization, and hardware noise.

16:05-16:45 Masaaki Uesaka (DataLabs, Inc.)

The reconstruction of polygonal curves from 2-dimensional points using curve shortening flow

We consider the problem of reconstructing the polygonal curves in 2-dimensional space from noisy point data. Different from the smooth curve, the polygonal curve may contain the corners, the number of which is unknown. In this talk, we explain the several approaches and numerical results on this problem from the viewpoint of curve shortening flow.

September 14th (Mon.)

10:00-10:40 Akari Ishida (University of Hyogo)

Local convergence analysis of the Levenberg–Marquardt method

We consider nonlinear inverse problems, which are typically ill-posed and require regularization methods. In this talk, we focus on the Levenberg–Marquardt method as an iterative regularization method. We present convergence results for a class of inverse problems satisfying a Hölder stability estimate.

10:40-11:20 Motoya Onishi (Ehime University)

Path signatures for control

Path signatures are a powerful representation of paths that efficiently captures the path's geometric characteristics, having useful algebraic properties called Chen's identity. In this talk, we introduce our work that generalizes the Bellman equation to the space of trajectories through path signatures, and shows its applications to control problems. We also introduce current progress with a note on a further extension.

11:35-12:15 Kaede Watanabe (Tohoku University)

Ocean Wave Spectrum Estimation from High-Frequency Radar Data with Nonnegative Regularization

High-frequency radar is a coastal remote sensing system that transmits electromagnetic waves toward the sea surface and observes the backscattered signals. The Doppler spectrum obtained from these signals contains information about ocean waves. In this research, we propose a method for reconstructing the ocean wave spectrum from high-frequency radar data using nonnegative regularization. The ocean wave spectrum provides a detailed description of the sea surface state and is therefore an important quantity for characterizing the ocean. The proposed method incorporates the physical constraint that the wave spectrum is nonnegative. Numerical experiments and applications to observational data are presented to examine the behavior of the proposed method and to discuss its applicability.