Finland-Japan Workshop in Industrial and Applied Mathematics

Abstracts

August 26-30, 2024
Yliopistonkatu 3, Porthania

Time	Monday	Tuesday	Wednesday	Thursday	Friday
9:00		Coffee	Lab tour	Coffee	Coffee
9:30		Johanna Tamminen	Lab tour	Alexander Meaney	Andreas Hauptmann
10:00	Registration/Coffee	Kenji Kajiwara	Lab tour	Antti Rasila	Siiri Rautio
10:30	Opening	Yuuya Takayama	Lab tour	Kazumi Tanuma	Tommi Heikkilä
11:00	Ken Hayami	Petri Kuusela	Lunch	Yuto Miyatake	Nuutti Hyvönen
11:30		Lunch	Lunch	Lunch	Lunch
12:00	Lunch	Lunch	Excursion	Lunch	Lunch
12:30	Lunch	Lunch	Excursion	Lunch	Lunch
13:00	Masaru Ikehata	Elli Karvonen	Excursion	Daisuke Tagami	Takanori Ide
13:30	Hiroshi Isozaki	Hiroyuki Chihara	Excursion	Mikko Räsänen	Hiromichi Itou
14:00	Matti Lassas	Daisuke Furihata	Excursion	Takuya Tsuchiya	Martin Ludvigsen
14:30	Manabu Machida	Meghdoot Mozumber	Excursion	Hjørdis Schlüter	Samuli Siltanen
15:00	Reception/poster	Coffee	Excursion	Coffee	Closing
15:30	Reception/poster	Toni Karvonen	Excursion	Kenta Kobayashi	
16:00	Reception/poster	Hiroshi Fujiwara	Excursion	Lauri Oksanen	
16:30		Vesa Kaarnioja	Excursion	Hisashi Morioka	
17:00		Hiroshi Takase	Excursion	Ziyao Zhao	
17:30			Excursion		
18:00			Dinner		

Monday, August 26th

Keynote 1, Monday 11:00 - 12:00

Session chair: Samuli Siltanen

GMRES Methods for Tomographic Reconstruction with an Unmatched Back Projector

Ken Hayami, National Institute of Informatics
Unmatched pairs of forward and back projectors are common in X-ray CT computations for large-scale problems; they are caused by the need for fast algorithms that best utilize the computer hardware, and it is an interesting and challenging task to develop fast and easy-to-use algorithms for these cases. Our approach is to use preconditioned GMRES, in the form of the AB- and BA-GMRES algorithms, to handle the unmatched normal equations associated with an unmatched pair. These algorithms are simple to implement, they rely only on computations with the available forward and back projectors, and they do not require the tuning of any algorithm parameters. We show that these algorithms are equivalent to well-known LSQR and LSMR algorithms in the case of a matched projector. Our numerical experiments demonstrate that AB- and BA-GMRES exhibit a desired semi-convergence behavior that is comparable with LSQR/LSMR and that standard stopping rules work well. Hence, AB- and BA-GMRES are suited for large-scale CT reconstruction problems with noisy data and unmatched projector pairs. We are presently trying to analyze the methods in order to understand why they work. This is joint work with Professor Per Christian Hansen (Technical University of Denmark) and Dr. Keiichi Morikuni (University of Tsukuba). Reference: Hansen, P.C., Hayami, K., Morikuni, K., GMRES Methods for Tomographic Reconstruction with an Unmatched Back Projector, J. Comput. Appl. Math., 413 (2022), 1–20. DOI: 10.1016/j.cam.2022.114352

Session A, Monday 13:00 - 15:00

Session chair: Takanori Ide

Integrating Probe and Singular Sources Methods

Masaru Ikehata, Professor Emeritus at Hiroshima University
This talk is concerned with methodology for inverse obstacle problems governed by partial differential equations. Recently the speaker introduced a skeleton of an integrated theory of the probe and singular sources methods which are well-known two analytical methods. In this talk, recent developments in this theory are reported.

Scattering of Rayleigh waves for a perturbed elastic equation in R^3_+.

Hiroshi Isozaki, Ritsumeikan University and Tsukuba University

A characteristic feature of the elastic equation in a perturbed half-space in R^3_+ is, in addition to the 3-dim. spherical waves spreading inside the body, the existence of 2-dim. spherical waves propagating along the boundary surface decaying exponentially inside the body. We have already obtained an asymptotic expansion of such waves uniform with respect to the direction involving both of body waves and surface waves simultaneously. We demonstrate a radiation condition which guarantees the uniqueness of these scattering waves. This is a joint work with M. Kadowaki and M. Watanabe.

Mapping properties of neural networks and inverse problems

Matti Lassas, University of Helsinki

We will consider mapping properties of neural networks and neural operators which are infinite dimensional generalizations of neural networks. In particular, we consider the injectivity of neural networks and universal approximation property of injective neural networks. In addition, we study approximation of probability measures using neural networks that are compositions of invertible flow networks and injective layers and present applications in inverse problems. We also discuss the similarities of neural operators and pseudodifferential operators. The talk is based on collaboration with Maarten de Hoop, Ivan Dokmanic, Takashi Furuya, and Michael Puthawala.

Non-iterative inversion scheme for optical tomography with inverse series

Manabu Machida, Kindai University

Inverse problems for optical tomography are nonlinear and severely ill-posed. Hence naive iterative numerical schemes such as the Gauss-Newton method and conjugate gradient method cannot be used in practical situations because the calculation is easily trapped by a local minimum with these iterative methods. Conventional direct methods such as the Born and Rytov approximations are more accurate but require linearization of the nonlinear inverse problems. When comparing these two methods, it is known that the Rytov approximation is superior to the Born approximation, i.e., better reconstructed images are obtained by the former algorithm. In this talk, we will consider the nonlinear Rytov approximation by constructing the inverse Rytov series. The stability and error estimates for the inverse Rytov series are proved. Moreover, the method is verified by a phantom experiment.

Poster session, Monday 15:00 - 16:30

Universal approximation for injective and bijective neural operators

Takashi Furuya, Shimane University
Recently, neural operators have been significant interest in operator learning, and their invertibility has been investigated, primarily motivated by inverse problems in PDEs. However, the approximation capabilities of invertible neural operators remain underdeveloped. In this talk, we discuss the universal approximation properties of injective and bijective neural operators.

Digital Design Support Technology Utilizing CAE and Machine Learning

Ichiro Kataoka, Hitachi, Ltd.
In the realm of manufacturing, designers utilize Computer Aided Engineering (CAE) for engineering tasks during the preliminary consideration of product and process design. The necessity to validate the implications on performance during design alterations via CAE presents a challenge. This challenge lies in diminishing the labor hours associated with the iterative process of verification and modification. In response to this, we have developed a technology that curtails labor hours by pre-establishing a machine learning model. It has assimilated the computational outcomes from CAE, enabling a swift evaluation of performance during design modifications.

Teaching Computational inverse problems: what can ChatGPT do?

Heli Virtanen, University of Helsinki
Recently, there has been a lot of talk about the effect of ChatGPT on assignments. At University of Helsinki, we teach inverse problems with a computational view and have exercises and an exam the students solve without supervision. Preliminary testing the assignments on ChatGPT show an acceptable answer when explaining concepts. However, when asked to provide code for the computational part, the code gives an error message after running it.

Solving the 4D fast ion distribution function by basis construction

Otso Hyvärinen, University of Helsinki
Fusion reactors, especially tokamaks, are one of the most promising concepts in future energy production. Currently, however, their performance is limited by the small confinement time of fast ions. Increasing the confinement time is therefore a vital research direction for viable fusion power in the future. However, the task of improving fast ion confinement time is limited by our

understanding of the fast ion distribution function in the full phase space. This study tackles the task of improving the fast ion distribution understanding by using inversion methods to reconstruct the fast ion distribution function from diagnostic data. The problem of reconstructing the fast ion distribution function is a very sparse tomography problem due to the high dimensionality of the distribution function (spatial and velocity), and the limited amount of data obtained from limited parts of the phase space. Conventional approaches to this tomography problem by embedding information about the plasma physics in the regularizer have been deemed laborious and computationally expensive for lower dimensional projections. The basis construction method reduces the complexity of the reconstruction and the needed data processing by embedding the prior information about slowing down plasma physics in the vector space in which the reconstruction is solved, thereby drastically reducing the time and effort for regularizer construction. The basis construction is a comparatively new tomography method in fast ion physics that was first introduced for velocity space tomography (2D), but due to good results, was also used for orbit tomography (3D), and now for 4D distribution function in this study. With the basis construction, the reconstruction problem changes to Tikhonov regularization of the coefficients of the vector space, whose linear combination gives the reconstructed fast ion distribution. The reconstruction of the 4D fast ion distribution was found to capture most of the features from a synthetic diagnostic data with added Poisson noise from neutral beam injector. Furthermore, some basis constructions led to a significantly better reconstructions, but the analysis of these is still ongoing. Some differences were observed for 0th order and 1st order Tikhonov regularization, suggesting that the 1st order regularization is better for basis with fewer basis vectors. The next step in our research is to enlarge the reconstruction model by adding basis vectors corresponding to other fast ion sources and sinks in the plasma, i.e., resonant frequency heating, fusion, modes.

Inverse boundary value problems for the magnetic Schrödinger operator by the enclosure method

Ryusei Yamashita, Polytechnic University of Japan
In this talk, we show a reconstruction formula of the convex hull of the defect D from the Dirichlet to Neumann map associated with the magnetic Schrödinger operator by using the enclosure method proposed by Ikehata in 2000, assuming certain higher regularity for the potentials of the magnetic Schrödinger operator, under the Robin condition on the boundary ∂D in the two and three dimensional case. In addition, Ikehata established the new estimates of the stationary Schrödinger equation for an impenetrable obstacle and a penetrable obstacle embedded in an absorbing medium in 2022. So, we extend this estimate for the magnetic Schrödinger operator under the Robin condition on the boundary D and Using the estimate, we improve the result.

Iterative reconstruction based on the Levenberg-Marquardt method for inverse problems

Akari Ishida, Nagoya University
We study the convergence of a nonlinear iterative method for inverse problems in Hilbert spaces. For a class of inverse problems satisfying a Lipschitz stability estimate, Alberti and Santacesaria presented a global reconstruction algorithm with a finite measurement in 2022. Their approach used the Landweber iteration. In contrast, we present a global reconstruction algorithm based on the Levenberg-Marquardt method. Furthermore, we prove local convergence and convergence rate for a class of inverse problems satisfying a Hölder stability estimate. This poster is based on a joint work with Sei Nagayasu (University of Hyogo) and Gen Nakamura (Hokkaido University).

TBA

Hiroya Ito, The University of Electro-Communications
TBA

Time series analysis of glucose-insulin data from mice fed high-fat diet by 9-compartment model

Shinya Uchiumi, Hokkaido University
It is important to find early signs of diabetes since this is a chronic disease. To understand the diabetes onset, we study time series of experimental data of mice including glucose, insulin, and C-peptide data for several weeks. The data were obtained from oral glucose tolerance test (OGTT). Regular food is given for one group of mice, and high-fat food is given for the other group. We propose a mathematical model of a system of ordinary differential equations (ODEs) which describe concentration of glucose, insulin and C-peptide in nine organs. Since the ODEs contain parameters to be determined, we estimate them by curve fittings. We simulate the metabolisms of glucose, insulin and C-peptide in nine organs using the estimated parameters, and we search a major factor and a time point of diabetes onset by comparing the two groups.

Reconstruction of Waddington's Landscape via Optimal Transport Theory

Toshiaki Yachimura, Tohoku University
In 1957, C.H. Waddington introduced the epigenetic landscape model for cell differentiation. Recently, with the development of measurement technology, many attempts have been made to reconstruct this conceptual model from gene expression data and to infer the trajectory of cell differentiation. In this talk, I will introduce scEGOT, a novel trajectory inference framework of cell differentiation for time series single-cell RNA sequencing data based on Entropic Gaussian mixture optimal transport. scEGOT allows us to infer not only the cell state graph

of cell differentiation that conventional trajectory inference methods have constructed but also the velocities and the dynamics of gene expression associated with cell differentiation for each cell. Furthermore, Waddington's epigenetic landscape can also be constructed by scEGOT.

Reproduction of hair follicle morphogenesis based on numerical simulation controlling cell cycle and extracellular matrix

Keiichiro Kagawa, Research Institute for Electronic Science, Hokkaido University

We conducted numerical simulations to reproduce the morphogenesis of hair follicles. These simulations are based on a mathematical model that integrates two primary components. First, the bead–spring model approximates skin tissue with particles and represents the motion of cells and tissues through the mechanical interactions between these particles. Second, the signal diffusion model describes how signals controlling the cell cycle and extracellular environment diffuse according to the diffusion equation. These signals originate from cells known as fibroblasts. Through these simulations, we successfully reproduced the morphogenesis of hair follicles, which are skin organs that enclose hair.

Mathematical modeling and parameter estimation of Glucose-Insulin metabolism dynamics.

Yuki Ueda, Hokkaido University

We propose a mathematical model of glucose-insulin metabolism dynamics, which is derived as a system of ODEs. In the proposed model, each ODE describes the blood glucose/insulin concentration in each organ. We focus on insulin secretion from pancreatic beta cells and insulin sensitivity in hepatic and skeletal muscle, and these mechanisms are included in our ODE system. We estimate the parameters of the proposed model using data obtained from the Oral Glucose Tolerance Test (OGTT) and the Intravenous Glucose Tolerance Test (IVGTT). To estimate the parameters, we use the Metropolis-Hastings method, which is used for sampling from probability density functions. The sampled ones, which provide small errors between the numerical result and the experimental data, are accepted as appropriate parameters. We verify the validity of the model by confirming that our numerical results support several medical findings.

Integration and function approximation on $\mathbb{R}^d$ using equispaced points and lattice points

Yuya Suzuki, Aalto University

We present results that by using equispaced points and lattice points for integration and function approximation on $\mathbb{R}^d$, one can attain the (almost) optimal convergence rate in many different settings. This includes the worst-case error with deterministic algorithms and the root-mean-squared worst-case error with randomized algorithms.

Tuesday, August 27th

Keynote 2 & 3, Tuesday 9:30 - 10:30

Session Chair: Hiromichi Itou

Overview of Center of Excellence in Inverse Modelling and Imaging

Johanna Tamminen, Finnish Meteorological Institute
In this presentation we give an overview of the Center of Excellence in Inverse Modelling and Imaging (CoE) which is funded by the Research Council of Finland 2018 – 2025. With its 19 Principal Investigators, the CoE forms a unique network of seven universities and one research institute to tackle theoretical and computational aspects of inverse problems and imaging. The application areas are versatile and include e.g., biomedical imaging, geosciences and satellite remote sensing as well as non-destructive material evaluation. We highlight here current research questions and recent outcomes of various aspects of inverse problems and also discuss practical aspects related to the large research network.

Challenges of Mathematics for Industry in Japan

Kenji Kajiwara, Institute of Mathematics for Industry, Kyushu University
In this talk, we exhibit various activities of "Mathematics for Industry" (MfI) in Japan, initiated by the Institute of Mathematics for Industry(IMI), Kyushu University founded in 2011. MfI intends to develop a new research area of mathematics formed by responding to the needs of industries associated with various relevant activities such as specific education program and network/platform formed by mathematicians and mathematical institutes. We present various challenges to realizing the idea of MfI in Japan.

Session C, Tuesday 10:30 - 11:30

Session Chair: Hiromichi Itou

Automatic Horizontal / Vertical Line Alignment for Photographs

Yuuya Takayama, Nikon Corporation
We introduce a tilt and rotation adjustment algorithm for photographs. If a camera is tilted and rotated, so will be even horizontal / vertical subjects in the photograph. This phenomenon is explained by modeling the camera projection process as a real projective plane RP^2. Here, we consider a linear fractional transformation for RP^2, i.e. homography, by which to adjust the tilted and rotated subjects into a horizontal / vertical position in the transformed photograph. In order to construct such homography, we focus on horizontal and vertical vanishing points, which are intersections of lines included in the horizontal and vertical subjects respectively. Each vanishing point has two-dimensional information, distance, and angle, and they correspond to the degree of the tilt and rotation of the photograph. In this talk, we start from the definition of camera projection, and then explain our detailed method to construct an homography which aligns subject lines into the horizontal or vertical lines.

Introducing OOEIT: object oriented electrical impedance tomography -software package for Matlab

Petri Kuusela, University of Eastern Finland
Electrical impedance tomography (EIT) is an imaging modality based on electrical injections and measurements conducted on electrodes on the boundary of the imaging domain. Computing the EIT reconstruction is an ill-posed inverse problem and an active field of research. To facilitate this research, we introduce an open source Matlab code package, object oriented EIT (OOEIT). The package is designed for ease of use without deep understanding of EIT algorithms, aiming to cover certain use-cases oof-the-shelf. Furthermore, the modular structure also promotes algorithm development.

Session D, Tuesday 13:00 - 15:00

Session chair: Alexander Meaney

TILT: Topological Interface Recovery in Limited-Angle Tomography

Elli Karvonen, University of Helsinki
In this poster, I present a reconstruction method for the severely ill-posed inverse problem of limited-angle tomography. Depending on the available measurement, angles specify a subset of the wavefront set of the unknown target, while some oriented singularities remain invisible in the data. Topological Interface recovery for Limited-angle Tomography (TILT) is based on lifting the visible part of the

wavefront set under a universal covering map. In the space provided, it is possible to connect the appropriate pieces of the lifted wavefront set correctly using complex wavelets, a dedicated metric, and persistent homology. The result is not only a suggested invisible boundary but also a computational representation for all interfaces in the target.

Geodesic X-ray transform and streaking artifacts on simple surfaces or on spaces of constant curvature

Hiroyuki Chihara, University of the Ryukyus
The X-ray transform on the plane or on the three-dimensional Euclidean space can be considered as the measurements of CT scanners for normal human tissue. If the human body contains metal regions such as dental implants in an oral cavity, stents in blood vessels, metal bones, etc., the beam-hardening effect for the energy level of the X-ray causes streaking artifacts in its CT image. This talk discusses this phenomenon for the geodesic X-ray transform on nontrapping simple compact Riemannian manifolds with strictly convex boundary. We show that the streaking artifacts result from the propagation of conormal singularities on the boundary of metal regions along the common tangent geodesics under the strong and seemingly strange assumption that the manifolds are two dimensional or spaces of constant curvature. This condition ensures that every Jacobi field takes the form of the product of a scalar function and parallel transport along the geodesic. Our results clarify the geometric meaning of the theory, which was imperceptible in the known results on the Euclidean space.

A particle method based on Voronoi mesh for the Cahn-Hilliard equation to preserve mass conservation law

Daisuke Furihata, Osaka University
We want to perform appropriate and fast numerical calculations using machine learning of the time-evolving operator of some conservation partial differential equations, such as the Cahn-Hilliard equation. Still, in the context of FDM and FEM, the amount of machine learning becomes enormous. Therefore, we have an idea to apply a particle method based on the Voronoi mesh and calculate particle behavior using machine learning.

Diffuse optical tomography utilizing nanosecond illumination and waveform detection

Meghdoot Mozumber, University of Eastern Finland
Diffuse optical tomography (DOT) uses visible or near-infrared light for imaging spatially varying optical parameters in biological tissues. Recently, we proposed utilizing nanosecond light sources in DOT, and the boundary measurements were acquired using an oscilloscope. Our motivation was to develop DOT systems that could be implemented with other imaging modalities, for example,

with EEG, MRI, ultrasound, and, photoacoustic tomography. The image reconstruction of DOT, involving the non-linear estimation of absolute absorption and scattering coefficients, was carried out in the Bayesian framework. The location of absorption and scattering inclusions could be distinguished in the reconstructions, with low cross-talk between the absorption and scattering coefficients. The results show that nanosecond laser sources and standard digital oscilloscope measurements can provide relatively robust DOT systems, that enable compatibility with other techniques such as ultrasound imaging (that uses signal waveform detection) and photoacoustic tomography (which uses signal waveform detection and nanosecond laser sources).

Session E, Tuesday 15:30 - 17:30

Session chair: Samuli Siltanen

Probabilistic Richardson extrapolation

Toni Karvonen, University of Helsinki
Richardson extrapolation is a classical technique to accelerate the rate of convergence of a numerical method. For example, Romberg's method uses Richardson extrapolation to estimate integrals and the Bulirsch-Stoer algorithm to solve ordinary differential equations. We use a probabilistic Richardson extrapolation method based on Gaussian processes that unifies classical extrapolation methods with multi-fidelity modelling and handles uncertain convergence orders by allowing these to be statistically estimated. Moreover, the probabilistic formulation enables statistical experimental design. We prove that the method achieves a polynomial speed-up compared to the original numerical method and apply it to cardiac modelling. Preprint: C. J. Oates, T. Karvonen, A. L. Teckentrup, M. Strocchi & S. A. Niederer (2024). Probabilistic Richardson extrapolation. arXiv:2401.07562.

A remark on the Cauchy problem of an elliptic equation and its application to x-ray tomography with partial measurement

Hiroshi Fujiwara, Kyoto University
This talk presents a stability estimate of a numerical method to the Cauchy problem of an elliptic equation without explicit regularization methods. This problem appears in x-ray tomography where measurement data is given on an arc of the boundary. We propose a novel method based on A-analytic theory by A. L. Bukhgeim, and show numerical examples using measurement data. This is a joint work with K. Sadiq (RICAM) and A. Tamasan (Univ. Central Florida).

Quasi-Monte Carlo for Bayesian design of experiment problems governed by parametric PDEs

Vesa Kaarnioja, University of Potsdam
The goal in Bayesian optimal experimental design (OED) is to maximize the expected information gain for the reconstruction of unknown quantities in an experiment by optimizing the placement of measurements. The objective function in the resulting optimization problem involves a multivariate double integral over the high-dimensional parameter and data domains. For the efficient approximation of these integrals, we consider two approaches: a full tensor product and a sparse tensor product combination of quasi-Monte Carlo (QMC) cubature rules over the parameter and data domains. Specifically, we show that the latter approach significantly improves the convergence rate, exhibiting performance comparable to that of QMC integration of a single high-dimensional integral. Furthermore, we numerically verify the predicted convergence rates for an elliptic PDE problem with an unknown diffusion coefficient, offering empirical evidence supporting the theoretical results. This talk is based on joint work with Claudia Schillings (FU Berlin). Reference: V. Kaarnioja and C. Schillings. Quasi-Monte Carlo for Bayesian design of experiment problems governed by parametric PDEs. Preprint 2024, arXiv:2405.03529 [math.NA]

Lipschitz stability for Cauchy problems of elliptic equations

Hiroshi Takase, Institute of Mathematics for Industry, Kyushu University
The Cauchy problem for elliptic equations is widely known as an ill-posed problem without stability properties. To overcome this situation, conditional stability has been studied, but in many cases, only very weak logarithmic stability is obtained assuming a priori boundedness of solutions. In this presentation, we show Lipschitz stability estimate for this problem under a new priori constraint. This work is based on joint research with Prof. Mourad Choulli.

Wednesday, August 28th

Excursion day (lab tour, excursion trip, and dinner). See the website for more information.

Thursday, August 29th

Session F, Thursday 9:30 - 11:30

Session chair: Siiri Rautio

3D image reconstruction for cone beam computed tomography using controlled gradient sparsity

Alexander Meaney, University of Helsinki
Cone beam computed tomography (CBCT) is an increasingly popular three-dimensional medical imaging technique. CBCT uses X-ray projection data to reconstruct a 3D model of the scanned object. However, in many settings it suffers from suboptimal image quality. In this work, we will present a new approach to modelbased iterative image reconstruction using total variation regularization. Our technique has an in-built automatic and dynamic choice of the regularization parameter, based on a priori knowledge on gradient magnitude sparsity. Combined with a novel primal-dual optimization algorithm, this results in an efficient technique for large-scale reconstruction with improved image quality.

Numerical Conformal Mappings and Applications

Antti Rasila,
We consider numerical computation of conformal mappings on simply and multiply connected domains on surfaces by using the conjugate function method. This method is based on conformal moduli of rings and quadrilaterals. These concepts are frequently applied in the geometric function theory, and they are are also very useful in numerical analysis. We recall the basic properties of these quantities and discuss their numerical as well as computation of mappings by using finite element methods and a recent stochastic approach that works in the planar case. We also discuss some contemporary applications of numerical conformal mappings, for example in modelling and optimization of cellular phone networks.

Surface waves in transversely-isotropic piezoelectric media and their perturbation

Kazumi Tanuma, Gunma University
Piezoelectric materials have been used in many engineering devices because of their intrinsic direct and converse piezoelectric effects which take place between mechanical deformations and electric fields. In piezoelectricity, the mechanical stress and the electric displacement are related to the mechanical displacement and the electric potential through the elasticity tensor, the piezoelectric tensor and the dielectric tensor. It is the piezoelectric tensor through which the elastic and electric fields are coupled with each other. Suppose that a half-space in the 3D Euclidean space is occupied by a homogeneous transversely-isotropic piezoelectric medium whose axis of rotational symmetry lies on the surface of the half-space, where the surface is subject to the mechanically-free and electrically-closed condition. It then follows that surface waves called Bleustein-Gulyaev (BG) waves and the Rayleigh-type surface waves can propagate along the surface in the direction perpendicular to the axis of rotational symmetry. Notably, the

mechanical displacement of BG waves at the surface is polarized in the direction normal to the sagittal plane, i.e., the plane which contains both the direction of propagation and the direction of the normal to the surface on which the BG waves propagate, from which BG waves are also called piezoelectric shear-horizontal (SH) surface waves, whereas the Rayleigh-type surface waves have their mechanical displacement at the surface polarized in the sagittal plane. We prove the stability of those waves, to investigate the perturbations of their phase velocity and polarizations when a fully anisotropic perturbation is added to the transversely-isotropic material constants. We are especially interested in investigating how BG waves are perturbed from their original state of SH modes as caused by a perturbation of no material symmetry. The inverse problem to obtain material information from measurements of BG waves will also be discussed.

Quantifying the discretization error in the numerical integration of evolution equations via Bayesian isotonic regression

Yuto Miyatake, Osaka University
In the numerical analysis of differential equations, understanding the discretization error is of significant importance. Error bounds, often dependent on discretization parameters such as time step size, are typically derived through theoretical analysis. However, there is a growing demand for more practical methods to quantify the discretization error, especially in the context of data assimilation and computational uncertainty quantification. The authors have recently proposed methods for error quantification based on the empirical observation that discretization error tends to increase almost monotonically as time integration progresses. These methods use isotonic regression to model the discretization error; however, they focus only on point estimation, limiting their direct applicability to Bayesian frameworks. In this presentation, we introduce a new method for discretization error quantification using Bayesian isotonic regression. The challenge lies in the choice of an appropriate prior that reflects the monotonicity assumption. We address this issue by employing a horseshoe prior. Additionally, we discuss efficient sampling algorithms within the proposed framework, enhancing its practical utility. The talk is based on joint work with Takeru Matsuda.

Session G, Thursday 13:00 - 15:00

Session chair: Andreas Hauptmann

Practical Applications of Iterative Domain Decomposition Methods to Industrial Software

Daisuke Tagami, Kyushu University
The iteratice domain decomposition method is well-known as one of the efficient numerical methods for ultra-huge scale computational models. In this talk, mathematical fundamentals of an iterative domain decomposition method for magnetic field problems are considered, and some corresponding numerical results are shown. Moreover, some applications of the iterative domain decomposition method are introduced to practical industrial software.

Imaging strain fields on solid surfaces by electrical impedance tomography

Mikko Räsänen, University of Eastern Finland
Measuring strains induced by loads on structural elements is a key component of structural health monitoring (SHM). Current methods are mostly based on localized measurements and offer limited information on distributed strain. We present results on distributed strain monitoring based on electrical impedance tomography (EIT) imaging of a painted, elastic surface coating. Anisotropic modelling of the electric conductivity is employed to obtain image reconstructions, which correlate well with the mechanical strain field.

Continuity and differentiability of eigenvalues of Laplacian with respect to domain perturbations

Takuya Tsuchiya, Osaka University
We consider the eigenvalue problems of Laplacian on bounded domains with Lipschitz boundaries. Suppose that a domain is smoothly perturbed, and the perturbation is parametrized in t. In this talk, we discuss about continuity and differentiability of perturbed eigenvalues with respect to the parameter t. Several numerical experiments confirm the theoretical results obtained.

Conductivity reconstruction on a torus

Hjørdis Schlüter, University of Jyväskylä
We study the hybrid inverse problem of recovering an electrical conductivity from interior measurements. The hybrid setting (Acousto-Electric Tomography) allows one to obtain interior power density data from exterior measurements combining Electrical Impedance Tomography and acoustic waves. Instead of considering the usual setting of a bounded, two-dimensional Euclidean domain we consider the setting of a torus with a disk removed, so that the torus has a boundary. We present theoretical results and supplement with numerical reconstructions of the conductivity.

Session H, Thursday 15:30 - 17:30

Session chair: Nuutti Hyvönen

Error estimation for finite element solutions on meshes that contain thin elements

Kenta Kobayashi, Hitotsubashi University
In an error estimation of finite element solutions to the Poisson equation, we usually impose the shape regularity assumption on the meshes to be used. In this study, we show that even if the shape regularity condition is violated, the standard error estimation can be obtained if "bad" elements (elements that violate the shape regularity or maximum angle condition) are covered virtually by simplices that satisfy the minimum angle condition.

Optimality of stabilized finite element methods for elliptic unique continuation

Lauri Oksanen, University of Helsinki
We consider finite element approximation in the context of the ill-posed elliptic unique continuation problem and introduce a notion of optimal error estimates that includes convergence with respect to a mesh parameter and perturbations in data. The rate of convergence is determined by the conditional stability of the underlying continuous problem and the polynomial order of the finite element approximation space. We present a stabilized finite element method satisfying the optimal estimate and discuss a proof showing that no finite element approximation can converge at a better rate. The talk is based on joint work with Erik Burman and Mihai Nechita.

A study on bond correction methods via inverse scattering for 1D elastic wave equations

Hisashi Morioka, Ehime University
We consider the impulse response for the 1D wave equation with an stratified media as an ideal case. In the experimental point of view, this setting corresponds to the case where the pulse is input from the transducer and reflected pulses are observed at the same point. For the ideal case, we can get the explicit formula for the reconstruction of the propagation speed of the sample from the measurement of the intensity for the second reflected pulse. For experimental datum, we have to detect the singularity from blurred waves. This study is a collaboration between the mathematical study of inverse problems on wave equations and the experiments of the ultrasonic interferometry for rocks and metals. We try to compare the mathematical scheme of the inverse problem with real datum of the experiments.

Finite element method for unique continuation with finite dimensional Neumann trace

Ziyao Zhao, University of Helsinki
In this talk, I will introduce an advance on computational unique continuation for functions with finite dimensional Neumann trace and its finite element approximation. Specifically, I will show Lipschitz stability of this unique continuation problem and propose a finite element method that exerts the finite dimensionality of the Neumann trace to possess optimal priori and posterior error estimates. At last, I will present some numerical results and discuss potential applications.

Friday, August 30th

Session I, Friday 9:30 - 11:30

Session chair: Heli Virtanen

Learned reconstruction methods and convergent regularization: linear plug-and-play denoiser

Andreas Hauptmann, University of Oulu
The question if a reconstruction algorithm provides a convergent regularization has been long studied in inverse problems, as it provides more than just the knowledge that a solution can be computed at a certain noise level. It tells us that stable solutions exist for all noise realizations and even more importantly that in the limit case, when noise vanishes, we obtain a solution of the underlying operator equation. In other words, we can guarantee mathematically that obtained solutions are indeed solutions to the inverse problem.

This is in contrast to the majority of novel data-driven approaches where we may only guarantee that obtained solutions are minimizers of the empirical loss, given suitable training data. Consequently, the concept of convergent data-driven reconstructions has gained considerable interest very recently in the inverse problems community.

In this talk we shortly give an overview of learned reconstruction methods with and without convergence guarantees and then continue to discuss the popular framework of plug-and-play (PnP) denoising, which uses of the shelf denoisers in an iterative framework. We will specifically consider linear denoisers and propose a novel spectral filtering technique to control the strength of regularization arising from the denoiser. This allows us to show that PnP with linear denoisers does provide indeed a convergent regularization scheme.

This is joint work with Subhadip Mukherjee, Carola-Bibiane Schönlieb, and Ferdia Sherry.

Computed tomography without X-rays: parallel-beam imaging from nonlinear current flows

Siiri Rautio, University of Helsinki
We introduce a new reconstruction algorithm for electrical impedance tomography, which provides a connection between EIT and traditional X-ray tomography, based on the idea of "virtual X-rays". We divide the exponentially ill-posed and nonlinear inverse problem of EIT into separate steps. We start by mathematically calculating so-called virtual X-ray projection data from the measurement data. Then we perform explicit algebraic operations and one-dimensional integration, ending up with a blurry and nonlinearly transformed Radon sinogram. We use a neural network to remove the higher-order scattering terms and perform deconvolution. Finally, we can compute a reconstruction of the conductivity using the inverse Radon transform. We demonstrate the method with experimental data. This is a joint work with Melody Alsaker, Fernando Silva de Moura, Juan Pablo Agnelli, Rashmi Murthy, Matti Lassas, and Samuli Siltanen.

Dynamic tomography regularization using optimal space-time priors

Tommi Heikkilä, LUT University
We consider a sequence of sparse and dynamic tomography problems by regularizing in both spatial- and temporal domains using the cylindrical shearlet representation system and sparsity promoting regularization. This choice of sparsity promoting regularization is motivated by the ability to optimally approximate functions in the class of cartoon-like videos, and properties of the (quasi-)Banach decomposition spaces for p ¿ 0. Using statistical inverse learning methods we obtain convergence rates for p ¿ 1 in different noise conditions which are supported by numerical tests using both simulated and real dynamic tomography measurements. This is a joint work with T. A. Bubba, D. Labate and L. Ratti

Linearized electrical impedance tomography: reconstruction and Lipschitz stability for infinite-dimensional spaces of perturbations

Nuutti Hyvönen, Aalto University
Linearized electrical impedance tomography is investigated in a two-dimensional bounded simply connected domain with a smooth enough boundary. After extending the linearised problem for square integrable perturbations, the space of perturbations is orthogonally decomposed and Lipschitz stability, with explicit Lipschitz constants, is proven for each of the infinite-dimensional subspaces. The stability estimates are based on using the Hilbert-Schmidt norm for the Neumann-to-Dirichlet boundary map and its Frechet derivative with respect to the conductivity coefficient. A direct reconstruction method that inductively

yields the orthogonal projections of a conductivity coefficient onto the aforementioned subspaces is devised and numerically tested with data corresponding to the original nonlinear forward problem.

Session J, Friday 13:00 - 15:00

Session chair: Matti Lassas

Detection of the inclusions using deep enclosure method in electrical impedance tomography

Takanori Ide, Jose University
Electrical Impedance Tomography (EIT) is non-destructive imaging method that recovers image of the inclusions from boundary measurements. We propose novel method to detect the inclusions in e (EIT) by using deep neural networks and enclosure method. As the application of proposed method, we will demonstrate numerical computation. This is the joint work with Professor Samuli Siltanen from University of Helsinki.

On frictional crack problems in linearized elasticity

Hiromichi Itou, Tokyo University of Science
Frictional crack problems are important issues and have expected application to various fields such as fault rupture in seismology. From a mathematical point of view, such problems are described as the governing equation for the body motion and deformation, together with conditions on the crack surfaces that express the contact and friction forces. A contact condition on the crack is the so-called non-penetration condition defined as a unilateral condition on the body displacement in order to exclude nonphysical phenomena such as the mutual penetration of the crack faces. On the other hand, friction conditions are phenomenologically derived as empirical laws and now many conditions are proposed accordingly. In this talk, some theoretical results relative with frictional crack problems are overviewed. Firstly, we introduce results for the static contact problem with friction obtained in [1]. Friction is a dynamic phenomenon, however the analysis is mathematically difficult and many certain problems remain unsolved despite their practical importance. Then, we discuss the unique existence of a solution for an initial boundary value problem in a linearized elastodynamic body under conditions that the crack is fixed and the frictional force acting on the crack is given and depends on the time as well as space variables (cf. [3]). Lastly, we consider a dynamic motion of a linearized elastic body with a crack imposed to the Signorini contact condition of dynamic type (named SCD condition) and the Tresca friction condition. The SCD condition is modified from non-penetration condition and involves both displacement and velocity. We show that there exists a unique strong solution to this model (cf. [4]).

References:

[1] Itou H., Kovtunenko V.A. and Tani A., The interface crack with Coulomb friction between two bonded dissimilar elastic media. Appl. Math., 56(2011), no. 1, pp. 69–97. (DOI: 10.1007/s10492-011-0010-7)

[2] Furtsev A., Itou H. and Rudoy E., Modeling of bonded elastic structures by a variational method: Theoretical analysis and numerical simulation. Internat. J. Solids Structures, 182–183(2020), pp. 100-111. (DOI: 10.1016/j.ijsolstr.2019.08.006)

[3] Itou H. and Kashiwabara T., Unique solvability of crack problem with time-dependent friction condition in linearized elastodynamic body, Mathematical notes of NEFU, 28(2021), pp. 121-134. (DOI: 10.25587/SVFU.2021.38.33.008)

[4] Kashiwabara T. and Itou H., Unique solvability of a crack problem with Signorini-type and Tresca friction conditions in a linearized elastodynamic body, Philos. Trans. Roy. Soc. A, 380(2022), no. 2236, 20220225. (DOI: 10.1098/rsta.2022.0225)

A Convergence Theory for Unpaired, Learnt mappings?

Martin Ludvigsen, Norwegian University of Science and Technology
We introduce the concept of unpaired learnt mappings and highlight their significance in solving inverse problems. A persistent challenge with learned models is their lack of robustness and the absence of convergence properties, often expected from traditional theoretical approaches. To address these limitations, we propose a novel model and framework that leads to a GAN-like training process. We establish theoretical guarantees by proving the existence, stability, and convergence of the solutions within this framework. This approach represents a unique integration of machine learning techniques with classical inverse problem theory. Finally, we present preliminary numerical examples that illustrate the practical effectiveness of our model. This is joint work with Markus Grasmair.

Popularizing mathematics via social media videos

Samuli Siltanen, University of Helsinki
Mathematics is an essential part of modern digital life, and it is important to communicate mathematics to general audiences, especially children. But how to reach young people? These days, social media videos may be the best way to go. This talk shows examples of successful science videos about inverse problems and other interesting mathematical topics. Also, possibilities of using videos in university education is discussed.