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Applied Inverse Problems

Göttingen Germany

Book of Abstracts

11th Applied Inverse Problems Conference in Göttingen

September 4-8, 2023

CRC 1456 MATHEMATICS OF EXPERIMENT

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DFG Deutsche Forschungsgemeinschaft

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CRC 1456
MATHEMATICS
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Deutsche
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Venue

Georg-August-Universität
Zentrales Hörsaalgebäude (ZHG)
Platz der Göttinger Sieben
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GEORG-AUGUST-UNIVERSITÄT
GÖTTINGEN

Registration

SAW Tagungsmanagement
78269 Volkertshausen

www.aip2023.de

Table of Contents

Plenary Talks

Mon Sep 4
9:50 am
ZHG 011

Giovanni S. Alberti

University of Genoa, Italy

On the sample complexity of inverse problems

Many inverse problems are modeled by integral or partial differential equations, including, for instance, the inversion of the Radon transform in computed tomography and the Calderón problem in electrical impedance tomography. As such, these inverse problems are intrinsically infinite dimensional and, in theory, require infinitely many measurements for the reconstruction. In this talk, I will discuss recovery guarantees with finite measurements, and with explicit estimates on the sample complexity, namely, on the number of measurements. These results use methods of sampling theory and compressed sensing, and work under the assumption that the unknown either belongs to a finite-dimensional subspace/submanifold or enjoys sparsity properties. I will consider both linear problems, such as the sparse Radon transform, and nonlinear problems, such as the Calderón problem and inverse scattering.

A similar issue arises when applying machine learning methods for solving inverse problems, for instance, to learn the regularizer, which may depend on infinitely many parameters. I will present sample complexity results on the size of the training set, both in the case of generalized Tychonov regularization, and with ℓ^1-type penalties.

This talk is based on a series of joint works with Á. Arroyo, P. Campodonico, E. De Vito, A. Felisi, T. Helin, M. Lassas, L. Ratti, M. Santacesaria, S. Sciutto and S. I. Trapasso.

Mon Sep 4
11:10 am
ZHG 011

Houssem Haddar

INRIA, France

An unexpected role of transmission eigenvalues in imaging algorithms

Transmission eigenvalues are frequencies related to resonances inside scatterers and by duality to non-scattering for an incident field being an associated eigenvector. Appearing naturally in the study of inverse scattering problems for inhomogeneous media, the associated spectral problem has a deceptively simple formulation but presents a puzzling mathematical structure, in particular it is a non-self-adjoint eigenvalue problem. It triggered a rich literature with a variety of theoretical results on the structure of the spectrum and also on applications for uniqueness results [1].

For inverse shape problems, these special frequencies were first considered as bad values (for some imaging algorithms, e.g., sampling methods) as they are associated with non-injectivity of the measurement operator. It later turned out, as proposed in [2], that transmission eigenvalues can be used in the design of an imaging algorithm capable of revealing density of cracks in highly fractured domains, thus exceeding the capabilities of traditional approaches to address this problem.

This new imaging concept has been further developed to produce average properties of highly heterogeneous scattering media at a fixed frequency (not necessarily a transmission eigenvalue) by encoding a special spectral parameter in the background that acts as transmission eigenvalues [3].

While targeting this unexpected additional value of transmission eigenvalues in imaging algorithms, the talk will also provide an opportunity to highlight some key results and open problems related to this active research area.

References

[1] F. Cakoni, D. Colton, H. Haddar. Inverse Scattering Theory and Transmission Eigenvalues, CBMS-NSF, 98, 2022.

[2] L. Audibert, L. Chesnel, H. Haddar, K. Napal. Qualitative indicator functions for imaging crack networks using acoustic waves. SIAM Journal on Scientific Computing, 2021.

[3] L. Audibert, H. Haddar, F. Pourre. Reconstruction of average indicators for highly heteregenous scatterers. Preprint, 2023.

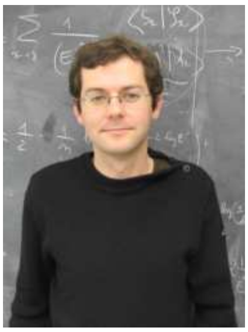
Angkana Rüland
University of Bonn, Germany

On the Fractional Calderon Problem

Tue Sep 5
10:00 am
ZHG 011

Inverse problem for prototypical nonlocal operators such as the fractional Laplacian display strikingly strong uniqueness, stability and single measurement results. These fundamentally rely on global variants of the unique continuation property for these nonlocal operators and dual flexibility properties in the form of Runge approximation results. In this talk, I introduce these properties and discuss some recent results on the relation between the classical and fractional Calderon problems.

This is based on joint work with G. Covi, T. Ghosh, M. Salo and G. Uhlmann.



Colin Guillarmou
CNRS, France

Microlocal applications to the study of marked length spectrum rigidity and lens rigidity in chaotic settings

Tue Sep 5
11:10 am
ZHG 011

The boundary rigidity problem asks if the boundary distance function on a simple Riemannian manifold determines the metric. For non simple manifolds with boundary or even for closed Riemannian manifolds, there are corresponding problems named lens rigidity and marked length spectrum rigidity. The general question is essentially reduced to knowing if a conjugacy between two geodesic flows on the unit tangent bundles necessarily comes from an isometry on the underlying Riemannian metrics.

The introduction of microlocal methods to understand the regularity of solutions of transport equations, of invariant distributions for the geodesic flow, has been key in the resolution of such problems that naturally arise when the geodesic flow is chaotic (hyperbolic). We will review recent results in this direction, in collaborations with Bonthonneau, Cekic, Jezequel, Lefeuvre and Paternain.

Wed Sep 6
11:20 am
ZHG 011

Gabriel Paternain

University of Cambridge, United Kingdom

Geometric inverse problems in 2D: a transport twistor perspective

I will discuss some landmark results in geometric inverse problems in 2D from the point of view of the transport twistor space, a natural complex surface designed to be sensitive to the transport operator (geodesic vector field). Towards the end of the lecture I will present some recent developments and open questions motivated by this point of view.

Thu Sep 7
9:00 am
ZHG 011

Laurent Gizon

MPI for Solar System Research, Germany

Correlation-based imaging and inverse problems in helioseismology

The outer 30% of the solar interior covers the Sun's convection zone. There, under the influence of rotation, convective motions drive the large-scale flows that power the global dynamo. The convection is also a source of stochastic excitation for the acoustic waves that permeate the solar interior.

Measurements of the frequencies of the modes of oscillation have been used very successfully to infer, for example, internal rotation as a function of radius and unsigned latitude. Current research focuses on developing improved methods to recover the 3D sound speed and vector flows in the interior from the correlations of the acoustic wavefield measured at the surface.

In this presentation, I intend to present recent uniqueness results for the passive inverse problem [1,2], as well as linear inversions of seismic data for the meridional flow [3], and advances in helioseismic holography - an imaging technique that enables us to see active regions on the Sun's far side [4]. I will then discuss a new and promising iterative method, which combines the computational efficiency of helioseismic holography and the quantitative nature of helioseismic tomography [5]. If time permits, I will mention the possibility of extending helioseismology to the interpretation of the recently discovered inertial modes of oscillation [6].

References

[1] A. D. Agaltsov, T. Hohage, R. G. Novikov. Monochromatic identities for the Green function and uniqueness results for passive imaging. SIAM J. Appl. Math. 78:2865, 2018. doi:10.1137/18M1182218

[2] A. D. Agaltsov, T. Hohage, R. G. Novikov. Global uniqueness in a passive inverse problem of helioseismology. Inverse Problems 36:055004, 2020. doi:10.1088/1361-6420/ab77d9

[3] L. Gizon et al. Meridional flow in the Sun's convection zone is a single cell in each hemisphere. Science 368:1469, 2020. doi:10.1126/science.aaz7119

[4] D. Yang, L. Gizon, H. Barucq. Imaging individual active regions on the Sun's far side with improved helioseismic holography. Astron. Astrophys. 669:A89, 2023. doi:10.1051/0004-6361/202244923

[5] B. Mueller et al. Quantitative passive imaging by iterated back propagation: The example of helioseismic holography. 2023. in preparation

[6] L. Gizon et al. Solar inertial modes: Observations, identification, and diagnostic promise. Astron. Astrophys. 652:L6, 2021. doi:10.1051/0004-6361/202141462

Jingni Xiao

Drexel University, United States of America

Always-Scattering, Non-Scattering, and Inverse Scattering

Thu Sep 7
9:50 am
ZHG 011

In this talk, I will present some recent progress on always-scattering, non-scattering, and their connections to inverse scattering.

We consider scattering problems when a medium is probed by incident waves and as a result scattered waves are induced. The aim of inverse scattering is to deduce information about an unknown medium by measuring the corresponding scattered waves outside the medium. Inverse scattering has applications in many fields of science and technology, of which radar is one of the most prevalent.

Non-scattering is a particular phenomenon that arises when a medium is probed but no scattered waves can be measured externally. Non-scattering impacts inverse scattering, and it has applications in invisibility where one tries to avoid detection of an object. Moreover, non-scattering is related to resonance, injectivity of the relative scattering operator, and free boundary problems. There can be situations when non-scattering never occurs for a given medium; this phenomenon is called always-scattering. The always-scattering feature has applications in inverse problems for uniquely determining the shape or other properties of a medium from scattering measurements.

Richard Nickl

University of Cambridge, United Kingdom

High-dimensional non-linear Bayesian inverse problems

Thu Sep 7
11:10 am
ZHG 011

We will review recent progress and open problems in our understanding of the statistical and computational performance of Bayesian inference algorithms in non-linear inverse regression problems arising with partial differential equation models.

Fri Sep 8
9:00 am
ZHG 011

Ali Feizmohammadi

University of Toronto, Canada

Inverse problems for wave equations

The main topic will be inverse problems for linear and nonlinear wave equations. I will describe results in both stationary and non-stationary spacetimes. An example of inverse problems in stationary spacetimes is the imaging of internal structure of the earth from surface measurements of seismic waves arising from earthquakes or artificial explosions. Here, the materialistic properties of the internal layers of the earth are generally assumed to be independent of time. On the other hand, inverse problems for non-stationary spacetimes are inspired by the theory of general relativity as well as gravitational waves where waves follow paths that curve not only in space but also in time. We introduce a method of solving such inverse boundary value problems, and show that lower order coefficients can be recovered under certain curvature bounds. The talk is based on joint works with Spyros Alexakis and Lauri Oksanen.

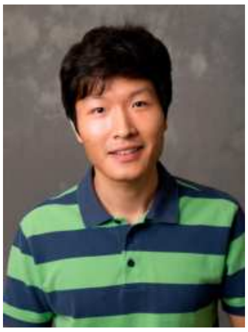
Fri Sep 8
9:50 am
ZHG 011

Xiang Xu

Zhejiang University, China, People's Republic of

On inverse problems for piezoelectric equations

During this talk, we will discuss recent advancements in inverse problems for piezoelectric equations. Specifically, we will present a uniqueness result that pertains to recovering coefficients of piecewise homogeneous piezoelectric equations from a localized Dirichlet-to-Neumann map on partial boundaries. Additionally, we obtained a first-order perturbation formula for the phase velocity of Bleustein-Gulyaev (BG) waves in a specific hexagonal piezoelectric equation. This formula expresses the shift in velocity from its comparative value, caused by the perturbation of the elasticity tensor, piezoelectric tensor, and dielectric tensor. This work has been done in collaboration with G. Nakamura, K. Tanuma, and J. Xu.



Yiran Wang

Emory University, United States of America

Fri Sep 8
11:10 am
ZHG 011

Reconstruction of spacetime structures in general relativity and Lorentzian geometry

The field of relativistic astrophysics has witnessed a major revolution with the development of increasingly more sensitive telescopes and gravitational wave detectors on Earth and in space. An outstanding question is what can be learned from the observed data. In this talk, we report recent progresses on two inverse problems of reconstructing spacetime structures. The first problem is the recovery of initial status of the universe from the Cosmic Microwave Background. Mathematically, the heart of the problem is an integral transform in Lorentzian geometry, called the light ray transform. We discuss its injectivity, stability and connections to wave equations and kinetic theory. The second problem is the recovery of black hole spacetimes from gravitational wave signals observed by LIGO. In particular, we show how to ”hear” the shape of black holes by using the characteristic frequencies (or quasi-normal modes) extracted from the black hole ring-down.

List of Minisymposia

MS01: Machine Learning for Inverse Problems in Medical Imaging

organized by C. Fiedler, J. Flemming

VG1.102 **Session:** Wed Sep 6, 9:00 am – 11:00 am

9:00 am **Chances and limitations of machine learning approaches to inverse problems**
J. Flemming

9:30 am **From Manual to Automatic: Streamlining MRI Marker Detection and Localization for Surgical Planning**
C. Fiedler, S. Kolbig

10:00 am **Approaches on Feature and Model Selection for high-dimensional data in Medical Research and Analysis**
P.-P. Jacobs, T. Denecke, H. Busse

10:30 am **Deceptive performance of artificial neural networks in semantic segmentation tasks on the example of lung delineation**
M. Wittig

MS02: Advances in regularization for some classes of nonlinear inverse problems

organized by B. Hofmann, R. Plato

VG1.102 **Session 1:** Tue Sep 5, 1:30 pm – 3:30 pm

1:30 pm **Deautoconvolution in the two-dimensional case**
Y. Deng, B. Hofmann, F. Werner

2:00 pm **Efficient minimization of variational functionals via semismooth* Newton methods**
S. Hubmer, R. Ramlau

2:30 pm **Convergence Nestorov acceleration for linear ill-posed problems**
S. Kindermann

3:00 pm **Analysis of the discrepancy principle for Tikhonov regularization under low order source conditions**
C. Klinkhammer, R. Plato

VG1.102 **Session 2:** Tue Sep 5, 4:00 pm – 5:30 pm

4:00 pm **New results for variational regularization with oversmoothing penalty term in Banach spaces**
B. Hofmann, C. Klinkhammer, R. Plato

4:30 pm **Iterative regularization methods for non-linear ill-posed operator equations in Banach spaces**
P. Mahale

5:00 pm **An Abstract Framework for Stochastic Elliptic Inverse Problems.**
A. Khan

MS03: Compressed Sensing meets Statistical Inverse Learning

organized by T. A. Bubba, L. Ratti, M. Santacesaria

Session 1: Mon Sep 4, 1:30 pm – 3:00 pm — VG2.103

Compressed sensing for the sparse Radon transform — 1:30 pm
G. S. Alberti, A. Felisi, M. Santacesaria, S. I. Trapasso

Regularization for learning from unlabeled data using related labeled data — 2:00 pm
W. Zellinger, S. V. Pereverzyev

Random tree Besov priors for detail detection — 2:30 pm
H. Kekkonen, M. Lassas, S. Siltanen

Session 2: Mon Sep 4, 4:00 pm – 6:00 pm — VG2.103

SGD for statistical inverse problems — 4:00 pm
A. Abhishake

Convex regularization in statistical inverse learning problems — 4:30 pm
T. Helin

An off-the-grid approach to multi-compartment magnetic fingerprinting — 5:00 pm
C. Poon

How many Neurons do we need? A refined Analysis. — 5:30 pm
M. Nguyen, N. Mücke

MS04: Statistical and computational aspects of non-linear inverse problems

organized by R. Nickl, S. Wang

Session 1: Tue Sep 5, 1:30 pm – 3:30 pm — VG2.102

Surface finite element approximation of Gaussian random fields on Riemannian manifolds — 1:30 pm
A. Lang

Concentration analysis of multivariate elliptic diffusions — 2:00 pm
C. Aeckerle-Willems, C. Strauch, L. Trottner

A Bernstein-von-Mises theorem for the Calderón problem with piecewise constant conductivities — 2:30 pm
J. Bohr

Bayesian estimation in a multidimensional diffusion model with high frequency data — 3:00 pm
M. Hoffmann, K. Ray

Session 2: Tue Sep 5, 4:00 pm – 6:00 pm — VG2.102

Parameter estimation for boundary conditions in ice sheet models — 4:00 pm
F. Seizilles

MCMC Methods for Low Frequency Diffusion Data — 4:30 pm
M. Giordano

Laplace priors and spatial inhomogeneity in Bayesian inverse problems — 5:00 pm
S. Wang, S. Agapiou

Analysis of a localized non-linear ensemble Kalman-Bucy filter with sparse observations — 5:30 pm
G. Hastermann, J. de Wiljes

MS05: Numerical meet statistical methods in inverse problems

organized by M. Hanke, M. Reiß, F. Werner

VG2.102 **Session 1:** Wed Sep 6, 9:00 am – 11:00 am

9:00 am **Aggregation by the Linear Functional Strategy in Regularized Domain Adaptation**
S. Pereverzyev

9:30 am **The Henderson problem and the relative entropy functional**
F. M. Frommer, M. Hanke

10:00 am **Early stopping for L^2-boosting in high-dimensional linear models**
B. Stankewitz

10:30 am **Early stopping for conjugate gradients in statistical inverse problems**
L. Hucker, M. Reiß

VG2.102 **Session 2:** Thu Sep 7, 1:30 pm – 3:30 pm

1:30 pm **Utilising Monte Carlo method for light transport in the inverse problem of quantitative photoacoustic tomography**
T. Tarvainen, N. Hänninen, A. Pulkkinen, S. Arridge

2:00 pm **Discretisation-adaptive regularisation via frame decompositions**
T. Jahn

2:30 pm **Operator Learning Meets Inverse Problems**
N. H. Nelsen, M. V. de Hoop, N. B. Kovachki, A. M. Stuart

3:00 pm **UNLIMITED: The UNiversal Lepskii-Inspired MInimax Tuning mEthoD**
H. Li, F. Werner

VG2.102 **Session 3:** Thu Sep 7, 4:00 pm – 6:00 pm

4:00 pm **Bayesian hypothesis testing in statistical inverse problems**
R. Kretschmann, F. Werner

4:30 pm **Predictive risk regularization for Gaussian and Poisson inverse problems**
F. Benvenuto

5:00 pm **Reconstruction of active forces in actomyosin droplets**
A. Wald, E. Klass

5:30 pm **Learning Linear Operators**
N. Mücke

MS06: Inverse Acoustic and Electromagnetic Scattering Theory - 30 years later

organized by F. Cakoni, H. Haddar

VG0.110 **Session 1:** Wed Sep 6, 9:00 am – 11:00 am

9:00 am **Celebrating Colton and Kress Contributions**
F. Cakoni, H. Haddar

9:30 am **Passive inverse obstacle scattering problems**
T. Hohage, M. Liu

10:00 am **Target Signatures for Thin Surfaces**
P. Monk

Learning Dynamical Models and Model Components from Observations 10:30 am
R. Potthast

Session 2: Thu Sep 7, 1:30 pm – 3:00 pm VG3.103

Nonlinearity parameter imaging in the frequency domain 1:30 pm
B. Kaltenbacher, W. Rundell

The Lippmann-Schwinger Lanczos algorithm for inverse scattering. 2:00 pm
J. Baker, E. Cherkaev, V. Druskin, S. Moskow, M. Zaslavsky

Analysis of topological derivative for qualitative defect imaging using elastic waves 2:30 pm
M. Bonnet

Session 3: Thu Sep 7, 4:00 pm – 5:30 pm VG3.103

The direct and inverse scattering problem of obliquely incident electromagnetic waves by an inhomogeneous infinitely long cylinder 4:00 pm
D. Gintides, L. Mindrinos, S. Giogiakas

Transmission Eigenvalues for a Conductive Boundary 4:30 pm
I. Harris

Generalized Sampling method 5:00 pm
L. Audibert

Session 4: Fri Sep 8, 1:30 pm – 3:30 pm VG3.103

Nonlinear integral equations for 3D inverse acoustic and electromagnetic scattering 1:30 pm
O. Ivanyshyn Yaman

Inverse scattering in a partially embedded waveguide 2:00 pm
L. Bourgeois, J.-F. Fritsch, A. Recoquillay

Revisiting the Hybrid method for the inverse scattering transmission problem 2:30 pm
P. Serranho, J. Paixão

Single Mode Multi-frequency Factorization Method for the Inverse Source Problem in Acoustic Waveguides 3:00 pm
S. Meng

MS07: Regularization for Learning from Limited Data: From Theory to Medical Applications

organized by M. Holzleitner, S. Pereverzyev, W. Zellinger

Session 1: Fri Sep 8, 1:30 pm – 3:30 pm VG1.101

Regularized Radon - Nikodym differentiation and some of its applications 1:30 pm
D. H. Nguyen, S. Pereverzyev, W. Zellinger

Explicit error rate results in the context of domain generalization 2:00 pm
M. Holzleitner

Addressing Parameter Choice Issues in Unsupervised Domain Adaptation by Aggregation 2:30 pm
M.-C. Dinu

Convex regularization in statistical inverse learning problems 3:00 pm
L. Ratti, T. A. Bubba, M. Burger, T. Helin

Session 2: Fri Sep 8, 4:00 pm – 6:00 pm VG1.101

4:00 pm **Imbalanced data sets in a magnetic resonance imaging case study of preterm neonates: a strategy for identifying informative variables**
S. Pereverzyev Jr.

4:30 pm **On Approximation for Multi-Source Domain Adaptation in the Space of Copulas**
P. Roy, B. Moser, W. Zellinger, S. Saminger-Platz

5:00 pm **Learning segmentation on unlabeled MRI data using labeled CT data**
L. Frischauf

5:30 pm **Parameter choice in distance-regularized domain adaptation**
W. Zellinger, S. V. Pereverzyev

MS08: Integral Operators in Potential Theory and Applications

organized by D. Choi, M. Lim, S. Shipman

VG2.102 **Session 1:** Fri Sep 8, 1:30 pm – 3:30 pm

1:30 pm **On the identification of small anomaly via MUSIC algorithm without background information**
W.-K. Park

2:00 pm **Construction of inclusions with vanishing generalized polarization tensors by imperfect interfaces**
D. Choi, M. Lim

2:30 pm **Spectral theory of surface plasmons in the nonlocal hydrodynamic Drude model**
H. Lee, M. Ruiz, S. Yu

3:00 pm **Numerical computation of Laplacian eigenvalues based on the layer potential formulation**
M. Lim, J. Hong

VG2.102 **Session 2:** Fri Sep 8, 4:00 pm – 5:30 pm

4:00 pm **Recovering an elastic inclusion using the shape derivative of the elastic moment tensors**
D. Cho, M. Lim

4:30 pm **Some aspects of the spectrum of the Neumann-Poincaré operator**
S. Shipman

5:00 pm **Spectrum of the Neumann-Poincaré operator on thin domains**
K. Ando, H. Kang, M. Yoshihisa

MS09: Forward and inverse domain uncertainty quantification

organized by V. Kaarnioja, C. Schillings

VG1.102 **Session:** Fri Sep 8, 1:30 pm – 3:30 pm

1:30 pm **Isogeometric multilevel quadrature for forward and inverse random acoustic scattering**
J. Dölz, H. Harbrecht, C. Jerez-Hanckes, M. Multerer

2:00 pm **Evolving surfaces driven by stochastic PDEs**
A. Lang

2:30 pm **Multilevel domain UQ in computational electromagnetics**
J. Zech, R. Aylwin, C. Jerez-Hanckes, C. Schwab

3:00 pm **Advantages of locality in random field representations for shape uncertainty quantification**
L. Scarabosio, W. van Harten

MS10: Optimization in Inverse Scattering: from Acoustics to X-rays

organized by R. I. Bot, R. Luke

Session 1: Thu Sep 7, 1:30 pm – 3:30 pm — VG1.103

Numerical Linear Algebra Networks for Solving Linear Inverse Problems — 1:30 pm
O. Scherzer

Regularization by Randomization: The Case of Partially Separable Optimization — 2:00 pm
R. Luke

Fast convex optimization via closed-loop time scaling of gradient dynamics — 2:30 pm
H. Attouch, R. I. Bot, D.-K. Nguyen

Fast Optimistic Gradient Descent Ascent method in continuous and discrete time — 3:00 pm
R. I. Bot, E. R. Csetnek, D.-K. Nguyen

Session 2: Thu Sep 7, 4:00 pm – 6:00 pm — VG1.103

PAC-Bayesian Learning of Optimization Algorithms — 4:00 pm
P. Ochs

Accelerated Griffin-Lim algorithm: A fast and provably convergent numerical method for phase retrieval — 4:30 pm
R. Nenov, D.-K. Nguyen, R. I. Bot, P. Balazs

Audio Inpainting — 5:00 pm
P. Balazs, G. Tauböck, S. Rajbamshi, N. Holighaus

Damage detection by guided ultrasonic waves and uncertainty quantification — 5:30 pm
D. Lorenz, N. K. Bellam Muralidhar, C. Gräßle, N. Rauter, A. Mikhaylenko, R. Lammering

Session 3: Fri Sep 8, 1:30 pm – 3:30 pm — VG1.103

Automated tight Lyapunov analysis for first-order methods — 1:30 pm
M. Upadhyaya, S. Banert, A. Taylor, P. Giselsson

Learned SVD for limited data inversion in PAT and X-ray CT — 2:00 pm
M. Haltmeier, J. Schwab, S. Antholzer

Multiscale hierarchical decomposition methods for ill-posed problems — 2:30 pm
T. Wolf, E. Resmerita, S. Kindermann

Scalable moment relaxations for graph-structured problems with values in a manifold: An optimal transport approach — 3:00 pm
R. Kenis, E. Laude, P. Patrinos

Session 4: Fri Sep 8, 4:00 pm – 5:30 pm — VG1.103

Phase retrieval from overexposed PSFs: theory and practice — 4:00 pm
O. A. Soloviev

Tensor-free algorithms for lifted quadratic and bilinear inverse problems — 4:30 pm
R. Beinert, K. Bredies

Implicit regularization via re-parametrization — 5:00 pm
C. Molinari

MS11: Defying the Curse of Dimensionality - Theory and Algorithms for Large Dimensional Bayesian Inversion

organized by R. Flock, Y. Dong

VG1.108 **Session:** Wed Sep 6, 9:00 am – 11:00 am

9:00 am **Efficient high-dimensional Bayesian multi-fidelity inverse analysis for expensive legacy solvers**
J. Nitzler, W. A. Wall, P.-S. Koutsourelakis

9:30 am **Goal-oriented Uncertainty Quantification for Inverse Problems via Variational Encoder-Decoder Networks**
J. Chung, M. Chung, B. Afkham

10:00 am **Coupled Parameter and Data Dimension Reduction for Bayesian Inference**
Q. Chen, E. Arnaud, R. Baptista, O. Zahm

10:30 am **Certified Coordinate Selection for large-dimensional Bayesian Inversion**
R. Flock, Y. Dong, O. Zahm, F. Uribe

MS12: Fast optimization-based methods for inverse problems

organized by T. Valkonen

VG2.102 **Session 1:** Mon Sep 4, 1:30 pm – 3:30 pm

1:30 pm **Parameter-Robust Preconditioning for Oseen Iteration Applied to Navier-Stokes Control Problems**
S. Leveque, J. Pearson

2:00 pm **Sparse Bayesian Inference with Regularized Gaussian Distributions**
J. M. Everink, Y. Dong, M. S. Andersen

2:30 pm **An Accelerated Level-Set Method for Inverse Scattering Problems**
L. Audibert, H. Haddar, X. Liu

3:00 pm **A first-order optimization method with simultaneous adaptive pde constraint solver**
B. Christian Skov Jensen, T. Valkonen

VG2.102 **Session 2:** Mon Sep 4, 4:00 pm – 6:00 pm

4:00 pm **Limited memory restarted $\ell^p - \ell^q$ minimization methods using generalized Krylov subspaces**
A. Buccini, L. Reichel

4:30 pm **A high order PDE-constrained optimization for the image denoising problem**
L. Afraites, A. Hadri, A. Laghrib, M. Nachaoui

5:00 pm **A primal dual projection algorithm for efficient constraint preconditioning**
A. Schiela, M. Weiser, M. Stöcklein

5:30 pm **An Inexact Trust-Region Algorithm for Nonsmooth Nonconvex Optimization**
R. Baraldi, D. P. Kouri

MS13: Stochastic iterative methods for inverse problems

organized by T. Jahn

Session 1: Fri Sep 8, 1:30 pm – 3:30 pm VG0.111

Beating the Saturation of the Stochastic Gradient Descent for Linear Inverse Problems 1:30 pm
B. Jin, Z. Zhou, J. Zou

Early stopping of untrained convolutional networks 2:00 pm
T. Jahn, B. Jin

Stochastic mirror descent method for linear ill-posed problems in Banach spaces 2:30 pm
Q. Jin

Early stopping for spectral filter estimators regularized by projection 3:00 pm
A. Celisse, S. Clementz

Session 2: Fri Sep 8, 4:00 pm – 6:00 pm VG0.111

From inexact optimization to learning via gradient concentration 4:00 pm
B. Stankewitz, N. Mücke, L. Rosasco

Principal component analysis in infinite dimensions 4:30 pm
M. Wahl

Learning Linear Operators 5:00 pm
N. Mücke

SGD for select inverse problems in Banach spaces 5:30 pm
Z. Kereta, B. Jin

MS14: Inverse Modelling with Applications

organized by D. Lesnic, K. Van Bockstal

Session 1: Mon Sep 4, 1:30 pm – 3:00 pm VG1.104

Scanning biological tissues using thermal-waves 1:30 pm
D. Lesnic

Identification of the time-dependent part of a heat source in thermoelasticity 2:00 pm
K. Van Bockstal, L. Marin

Uniqueness of determining a space-dependent source for inverse source problems in thermoelasticity 2:30 pm
F. Maes, K. Van Bockstal

Session 2: Mon Sep 4, 4:00 pm – 6:00 pm VG1.104

Boundary identification in cantilever beam equation related to the atomic force microscopy 4:00 pm
O. Baysal, A. Hasanov, A. Kawano

Recent developments on integral equation approaches for Electrical Impedance Tomography 4:30 pm
C. Sebu

Inverse problem of determining time-dependent diffusion coefficient in the time-fractional heat equation 5:00 pm
D. Serikbaev

5:30 pm **Determining an Iwatsuka Hamiltonian through quantum velocity measurement**
É. Soccorsi

VG1.104 **Session 3:** Tue Sep 5, 1:30 pm – 3:00 pm

1:30 pm **Inverse Problems for Generalized Subdiffusion Equations**
N. Kinash

2:00 pm **Numerical solution to inverse source problems for a parabolic equation with nonlocal conditions**
A. Rahimov, K. Aida-zade

2:30 pm **Advances in object characterisation for metal detection inverse problems**
P. D. Ledger, W. R. B. Lionheart, J. Elgy

MS15: Experimental and Algorithmic Progress in Photoemission Orbital Imaging

organized by R. Luke, S. Mathias

VG1.102 **Session 1:** Mon Sep 4, 1:30 pm – 3:30 pm

1:30 pm **Imaging valence and excited states of fullerenes in momentum space**
B. Stadtmüller, M. Aeschlimann

2:00 pm **Imaging molecular wave functions with photoemission orbital tomography: An introduction**
F. S. Tautz

2:30 pm **Time-resolved photoemission orbital tomography of organic interfaces**
U. Höfer

3:00 pm **Exciton Photoemission Orbital Tomography: Probing the electron and the hole contributions**
G. S. M. Jansen

VG1.102 **Session 2:** Mon Sep 4, 4:00 pm – 6:00 pm

4:00 pm **A minimalist approach to 3D photoemission orbital tomography: how many measurements are enough?**
T. L. Dinh

4:30 pm **Experimental progress towards time-resolved three-dimensional orbital tomography**
W. Bennecke, J. P. Bange, D. Schmitt, T. L. Dinh, D. Steil, S. Steil, D. R. Luke, M. Reutzel, G. S. M. Jansen, S. Mathias

5:00 pm **Element-Selective Structural Information by Hard X-ray Photoelectron Diffraction**
H.-J. Elmers

5:30 pm **Imaging molecular wave functions with photoemission orbital tomography: Recent developments**
P. Puschnig

MS16: Wave propagation and quantitative tomography

organized by L. Mindrinos, L. Veselka

VG0.111 **Session 1:** Thu Sep 7, 1:30 pm – 3:30 pm

1:30 pm **Phase-contrast THz-CT for non-destructive testing**
S. Hubmer, R. Ramlau

Diffraction tomography for a generalized incident beam wave 2:00 pm
N. Naujoks

Bias-free localizations in cryo-single molecule localization microscopy 2:30 pm
F. Hinterer

Uncertainty-aware blob detection in astronomical imaging 3:00 pm
F. Parzer, P. Jethwa, A. Boecker, M. Alfaro-Cuello, O. Scherzer, G. van de Ven

Session 2: Thu Sep 7, 4:00 pm – 6:00 pm VG0.111

Source Reconstruction from Partial Boundary Data in Radiative Transport 4:00 pm
K. Sadiq

Solving Cauchy problems using semi-discretization techniques and BIE 4:30 pm
L. Mindrinos

Quantitative Parameter Reconstruction from Optical Coherence Tomographic Data 5:00 pm
L. Veselka, W. Drexler, P. Elbau, L. Krainz

Augmented total variation regularization in imaging inverse problems 5:30 pm
N. E. Protonotarios, C.-B. Schönlieb, N. Dikaios, A. Charalambopoulos

MS17: Machine Learning Techniques for Bayesian Inverse Problems

organized by A. Senchukova

Session: Tue Sep 5, 4:00 pm – 5:30 pm VG1.104

Stochastic Normalizing Flows for Inverse Problems via Markov Chains 4:00 pm
P. Hagemann, J. Hertrich, G. Steidl

Bayesian computation with Plug & Play priors for inverse problems in imaging 4:30 pm
R. Laumont, V. De bortoli, A. Almansa, J. Delon, A. Durmus, M. Pereyra

Edge-preserving inversion with heavy-tailed Bayesian neural networks priors 5:00 pm
A. Senchukova, F. Uribe, J. de Wiljes, L. Roininen

MS18: Inverse problems for fractional and nonlocal equations

organized by Y.-H. Lin, J. Railo, M. Salo

Session 1: Mon Sep 4, 1:30 pm – 3:30 pm VG1.103

On the determination of a coefficient in a space-fractional equation with operators of Abel type 1:30 pm
B. Kaltenbacher, W. Rundell

Nonlocality Helps 2:00 pm
G. Uhlmann

Fractional p-Calderón problems 2:30 pm
P. Zimmermann

Uniqueness in an inverse problem for the anisotropic fractional conductivity equation 3:00 pm
G. Covi

Session 2: Mon Sep 4, 4:00 pm – 6:00 pm VG1.103

The Calderón problem for directionally antilocal operators 4:00 pm
M. Á. García-Ferrero

4:30 pm **An Inverse Problem for Nonlinear Fractional Magnetic Schrodinger Equation**
R.-Y. Lai

5:00 pm **Properties of solutions for anisotropic viscoelastic systems**
M. de Hoop, M. Kimura, C.-L. Lin, G. Nakamura

5:30 pm **Fractional anisotropic Calderon problem on Riemannian manifolds**
K. Krupchyk

VG1.103 **Session 3:** Tue Sep 5, 1:30 pm – 3:00 pm

1:30 pm **Inverse Problems for Subdiffusion from Observation at an Unknown Terminal Time**
B. Jin

2:00 pm **UCP and counterexamples to UCP involving generalized ray transforms**
V. Krishnan

2:30 pm **An inverse problem related to fractional wave equation**
P.-Z. Kow

MS19: Theory and algorithms of super-resolution in imaging and inverse problems

organized by H. Ammari, P. Liu

VG3.103 **Session 1:** Tue Sep 5, 1:30 pm – 3:30 pm

1:30 pm **Stability and super-resolution of MUSIC and ESPRIT for multi-snapshot spectral estimation**
W. Li

2:00 pm **A Mathematical Theory of Computational Resolution Limit and Super-resolution**
P. Liu, H. Ammari

2:30 pm **Total variation regularized problems: a support stability result**
Y. De Castro, V. Duval, R. Petit

3:00 pm **Theoretical and numerical off-the-grid curve reconstruction**
B. Laville, L. Blanc-Féraud, G. Aubert

VG3.103 **Session 2:** Tue Sep 5, 4:00 pm – 6:00 pm

4:00 pm **IFF: A Super-resolution Algorithm for Multiple Measurements**
Z. Fei, H. Zhang

4:30 pm **Vectorized Hankel Lift: A Convex Approach for Blind Super-Resolution of Point Sources**
K. Wei

5:00 pm **Super-resolved Lasso**
C. Poon

5:30 pm **Approximate inverse scattering via convex programming**
G. Alberti, R. Petit, M. Santacesaria

VG3.103 **Session 3:** Wed Sep 6, 9:00 am – 11:00 am

9:00 am **On Beurling-Selberg Approximations and the Stability of Super-Resolution**
M. Ferreira Da Costa

9:30 am **A Parameter Identification Algorithm for Gaussian Mixture Models**
X. Liu, H. Zhang

Super-localisation of a point-like emitter in a resonant environment : correction of the mirage effect 10:00 am
P. Millien

Optimal super-resolution of close point sources and stability of Prony's method 10:30 am
R. Katz, N. Diab, D. Batenkov

MS20: Recent advances in inverse problems for elliptic and hyperbolic equations

organized by R.-Y. Lai

Session 1: Thu Sep 7, 1:30 pm – 3:30 pm VG3.104

Determining a nonlinear hyperbolic system with unknown sources and nonlinearity 1:30 pm
Y.-H. Lin

Uniqueness in an inverse problem of fractional elasticity 2:00 pm
G. Covi

Calderon problem for elliptic systems via complex ray transform 2:30 pm
M. Cekic

Asymptotics Applied to Small Volume Inverse Shape Problems 3:00 pm
I. Harris

Session 2: Thu Sep 7, 4:00 pm – 5:00 pm VG3.104

Fixed angle inverse scattering for velocity 4:00 pm
R. Rakesh

Inverse Problems for Some Nonlinear Schrodinger Equations 4:30 pm
T. Zhou

MS21: Prior Information in Inverse Problems

organized by A. Horst, J. Lemvig

Session 1: Tue Sep 5, 1:30 pm – 3:30 pm VG2.103

Reconstructing spatio-temporal, sparse tomographic data using cylindrical shearlets 1:30 pm
T. A. Bubba

Fractal priors for imaging using random wavelet trees 2:00 pm
S. Siltanen

Sampling from a posterior with Besov prior 2:30 pm
A. Horst, B. M. Afkham, Y. Dong, J. Lemvig

Regularizing Inverse Problems through Translation Invariant Diagonal Frame Decompositions 3:00 pm
J. Frikel

Session 2: Tue Sep 5, 4:00 pm – 6:00 pm VG2.103

Regularized, pretrained and subspace-restricted Deep Image Prior for CT reconstruction 4:00 pm
R. Barbano, J. Antorán, J. Leuschner, B. Jin, J. M. Hernández-Lobato, Z. Kereta, D. O. Baguer, M. Schmidt, A. Denker, A. Hauptmann, P. Maaß

Monitoring of hemorrhagic stroke using Electrical Impedance Tomography 4:30 pm
V. Kolehmainen

5:00 pm **Edge-preserving inversion with α-stable priors**
J. Suuronen, T. Soto, N. Chada, L. Roininen

5:30 pm **Optimal learning of high-dimensional classification problems using deep neural networks**
F. Voigtlaender

MS22: Imaging with Non-Linear Measurements: Tomography and Reconstruction from Phaseless or Folded Data

organized by M. Beckmann, R. Beinert, M. Quellmalz

VG1.101 **Session 1:** Tue Sep 5, 1:30 pm – 3:30 pm

1:30 pm **Gradient Methods for Blind Ptychography**
O. Melnyk

2:00 pm **Inversion of the Modulo Radon Transform via Orthogonal Matching Pursuit**
M. Beckmann

2:30 pm **Phaseless sampling of the short-time Fourier transform**
L. Liehr

3:00 pm **Phase Retrieval in Optical Diffraction Tomography**
R. Beinert, M. Quellmalz

VG1.101 **Session 2:** Tue Sep 5, 4:00 pm – 6:00 pm

4:00 pm **Uniqueness theory for 3D phase retrieval and unwrapping**
A. Fannjiang

4:30 pm **Interaction Models in Ptychography**
B. Diederichs

5:00 pm **Tackling noise in multiple dimensions via hysteresis modulo sampling**
D. Florescu, A. Bhandari

5:30 pm **Multi-window STFT phase retrieval**
M. Rathmair

VG1.101 **Session 3:** Wed Sep 6, 9:00 am – 11:00 am

9:00 am **Phase retrieval from time-frequency structured data**
R. Alaifari

9:30 am **Computational Imaging from Structured Noise**
A. Bhandari

10:00 am **Phase retrieval framework for direct reconstruction of the projected refractive index applied to ptychography and holography**
J. Hagemann, F. Wittwer, C. G. Schroer

10:30 am **Zero-optics X-ray dark-field imaging using dual energies**
J. N. Ahlers, K. M. Pavlov, M. J. Kitchen, K. S. Morgan

MS23: Recent developments in reconstruction methods for inverse scattering and electrical impedance tomography

organized by R. Griesmaier, N. Hyvönen

VG1.103 **Session 1:** Tue Sep 5, 4:00 pm – 6:00 pm

Nonlinear impedance boundary conditions in inverse obstacle scattering 4:00 pm
L. Fink

Far field operator splitting and completion for inhomogeneous medium scattering 4:30 pm
L. Schätzle

Uniqueness, error bounds and global convergence for an inverse Robin transmission problem with a finite number of electrodes 5:00 pm
A. Brojatsch

Subspace surrogate methods for Electrical Impedance Tomography 5:30 pm
A. O. Autio, A. Hannukainen

Session 2: Wed Sep 6, 9:00 am – 11:00 am VG1.103

Inverse medium scattering for a nonlinear Helmholtz equation 9:00 am
R. Griesmaier

Linearised inverse conductivity problem: reconstruction and Lipschitz stability for infinite-dimensional spaces of perturbations 9:30 am
H. Garde, N. Hyvönen

Optimizing electrode positions in electrical impedance tomography for head imaging 10:00 am
R. R. Maity, N. Hyvönen, A. Hannukainen, A. Vavilov

Immersed boundary method for electrical impedance tomography in the frame of electrocardiography 10:30 am
J. Dardé, N. Nasr, L. Weynans

MS24: Learned Regularization for Solving Inverse Problems

organized by J. Hertrich, S. Neumayer

Session 1: Thu Sep 7, 1:30 pm – 3:30 pm VG1.101

The Power of Patches for Training Normalizing Flows 1:30 pm
F. Altekrüger, A. Denker, P. Hagemann, J. Hertrich, P. Maass, G. Steidl

Trust your source: quantifying source condition elements for variational regularisation methods 2:00 pm
M. Benning, T. Bubba, L. Ratti, D. Riccio

Plug-and-Play image reconstruction is a convergent regularization method 2:30 pm
A. Ebner, M. Haltmeier

Provably Convergent Plug-and-Play Quasi-Newton Methods 3:00 pm
H. Y. Tan, S. Mukherjee, J. Tang, C.-B. Schönlieb

Session 2: Thu Sep 7, 4:00 pm – 5:30 pm VG1.101

Learning Sparsifying Regularisers 4:00 pm
S. Neumayer

Shared Prior Learning of Energy-Based Models for Image Reconstruction 4:30 pm
T. Pinetz, E. Kobler, T. Pock, A. Effland

Gradient Step and Proximal denoisers for convergent plug-and-play image restoration. 5:00 pm
S. Hurault, A. Leclaire, N. Papadakis

MS25: Hyperparameter estimation in imaging inverse problems: recent advances on optimisation-based, learning and statistical approaches

organized by L. Calatroni, M. Pragliola

VG0.111 **Session 1:** Mon Sep 4, 1:30 pm – 3:30 pm

1:30 pm **Automatic Differentiation of Fixed-Point Algorithms for Structured Non-smooth Optimization**
P. Ochs

2:00 pm **Learning data-driven priors for image reconstruction: From bilevel optimisation to neural network-based unrolled schemes**
K. Papafitsoros, A. Kofler, F. Altekrüger, F. Antarou Ba, C. Kolbitsch, E. Papoutsellis, D. Schote, C. Sirotenko, F. Zimmermann

2:30 pm **Learned proximal operators in accelerated unfolded methods with pseudodifferential operators**
A. Sebastiani, T. A. Bubba, L. Ratti, S. Mukherjee

3:00 pm **Masked and Unmasked Principles for Automatic Parameter Selection in Variational Image Restoration for Poisson Noise Corruption**
F. Bevilacqua, A. Lanza, M. Pragliola, F. Sgallari

VG0.110 **Session 2:** Mon Sep 4, 4:00 pm – 6:00 pm

4:00 pm **Learning a sparsity-promoting regularizer for linear inverse problems**
L. Ratti, G. S. Alberti, E. De Vito, T. Helin, M. Lassas, M. Santacesaria

4:30 pm **Noise Estimation via Tractable Diffusion**
M. Zach, T. Pock, E. Kobler, A. Chambolle

5:00 pm **Speckle noise removal via learned variational models**
S. Cuomo, M. De Rosa, S. Izzo, M. Pragliola, F. Piccialli

5:30 pm **Bayesian sparse optimization for dictionary learning**
A. Bocchinfuso, D. Calvetti, E. Somersalo

MS26: Trends and open problems in cryo electron microscopy

organized by C. Esteve-Yague, J. Schwab

VG3.102 **Session 1:** Wed Sep 6, 9:00 am – 10:30 am

9:00 am **Joint Cryo-ET Alignment and Reconstruction with Neural Deformation Fields**
V. Debarnot, S. Gupta, K. Kothari, I. Dokmanić

9:30 am **Manifold-based Point Cloud Deformations: Theory and Applications to Protein Conformation Processing**
W. Diepeveen, C. Esteve-Yagüe, J. Lellmann, O. Öktem, C.-B. Schönlieb

10:00 am **Spectral decomposition of atomic structures in heterogeneous cryo-EM**
C. Esteve-Yague, W. Diepeveen, O. Oktem, C.-B. Schönlieb

VG3.102 **Session 2:** Thu Sep 7, 1:30 pm – 3:30 pm

1:30 pm **High Dimensional Covariance Estimation in Cryo-EM**
M. A. Gilles, A. Singer

Bayesian random tomography 2:00 pm
M. Habeck

Advancements and New Questions in Analysing the Geometry of Molecular Conformations in Cryo-EM 2:30 pm
R. R. Lederman

Optimal transport: a promising tool for cryo-electron microscopy 3:00 pm
A. Moscovich

Session 3: Thu Sep 7, 4:00 pm – 5:30 pm VG3.102

Stochastic optimization for high-resolution refinement in cryo-EM 4:00 pm
B. Toader, M. A. Brubaker, R. R. Lederman

Fast Principal Component Analysis for Cryo-EM Images 4:30 pm
N. Marshall, O. Mickelin, Y. Shi, A. Singer

Reconstructing Molecular Flexibility in Cryogenic Electron Microscopy 5:00 pm
J. Schwab, D. Kimanius, S. Scheres

MS28: Modelling and optimisation in non-Euclidean settings for inverse problems

organized by L. Calatroni, C. Estatico, D. Lorenz

Session 1: Tue Sep 5, 1:30 pm – 3:00 pm VG1.108

A lifted Bregman formulation for the inversion of deep neural networks 1:30 pm
X. Wang, M. Benning

A Bregman-Kaczmarz method for nonlinear systems of equations 2:00 pm
M. Winkler

Regularization in non-Euclidean spaces meets numerical linear algebra 2:30 pm
C. Estatico, B. Bonino, L. Calatroni, F. D. Benedetto, M. Lazzaretti, F. Lenti

Session 2: Tue Sep 5, 4:00 pm – 6:00 pm VG1.108

Gradient descent-based algorithms for inverse problems in variable exponent Lebesgue spaces 4:00 pm
M. Lazzaretti, Z. Kereta, L. Calatroni, C. Estatico

Multiscale hierarchical decomposition methods for images corrupted by multiplicative noise 4:30 pm
J. Barnett, W. Li, E. Resmerita, L. Vese

Proximal point algorithm in spaces with semidefinite inner product 5:00 pm
E. Naldi, E. Chenchene, D. A. Lorenz, J. Marquardt

Asymptotic linear convergence of fully-corrective generalized conditional gradient methods 5:30 pm
K. Bredies, M. Carioni, S. Fanzon, D. Walter

MS29: Eigenvalues in inverse scattering

organized by M. Halla, P. Monk

Session 1: Mon Sep 4, 1:30 pm – 3:00 pm VG3.104

Interior transmission eigenvalue trajectories 1:30 pm
A. Kleefeld, L. Pieronek

2:00 pm **A new family of modified interior transmission eigenvalues for a fluid-solid interaction**
P. Monk, V. Selgas

2:30 pm **Computation of transmission eigenvalues in singular configurations using a corner perfectly matched layer**
A.-S. Bonnet-Ben Dhia, L. Chesnel, F. Monteghetti

VG3.104 **Session 2:** Mon Sep 4, 4:00 pm – 6:00 pm

4:00 pm **A duality between scattering poles and transmission eigenvalues in scattering theory**
F. Cakoni, D. Colton, H. Haddar, D. Zilberberg

4:30 pm **Prolate eigensystem and its application in Born inverse scattering**
S. Meng

5:00 pm **Scattering from corners and other singularities**
E. L. K. Blåsten

5:30 pm **The inverse spectral problem for a spherically symmetric refractive index using modified transmission eigenvalues**
D. Gintides, N. Pallikarakis, K. Stratouras

VG3.104 **Session 3:** Tue Sep 5, 1:30 pm – 3:00 pm

1:30 pm **A new family of nearly singular interior transmission eigenvalues for inverse scattering**
M. Halla

2:00 pm **Interior transmission problems related to imaging periodic layers**
H. Haddar, N. Jenhani

2:30 pm **Transparent scatterers and transmission eigenvalues of infinite multiplicity**
R. Novikov, P. G. Grinevich

MS30: Inverse Problems on Graphs and Machine Learning

organized by E. L. K. Blåsten, M. Lassas, J. Lu

VG2.103 **Session 1:** Wed Sep 6, 9:00 am – 11:00 am

9:00 am **Continuum limit for lattice Hamiltonians**
H. Isozaki

9:30 am **Quantum computing algorithms for inverse problems on graphs**
J. Ilmavirta, M. Lassas, J. Lu, L. Oksanen, L. Ylinen

10:00 am **Inverse problems for the graph Laplacian**
E. Blåsten, H. Isozaki, M. Lassas, J. Lu

10:30 am **Inverse problems on manifolds via graph-based semi-supervised learning**
D. Sanz-Alonso, R. Yang

VG2.103 **Session 2:** Thu Sep 7, 1:30 pm – 3:30 pm

1:30 pm **Deep Invertible Approximation of Topologically Rich Maps between Manifolds**
M. Puthawala, M. Lassas, I. Dokmanic, P. Pankka, M. de Hoop

2:00 pm **Some inverse problems on graphs with internal functionals**
F. Guevara Vasquez, G. Yang

2:30 pm **Imaging water supply pipes using pressure waves**
E. L. K. Blåsten, F. Zouari, M. Louati, M. S. Ghidaoui

3:00 pm **Recontructing Interactions from Dynamics**
I. Dokmanic, L. Pan, C. Shi

Session 3: Thu Sep 7, 4:00 pm – 4:30 pm VG2.103

Learned Solvers for Forward and Backward Image Flow Schemes 4:00 pm
S. R. Arridge, A. S. Hauptmann, G. di Sciacca, W. Mehanda

MS31: Inverse Problems in Elastic Media

organized by A. Aspri, E. Sherina

Session 1: Fri Sep 8, 1:30 pm – 3:30 pm VG3.104

Hybrid Inverse Problems for Nonlinear Elasticity 1:30 pm
A. Waters, H. Carrillo-Lincopi

Quantitative reconstruction of viscoelastic media with attenuation model uncertainty. 2:00 pm
F. Faucher, O. Scherzer

An Intensity-based Inversion Method for Quasi-Static Optical Coherence Elastography 2:30 pm
E. Sherina, L. Krainz, S. Hubmer, W. Drexler, O. Scherzer

On the identification of cavities and inclusions in linear elasticity with a phase-field approach 3:00 pm
E. Beretta, A. Aspri, M. Verani, E. Rocca, C. Cavaterra

Session 2: Fri Sep 8, 4:00 pm – 5:00 pm VG3.104

An inverse problem for the porous medium equation 4:00 pm
C. I. Carstea, T. Ghosh, G. Nakamura

Comparison of variational formulations for the direct solution of an inverse problem in linear elasticity 4:30 pm
P. E. Barbone, O. Babaniyi

MS32: Parameter identification in time dependent partial differential equations

organized by B. Kaltenbacher, W. Rundell

Session 1: Wed Sep 6, 9:00 am – 11:00 am VG1.104

Spacetime finite element methods for inverse and control problems subject to the wave equation 9:00 am
L. Oksanen, S. Alexakis, A. Feizmohammadi

Mathematical challenges in Full Waveform inversion 9:30 am
L. Pieronek

Optimality of pulse energy for photoacoustic tomography 10:00 am
B. Kaltenbacher, P. T. Huynh

Bi-level iterative regularization for inverse problems in nonlinear PDEs 10:30 am
T. Nguyen

Session 2: Thu Sep 7, 1:30 pm – 3:00 pm VG1.104

On the identification of cavities in a nonlinear diffusion-reaction model arising from cardiac electrophysiology 1:30 pm
E. Beretta, A. Aspri, E. Francini, D. Pierotti, S. Vessella

Identification of the electric potential of the time-fractional Schrödinger équation by boundary measurement 2:00 pm
É. Soccorsi

The Recovery of Coefficients in Wave Equations from Time-trace Data 2:30 pm
B. Kaltenbacher, W. Rundell

MS33: Quantifying uncertainty for learned Bayesian models

organized by M. M. Betcke, M. Holler

VG1.105 **Session 1:** Wed Sep 6, 9:00 am – 11:00 am

9:00 am **Equivariant Neural Networks for Indirect Measurements**
N. Heilenkötter, M. Beckmann

9:30 am **Bayesian MRI reconstruction with joint uncertainty estimation using diffusion priors**
G. Luo, M. Blumenthal, M. Heide, M. Uecker

10:00 am **Utilizing variational autoencoders in the Bayesian inverse problem of photoacoustic tomography**
T. Sahlström, T. Tarvainen

10:30 am **Scalable Bayesian uncertainty quantification with learned convex regularisers**
T. I. Liaudat, M. Betcke, J. D. McEwen, M. Pereyra

VG1.105 **Session 2:** Thu Sep 7, 1:30 pm – 3:30 pm

1:30 pm **Calibration-Based Probabilistic Error Bounds for Inverse Problems in Imaging**
M. Zach, A. Habring, M. Holler, D. Narnhofer, T. Pock

2:00 pm **Posterior-Variance-Based Error Quantification for Inverse Problems in Imaging**
D. Narnhofer, A. Habring, M. Holler, T. Pock

2:30 pm **How to sample from a posterior like you sample from a prior**
B. Maboudi Afkham, M. Chung, J. Chung

3:00 pm **Uncertainty Quantification for Computed Tomography via the Linearised Deep Image Prior**
R. Barbano

MS34: Learned reconstructions for nonlinear inverse problems

organized by S. R. Arridge, A. S. Hauptmann

VG3.103 **Session 1:** Mon Sep 4, 1:30 pm – 3:30 pm

1:30 pm **Continuous generative models for nonlinear inverse problems**
M. Santacesaria, G. S. Alberti, J. Hertrich, S. Sciutto

2:00 pm **Data-driven quantitative photoacoustic imaging**
J. Grohl

2:30 pm **Mapping properties of neural networks and inverse problems**
M. Lassas, M. Puthawala, I. Dokmanić, M. de Hoop

3:00 pm **Data-driven regularization theory of invertible ResNets for solving inverse problems**
J. Nickel, C. Arndt, T. Kluth, S. Dittmer, A. Denker, M. Iske, N. Heilenkötter, P. Maass

VG3.103 **Session 2:** Mon Sep 4, 4:00 pm – 5:30 pm

4:00 pm **Learned iterative model-based approaches in quantitative photoacoustic tomography**
A. Manninen, A. Hauptmann, F. Lucka

4:30 pm **Autocorrelation analysis for cryo-EM with sparsifying priors**
O. Mickelin

5:00 pm **Model corrections in linear and nonlinear inverse problems**
A. Hauptmann, A. Arjas, M. Sillanpää

MS35: Edge-preserving uncertainty quantification for imaging

organized by A. M. A. Alghamdi, J. S. Jørgensen

Session: Mon Sep 4, 4:00 pm – 6:00 pm VG2.105

Efficient Bayesian computation for low-photon imaging problems 4:00 pm
S. Melidonis, P. Dobson, Y. Altmann, M. Pereyra, K. C. Zygalakis

Advancements of α-stable priors for Bayesian inverse problems 4:30 pm
N. Chada, L. Roininen, T. Soto, J. Suuronen

Edge preserving Random Tree Besov Priors 5:00 pm
H. Kekkonen, M. Lassas, E. Saksman, S. Siltanen

CUQIpy - Computational Uncertainty Quantification for Inverse problems in Python 5:30 pm
J. S. Jørgensen, A. Alghamdi, N. Riis

MS36: Advances in limited-data X-ray tomography

organized by J. S. Jørgensen, S. Siltanen

Session 1: Thu Sep 7, 1:30 pm – 3:30 pm VG3.101

Learned proximal operators meets unrolling: a deeply learned regularisation for limited angle tomography 1:30 pm
T. A. Bubba

A new variational appraoch for limited data reconstructions in x-ray tomography 2:00 pm
J. Frikel

Material Decomposition Techniques for Spectral Computed Tomography 2:30 pm
F. Bevilacqua, Y. Dong, J. S. Jørgensen, A. Lanza, M. Pragiola

Bayesian approach to limited-data CT reconstruction for inspection of subsea pipes 3:00 pm
J. S. Jørgensen

Session 2: Thu Sep 7, 4:00 pm – 6:00 pm VG3.101

Approaches to the Helsinki Tomography Challenge 2022 4:00 pm
C. Arndt, A. Denker, S. Dittmer, J. Leuschner, J. Nickel

Directional regularization with the Core Imaging Library for limited-angle CT in the Helsinki Tomography Challenge 2022 4:30 pm
E. Pasca, J. Jørgensen, E. Papoutsellis, L. Murgatroyd, G. Fardell

VAEs with structured image covariance as priors to inverse imaging problems 5:00 pm
M. Duff

Limited-Angle Tomography Reconstruction via Deep Learning on Synthetic Data 5:30 pm
T. Germer, J. Robine, S. Konietzny, S. Harmeling, T. Uelwer

MS37: Passive imaging in terrestrial and extra-terrestrial seismology

organized by F. Faucher, D. Fournier

Session 1: Thu Sep 7, 1:30 pm – 3:30 pm VG1.102

Source-free seismic imaging with reciprocity-gap misfit criterion. 1:30 pm
F. Faucher

2:00 pm **Improving our Understanding of Jupiter's and Saturn's Interior Structure**
B. Militzer

2:30 pm **Full-Waveform Inversion and Reverse-Time Migration in Earthquake and Exploration Seismology**
F. J. Simons, Q. Liu, Z. Zhang, Z. Liu, E. Bachmann, A. L. Burky, C. Cui, J. C. E. Irving, J. Tromp

3:00 pm **Passive seismic body waves imaging for the deep Earth.**
M. Campillo

VG1.102 **Session 2:** Thu Sep 7, 4:00 pm – 6:00 pm

4:00 pm **Reduced order model approach for active and passive imaging with waves**
L. Borcea, J. Garnier, A. Mamonov, J. Zimmerling

4:30 pm **Three-dimensional random wave coupling along a boundary with scaling representative of Mars' crust, and an associated inverse problem**
M. V. de Hoop, J. Garnier, K. Solna

5:00 pm **Frequency-Difference Backprojection of Earthquakes**
J. C. Neo, W. Fan, Y. Huang, D. R. Dowling

5:30 pm **Quantitative passive imaging in helioseismology**
B. Müller

MS38: Inverse eigenvalue problems in astrophysics

organized by C. Gehan, D. Fournier

VG2.105 **Session 1:** Tue Sep 5, 1:30 pm – 3:30 pm

1:30 pm **No planet is an island: what we can learn from how Saturn interacts with its surroundings**
J. W. Dewberry

2:00 pm **Inversion methods in asteroseismology**
D. R. Reese

2:30 pm **Internal structure of giant planets from gravity data**
F. Debras, G. Chabrier

3:00 pm **Accurate asteroseismic surface rotation rates for evolved red giants**
F. Ahlborn, E. P. Bellinger, S. Hekker, S. Basu, D. Mokrytska

VG2.105 **Session 2:** Tue Sep 5, 4:00 pm – 6:00 pm

4:00 pm **Mode identification in rapidly-rotating stars: paving the way to inverse methods**
G. M. Mirouh

4:30 pm **Progress in Asteroseismology: Where We Stand and Where We'll Go**
E. Bellinger

5:00 pm **Helioseismic inversions for active latitudes**
S. G. Kashyap, L. Gizon

5:30 pm **Probing solar turbulent viscosity with inertial modes**
J. Philidet, L. Gizon

MS39: Statistical inverse problems: regularization, learning and guarantees

organized by K. Knudsen, A. Abhishake

Session: Mon Sep 4, 1:30 pm – 3:30 pm VG2.105

On the Regularized Functional Regression 1:30 pm
S. Pereverzyev

Inverse learning in Hilbert scales 2:00 pm
A. Abhishake

Stability and Generalization for Stochastic Gradient Methods 2:30 pm
Y. Ying

Causality and Consistency in Bayesian Inference Paradigms 3:00 pm
K. Mosegaard

MS40: Dynamic Imaging

organized by P. Elbau

Session: Tue Sep 5, 1:30 pm – 3:30 pm VG2.107

Iterative and data-driven motion compensation in tomography 1:30 pm
B. Hahn, M. Feinler

Sparse optimization algorithms for dynamic imaging 2:00 pm
S. Fanzon, K. Bredies, M. Carioni, F. Romero, D. Walter

New approaches for reconstruction in dynamic nano-CT imaging 2:30 pm
A. Wald, B. Ehlers, A. Oberacker, B. Hahn-Rigaud, T. Salditt, J. Lucht

Artifact reduction for time dependent image reconstruction in magnetic particle imaging 3:00 pm
C. Brandt, S. Blanke

MS41: Geomathematics

organized by J. Ilmavirta

Session 1: Fri Sep 8, 1:30 pm – 3:30 pm VG3.101

Geodesic X-ray tomography on manifolds of low regularity 1:30 pm
A. K. Kykkänen

Invariance of the elastic wave equation in the context of Finsler geometry 2:00 pm
H. A. Schlüter

Geometrization of inverse problems in seismology 2:30 pm
J. Ilmavirta

Reconstruction of anisotropic stiffness tensors using algebraic geometry 3:00 pm
M. de Hoop, J. Ilmavirta, M. Lassas, A. Varilly-Alvarado

Session 2: Fri Sep 8, 4:00 pm – 5:30 pm VG3.101

Inverse scattering: Regularized Lanczos method for the Lippmann-Schwinger equation 4:00 pm
J. Baker, E. Cherkaev, V. Druskin, S. Moskow, M. Zaslavsky

4:30 pm **Travel Time Tomography in Transversely Isotropic Elasticity via Microlocal Analysis**
Y. Zou

5:00 pm **An inverse source problem for the elasto-gravitational equations**
L. Baldassari, M. V. de Hoop, E. Francini, S. Vessella

MS42: Inverse Problems with Anisotropy

organized by K. Knudsen

VG3.104 **Session:** Tue Sep 5, 4:00 pm – 6:00 pm

4:00 pm **A density property for tensor products of gradients of harmonic functions**
C. I. Carstea

4:30 pm **Reconstructing anisotropic conductivities on manifolds**
H. A. Schlüter

5:00 pm **Imaging anisotropic conductivities from current densities**
B. Jin

5:30 pm **Stability and reconstruction for anisotropic inverse problems.**
R. Gaburro

MS43: Inverse Problems in radiation protection and nuclear safety

organized by L. Kuger, S. Siltanen

VG1.108 **Session 1:** Mon Sep 4, 1:30 pm – 3:30 pm

1:30 pm **Passive Gamma Emission Tomography (PGET) of spent nuclear fuel**
R. Virta, T. A. Bubba, M. Moring, S. Siltanen, T. Honkamaa, P. Dendooven

2:00 pm **Bayesian modelling and inference for radiation source localisation**
C. Tarpau, M. Fang, Y. Altmann, A. Di Fulvio, M. Pereyra, K. Zygalakis

2:30 pm **Image reconstruction for Passive Gamma Emission Tomography of spent nuclear fuel**
P. Dendooven, R. Virta, T. A. Bubba, M. Moring, S. Siltanen, T. Honkamaa

3:00 pm **Exact inversion of an integral transform arising in passive detection of gamma-ray sources with a Compton camera**
F. Terzioglu

VG1.108 **Session 2:** Mon Sep 4, 4:00 pm – 5:30 pm

4:00 pm **Gamma spectrum analysis in nuclear decommissioning**
M. Bruch, L. Kuger, M. Burger

4:30 pm **Practical gamma ray imaging with monolithic scintillation detector Compton cameras**
L. Kuger, M. Burger

5:00 pm **Machine Learning Techniques applied to Compton Cameras**
S. Petrak, K. Hölzer

MS44: Modelling in Earth and planetary sciences by data inversion at various scales

organized by C. Gerhards, V. Michel, F. J. Simons

Session 1: Mon Sep 4, 1:30 pm – 3:30 pm VG2.104

Inverse magnetization problems in geoscience at various scales 1:30 pm
C. Gerhards

Slepian concentration problem for polynomials on the Ball 2:00 pm
X. Huang

Regularized matching pursuits with a learning add-on for geoscientific inverse problems 2:30 pm
N. Schneider

Non-unique Inversions in Earth Sciences - an Underestimated Pitfall? 3:00 pm
V. Michel

Session 2: Mon Sep 4, 4:00 pm – 6:00 pm VG2.104

Efficient Parameter Estimation of Sampled Random Fields 4:00 pm
F. J. Simons, A. P. Guillaumin, A. M. Sykulski, S. C. Olhede

Co-estimation of core and lithospheric signals in satellite magnetic data 4:30 pm
M. Otzen, C. Finlay

Transdimensional joint inversion of gravity and surface wave phase velocities 5:00 pm
W. Szwillus

The inverse problem of micromagnetic tomography in rock- and paleomagnetism 5:30 pm
K. Fabian

MS45: Optimal Transport meets Inverse Problems

organized by M. Carioni, J.-F. Pietschmann, M. Schlottbom

Session 1: Tue Sep 5, 4:00 pm – 6:00 pm VG0.111

Efficient adversarial regularization for inverse problems 4:00 pm
S. Mukherjee, M. Carioni, O. Öktem, C.-B. Schönlieb

Data Driven Gradient Flows 4:30 pm
J.-F. Pietschmann, M. Schlottbom

The quadratic Wasserstein metric for inverse data matching 5:00 pm
B. Engquist, K. Ren, Y. Yang

Quadratic regularization of optimal transport problems 5:30 pm
D. Lorenz, H. Mahler, P. Manns, C. Meyer

Session 2: Wed Sep 6, 9:00 am – 11:00 am VG0.111

Inverse problems in imaging and information fusion via structured multimarginal optimal transport 9:00 am
J. Karlsson, Y. Chen, F. Elvander, I. Haasler, A. Ringh

Wasserstein PDE G-CNN 9:30 am
O. Mula, D. Bon

An Optimal Transport-based approach to Total-Variation regularization for the Diffusion MRI problem 10:00 am
R. Assereto, K. Bredies, M. I. Menzel, E. Naldi, C. Verdun

A game-based approach to learn interaction rules for systems of rational agents 10:30 am
M. Bonafini, M. Fornasier, B. Schmitzer

MS46: Inverse problems for nonlinear equations

organized by L. Oksanen, T. K. Tyni

VG1.104 **Session 1:** Thu Sep 7, 4:00 pm – 6:00 pm

4:00 pm **Weakly nonlinear geometric optics and inverse problems for hyperbolic nonlinear PDEs**
P. Stefanov

4:30 pm **Identification of nonlinear effects in X-ray tomography**
Y. Wang

5:00 pm **Inverse problems for non-linear hyperbolic equations and many-to-one scattering relations**
M. Lassas

5:30 pm **Inverse problems for nonlinear elliptic PDE**
K. Krupchyk

VG1.104 **Session 2:** Fri Sep 8, 1:30 pm – 4:00 pm

1:30 pm **Inverse source problems for nonlinear equations**
Y.-H. Lin

2:00 pm **Inverse problem for the minimal surface equation and nonlinear CGO calculus in dimension 2**
T. Liimatainen

2:30 pm **Inverse scattering problems for semi-linear wave equations on manifolds**
T. Tyni, S. Alexakis, H. Isozaki, M. Lassas

3:00 pm **Determining a Lorentzian metric from the source-to-solution map for the relativistic Boltzmann equation**
T. Balehowsky, A. Kujanpaa, M. Lassas, T. Liimatainen

3:30 pm **Determining Lorentzian manifold from non-linear wave observation at a single point**
M. Nursultanov

MS47: Scattering and spectral imaging: inverse problems and algorithms

organized by E. T. Quinto, G. Rigaud

VG3.101 **Session 1:** Tue Sep 5, 1:30 pm – 3:30 pm

1:30 pm **Microlocal properties and injectivity for Ellipsoidal and hyperbolic Radon transforms**
J. Webber, S. Holman, E. T. Quinto

2:00 pm **Motion detection in diffraction tomography**
M. Quellmalz, P. Elbau, O. Scherzer, G. Steidl

2:30 pm **Deep learning to tackle model inexactness and motion in Compton Scattering Tomography**
G. Rigaud, D. Frank

3:00 pm **Diffusion based regularization for multi-energy CT with limited data**
B. Hahn-Rigaud, G. Rigaud, R. Schmähl

VG3.101 **Session 2:** Tue Sep 5, 4:00 pm – 6:00 pm

4:00 pm **V-line tensor tomography**
G. Ambartsoumian, M. J. Latifi, R. K. Mishra, I. Zamindar

Optimal parameter design for spectral CT 4:30 pm
F. Terzioglu, G. Bal, E. Sidky

Gamma ray imaging with bidirectional Compton cameras 5:00 pm
L. Kuger, M. Burger

A hybrid algorithm for material decomposition in multi-energy CT 5:30 pm
L. Neumann, M. Haltmeier, T. Prohaszka

Session 3: Wed Sep 6, 9:00 am – 10:00 am VG3.101

Analytic and Deep learning-based Inversions in Circular Compton Scattering Tomography 9:00 am
M. K. Nguyen, C. Tarpau, J. Cebeiro, I. Ayad

On a cylindrical scanning modality in three-dimensional Compton scatter tomography 9:30 am
J. Webber

MS48: Robustness and reliability of Deep Learning for noisy medical imaging

organized by A. Benfenati, E. Morotti

Session: Thu Sep 7, 4:00 pm – 6:00 pm VG2.104

The graphLa+ method: a dynamic regularization based on the graph Laplacian 4:00 pm
D. Bianchi

Investigating the human body by light: the challenge of problem inversion 4:30 pm
P. Causin, A. Benfenati

Investigating the Human Body by Light: Neural Networks for Data-Driven and Physics-Driven Approches 5:00 pm
A. Benfenati, P. Causin

Medical image reconstruction in realistic scenarios: what to do if the ground-truth is missing? 5:30 pm
D. Evangelista, E. Morotti, E. Loli Piccolomini

MS49: Applied parameter identification in physics

organized by T. Nguyen, A. Wald

Session 1: Tue Sep 5, 1:30 pm – 3:30 pm VG3.102

Photoacoustic imaging in acoustic attenuating media 1:30 pm
O. Scherzer, P. Elbau, C. Shi

Fully Stochastic Reconstruction Methods in Coupled Physics Imaging 2:00 pm
S. R. Arridge

Some coefficient identification problems from boundary data satisfying range invariance for Newton type methods 2:30 pm
B. Kaltenbacher

Traction force microscopy - a testbed for solving the inverse problem of elasticity 3:00 pm
U. Schwarz

Session 2: Tue Sep 5, 4:00 pm – 6:00 pm VG3.102

A phase-field approach to shape optimization of acoustic waves in dissipative media 4:00 pm
V. Nikolic

4:30 pm **Parameter identification in helioseismology**
D. Fournier

5:00 pm **Parameter identification in magnetization models for large ensembles of magnetic nanoparticles**
H. Albers, T. Kluth

5:30 pm **Lipschitz stable determination of polyhedral conductivity inclusions from local boundary measurements**
A. Aspri

MS50: Mathematics and Magnetic Resonance Imaging

organized by K. Bredies, C. Clason, M. Uecker

VG1.105 **Session 1:** Fri Sep 8, 1:30 pm – 3:30 pm

1:30 pm **Deep learning MR image reconstruction and task-based evaluation**
F. Knoll, J. Kim, M. Vornehm, V. Saksena, Z. Tan, B. Kainz

2:00 pm **Learning Fourier sampling schemes for MRI by density optimization**
A. Gossard, F. de Gournay, P. Weiss

2:30 pm **Acceleration strategies for Magnetic Resonance Spin Tomography in Time-Domain (MR-STAT) reconstructions**
H. Liu, O. van der Heide, M. Stefano, V. Edwin, F. Miha, C. A. T. van den Berg, A. Sbrizzi

3:00 pm **Learning Spatio-Temporal Regularization Parameter-Maps for Total Variation-Minimization Reconstruction in Dynamic Cardiac MRI**
A. Kofler, F. Altekrüger, F. A. Ba, C. Kolbitsch, E. Papoutsellis, D. Schote, C. Sirotenko, F. F. Zimmermann, K. Papafitsoros

VG1.105 **Session 2:** Fri Sep 8, 4:00 pm – 6:00 pm

4:00 pm **MRI Pulse Design via discrete-valued optimal control**
C. Clason

4:30 pm **Null Space Networks for undersampled Fourier data**
M. Haltmeier

5:00 pm **Deep Learning Approaches for Non-Linear Inverse Problems in MRI Reconstruction**
M. Blumenthal, G. Luo, M. Schilling, M. Uecker

5:30 pm **Mathematical Methods in Parallel MRI**
B. Kocurov

MS51: Analysis, numerical computation, and uncertainty quantification for stochastic PDE-based inverse problems

organized by M. Karamehmedovic, F. Triki

VG1.108 **Session 1:** Thu Sep 7, 1:30 pm – 3:30 pm

1:30 pm **Deep Learning Methods for Partial Differential Equations and Related Parameter Identification Problems**
D. Nganyu Tanyu, J. Ning, T. Freudenberg, N. Heilenkötter, A. Rademacher, U. Iben, P. Maass

2:00 pm **Fourier method for inverse source problem using correlation of passive measurements**
K. Linder-Steinlein, M. Karamehmedović, F. Triki

Feynman's inverse problem - an inverse problem for water waves 2:30 pm
A. Kirkeby, M. Karamehmedović

Inference in Stochastic Differential Equations using the Laplace Appromixation 3:00 pm
U. H. Thygesen

Session 2: Thu Sep 7, 4:00 pm – 6:00 pm VG1.108

Spectral properties of radiation for the Helmholtz equation with a random coefficient 4:00 pm
M. Karamehmedovic, K. Linder-Steinlein

Optimization under uncertainty for the Helmholtz equation with application to photonic nanojets configuration 4:30 pm
A. Alghamdi, P. Chen, M. Karamehmedovic

Posterior consistency for Bayesian inverse Problems with piecewise constant inclusions 5:00 pm
B. M. Afkham., K. Knudsen, A. Rasmussen, T. Tarvainen

On uncertainty quantification for nonlinear inverse problems 5:30 pm
K. Ren

MS52: Integral geometry, rigidity and geometric inverse problems

organized by F. S. Monard, P. Stefanov

Session 1: Mon Sep 4, 1:30 pm – 2:30 pm VG1.105

Inverse problem for Yang-Mills-Higgs fields 1:30 pm
L. Oksanen, X. Chen, M. Lassas, G. Paternain

The Lorentzian scattering rigidity problem and rigidity of stationary metrics 2:00 pm
P. Stefanov

Session 2: Mon Sep 4, 4:00 pm – 6:00 pm VG1.105

Resonant forms at zero for dissipative Anosov flows 4:00 pm
M. Cekic, G. Paternain

Ray transform problems arising from seismology 4:30 pm
J. Ilmavirta

X-ray mapping properties and degenerately elliptic operators 5:00 pm
Y. Zou, F. Monard, R. K. Mishra

The range of the non-Abelian X-ray transform 5:30 pm
J. Bohr

Session 3: Tue Sep 5, 1:30 pm – 2:30 pm VG1.105

Marked length spectrum rigidity for Anosov surfaces 1:30 pm
T. Lefeuvre

Weakly nonlinear geometric optics for the Westervelt equation 2:00 pm
N. Eptaminitakis

MS53: Uniqueness and stability in inverse problems for partial differential equations

organized by S. Foschiatti, E. Francini, E. Sincich

VG3.104 **Session:** Wed Sep 6, 9:00 am – 11:00 am

9:00 am **Stability for the inverse problem of the determination on an inclusion in a Schrödinger type equation using Cauchy data.**
S. Foschiatti

9:30 am **Refined instability estimates for two inverse problems**
J.-N. Wang

10:00 am **Stability estimates for the inverse fractional conductivity problem**
J. Railo

10:30 am **Uniqueness and stability for anisotropic inverse problems.**
R. Gaburro

MS54: The x-ray transform and its generalizations: Theory, methods, and applications

organized by S. K. Sahoo

VG1.101 **Session 1:** Mon Sep 4, 1:30 pm – 3:30 pm

1:30 pm **Unique continuation for the momentum ray transform**
J. Ilmavirta, P.-Z. Kow, S. K. Sahoo

2:00 pm **The linearized Calderon problem for polyharmonic operators**
S. K. Sahoo, M. Salo

2:30 pm **The star transform and its links to various areas of mathematics**
G. Ambartsoumian, M. J. Latifi

3:00 pm **Linearized Calderon problem for biharmonic operator with partial data**
D. Agrawal, R. S. Jaiswal, S. K. Sahoo

VG1.101 **Session 2:** Mon Sep 4, 4:00 pm – 6:00 pm

4:00 pm **Inversion of the momenta X-ray transform of symmetric tensor fields in the plane**
K. Sadiq

4:30 pm **Simultaneous recovery of attenuation and source density in SPECT and multibang regularisation**
S. Holman

5:00 pm **Inversion of a restricted transverse ray transform on symmetric m-tensor fields in $\mathbb{R}^3$**
R. K. Mishra, C. Thakkar

5:30 pm **Inverse problems, unique continuation and the fractional Laplacian**
J. Railo

VG1.105 **Session 3:** Tue Sep 5, 4:00 pm – 6:00 pm

4:00 pm **The Calderón problem for space-time fractional parabolic operators with variable coefficients**
A. Banerjee, S. Senapati

4:30 pm **Rich tomography reconstruction problems in applications.**
W. Lionheart

Localized artifacts in medical imaging 5:00 pm
R. Alaifari

Explicit inversion of momentum ray transform 5:30 pm
S. R. Jathar

MS55: Nonlinear Inverse Scattering and Related Topics

organized by Y. Yang

Session 1: Mon Sep 4, 1:30 pm – 3:30 pm VG3.101

An Inverse Problem for Nonlinear Time-dependent Schrodinger Equations with Partial Data 1:30 pm
T. Zhou

Supercomputing-based inverse modeling of high-resolution atmospheric contaminant source intensity distribution using remote sensing data 2:00 pm
M. Huang, Y. Heng, J. Chen, Y. Han, L. Hoffmann, S. Gross

Some progresses in Carleman estimates and their applications in inverse problems for stochastic partial differential equations 2:30 pm
F. Dou, W. Du, P. Lu

Inverse scattering problems with incomplete data 3:00 pm
X. Liu

Session 2: Mon Sep 4, 4:00 pm – 5:00 pm VG3.101

Imaging with two-photon absorption optics 4:00 pm
Y. Zhong

Hopf lemma for fractional diffusion equations and application to inverse problem 4:30 pm
D. Jiang, Z. Li

MS56: Inverse Problems of Transport Equations and Related Topics

organized by R.-Y. Lai, H. Zhou

Session 1: Mon Sep 4, 1:30 pm – 3:30 pm VG2.106

Multiscale Parameter Identification: mesoscopic kernel reconstruction from macroscopic data 1:30 pm
K. Hellmuth

A 1-Wasserstein framework for forward-peaked diffusive transport 2:00 pm
G. Bal, B. Palacios

Recovery of coefficients in nonlinear transport equations 2:30 pm
H. Zhou

Mapping properties and functional relations for the hyperbolic X-ray transform 3:00 pm
F. S. Monard, N. Eptaminitakis, Y. Zou

Session 2: Mon Sep 4, 4:00 pm – 5:30 pm VG2.106

Reconstruction of the doping profile in Vlasov-Poisson 4:00 pm
W. Sun, R.-y. Lai, Q. Li

Quantitative reconstructions in inverse transport problems 4:30 pm
K. Ren

Imaging with two-photon absorption optics 5:00 pm
Y. Zhong

MS57: Inverse Problems in Time-Domain Imaging at the Small Scales

organized by E. Bonnetier, X. Cao, M. Sini

VG3.102 **Session 1:** Mon Sep 4, 1:30 pm – 3:30 pm

1:30 pm **Inverse wave scattering in the time domain**
A. Mantile, A. Posilicano

2:00 pm **A new approach to an inverse source problem for the wave equation**
M. Sini, H. Wang

2:30 pm **Simultaneous Reconstruction Of Optical And Acoustical Properties In PA-Imaging Using Plasmonics.**
A. Ghandriche, M. Sini

3:00 pm **Time domain analysis of body resonant-modes for classical waves**
A. Mantile, A. Posilicano

VG3.102 **Session 2:** Mon Sep 4, 4:00 pm – 6:00 pm

4:00 pm **A mathematical theory of resolution limits for dynamic super-resolution in particle tracking problems**
P. Liu, H. Ammari

4:30 pm **Heat Generation Using Lorentzian Nanoparticles. The Full Maxwell System**
A. Mukherjee, M. Sini

5:00 pm **Lipschitz stability for some inverse problems for a hyperbolic PDE with space and time dependent coefficients**
V. P. Krishnan, S. Senapati, R. Rakesh

5:30 pm **Scattering of electromagnetic waves by small obstacles**
S. Tordeux

VG2.107 **Session 3:** Tue Sep 5, 4:00 pm – 5:30 pm

4:00 pm **The electromagnetic waves generated by a cluster of nanoparticles with high refractive indices and corresponding effective medium theory.**
X. Cao

4:30 pm **Galerkin Foldy-Lax asymptotic models for time-domain scattering by small particles**
M. Kachanovska

5:00 pm **Electromagnetic waves generated by a moving dielectric under the special relativity assumptions**
M. Kar

MS58: Shape Optimization and Inverse Problems

organized by L. Afraites, A. Laurain, J. F. T. Rabago

VG2.104 **Session 1:** Tue Sep 5, 1:30 pm – 3:00 pm

1:30 pm **Isogeometric Shape Optimization of Periodic Structures in Three Dimensions**
H. Harbrecht, M. Multerer, R. von Rickenbach

2:00 pm **Stokes Traction Method: A Numerical Approach to Volume Constrained Shape Optimization Problems**
J. S. H. Simon

Non-conventional shape optimization methods for solving shape inverse problems 2:30 pm
J. F. T. Rabago, L. Afraites, A. Hadri

Session 2: Tue Sep 5, 4:00 pm – 5:30 pm VG2.104

Minimization of blood damage induced by non-newtonian fluid flows in moving domains 4:00 pm
V. Calisti, S. Necasova

On the new coupled complex boundary method for shape inverse problem with the Robin homogeneous condition 4:30 pm
L. Afraites, J. Fergy T. Rabago

Shape optimization approach for sharp-interface reconstructions in time-domain full waveform inversion. 5:00 pm
A. Laurain

MS59: Advanced Reconstruction and Phase Retrieval in Nano X-ray Tomography

organized by T. Salditt, A. Wald

Session 1: Fri Sep 8, 1:30 pm – 3:30 pm VG2.103

Resolution of reconstruction from discrete Radon transform data 1:30 pm
A. Katsevich

Deep Learning for Reconstruction in Nano CT 2:00 pm
A. Oberacker, A. Wald, B. Hahn-Rigaud, T. Kluth, J. Leuschner, M. Schmidt, T. Schuster

Learned post-processing approaches for nano-CT reconstruction 2:30 pm
T. Lütjen, F. Schönfeld, A. Oberacker, M. Schmidt, J. Leuschner, T. Kluth, A. Wald

X-ray phase and dark-field retrieval from propagation-based images, via the Fokker-Planck Equation 3:00 pm
K. S. Morgan, T. Leatham, M. Beltran, J. Ahlers, S. Alloo, M. Kitchen, K. Pavlov, D. Paganin

Session 2: Fri Sep 8, 4:00 pm – 6:00 pm VG2.103

Multi-stage Deep Learning Artifact Reduction for Computed Tomography 4:00 pm
J. Shi, D. Pelt, J. Batenburg

Deep learning for phase retrieval from Fresnel diffraction patterns 4:30 pm
M. Langer, K. Mom, B. Sixou

Time resolved and multi-resolution tomographic reconstruction strategies in practice. 5:00 pm
R. Mokso, V. Nikitin

Tomographic Reconstruction in X-ray Near-field Diffractive Imaging: from Laboratory μCT to Synchrotron Nano-Imaging 5:30 pm
T. Salditt

Talks in alphabetical order

CT11
Fri Sep 8
2:00 pm
2:30 pm
VG1.108

Optimal design for aeroacoustics with correlation data

C. Aarset, T. Hohage

A key problem in aeroacoustics is the inverse problem of estimating an unknown random source from correlation data sampled from surrounding sensors. We study optimal design for this and related problems, that is, we identify the sensor placement minimising covariance of the solution to the inverse random source problem, while remaining sparse. To achieve this, we discuss the assumption of gaussianity and how to adapt this to our setting of correlation data, and demonstrate how this model can lead to sparse designs for aeroacoustic experiments.

CT14
Fri Sep 8
5:00 pm
5:30 pm
VG2.106

Approximation with neural networks in Sobolev setting

A. Abdeljawad

Solutions of the evolution equation generally lie in certain Bochner-Sobolev spaces, in which the solutions may have regularity and integrability properties for the time variable that can be different for the space variables. Therefore, in our paper, we developed a framework that shows that deep neural networks can approximate Sobolev-regular functions with respect to Bochner-Sobolev spaces. In this talk we will present the power of using the so-called Rectified Cubic Unit (ReCU) as an activation function in the networks. This activation function allows us to deduce approximation results of the neural networks. While avoiding issues caused by the non regularity of the most commonly used Rectified Linear Unit (ReLU) activation function. This is a joint work with Philipp Grohs.

References

[1] A. Abdeljawad, P. Grohs. Approximations with deep neural networks in Sobolev time-space. Analysis and Applications 20.03 (2022): 499-541.

MS03 2
Mon Sep 4
4:00 pm
4:30 pm
VG2.103

SGD for statistical inverse problems

A. Abhishake

We study a statistical inverse learning problem, where we observe the noisy image of a quantity through an operator at some random design points. We consider the SGD schemes to reconstruct the estimator of the quantity for the ill-posed inverse problem. We develop a theoretical analysis for the minimizer of the regularization scheme using the approach of reproducing kernel Hilbert spaces. We discuss the rates of convergence for the proposed scheme, uniformly over classes of admissible solutions, defined through appropriate source conditions.

MS39
Mon Sep 4
2:00 pm
2:30 pm
VG2.105

Inverse learning in Hilbert scales

A. Abhishake

We study the linear ill-posed inverse problem with noisy data in the statistical learning setting. Approximate reconstructions from random noisy data are sought with general regularization schemes in Hilbert scale. We discuss the rates of convergence for the regularized solution under the prior assumptions and a certain link condition. We express the error in terms of certain distance functions. For regression functions with smoothness given in terms of source conditions, the error bound can then be explicitly established.

Posterior consistency for Bayesian inverse Problems with piecewise constant inclusions

MS51 2
Thu Sep 7
5:00 pm
5:30 pm
VG1.108

B. M. Afkham., K. Knudsen, A. Rasmussen, T. Tarvainen

In Bayesian Inverse Problems the aim is to recover the posterior distribution for the quantity of interest. This distribution is given in terms of the prior distribution modeling a priori knowledge and the likelihood distribution modeling the noise. In many applications, one single estimator, e.g., the posterior mean, is desired and reported, however it is crucial for the fundamental understanding that this estimator is consistent, meaning that the estimator converges in probability to the ground truth when the noise level tends to zero.

In this talk we will explore the fundamental questions and see, how consistency indeed is possible in the case of PDE driven problems such as Photo-Acoustic Tomography with parametrized inclusions.

A high order PDE-constrained optimization for the image denoising problem

MS12 2
Mon Sep 4
4:30 pm
5:00 pm
VG2.102

L. Afraites, A. Hadri, A. Laghrib, M. Nachaoui

In the present work, we investigate the inverse problem of identifying simultaneously the denoised image and the weighting parameter that controls the balance between two diffusion operators for an evolutionary partial differential equation (PDE). The problem is formulated as a non-smooth PDE-constrained optimization model. This PDE is constructed by second- and fourth-order diffusive tensors that combines the benefits from the diffusion model of Perona-Malik in the homogeneous regions, the Weickert model near sharp edges and the fourth-order term in reducing staircasing. The existence and uniqueness of solutions for the proposed PDE-constrained optimization system are provided in a suitable Sobolev space. Also, an optimization problem for the determination of the weighting parameter is introduced based on the Primal-Dual algorithm. Finally, simulation results show that the obtained parameter usually coincides with the better choice related to the best restoration quality of the image.

On the new coupled complex boundary method for shape inverse problem with the Robin homogeneous condition

MS58 2
Tue Sep 5
4:30 pm
5:00 pm
VG2.104

L. Afraites, J. Fergy T. Rabago

We consider the problem of identifying an unknown portion Γ of the boundary with a Robin condition of a d-dimensional $(d = 2; 3)$ body Ω by a pair of Cauchy data $(f; g)$ on the accessible part Σ of the boundary of a harmonic function u. For a fixed constant impedance α, it is known [1] that a single measurement of $(f; g)$ on Σ can give rise to infinitely many different domains . Nevertheless, a well-known approach to numerically solve the problem and obtain fair detection of the unknown boundary is to apply shape optimization methods. First, the inverse problem is recast into three different shape optimization formulations and the shape derivative of the cost function associated with each formulations are obtained [3]. Second, in this investigation, a new application of the so-called coupled complex boundary method - first put forward by Cheng et al. [2] to deal with inverse source problems - is presented to resolve the problem. The over-specified problem is transformed to a complex boundary value problem with a complex Robin boundary condition coupling the Cauchy pair on the accessible exterior boundary. Then, the cost function constructed by the imaginary part of the solution in the whole domain is minimized in order to identify the interior unknown boundary. The shape derivative of the complex state as well as the shape gradient of the cost functional with respect to the domain are computed. In addition, the shape Hessian at the critical point is characterized to study the ill-posedness of the problem. Specifically, the Riesz operator corresponding to the quadratic shape Hessian is shown to be compact. Also, with the shape gradient information, we devise an iterative algorithm based on a Sobolev gradient to solve the minimization problem. The numerical realization of the scheme is carried out via finite element method and is tested to various concrete example of the problem, both in two and three spatial dimensions.

References

[1] F. Cakoni, R. Kress. Integral equations for inverse problems in corrosion detection from partial cauchy data, Inverse Prob. Imaging, 1:229-245, 2007.

[2] X. L. Cheng, R. F. Gong, W. Han, X. Zheng. A novel coupled complex boundary method for solving inverse source problems, Inverse Problems, 30, 055002, 2014.

[3] L. Afraites, J. F. T. Rabago. Shape optimization methods for detecting an unknown boundary with the Robin condition by a single measurement, Discrete Contin. Dyn. Syst. - S, 2022. [10.3934/dcdss.2022196]

MS54 1
Mon Sep 4
3:00 pm
3:30 pm
VG1.101

Linearized Calderon problem for biharmonic operator with partial data

D. Agrawal, R. S. Jaiswal, S. K. Sahoo

The product of solutions of the Laplace equation vanishing on an arbitrary closed subset of the boundary is dense in the space of integrable functions ([1]). In this talk, we will discuss a similar problem with the biharmonic operator replacing the Laplace operator. More precisely, we show that the integral identity

$$\int \left[a\Delta uv + \sum a_i^1 \partial_i uv + a^0 uv \right] \mathrm{d}x = 0$$

for all biharmonic functions vanishing on an proper closed subset of the boundary implies that (a, a^1, a^0) vanish identically. This work is a collaboration with R. S. Jaiswal and S. K. Sahoo.

References

[1] D. Ferreira, C. E. Kenig, J. Sjostrand, G. Uhlmann. On the linearized local Calderon problem. Math. Res. Lett. 16: 955-970, 2009.

MS38 1
Tue Sep 5
3:00 pm
3:30 pm
VG2.105

Accurate asteroseismic surface rotation rates for evolved red giants

F. Ahlborn, E. P. Bellinger, S. Hekker, S. Basu, D. Mokrytska

The understanding of the internal stellar rotation and its evolution are important ingredients for the construction of accurate stellar models. We use asteroseismology, the study of global stellar oscillations, to probe the interior rotation of stars, particularly that of red giants. Large systematic errors previously hindered the accurate determination of near-surface rotation rates in evolved red giants e.g. [1]. We have developed a method of effectively eliminating these systematic errors by introducing an extension to a currently used rotational inversion method for red-giant stars [2].

We demonstrate the ability of the new inversion technique to compute accurate envelope rotation rates of stars along the red giant branch (RGB). Furthermore, we show the resulting improvement of our new method compared to other seismic inversion methods. Subsequently, we aim at quantifying systematic uncertainties in asteroseismic rotational inversions occurring due to inaccurate stellar modelling (Ahlborn et al. in prep). More accurate surface rotation rates for evolved red giants will be an important probe to understand the loss of angular momentum in red-giant cores, and an important milestone to improve the theory of rotation in stellar models.

References

[1] F. Ahlborn, E. P. Bellinger, S. Hekker, S. Basu and G. C. Angelou. Asteroseismic sensitivity to internal rotation along the red-giant branch, Astronomy and Astrophysics, 639:A98, 2020. https://doi.org/10.1051/0004-6361/201936947

[2] F. Ahlborn, E. P. Bellinger, S. Hekker, S. Basu and D. Mokrytska. Improved asteroseismic inversions for red-giant surface rotation rates, Astronomy and Astrophysics, 668:A98, 2022. https://doi.org/10.1051/0004-6361/202142510

Zero-optics X-ray dark-field imaging using dual energies

MS22 3
Wed Sep 6
10:30 am
11:00 am
VG1.101

J. N. Ahlers, K. M. Pavlov, M. J. Kitchen, K. S. Morgan

Traditional X-ray imaging achieves contrast using the attenuation of photons, making differentiation of materials of a similar density difficult. Improvements in the coherence of X-ray sources opened the way for phase changes in a material to be measured in an intensity image. In addition, the scattered component of the X-ray beam has been probed in X-ray dark-field imaging. Novel dark-field imaging techniques show promise in the detection and assessment of samples with significant micro-scale porosity, such as human lungs. Advanced dark-field imaging techniques rely on measuring sample-induced deviations on a patterned and interferometrically probed beam, requiring a highly-stable set-up and multiple exposures. Propagation-based imaging (PBI) is an experimentally-simple phase-contrast imaging technique, which relies on the downstream interference of refracted and diffracted coherent X-rays to reconstruct sample phase. Recently, PBI has been extended to dark-field reconstruction by modelling the downstream intensity using an X-ray imaging version of the Fokker-Planck diffusion equation [1, 2]. Separating the effects of refraction and diffusion on the beam requires multiple measurements, which was first achieved by imaging the sample at multiple propagation distances [3]. A multi-energy beam creates another possibility; the recent proliferation of energy-discriminating photon-counting detectors has led to an increased interest in spectral methods of coherent X-ray imaging [4]. In this talk we present the first results of inverting and solving the Fokker-Planck equation using spectral information, under assumption of a single-material sample. A linearised model is used to reconstruct sample projected thickness and dark-field in simulated and measured images. Strong attenuation energy-dependence presents challenges in reconstruction when deviating from strict single-material samples. We discuss Fokker-Planck dark-field reconstruction, and present a hybrid approach to the inverse problem, based on treating the post-sample wavefront as pseudo-patterned intensity, which improves stability in multi-material samples. Exploiting spectral dependence to reconstruct phase and dark-field would allow for imaging without having to move any part of the set-up, and would enable single-exposure imaging when combining a polychromatic source with an energy-discriminating detector. This would avoid registration issues, reduce the required dose, and open the door for time-resolved propagation-based dark-field imaging and fast

CT.

References

[1] K. S. Morgan, D. M. Paganin. Applying the Fokker-Planck equation to grating-based x-ray phase and dark-field imaging, Scientific Reports 9(1): 17465, 2019.

[2] D. M. Paganin, K. S. Morgan. X-ray Fokker-Planck equation for paraxial imaging, Scientific Reports 9(1): 17537, 2019.

[3] T. A. Leatham, D. M. Paganin, K. S. Morgan. X-ray dark-field and phase retrieval without optics, via the Fokker-Planck equation, IEEE Transactions on Medical Imaging, 2023.

[4] F. Schaff, K. S. Morgan, J. A. Pollock, L. C. P. Croton, S. B. Hooper, & M. J. Kitchen. Material Decomposition Using Spectral Propagation-Based Phase-Contrast X-Ray Imaging, IEEE Transactions on Medical Imaging 39(12): 3891-3899, 2020.

MS54 3
Tue Sep 5
5:00 pm
5:30 pm
VG1.105

Localized artifacts in medical imaging

R. Alaifari

Medical imaging reconstruction is typically regularized with methods that lead to stability in an L^2 sense. However, we argue that the L^2 norm is not always a good metric with which to assess the quality of image reconstruction. For instance, two objects might be close in L^2, while one of them carries a localized, clearly visible artifact, not present in the other. While this issue has been raised for deep learning based algorithms, we show as an example, that the classical regularization method of compressed sensing for MRI is also not protected from such possible instabilities. This is joint work with Giovanni S. Alberti (University of Genoa) and Tandri Gauksson (ETH Zurich).

MS22 3
Wed Sep 6
9:00 am
9:30 am
VG1.101

Phase retrieval from time-frequency structured data

R. Alaifari

Certain imaging and audio processing applications require the reconstruction of an image or signal from its phaseless time-frequency or time-scale representation, such as the magnitude of its Gabor or wavelet transform.

Such problems are inherently unstable, however, we formulate a relaxed notion of solution, meaningful for audio processing applications, under which stability can be restored.

The question of uniqueness becomes particularly delicate in the sampled setting. There, we show the first result evidencing the fundamental non-uniqueness property of phase retrieval from Gabor transform measurements. By restricting to appropriate function classes, positive results on the uniqueness can be obtained.

Furthermore, we present our most recent result which establishes uniqueness of phase retrieval from sampled wavelet transform measurements, without restricting the function class, when 3 wavelets are employed.

CT08
Thu Sep 7
5:30 pm
6:00 pm
VG2.105

Fractional graph Laplacian for image reconstruction

S. Aleotti, A. Buccini, M. Donatelli

Image reconstruction problems, like image deblurring and computer tomography, are usually ill-posed and require regularization. A popular approach to regularization is to substitute the original problem with an optimization problem that minimizes the sum of two terms, an ℓ^2 term and an ℓ^q term with $0 < q \leqslant 1$. The first penalizes the distance between the measured data and the reconstructed one, the latter imposes sparsity on some features of the computed solution.

In this work, we propose to use the fractional Laplacian of a properly constructed graph in the ℓ^q term to compute extremely accurate reconstructions of the desired images. A simple model with a fully plug-and-play method is used to construct the graph and enhanced diffusion on the graph is achieved with the use of a fractional exponent in the Laplacian operator. Since this is a global operator, we propose to replace it with an approximation in an appropriate Krylov subspace. We show that the algorithm is a regularization method under some reasonable assumptions. Some selected numerical examples in image deblurring and computer tomography show the performances of our proposal.

References

[1] D. Bianchi, A. Buccini, M. Donatelli, E. Randazzo. Graph Laplacian for image deblurring. Electronic Transactions on Numerical Analysis, 55:169-186, 2021.

[2] A. Buccini, M. Donatelli. Graph Laplacian in $\ell^2 - \ell^q$ regularization for image reconstruction. Proceedings - 2021 21st International Conference on Computational Science and Its Applications, ICCSA 2021:29-38, 2021.

[3] S. Aleotti, A. Buccini, M. Donatelli. Fractional Graph Laplacian for image reconstruction.In progress, Applied Numerical Mathematics, 2023

Optimization under uncertainty for the Helmholtz equation with application to photonic nanojets configuration

MS51 2
Thu Sep 7
4:30 pm
5:00 pm
VG1.108

A. Alghamdi, P. Chen, M. Karamehmedovic

Photonic nanojets (PNJs) have promising applications as optical probes in super-resolution optical microscopy, Raman microscopy, as well as fluorescence microscopy. In this work, we consider optimal design of PNJs using a heterogeneous lens refractive index with a fixed lens geometry and uniform plane wave illumination. In particular, we consider the presence of manufacturing error of heterogeneous lens, and propose a computational framework of Optimization Under Uncertainty (OUU) for robust optimal design of PNJ. We formulate a risk-averse stochastic optimization problem with the objective to minimize both the mean and the variance of a target function, which is constrained by the Helmholtz equation that governs the 2D transverse electric (2D TE) electromagnetic field in a neighborhood of the lens. The design variable is taken as a spatially-varying field variable, where we use a finite element method for its discretization, impose a total variation penalty to promote its sparsity, and employ an adjoint-based BFGS method to solve the resulting high-dimensional optimization problem. We demonstrate that our proposed OUU computational framework can achieve more robust optimal design than a deterministic optimization scheme to significantly mitigate the impact of manufacturing uncertainty.

The Power of Patches for Training Normalizing Flows

MS24 1
Thu Sep 7
1:30 pm
2:00 pm
VG1.101

F. Altekrüger, A. Denker, P. Hagemann, J. Hertrich, P. Maass, G. Steidl

We introduce two kinds of data-driven patch priors learned from very few images: First, the Wasserstein patch prior penalizes the Wasserstein-2 distance between the patch distribution of the reconstruction and a possibly small reference image. Such a reference image is available for instance when working with materials' microstructures or textures. The second regularizer learns the patch distribution using a normalizing flow. Since already a small image contains a large number of patches, this enables us to train the regularizer based on very few training images. For both regularizers, we show that they induce indeed a probability distribution such that they can be used within a Bayesian setting. We demonstrate the performance of patch priors for MAP estimation and posterior sampling within Bayesian inverse problems. For both approaches, we observe numerically that only very few clean reference images are required to achieve high-quality results and to obtain stability with respect to small perturbations of the problem.

MS54 1
Mon Sep 4
2:30 pm
3:00 pm
VG1.101

The star transform and its links to various areas of mathematics

G. Ambartsoumian, M. J. Latifi

The divergent beam transform maps a function f in $\mathbb{R}^n$ to an n-dimensional family of its integrals along rays, emanating from a variable vertex location inside the support of f. The star transform is defined as a linear combination of divergent beam transforms with known coefficients. The talk presents some recent results about the properties of the star transform, its inversion, and a few interesting connections to different areas of mathematics.

MS47 2
Tue Sep 5
4:00 pm
4:30 pm
VG3.101

V-line tensor tomography

G. Ambartsoumian, M. J. Latifi, R. K. Mishra, I. Zamindar

The V-line transform (VLT) maps a function to its integrals along V-shaped trajectories with a vertex inside the support of the function. This transform and its various generalizations appear in mathematical models of several imaging techniques utilizing scattered particles. The talk presents recent results on inversion of generalized VLTs defined on vector fields and symmetric 2-tensor fields in the plane.

MS08 2
Fri Sep 8
5:00 pm
5:30 pm
VG2.102

Spectrum of the Neumann-Poincaré operator on thin domains

K. Ando, H. Kang, M. Yoshihisa

We consider the spectral structure of the Neumann-Poincaré operators defined on the boundaries of thin domains in two and three dimensions. In two dimensions, we consider rectangle-shaped domains. We prove that as the aspect ratio of the domains tends to ∞, or equivalently, as the domains get thinner, the spectra of the Neumann-Poincaré operators are densely distributed in $[-\frac{1}{2}, \frac{1}{2}]$. In three dimensions, we consider two different kinds of thin domains: thin oblate domains and thin cylinders. We show that in the first case the spectra are distributed densely in the interval $[-\frac{1}{2}, \frac{1}{2}]$ as as the domains get thinner. In the second case, as a partial result, we show that the spectra are distributed densely in the half interval $[-\frac{1}{2}, \frac{1}{2}]$ as the domains get thinner.

MS36 2
Thu Sep 7
4:00 pm
4:30 pm
VG3.101

Approaches to the Helsinki Tomography Challenge 2022

C. Arndt, A. Denker, S. Dittmer, J. Leuschner, J. Nickel

In 2022, the Finnish Inverse Problems Society organized the Helsinki Tomography Challenge (HTC) 2022 with the aim of reconstructing an image using only limited-angle measurements. As part of this challenge, we implemented two methods, namely an Edge Inpainting method and a Learned Primal-Dual (LPD) reconstruction. The Edge Inpainting method consists of several successive steps: A classical reconstruction using Perona-

Malik, extraction of visible edges, inpainting of invisible edges using a U-Net and a final segmentation using a U-Net. The Learned Primal-Dual approach adapts the classical LPD in two ways, namely replacing the adjoint with the generalized inverse (FBP) and using large U-Nets in the primal update. For the training of the networks we generated a synthetic dataset since only five samples were provided in the challenge. The results of the challenge showed that the Edge Inpainting Method was competitive for a viewing range up to 70 degrees. In contrast, the Learned Primal Dual approach performed well on all viewing ranges of the challenge and scored second best.

Fully Stochastic Reconstruction Methods in Coupled Physics Imaging

MS49 1
Tue Sep 5
2:00 pm
2:30 pm
VG3.102

S. R. Arridge

Coupled Physics Imaging methods combine image contrast from one physical process with observations using a secondary process; several modalities in acousto-optical imaging follow this concept wherein optical contrast is observed with acoustic measurements. For the inverse problem both an optical and acoustic model need to be inverted. Classical methods that involve a non-linear optimisation approach can be combined with advances in stochastic subsamplings strategies that are in part inspired by machine learning applications. In such approaches the forward problem is considered deterministic and the stochasticity involves splitting of an objective function into sub functions that approach the fully sampled problem in an expectation sense.

In this work we consider where the forward problem is also solved stochastically, by a Monte Carlo simulation of photon propagation. By adjusting the batch size in the forward and inverse problems together, we can achieve better performance than if subsampling is performed seperately.

Joint work with : S. Powell, C. Macdonald, N. Hänninen, A. Pulkkinen, T. Tarvainen

Learned Solvers for Forward and Backward Image Flow Schemes

MS30 3
Thu Sep 7
4:00 pm
4:30 pm
VG2.103

S. R. Arridge, A. S. Hauptmann, G. di Sciacca, W. Mehanda

It is increasingly recognised that there is a close relationship between some network architectures and iterative solvers for partial differential equations. In this talk we present a network architecture for forward and inverse problems in non-linear diffusion. By design the architecture is non-linear, learning an anisotropic diffusivity function for each layer from the output of the previous layer. The performed updates are explicit, by which we obtain better interpretability and generalisability compared to classical architectures. Since backward diffusion is unstable, a learned regularisation is implicitly learned to stabilise this process. We test results on synthetic image data sets that have undergone edge-preserving diffusion and on experimental data of images view through variable density scattering media.

Lipschitz stable determination of polyhedral conductivity inclusions from local boundary measurements

MS49 2
Tue Sep 5
5:30 pm
6:00 pm
VG3.102

A. Aspri

In this talk, we consider the problem of determining a polyhedral conductivity inclusion embedded in a homogeneous isotropic medium from boundary measurements. Specifically, we prove global Lipschitz stability for the polyhedral inclusion from the local Dirichlet-to-Neumann map.

MS45 2
Wed Sep 6
10:00 am
10:30 am
VG0.111

An Optimal Transport-based approach to Total-Variation regularization for the Diffusion MRI problem

R. Assereto, K. Bredies, M. I. Menzel, E. Naldi, C. Verdun

Diffusion Magnetic Resonance Imaging (dMRI) is a non-invasive imaging technique that draws structural information from the interaction between water molecules and biological tissues. Common ways of tackling the derived inverse problem include, among others, Diffusion Tensor Imaging (DTI), High Angular Resolution Diffusion Imaging (HARDI) and Diffusion Spectrum Imaging (DSI). However, these methods are structurally unable to recover the full diffusion distribution, only providing partial information about particle displacement. In our work, we introduce a Total-Variation (TV) regularization defined from an optimal transport perspective using 1-Wasserstein distances. Such a formulation produces a variational problem that can be handled by well-known algorithms enjoying good convergence properties, such as the primal-dual proximal method by Chambolle and Pock. It allows for the reconstruction of the complete diffusion spectrum from measured undersampled k/q space data.

MS06 3
Thu Sep 7
5:00 pm
5:30 pm
VG3.103

Generalized Sampling method

L. Audibert

The Generalized Sampling Method has been introduced to justify the so-called Linear Sampling Method of Colton and Kirsch (1996). It offers a framework that allow more flexibility than the Factorization Method of Kirsch which made it possible to extended a little the theoretical analysis of sampling methods. In this contribution we will point out the remaining difficulties of the Generalized Linear Sampling methods namely the form of the regularization term, the treatment of noisy measurements and some configuration of the sources and the receivers that break the symmetry of the near field operator. We will propose solution to address some of this challenges. Numerical illustrations will be provided on various type of measurements from Electrical Impedance Tomography, acoustics and elasticity scattering.

MS23 1
Tue Sep 5
5:30 pm
6:00 pm
VG1.103

Subspace surrogate methods for Electrical Impedance Tomography

A. O. Autio, A. Hannukainen

Iterative reconstruction methods for Electrical Impedance Tomography (EIT) often require solving the forward problem multiple times with different inner conductivity parameters using the Finite Element Method (FEM). The solution of the FEM problem requires solving a large sparse linear system of equations during each round of iteration. We present novel subspace methods for solving these linear systems using the same subspace for any conductivity parameter. We report that there seems to be structure in the problem that generally allows the size of these subspaces to stay small, enabling efficient computation.

Audio Inpainting

MS10 2
Thu Sep 7
5:00 pm
5:30 pm
VG1.103

P. Balazs, G. Tauböck, S. Rajbamshi, N. Holighaus

The goal of audio inpainting is to fill missing data, i.e., gaps, in an acoustical signal. Depending on the length of the gap this procedure should either recreate the original signal, or at least provide a perceptually pleasant and meaningful solution.

We give an overview of existing methods for different gap lengths, and discuss details of our own method [1] for gaps of medium duration. This approach is based on promoting sparsity in the time-frequency domain, combined with a convexifaction using ADMM with a dictionary learning technique that perturbs the time-frequency atoms around the gap, using an optimization technique originally developed in the context of channel estimation.

References

[1] G. Tauböck, S. Rajbamshi, P. Balazs. Dictionary learning for sparse audio inpainting, IEEE Journal of Selected Topics in Signal Processing 15 no. 1: 104-119, 2021.

Determining a Lorentzian metric from the source-to-solution map for the relativistic Boltzmann equation

MS46 2
Fri Sep 8
3:00 pm
3:30 pm
VG1.104

T. Balehowsky, A. Kujanpaa, M. Lassas, T. Liimatainen

In this talk, we consider the following inverse problem: Given the source-to-solution map for a relativistic Boltzmann equation on a neighbourhood V of an observer in a Lorentzian spacetime (M, g) and knowledge of $g|_V$, can we determine (up to diffeomorphism) the spacetime metric g on the domain of causal influence for the set V?

We will show that the answer is yes for certain cases. We will introduce the relativistic Boltzmann equation and the concept of an inverse problem. We then will highlight the key ideas of the proof of our main result. One such key point is that the nonlinear term in the relativistic Boltzmann equation which describes the behaviour of particle collisions captures information about a source-to-solution map for a related linearized problem. We use this relationship together with an analysis of the behaviour of particle collisions by classical microlocal techniques to determine the set of locations in V where we first receive light particle signals from collisions in the unknown domain. From this data we are able to parametrize the unknown region and determine the metric.

An Inexact Trust-Region Algorithm for Nonsmooth Nonconvex Optimization

MS12 2
Mon Sep 4
5:30 pm
6:00 pm
VG2.102

R. Baraldi, D. P. Kouri

In this talk, we develop a new trust-region method to minimize the sum of a smooth nonconvex function and a nonsmooth convex function. Our method is unique in that it permits and systematically controls the use of inexact objective function and derivative evaluations. We prove global convergence of our method in Hilbert space and analyze the worst-case complexity to reach a prescribed tolerance. Our method employs the proximal mapping of the nonsmooth objective function and is simple to implement. Moreover, when using a quadratic Taylor model, our algorithm represents a matrix-free proximal Newton-type method that permits indefinite Hessians. We additionally elaborate on potential trust-region sub-problem solvers and discuss local convergence guarantees. We demonstrate the efficacy of our algorithm on various examples from PDE-constrained optimization.

MS33 2
Thu Sep 7
3:00 pm
3:30 pm
VG1.105

Uncertainty Quantification for Computed Tomography via the Linearised Deep Image Prior

R. Barbano

Existing deep-learning based tomographic image reconstruction methods do not provide accurate estimates of reconstruction uncertainty, hindering their real-world deployment. In this talk we present a method, termed as the linearised deep image prior (DIP) that estimates the uncertainty associated with reconstructions produced by the DIP with total variation regularisation (TV). We discuss how to endow the DIP with conjugate Gaussian-linear model type error-bars computed from a local linearisation of the neural network around its optimised parameters. This approach provides pixel-wise uncertainty estimates and a marginal likelihood objective for hyperparameter optimisation. Throughout the talk we demonstrate the method on synthetic data and real-measured high-resolution 2D μCT data, and show that it provides superior calibration of uncertainty estimates relative to previous probabilistic formulations of the DIP.

MS31 2
Fri Sep 8
4:30 pm
5:00 pm
VG3.104

Comparison of variational formulations for the direct solution of an inverse problem in linear elasticity

P. E. Barbone, O. Babaniyi

Given one or more observations of a displacement field within a linear elastic, isotropic, incompressible object, we seek to identify the material property distribution within that object. This is a mildly ill-posed inverse problem in linear elasticity. While most common approaches to solving this inverse problem use forward iteration, several variational formulations have been proposed that allow its direct solution. We review five such direct variational formulations for this inverse problem: Least Squares, Adjoint Weighted Equation, Virtual Fields, Inverse Least Squares, Direct Error in Constitutive Eqn. [1, 2, 3, 4, 5]. We briefly review their derivations, their mathematical properties, and their compatibility with Galerkin discretization and numerical solution. We demonstrate these properties through numerical examples.

References

[1] P. B. Bochev, M. D. Gunzburger. Finite element methods of least-squares type, SIAM Review, 40(4): 789–837, 1998.

[2] P. E. Barbone, C. E. Rivas, I. Harari, U. Albocher, A. A. Oberai, Y. Zhang. Adjoint-weighted variational formulation for the direct solution of inverse problems of general linear elasticity with full interior data, International Journal for Numerical Methods in Engineering 81(13): 1713–1736, 2010.

[3] F. Pierron, M. Grédiac. The Virtual Fields Method: Extracting Constitutive Mechanical Parameters from Full-field Deformation Measurements, Springer Science & Business Media, 2012.

[4] G. Bal, C. Bellis, S. Imperiale, F. Monard. Reconstruction of constitutive parameters in isotropic linear elasticity from noisy full-field measurements, Inverse Problems 30(12): 125004, 2014.

[5] O. A. Babaniyi, A. A. Oberai, P. E. Barbone. Direct error in constitutive equation formulation for plane stress inverse elasticity problem, Computer Methods in Applied Mechanics and Engineering 314: 3–18, 2017.

MS14 2
Mon Sep 4
4:00 pm
4:30 pm
VG1.104

Boundary identification in cantilever beam equation related to the atomic force microscopy

O. Baysal, A. Hasanov, A. Kawano

In this work, identification of the shear force in the Atomic Force Microscopy cantilever tip-sample interaction is considered. This interaction is governed by the following dynamic Euler-Bernoulli beam equation.

$$\begin{cases} \rho_A(x)u_{tt} + \mu(x)u_t + (r(x)u_{xx} + \kappa(x)u_{xxt})_{xx} = 0,\ (x,t) \in \Omega_T, \\ u(x,0) = u_t(x,0) = 0,\ x \in (0,\ell), \\ u(0,t) = u_x(0,t) = 0,\ \ (r(x)u_{xx} + \kappa(x)u_{xxt})_{x=\ell} = M(t), \\ \qquad\qquad (-(r(x)u_{xx} + \kappa(x)u_{xxt})_x)_{x=\ell} = g(t),\ t \in [0,T], \end{cases}$$

where the momentum $M(t)$ is correlated with the transverse shear force $g(t)$ by a certain formula. For the identification of $g(t)$ the deflection on the right hand tip is used as an measured data to minimize the corresponding objective functional by an explicit gradient formula. As a next step, the conjugate gradient algorithm (CGA) is designed for the reconstruction process to have numerical solution of the considered inverse problem. This algorithm is based on the weak solution theory, adjoint problem approach and method of lines combined with Hermite finite elements. Computational results, obtained for noisy output data, are illustrated to show an efficiency and accuracy of the proposed approach, for typical classes of shear force functions with realistic problem parameters.

Inversion of the Modulo Radon Transform via Orthogonal Matching Pursuit

MS22 1
Tue Sep 5
2:00 pm
2:30 pm
VG1.101

M. Beckmann

In the recent years, the topic of high dynamic range (HDR) tomography has started to gather attention due to recent advances in the hardware technology. The issue is that registering high-intensity projections that exceed the dynamic range of the detector cause sensor saturation, which, in turn, leads to a loss of information. Inspired by the multi-exposure fusion strategy in computational photography, a common approach is to acquire multiple Radon Transform projections at different exposure levels that are algorithmically fused to facilitate HDR reconstructions.

As opposed to this, a single-shot alternative to the multi-exposure fusion approach has been proposed in our recent line of work which is based on the Modulo Radon Transform, a novel generalization of the conventional Radon transform. In this case, Radon Transform projections are folded via a modulo non-linearity, which allows HDR values to be mapped into the dynamic range of the sensor and, thus, avoids saturation or clipping. The folded measurements are then mapped back to their ambient range using reconstruction algorithms.

In this talk we introduce a novel Fourier domain recovery method, namely the OMP-FBP method, which is based on the Orthogonal Matching Pursuit (OMP) algorithm and Filtered Back Projection (FBP) formula. The proposed OMP-FBP method offers several advantages; it is agnostic to the modulo threshold or the number of folds, can handle much lower sampling rates than previous approaches and is empirically stable to noise and outliers. The effectivity of the OMP-FBP recovery method is illustrated by numerical experiments.

This talk is based on joint work with Ayush Bhandari (Imperial College London).

Phase Retrieval in Optical Diffraction Tomography

MS22 1
Tue Sep 5
3:00 pm
3:30 pm
VG1.101

R. Beinert, M. Quellmalz

Optical diffraction tomography (ODT) consists in the recovery of the three-dimensional scattering potential of a microscopic object rotating around its center from a series of illuminations with coherent light. Standard reconstruction algorithms such as the filtered backpropagation require knowledge of the complex-valued wave at the measurement plane. In common physical measurement setups, the collected data only consists in intensities; so only phaseless measurements are available. To overcome the loss of the required phases, we propose a new reconstruction approach for ODT based on three key ingredients. First, the light propagation is modeled using Born's approximation enabling us to use the Fourier diffraction theorem. Second, we stabilize the inversion of the non-uniform discrete Fourier transform via total variation regularization utilizing a primal-dual iteration, which also yields a novel numerical inversion formula for ODT with known phase. The third ingredient is a hybrid input-output scheme. We achieve convincing numerical results showing that the computed 2D and 3D reconstructions are even comparable to the ones obtained with known phase. This indicate that ODT with phaseless data is possible.

MS38 2
Tue Sep 5
4:30 pm
5:00 pm
VG2.105

Progress in Asteroseismology: Where We Stand and Where We'll Go

E. Bellinger

Over the past decade, asteroseismic inversion techniques have emerged as crucial tools to help identify the missing physics in our understanding of stellar evolution. In this talk, I will provide a comprehensive overview of the recent progress in asteroseismology and showcase the major advancements in the field, with a focus on novel methods for probing stellar structure and evolution. I will present new inferences into various different types of pulsating stars and improvements in our ability to infer internal stellar dynamics. I will also share our latest research on non-linear inversion methods and the application of inversions to massive stars. Finally, I will discuss the future of asteroseismology, including the expected yield of several forthcoming missions. This talk aims to highlight the remarkable progress in asteroseismology and stimulate discussions on future avenues for continued advancement.

MS48
Thu Sep 7
5:00 pm
5:30 pm
VG2.104

Investigating the Human Body by Light: Neural Networks for Data-Driven and Physics-Driven Approches

A. Benfenati, P. Causin

Diffuse Optical Tomography is a medical imaging technique for functional monitoring of body tissues. Unlike other CT technologies (i.e. X-ray CT), DOT employs a non-ionizing light signal and thus can be used for multiple screenings [1]. DOT reconstruction in CW modality leads to an inverse problem for the unknown distribution of the optical absorption coefficient inside the tissue, which has diagnostic relevance.

The classic approach consists in solving an optimization problem, involving a fit-to-data functional (usually, the Least Square functional) coupled with a regularization (e.g., l^1, Tikhonov, Elastic Net [2]). In this talk, we refer about our research in adopting a deep learning approach, which exploits both data-driven and hybrid-physics driven techniques. In the first case, we employ neural networks to construct a Learned Singular Value Decomposition [3], whilst in the second case the network architecture is built upon *a priori* knowledge on the physical phenomena. We will present numerical results obtained from synthetic datasets which show robustness even on noisy data.

References

[1] S. R. Arridge, J. C. Schotland. Optical tomography: forward and inverse problems, Inverse problems 25(12): 123010, 2009.

[2] A. Benfenati, P. Causin, M. G. Lupieri, G. Naldi. Regularization techniques for inverse problem in DOT applications, Journal of Physics: Conference Series (IOP Publishing) 1476(1): 012007, 2020.

[3] A. Benfenati, G. Bisazza, P. Causin. A Learned SVD approach for Inverse Problem Regularization in Diffuse Optical Tomography, 2021. [arXiv preprint arXiv:2111.13401]

Experimental progress towards time-resolved three-dimensional orbital tomography

MS15 2
Mon Sep 4
4:30 pm
5:00 pm
VG1.102

W. Bennecke, J. P. Bange, D. Schmitt, T. L. Dinh, D. Steil, S. Steil, D. R. Luke, M. Reutzel, G. S. M. Jansen, S. Mathias

Photoemission Orbital Tomography (POT) is a powerful tool for probing the full electronic structure of oriented molecular thin films which allows a direct comparison of angle-resolved photoemission spectroscopy (ARPES) data with density functional theory calculations. Moreover, the application of numerical phase retrieval algorithms in the POT framework has enabled a complete recovery of the initial molecular orbital independent of theoretical calculations [1, 2]. In combination with ultrafast pump-probe spectroscopy this approach promises to image excited state wavefunctions with Angstrom-level spatial and femtosecond temporal resolution.

However, most POT experiments to date have been restricted to a single probe photon energy, providing only a two-dimensional view of the initial wavefunction. This has limited the access to the full three-dimensional wavefunction to specialized, synchrotron-based facilities, where the implementation of femtosecond time-resolved experiments is challenging. At the same time, a time-resolved access to the third dimension is highly desirable, as it would enable the study of light-induced charge-transfer processes at hybrid molecular interfaces.

We overcome this limitation by implementing an EUV monochromator into the existing high harmonic generation beamline of our femtosecond photoemission setup with the ultimate goal of performing time-resolved three-dimensional orbital tomography. In this talk, I will report on our newly built-up setup and present our first energy-dependent photoemission data of molecules.

References

[1] P. Puschnig, S. Berkebile, A.J. Fleming, G. Koller, K. Emtsev, T. Seyller, J.D. Riley, C. Ambrosch-Draxl, F.P. Netzer, M.G. Ramsey. Reconstruction of Molecular Orbital Densities from Photoemission Data, Science 326: 702-706, 2009.

[2] G.S.M. Jansen, M. Keunecke, M. Düvel, C. Möller, D. Schmitt, W. Bennecke, F.J.S. Kappert, D. Steil, D.R. Luke, S. Steil, S. Mathia. Efficient orbital imaging based on ultrafast momentum microscopy and sparsity-driven phase retrieval, New J. Phys. 22, 2020.

A lifted Bregman formulation for the inversion of deep neural networks

MS28 1
Tue Sep 5
1:30 pm
2:00 pm
VG1.108

X. Wang, M. Benning

We propose a novel framework for the regularised inversion of deep neural networks. The framework is based on the authors' recent work on training feed-forward neural networks without the differentiation of activation functions. The framework lifts the parameter space into a higher dimensional space by introducing auxiliary variables and penalises these variables with tailored Bregman distances. We propose a family of variational regularisations based on these Bregman distances, present theoretical results and support their practical application with numerical examples. In particular, we present the first convergence result (to the best of our knowledge) for the regularised inversion of a single-layer perceptron that only assumes that the solution of the inverse problem is in the range of the regularisation operator.

MS24 1
Thu Sep 7
2:00 pm
2:30 pm
VG1.101

Trust your source: quantifying source condition elements for variational regularisation methods

M. Benning, T. Bubba, L. Ratti, D. Riccio

Source conditions are a key tool in variational regularisation to derive error estimates and convergence rates for ill-posed inverse problems. In this paper, we provide a recipe to practically compute source condition elements as the solution of convex minimisation problems that can be solved with first-order algorithms. We demonstrate the validity of our approach by testing it for two inverse problem case studies in machine learning and image processing: sparse coefficient estimation of a polynomial via LASSO regression and recovery of an image from a subset of the coefficients of its Fourier transform. We further demonstrate that the proposed approach can easily be modified to solve the learning task of identifying the optimal sampling pattern in the Fourier domain for given image and variational regularisation method, which has applications in the context of sparsity promoting reconstruction from magnetic resonance imaging data. We conclude by presenting a methodology with which data-driven regularisations with quantitative error estimates can be designed and trained.

MS05 3
Thu Sep 7
4:30 pm
5:00 pm
VG2.102

Predictive risk regularization for Gaussian and Poisson inverse problems

F. Benvenuto

In this talk, we present two methods for the choice of the regularization parameter in statistical inverse problems based on the predictive risk estimation, in the case of Gaussian and Poisson noise. In the first case, the criterion for choosing the regularization parameter in Tikhonov regularization is motivated by stability issue in the case of small sized samples and it minimizes a lower bound of the predictive risk. It is applicable when both data norm and noise variance are known, minimizing a function which depends on the signal-to-noise ratio, and also when they are unknown, using an iterative algorithm which alternates between a minimization step of finding the regularization parameter and an estimation step of estimating signal-to-noise ratio. In this second case, we introduce a novel estimator of the predictive risk with Poisson data, when the loss function is the Kullback-Leibler divergence, in order to define a regularization parameter's choice rule for the expectation maximization (EM) algorithm. We present a Poisson counterpart of the Stein's Lemma for Gaussian variables, and from this result we derive the proposed estimator which is asymptotically unbiased with increasing number of measured counts, when the EM algorithm for Poisson data is considered. In both cases we present some numerical tests with synthetic data.

On the identification of cavities in a nonlinear diffusion-reaction model arising from cardiac electrophysiology

MS32 2
Thu Sep 7
1:30 pm
2:00 pm
VG1.104

E. Beretta, A. Aspri, E. Francini, D. Pierotti, S. Vessella

Detecting ischemic regions from noninvasive (or minimally invasive) measurements is of primary importance to prevent lethal ventricular ischemic tachycardia. This is usually performed by recording the electrical activity of the heart, by means of either body surface or intracardiac measurements. Mathematical and numerical models of cardiac electrophysiology can be used to shed light on the potentialities of electrical measurements in detecting ischemia. More specifically, the goal is to combine boundary measurements of (body-surface or intracavitary) potentials and a mathematical description of the electrical activity of the heart in order to possibly identify the position, shape, and size of heart ischemias and/or infarctions. The ischemic region is a non-excitable tissue that can be modeled as an electrical insulator (cavity) and the cardiac electrical activity can be comprehensively described in terms of the monodomain model, consisting of a boundary value problem for the nonlinear reaction-diffusion monodomain system. In my talk, I will illustrate some recent results concerning the inverse problem of detecting the cavity from boundary measurements.

On the identification of cavities and inclusions in linear elasticity with a phase-field approach

MS31 1
Fri Sep 8
3:00 pm
3:30 pm
VG3.104

E. Beretta, A. Aspri, M. Verani, E. Rocca, C. Cavaterra

I analyze the geometric inverse problem of recovering cavities and inclusions embedded in a linear elastic isotropic medium from boundary displacement measurements. Starting from a constrained minimization problem involving a boundary quadratic misfit functional with a regularization term penalizing the perimeter of the cavity or inclusion we consider a family of relaxed functionals using a phase-field approach and derive a robust algorithm for the reconstruction of elastic inclusions and cavities modeled as inclusions with a very small elasticity tensor.

Material Decomposition Techniques for Spectral Computed Tomography

MS36 1
Thu Sep 7
2:30 pm
3:00 pm
VG3.101

F. Bevilacqua, Y. Dong, J. S. Jørgensen, A. Lanza, M. Pragiola

Spectral computed tomography is an evolving technique which exploits the property of materials to attenuate X-rays in different ways depending on the specific energy. Compared to conventional CT, spectral CT employs a photon-counting detector that records the energy of individual photons and produce a fine grid of discrete energy-dependent data. In this way it is easier to distinguish materials that have similar attenuation coefficients in an energy range, but different in others. The material decomposition process allows to not only reconstruct the object, but also to estimate the concentration of the materials that compose it.

Different strategies to reconstruct material-specific images have been developed in the last years, but many improvements have yet to be made especially for low-dose cases and few projections. This setup is justified by the slowness and flux limit of the high energy resolution photon counting detectors, but leads to noisier data, especially across the energy channels, and less spatial information. The study of the noise distribution, together with the usage of suitable regularizers and the selection of their parameters become crucial to obtain a good quality reconstruction and material decomposition. The talk will address all these issues by focusing on the case study of materials that have high atomic number with similar attenuation coefficients and K-edges in the considered energy range.

MS25 1
Mon Sep 4
3:00 pm
3:30 pm
VG0.111

Masked and Unmasked Principles for Automatic Parameter Selection in Variational Image Restoration for Poisson Noise Corruption

F. Bevilacqua, A. Lanza, M. Pragliola, F. Sgallari

Due to the statistical nature of electromagnetic waves, Poisson noise is a widespread cause of data degradation in many inverse imaging problems. It arises whenever the acquired data is formed by counting the number of photons irradiated by a source and hitting the image domain. Poisson noise removal is a crucial issue typical in astronomical and medical imaging, where the scenarios are characterized by a low photon count. For the former case, this is related to the acquisition set-up, while in the latter it is desirable to irradiate the patient with lower electromagnetic doses in order to keep it safer. However, the weaker the light intensity, the stronger the Poisson noise degradation in the acquired images and the more difficult the reconstruction problem.

An effective model-based approach for reconstructing images corrupted by Poisson noise is the use of variational methods. Despite the successful results, their performance strongly depends on the selection of the regularization parameter that balances the effect of the regularization term and the data fidelity term. One of the most used approaches for choosing the parameter is the discrepancy principle proposed in [1] that relies on imposing that the data term is equal to its approximate expected values. It works well for mid- and high-photon counting scenarios but leads to poor results for low-count Poisson noise. The talk will address novel parameter selection strategies that outperform the state-of-the-art discrepancy principles in [1], especially for low-count regime. The approaches are based on decreasing the approximation error in [1] by means of a suitable Montecarlo simulation [2], on applying a so-called Poisson whiteness principle [3] and on cleverly masking the data used for the parameter selection [4], respectively. Extensive experiments are presented which prove the effectiveness of the three novel methods.

References

[1] M. Bertero, P. Boccacci, G. Talenti, R. Zanella, L. Zanni. A discrepancy principle for Poisson data, Inverse Problems 26(10), 2010. [105004]

[2] F. Bevilacqua, A. Lanza, M. Pragliola, F. Sgallari. Nearly exact discrepancy principle for low-count Poisson image restoration, Journal of Imaging 8(1): 1-35, 2022.

[3] F. Bevilacqua, A. Lanza, M. Pragliola, F. Sgallari. Whiteness-based parameter selection for Poisson data in variational image processing, Applied Mathematical Modelling 117: 197-218, 2023.

[4] F. Bevilacqua, A. Lanza, M. Pragliola, F. Sgallari. Masked unbiased principles for parameter selection in variational image restoration under Poisson noise, Inverse Problems 39(3), 2023. [034002]

MS22 3
Wed Sep 6
9:30 am
10:00 am
VG1.101

Computational Imaging from Structured Noise

A. Bhandari

Almost all modern day imaging systems rely on digital capture of information. To this end, hardware and consumer technologies strive for high resolution quantization based acquisition. Antithetical to folk wisdom, we show that sampling quantization noise results in unconventional advantages in computational sensing and imaging. In particular, this leads to a novel, single-shot, high-dynamic-range imaging approach. Application areas include consumer and scientific imaging, computed tomography, sensor array imaging and time-resolved 3D imaging. In each case, we present a mathematically guaranteed recovery algorithm and also demonstrate a first hardware prototype for basic digital acquisition of quantization noise.

The graphLa+ method: a dynamic regularization based on the graph Laplacian

MS48
Thu Sep 7
4:00 pm
4:30 pm
VG2.104

D. Bianchi

We investigate a Tikhonov method that embeds a graph Laplacian operator in the penalty term (graphLa+). The novelty lies in building the graph Laplacian based on a first approximation of the solution derived by any other reconstruction method. Consequently, the penalty term becomes dynamic, depending on and adapting to the observed data and noise. We demonstrate that graphLa+ is a regularization method and we rigorously establish both its convergence and stability properties. Moreover, we present some selected numerical experiments in 2D computerized tomography, where we combine the graphLa+ method with several reconstructors: Filter Back Projection (graphLa+FBP), standard Tikhonov (graphLa+Tik), Total Variation (graphLa+TV) and a trained deep neural network (graphLa+Net). The quality increase of the approximated solutions granted by the graphLa+ approach is outstanding for each given method. In particular, graphLa+Net outperforms any other method, presenting a robust and stable implementation of deep neural networks for applications involving inverse problems.

Deep Learning Approaches for Non-Linear Inverse Problems in MRI Reconstruction

MS50 2
Fri Sep 8
5:00 pm
5:30 pm
VG1.105

M. Blumenthal, G. Luo, M. Schilling, M. Uecker

MRI is an important tool for clinical diagnosis. Although recognized for being non-invasive and producing images of high quality and excellent soft tissue contrast, its long acquisition times and high cost are problematic. Recently, deep learning techniques have been developed to help solve these issues by improving acquisition speed and image quality.

The multi-coil measurement process is modeled by a linear operator, the SENSE encoding model

$$\begin{aligned} A : \mathbb{C}^{N_x \times N_y} &\to \mathbb{C}^{N_S \times N_C} \\ x &\mapsto y = \mathcal{P}\mathcal{F}\mathcal{C}x. \end{aligned}$$

The discretized image x corresponds to the complex-valued transversal magnetization in the tissue. In the encoding process, it is first weighted with the coil-sensitivity maps of the N_C receive $\mathcal{C}$oils, then $\mathcal{F}$ourier transformed and finally projected to the N_S sample points of the acquired sampling $\mathcal{P}$attern. Unrolled model-based deep learning approaches are motivated by classical optimization algorithm of the linear inverse problem and integrate learned prior knowledge by learned regularization terms. Typical examples of end-2-end trained networks from the field of MRI are the Variational Network [1] or MoDL [2].

Despite MRI reconstruction often being treated linearly, there are many applications that require non-linear approaches. For instance, the estimation of coil-sensitivity maps can be challenging. An alternative to the use of calibration measurements or preestimation of the sensitivity maps from fully-sampled auto-calibration regions is to integrate the estimation into the reconstruction problem. This results in a non-linear - in fact, bilinear - forward model of the form

$$F : \mathbb{C}^{N_x \times N_y} \times \mathbb{C}^{N_x \times N_y \times N_c} \to \mathbb{C}^{N_S \times N_C}$$
$$x = \begin{pmatrix} x_{\text{img}} \\ x_{\text{col}} \end{pmatrix} \mapsto y = \mathcal{P}\mathcal{F}\left(x_{\text{img}} \odot x_{\text{col}}\right) .$$

A possible approach to solve the corresponding inverse problem is the iteratively regularized Gauss-Newton method (IRGNM) [3], which can in turn be combined with deep-learning based regularization [4] similarly to MoDL.

Another source of non-linearity in the reconstruction is the temporal evolution of transverse magnetization. The magnetization follows the Bloch equations, which are parametrized by tissue-specific relaxation parameters T_1 and T_2. In quantitative (q)MRI, parameter maps x_{par} are estimated instead of qualitative images x_{img} of transverse magnetization. In model-based qMRI, physical models that map the parameter maps x_{par} to the transverse magnetization are combined with encoding models to create non-linear forward models of the form [5]:

$$F : \mathbb{C}^{N_x \times N_y \times N_p} \times \mathbb{C}^{N_x \times N_y \times N_c} \to \mathbb{C}^{N_S \times N_C}$$
$$x = \begin{pmatrix} x_{\text{par}} \\ x_{\text{col}} \end{pmatrix} \mapsto y = \mathcal{P}\mathcal{F}\left(\mathcal{M}(x_{\text{par}}) \odot x_{\text{col}}\right)$$

An efficient way to solve a particular class of such non-linear inverse problems is the approximation of the non-linear signal model in linear subspaces, which in turn can be well combined with deep-learning based regularization [6]. This talk will cover deep-learning based approaches to solve the non-linear inverse problems defined above.

References

[1] K. Hammernik, T. Klatzer, E. Kobler, M. P. Recht, D. K. Sodickson, T. Pock, F. Knoll. Learning a variational network for reconstruction of accelerated MRI data, Magn. Reson. Med. 79: 3055-3071, 2018.

[2] H. K. Aggarwal, M. P. Mani, M. Jacob. MoDL: Model-Based Deep Learning Architecture for Inverse Problems, IEEE Trans. Med. Imaging. 38: 394-405, 2019.

[3] M. Uecker, T. Hohage, K. T. Block, J. Frahm. Image reconstruction by regularized nonlinear inversion–Joint estimation of coil sensitivities and image content, Magn. Reson. Med. 60: 674-682, 2018.

[4] M. Blumenthal, G. Luo, M. Schilling, M. Haltmeier, M. Uecker, NLINV-Net: Self-Supervised End-2-End Learning for Reconstructing Undersampled Radial Cardiac Real-Time Data, Proc. Intl. Soc. Mag. Reson. Med. 28: 0499, 2022

[5] X. Wang et al. Physics-based reconstruction methods for magnetic resonance imaging. Phil. Trans. R. Soc. A. 379: 20200196, 2021

[6] M. Blumenthal et al. Deep Subspace Learning for Improved T1 Mapping using Single-shot Inversion-Recovery Radial FLASH. Proc. Intl. Soc. Mag. Reson. Med. 28: 0241, 2022

MS30 2
Thu Sep 7
2:30 pm
3:00 pm
VG2.103

Imaging water supply pipes using pressure waves

E. L. K. Blåsten, F. Zouari, M. Louati, M. S. Ghidaoui

I will present a collaboration with applied mathematicians and civil engineers from the mathematical point of view. We worked on the problem of imaging water supply pipes for problem detection (is there a problem? where is the problem? how severe is the problem?). I will talk about the one-dimensional setting and also present a reconstruction algorithm for tree networks. The problem is modeled mathematically by a quantum tree graph with fluid pressure and flow, and the pipe's internal cross-sectional area as an unknown. The method is based on a simple time reversal boundary control method originally presented by Sondhi and Gopinath for one dimensional problems and later by Oksanen to higher dimensional manifolds.

Scattering from corners and other singularities

MS29 2
Mon Sep 4
5:00 pm
5:30 pm
VG3.104

E. L. K. Blåsten

I will present a summary of my and my collaborators' work on fixed wavenumber scattering from corners and other geometric shapes of interest from the past 10 years. Our early work showed that in potential scattering, corners produce patterns in the far-field which cannot be cancelled by any other structure nearby or far away. This led to interesting finds such as unique shape determination of polyhedral or pixelated scattering potentials by the far-field made by any single incident wave. It also led to the study of how geometry of the domain affects the distribution of energy of the transmission eigenfunctions. Complete understanding is still away, and different geometrical configurations are being studied. In this talk I present shortly past results and also newer results related to general conical singularities and scattering screens.

The range of the non-Abelian X-ray transform

MS52 2
Mon Sep 4
5:30 pm
6:00 pm
VG1.105

J. Bohr

We discuss a nonlinear analogue of the Pestov-Uhlmann range characterisation for geodesic X-ray transforms on simple surfaces. The transform under consideration takes as input matrix-valued and possibly direction dependent functions (which may encode magnetic fields or connections on a vector bundle) and outputs their 'scattering data' at the boundary. The range of this transform can be completely described in terms of boundary objects, and this description is reminiscent of the Ward correspondence for anti-self-dual Yang-Mills fields, but without solitonic degrees of freedom. The talk is based on joint work with Gabriel Paternain.

A Bernstein-von-Mises theorem for the Calderón problem with piecewise constant conductivities

MS04 1
Tue Sep 5
2:30 pm
3:00 pm
VG2.102

J. Bohr

The talk presents a finite dimensional statistical model for the Calderón problem with piecewise constant conductivities. In this setting one can consider a classical i.i.d noise model and the injectivity of the forward map and its linearisation suffice to prove the invertibility of the information operator. This results in a BvM-theorem and optimality guarantees for estimation in Bayesian posterior means.

Wasserstein PDE G-CNN

MS45 2
Wed Sep 6
9:30 am
10:00 am
VG0.111

O. Mula, D. Bon

PDE GCNNs are neural networks where each layer is seen as a set of PDE-solvers where geometrically meaningful PDE-coefficients become the layer's trainable weights. In this talk, we present a contribution on building new layers that are based either on Wasserstein gradient flows or on normalizing measures that take inspiration from optimal transport maps. The tunable parameters are either connected to parameters of the gradient flow, or the transport maps, so the whole procedure can be interpreted as an inverse problem.

MS45 2
Wed Sep 6
10:30 am
11:00 am
VG0.111

A game-based approach to learn interaction rules for systems of rational agents

M. Bonafini, M. Fornasier, B. Schmitzer

The modelling of the dynamic of a system of rational agents may take inspiration from various sources, depending on the particular application one has in mind. We can consider for example to model interactions via a Newtonian-like system, taking inspiration from physics, or via a game-based approach stemming from classical game theory or mean field games. In both cases, once we ensured the well-posedness of the proposed model, the model itself can be used as a tool to learn from real world observations, by means of learning (some) unknown components of it.

In [1], the authors study a class of spatially inhomogeneous evolutionary games to model the interactions between a finite number of agents: each agent evolves in space with a velocity which depends on a certain underlying mixed strategy, in turn evolving according to a replicator dynamic. In this talk we move from such a formulation, and introduce an entropic limiting version of it, which boils down to a purely spatial ODE. For a bounded set of pure strategies $U \subset \mathbb{R}^u$, $0 < \eta \in P(U)$ a probability measure on U, an "entropic" parameter $\varepsilon > 0$, and maps $e\colon \mathbb{R}^d \times U \to \mathbb{R}$ and $J\colon \mathbb{R}^d \times U \times \mathbb{R}^d \to \mathbb{R}$, the N-agents system we consider is the following:

$$\begin{aligned} \partial_t x_i(t) &= v_i^J(x_1(t), \ldots, x_N(t)) \quad \text{for } i = 1, \ldots, N \\ v_i^J(x_1, \ldots, x_N) &= \int_U e(x_i, u)\, \sigma_i^J(x_1, \ldots, x_N)(u)\; d\eta(u) \\ \sigma_i^J(x_1, \ldots, x_N) &= \frac{\exp\left(\frac{1}{\varepsilon N}\sum_{j=1}^N J(x_i, \cdot, x_j)\right)}{\int_U \exp\left(\frac{1}{\varepsilon N}\sum_{j=1}^N J(x_i, v, x_j)\right)\; d\eta(v)}. \end{aligned}$$

We study the well-posedness and the mean field limit of such a system, and use it as the backbone of a learning procedure. In particular, we focus on the learnability of the interaction kernel J, all the rest given. Building on ideas of [3, 4, 5], we infer J by penalizing the empirical mean squared error between observed velocities and predicted velocities, and also consider the choice of penalizing observed mixed strategies and predicted mixed strategies. We study the quality of the inferred kernel both as N increases (i.e., as we have observations of an increasingly high number of agents) and in the limit of repeated observations with fixed N (i.e., as we have repeated observations of the same number of agents). We show the effectiveness of the proposed inference on many different examples, from classical Newtonian systems to system modelling pedestrian dynamics.

References

[1] L. Ambrosio, M. Fornasier, M. Morandotti, G. Savaré. Spatially inhomogeneous evolutionary games, Communications on Pure and Applied Mathematics 74.7: 1353-1402, 2021.

[2] M. Bonafini, M. Fornasier, B. Schmitzer. Data-driven entropic spatially inhomogeneous evolutionary games, European Journal of Applied Mathematics 34.1: 106-159, 2023.

[3] M. Bongini, M. Fornasier, M. Hansen, M. Maggioni. Inferring interaction rules from observations of evolutive systems I: The variational approach, Mathematical Models and Methods in Applied Sciences 27.05: 909-951, 2016.

[4] F. Cucker, S. Smale. On the mathematical foundations of learning, Bulletin of the American mathematical society 39.1: 1-49, 2002.

[5] F. Lu, M. Maggioni, S. Tang. Learning interaction kernels in heterogeneous systems of agents from multiple trajectories, The Journal of Machine Learning Research 22.1: 1518-1584, 2021.

Analysis of topological derivative for qualitative defect imaging using elastic waves

MS06 2
Thu Sep 7
2:30 pm
3:00 pm
VG3.103

M. Bonnet

The concept of topological derivative has proved effective as a qualitative inversion tool for wave-based identification of finite-sized objects. This approach is often based on a heuristic interpretation of the topological derivative. Its mathematical justification has however also been studied, in particular in cases where the true obstacle is small enough for asymptotic approximations of wave scattering to be applicable, and also for finite-sized objects in the scalar wave framework. This work extends our previous efforts in the latter direction to the identification of elastic inhomogeneities embedded in elastic media interrogated by elastic waves. The data used for identification, assumed to be of near-field nature (i.e. no far-field approximation is introduced), is introduced through a misfit functional J. The imaging functional that reveals embedded inhomogeneities then consists of the topological derivative $\mathcal{T}_J$ of J (in particular, the actual minimization of J is not performed, making the procedure significantly faster than standard inversion based on PDE-constrained minimization). Our main contribution consists in an analysis of $\mathcal{T}_J$ using a suitable factorization of the near fields, achievable thanks to a convenient reformulation of the volume integral equation formulation of the forward elastodynamic scattering problem established earlier. Our results include justification of both the sign heuristics for $\mathbf{z} \mapsto \mathcal{T}_J(\mathbf{z})$ (which is expected to be most negative at points $\mathbf{z}$ inside, or close to, the support of the sought flaw) and the spatial decay of $\mathcal{T}_J(\mathbf{z})$ as $\mathbf{z}$ moves away from the flaw support. This result, subject to a limitation on the strength of the inhomogeneity to be identified, provides a theoretical conditional validation of the usual heuristic interpretation of $\mathcal{T}_J$ as an imaging functional. Our findings are demonstrated on 3D computational experiments.

Fast Optimistic Gradient Descent Ascent method in continuous and discrete time

MS10 1
Thu Sep 7
3:00 pm
3:30 pm
VG1.103

R. I. Bot, E. R. Csetnek, D.-K. Nguyen

In this talk we address continuous in time dynamics as well as numerical algorithms for the problem of approaching the set of zeros of a single-valued monotone and continuous operator V ([1,2]). The starting point of our investigations is a second order dynamical system that combines a vanishing damping term with the time derivative of V along the trajectory, which can be seen as an analogous of the Hessian-driven damping in case the operator is originating from a potential. Our method exhibits fast convergence rates for the norm of the operator along the trajectory and also for the restricted gap function, which is a measure of optimality for variational inequalities. We also prove the weak convergence of the trajectory to a zero of V.

Temporal discretizations of the dynamical system generate implicit and explicit numerical algorithms, which can be both seen as accelerated versions of the Optimistic Gradient Descent Ascent (OGDA) method for monotone operators, for which we prove that they share the asymptotic features of the continuous dynamics. All convergence rate statements are last iterate convergence results. Numerical experiments indicate the that explicit numerical algorithm outperform other methods designed to solve equations governed by monotone operators.

References

[1] R. I. Bot, E. R. Csetnek, D.-K. Nguyen. Fast OGDA in continuous and discrete time, arXiv:2203.10947, 2022.

[2] R. I. Bot, D.-K. Nguyen. Fast Krasnosel'skii-Mann algorithm with a convergence rate of the fixed point iteration of $o(1/k)$, arXiv:2206.09462, 2022

CT13
Fri Sep 8
4:30 pm
5:00 pm
VG2.105

Imaging of Gravity Dam-Foundation contact by a shape optimization method using non-destructive seismic waves

M. A. Boukraa, L. Audibert, M. Bonazzoli, H. Haddar, D. Vautrin

The knowledge of concrete-rock foundation interface is a key factor to evaluate the stability of gravity dams as well as understanding their mechanical behavior under water pressure. Being an inaccessible part of the structure, the exploration of this region is a complex procedure. Coring techniques can be used, but they only give limited information about a specific location and can be damaging in some situations. Hence the usefulness of non-destructive seismic waves.

We model several non-destructive seismic waves and we propose an inversion scheme for ob- taining the shape of the interface. Our approach consists in solving an inverse problem using "full-wave inversion" type techniques from wave measurements simulated by the finite element method. The inverse problem is modeled as an optimization for a least square cost functional with perimeter regularization associated with sparse data collected on the dam wall. We model different type of measurements such as elastic waves when the source is on the dam wall or acoustic waves when the source is in the water. Moreover, in order to numerically model the radiation conditions in the rock and in the water we employ PML techniques.

We present some validating results on realistic experiments. We demonstrate in particular how our proposed methodology is capable of accurately reconstructing the interface wile classical reverse time migration techniques fail. We then discuss sensitivity with respect to the position and the number of sensors, the wave number as well as to the propagation medium (for example shape of the dam) and the properties of the materials.

MS06 4
Fri Sep 8
2:00 pm
2:30 pm
VG3.103

Inverse scattering in a partially embedded waveguide

L. Bourgeois, J.-F. Fritsch, A. Recoquillay

This talk concerns the identification of defects in a closed waveguide which is partially embedded in a surrounding medium, from scattering measurements on the free part of the waveguide. We wish to model for example a NDT experiment on a steel cable embedded in concrete. There are two main issues: the back-scattering situation and the leakage of waves from the closed waveguide to the surrounding medium. We will first introduce Perfectly Matched Layers in the transverse direction in order to transform the structure into a junction of two closed-half waveguides, one of them being a complex stratified medium. Then, after discussing the well-posedness of the forward problem and its numerical resolution, we will show how we can solve the inverse problem with the help of a modal formulation of the Linear Sampling Method. Some 2D numerical experiments will be shown.

Source separation for Electron Paramagnetic Resonance Imaging

CT11
Fri Sep 8
2:30 pm
3:00 pm
VG1.108

M. Boussâa, R. Abergel, S. Durand, Y. Frapart

Electron Paramagnetic Resonance Imaging (EPRI) is a versatile imaging modality that enables the study of free radical molecules or atoms from materials *in-vitro* to *in-vivo* appplication in biomedical research. Clinical applications are currently under investigation. While recent advancements in EPRI techniques have made it possible to study a single free radical, or source, inside the imaging device [1], the reconstruction of multiple sources, or source separation, remains a challenging task. The state-of-the-art technique heavily relies on time-consuming acquisition and voxel-wise direct inverse methods, which are prone to artifacts and do not leverage the spatial consistency of the source images to reconstruct. To address this issue, we propose a variational formulation of the source separation problem with a Total Variation *a-priori*, which emphasizes the spatial consistency of the source. This approach drastically reduces the needed number of acquisitions without sacrificing the quality of the source separation. An EPRI experimental study has been conducted, and we will present some of the results obtained.

References

[1] S. Durand, Y.-M. Frapart, M. Kerebel. Electron paramagnetic resonance image reconstruction with total variation and curvelets regularization. Inverse Problems, 33(11):114002, 2017.

Artifact reduction for time dependent image reconstruction in magnetic particle imaging

MS40
Tue Sep 5
3:00 pm
3:30 pm
VG2.107

C. Brandt, S. Blanke

Magnetic particle imaging (MPI) is a preclinical imaging modality exploiting the nonlinear magnetization response of magnetic nanoparticles to applied dynamic magnetic fields. We focus on MPI using a field-free line for spatial encoding because under ideal assumptions such as static objects, ideal magnetic fields and sequential line rotation, the MPI data are obtained by Radon transformed particle distributions. In practice, field imperfections and moving objects occur such that we have to adapt the Radon transform and jointly reconstruct time dependent particle distributions and adapted Radon data by means of total variation regularization.

Asymptotic linear convergence of fully-corrective generalized conditional gradient methods

MS28 2
Tue Sep 5
5:30 pm
6:00 pm
VG1.108

K. Bredies, M. Carioni, S. Fanzon, D. Walter

We discuss a fully-corrective generalized conditional gradient (FC-GCG) method [1] for the minimization of Tikhonov functionals associated with a linear inverse problem, a convex discrepancy and a convex one-homogeneous regularizer over a Banach space. The algorithm alternates between updating a finite set of extremal points of the unit ball of the regularizer [2] and optimizing on the conical hull of these extremal points, where each iteration requires the solution of one linear problem and one finite-dimensional convex minimization problem. We show that the method converges sublinearly to a solution and that imposing additional assumptions on the associated dual variables accelerates the method to a linear rate of convergence. The proofs rely on lifting, via Choquet's theorem, the considered problem to a particular space of Radon measures well as the equivalence of the FC-CGC method to a primal-dual active point (PDAP) method for which linear convergence was recently established. Finally, we present applications scenarios where the stated assumptions for accelerated convergence can be satisfied [3].

References

[1] Kristian Bredies, Marcello Carioni, Silvio Fanzon and Daniel Walter. Asymptotic linear convergence of fully-corrective generalized conditional gradient methods, 2021. [ArXiv preprint 2110.06756]

[2] Kristian Bredies and Marcello Carioni. Sparsity of solutions for variational inverse problems with finite-dimensional data, Calculus of Variations and Partial Differential Equations 59(14), 2020.

[3] Kristian Bredies, Marcello Carioni, Silvio Fanzon and Francisco Romero. A generalized conditional gradient method for dynamic inverse problems with optimal transport regularization, Foundations of Computational Mathematics, 2022.

MS10 4
Fri Sep 8
4:30 pm
5:00 pm
VG1.103

Tensor-free algorithms for lifted quadratic and bilinear inverse problems

R. Beinert, K. Bredies

We present a class of novel algorithms that aim at solving bilinear and quadratic inverse problems. It bases on first-order proximal algorithms for minimizing a Tikhonov functional associated with the respective tensorial lifted problem with nuclear norm regularization [1]. It is well known, however, that a direct application of such algorithms involves computations in the tensor-product space, in particular, singular-value thresholding. Due to the prohibitively high dimension of the latter space, such algorithms are infeasible without appropriate modification. Thus, to overcome this limitation, we show that all computational steps can be adapted to perform on low-rank representations of the iterates, yielding feasible, memory and computationally efficient tensor-free algorithms [2]. We present and discuss the numerical performance of these methods for the two-dimensional Fourier phase retrieval problem. In particular, we show that the incorporation of smoothness constraints within the framework greatly improve image recovery results.

References

[1] R. Beinert, K. Bredies. Non-convex regularization of bilinear and quadratic inverse problems by tensorial lifting, Inverse Problems 35(1): 015002, 2019.

[2] R. Beinert, K. Bredies. Tensor-free proximal methods for lifted bilinear/quadratic inverse problems with applications to phase retrieval, Foundations of Computational Mathematics 21(5): 1181-1232, 2021.

MS23 1
Tue Sep 5
5:00 pm
5:30 pm
VG1.103

Uniqueness, error bounds and global convergence for an inverse Robin transmission problem with a finite number of electrodes

A. Brojatsch

Medical imaging and non-destructive testing holds the challenge of determining information of the interior of the body by taking measurements at its boundary. We consider an inverse coefficient problem that is motivated by impedance-based corrosion detection. The aim is to reconstruct an unknown transmission coefficient function in an elliptic PDE from finitely many measurements that correspond to voltage/current measurements on electrodes attached to the domain's outer boundary. We mathematically characterize how many electrodes are required to achieve a desired resolution, we derive stability and error estimates, and we discuss globally convergent numerical reconstruction methods by rewriting the problem as convex non-linear semidefinite optimization problem.

Gamma spectrum analysis in nuclear decommissioning

MS43 2
Mon Sep 4
4:00 pm
4:30 pm
VG1.108

M. Bruch, L. Kuger, M. Burger

In the radiological characterisation of nuclear power stations, gamma spectroscopy builds the basis for many further investigation methods. The measurements of scintillation detectors in, e.g. a Compton camera, can be used to identify a priori the present radioactive nuclides. We formulate this gamma spectrum analysis problem as a Bayesian inverse problem with Poisson-distributed data. Techniques from convex analysis are used to compute the resulting maximum likelihood estimator given by a list of present nuclides and their corresponding intensities. The approach is tested on coincidence data measured with a Compton camera in potential use cases.

Learned proximal operators meets unrolling: a deeply learned regularisation for limited angle tomography

MS36 1
Thu Sep 7
1:30 pm
2:00 pm
VG3.101

T. A. Bubba

In recent years, limited angle CT has become a challenging testing ground for several theoretical and numerical studies, where both variational regularisation and data-driven techniques have been investigated extensively. In this talk, I will present a hybrid reconstruction framework where the proximal operator of an accelerated unrolled scheme is learned to ensure suitable theoretical guarantees. The recipe relays on the interplay between sparse regularization theory, harmonic analysis, microlocal analysis and Plug and Play methods. The numerical results show that these approaches significantly surpasses both pure model- and more data-based reconstruction methods.

Reconstructing spatio-temporal, sparse tomographic data using cylindrical shearlets

MS21 1
Tue Sep 5
1:30 pm
2:00 pm
VG2.103

T. A. Bubba

In this talk, I will present a motion-aware variational approach, based on a new multiscale directional system of functions called cylindrical shearlets, to reconstruct moving objects from sparse dynamic data. Compared to conventional separable representations, cylindrical shearlets are very efficient in representing spatio-temporal data, since they are better suited to handle the geometry of these data. We test our approach on both simulated and measured data. Numerical results demonstrate the advantages of our novel approach with respect to conventional multiscale methods.

Limited memory restarted $\ell^p - \ell^q$ minimization methods using generalized Krylov subspaces

MS12 2
Mon Sep 4
4:00 pm
4:30 pm
VG2.102

A. Buccini, L. Reichel

Regularization of certain linear discrete ill-posed problems, as well as of certain regression problems, can be formulated as large-scale, possibly nonconvex, minimization problems, whose objective function is the sum of the p-th power of the ℓ^p-norm of a fidelity term and the q-th power of the ℓ^q-norm of a regularization term, with $0 < p, q \leqslant 2$. We describe new restarted iterative solution methods that require less computer storage and execution time than the methods described by [1]. The reduction in computer storage and execution time is achieved by periodic restarts of the method. Computed examples illustrate that restarting does not reduce the quality of the computed solutions.

References

[1] G.-X. Huang, A. Lanza, S. Morigi, L. Reichel and F. Sgallari. Majorization-minimization generalized Krylov subspace methods for $\ell_p - \ell_q$ optimization applied to image restoration, BIT Numerical Mathematics 57: 351-378, 2017.

CT13
Fri Sep 8
5:00 pm
5:30 pm
VG2.105

Structure inversions for sound speed differences in solar-like stars

L. Buchele, E. Bellinger, S. Basu, S. Hekker

Data from the Kepler Space telescope have allowed stellar astrophysicists to measure the frequencies of oscillation modes in many stars. These frequencies carry information about the internal structure of the stars, providing ways to test stellar theory. One method, called structure inversions, seeks to infer differences in internal sound speed between a star and its model using the differences in oscillation frequencies. While this method was used extensively to study the structure of the Sun, the number of other stars studied with structure inversions remains low. In the case of main-sequence stars without a convective core, sound speed inversion results are currently only available for two stars other than the Sun. I will present the results of structure inversions for about 10 solar-like stars and discuss what these results imply about our current understanding of stellar structure.

MS06 1
Wed Sep 6
9:00 am
9:30 am
VG0.110

Celebrating Colton and Kress Contributions

F. Cakoni, H. Haddar

The first edition of the book "Inverse Acoustic and Electromagnetic Scattering Theory" by D. Colton and R. Kress appeared in 1992. It was a comprehensive exposition of fundamental mathematical background as well as exciting developments happening at the time in inverse scattering theory, from uniqueness results to reconstruction algorithms. The book became a classic in the field. The fourth edition of this book was published in 2019, about 30 years later, in a much extended version. The added 200 pages represent a part of the myriad directions that the research in inverse scattering has taken. This includes development of novel non-iterative reconstruction approaches, such as factorization, generalized linear sampling and other direct imaging methods, the design and analysis of more advanced and efficient optimization algorithms, the investigation of special sets of frequencies, namely transmission eigenvalues, non-scattering wave numbers and scattering poles, and their applications in solving inverse scattering problems. We shall review some of the key moments, places and anecdotes that contributed to this achievement.

MS29 2
Mon Sep 4
4:00 pm
4:30 pm
VG3.104

A duality between scattering poles and transmission eigenvalues in scattering theory

F. Cakoni, D. Colton, H. Haddar, D. Zilberberg

Spectral properties of operators associated with scattering phenomena carry essential information about the scattering media. The theory of scattering resonances is a rich and beautiful part of scattering theory and, although the notion of resonances is intrinsically dynamical, an elegant mathematical formulation comes from considering them as the poles of the meromorphic extension of the scattering operator. The scattering poles exist and they are complex with negative imaginary part. They capture physical information by identifying the rate of oscillations with the real part of a pole and the rate of decay with its imaginary part. At a scattering pole, there is a non-zero scattered field in the absence of the incident field. On the flip side of this characterization of the scattering poles one could ask if there are frequencies for which there exists an incident field that doesn't scatterer by the scattering object. The answer to this question for scattering by inhomogeneous media leads to the introduction of transmission eigenvalues.

In this talk we discuss a conceptually unified approach for characterizing and determining scattering poles and transmission eigenvalues for the scattering problem for inhomogenous media. Our approach explores a duality stemming from interchanging the roles of incident and scattered fields in our analysis. Both sets are related to the kernel of the relative scattering operator mapping incident fields to scattered fields, corresponding to the exterior scattering problem for the transmission eigenvalues, and the interior scattering problem for scattering poles.

Minimization of blood damage induced by non-newtonian fluid flows in moving domains

MS58 2
Tue Sep 5
4:00 pm
4:30 pm
VG2.104

V. Calisti, S. Necasova

The use of blood pumps may be necessary for people with heart problems, but there are potential risks of complications associated with this type of device, in particular hemolysis (destruction of red blood cells). Many engineering works are interested in the parametric optimization of these pumps to minimize hemolysis. In order to generalize this approach in the present work, we study the shape continuity of a coupled system of PDE modeling blood flows and hemolysis evolution in moving domains, governed respectively by non-Newtonian Navier-Stokes and by transport equations.

First, the shape continuity of the blood fluid velocity u is shown. This development, which extends the one led in [1], is based on the recent progress made in [2]. Indeed, the non- Newtonian stress for blood flows can be described by the following rheological law:

$$S(Du) := (1 + |Du|)^{q-2} Du,$$

where $S(Du)$ is the stress tensor, the symmetric gradient is given by $Du := \frac{1}{2}(\nabla u + \nabla u^\top)$, and where $q < 2$. Such fluids are called shear thinning fluids. Yet in [2], an existence result is provided for the case $q > 6/5$ in moving domains, by means of the study of Generalized Bochner spaces and the Lipschitz truncation method. Thus, these techniques are extended to the present framework of a sequence of converging moving domains.

After calculating the blood flow solutions, the velocity and stress field of the fluid are used as the coefficients for the transport equation governing the evolution of the hemolysis rate h:

$$\partial_t h + u \cdot \nabla h = |S(Du)|^\gamma (1 - h),$$

where the right hand side plays the role of a source term with saturation, for some $\gamma > 1$. From this, the shape continuity of the hemolysis rate is also proved.

Finally, these results allow to show the existence of minimum for a class of shape optimization problems based on the minimization of the hemolysis rate, in the framework of moving domains. The lack of uniqueness for shear thinning fluids solutions prevents the study of shape sensitivity from being pursued, so that an extension of this work for the purpose of computing a shape gradient must somehow consider a regularization of the present model.

References

[1] J. Sokolowski, J. Stebel. Shape optimization for non-Newtonian fluids in time-dependent domains, Evol. Equ. Control Theory, 3(2):331-348, 2014.

[2] P. Nagele, M. Ruzicka. Generalized Newtonian fluids in moving domains, J. Differential Equations, 264(2):835-866, 2018.

MS37 1
Thu Sep 7
3:00 pm
3:30 pm
VG1.102

Passive seismic body waves imaging for the deep Earth.

M. Campillo

The ambient seismic noise has been widely used for surface wave tomography. We present examples of imaging of geological structures of interest at different depths and different scales: the region of the core-mantle boundary and an active fault in the crust. In both cases, we use continuous data from large arrays of sensors. We discuss the global spatial correlation properties of seismic ambient vibrations and their relations with body waves [1-2]. We show the signature of the heterogeneity of the lowermost mantle in contrast to the almost transparent upper core [3]. For the case of the fault systems, a major issue is the strong lateral variations of seismic velocity in the first kilometers that degrade the quality of the imaging. In this case an aberration correction is performed to the data of a dense array through the reflection matrix framework [4].

References

[1] P. Boué, P. Poli, M. Campillo, P. Roux. Reverberations, coda waves and ambient noise : correlations at the global scale and retrieval of the deep phases, Earth and Planetary Science Let. 391, 137-145, 2014.

[2] L. Li, P. Boué, M. Campillo. Observation and explanation of spurious seismic signals emerging in teleseismic noise correlations Solid Earth 11, 173-184, 2020.

[3] L. Retailleau, P. Boué, L. Li, M. Campillo. Ambient seismic noise imaging of the lowermost mantle beneath the North Atlantic Ocean Geophysical J. Int. 222 (2), 1339-1351, 2020.

[4] R. Touma, T. Blondel, A. Derode, M. Campillo, A. Aubry. A Distortion Matrix Framework for High-Resolution Passive Seismic 3D Imaging: Application to the San Jacinto Fault Zone, California Geophysical J. Int., 226, 780-794, 2021.

MS57 3
Tue Sep 5
4:00 pm
4:30 pm
VG2.107

The electromagnetic waves generated by a cluster of nanoparticles with high refractive indices and corresponding effective medium theory.

X. Cao

We estimate the electromagnetic fields generated by a cluster of dielectric nanoparticles which are small scaled but enjoy high contrast of their relative permittivity, embedded into a background made of a vacuum. Under certain ratio between their size and contrast, these nanoparticles generate resonances, called dielectric resonances. We first characterize the dominant field generated by a cluster of such dielectric-resonating nanoparticles. In this point-interaction approximation, the nanoparticles can be distributed to occupy volume-like domains or low dimensional hypersurfaces where periodicity is not required. Then we investigate the corresponding effective electromagnetic medium with periodic distribution under some mild assumptions. We show that even though the dielectric nanoparticles are merely generated by the contrasts of their permittivity (and not their permeability), the effective medium is a perturbation of the permeability and not the permittivity. Both of the cases for the effective permeability being positive and negative are studied.

An inverse problem for the porous medium equation

MS31 2
Fri Sep 8
4:00 pm
4:30 pm
VG3.104

C. I. Carstea, T. Ghosh, G. Nakamura

The porous medium equation is a degenerate parabolic type quasilinear equation that models, for example, the flow of a gas through a porous medium. In this talk I will present recent results on uniqueness in the inverse boundary value problem for this equation. These are the first such results to be obtained for a degenerate parabolic equation.

A density property for tensor products of gradients of harmonic functions

MS42
Tue Sep 5
4:00 pm
4:30 pm
VG3.104

C. I. Carstea

In this talk I will present a recent result showing that linear combinations of tensor products of k gradients of harmonic functions, with k at least three, are dense in $C(\overline{\Omega})$, for any bounded domain Ω in dimension 3 or higher. This kind of density result has applications to inverse problems for elliptic quasilinear equations/systems in divergence form, where the nonlinear part of the "conductivity" is anisotropic. The talk will be based on two papers written in collaboration with A. Feizmohammadi.

Investigating the human body by light: the challenge of problem inversion

MS48
Thu Sep 7
4:30 pm
5:00 pm
VG2.104

P. Causin, A. Benfenati

In the past decades, the use of Computerized Tomography (CT) has increased dramatically owing to its excellent diagnostic performance, easy accessibility, short scanning time, and cost-effectiveness. Enabling CT technologies with a reduced/null radiation dose while preserving/enhancing the diagnostic quality is a key challenge in modern medical imaging. Increased noise levels are, however, an expected downfall of all these new technologies.

In this series of two successive talks we will refer about our research focused on Diffuse Optical Tomography (DOT), a CT technology based on NIR light as investigating signal [1]. Strong light scattering in biological tissues makes the DOT reconstruction problem severely ill-conditioned, so that denoising is a crucial step. In the present talk, after a brief description of the DOT modality, first we will present our results in exploring variational approaches based on partial differential equation models endowed with different regularizers to compute a stable DOT-CT reconstruction [2,3]. Then, we will discuss our recent research on the use of DL-based generative models to produce more effective soft priors which, used in combination with standard forward problem solvers or DL-based forward problem solvers, allow to improve spatial resolution in high contrast zones and reduce noise in low-contrast zones, typical of medical imaging.

References

[1] S.R. Arridge. Optical tomography in medical imaging, Inverse problems 15(2): R41, 1999.

[2] P. Causin, M.G. Lupieri, G. Naldi, R.M. Weishaeupl. Mathematical and numerical challenges in optical screening of female breast, Int. J. Num. Meth. Biomed. Eng. 36(2): e3286, 2020.

[3] A. Benfenati, P. Causin, M.G. Lupieri, G. Naldi. Regularization techniques for inverse problem in DOT applications. In Journal of Physics: Conference Series (IOP Publishing) 1476(1): 012007, 2020.

MS20 1
Thu Sep 7
2:30 pm
3:00 pm
VG3.104

Calderon problem for elliptic systems via complex ray transform

M. Cekic

Let (M, g) be a Riemannian manifold embedded (up to a conformal factor) into the product $\mathbb{R}^2 \times (M_0, g_0)$, let A be a skew-Hermitian matrix of 1-forms and let Q be a matrix potential. In this talk, I will explain how to simultaneously recover the pair (A, Q), up to gauge-equivalence, from the associated Dirichlet-to-Neumann map of the Schroedinger operator $d_A^* d_A + Q := (d + A)^*(d + A) + Q$. Techniques involve constructing complex geometric optics (CGO) solutions and analysing a complex ray transform that arises. This improves on the previously known results.

MS52 2
Mon Sep 4
4:00 pm
4:30 pm
VG1.105

Resonant forms at zero for dissipative Anosov flows

M. Cekic, G. Paternain

The Ruelle Zeta Function of a chaotic (Anosov) flow is a meromorphic function in the complex plane defined as an infinite product over closed orbits. Its behaviour at zero is expected to carry interesting topological and dynamical information, and is encoded in certain resonant spaces of differential forms for the action of the Lie derivative on suitable spaces with anisotropic regularity. In this talk, I will introduce a new notion of helicity (average self-linking), and explain how this can be used to compute the resonant spaces for any Anosov flow in 3D, with particular emphasis in the dissipative (non volume-preserving) case. A prototype example is given by the geodesic flow of an affine connection with torsion and we shall see that for such a flow the order of vanishing drops by 1 in relation to the usual geodesic flow due to the Sinai-Ruelle-Bowen measure having non-zero winding cycle.

MS13 1
Fri Sep 8
3:00 pm
3:30 pm
VG0.111

Early stopping for spectral filter estimators regularized by projection

A. Celisse, S. Clementz

When using iterative algorithms such as gradient descent, a classical problem is the choice of the number of iterations to perform in practice. This is a crucial question since the number of iterations determines the final statistical performance of the resulting estimator.

The main purpose of the present talk is to design such data-criven stopping rules called "early stopping rules" (ESR) that will answer the above question not only for gradient descent but also for the broader class of spectral filter estimators among which ridge regression for instance.

Compared to previous works in this direction, the present contribution focuses on the computational issue raised by the use of spectral filter estimators in the context of a huge amount of data. In particular this requires the additional use of regularization by projection techniques for efficiently computing (approximations to) the spectral filter estimators.

In this talk we develop a theoretical analysis of the behavior of these projection-based spectral filter (PSF) estimators. Oracle inequalities also quantify the performance of the data-driven early stopping rule applied to these PSF estimators.

Advancements of α-stable priors for Bayesian inverse problems

MS35
Mon Sep 4
4:30 pm
5:00 pm
VG2.105

N. Chada, L. Roininen, T. Soto, J. Suuronen

In this talk, we will summarize the recent advacements made for non-Gaussian process priors for statistical inversion. This will be primarily focused on α-stable distributions which provide a natural generalization of a family of distributions, such as the normal and Cauchy. We discuss recently proposed priors which include various Cauchy priors, hierarchical and neural-network based α-stable priors. The focus will be computational where we demonstrate their gains on a range of examples for fully Bayesian and MAP-based estimation. We also provide some theoretical insights which include error bounds.

Coupled Parameter and Data Dimension Reduction for Bayesian Inference

MS11
Wed Sep 6
10:00 am
10:30 am
VG1.108

Q. Chen, E. Arnaud, R. Baptista, O. Zahm

We introduce a new method to reduce the dimension of the parameter and data space of high-dimensional Bayesian inverse problems. Commonly, different dimension reduction methods are applied separately to the two spaces. However, choosing a low-dimensional informed parameter subspace influences which data subspace is informative and vice versa. We thus propose a coupled method that, in addition, naturally reveals optimal experimental designs. Our method is based on the gradient of the forward operator of a Gaussian likelihood. It computes two projectors with an efficient and simple alternating singular value decomposition. Moreover, we control the approximation error through a certified L^2-error bound on the forward operator. We demonstrate the method on a large-scale Bayesian inverse problem in ocean modelling and use it to derive optimal sensor placements.

Inverse scattering: Regularized Lanczos method for the Lippmann-Schwinger equation

MS41 2
Fri Sep 8
4:00 pm
4:30 pm
VG3.101

J. Baker, E. Cherkaev, V. Druskin, S. Moskow, M. Zaslavsky

Inverse scattering techniques have broad applicability in geophysics, medical imaging, and remote sensing. This talk presents a robust direct reduced-order model method for solving inverse scattering problems. The approach is based on a Lippmann-Schwinger-Lanczos (LSL) algorithm in the frequency domain with two levels of regularization. Numerical experiments for Helmholtz and Schrödinger problems show that the proposed regularization scheme significantly improves the performance of the LSL algorithm, allowing for good reconstructions with noisy data.

Recovering an elastic inclusion using the shape derivative of the elastic moment tensors

MS08 2
Fri Sep 8
4:00 pm
4:30 pm
VG2.102

D. Cho, M. Lim

An elastic inclusion embedded in a homogeneous background induces a perturbation for a given far-field loading. This perturbation admits a multipole expansion with coefficients known by Elastic Moment Tensors (EMTs), which contain information on the material and geometric properties of the inclusion. Iterative optimization approaches to recover the shape of the inclusion involving the EMTs have been reported. In this talk, we focus on the shape derivative of the EMTs for planar inclusion. In particular, we derive asymptotic expressions for the shape deformation of inclusion from a disk, based on the complex formulation for the solution to the plane elastostatic problem.

MS08 1
Fri Sep 8
2:00 pm
2:30 pm
VG2.102

Construction of inclusions with vanishing generalized polarization tensors by imperfect interfaces

D. Choi, M. Lim

We address this question and provide a new construction scheme to find GPT-vanishing structures by imperfect interfaces. In particular, we construct GPT-vanishing structures of general shape with imperfect interfaces, where the inclusions have arbitrarily finite conductivity.

MS12 1
Mon Sep 4
3:00 pm
3:30 pm
VG2.102

A first-order optimization method with simultaneous adaptive pde constraint solver

B. Christian Skov Jensen, T. Valkonen

We consider a pde-constrained optimization problem and based on the nonlinear primal dual proximal splitting method, a nonconvex generalization of the well-known Chambolle-Pock algorithm, we develop a new iterative algorithmic approach to the problem by splitting the inner problem of solving the pde in each step over the outer iterations. In our work we split our pde-problem in a fashion similar to the classical Gauss-Seidel and Jacobi methods, though other iterative schemes may be fruitful too. We show through numerical experiments that significant speed ups can be attained compared to a naive full pde-solve in each step, and we prove convergence under sufficients second-order growth conditions.

MS11
Wed Sep 6
9:30 am
10:00 am
VG1.108

Goal-oriented Uncertainty Quantification for Inverse Problems via Variational Encoder-Decoder Networks

J. Chung, M. Chung, B. Afkham

In this work, we describe a new approach that uses variational encoder-decoder (VED) networks for efficient goal-oriented uncertainty quantification for inverse problems. Contrary to standard inverse problems, these approaches are goal-oriented in that the goal is to estimate some quantities of interest (QoI) that are functions of the solution of an inverse problem, rather than the solution itself. Moreover, we are interested in computing uncertainty metrics associated with the QoI, thus utilizing a Bayesian approach for inverse problems that incorporates the prediction operator and techniques for exploring the posterior. By harnessing recent advancements in the field of machine learning for large-scale inverse problems, in particular, by exploiting VED networks, we describe a data-driven approach for real-time goal-oriented uncertainty quantification for inverse problems.

MRI Pulse Design via discrete-valued optimal control

MS50 2
Fri Sep 8
4:00 pm
4:30 pm
VG1.105

C. Clason

Magnetic Resonance Imaging (MRI) is an active imaging methodology that uses radio frequency excitation and response of magnetic spin ensembles under a strong static external magnetic field to measure the distribution of hydrogen atoms in a sample. This distribution correlates with different tissues in a human body, allowing non-invasive medical imaging without ionizing radiation. The mathematical model for the behavior of magnetic spin ensembles under magnetic fields is the so-called Bloch equation, which is a bilinear differential equation. The problem of generating optimal excitation pulses for imaging purposes can thus be formulated and solved as an optimal control problem. We present the basic setup and methods, show practical examples, and discuss how to incorporate structural constraints on the optimal pulses.

Uniqueness in an inverse problem for the anisotropic fractional conductivity equation

MS18 1
Mon Sep 4
3:00 pm
3:30 pm
VG1.103

G. Covi

We study an inverse problem for the fractional anisotropic conductivity equation. Our nonlocal operator is based on the well-developed theory of nonlocal vector calculus, and differs substantially from other generalizations of the classical anisotropic conductivity operator obtained spectrally. We show that the anisotropic conductivity matrix can be recovered uniquely from fractional Dirichlet-to-Neumann data up to a natural gauge. Our analysis makes use of techniques recently developed for the study of the isotropic fractional elasticity equation, and generalizes them to the case of non-separable, anisotropic conductivities. The motivation for our study stems from its relation to the classical anisotropic Calderòn problem, which is one of the main open problems in the field.

Uniqueness in an inverse problem of fractional elasticity

MS20 1
Thu Sep 7
2:00 pm
2:30 pm
VG3.104

G. Covi

We study an inverse problem for fractional elasticity. In analogy to the classical problem of linear elasticity, we consider the unique recovery of the Lamé parameters associated to a linear, isotropic fractional elasticity operator from fractional Dirichlet-to-Neumann data. In our analysis we make use of a fractional matrix Schrödinger equation via a generalization of the so-called Liouville reduction, a technique classically used in the study of the scalar conductivity equation. We conclude that unique recovery is possible if the Lamé parameters agree and are constant in the exterior, and their Poisson ratios agree everywhere. Our study is motivated by the significant recent activity in the field of nonlocal elasticity.

This is a joint work with Prof. Maarte de Hoop and Prof. Mikko Salo.

Choosing observations to mitigate model error in Bayesian inverse problems

CT07
Thu Sep 7
5:30 pm
6:00 pm
VG1.105

N. Cvetkovic, H. C. Lie, H. Bansal, K. Veroy–Grepl

In inverse problems, one often assumes a model for how the data is generated from the underlying parameter of interest. In experimental design, the goal is to choose observations to reduce uncertainty in the parameter. When the true model is unknown or expensive, an approximate model is used that has nonzero 'model error' with respect to the true data-generating model. Model error can lead to biased parameter estimates. If the bias is large, uncertainty reduction around the estimate is undesirable. This raises the need for experimental design that takes model error into account. We present a framework for model error-aware experimental design in Bayesian inverse problems. Our framework is based on Lipschitz stability results for the posterior with respect to model perturbations. We use our framework to show how one can combine experimental design with models of the model error in order to improve the results of inference.

MS26 1
Wed Sep 6
9:00 am
9:30 am
VG3.102

Joint Cryo-ET Alignment and Reconstruction with Neural Deformation Fields

V. Debarnot, S. Gupta, K. Kothari, I. Dokmanić

We propose a framework to jointly determine the deformation parameters and reconstruct the unknown volume in electron cryotomography (CryoET). CryoET aims to reconstruct three-dimensional biological samples from two-dimensional projections. A major challenge is that we can only acquire projections for a limited range of tilts, and that each projection undergoes an unknown deformation during acquisition. Not accounting for these deformations results in poor reconstruction. The existing CryoET software packages attempt to align the projections, often in a workflow which uses manual feedback. Our proposed method sidesteps this inconvenience by automatically computing a set of undeformed projections while simultaneously reconstructing the unknown volume. We achieve this by learning a continuous representation of the undeformed measurements and deformation parameters. We show that our approach enables the recovery of high-frequency details that are destroyed without accounting for deformations.

MS38 1
Tue Sep 5
2:30 pm
3:00 pm
VG2.105

Internal structure of giant planets from gravity data

F. Debras, G. Chabrier

The Juno and Cassini spacecrafts have measured the gravity fields of Jupiter and Saturn with exquisite precision. The gravity field can then be projected onto the Legendre polynomials to obtain the gravitational moments, signatures of the density distribution in the planet as a function of radius and angle. In the past few years, a lot of effort has thus been dedicated to create precise methods to calculate gravitational moments from synthetic models and optimise the retrieval of internal structure by comparing with Juno and Cassini data.

In this talk, I will detail how we tackled this inverse problem in the case of Jupiter and Saturn. I will quickly introduce the concentric Maclaurin spheroid method used to calculate gravitational moments, before detailing the recovered internal structures. I will expose the dominant influence of winds on the gravity field and how planetary oscillations can constrain further the recovered density profiles. These results have strong implication for the formation and evolution of the giant planets and solar system in general.

Image reconstruction for Passive Gamma Emission Tomography of spent nuclear fuel

MS43 1
Mon Sep 4
2:30 pm
3:00 pm
VG1.108

P. Dendooven, **R. Virta, T. A. Bubba, M. Moring, S. Siltanen, T. Honkamaa**

A Passive Gamma Emission Tomography (PGET) device is part of the IAEA-approved tools for safeguards inspections of spent nuclear fuel assemblies. In Finland, PGET has been selected to be part of the nuclear safeguards procedures at the geological repository for spent nuclear fuel (SNF), ONKALO [1]. In recent years, we have developed the PGET method for this purpose. This contribution will focus on the data analysis and image reconstruction methods. It will show how the methods chosen are dictated and influenced by the requirements and the physics of the application, as well as the characteristics of the tomographic device that is being used. The characteristics and performance of the reconstruction algorithm will be illustrated with examples from PGET measurements at the SNF storage pools at the Finnish nuclear power plants. The design and operation of the PGET device and the most important results will be discussed in a separate contribution to this minisymposium.

A safeguards inspection aims to verify that all nuclear material is present as declared, to assure that none has been diverted for non-declared use, most specifically the development of nuclear weapons. Because of this requirement, a PGET measurement should not assume any prior information on the object under tomographic investigation. An SNF assembly consists essentially of rods of highly radioactive uranium dioxide, highly attenuating for gamma rays, immersed in non-radioactive water with much lower gamma ray attenuation. Good images thus require some form of attenuation correction. It is in practice very challenging to independently measure an attenuation map of SNF, e.g. by transmission tomography. Also, given the binary nature of the object (fuel rods and water), a good attenuation map needs knowledge of the geometry of the SNF. We have dealt with this conflict between the need of a good attenuation map and the requirement not to use prior information by developing an image reconstruction algorithm that reconstructs a gamma ray emission and attenuation image simultaneously, mathematically treating both in the same way.

The image reconstruction involves 2 steps. The first step is a filtered back-projection (FBP) which uses no prior information at all. Experimentally we observe that the quality of the FBP image is good enough to deduce the SNF assembly geometry. The second step, which produces the final image, is an iterative image reconstruction algorithm which uses the knowledge of the assembly geometry as a regularization term, thus favouring images that resemble the SNF assembly type identified from the FBP image in step 1. The reconstruction problem is formulated as a constrained minimization problem with a least squares data mismatch term (i.e. it implicitly assumes a Gaussian distribution for the noise) and several regularization terms. Next to the geometry regularization term, there are 2 terms related to corrections for the variation of the sensitivity amongst the detectors. Physics knowledge is used to establish upper and lower bounds on the image of attenuation coefficients. The attenuation image is constrained to values between the attenuation coefficient of the relevant gamma ray energy in water (lower bound) and uranium dioxide (upper bound). Most often, imaging is focused on the 662 keV gamma rays emitted by 137Cs, the dominant gamma ray emitter in SNF. The PGET image reconstruction method and its practical implementation will be discussed in some detail. Full details are given in [2-4].

Since 2017, over 100 different SNF assemblies have been measured at the Finnish nuclear power plants. Some representative examples from this vast data set will be used to highlight the performance of the image reconstruction method, especially in identifying missing fuel rods [3,5].

Points for improvement that have been identified over the past few years will be discussed. These are e.g. careful selection of the set of viewing angles, careful selection of the gamma ray energy windows and combining sinograms from different gamma ray energy windows. Improving imaging of the centre of spent fuel assemblies is a major development goal.

References

[1] www.posiva.fi

[2] P. Dendooven, T. A. Bubba. Gamma ray emission imaging in the medical and nuclear safeguards fields, Lecture Notes in Physics 1005: 245-295, 2022.

[3] R. Virta, R. Backholm, T. A. Bubba, T. Helin, M. Moring, S. Siltanen, P. Dendooven, T. Honkamaa. Fuel rod classification from Passive Gamma Emission Tomography (PGET) of spent nuclear fuel assemblies, ESARDA Bulletin 61: 10-21, 2020.

[4] R. Backholm, T. A. Bubba, C. Bélanger-Champagne, T. Helin, P. Dendooven, S. Siltanen. Simultaneous reconstruction of emission and attenuation in passive gamma emission tomography of spent nuclear fuel, Inv. Probl. Imag. 14: 317-337, 2020.

[5] R. Virta, T. A. Bubba, M. Moring, S. Siltanen, T. Honkamaa, P. Dendooven. Improved Passive Gamma Emission Tomography image quality in the central region of spent nuclear fuel, Scientific Reports 12: 12473, 2022.

MS02 1
Tue Sep 5
1:30 pm
2:00 pm
VG1.102

Deautoconvolution in the two-dimensional case

Y. Deng, B. Hofmann, F. Werner

There is extensive mathematical literature on the inverse problem of deautoconvolution for a function with support in the unit interval $[0,1] \subset \mathcal{R}$, but little is known about the multidimensional situation. We try to fill this gap with analytical and numerical studies on the reconstruction of a real function of two real variables over the unit square from observations of its autoconvolution on $[0,2]^2 \subset \mathcal{R}^2$ (full data case) or on $[0,1]^2$ (limited data case). In an L^2-setting, twofoldness and uniqueness assertions are presented for the deautoconvolution problem in 2D. Moreover, its ill-posedness is characterized and illustrated. Extensive numerical case studies give an overview of the behaviour of stable approximate solutions to the two-dimensional deautoconvolution problem obtained by Tikhonov-type regularization with different penalties and the iteratively regularized Gauss-Newton method.

MS38 1
Tue Sep 5
1:30 pm
2:00 pm
VG2.105

No planet is an island: what we can learn from how Saturn interacts with its surroundings

J. W. Dewberry

Direct observations provide limited information about the deep internal structures and basic properties of gaseous planets, even in our own Solar system. However, more can be learned from how planets interact with their surroundings. I will introduce research focused on interpreting the satellite Cassini's observations of Saturn's gravitational interactions with its rings and satellite moons. Observing these interactions yields information about Saturn's internal oscillation modes and tidally excited waves, the successful inversion of which may provide our best hope for constraining the planet's deep internal structure and rotation state.

Optimal super-resolution of close point sources and stability of Prony's method

MS19 3
Wed Sep 6
10:30 am
11:00 am
VG3.103

R. Katz, N. Diab, D. Batenkov

We consider the problem of recovering a linear combination of Dirac masses from noisy Fourier samples, also known as the problem of super-resolution. Following recent derivation of min-max bounds for this problem when some of the sources collide, we develop an optimal algorithm which provably achieves these bounds in such a challenging scenario. Our method is based on the well-known Prony's method for exponential fitting, and a novel analysis of its stability in the near-colliding regime, combined with the decimation technique for improving the conditioning of the problem.

Based on joint works with N.Diab and R.Katz:

References

[1] R. Katz, N. Diab, D. Batenkov. Decimated Prony's Method for Stable Super-resolution. 2022. http://arxiv.org/abs/2210.13329

[2] R. Katz, N. Diab, D. Batenkov. On the accuracy of Prony's method for recovery of exponential sums with closely spaced exponents. 2023. http://arxiv.org/abs/2302.05883

Interaction Models in Ptychography

MS22 2
Tue Sep 5
4:30 pm
5:00 pm
VG1.101

B. Diederichs

Over the recent years, ptychography became a standard technique for high resolution scanning transmission electron microscopy. To achieve better and better resolutions, the mathematical model had to be refined several times. In the simplest approach the measurements can be understood as a discrete, phaseless short-time Fourier transform

$$I(s) = |\mathcal{F}[\phi \cdot \tau_s w]|^2 .$$

Here, $\tau_s w$ is an (often unknown) window function, shifted by s, ϕ the object we would like to recover and $I(s)$ the measured intensity at position s. Typically, a few thousands of such measurements are recorded, where s lies on a regular grid. However, for specimens thicker than a few nanometers, this approximation already breaks down. A more sophisticated interaction model $M(\phi, \tau_s w)$ is needed.

Furthermore, the incoherence of the microscope is a crucial limit and has to be considered as well. We end up with a model like

$$I(s) = \sum_j |\mathcal{F}[M(\phi, \tau_s w_j)]|^2 .$$

In this talk we give an overview over these approaches and discuss their challenges. We also show reconstructions of experimental data.

Manifold-based Point Cloud Deformations: Theory and Applications to Protein Conformation Processing

MS26 1
Wed Sep 6
9:30 am
10:00 am
VG3.102

W. Diepeveen, C. Esteve-Yagüe, J. Lellmann, O. Öktem, C.-B. Schönlieb

Motivated by data analysis for protein conformations, we construct a smooth quotient manifold of point clouds and equip it with a non-trivial metric tensor field, that models which point clouds are close together and which are far apart. We analyse properties of the Riemannian manifold and obtain cheap to compute expressions for important manifold mappings. Furthermore, we investigate potential numerical advantages of using the Riemannian manifold structure in several data processing tasks such as interpolation, computing means and principal component analysis of simulated molecular dynamics (MD) data sets. For the latter, we observe that MD trajectories live in a low-dimensional sub-manifold in the proposed metric.

MS15 2
Mon Sep 4
4:00 pm
4:30 pm
VG1.102

A minimalist approach to 3D photoemission orbital tomography: how many measurements are enough?

T. L. Dinh

Photoemission orbital tomography provides a unique access to the real-space molecular orbitals of well-ordered organic semiconductor layers. Specifically, the application of phase retrieval algorithms to photon-energy- and angle-resolved photoemission patterns enables the reconstruction of full 3D molecular orbitals independent of density functional theory calculations. However, until now this procedure has remained challenging due to the need for densely-sampled, well-calibrated 3D photoemission data. Here, we present an iterative projection algorithm that completely eliminates this challenge: For the benchmark case of the Pentacene frontier orbitals, we demonstrate reconstruction of the full orbital based on a data set containing only seven photoemission momentum maps. Based upon application to simulated data, we discuss the algorithm performance, sampling requirements with respect to the photon energy, optimal measurement strategies and the accuracy of orbital images that can be achieved.

MS07 1
Fri Sep 8
2:30 pm
3:00 pm
VG1.101

Addressing Parameter Choice Issues in Unsupervised Domain Adaptation by Aggregation

M.-C. Dinu

We study the problem of choosing algorithm hyper-parameters in unsupervised domain adaptation, i.e., with labeled data in a source domain and unlabeled data in a target domain, drawn from a different input distribution. We follow the strategy to compute several models using different hyper-parameters, and, to subsequently compute a linear aggregation of the models. While several heuristics exist that follow this strategy, methods are still missing that rely on thorough theories for bounding the target error. In this turn, we propose a method that extends weighted least squares to vector-valued functions, e.g., deep neural networks. We show that the target error of the proposed algorithm is asymptotically not worse than twice the error of the unknown optimal aggregation. We also perform a large scale empirical comparative study on several datasets, including text, images, electroencephalogram, body sensor signals and signals from mobile phones. Our method outperforms deep embedded validation (DEV) and importance weighted validation (IWV) on all datasets, setting a new state-of-the-art performance for solving parameter choice issues in unsupervised domain adaptation with theoretical error guarantees. We further study several competitive heuristics, all outperforming IWV and DEV on at least five datasets. However, our method outperforms each heuristic on at least five of seven datasets. This talk is based on [1].

References

[1] M.-C. Dinu, M. Holzleitner, M. Beck, H. D. Nguyen, A. Huber, H. Eghbal-zadeh, B. A. Moser, S. Pereverzyev, S. Hochreiter, W. Zellinger. Addressing Parameter Choice Issues in Unsupervised Domain

Adaptation by Aggregation. The Eleventh International Conference on Learning Representations (ICLR), 2023.

Recontructing Interactions from Dynamics

MS30 2
Thu Sep 7
3:00 pm
3:30 pm
VG2.103

I. Dokmanic, L. Pan, C. Shi

Simple interactions between particles, people, or neurons give rise to astoundigly complex dynamics on the underlying interaction graphs. I will describe a class of models for dynamical systems on graphs which seems to provide an accurate description for a variety of phenomena from diverse domains. I will then show how this "deep graph dynamics prior" leads to an algorithm to reconstruct the unknown interaction graph when only the dynamics are observed. Potential applications in physics, publich health, Earth science, and neuroscience are important and numerous.

Stable reconstruction of anisotropic conductivity in magneto-acoustic tomography with magnetic induction

CT09
Thu Sep 7
5:30 pm
6:00 pm
VG2.107

N. Donlon

We study the issues of stability and reconstruction of the anisotropic conductivity σ of a biological medium $\Omega \subset \mathbb{R}^3$ by the hybrid inverse problem of Magneto-Acoustic Tomography with Magnetic Induction (MAT-MI). More specifically, we consider a class of anisotropic conductivities given by the symmetric and uniformly positive definite matrix-valued functions $A(x, \gamma(x))$, $x \in \Omega$, where the one-parameter family $t \mapsto A(x,t)$, $t \in [\lambda^{-1}, \lambda]$, is assumed to be *a-priori* known. Under suitable conditions that include $A(\cdot, \gamma(\cdot)) \in C^{1,\beta}(\Omega)$, with $0 < \beta \leqslant 1$, we obtain a Lipschitz type stability estimate of the scalar function γ in the $L^2(\Omega)$ norm in terms of an internal functional that can be physically measured in the MAT-MI experiment. We demonstrate the effectiveness of our theoretical framework in several numerical experiments, where γ is reconstructed in terms of the internal functional. Our result extends previous results in MAT-MI where the conductivity σ was either isotropic or of the simpler anisotropic form γD, with D an *a priori* known matrix-valued function in Ω. In particular, the more general type of anisotropic conductivity considered here allows for the anisotropic structure to depend non-linearly on the unknown scalar parameter γ to be reconstructed. This is joint work with Romina Gaburro, Shari Moskow and Isaac Woods

Phase retrieval in the wild: In situ optimized reconstruction for X-ray in-line holography

CT12
Fri Sep 8
2:30 pm
3:00 pm
VG2.104

J. Dora, J. Hagemann, S. Flenner, C. Schroer, T. Knopp

The phase problem is a well known challenge in propagation-based phase-contrast X-ray imaging, describing the situation that whenever a detector measures a complex X-ray wavefield, the phase information is lost, i.e. only the magnitude of the measured wavefield remains as a usable data set. The resulting inverse problem is ill-posed and non-convex, requiring twice as many variables to be reconstructed to obtain the complex-valued image of the object under study.

In a recent development we have changed the representation of the reconstructed image [1]. The classical representation as amplitude and phase suffers from phase wrapping ambiguities. The representation as the projected refractive index of the object avoids these problems. However, this algorithm still suffers from slow convergence and convergence to local minima.

In our work, we have investigated the main causes of slow convergence and local minima for the Nesterov accelerated projected gradient descent type of algorithm that is currently used in practice. We propose a framework of different techniques to address these problems and show that by combining the proposed methods, the reconstruction result can be dramatically improved in terms of reconstruction speed and quality. We apply our proposed methods to several datasets obtained from the nano-imaging experiment at the Hereon-operated beamline P05 at DESY (Hamburg, Germany). We demonstrate that our proposed framework can cope with single-distance measurements, which is a requirement for in-situ/operando experiments, and without a compact support constraint, while maintaining robustness along a wide range of samples.

References

[1] F. Wittwer, J.Hagemann et al. Phase retrieval framework for direct reconstruction of the projected refractive index applied to ptychography and holography, Optica 9: 295-302, 2022

MS55 1
Mon Sep 4
2:30 pm
3:00 pm
VG3.101

Some progresses in Carleman estimates and their applications in inverse problems for stochastic partial differential equations

F. Dou, W. Du, P. Lu

This talk studies Carleman estimates and their applications for inverse problems of stochastic partial differential equations. By establishing new Carleman estimates for the stochastic parabolic and hyperbolic systems, conditional stability for inverse problems of these systems are proven. Based on the idea of Tikhonov method, regularized solutions are proposed. The analysis of the existence and uniqueness of the regularized solutions, and proofs for error estimate under an a priori assumption are presented. Numerical verification of the regularization, based on the idea of kernel- based learning method, including numerical algorithms and examples are also illustrated.

MS36 2
Thu Sep 7
5:00 pm
5:30 pm
VG3.101

VAEs with structured image covariance as priors to inverse imaging problems

M. Duff

This talk explores how generative models, trained on ground-truth images, can be used as priors for inverse problems, penalizing reconstructions far from images the generator can produce. We utilize variational autoencoders that generate not only an image but also a covariance uncertainty matrix for each image. The covariance can model changing uncertainty dependencies caused by structure in the image, such as edges or objects, and provides a new distance metric from the manifold of learned images. We evaluate these novel generative regularizers on retrospectively sub-sampled real-valued MRI measurements from the fastMRI dataset.

Authors: Margaret A G Duff (Science and Technology Facilities Council (UKRI)) Ivor J A Simpson (University of Sussex) Matthias J Ehrhardt (University of Bath) Neill D F Campbell (University of Bath)

Regularized Maximum Likelihood Estimation for the Random Coefficients Model

CT10
Fri Sep 8
2:00 pm
2:30 pm
VG3.102

F. Dunker, E. Mendoza, M. Reale

The random coefficients regression model $Y_i = \beta_{0i} + \beta_{1i}X_{1i} + \beta_{2i}X_{2i} + \ldots + \beta_{di}X_{di}$, with $\boldsymbol{X}_i$, Y_i, $\boldsymbol{\beta}_i$ i.i.d random variables, and $\boldsymbol{\beta}_i$ independent of $\boldsymbol{X}_i$ is often used to capture unobserved heterogeneity in a population. Reconstructing the joint density of random coefficients $\boldsymbol{\beta}_i = (\beta_{0i}, \ldots, \beta_{di})$ implicitly involves the inversion of a Radon transformation. We propose a regularized maximum likelihood method with non-negativity and $\|\cdot\|_{L^1} = 1$ constraint to estimate the density. We analyse the convergence of the method under general assumptions and illustrate the performance in a real data application and in simulations comparing it to the method of approximate inverse.

Inverse problems for hyperbolic conservation laws

CT01
Wed Sep 6
9:30 am
10:00 am
VG2.104

D.-L. Duong

Hyperbolic conservation laws are central in the theory of PDEs. One of their typical features is the development of shock waves. This poses many challenges to the mathematical theory of both forward and inverse problems. It is well-known that two different initial data may involve into the same solution. In this talk, we will present a number of ways to overcome this difficulty, with emphasis on the Bayesian approach, and survey some recent results.

Total variation regularized problems: a support stability result

MS19 1
Tue Sep 5
2:30 pm
3:00 pm
VG3.103

Y. De Castro, V. Duval, R. Petit

The total (gradient) variation has been used in many imaging applications following the seminal work of Rudin, Osher and Fatemi.[1] In this talk, I will describe a "support stability" result for total-variation regularized inverse problems: under some assumptions, the solutions at low noise and low regularization have the same number of values as the unknown image, and their level sets converge to those of the unknown image.

It is a joint work with Romain Petit and Yohann De Castro.

References

[1] L. I. Rudin, S. Osher, E. Fatemi. Nonlinear total variation based noise removal algorithms. Physica D: Nonlinear Phenomena, Volume 60, Issues 1-4, 1 November 1992, Pages 259-268.

Isogeometric multilevel quadrature for forward and inverse random acoustic scattering

MS09
Fri Sep 8
1:30 pm
2:00 pm
VG1.102

J. Dölz, H. Harbrecht, C. Jerez-Hanckes, M. Multerer

We study the numerical solution of forward and inverse time-harmonic acoustic scattering problems by randomly shaped obstacles in three-dimensional space using a fast isogeometric boundary element method. Within the isogeometric framework, realizations of the random scatterer can efficiently be computed by simply updating the NURBS mappings which represent the scatterer. This way, we end up with a random deformation field. In particular, we show that it suffices to know the deformation field's expectation and covariance at the scatterer's boundary to model the surface's Karhunen-Loève expansion.

Leveraging on the isogeometric framework, we employ multilevel quadrature methods to approximate quantities of interest such as the scattered wave's expectation and variance. By computing the wave's Cauchy data at an artificial, fixed interface enclosing the random obstacle, we can also directly infer quantities of interest in free space. Adopting the Bayesian paradigm, we finally compute the expected shape and variance of the scatterer from noisy measurements of the scattered wave at the artificial interface. Numerical results for the forward and inverse problems validate the proposed approach.

MS24 1
Thu Sep 7
2:30 pm
3:00 pm
VG1.101

Plug-and-Play image reconstruction is a convergent regularization method

A. Ebner, M. Haltmeier

Non-uniqueness and instability are characteristic features of image reconstruction processes. As a result, it is necessary to develop regularization methods that can be used to compute reliable approximate solutions. A regularization method provides of a family of stable reconstructions that converge to an exact solution of the noise-free problem as the noise level tends to zero. The standard regularization technique is defined by variational image reconstruction, which minimizes a data discrepancy augmented by a regularizer. The actual numerical implementation makes use of iterative methods, often involving proximal mappings of the regularizer. In recent years, plug-and-play image reconstruction (PnP) has been developed as a new powerful generalization of variational methods based on replacing proximal mappings by more general image denoisers. While PnP iterations yield excellent results, neither stability nor convergence in the sense of regularization has been studied so far. In this work, we extend the idea of PnP by considering families of PnP iterations, each being accompanied by its own denoiser. As our main theoretical result, we show that such PnP reconstructions lead to stable and convergent regularization methods. This shows for the first time that PnP is mathematically equally justified for robust image reconstruction as variational methods.

MS24 2
Thu Sep 7
4:30 pm
5:00 pm
VG1.101

Shared Prior Learning of Energy-Based Models for Image Reconstruction

T. Pinetz, E. Kobler, T. Pock, A. Effland

In this talk, we propose a novel learning-based framework for image reconstruction particularly designed for training without ground truth data, which has three major building blocks: energy-based learning, a patch-based Wasserstein loss functional, and shared prior learning. In energy-based learning, the parameters of an energy functional composed of a learned data fidelity term and a data-driven regularizer are computed in a mean-field optimal control problem. In the absence of ground truth data, we change the loss functional to a patch-based Wasserstein functional, in which local statistics of the output images are compared to uncorrupted reference patches. Finally, in shared prior learning, both aforementioned optimal control problems are optimized simultaneously with shared learned parameters of the regularizer to further enhance unsupervised image reconstruction. We derive several time discretization schemes of the gradient flow and verify their consistency in terms of Mosco convergence. In numerous numerical experiments, we demonstrate that the proposed method generates state-of-the-art results for various image reconstruction applications - even if no ground truth images are available for training.

Element-Selective Structural Information by Hard X-ray Photoelectron Diffraction

MS15 2
Mon Sep 4
5:00 pm
5:30 pm
VG1.102

H.-J. Elmers

X-ray photoelectron diffraction (XPD) is a powerful technique that yields detailed structural information of solids and thin films that complements electronic structure measurements. Among the strongholds of XPD we can identify dopant sites, track structural phase transitions, and perform holographic reconstruction. High-resolution imaging of momentum-distributions (momentum microscopy) presents a new approach to core-level photoemission. It yields full-field XPD patterns with unprecedented acquisition speed and richness in details. Beyond the pure intensity-related diffraction information, XPD patterns exhibit pronounced circular dichroism in the angular distribution (CDAD) with asymmetries up to 80%. Experimental results for a number of examples prove that core-level CDAD is a general phenomenon that is independent of atomic number. Calculations using both the Bloch-wave approach and one-step photoemission reveal the origin of the fine structure that represents the signature of Kikuchi diffraction. Comparison to theory allow to disentangle the roles of photoexcitation and diffraction.

References

[1] O. Fedchenko, A. Winkelmann, K. Medjanik, S. Babenkov, D. Vasilyev, S. Chernov, C. Schlueter, A. Gloskovskii, Yu. Matveyev, W. Drube, B. Schönhense, H.J. Elmers, G. Schönhense. High-resolution hard-x-ray photoelectron diffraction in a momentum microscope - The model case of graphite, New. J. Phys. 21, 2019.

[2] K. Medjanik, O. Fedchenko, O. Yastrubchak, J. Sadowski, M. Sawicki, L. Gluba, D. Vasilyev, S. Babenkov, S. Chernov, A. Winkelmann, H.J. Elmers, G. Schönhense. Site-specific atomic order and band structure tailoring in the diluted magnetic semiconductor (In, Ga, Mn) As, Phys. Rev. B 103, 2021.

Weakly nonlinear geometric optics for the Westervelt equation

MS52 3
Tue Sep 5
2:00 pm
2:30 pm
VG1.105

N. Eptaminitakis

In this talk we will discuss the non-diffusive Westervelt equation, which describes the time evolution of pressure in a medium relative to an equilibrium position. It is a second order quasilinear hyperbolic equation, involving a space dependent parameter which multiplies the nonlinear term. Given a medium with compactly supported but unknown nonlinearity, we would like to recover the latter by probing the medium from different directions with high frequency waves and measuring the exiting wave. To do so, we construct approximate solutions for the forward problem via nonlinear geometric optics and discuss its well posedness. We then explain how the X-ray transform of the nonlinearity can be recovered from the measurements, which allows for it to be reconstructed. Based on joint work with Plamen Stefanov.

Regularization in non-Euclidean spaces meets numerical linear algebra

MS28 1
Tue Sep 5
2:30 pm
3:00 pm
VG1.108

C. Estatico, B. Bonino, L. Calatroni, F. D. Benedetto, M. Lazzaretti, F. Lenti

Inverse problems modeled by a functional equation $A(x) = y$ characterized by an ill-posed operator $A : X \longrightarrow Y$ between two non-Euclidean normed spaces X and Y are here considered. The iterative minimization of a functional based on the residual $\|A(x) - y\|_Y$ is a common approach in this setting, where generally no (closed form of the) inverse of A

exists. In particular, one-step gradient methods act as implicit regularization algorithms, when combined with an early-stopping criterion to prevent over-fitting of the noise on the data y.

In this talk, we review iterative methods involving the dual spaces X^* and Y^*, showing that they can be fully understood in the context of proximal operator theory, with suitable Bregman distances as proximity measure [1]. Moreover, many relationships of such iterative methods with classical projection algorithms, such us Cimmino and ART (Algebraic Reconstruction Techniques) ones, are discussed, as well as with classical preconditioning theory for structured linear systems arising in numerical linear algebra. Applications to deblurring and inverse scattering problems will be shown.

References

[1] B. Bonino, C. Estatico, M. Lazzaretti. Dual descent regularization algorithms in variable exponent Lebesgue spaces for imaging, Numer. Algorithms 92: 149-182, 2023.

[2] M. Lazzaretti, L. Calatroni, C. Estatico. Modular-proximal gradient algorithms in variable exponent Lebesgue spaces, SIAM J. Sci. Compu. 44: 1-23, 2022.

MS26 1
Wed Sep 6
10:00 am
10:30 am
VG3.102

Spectral decomposition of atomic structures in heterogeneous cryo-EM

C. Esteve-Yague, W. Diepeveen, O. Oktem, C.-B. Schönlieb

We consider the problem of recovering the three-dimensional atomic structure of a flexible macromolecule from a heterogeneous single-particle cryo-EM dataset. Our method combines prior biological knowledge about the macromolecule of interest with the cryo-EM images. The goal is to determine the deformation of the atomic structure in each image with respect to a specific conformation, which is assumed to be known. The prior biological knowledge is used to parametrize the space of possible atomic structures. The parameters corresponding to each conformation are then estimated as a linear combination of the leading eigenvectors of a graph Laplacian, constructed by means of the cryo-EM dataset, which approximates the spectral properties of the manifold of conformations of the underlying macromolecule.

MS48
Thu Sep 7
5:30 pm
6:00 pm
VG2.104

Medical image reconstruction in realistic scenarios: what to do if the ground-truth is missing?

D. Evangelista, E. Morotti, E. Loli Piccolomini

Deep learning algorithms have recently emerged as the state-of-the-art in solving Inverse Problems, overcoming classical variational methods in terms of both accuracy and efficiency. However, most deep learning algorithms require supervised training, which necessitates a collection of matched low-quality and ground-truth data. This poses a significant challenge in medical imaging, as obtaining such a dataset would require subjecting the patient to approximately double the amount of radiation. As a result, it is common to mathematically simulate the degradation process, which can introduce biases that degrade model performance when tested on real data. To address this issue, we propose a general self-supervised procedure for training neural networks in a setting where the ground truth is missing, but the mathematical model is approximately known. We demonstrate that our proposed method produces results of comparable quality to supervised techniques while being more robust to perturbations. We will provide formal proof of the effectiveness of our proposed method.

Sparse Bayesian Inference with Regularized Gaussian Distributions

MS12 1
Mon Sep 4
2:00 pm
2:30 pm
VG2.102

J. M. Everink, Y. Dong, M. S. Andersen

In this talk, we will present a method for Bayesian inference by implicitly defining a posterior distribution as the solution to a regularized linear least-squares problem with randomized data. This method combines Gaussian distributions with the deterministic effects of sparsity-inducing regularization like l_1 norms, total variation and/or constraints. The resulting posterior distributions assign positive probability to various low-dimensional subspaces and therefore promote sparsity. Samples from this distribution can be generated by repeatedly solving regularized linear least-squares problems with properly chosen data perturbations, thus, existing tools from optimization theory can be used for sampling. We will discuss some properties of the methodology and discuss an efficient algorithm for sampling from a Bayesian hierarchical model with sparsity structure.

The inverse problem of micromagnetic tomography in rock- and paleomagnetism

MS44 2
Mon Sep 4
5:30 pm
6:00 pm
VG2.104

K. Fabian

The intrinsic non-uniqueness of potential-field inversion of surface scanning data can be circumvented by solving for the potential field of known individual source regions. A uniqueness theorem characterizes the mathematical background of the corresponding inversion problem, and determines when a potential-field measurement on a surface uniquely defines the magnetic potentials of the individual source regions. For scanning magnetometers in rock magnetism, this result implies that dipole magnetization vectors of many individual magnetic particles can be reconstructed from surface scans of the magnetic field. It is shown that finite sensor size still retains this conceptual uniqueness. The technique of micromagnetic tomography (MMT) combines X-ray micro computed tomography and scanning magnetometry to invert for the magnetic potential of individual magnetic grains within natural and synthetic samples. This provides a new pathway to study the remanent magnetization that carries information about the ancient geomagnetic field and is the basis of all paleomagnetic studies. MMT infers the magnetic potential of individual grains by numerical inversion of surface magnetic measurements using spherical harmonic expansions. Because the full magnetic potential of the individual particles in principle is uniquely determined by MMT, not only the dipole but also more complex, higher order, multipole moments can be recovered. Even though a full reconstruction of complex magnetization structures inside the source minerals is mathematically impossible, these additional constraints by far-field multipole terms can substantially reduce the number of possible micromagnetic energy minima. For complex particles with many micromagnetic energy minima it is possible to include the far-field constraints into the micromagnetic minimization algorithm.

ADMM methods for Phase Retrieval and Ptychography

CT12
Fri Sep 8
2:00 pm
2:30 pm
VG2.104

A. Fannjiang

We present a systematic derivation and local convergence analysis for various ADMM algorithms in phase retrieval and ptychography.

We also discuss the extension of these algorithms to blind ptychography where the probe is unknown and compare their numerical performance.

MS22 2
Tue Sep 5
4:00 pm
4:30 pm
VG1.101

Uniqueness theory for 3D phase retrieval and unwrapping

A. Fannjiang

We present general measurement schemes with which unique conversion of diffraction patterns into the phase projection for a strong phase object (respectively, the projection for a weak phase object) in each direction can be guaranteed without the knowledge of relative orientations and locations.

This approach has the practical implication of enabling classification and alignment, when relative orientations are unknown, to be carried out in terms of (phase) projections, instead of diffraction patterns.

We also discuss conditions for unique determination of a strong phase object from its phase projection data, including, but not limited to, random tilt schemes densely sampled from a spherical triangle of vertexes in three orthogonal directions and other deterministic tilt schemes.

MS40
Tue Sep 5
2:00 pm
2:30 pm
VG2.107

Sparse optimization algorithms for dynamic imaging

S. Fanzon, K. Bredies, M. Carioni, F. Romero, D. Walter

In this talk we introduce a Frank-Wolfe-type algorithm for sparse optimization in Banach spaces. The functional we want to optimize consist of the sum of a smooth fidelity term and of a convex one-homogeneous regularizer. We exploit the sparse structure of the variational problem by designing iterates as linear combinations of extremal points of the unit ball of the regularizer. For such iterates we prove global sublinear convergence of the algorithm. Then, under additional structural assumptions, we prove a local linear convergence rate. We apply this algorithm to the problem of particles tracking from heavily undersampled dynamic MRI data. This talk is based on the works cited below.

References

[1] K.Bredies, M.Carioni, S.Fanzon, D.Walter. Asymptotic linear convergence of Fully-Corrective Generalized Conditional Gradient methods. Mathematical Programming, 2023.

[2] K.Bredies, S.Fanzon. An optimal transport approach for solving dynamic inverse problems in spaces of measures. ESAIM:M2AN, 54(6): 2351-2382, 2020.

[3] K.Bredies, M.Carioni, S.Fanzon, F.Romero. A Generalized Conditional Gradient Method for Dynamic Inverse Problems with Optimal Transport Regularization. Found Comput Math, 2022

[4] K.Bredies, M.Carioni, S.Fanzon. On the extremal points of the ball of the Benamou-Brenier energy. Bull. London Math. Soc., 53: 1436-1452, 2021.

[5] K.Bredies, M.Carioni, S.Fanzon. A superposition principle for the inhomogeneous continuity equation with Hellinger-Kantorovich-regular coefficients. Communications in Partial Differential Equations, 47(10): 2023-2069, 2022.

MS31 1
Fri Sep 8
2:00 pm
2:30 pm
VG3.104

Quantitative reconstruction of viscoelastic media with attenuation model uncertainty.

F. Faucher, O. Scherzer

We consider the inverse wave problem of reconstructing the properties of a viscoelastic medium. The data acquisition corresponds to probing waves that are sent and measured outside of the sample of interest, in the configuration of non-intrusive inversion. In media with attenuation, waves lose energy when propagating through the domain. Attenuation is a frequency-dependent phenomenon with several models existing [1], each leading to different models of wave equations. Therefore, in addition to adding unknown coefficients to the inverse problem, the attenuation law characterizing a medium is typically unknown prior to the reconstruction, hence further increasing the ill-posedness. In this work, we consider time-harmonic waves which are convenient to unify the different models of attenuation using complex-valued parameters. We illustrate the difference in wave propagation depending on the attenuation law and carry out the reconstruction with attenuation model uncertainty [2]. That is, we perform the reconstruction procedure with different attenuation models used for the (synthetic) data generation and for the reconstruction. In this way, we show the robustness of the reconstruction method. Furthermore, we investigate a configuration with reflecting boundary surrounding the sample. To handle the resulting multiple reflections, we introduce a strategy of reconstruction with a progression of complex frequencies. We illustrate with experiments of ultrasound imaging.

References

[1] J. M. Carcione. Wave Fields in Real Media: Wave Propagation in Anisotropic, Anelastic, Porous and Electromagnetic Media, third ed., Elsevier, 2015.

[2] F. Faucher, O. Scherzer. Quantitative inverse problem in visco-acoustic media under attenuation model uncertainty, Journal of Computational Physics 472: 111685, 2023. https://doi.org/10.1016/j.jcp.2022.111685

Source-free seismic imaging with reciprocity-gap misfit criterion.

MS37 1
Thu Sep 7
1:30 pm
2:00 pm
VG1.102

F. Faucher

We consider the quantitative inverse problem of recovering sub-surface Earth's parameters from measurements obtained near surface. The reconstruction procedure uses the iterative minimization of a misfit criterion that evaluates the discrepancy between the observed and simulated signals, following the principles of Full Waveform Inversion. In the context of passive imaging, the position and characterization of the source signature are unknown, hence increasing the difficulty of inversion. In this work, we propose a new misfit criterion based upon reciprocity formulas, and that allows for source-free inversion, such that no information regarding the probing sources is required, making it an interesting candidate for ambient noise imaging. Our misfit criterion relies on the deployment of new sensing devices such as dual-sensors and distributed acoustic sensing technology, that offer the perspective of measuring different wave fields. It is the combination of these wave fields that makes the essence of our Full Reciprocity-gap Waveform Inversion method, [1, 2]. with two and three-dimensional reconstructions of acoustic and elastic media.

References

[1] F. Faucher, G. Alessandrini, H. Barucq, M. V. de Hoop, R. Gaburro, E. Sincich. Full Reciprocity-Gap Waveform Inversion, enabling sparse-source acquisition, Geophysics, 85 (6), 2020. https://dx.doi.org/10.1190/geo2019-0527.1

[2] F. Faucher, M. V. de Hoop, O. Scherzer. Reciprocity-gap misfit functional for Distributed Acoustic Sensing, combining data from active and passive sources , Geophysics, 86 (2), 2021. https://doi.org/10.1190/geo2020-0305.1

IFF: A Super-resolution Algorithm for Multiple Measurements

MS19 2
Tue Sep 5
4:00 pm
4:30 pm
VG3.103

Z. Fei, H. Zhang

The problem of reconstructing one-dimensional point sources from their Fourier measurements in a bounded interval $[-\Omega, \Omega]$ is known to be challenging in the regime where the spacing of the sources is below the Rayleigh length $\frac{\pi}{\Omega}$. In this talk, we present a super-resolution algorithm, called Iterative Focusing-localization and Filtering (IFF), to resolve closely spaced point sources from their multiple measurements that are obtained by using multiple unknown illumination patterns. The new proposed algorithm requires no prior information about the source numbers and allows for a subsampling strategy that can circumvent the computation of singular-value decomposition for large matrices as in the usual subspace methods. In the talk, we will also discuss the theoretical results of the methods behind the algorithm. The derived results imply a phase transition phenomenon. Numerical results show that the algorithm can achieve a stable reconstruction for point sources with a minimum separation distance that is close to the theoretical limit as well as the phase transition phenomenon predicted by the theoretical analysis.

MS03 1
Mon Sep 4
1:30 pm
2:00 pm
VG2.103

Compressed sensing for the sparse Radon transform

G. S. Alberti, A. Felisi, M. Santacesaria, S. I. Trapasso

Compressed sensing allows for the recovery of sparse signals from few measurements, whose number is proportional to the sparsity of the unknown signal, up to logarithmic factors. The classical theory typically considers either random linear measurements or subsampled isometries and has found many applications, including accelerated magnetic resonance imaging, which is modeled by the subsampled Fourier transform. In our work, we develop a general theory of infinite-dimensional compressed sensing for abstract inverse problems, possibly ill-posed, involving an arbitrary forward operator. This is achieved by considering a generalized restricted isometry property, and a quasi-diagonalization property of the forward map. As a notable application, we obtain rigorous recovery estimates for the sparse Radon transform (i.e., with a finite number of angles $\theta_1, \ldots, \theta_m$), which models computed tomography. In the case when the unknown signal is s-sparse with respect to an orthonormal basis of compactly supported wavelets, we prove exact recovery under the condition $m \gtrsim s$, up to logarithmic factors.

References

[1] G. S. Alberti, A. Felisi, M. Santacesaria, I. Trapasso. Compressed sensing for inverse problems and the sample complexity of the sparse Radon transform, ArXiv e-prints, arXiv:2302.03577, 2023.

MS19 3
Wed Sep 6
9:00 am
9:30 am
VG3.103

On Beurling-Selberg Approximations and the Stability of Super-Resolution

M. Ferreira Da Costa

Of particular interest for super-resolution is the line spectrum estimation problem, which consists in recovering a stream of spikes (point sources) from the noisy observation of a few number of its first trigonometric moments weighted by the ones of the point-spread function (PSF). The empirical feasibility of this problem has been known since the work of Rayleigh on diffraction to be essentially driven by the separation between the spikes to recover.

We present a novel statistical framework based on the spectrum of the Fisher information matrix (FIM) to quantify the stability limit of super-resolution as a function of the PSF. In the regime where the minimal separation is inversely proportional to the number of acquired moments, we show the existence of a separation constant above which the minimal eigenvalue of the FIM is not asymptotically vanishing–defining a statistical resolution limit. Notably, a relationship between the total variation of the autocorrelation function of the PSF and its association resolution limit is highlighted. Those novel bounds are derived by relating the extremal eigenvalues of the FIM with a higher-order Beurling-Selberg type extremal approximation problem over the functions of bounded variation, for which we provide solutions.

From Manual to Automatic: Streamlining MRI Marker Detection and Localization for Surgical Planning

MS01
Wed Sep 6
9:30 am
10:00 am
VG1.102

C. Fiedler, **S. Kolbig**

The accurate detection and localization of natural or artificial structures in medical images is essential for effective diagnostics and surgical planning. In particular, determining the pose of artificial markers in MRI images is a foundational step for subsequent spatial adjustments, such as the registration between imaging modalities and with surgical devices. Manual detection and localization of these markers can be tedious and time-consuming, which has prompted the exploration of reliable, and highly automated approaches that can significantly reduce the need for human interaction. In recent years, automatic approaches based on neural networks have shown remarkable success in the detection and semantic segmentation of natural, anatomical structures. In contrast to these structures, the geometry of artificial markers is typically known, which enables the development of relatively simple algorithms that can perform well without the need for complex neural network architectures. The challenge often lies in the incomplete and inhomogeneous representation of the markers within the MRI images, due to noise, distortions, artifacts and further image defects. In this talk, we will explore different automatic approaches to MRI marker localization from a practical perspective, including conventional image processing pipelines utilizing basic methods such as convolution filters or connected component analysis and labeling as well as approaches based on neural networks. By addressing the benefits and challenges of using these methods, we gain a better understanding of their potential applications and impact on clinical image processing workflows.

Nonlinear impedance boundary conditions in inverse obstacle scattering

MS23 1
Tue Sep 5
4:00 pm
4:30 pm
VG1.103

L. Fink

Nonlinear impedance boundary conditions in acoustic scattering are used as a model for perfectly conducting objects coated with a thin layer of a nonlinear medium. We consider a scattering problem for the Helmholtz equation with a nonlinear impedance boundary condition of the form

$$\frac{\partial u}{\partial \nu} + ik\lambda u = g(\cdot, u) \quad \text{on } \partial D,$$

where ν denotes the unit normal vector, $\lambda \in L^\infty(\partial D)$ is a complex-valued impedance function, and $g : \partial D \times \mathbb{C} \to \mathbb{C}$ gives an additional nonlinear term with respect to the total field u. The contributed talk is devoted to the well-posedness of the direct problem, the determination of the domain derivative, and the inverse problem, which consists in reconstructing the shape of the scattering object from given far field data. Numerical results are presented relying on an all-at-once regularized Newton-type method based on the linearization of the forward problem and of the domain-to-far-field operator.

MS44 2
Mon Sep 4
4:30 pm
5:00 pm
VG2.104

Co-estimation of core and lithospheric signals in satellite magnetic data

M. Otzen, C. Finlay

Satellite observations of the geomagnetic field contain signals originating both from electrical currents in the core and from magnetized rocks in the lithosphere. At short wavelengths the lithospheric signal dominates, obscuring the signal from the core. Here we present details of a method to co-estimate separate models for the core and lithospheric fields, which are allowed to overlap in spherical harmonic degree, that makes use of prior information regarding the sources. Using a maximum entropy method, we estimate a time-dependent model of the core field together with a static model of the lithospheric field that satisfy the constraints provided by satellite observations as well as statistical prior information, but are otherwise maximally non-committal with regard to the distribution of radial magnetic field at the source surfaces. Tests based on synthetic data are encouraging, demonstrating it is possible to retrieve parts of the core field beyond degree 13 and the lithospheric field below degree 13. Results will be presented from our new model of the time-dependent core surface field up to spherical harmonic degree 30 and implications regarding our understanding of the core dynamo discussed.

MS01
Wed Sep 6
9:00 am
9:30 am
VG1.102

Chances and limitations of machine learning approaches to inverse problems

J. Flemming

Machine learning techniques, especially artificial neural networks, share many ideas and features with classical (that is, non-ML) methods for solving inverse problems. Examples are underlying Tikhonov-type optimization problems and the interpretation of deep neural networks as iterative methods structured like typical forward-backward splitting. In the talk we discuss those similarities and draw conclusions on possible directions for future research. Chances and limitations of ML techniques are discussed in the context of inverse problems from medical imaging. Of particular interest will be susceptibility weighted MR imaging (SWI).

MS11
Wed Sep 6
10:30 am
11:00 am
VG1.108

Certified Coordinate Selection for large-dimensional Bayesian Inversion

R. Flock, Y. Dong, O. Zahm, F. Uribe

We are presenting a method to solve large dimensional Bayesian inverse problems where the parameter vector is assumed to be sparse. To this end, we use a Laplace-prior and show how the posterior density can be approximated based on a suitable coordinate splitting. Using an upper bound on the Hellinger distance between the exact and approximated posterior density, we show how the coordinate splitting can be performed.

Sampling from the approximated posterior is then straightforward and very efficient. Our theoretical framework allows also for sampling the exact posterior using a pseudo-marginal MCMC. However, this algorithm is relying heavily on a good coordinate splitting which might not be feasible in practice. Therefore, we propose a modified random-scan MCMC algorithm to sample from the exact posterior which is more robust and flexible.

In the end, we first illustrate the methodology on a simple example and then present the practical applicability on a large-dimensional 2D deblurring problem.

Tackling noise in multiple dimensions via hysteresis modulo sampling

MS22 2
Tue Sep 5
5:00 pm
5:30 pm
VG1.101

D. Florescu, A. Bhandari

Mapping a multi-dimensional function in a predefined bounded amplitude range can be achieved via a transformation known as the modulo nonlinearity. The recovery of the function from the modulo samples was addressed for the one-dimensional case as part of the Unlimited Sensing Framework (USF) based on uniform samples [1-3], but also based on neuroscience inspired time encoded samples [4]. Alternative analyses implemented denoising of modulo data in one and multiple dimensions [5]. Extensions of the recovery to multi-dimensional inputs typically amount to a line-by-line analysis of the data on one-dimensional slices. Apart from enabling the reconstruction of a wider class of inputs, this approach does not show an inherent need to apply modulo for high dimensional inputs.

In this talk, we present a modulo sampling operator specifically tailored to multiple dimensional inputs, called multi-dimensional modulo-hysteresis [6]. It is shown that the model can use dimensions two and above to generate redundancy that can be exploited for robust input recovery. This redundancy is particularly made possible by the hysteresis parameter of the operator. A few properties of the new operator are proven, followed by a guaranteed input recovery approach. We demonstrate theoretically and via numerical examples that when the input is corrupted by Gaussian noise the reconstruction error drops asymptotically to 0 for high enough sampling rates, which was not possible for the one-dimensional scenario. We additionally extend the recovery guarantees to classes of non-bandlimited inputs from shift-invariant spaces and include additional simulations with different noise distributions. This work enables extensions to multi-dimensional inputs for neuroscience inspired sampling schemes [4], inherently known for their noisy characteristics.

References

[1] Bhandari, F. Krahmer, R. Raskar. On unlimited sampling and reconstruction. IEEE Trans. Sig. Proc. 69 (2020) 3827-3839. doi:10.1109/tsp.2020.3041955

[2] Bhandari, F. Krahmer, T. Poskitt. Unlimited sampling from theory to practice: Fourier-Prony recovery and prototype ADC. IEEE Trans. Sig. Proc. (2021) 1131-1141. doi:10.1109/TSP.2021.3113497.

[3] D. Florescu, F. Krahmer, A. Bhandari. The surprising benefits of hysteresis in unlimited sampling: Theory, algorithms and experiments. IEEE Trans. Sig. Proc. 70 (2022) 616-630. doi:10.1109/tsp.2022.3142507

[4] D. Florescu, A. Bhandari. Time encoding via unlimited sampling: theory, algorithms and hardware validation. IEEE Trans. Sig. Proc. 70 (2022) 4912-4924.

[5] H. Tyagi. Error analysis for denoising smooth modulo signals on a graph. Applied and Computational Harmonic Analysis 57 (2022) 151-184.

[6] D. Florescu, A. Bhandari. Multi-Dimensional Unlimited Sampling and Robust Reconstruction. arXiv preprint 2002 arXiv:2209.06426.

Stability for the inverse problem of the determination on an inclusion in a Schrödinger type equation using Cauchy data.

MS53
Wed Sep 6
9:00 am
9:30 am
VG3.104

S. Foschiatti

We consider the stability issue for a broad class of inverse problems described by second-order elliptic equations with anisotropic and scalar coefficients that are finite-dimensional. This class of problems encompasses the well-studied conductivity equation, the Helmholtz equation and the Schrödinger equation. The applications of this study range from medicine, for example EIT, where the coefficient to be reconstructed is the conductivity, to the reconstruction of the wave-speed in a medium. It is well known that these inverse problems are ill-posed.

In this talk we prove a logarithmic stability estimate for the inverse problem that regards the determination of an inclusion in terms of local Cauchy data, since the Dirichlet to Neumann map that can encode the data at the boundary is not always available. This talk is based on a joint work with Eva Sincich.

MS49 2
Tue Sep 5
4:30 pm
5:00 pm
VG3.102

Parameter identification in helioseismology

D. Fournier

Helioseismology aims at recovering the properties of the solar interior from the observations of line-of-sight Doppler velocities at the surface. Interpreting these observations requires first to solve a forward problem describing the propagation of waves in a highly-stratified medium representing the interior of the Sun. Considering only acoustic waves, the forward problem can be written as

$$\mathcal{L}\psi := -\frac{1}{\rho c^2}(\omega^2 + 2i\omega\gamma + 2i\omega\mathbf{u}\cdot\nabla)\psi - \nabla\left(\frac{1}{\rho}\nabla\psi\right) = s,$$

where ρ is the density, c the sound speed, $\mathbf{u}$ the flow and ψ the Lagrangian pressure perturbation. The source term s is stochastic and caused by the excitation of waves by convection. As the signal is incoherent, we cannot study directly the wavefield ψ but only its cross-covariance $C(r_1, r_2, \omega) = \psi(r_1, \omega)^*\psi(r_2, \omega)$. Under the hypothesis of energy equipartition, the expectation value of the cross-covariance is proportional to the imaginary part of the Green's function associated to $\mathcal{L}$. The inverse problem is then to reconstruct the parameters $q \in \{\rho, c, \mathbf{u}\}$ from the observations of $\text{Im}[G(r_1, r_2, \omega)]$ for any two points r_1, r_2 at the solar surface. To increase the signal-to-noise ratio and reduce the size of the input data, wave travel times are usually extracted from the cross-covariances and serve as input data for the inversions. We will present inversions of large-scale flows (differential rotation and meridional circulation) from travel-time measurements using synthetic and observed data.

MS41 2
Fri Sep 8
5:00 pm
5:30 pm
VG3.101

An inverse source problem for the elasto-gravitational equations

L. Baldassari, M. V. de Hoop, E. Francini, S. Vessella

We study an inverse source problem for a system of elastic-gravitational equations, describing the oscillations of the Earth due to an earthquake.

The aim is to determine the seismic-moment tensor and the position of the point source by using only measurements of the disturbance in the gravity field induced by the earthquake, for an arbitrarily small time window.

The problem is inspired by the recently discovered speed-of-light prompt elasto-gravity signals (PEGS), which can prove beneficial for earthquake early warning systems (EEWS).

A new variational appraoch for limited data reconstructions in x-ray tomography

MS36 1
Thu Sep 7
2:00 pm
2:30 pm
VG3.101

J. Frikel

It is well known that image reconstructions from limited tomographic data often suffer from significant artifacts and missing features. To remove these artifacts and to compensate for the missing information, reconstruction methods have to incorporate additional information about the objects of interest. An important example of such methods is TV reconstruction. It is well known that this technique can efficiently compensate for missing information and reduce reconstruction artifacts. At the same time, however, tomographic data are also contaminated by noise, which poses an additional challenge. The use of a single penalty term (regularizer) within a variational regularization framework must therefore account for both the missing data and the noise. However, it is known that a single regularizer does not work perfectly for both tasks. In this talk, we introduce a new variational formulation that combines the advantages of two different regularizers, one aimed at accurate reconstruction in the presence of noise and the other aimed at selecting a solution with reduced artifacts. Both reconstructions are linked by a data consistency condition that makes them close to each other in the data domain. We demonstrate the proposed method for the limited angle CT problem using a combined curvelet and TV approach.

Regularizing Inverse Problems through Translation Invariant Diagonal Frame Decompositions

MS21 1
Tue Sep 5
3:00 pm
3:30 pm
VG2.103

J. Frikel

We consider the challenge of solving the ill-posed reconstruction problem in computed tomography using a translation-invariant diagonal frame decomposition (TI-DFD). First, we review the concept of diagonal frame decompositions (DFD) and their translation-invariant counterparts for general linear operators. Subsequently, we explain how the filter-based regularization methods can be defined using these frame decompositions. Finally, as an example, we introduce the TI-DFD for the Radon transform on $L^2(\mathbb{R}^2)$ and provide an exemplary construction using the TI wavelet transform. In numerical results, we demonstrate the advantages of our approach over non-translation invariant counterparts.

Learning segmentation on unlabeled MRI data using labeled CT data

MS07 2
Fri Sep 8
5:00 pm
5:30 pm
VG1.101

L. Frischauf

The goal of supervised learning is that of deducing a classifier from a given labeled data set. In several concrete applications, such as medical imagery, one however often operates in the setup of domain adaptation. Here, a classifier is learnt from a source labeled data set and generalised to a target unlabeled data set, with the two data sets moreover belonging to different domains (e.g. different patients, different machine setups etc.).

In our work, we use the SIFA framework [1] as a basis for medical image segmentation for a cross-modality adaptation between MRI and CT images. We have combined the

SIFA algorithm with linear aggregation as well as importance-weighted validation of those trained models to remove the arbitrariness in the choice of parameters.

This presentation shall give an overview of domain adaptation and show the latest version of our experiments.

References

[1] C. Chen, Q. Dou, H. Chen, J. Qin, P. Heng. Unsupervised Bidirectional Cross-Modality Adaptation via Deeply Synergistic Image and Feature Alignment for Medical Image Segmentation. IEEE Transactions on Medical Imaging 39: 2494-2505, 2020.

MS05 1
Wed Sep 6
9:30 am
10:00 am
VG2.102

The Henderson problem and the relative entropy functional

F. M. Frommer, **M. Hanke**

The inverse Henderson problem of statistical mechanics is the theoretical foundation for many bottom-up coarse-graining techniques for the numerical simulation of complex soft matter physics. This inverse problem concerns classical particles in continuous space which interact according to a pair potential depending on the distance of the particles. Roughly stated, it asks for the interaction potential given the equilibrium pair correlation function of the system. In 1974 Henderson proved that this potential is uniquely determined in a canonical ensemble and recently it has been argued by Rosenberger et al. that this potential minimises a relative entropy. Here we provide a rigorous extension of these results for the thermodynamical limit and define a corresponding relative entropy density for this. We investigate further properties of this functional for suitable classes of pair potentials.

MS42
Tue Sep 5
5:30 pm
6:00 pm
VG3.104

Stability and reconstruction for anisotropic inverse problems.

R. Gaburro

In this talk we investigate the issues of stability and reconstruction in inverse problems in the presence of anisotropy. As is well-known, there is a fundamental obstruction to the unique determination of the anisotropic conductivity of materials. Such obstruction is based on the observation that any deffeomorphism of a domain Ω that keeps its boundary $\partial\Omega$ fixed, changes the conductivity in Ω by keeping the boundary measurements unchanged. In this talk we will investigate how to circumvent this obstruction and restore well-posedness in the problem.

MS53
Wed Sep 6
10:30 am
11:00 am
VG3.104

Uniqueness and stability for anisotropic inverse problems.

R. Gaburro

In this talk we investigate the issue of uniqueness and stability for certain inverse problems which forward problem is modelled by a second order elliptic partial differential equation. As is well known, there is a fundamental obstruction to uniquely determine physical properties of anisotropic materials from boundary maps/measurements. In fact, any diffeomorphism of the domain under investigation, that keeps the domain's boundary fixed, changes its material's properties without changing its boundary measurements. In this talk we will provide some positive answers to the issues of uniqueness and stability of certain type of anisotropy in terms to the correspondent boundary measurements.

The Foldy-Lax approximation of scattered field by many small inclusions near the resonating frequencies for Lamè system

CT03
Wed Sep 6
9:00 am
9:30 am
VG2.107

D. Gangadaraiah, D. P. Challa, M. Sini

We are concerned with the time harmonic elastic scattering in the presence of multiple small-scaled inclusions. The main property we use in this work is the local enhancement of scattering, which occurs at a specific incident frequency when the medium is perturbed with highly contrasted small inhomogeneities; for instance, one can consider contrast on the mass density. Such highly contrasting inclusions generate few local spots at their locations. These spots are generated as possible body waves related to elastic resonances. A family of these resonances is related to the eigenvalues of the elastic Newtonian operator.

Our goal is to derive the approximation of elastic scattered field for incident frequencies near to elastic resonances with suitable sufficient conditions. The dominating field generated due to the multiple interactions between a cluster of small inhomogeneities, of sub-wavelength size, is the Foldy-Lax field. The derived result has several applications, to mention a few, firstly in the theory of effective medium to design the materials with desired properties and, secondly, in elastic imaging to solve the inverse problem of recovering the properties of the background medium.

The Calderón problem for directionally antilocal operators

MS18 2
Mon Sep 4
4:00 pm
4:30 pm
VG1.103

M. Á. García-Ferrero

The Calderón problem for the fractional Schrödinger equation, introduced by T. Ghosh, M. Salo and G. Uhlmann, satisfies global uniqueness with only one single measurement. This result exploits the antilocality property of the fractional Laplacian, that is, if a function and its fractional Laplacian vanish in a subset, then the function is zero everywhere.

Nonlocal operators which only see the functions in some directions and not on the whole space cannot satisfy an analogous antilocality property. In theses cases, only directional antilocality conditions may be expected.

In this talk, we will consider antilocality in cones, introduced by Y. Ishikawa in the 80s, and its possible implications in the corresponding Calderón problem. In particular, we will see that uniqueness for the associated Calderón problem holds even with a singe measurement, but new geometric conditions are required.

This is a joint work with G. Covi and A. Rüland.

Reduced order model approach for active and passive imaging with waves

MS37 2
Thu Sep 7
4:00 pm
4:30 pm
VG1.102

L. Borcea, J. Garnier, A. Mamonov, J. Zimmerling

We consider the velocity estimation problem for the scalar wave equation using the array response matrix of sensors. In the active configuration, the sensors probe the unknown medium to be imaged with a pulse and measure the backscattered waves which gives directly the array response matrix. In the passive configuration, the sensors are passive receivers that record the signals transmitted by unknown, ambient noise or opportunistic sources and the array response matrix can be obtained by cross correlating the recorded signals. Under such circumstances, conventional Full Waveform Inversion (FWI) is carried out by nonlinear least-squares fitting of the array response matrix. It turns out that the

FWI misfit function is high-dimensional and non-convex with many local minima. A novel approach to FWI based on a data driven reduced order model (ROM) of the wave equation operator is introduced and it is shown that the minimization of ROM misfit function performs much better.

MS44 1
Mon Sep 4
1:30 pm
2:00 pm
VG2.104

Inverse magnetization problems in geoscience at various scales

C. Gerhards

The inversion of magnetic field data for the underlying magnetization is a frequent problem in geoscience. It occurs at planetary scales, inverting satellite magnetic field information for lithospheric sources, as well as at microscopic scales, inverting for the sources in thin slices of rock samples. All scales have in common that the inverse problem is nonunique and highly instable. Here, we want to provide an overview on this topic and indicate various scenarios for which additional assumptions may ameliorate some of the issues of ill-posedness. This ranges from the assumption of an (infinitely) thin lithosphere (where the Hardy-Hodge decomposition can be used for the characterization of uniqueness) to a priori knowledge about the location or shape of magnetic inclusions within a rock sample (where the Helmholtz decomposition plays a role for the uniqueness aspect).

MS57 1
Mon Sep 4
2:30 pm
3:00 pm
VG3.102

Simultaneous Reconstruction Of Optical And Acoustical Properties In PA-Imaging Using Plasmonics.

A. Ghandriche, M. Sini

We propose an approach for the simultaneous reconstruction of the electromagnetic and acoustic material parameters, in the given medium Ω where to image, using the photoacoustic pressure, measured on a single point of the boundary of Ω, generated by plasmonic nano-particles. We prove that the generated pressure, that we denote by $p^\star(x,s,\omega)$, depending on only one fixed point $x \in \partial\Omega$, the time variable s, in a large enough interval, and the incidence frequency ω, in a large enough band, is enough to reconstruct both the sound speed, the mass density and the permittivity inside Ω. Indeed, from the behaviour of the measured pressure in terms of time, we can estimate the travel time of the pressure, for arriving points inside Ω, then using the eikonal equation we reconstruct the acoustic speed of propagation, inside Ω. In addition, we reconstruct the internal values of the acoustic Green's function. From the singularity analysis of this Green's function, we extract the integrals along the geodesics, for internal arriving points, of the logarithmic-gradient of the mass density. Solving this integral geometric problem provides us with the values of the mass density function inside Ω. Finally, from the behaviour of $p^\star(x,s,\omega)$ with respect to the frequency ω, we detect the generated plasmonic resonances from which we reconstruct the permittivity inside Ω.

MS26 2
Thu Sep 7
1:30 pm
2:00 pm
VG3.102

High Dimensional Covariance Estimation in Cryo-EM

M. A. Gilles, A. Singer

Cryogenic electron-microscopy (cryo-EM) is an imaging technique able to recover the 3D structures of proteins at near-atomic resolution. A unique characteristic of cryo-EM is the possibility of recovering the structure of flexible proteins in different conformations from a single electron microscopy image dataset. One way to estimate these conformations relies on estimating the covariance matrix of the scattering potential directly from the electron data. From that matrix, one can perform principal component analysis to recover the distribution of conformations of a protein. While theoretically attractive, this method has been constrained to low resolutions because of high storage and computational complexity; indeed, the covariance matrix contains N^6 entries where images are of size $N \times N$. In this talk, we present a new estimator for the covariance matrix and show that we can compute it in a rank k-approximate covariance in $O(kN^3)$. Finally, we demonstrate on simulated and real datasets that we can recover the conformations of structures at high resolution.

The direct and inverse scattering problem of obliquely incident electromagnetic waves by an inhomogeneous infinitely long cylinder

MS06 3
Thu Sep 7
4:00 pm
4:30 pm
VG3.103

D. Gintides, L. Mindrinos, S. Giogiakas

We consider the scattering problem of electromagnetic waves by an infinitely long cylinder in three dimensions.The cylinder is dielectric, isotropic and inhomogeneous(with respect to the lateral directions). The incoming wave is time-harmonic and obliquely incident on the scatterer. We examine the well-posedness of the direct problem (uniqueness and existence of solution) using a Lippmann- Schwinger integral equation formulation. We prove uniqueness of the inverse problem to reconstruct the refractive index of an isotropic circular cross-section using the discreteness of the corresponding transmission eigenvalue problem and solutions based on separation of variables. We solve numerically the inverse problem for media with radial symmetric parameters using a Newton - type scheme. The direct problem is also solved numerically to provide us with the necessary far-field patterns of the scattered fields. We present numerical reconstructions justifying the applicability of the proposed method.

MCMC Methods for Low Frequency Diffusion Data

MS04 2
Tue Sep 5
4:30 pm
5:00 pm
VG2.102

M. Giordano

The talk will consider Bayesian nonparametric inference in multi-dimensional diffusion models from low-frequency data. Implementation of Bayesian procedures in such settings is a notoriously delicate task, due to the intractability of the likelihood, often requiring involved augmentation techniques. For the nonlinear inverse problem of inferring the diffusivity function in a stochastic differential equation, we rather propose to exploit the underlying PDE characterization of the transition densities, which allows the numerical evaluation of the likelihood via standard numerical methods for elliptic eigenvalue problems. A simple Metropolis-Hastings-type MCMC algorithm for inference on the diffusivity is then constructed, based on Gaussian process priors. The performance of the the algorithm will be illustrated via the results of numerical experiments. The talk will then discuss theoretical computational guarantees for MCMC methods in the considered inferential problem, based on derived local curvature properties for the log-likelihood, and connected to the 'hot spots' conjecture from spectral geometry.

Joint work with S. Wang (MIT).

CT05
Thu Sep 7
1:30 pm
2:00 pm
VG2.105

Quaternary image decomposition with cross-correlation-based multi-parameter selection

L. Girometti, M. Huska, A. Lanza, S. Morigi

Separating different features in images is a challenging problem, especially in the separation of the textural component when the image is noisy. In the last two decades many papers were published on image decomposition, addressing modeling and algorithmic aspects and presenting the use of image decomposition in cartooning, texture separation, denoising, soft shadow/spot light removal and structure retrieval. Given the desired properties of the image components, all the valuable contributions to this problem rely on a variational-based formulation which minimizes the sum of different energy norms: total variation semi-norm, L^1-norm, G-norm, approximation of the G-norm by the $div(L^p)$-norm and by the H^{-1}-norm, homogeneous Besov space, to model the oscillatory component of an image. The intrinsic difficulty with these minimization problems comes from the numerical intractability of the considered norms, from the tuning of the numerous model parameters, and, overall, from the complexity of extracting noise from a textured image, given the strong similarity between these two components.

In this talk, I will present a two-stage variational model for the additive decomposition of images into piecewise constant, smooth, textured and white noise components. Then, I will discuss how the challenging separation of noise from textured images can be successfully overcome by integrating a whiteness constraint in the model, and how the selection of the regularization parameters can be performed based on a novel multi-parameter cross-correlation principle. Finally, I will present numerical results that show the potentiality of the proposed model for the decomposition of textured images corrupted by several kinds of additive white noises.

MS10 3
Fri Sep 8
1:30 pm
2:00 pm
VG1.103

Automated tight Lyapunov analysis for first-order methods

M. Upadhyaya, S. Banert, A. Taylor, P. Giselsson

We present a methodology for establishing the existence of quadratic Lyapunov inequalities for a wide range of first-order methods used to solve convex optimization problems. In particular, we consider

i) classes of optimization problems of finite-sum form with (possibly strongly) convex and possibly smooth functional components,

ii) first-order methods that can be written as a linear system on state-space form in feedback interconnection with the subdifferentials of the functional components of the objective function, and

iii) quadratic Lyapunov inequalities that can be used to draw convergence conclusions.

We provide a necessary and sufficient condition for the existence of a quadratic Lyapunov inequality that amounts to solving a small-sized semidefinite program. We showcase our methodology on several first-order methods that fit the framework. Most notably, our methodology allows us to significantly extend the region of parameter choices that allow for duality gap convergence in the Chambolle-Pock method when the linear operator is the identity mapping.

Sparsity-promoting hierarchical Bayesian inverse problems and uncertainty quantification

CT08
Thu Sep 7
4:30 pm
5:00 pm
VG2.105

J. Glaubitz

Recovering sparse generative models from limited and noisy measurements presents a significant and complex challenge. Given that the available data is frequently inadequate and affected by noise, it is crucial to assess the resulting uncertainty in the relevant parameters. Notably, this uncertainty in the parameters directly impacts the reliability of predictions and decision-making processes.

In this talk, we explore the Bayesian framework, which facilitates the quantification of uncertainty in parameter estimates by treating involved quantities as random variables and leveraging the posterior distribution. Within the Bayesian framework, sparsity promotion and computational efficiency can be attained with hierarchical models with conditionally Gaussian priors and gamma hyper-priors. However, most of the existing literature focuses on the numerical approximation of maximum a posteriori (MAP) estimates, and less attention has been given to sampling methods or other means for uncertainty quantification. To address this gap, our talk will delve into recent advancements and developments in uncertainty quantification and sampling techniques for sparsity-promoting hierarchical Bayesian inverse problems.

Parts of this talk are joint work with Anne Gelb (Dartmouth), Youssef Marzouk (MIT), and Jonathan Lindbloom (Dartmouth).

Learning Fourier sampling schemes for MRI by density optimization

MS50 1
Fri Sep 8
2:00 pm
2:30 pm
VG1.105

A. Gossard, F. de Gournay, P. Weiss

An MRI scanner roughly allows measuring the Fourier transform of the image representing a volume at user-specified locations. Finding an optimal sampling pattern and reconstruction algorithm is a longstanding issue. While Shannon and compressed sensing theories dominated the field over the last decade, a recent trend is to optimize the sampling scheme for a specific dataset. Early works investigated algorithms that find the best subset among a set of feasible trajectories. More recently, some works proposed to optimize the positions of the sampling locations continuously [3].

In this talk, we will first show that this optimization problem usually possesses a combinatorial number of spurious minimizers [1]. This effect can however be mitigated by using large datasets of signals and specific preconditioning techniques. Unfortunately, the dataset size, the costly reconstruction processes and the computation of the non-uniform Fourier transform makes the problem computationally challenging. By optimizing the sampling density rather than the points locations, we show that the problem can be solved significantly faster while preserving competitive results [2].

References

[1] A. Gossard, F. de Gournay, P. Weiss. Spurious minimizers in non uniform Fourier sampling optimization, Inverse Problems 38: 105003, 2022.

[2] A. Gossard, F. de Gournay, P. Weiss. Bayesian Optimization of Sampling Densities in MRI, arXiv: 2209.07170, 2022.

[3] G. Wang, T. Luo, J.-F. Nielsen, D. C Noll, J. A Fessler. B-spline parameterized joint optimization of reconstruction and k-space trajectories (BJORK) for accelerated 2d MRI, IEEE Transactions on Medical Imaging 41: 2318–2330, 2022.

CT14
Fri Sep 8
4:00 pm
4:30 pm
VG2.106

On accuracy and existence of approximate decoders for ill-posed inverse problems

N. M. Gottschling, P. Campodonico, V. Antun, A. C. Hansen

Based on work by Cohen, Damen and Devore [1] and Bourrier et al. [2], we propose a framework that highlights the importance of knowing the measurement model F and model class $\mathcal{M}_1$, when solving ill-posed (non-)linear inverse problems, by introducing the concept of kernel size. Previous work has assumed that the problem is injective on the model class $\mathcal{M}_1$ and we obviate the need for this assumption. Thus, it is applicable in Deep Larning (DL) based settings where $\mathcal{M}_1$ can be an arbitrary data set.

Setting and initial main result Let $\mathcal{X}$, $\mathcal{Y}$ and $\mathcal{Z}$ be non-empt sets, $\mathcal{M}_1 \subset \mathcal{X}$ be the *model class*, $\mathcal{E} \subset \mathcal{Z}$ be the *noise class*" and $F\colon \mathcal{M}_1 \times \mathcal{E} \to \mathcal{Y}$ be the *forward map*. An inverse problem has the form:

$$\text{Given noisy measurements } y = F(x, e) \text{ of } x \in \mathcal{M}_1 \text{ and } e \in \mathcal{E}, \text{ recover } x. \quad (1)$$

Here e represent the model noise and x the signal (function or vector) we wish to recover or approximate. This also includes linear cases with additive noise, where $\mathcal{Y} = \mathcal{Z}$, $A\colon \mathcal{X} \to \mathcal{Y}$ is a linear map between vector spaces and the forward map is

$$F(x, e) = Ax + e. \quad (2)$$

To measure accuracy we equip $\mathcal{X}$, $\mathcal{Y}$ and $\mathcal{Z}$ with metrics $d_\mathcal{X}$, $d_\mathcal{Y}$ and $d_\mathcal{Z}$, such that the induced topology is second countable (it admits a countable base). We assume that the metrics $d_\mathcal{X}$ and $d_\mathcal{Z}$ satisfy the Heine-Borel property, i.e., all closed and bounded sets are compact, and that for every $y \in \mathcal{M}_2^\mathcal{E}$ the *feasible set*

$$\pi_1(F^{-1}(y)) = \{x \in \mathcal{M}_1 : \exists e \in \mathcal{E} \text{ s.t. } F(x, e) = y\}$$

is compact. Under these assumptions we define the optimality constant as the smallest error any reconstruction map can achieve, and study both the case of worst-case noise (critical when there is risk of adversarial attacks) and average random noise (more typical in practical applications). We prove that the optimality constant is bounded from below and from above (sharply) by the *kernel size*, which is a quantity intrinsic to the inverse problem. For simplicity, we restrict to the best worst-case reconstruction error here. As we consider set-valued reconstruction maps $\varphi\colon \mathcal{M}_2^\mathcal{E} \rightrightarrows \mathcal{X}$, we use the Hausdorff distance $d_\mathcal{X}^H(\cdot, \cdot)$.

Definition: Optimality constant under worst-case noise The *optimality constant* of (1) is

$$c_{\text{opt}}(F, \mathcal{M}_1, \mathcal{E}) = \inf_{\varphi\colon \mathcal{M}_2^\mathcal{E} \rightrightarrows \mathcal{X}} \sup_{x \in \mathcal{M}_1} \sup_{e \in \mathcal{E}} d_\mathcal{X}^H(x, \varphi(F(x, e)))$$

A mapping $\varphi\colon \mathcal{M}_2^\mathcal{E} \rightrightarrows \mathcal{X}$ that attains such an infimum is called an *optimal map*.

Definition: Kernel size with worst-case noise The kernel size of the problem (1) is

$$\text{kersize}(F, \mathcal{M}_1, \mathcal{E}) = \sup_{\substack{(x,e),(x',e') \in \mathcal{M}_1 \times \mathcal{E} \text{ s.t.} \\ F(x,e) = F(x',e')}} d_\mathcal{X}(x, x').$$

Theorem: Worst case optimality bounds Under the stated assumptions, the following holds.

(i) We have that

$$\text{kersize}(F, \mathcal{M}_1, \mathcal{E})/2 \leqslant c_{\text{opt}}(F, \mathcal{M}_1, \mathcal{E}) \leqslant \text{kersize}(F, \mathcal{M}_1, \mathcal{E}). \quad (3)$$

(*ii*) Moreover, the map

$$\Psi(y) = \underset{z\in\mathcal{X}}{\operatorname{argmin}} \sup_{(x,e)\in F^{-1}(y)} d_{\mathcal{X}}(x,z) = \underset{z\in\mathcal{X}}{\operatorname{argmin}}\, d^H_{\mathcal{X}}(z, \pi_1(F^{-1}(y))),$$

has non-empty, compact values and it is an optimal map.

This illustrates a fundamental limit for the inverse problem (1). Indeed, one would hope to find a solution for (1) whose error is as small as possible. The lower bound in (3) shows that there is a constant intrinsic to the problem – the kernel size – such that no reconstruction error can be made smaller than this constant for all possible choices of $x \in \mathcal{M}_1$. Note that the above theorem is extended to the average reconstruction error in our work.

Background and related work

Linear inverse problems (2) arise in image reconstruction for scientific, industrial and medical applications [3-7]. Traditional image reconstruction methods are model-based, and they have also been studied in a Bayesian setting [8]. Less studied are non-linear inverse problems, which appear in geophysics [9,10] and in inverse scattering problems [11,12]. Accuracy and error bounds have been studied in [13]. In many cases, today, DL-based methods obtain higher accuracy than traditional methods, and an overview is given in [14-17]. The key point of DL based methods for solving inverse problems in imaging is that given enough data a neural network can be trained to approximate a decoder to solve (2).

References

[1] A. Cohen, W. Dahmen, R. DeVore. Compressed sensing and best k-term approximation. Journal of the American mathematical society, 22(1):211-231, 2009.

[2] A. Bourrier, M. E. Davies, T. Peleg, P. Perez, R. Gribonval. Fundamental performance limits for ideal decoders in high- dimensional linear inverse problems. IEEE Transactions on Information Theory, 60(12):7928-7946, 2014.

[3] C. A. Bouman. Foundations of Computational Imaging: A Model-Based Approach. SIAM, Philadelphia, PA, 2022.

[4] H. H. Barrett, K. J. Myers. Foundations of image science. John Wiley & Sons, 2013.

[5] C. L. Epstein. Introduction to the mathematics of medical imaging. SIAM, 2007.

[6] P. Kuchment. The Radon transform and medical imaging. SIAM, 2013.

[7] F. Natterer, F. Wubbeling. Mathematical methods in image reconstruction. SIAM, 2001.

[8] A. M. Stuart. Inverse problems: A Bayesian perspective. Acta numerica, 19:451-559, 2010.

[9] C. G. Farquharson, D. W. Oldenburg. Non-linear inversion using general measures of data misfit and model structure. Geophysical Journal International, 134(1):213-227, 1998.

[10] C. G. Farquharson, D. W. Oldenburg. A comparison of automatic techniques for estimating the regularization parameter in non-linear inverse problems. Geophysical Journal International, 156(3):411-425, 2004.

[11] J. L. Mueller, S. Siltanen. Linear and nonlinear inverse problems with practical applications. SIAM, 2012.

[12] M. T. Bevacqua, L. Crocco, L. Di Donato, T. Isernia. An algebraic solution method for nonlinear inverse scattering. IEEE Transactions on Antennas and Propagation, 63(2):601-610, 2014.

[13] N. Keriven, R. Gribonval. Instance optimal decoding and the restricted isometry property. In Journal of Physics: Conference Series, IOP Publishing:012002. 2018.

[14] M. T. McCann, M. Unser. Biomedical image reconstruction: From the foundations to deep neural networks. Foundations and Trends in Signal Processing, 13(3):283-359, 2019.

[15] S. Arridge, P. Maass, O. Oktem, C.-B. Sch onlieb. Solving inverse problems using data-driven models. Í Acta Numer., 28:1-174, 2019.

[16] G. Wang, J. C. Ye, K. Mueller, J. A. Fessler. Image reconstruction is a new frontier of machine learning. IEEE Trans. Med. Imaging, 37(6):1289-1296, 2018.

[17] H. Ben Yedder, B. Cardoen, G. Hamarneh. Deep learning for biomedical image reconstruction: A survey. Artificial intelligence review, 54(1):215-251, 2021.

MS23 2
Wed Sep 6
9:00 am
9:30 am
VG1.103

Inverse medium scattering for a nonlinear Helmholtz equation

R. Griesmaier

The linear Helmholtz equation is used to model the propagation of sound waves or electromagnetic waves of small amplitude in inhomogeneous isotropic media in the time-harmonic regime. However, if the amplitudes are large then intensity-dependent material laws are required and nonlinear Helmholtz equations are more appropriate. A prominent example are Kerr-type nonlinear media. In this talk we discuss an inverse medium scattering problem for a class of nonlinear Helmholtz equations

$$\Delta u + k^2 u \ = \ -k^2 q(x,|u|)u\,, \qquad x \in \mathbb{R}^d\,,\ d = 2,3\,,$$

that covers generalized Kerr-type nonlinear media of the form

$$q(x,|z|) \ = \ q_0(x) + \sum_{l=1}^{L} q_l(x)|z|^{\alpha_l}\,, \qquad x \in \mathbb{R}^d\,,\ z \in \mathbb{C}\,,$$

where $q_0, \ldots, q_L \in L^\infty(\mathbb{R}^d)$ with support in some bounded open set $D \subset \mathbb{R}^d$, the lowest order term satisfies $\operatorname{essinf} q_0 > -1$ in $\mathbb{R}^d$, and the exponents fulfill $0 < \alpha_1 < \cdots < \alpha_L < \infty$.

Assuming the knowledge of a nonlinear far field operator, which maps Herglotz incident waves to the far field patterns of the corresponding unique small solutions of the nonlinear scattering problem, we show that the nonlinear index of refraction is uniquely determined.

This is joint work with Marvin Knöller and Rainer Mandel (KIT).

MS34 1
Mon Sep 4
2:00 pm
2:30 pm
VG3.103

Data-driven quantitative photoacoustic imaging

J. Grohl

Photoacoustic imaging faces the challenge of accurately quantifying measurements to accurately reconstruct chromophore concentrations and thus improve patient outcomes in clinical applications. Proposed approaches to solve the quantification problem are often limited in scope or only applicable to simulated data. We use a collection of well-characterised imaging targets (phantoms) as well as simulated data to enable supervised training and validation of quantification methods and train a U-Net on the data set. Our experiments demonstrate that phantoms can serve as reliable calibration objects and that deep learning methods can generalize to estimate the optical properties of previously unseen test images. Application of the trained model to a blood flow phantom and a mouse model highlights the strengths and weaknesses of the proposed approach.

MS30 2
Thu Sep 7
2:00 pm
2:30 pm
VG2.103

Some inverse problems on graphs with internal functionals

F. Guevara Vasquez, G. Yang

We consider the problem of finding the resistors in a network from knowing the power that they dissipate under loads imposed at a few terminal nodes. This data could be obtained e.g. from thermal imaging of the network. We use a method inspired by Bal [1] to give sufficient conditions under which the linearized problem admits a unique solution. Similar results are shown for a discrete analogue to the Schrödinger equation and for the case of impedances or complex valued conductivities.

References

[1] Bal, Guillaume. Hybrid inverse problems and redundant systems of partial differential equations, Inverse problems and applications 619: 15-48, 2014.

Bayesian random tomography

MS26 2
Thu Sep 7
2:00 pm
2:30 pm
VG3.102

M. Habeck

The reconstruction problem in random tomography is to reconstruct a 3D volume from 2D projection images acquired in unknown random directions. Random tomography is a common problem in imaging science and highly relevant to cryo-electron microscopy. This talk outlines a Bayesian approach to random tomography [1, 2]. At the core of the approach is a meshless representation of the 3D volume based on a Gaussian radial basis function kernel. Each Gaussian can be interpreted as a particle such that the unknown volume is represented by a cloud of particles. The particle representation allows us to speed up the computation of projection images and to represent a large variety of molecular structures accurately and efficiently. Another innovation is the use of Markov chain Monte Carlo algorithms to infer the particle positions as well as the unknown orientations. Posterior sampling is challenging due to the high dimensionality and multimodality of the posterior distribution. We tackle these challenges by using Hamiltonian Monte Carlo and a recently developed Geodesic slice sampler [3]. We demonstrate the strengths of the approach on various simulated and real datasets.

References

[1] P. Joubert, M. Habeck. Bayesian inference of initial models in cryo-electron microscopy using pseudo-atoms, Biophysical journal 108(5): 1165-1175, 2015.

[2] N. Vakili, M. Habeck. Bayesian Random Tomography of Particle Systems, Frontiers in Molecular Biosciences 8, 2021. [658269]

[3] M. Habeck, M. Hasenpflug, S. Kodgirwar, D. Rudolf. Geodesic slice sampling on the sphere, arXiv preprint arXiv:2301.08056, 2023.

Interior transmission problems related to imaging periodic layers

MS29 3
Tue Sep 5
2:00 pm
2:30 pm
VG3.104

H. Haddar, N. Jenhani

The extension of sampling methods to the imaging of locally perturbed periodic layers [1] requires the analysis of interior transmission problems in unbounded waveguides. The resulting problem is no longer of Fredholm type and its study necessitates additional tools to those classically used for the case of bounded domains. We shall present a proof of well posdeness in the case of absorbing background using Floquet-Bloch transform and finite dimensional approximation with respect to the Floquet-Bloch variable. The analysis of absorption free problem and related transmission eigenvalues is an open problem that we shall also briefly discuss. We plan to additionally present the so-called differential sampling method where some specific single Floquet-Bloch variable transmission eigenvalue problems shows up. These problems had been adressed in the case of periodically distributed defects in [2].

References

[1] Y. Boukari, H. Haddar, N. Jenhani. Analysis of sampling methods for imaging a periodic layer and its defects, Inverse Problems, 2023.

[2] F. Cakoni, H. Haddar, T.-P. Nguyen. New interior transmission problem applied to a single Floquet-Bloch mode imaging of local perturbations in periodic media, Inverse Problems, 2018.

MS22 3
Wed Sep 6
10:00 am
10:30 am
VG1.101

Phase retrieval framework for direct reconstruction of the projected refractive index applied to ptychography and holography

J. Hagemann, F. Wittwer, C. G. Schroer

The interaction of an object with a coherent (x-ray) probe often encodes its properties in a complex-valued function, which is then detected in an intensity-only measurement. Phase retrieval methods commonly infer this complex-valued function from the intensity. However, the decoding of the object from the complex-valued function often involves some ambiguity in the phase, e.g., when the phase shift in the object exceeds 2π. Here, we present a phase retrieval framework to directly recover the amplitude and phase of the object. This refractive framework is straightforward to integrate into existing algorithms. As examples, we introduce refractive algorithms for ptychography and near-field holography and demonstrate this method using measured data.

MS40
Tue Sep 5
1:30 pm
2:00 pm
VG2.107

Iterative and data-driven motion compensation in tomography

B. Hahn, M. Feinler

Most tomographic modalities record the data sequentially, i.e. temporal changes of the object lead to inconsistent measurements. Consequently, suitable models and algorithms have to be developed in order to provide artefact free images. In this talk, we provide an overview of different strategies, including a data-driven approach to extract explicit motion maps which can then be incorporated within direct or iterative reconstruction methods for the underlying dynamic inverse problem. Our methods are illustrated by numerical results from real as well as simulated data of different imaging modalities.

MS29 3
Tue Sep 5
1:30 pm
2:00 pm
VG3.104

A new family of nearly singular interior transmission eigenvalues for inverse scattering

M. Halla

I propose a new family of nearly singular interior transmission eigenvalue problems for inverse scattering. For a known support of the inhomogeneity the eigenvalues allow to identify e.g. the piece-wise constant values of the refractive index. For an unknown support of the inhomogeneity the eigenvalues allow to construct an indicator function, I present an analysis for ideal settings and numerical examples for general cases.

MS10 3
Fri Sep 8
2:00 pm
2:30 pm
VG1.103

Learned SVD for limited data inversion in PAT and X-ray CT

M. Haltmeier, J. Schwab, S. Antholzer

We present a data-driven regularization method for inverse problems introduced in [1,2]. Our approach consists of two steps. In the first step, an intermediate reconstruction is performed by applying the truncated singular value decomposition (SVD). To prevent noise amplification, only coefficients corresponding to sufficiently large singular values are used, while the remaining coefficients are set to zero. In a second step, a trained deep neural network is used to recover the truncated SVD coefficients. We show that the proposed scheme yields a convergent regularization method. Numerical results are presented for limited data problems in PAT (photacoustic tomography) and X-ray CT (computed tomography), showing that learned SVD regularization significantly improves pure truncated SVD regularization.

References

[1] J. Schwab, S. Antholzer, M. Haltmeier. Big in Japan: Regularizing networks for solving inverse problems, Journal of Mathematical Imaging and Vision, 62(3): 445-455, 2020.

[2] J. Schwab, S. Antholzer, R. Nuster, G. Paltauf, M. Haltmeier. Deep learning of truncated singular values for limited view photoacoustic tomography, Photons Plus Ultrasound: Imaging and Sensing 10878: 254-262, 2019.

Null Space Networks for undersampled Fourier data

MS50 2
Fri Sep 8
4:30 pm
5:00 pm
VG1.105

M. Haltmeier

Preserving data consistency is a key property of learned image reconstruction. This can be achieved either by specific network architecture or by subsequent projection of the network reconstruction. In this talk, we analyze null-space networks for undersampled image reconstruction. We numerically compare image reconstruction from undersampled Fourier data and investigate the effect integrating data consistency in the network architecture

Transmission Eigenvalues for a Conductive Boundary

MS06 3
Thu Sep 7
4:30 pm
5:00 pm
VG3.103

I. Harris

In this talk, we will investigate the acoustic transmission eigenvalue problem associated with an inhomogeneous media with a conductive boundary. These are a new class of eigenvalue problems that is not elliptic, not self-adjoint, and non-linear, which gives the possibility of complex eigenvalues. We will discuss the existence of the eigenvalues as well as their dependence on the material parameters. Due to the fact that this is a non-standard eigenvalue problem, a discussion of the numerical calculations will also be highlighted. This is joint work with: R.-C. Ayala, O. Bondarenko, A. Kleefeld, and N. Pallikarakis.

Asymptotics Applied to Small Volume Inverse Shape Problems

MS20 1
Thu Sep 7
3:00 pm
3:30 pm
VG3.104

I. Harris

We consider two inverse shape problems coming from diffuse optical tomography and inverse scattering. For both problems, we assume that there are small volume subregions that we wish to recover using the measured Cauchy data. We will derive an asymptotic expansion involving their respective fields. Using the asymptotic expansion, we derive a MUSIC-type algorithm for the Reciprocity Gap Functional, which we prove can recover the subregion(s) with a finite amount of Cauchy data. Numerical examples will be presented for both problems in two dimensions in the unit circle.

Analysis of a localized non-linear ensemble Kalman-Bucy filter with sparse observations

MS04 2
Tue Sep 5
5:30 pm
6:00 pm
VG2.102

G. Hastermann, **J. de Wiljes**

With large scale availability of precise real time data, their incorporation into physically based predictive models, became increasingly important. This procedure of combining the prediction and observation is called data assimilation. One especially popular algorithm of the class of Bayesian sequential data assimilation methods is the ensemble Kalman filter which successfully extends the ideas of the Kalman filter to the non-linear situation. However, in case of spatio-temporal models one regularly relies on some version of localization, to avoid spurious oscillations.

In this work we develop a-priori error estimates for a time continuous variant of the ensemble Kalman filter, known as localized ensemble Kalman–Bucy filter. More specifically we aim for the scenario of sparse observations applied to models from fluid dynamics and space weather.

MS34 2
Mon Sep 4
5:00 pm
5:30 pm
VG3.103

Model corrections in linear and nonlinear inverse problems

A. Hauptmann, A. Arjas, M. Sillanpää

Solving inverse problems in a variational formulation requires repeated evaluation of the forward operator and its derivative. This can lead to a severe computational burden, especially so for nonlinear inverse problems, where the derivative has to be recomputed at every iteration. This motivates the use of faster approximate models to make computations feasible, but due to an arising approximation error the need to introduce a designated correction arises.

In this talk we first discuss the concept of learned model corrections applied to linear inverse problems, when computationally fast but approximate forward models are used. We then proceed to examine the possibility to approximate nonlinear models with a linear one and then solve the linear problem instead, avoiding differentiation of the nonlinear model. To correct for the arising approximation errors, we sequentially estimate the error between linear and nonlinear model and update a correction term in the variational formulation. In both cases we discuss convergence properties to solutions of the variational problem given the accurate models.

MS33 1
Wed Sep 6
9:00 am
9:30 am
VG1.105

Equivariant Neural Networks for Indirect Measurements

N. Heilenkötter, M. Beckmann

In the recent years, deep learning techniques have shown great success in various tasks related to inverse problems, where a target quantity of interest can only be observed through indirect measurements of a forward operator. Common approaches apply deep neural networks in a post-processing step to the reconstructions obtained by classical reconstruction methods. However, the latter methods can be computationally expensive and introduce artifacts that are not present in the measured data and, in turn, can deteriorate the performance on the given task.

To overcome these limitations, we propose a class of equivariant neural networks that can be directly applied to the measurements to solve the desired task. To this end, we build appropriate network structures by developing layers that are equivariant with respect to data transformations induced by symmetries in the domain of the forward operator. We rigorously analyze the relation between the measurement operator and the resulting group representations and prove a representer theorem that characterizes the class of linear operators that translate between a given pair of group actions.

Based on this theory, we extend the existing concepts of Lie group equivariant deep learning to inverse problems and introduce new representations that are the results of the involved measurement operations. This allows us to efficiently solve classification, regression or even reconstruction tasks based on indirect measurements also for very sparse data problems, where a classical reconstruction based approach may be hard or even impossible. To illustrate the effectiveness of our approach, we perform numerical experiments on selected inverse problems and compare our results to existing methods.

Convex regularization in statistical inverse learning problems

MS03 2
Mon Sep 4
4:30 pm
5:00 pm
VG2.103

T. Helin

Statistical inverse learning aims at recovering an unknown function f from randomly scattered and possibly noisy point evaluations of another function g, connected to f via an ill-posed mathematical model. In this talk I blend statistical inverse learning theory with convex regularization strategies and derive convergence rates for the corresponding estimators.

Multiscale Parameter Identification: mesoscopic kernel reconstruction from macroscopic data

MS56 1
Mon Sep 4
1:30 pm
2:00 pm
VG2.106

K. Hellmuth

Motivated from a biological application, we study mesoscopic velocity jump (run-and-tumble) models for particle motion in the phase space. The motion is characterized by a sudden change of direction which is governed by the turning rate. The inverse problem is to determining this mesoscopic turning rate from macroscopic, i.e. directionally averaged data. The lack of directional information in the measurements poses problems in the reconstruction of the mesoscopic quantity. These problems can be leveraged by the use of time dependent interior domain data, as theoretical results on the reconstructability suggest. We then investigate the macroscopic limit behaviour for the inverse problem on the macroscopic regime and present first results on the numerical inversion.

This is joint work with Christian Klingenberg (Würzburg, Germany), Qin Li (Madison, Wisc., USA) and Min Tang (Shanghai, China).

Supercomputing-based inverse modeling of high-resolution atmospheric contaminant source intensity distribution using remote sensing data

MS55 1
Mon Sep 4
2:00 pm
2:30 pm
VG3.101

M. Huang, Y. Heng, J. Chen, Y. Han, L. Hoffmann, S. Gross

Atmospheric pollution prevention and control is an important global issue[1]. Observing the emission of harmful trace gases and their atmospheric transport dynamics on a global scale is of great significance for in-depth study of major problems, such as climate change and ecological and environmental change[2, 3]. In recent years, the inverse problem of atmospheric contaminant source intensity distribution has attracted more and more attention from researchers[4]. Due to its mathematical ill-posedness and high computational costs, it is necessary to develop new computational tools[5]. Accurate, rapid, and stable inverse analysis of atmospheric contaminant source intensity distribution, and subsequently using high-resolution numerical simulation methods to predict the local or large-scale, short-term or long-term atmospheric environmental impacts caused by major sudden natural disasters and industrial pollution events, has important scientific significance and practical value.

By using limited information of satellite observation data obtained through NIS (Nonlinear Inverse Scattering) technology[7, 8, 9], we have established a high-throughput parallel computing framework for solving the mathematical and physical inverse problem of high-resolution spatiotemporal atmospheric contaminant sources distribution[10, 11, 12]. A real-time inverse analysis and transport simulation of atmospheric contaminant source intensity distribution with high resolution, stability, and reliability are realized. And thus the high-resolution reanalysis data and prediction information on a global scale are available, which can not be directly obtained by current satellite or optical radar measurement technologies. Considering the influence of complex physical and chemical processes, such as the transport of particles in wind fields and the scattering of particles due to light irradiation, the relationship between unknown source parameters and observed contaminant concentrations is usually nonlinear[2, 5, 7, 13, 14, 15]. Therefore, we comprehensively use numerical simulation, optimization methods, and statistical inference techniques[6, 16, 17]. Taking volcanic eruption and forest fire as examples, based on remote sensing data, we use the jointly developed Lagrangian transport model MPTRAC (Massive Parallel Trajectory Calculation) for forward simulation[11]. Combined with heuristic methods such as segmented strong constraint "product rule" proposed by us, the computational bottleneck of traditional serial regularization methods for solving such inverse problems is overcome[10, 12]. And a million-core supercomputing-based inverse calculation strategy is developed, which greatly reduces time costs while ensuring accuracy and reliability, meeting the needs of future real-time prediction tools.

This study provides practical application scenarios for NIS technology, and plays an important theoretical and practical role in ensuring aviation safety, exploring the mechanism of pollutant degradation, and revealing the causes of global climate change.

References

[1] N.-N. Zhang et al. Spatiotemporal trends in PM2. 5 levels from 2013 to 2017 and regional demarcations for joint prevention and control of atmospheric pollution in China, Chemosphere 210: 1176-1184, 2018.

[2] S. Huang et al. Inverse problems in atmospheric science and their application, Journal of Physics: Conference Series, IOP Publishing, 2005.

[3] W. Freeden et al. Handbook of geomathematics, 2nd edition. Springer Berlin Heidelberg, 2015.

[4] M. S. Zhdanov. Inverse Theory and Applications in Geophysics, 2nd edition. Elsevier Science, 2015.

[5] J. L. Mueller, S. Siltanen. Linear and nonlinear inverse problems with practical applications, SIAM, 2012.

[6] Y. Bai et al. Computational methods for applied inverse problems, Walter de Gruyter, 2012.

[7] D. Efremenko, A. Kokhanovsky. Foundations of Atmospheric Remote Sensing, Springer, 2021.

[8] W. C. Chew et al. Nonlinear diffraction tomography: The use of inverse scattering for imaging, Int J Imaging Syst Technol. 7(1):16-24, 1996.

[9] T. Hasegawa, T. Iwasaki. Microwave imaging by quasi-inverse scattering, Electron Comm Jpn Pt I. 87(5):52-61, 2004.

[10] Y. Heng et al. Inverse transport modeling of volcanic sulfur dioxide emissions using large-scale simulations, Geoscientific Model Development 9(4): 1627-1645, 2016.

[11] L. Hoffmann et al. Massive-Parallel Trajectory Calculations version 2.2 (MPTRAC-2.2): Lagrangian transport simulations on graphics processing units (GPUs), Geoscientific Model Development 15(7): 2731-2762, 2022.

[12] M. Liu et al. High-Resolution Source Estimation of Volcanic Sulfur Dioxide Emissions Using Large-Scale Transport Simulations, Computational Science - ICCS 2020: 60-73, 2020.

[13] K. Chadan et al. An introduction to inverse scattering and inverse spectral problems, Society for Industrial and Applied Mathematics, 1997.

[14] D. P. Winebrenner, J. Sylvester. Linear and nonlinear inverse scattering, SIAM Journal on Applied Mathematics, 59(2): 669-699, 1998.

[15] V. Isakov. Inverse problems for partial differential equations, Springer, 2006.

[16] E. Haber et al. On optimization techniques for solving nonlinear inverse problems, Inverse problems, 6(5): 1263, 2000.

[17] R. C. Aster et al. Parameter estimation and inverse problems, Elsevier, 2018.

Stochastic Normalizing Flows for Inverse Problems via Markov Chains

MS17
Tue Sep 5
4:00 pm
4:30 pm
VG1.104

P. Hagemann, J. Hertrich, G. Steidl

Normalizing flows aim to learn the underlying probability distribution of given samples. For this, we train a diffeomorphism which pushes forward a simple latent distribution to the data distribution. However, recent results show that normalizing flows suffer from topolgical constraints and limited expressiveness. Stochastic normalizing flows can overcome these topological constraints and improve the expressiveness of normalizing flow architectures by combining deterministic, learnable flow transformations with stochastic sampling methods. We consider stochastic normalizing flows from a Markov chain point of view. In particular, we replace transition densities by general Markov kernels and establish proofs via Radon-Nikodym derivatives which allows to incorporate distributions without densities in a sound way. Further, we generalize the results for sampling from posterior distributions as required in inverse problems. The performance of the proposed conditional stochastic normalizing flow is demonstrated by numerical examples.

Bias-free localizations in cryo-single molecule localization microscopy

MS16 1
Thu Sep 7
2:30 pm
3:00 pm
VG0.111

F. Hinterer

Single molecule localization microscopy (SMLM) has the potential to resolve structural details of biological samples at the nanometer length scale. Compared to room temperature experiments, SMLM performed under cryogenic temperature achieves higher photon yields and, hence, higher localization precision. However, to fully exploit the resolution it is crucial to account for the anisotropic emission characteristics of fluorescence dipole emitters with fixed orientation. In this talk, I will present recent advances along this avenue.

Passive inverse obstacle scattering problems

MS06 1
Wed Sep 6
9:30 am
10:00 am
VG0.110

T. Hohage, M. Liu

We report on the determination of the shape and location of scattering obstacles by passive imaging techniques. More precisely, we assume that the available data are correlations of randomly excited waves with zero mean. Passive imaging techniques are employed in seismology, ocean acoustics, experimental aeroacoustics, ultrasonics, and local helioseismology. They have also been thoroughly investigated mathematically, typically as a qualitative imaging modality, but the study of inverse obstacle problems seems to be new in this context.

We assume that wave propagation is described by the Helmholtz equation in two or three space dimensions. Furthermore, the random source is assumed to be uncorrelated and either compactly supported or at infinite distance. The source strength is considered as an additional unknown of the inverse problem.

As a main theoretical result, we show that both the shape of a smooth obstacle without holes and the source strength are uniquely determined by correlation data, both in the near-field and in the far-field. We also show numerical simulations supporting our theoretical results.

MS33 2
Thu Sep 7
2:00 pm
2:30 pm
VG1.105

Posterior-Variance-Based Error Quantification for Inverse Problems in Imaging

D. Narnhofer, A. Habring, M. Holler, T. Pock

We present a method for obtaining pixel-wise error bounds in Bayesian regularization of inverse imaging problems. The proposed approach employs estimates of the posterior variance together with techniques from conformal prediction in order to obtain error bounds with coverage guarantees, without making any assumption on the underlying data distribution. It is generally applicable to Bayesian regularization approaches, independent, e.g., of the concrete choice of the prior. Furthermore, the coverage guarantees can also be obtained in case only approximate sampling from the posterior is possible. With this in particular, the proposed framework is able to incorporate any learned prior in a black-box manner.

Such a guaranteed coverage without assumptions on the underlying distributions is only achievable since the magnitude of the error bounds is, in general, unknown in advance. Nevertheless, as we confirm with experiments with multiple regularization approaches, the obtained error bounds are rather tight.

A preprint of this work is available at https://arxiv.org/abs/2212.12499

MS54 2
Mon Sep 4
4:30 pm
5:00 pm
VG1.101

Simultaneous recovery of attenuation and source density in SPECT and multibang regularisation

S. Holman

I will discuss results about simultaneous recovery of the attenuation and source density in the SPECT inverse problem, which is given mathematically by the attenuated ray transform. Assuming the attenuation is piecewise constant and the source density piecewise smooth we show that, provided certain conditions are satisfied, it is possible to uniquely determine both. I will also discuss a numerical algorithm that allows for determination of both parameters in the case when the range of the piecewise constant attenuation is known and look at some synthetic numerical examples. This is based on joint work with Philip Richardson.

MS07 1
Fri Sep 8
2:00 pm
2:30 pm
VG1.101

Explicit error rate results in the context of domain generalization

M. Holzleitner

Given labeled data from different source distributions, the problem of domain generalization is to learn a model that is expected to generalize well on new target distributions for which you only have unlabeled samples. We frame domain generalization as a problem of functional regression. This concept leads to a new algorithm for learning a linear operator from marginal distributions of inputs to the corresponding conditional distributions of outputs given inputs. Our algorithm allows a source distribution-dependent construction of reproducing kernel Hilbert spaces for prediction and satisfies non-asymptotic error bounds for the idealized risk. We intend to give a short overview on the required mathematical concepts and proof techinques, and illustrate our approach by a numerical example. The talk is based on [1].

References

[1] M. Holzleitner, S. V. Pereverzyev, W. Zellinger. Domain Generalization by Functional Regression. arXiv:2302.04724, 2023.

Three-dimensional random wave coupling along a boundary with scaling representative of Mars' crust, and an associated inverse problem

MS37 2
Thu Sep 7
4:30 pm
5:00 pm
VG1.102

M. V. de Hoop, J. Garnier, K. Solna

We consider random wave coupling along a flat boundary in dimension three, where the coupling is between surface and body modes and is induced by scattering by a randomly heterogeneous medium. In an appropriate, anisotropic scaling regime we obtain a system of radiative transfer equations which are satisfied by the mean Wigner transform of the mode amplitudes. Interestingly, seismograms recently acquired with SEIS on Mars (InSight mission) show a behavior that fits the hypotheses of our analysis about the properties of its crust. We provide a rigorous probabilistic framework for describing solutions to the mentioned system using that it has the form of a Kolmogorov equation for some Markov process. We then prove statistical stability of the smoothed Wigner transform under the Gaussian approximation. We conclude with analyzing the nonlinear inverse problem for the radiative transfer equations and establish the unique recovery of phase and group velocities as well as power spectral information for the medium fluctuations from the observed smoothed Wigner transform.

Sampling from a posterior with Besov prior

MS21 1
Tue Sep 5
2:30 pm
3:00 pm
VG2.103

A. Horst, B. M. Afkham, Y. Dong, J. Lemvig

Besov priors for Bayesian inverse problems are interesting since they promote various types of regularity on the unknown, especially non-smooth regularity, depending on the choice of basis and parameters of the prior. Besov priors introduces a p-norm into the posterior, which makes effective Gaussian samplers inapplicable. Randomize-Then-Optimize (RTO) is an optimization-based sampling algorithm, that computes exact independent samples from a posterior with Gaussian prior and a linear forward operator. We introduce a prior transformation that transforms a Besov prior into a Gaussian prior, which makes Gaussian samplers like RTO applicable. The caveat of the transformation is that the forward operator becomes non-linear even though it originally was linear. To sample from the transformed posterior we use RTO samples as proposals for the Metropolis-Hastings algorithm. We apply this sampling method to a deconvolution problem where the type of Besov prior is varied, to discover the quality of the method and the posterior dependencies on the choice of Besov prior. Our results validate that the computed samples come from the original posterior with Besov prior and shows that the choice of prior basis and parameters has a significant impact on the posterior.

Slepian concentration problem for polynomials on the Ball

MS44 1
Mon Sep 4
2:00 pm
2:30 pm
VG2.104

X. Huang

The sources of geophysical signals are often spatially localized. Thus, adequate basis functions are required to model such properties. Slepian functions have proven to be a very successful tool.

Here, we consider theoretical properties of the Slepian spatial-spectral concentration problem for the space of multi-variate polynomials on the unit ball in $\mathbb{R}^d$ normalized under Jacobi weights. In particular, we show the phenomena of the step-like shape of the eigenvalue distribution of concentration operators, and characterize the transition by the Jacobi weight W_0, which serves as an analogue of the $2\Omega T$ rule in the classical Slepian theory. A numerical demonstration is performed for the 3-D ball with Lebesgue weights.

CT10
Fri Sep 8
3:00 pm
3:30 pm
VG3.102

The Range of Projection Pair Operators

R. Huber, R. Clackdoyle, L. Desbat

Tomographic techniques have become a vital tool in medicine, allowing doctors to observe patients' interior features. Modeling the measurement process (and the underlying physics) are projection operators, the most well-known one being the classical Radon transform. Identifying the range of projection operators has proven itself useful in various tomography-related applications [1-3], such as geometric calibration, motion detection, or more general projection model parameter identification. Projection operators feature the integration of density functions along certain curves (typically straight lines representing paths of radiation), and are subdivided into individual projections – data obtained during a single step of the measurement process.

Mathematically, given a bounded open set $\Omega \subset \mathbb{R}^2$ and bounded open sets $R, T \subset \mathbb{R}$, a function $\gamma\colon R \times T \to \mathbb{R}^2$ that diffeomorphically covers Ω and a function $\rho\colon R \times T \to \mathbb{R}^+$, an individual projection is an operator $p\colon L^2(\Omega) \to L^2(R)$ with

$$[pf](r) = \int_T f\big(\gamma(r,t)\big)\rho\big(r,t\big)\,\mathrm{d}t \qquad \text{for all } r \in R$$

for $f \in \mathcal{C}_c^\infty(\Omega)$ (the unknown density). In other words, r determines an integration curve $\gamma(r,\cdot)$, and $[pf](r)$ is the associated line integral weighted by ρ (representing physical effects such as attenuation). Note that we do not allow projection truncation as Ω is covered by γ. More general projection operators are $P\colon L^2(\Omega) \to L^2(R_1) \times \cdots \times L^2(R_N)$ with $Pf = (p_1 f, \ldots, p_N f)$ with N projections (with associated $\gamma_n, \rho_n, R_n, T_n$ for $n \in \{1, \ldots, N\}$). In this work, we are concerned with characterizing the range of what we call projection pair operators, i.e., projection operators $P = (p_1, p_2)$ consisting of only two projections ($N = 2$). Conditions on the range of projection pair operators naturally impose properties on larger projection operators' ranges. These pairwise range conditions are particularly convenient for applications.

A natural approach for identifying the range is determining the range's orthogonal complement. The orthogonal complement being small would facilitate determining whether a projection pair is inside the range. We find that such normal vectors naturally consist of two functions G_1 and G_2 – one per projection – that need to satisfy

$$-\frac{\rho_1\big(\gamma_1^{-1}(x)\big)\left|\det\left(\frac{\mathrm{d}\gamma_1^{-1}}{\mathrm{d}x}(x)\right)\right|}{\rho_2\big(\gamma_2^{-1}(x)\big)\left|\det\left(\frac{\mathrm{d}\gamma_2^{-1}}{\mathrm{d}x}(x)\right)\right|} = \frac{G_2(r_2(x))}{G_1(r_1(x))} \qquad \text{for a.e. } x \in \Omega,$$

where $r_1(x)$ is such that $x \in \gamma_1(r_1(x), \cdot)$ and analogously for $r_2(x)$. This uniquely determines the orthogonal direction; therefore, the orthogonal complement's dimension is at most one. Thus, two projections' information can only overlap in a single way. Due to this equation's specific structure – the right-hand side is a ratio of functions depending only on r_1 and r_2, respectively – it is easy to imagine that this equation is not always solvable. While it is solvable for some standard examples like the conventional and exponential Radon transforms (whose ranges were already characterized [4,5]), we find that no solution exists for the exponential fanbeam transform and for the Radon transform with specific depth-effects. The fact that no solution exists implies that the operator's range is dense. Range conditions of this type can only precisely characterize the range when it is closed (otherwise, only the closure is characterized). In this regard, we find that the question of the range's closedness is equivalent for all projection pair operators whose γ and ρ functions are suitably related.

Acknowledgment: This work was supported by the ANR grant ANR-21-CE45-0026 'SPECT-Motion-eDCC'.

References

[1] F. Natterer. "Computerized Tomography with Unknown Sources". SIAM Journal on Applied Mathematics 43.5,DOI : 10.1137/0143079:1201-1212 1983.

[2] J. Xu, K. Taguchi, B. Tsui. "Statistical Projection Completion in X-ray CT Using Consistency Conditions". IEEE Trans. Med. Imaging 29, DOI : 10.1109/TMI.2010. 2048335: 1528-1540 2010.

[3] R. Clackdoyle, L. Desbat. "Data consistency conditions for truncated fanbeam and parallel projections." Medical physics 42 2:831-45, 2015.

[4] V. Aguilar, P. Kuchment. "Range conditions for the multidimensional exponential X-ray transform". Inverse Problems 11.5 ,DOI : 10.1088/0266-5611/11/5/002: 977, 1995.

[5] F. Natterer. The Mathematics of Computerized Tomography. Philadelphia: Society for Industrial and Applied Mathematics, Chap. II.4, 2001.

Phase-contrast THz-CT for non-destructive testing

MS16 1
Thu Sep 7
1:30 pm
2:00 pm
VG0.111

S. Hubmer, **R. Ramlau**

In this talk, we consider the imaging problem of THz computed tomography (THz-CT), in particular for the non-destructive testing of extruded plastic profiles. We derive a general nonlinear mathematical model describing a full THz tomography experiment, and consider several approximations connecting THz tomography with standard computerized tomography and the Radon transform. The employed models are based on geometrical optics, and contain both the THz signal amplitude and the phase. We consider several reconstruction approaches using the corresponding phase-contrast sinograms, and compare them both qualitiatively and quantitatively on experimental data obtained from 3D printed plastic profiles which were scanned with a THz time-domain spectrometer in transmission geometry.

Efficient minimization of variational functionals via semismooth* Newton methods

MS02 1
Tue Sep 5
2:00 pm
2:30 pm
VG1.102

S. Hubmer, **R. Ramlau**

In this talk, we consider the efficient numerical minimization of variational functionals as they appear for example in L_p or TV regularization of nonlinear inverse problems. For this, we consider so-called semismooth* Newton methods, which are a class of optimization methods for non-differentiable and set-valued mappings. Based on the concept of (limiting) normal cones, which are a purely geometrical generalization of derivatives, these methods can be shown to converge locally superlinearly under suitable assumptions. Furthermore, we show how they can be applied to efficiently minimize variational functionals with general convex and in some special cases even non-convex penalty terms.

MS05 1
Wed Sep 6
10:30 am
11:00 am
VG2.102

Early stopping for conjugate gradients in statistical inverse problems

L. Hucker, M. Reiß

We consider estimators obtained by applying the conjugate gradient algorithm to the normal equation of a prototypical statistical inverse problem. For such iterative procedures, it is necessary to choose a suitable iteration index to avoid under- and overfitting. Unfortunately, classical model selection criteria can be prohibitively expensive in high dimensions. In contrast, it has been shown for several methods that sequential early stopping can achieve statistical and computational efficiency by halting at a data-driven index depending on previous iterates only. Residual-based stopping rules, similar to the discrepancy principle for deterministic problems, are well understood for linear regularization methods. However, in the case of conjugate gradients, the estimator depends nonlinearly on the observations, allowing for greater flexibility. This significantly complicates the error analysis. We establish adaptation results in this setting.

MS24 2
Thu Sep 7
5:00 pm
5:30 pm
VG1.101

Gradient Step and Proximal denoisers for convergent plug-and-play image restoration.

S. Hurault, A. Leclaire, N. Papadakis

Plug-and-Play (PnP) methods constitute a class of iterative algorithms for imaging problems where regularization is performed by an off-the-shelf denoiser. Specifically, given an image dataset, optimizing a function (e.g. a neural network) to remove Gaussian noise is equivalent to approximating the gradient or the proximal operator of the log prior of the training dataset. Therefore, any off-the-shelf denoiser can be used as an implicit prior and inserted into an optimization scheme to restore images. The PnP and Regularization by Denoising (RED) frameworks provide a basis for this approach, for which various convergence analyses have been proposed in the literature. However, most existing results require either unverifiable or suboptimal hypotheses on the denoiser, or assume restrictive conditions on the parameters of the inverse problem. We will introduce the Gradient Step and Proximal denoisers, and their variants, recently proposed to restore RED and PnP algorithms to their original form as (nonconvex) real proximal splitting algorithms. These new algorithms are shown to converge towards stationary points of an explicit functional and to perform state-of-the-art image restoration, both quantitatively and qualitatively.

MS32 1
Wed Sep 6
10:00 am
10:30 am
VG1.104

Optimality of pulse energy for photoacoustic tomography

B. Kaltenbacher, P. T. Huynh

Photoacoustic tomography (PAT) is a rapidly evolving imaging technique that combines high contrast of optical imaging with high resolution of ultrasound imaging. Using typically noisy measurement data, one is interested in identifying some parameters in the governing PDEs for the photoacoustic tomography system. Hence, an essential factor in estimating these parameters is the design of the system, which typically involves multiple factors that can impact the accuracy of reconstruction. In this work, employing a Bayesian approach to a PAT inverse problem we are interested in optimizing the laser pulse of the PAT system in order to minimize the uncertainty of the reconstructed parameter. Additionally, we take into account wave propagation attenuation for the inverse problem of PAT, which is governed by a fractionally damped wave equation. Finally, we illustrate the effectiveness of our proposed method using a numerical simulation.

Linearised inverse conductivity problem: reconstruction and Lipschitz stability for infinite-dimensional spaces of perturbations

MS23 2
Wed Sep 6
9:30 am
10:00 am
VG1.103

H. Garde, N. Hyvönen

The linearised inverse conductivity problem 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 Fréchet 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 simulated by solving the original nonlinear forward problem.

Heuristic parameter choice from local minimum points of the quasioptimality function for the class of regularization methods

CT05
Thu Sep 7
2:00 pm
2:30 pm
VG2.105

U. Hämarik, T. Raus

We consider an operator equation

$$Au = f, \quad f \in R(A), \tag{1}$$

where $A \in L(H, F)$ is the linear continuous operator between real Hilbert spaces H and F. In general this problem is ill-posed: the range $R(A)$ may be non-closed, the kernel $N(A)$ may be non-trivial. Instead of an exact right-hand side f_* we have only an approximation $f \in F$. For the regularization of problem (1) we consider the following class of regularization methods:

$$u_r = (I - A^*Ag_r(A^*A))u_0 + g_r(A^*A)A^*f.$$

Here u_0 is the initial approximation, r is the regularization parameter, I is the identity operator and the generating function $g_r(\lambda)$ satisfies the conditions

$$\sup_{0\leqslant\lambda\leqslant\|A^*A\|} |g_r(\lambda)| \leqslant \gamma r, \quad r \geqslant 0, \quad \gamma > 0.$$

$$\sup_{0\leqslant\lambda\leqslant\|A^*A\|} \lambda^p |1 - \lambda g_r(\lambda)| \leqslant \gamma_p r^{-p}, \quad r \geqslant 0, \quad 0 \leqslant p \leqslant p_0, \quad \gamma_p > 0.$$

Examples of methods of this class are (iterated) Tikhonov method, Landweber iteration method, implicite iteration method, method of asymptotical regularization, the truncated singular value decomposition methods etc.

If the noise level of data is unknown, for the choice of the regularization parameter r heuristic rule is needed. We propose to choose r from the set L_{min} of the local minimum points of the quasioptimality criterion function

$$\psi_Q(r) = r\|A^*(I - AA^*g_r(AA^*))^{\frac{2}{p_0}}(Au_r - f)\|$$

on the set of parameters $\Omega = \{r_j : r_j = qr_{j-1},\, j = 1, 2, ..., M,\, q > 1\}$. Then the following error estimates hold:

a)

$$\min_{r \in L_{min}} \|u_r - u_*\| \leqslant C \min_{r_0 \leqslant r \leqslant r_M} \left\{ \left\|u_r^+ - u_*\right\| + \left\|u_r - u_r^+\right\| \right\}.$$

Here u_* and u_r^+ are the exact and regularized solutions of equation $Au = f_*$ and the constant $C \leqslant c_q \ln(r_M/r_0)$ can be computed for each individual problem $Au = f$.

b) Let $u_* = (A^*A)^{p/2}v$, $\|v\| \leqslant \rho$. If $r_0 = 1$, $r_M = c\,\|f - f_*\|^{-2}$, $c = (2\,\|u_*\|)^2$, then

$$\min_{r \in L_{min}} \|u_r - u_*\| \leqslant c_{p,q}\rho^{1/(p+1)} \left|\ln \|f - f_*\|\right| \|f - f_*\|^{p/(p+1)}, 0 < p \leqslant 2p_0.$$

We consider some algorithms for parameter choice from the set L_{min}.

MS15 1
Mon Sep 4
2:30 pm
3:00 pm
VG1.102

Time-resolved photoemission orbital tomography of organic interfaces

U. Höfer

Charge transfer across molecular interfaces is reflected in the population of electronic orbitals. For ordered organic layers, time-resolved photoemission orbital tomography (tr-POT) is capable of spectroscopically identifying the involved orbitals and deducing their population from the measured angle-resolved photoemission intensity with high temporal resolution [1]. As examples, I will present recent results obtained for PTCDA and CuPc adsorbed on Cu(100)-2O. We observe two distinct excitation pathways with visible light. While the parallel component of the electric field makes a direct HOMO-LUMO transition, the perpendicular component can transfer a substrate electron into the molecular LUMO. The experimental data are modelled by a density matrix description of the excitation and photoemission process. We find similar LUMO lifetimes for both excitation pathways, whereas the true dephasing times differ by two orders of magnitude.

Future tr-POT experiments will employ a two-pulse coherent control excitation scheme to steer the charge transfer. In some cases, this scheme will allow us to deduce the relative phase of the involved orbitals directly from the experiment. Furthermore, the combination with strong THz excitation and subcycle time resolution will make it possible to monitor charge transfer processes and hybridization during surface bond formation with POT.

References

[1] R. Wallauer, M. Raths, K. Stallberg, L. Münster, D. Brandstetter, X. Yang, J. Güdde, P. Puschnig, S. Soubatch, C. Kumpf, F. C. Bocquet, F. S. Tautz, U. Höfer. Tracing orbital images on ultrafast time scales, Science 371: 1056-1059, 2021. https://doi.org/10.1126/science.abf3286

CT06
Thu Sep 7
3:00 pm
3:30 pm
VG2.107

Solution of the fractional order differential equation for Laplace transform of a boundary functional of a semi-Markov process using inverse Laplace transform

E. Ibayev

Let $\{\xi_k\}_{k=1}^{\infty}$, and $\{\zeta_k\}_{k=1}^{\infty}$ be two independent sequences of random variables defined on any probability space $(\Omega,\, F, P)$, such that the random variables in each sequence are independent, positive and identically distributed. Now we can construct the stochastic process $X_1\,(t)$ as follows

$X_1\,(t) = z - t + \sum_{i=0}^{k-1} \zeta_i$, if $\sum_{i=0}^{k-1} \xi_i \leqslant t < \sum_{i=0}^{k} \xi_i$, where $\xi_0 = \zeta_0 = 0$. The process $X_1(t)$ is called the semi-Markov random walk process with negative drift, positive jumps. Let this process is delayed by a barrier zero:

$$X(t) = X_1(t) - \inf_{0 \leqslant s \leqslant t} \{0, X_1(s)\}$$

Now, we introduce the random variable $\tau_0 = \inf\{t : X(t) = 0\}$. We set $\tau_0 = \infty$ if $X(t) > 0$for all t. It is obvious that the random variable τ_0 is the time of the first crossing of the process $X(t)$ into the delaying barrier at zero level. τ_0 is called the boundary functional of the semi-Markov random walk process with negative drift, positive jumps.

The aim of the present work is to determine the Laplace transform of the conditional distribution of the random variable τ_0. Laplace transform of the conditional distribution of the random variable τ_0. by

$$L(\theta \,|z) = E\left[e^{-\theta\tau_0} \,|X(0) = z\right], \quad \theta > 0, \; z \geqslant 0.$$

Let us denote the conditional distribution of random variable of τ_0 and the Laplace transform of the conditional distribution with

$$N(t \,|z) = P\left[\tau_0 > t \,|X(0) = z\right],$$

and

$$\tilde{N}(\theta \,|z) = \int_{t=0}^{\infty} e^{-\theta t} N(t \,|z) dt,$$

respectively.

Thus, we can easily obtain that

$$\tilde{N}(\theta \,|z) = \frac{1 - L(\theta \,|z)}{\theta}$$

or, equivalently,

$$L(\theta \,|z) = 1 - \theta \tilde{N}(\theta \,|z).$$

We construct an integral equation for the $\tilde{N}(\theta \,|z)$. In particular, constructed integral equation reduced to the fractional order differential equation in the class of gamma distributions. The fractional derivatives are described in the Riemann-Liouville sense. Finally , Laplace transform of $\tilde{N}(\theta \,|z)$ is obtained in the form of a threefold sum.

Ray transform problems arising from seismology

MS52 2
Mon Sep 4
4:30 pm
5:00 pm
VG1.105

J. Ilmavirta

Many different ray transform problems arise from seismology. My examples are periodic ray transform problems in the presence of interfaces, linearized travel time tomography in strong anisotropy, and a partial data problem originating from shear wave splitting. I will discuss the underlying inverse problems and the arising integral geometry problems. This talk is based on joint work with de Hoop, Katsnelson, and Mönkkönen.

Geometrization of inverse problems in seismology

MS41 1
Fri Sep 8
2:30 pm
3:00 pm
VG3.101

J. Ilmavirta

Seismic waves can be modeled by the elastic wave equation, which has two material parameters: the stiffness tensor and the density. The inverse problem is to reconstruct these two fields from boundary data, and the stiffness tensor can be anisotropic. I will discuss how this problem can be tackled by geometric methods and how that leads to geometric inverse problems in Finsler geometry. This talk is related several other talks in the same minisymposium.

Talks in alphabetical order

MS30 1
Wed Sep 6
9:00 am
9:30 am
VG2.103

Continuum limit for lattice Hamiltonians

H. Isozaki

We consider the Hamiltonian perturbed by a potential on an infinite periodic lattice. We are interested in the behavior of the solution for the lattice model to that for the equation for the continuous model as the mesh size tends to 0. For some lattices such as square, triangular and hexagonal lattices, we show that the scattering solutions (i.e. the soultions associated with the continuous spectrum) converge to the solution to the Shrodedinger equation in the continuous model. For the case of the hexagonal lattice, we can also derive the convergence to the massless Dirac equation. The idea of the proof relies on the micro-local calculus for lattice Schroedinger operators and the classical method of the limiting absorption principle.

MS06 4
Fri Sep 8
1:30 pm
2:00 pm
VG3.103

Nonlinear integral equations for 3D inverse acoustic and electromagnetic scattering

O. Ivanyshyn Yaman

We present two extensions of the method, originally developed by Kress and Rundell in 2005 for a 2D inverse boundary value problem for the Laplace equation. In particular, we consider the reconstruction of a 3D perfectly electric conductor obstacle, and the reconstruction of generalized surface impedance functions for acoustic scattering from the knowledge of far-field measurements of a scattered wave associated with a few incident plane waves. Inverse scattering problems are solved numerically by the approach based on the reformulation of a problem as a system of nonlinear and ill-posed integral equations for the unknown boundary (or boundary condition) and the measurements. The iteratively regularized Gauss-Newton method is applied to the resulting system.

References

[1] R. Kress, W. Rundell. Nonlinear integral equations and the iterative solution for an inverse boundary value problem. Inverse Probl. 21(4): 1207–1223, 2005.

[2] O. Ivanyshyn Yaman, F. Le Louër. Material derivatives of boundary integral operators in electromagnetism and application to inverse scattering problems. Inverse Probl. 32(9): 095003, 2016.

[3] O. Ivanyshyn Yaman. Reconstruction of generalized impedance functions for 3D acoustic scattering. J. Comput. Phys, 392(1): 444–455, 2019.

MS01
Wed Sep 6
10:00 am
10:30 am
VG1.102

Approaches on Feature and Model Selection for high-dimensional data in Medical Research and Analysis

P.-P. Jacobs, T. Denecke, H. Busse

In recent years the availability of multi-omics data, had a great impact on medical research. Such high-dimensional data-sets contain molecular as well as radiological variables from genomics, epigenomics, transcriptomics, proteomics, metabolomics, microbiomics and radiomics. The challenge when working with this kind of data is to find a subset of meaningful variables in order to deduce disease specific characteristics or make predictions on clinical endpoint variables. The process of eliminating non-informative and redundant features is called feature selection. Feature selection can be considered a necessary preprocessing for the actual modeling step in which statistical or machine-learning models are built in order to conduct classification tasks or time-to-event-data analysis. Given the pre-selected subset of features and a variety of candidate models, finding the most accurate as well as informative model is thereafter the remaining challenge also referred to as model selection. The goal of model selection is eliciting a parsimonious model, which uses only a small set of explanatory variables, which can then be considered as clinical covariates or biomarkers and in turn provide information how the treatment of the disease can be improved. Further, model selection is a step to prevent misleading conclusions due to possible over-fitting of the data inherent noise. In this talk, we present recent methodologies in feature and model selection. An introduction of rather simple feature selection techniques like statistical filter and classifier performance focused methods is followed by a description of more sophisticated regularization and shrinkage methods as well as the utilization of decision tree analysis algorithms. Finally we discuss how statistical as well as machine-learning models can benefit from the application of various information criteria for model selection.

Discretisation-adaptive regularisation via frame decompositions

MS05 2
Thu Sep 7
2:00 pm
2:30 pm
VG2.102

T. Jahn

We consider linear inverse problems under white (non-Gaussian) noise. We introduce a discretisation scheme to apply the discrepancy principle and the heuristic discrepancy principle, which require bounded data norm. Choosing the discretisation dimension in an adaptive fashion yields convergence, without further restrictions for the operator, the distribution of the white noise or the unknown ground solution. We discuss connections to Lepski's method and apply the technique to ill-posed integral equations with noisy point evaluations and show that here discretisation-adaptive regularisation can be used in order to reduce the numerical complexity. Finally, we apply the technique to methods based on the frame decomposition, tailored for applications in atmospheric tomography.

Early stopping of untrained convolutional networks

MS13 1
Fri Sep 8
2:00 pm
2:30 pm
VG0.111

T. Jahn, B. Jin

In recent years new regularisation methods based on neural networks have shown promising performance for the solution of ill-posed problems, e.g., in imaging science. Due to the non-linearity of the networks, these methods often lack profound theoretical justification. In this talk we rigorously discuss convergence for an untrained convolutional network. Untrained networks are particulary attractive for applications, since they do not require any training data. Its regularising property is solely based on the architecture of the network. Because of this, appropriate early stopping is essential for the success of the method. We show that the discrepancy principle is an adequate method for early stopping here, as it yields minimax optimal convergence rates.

Exciton Photoemission Orbital Tomography: Probing the electron and the hole contributions

MS15 1
Mon Sep 4
3:00 pm
3:30 pm
VG1.102

G. S. M. Jansen

Time-resolved photoemission orbital tomography is a promising technique for the characterization of light-matter interaction in organic semiconductors. However, its state-of-the-art analysis approach based on density functional theory and the plane-wave model of photoemission cannot account for the correlated many-body nature of excitonic wave-functions, which nevertheless represent the dominant optoelectronic response of organic semiconductors. Building on the many-body interaction formalisms of the *GW* approach and the Bethe-Salpeter equation, we present a complete description of the angle-resolved exciton photoemission spectrum, and apply this model to the exemplary exciton relaxation cascade in multilayer C_{60} crystals to investigate an intriguing property of the excitonic wavefunction: In C_{60}, and more generally in organic semiconductors, excitons can be of multiorbital nature, with both the electron and hole spread over multiple orbitals. We elucidate how photoemission orbital tomography is uniquely sensitive to this multiorbital nature and exploit it to directly access the hole part of the excitonic wavefunction in addition to its electron counterpart. With this capability, exciton photoemission orbital tomography provides a versatile probe of key exciton properties such as localization, charge transfer, and relaxation dynamics.

MS54 3
Tue Sep 5
5:30 pm
6:00 pm
VG1.105

Explicit inversion of momentum ray transform

S. R. Jathar

The inversion of the ray transform serves as an important mathematical tool for investigating object properties from external measurements with extensive applications spanning medical imaging to geophysics. However, the inversion of the ray transform on symmetric tensor fields is constrained by the presence of an infinite dimensional null space. One natural question is whether we can utilize supplementary data in the form of higher order moments of the ray transform for the explicit recovery of the entire tensor field. In this talk, we will focus our attention on normal operators associated to momentum ray transforms (the composition of the transform with its formal L^2 adjoint), and introduce an approach for the explicit reconstruction of entire symmetric m tensor field from this data.

MS18 3
Tue Sep 5
1:30 pm
2:00 pm
VG1.103

Inverse Problems for Subdiffusion from Observation at an Unknown Terminal Time

B. Jin

Inverse problems of recovering space-dependent parameters, e.g., initial condition, space-dependent source or potential coefficient, in a subdiffusion model from the terminal observation have been extensively studied in recent years. However, all existing studies have assumed that the terminal time at which one takes the observation is exactly known. In this talk, we present uniqueness and stability results for three canonical inverse problems, e.g., backward problem, inverse source and inverse potential problems, from the terminal observation at an unknown time. The subdiffusive nature of the problem indicates that one can simultaneously determine the terminal time and space-dependent parameter. The analysis is based on explicit solution representations, asymptotic behavior of the Mittag-Leffler function, and mild regularity conditions on the problem data. Further, we present several one- and two-dimensional numerical experiments to illustrate the feasibility of the approach.

MS42
Tue Sep 5
5:00 pm
5:30 pm
VG3.104

Imaging anisotropic conductivities from current densities

B. Jin

In this talk, we discuss a reconstruction algorithm for imaging an anisotropic conductivity tensor in a second-order elliptic PDE with a nonzero Dirichlet boundary condition from internal current densities. The approach is based on a regularized output least-squares formulation with the standard L^2 penalty, which is then discretized by the standard Galerkin finite element method. We discuss the analysis of the discretized problem, especially the convergence of the discrete approximations with respect to the mesh size, using the discrete counterpart of H-convergence, when the discretization is uniform or adaptive. We present extensive two-dimensional numerical examples to show the efficiency of the proposed method.

Stochastic mirror descent method for linear ill-posed problems in Banach spaces

MS13 1
Fri Sep 8
2:30 pm
3:00 pm
VG0.111

Q. Jin

Consider linear ill-posed problems governed by the system $A_i x = y_i$ for $i = 1, \cdots, p$, where each A_i is a bounded linear operator from a Banach space X to a Hilbert space Y_i. In case p is huge, solving the problem by an iterative regularization method using the whole information at each iteration step can be very expensive, due to the huge amount of memory and excessive computational load per iteration. To solve such large-scale ill-posed systems efficiently, we develop a stochastic mirror descent method which uses only a small portion of equations randomly selected at each iteration steps and incorporates convex regularization terms into the algorithm design. Therefore, our method scales very well with the problem size and has the capability of capturing features of sought solutions. The convergence property of the method depends crucially on the choice of step-sizes. We consider various rules for choosing step-sizes and obtain convergence results under a priori stopping rules. Furthermore, we establish an order optimal convergence rate result when the sought solution satisfies a benchmark source condition. Various numerical simulations are reported to test the performance of the method. This is a joint work with Xiliang Lu and Liuying Zhang.

CUQIpy - Computational Uncertainty Quantification for Inverse problems in Python

MS35
Mon Sep 4
5:30 pm
6:00 pm
VG2.105

J. S. Jørgensen, A. Alghamdi, N. Riis

In this talk we present CUQIpy (pronounced ”cookie pie”) - a new computational modelling environment in Python that uses uncertainty quantification (UQ) to access and quantify the uncertainties in solutions to inverse problems. The overall goal of the software package is to allow both expert and non-expert (without deep knowledge of statistics and UQ) users to perform UQ related analysis of their inverse problem while focusing on the modelling aspects. To achieve this goal the package utilizes state-of-the-art tools and methods in statistics and scientific computing specifically tuned to the ill-posed and often large-scale nature of inverse problems to make UQ feasible. We showcase the software on problems relevant to imaging science such as computed tomography and partial differential equation-based inverse problems. CUQIpy is developed as part of the CUQI project at the Technical University of Denmark and is available at https://github.com/CUQI-DTU/CUQIpy.

MS36 1
Thu Sep 7
3:00 pm
3:30 pm
VG3.101

Bayesian approach to limited-data CT reconstruction for inspection of subsea pipes

J. S. Jørgensen

In subsea pipe inspection using X-ray computed tomography (CT), obtaining data is time-consuming and costly due to the challenging underwater conditions. We propose an efficient Bayesian CT reconstruction method with a new class of structural Gaussian priors incorporating known material properties to enhance quality from limited data. Experiments with real and synthetic data demonstrate artifact reduction, increased contrast, and enhanced reconstruction certainty compared to conventional reconstruction methods.

Authhors: Silja L. Christensen, Nicolai A. B. Riis, Felipe Uribe and Jakob S. Jørgensen

CT07
Thu Sep 7
4:30 pm
5:00 pm
VG1.105

Quasi-Monte Carlo methods for Bayesian optimal experimental design problems governed by PDEs

V. Kaarnioja

The goal in Bayesian optimal experimental design is to maximize the expected information gain for the reconstruction of unknown quantities when there is a limited budget for collecting measurement data. We consider Bayesian inverse problems governed by partial differential equations. This leads us to consider an optimization problem, where the objective functional involves nested high-dimensional integrals which we approximate by using tailored rank-1 lattice quasi-Monte Carlo (QMC) rules. We show that these QMC rules achieve faster-than-Monte Carlo convergence rates. Numerical experiments are presented to assess the theoretical results.

MS57 3
Tue Sep 5
4:30 pm
5:00 pm
VG2.107

Galerkin Foldy-Lax asymptotic models for time-domain scattering by small particles

M. Kachanovska

Foldy-Lax models are asymptotic models of wave scattering by multiple obstacles, in the regime when their characteristic size tends to zero. While frequency-domain Foldy-Lax models are now fairly well-studied (see e.g. [1,2,3]), their time-domain counterparts were considered only very recently, see [4,5].

This talk is dedicated to the derivation, stability and convergence analysis of a time-domain Foldy-Lax model for sound-soft scattering by small obstacles. We start with the analysis of the time-domain counterpart of the respective frequency-domain model for circular scatterers from [6] and show that it is unstable for some geometric configurations. To stabilize it, we propose its reinterpretation as a perturbed Galerkin discretization of a single layer boundary integral equation.

Its unperturbed Galerkin discretization is then automatically stable due to a coercivity-like property of the underlying operator and thus serves as a basis to derive the stabilized model. Let us remark that this reinterpretation provides us with an alternative way to derive asymptotic models as Galerkin discretizations of boundary integral formulations with well-chosen basis functions.

We will present the convergence analysis of the new model, discuss its numerical implementation, and illustrate our findings with numerical experiments.

References

[1] P. Martin. Multiple scattering, vol. 107 of Encyclopedia of Mathematics and its Applications, Cambridge University Press, Cambridge, 2006.

[2] D.P. Challa, M. Sini. On the justification of the Foldy-Lax approximation for the acoustic scattering by small rigid bodies of arbitrary shapes, Multiscale Model. Simul., 12 , pp. 55-108, 2014.

[3] D.P. Challa, M. Sini. The Foldy-Lax approximation of the scattered waves by many small bodies for the Lamé system, Math. Nachr., 288, pp. 1834-1872, 2015.

[4] H. Barucq, J. Diaz, V. Mattesi, S. Tordeux. Asymptotic behavior of acoustic waves scattered by very small obstacles, ESAIM Math. Model. Numer. Anal., 55, pp. S705-S731, 2021.

[5] M. Sini, H. Wang, Q. Yao. Analysis of the acoustic waves reflected by a cluster of small holes in the time-domain and the equivalent mass density, Multiscale Model. Simul., 19, pp. 1083-1114, 2021.

[6] M. Cassier, C. Hazard. Multiple scattering of acoustic waves by small sound-soft obstacles in two dimensions: mathematical justification of the Foldy-Lax model, Wave Motion, 50, pp. 18-28, 2013.

On the determination of a coefficient in a space-fractional equation with operators of Abel type

MS18 1
Mon Sep 4
1:30 pm
2:00 pm
VG1.103

B. Kaltenbacher, **W. Rundell**

We consider the inverse problem of recovering an unknown, spatially-dependent coefficient $q(x)$ from the fractional order equation $\mathbb{L}_\alpha u = f$ defined in a region of $\mathbb{R}^2$ from boundary information. Here $\mathbb{L}_\alpha = D_x^{\alpha_x} + D_y^{\alpha_y} + q(x)$ where the operators $D_x^{\alpha_x}$, $D_y^{\alpha_y}$ denote fractional derivative operators based on the Abel fractional integral. In the classical case this reduces to $-\triangle u + q(x)u = f$ and this has been a well-studied problem. We develop both uniqueness and reconstruction results and show how the ill-conditioning of this inverse problem depends on the geometry of the region and the fractional powers α_x and α_y.

Some coefficient identification problems from boundary data satisfying range invariance for Newton type methods

MS49 1
Tue Sep 5
2:30 pm
3:00 pm
VG3.102

B. Kaltenbacher

Range invariance is a property that - like the tangential cone condition - enables a proof of convergence of iterative methods for inverse problems. In contrast to the tangential cone condition it can also be verified for some parameter identification problems in partial differential equations PDEs from boundary measurements, as relevant, e.g., in tomographic applications. The goal of this talk is to highlight some of these examples of coefficient identification from boundary observations in elliptic and parabolic PDEs, among them: combined diffusion and absorption identification (e.g., in steady-state diffuse optical tomography), reconstruction of a boundary coefficient (e.g. in corrosion detection), reconstruction of a coefficient in a quasilinear wave equation (for nonlinearity coefficient imaging).

Electromagnetic waves generated by a moving dielectric under the special relativity assumptions

MS57 3
Tue Sep 5
5:00 pm
5:30 pm
VG2.107

M. Kar

In this talk, we will consider the electromagntic waves generated by an in- clusion moving at a uniformly constant speed. We will discuss the direct and inverse scattering problem for the corresponding transmission problem. We first show that the scattering electromagnetic fields satisfy a related Lippmann-Schwinger system of equations and the solutions of this system of integral equations can be written in terms of the Neumann series under certain assumption on the ratio between the speed of the moving object and the speed of light in the vaccum. Finally, as an application of this result, we will prove that the far-field map uniquely determines the unknown moving object.

MS51 2
Thu Sep 7
4:00 pm
4:30 pm
VG1.108

Spectral properties of radiation for the Helmholtz equation with a random coefficient

M. Karamehmedovic, K. Linder-Steinlein

For the Helmholtz equation with a Gaussian random field coefficient, we approximate and characterize spectrally the source-to-measurement map. To this end, we first analyze the case with a deterministic coefficient, and here discover and quantify a 'spectral leakage' effect. We compare the theoretically predicted forward operator spectrum with a Finite Element Method computation. Our results are applicable in the analysis of the robustness of solution of inverse source problems in the presence of deterministic and random media.

CT01
Wed Sep 6
10:00 am
10:30 am
VG2.104

X-ray holographic imaging using intensity correlations

M. Karimi, T. Hohage

Holographic coherent x-ray imaging enables nanoscale imaging of biological cells and tissue, rendering both phase and absorption contrast, i.e. real and imaginary part of the refractive index. A main challenge of this imaging technique is radiation damage. We present a different modality of this imaging technique using a partially incoherent incident beam and time-resolved intensity measurements based on new measurement technologies. This enables the acquisition of intensity correlations in addition to the commonly used expectations of intensities. In this talk we explore information content of holographic intensity correlation data, analytically showing that in the linearized model both phase and absorption contrast can uniquely be determined by the intensity correlation data. The uniqueness theorem is derived using multi-dimensional Kramers-Kronig relations. We also deduce a uniqueness theorem for ghost holography imaging as an unconventional X-ray imaging scheme.

For regularized reconstruction it is important to take into account the statistical distribution of the correlation data. The measured intensity data are described by a so-called Cox-processes, roughly speaking a Poisson process with random intensity. For medium-size data sets, we use adaptations of the iteratively regularized Gauss-Newton method and the FISTA method as reconstruction methods. Our numerical results even in the full nonlinear model confirm that both phase and absorption contrast can jointly be reconstructed from only intensity correlations without the use of average intensities. Although these results are encouraging concerning the information content of the new intensity correlation data, the increased dimensionality of these data causes severe computational challenges.

MS45 2
Wed Sep 6
9:00 am
9:30 am
VG0.111

Inverse problems in imaging and information fusion via structured multimarginal optimal transport

J. Karlsson, Y. Chen, F. Elvander, I. Haasler, A. Ringh

The optimal mass transport problem is a classical problem in mathematics, and dates back to 1781 and work by G. Monge where he formulated an optimization problem for minimizing the cost of transporting soil for construction of forts and roads. Historically the optimal mass transport problem has been widely used in economics in, e.g., planning and logistics, and was at the heart of the 1975 Nobel Memorial Prize in Economic Sciences. In the last two decades there has been a rapid development of theory and methods for optimal mass transport and the ideas have attracted considerable attention in several economic and engineering fields. These developments have led to a mature framework for optimal mass transport with computationally efficient algorithms that can be used to address problems in the many areas.

In this talk, we will consider optimization problems consisting of optimal transport costs together with other functionals to address inverse problems in many domains, e.g., in medical imaging, radar imaging, and spectral estimation. This is a flexible framework and allows for incorporating forward models, specifying dynamics of the object and other dependencies. These problem can often be formulated as a multi-marginal optimal transport problem and we show how common problems, such as barycenter and tracking problems, can be seen as special cases of this. This naturally leads to consider structured optimal transport problems, which can be solved efficiently using customized methods inspired by the Sinkhorn iterations.

Helioseismic inversions for active latitudes

MS38 2
Tue Sep 5
5:00 pm
5:30 pm
VG2.105

S. G. Kashyap, L. Gizon

The eleven-year solar activity cycle is known to affect the acoustic p-modes; higher activity is correlated with increase in mode frequencies and decrease in their lifetimes. This is also seen in the autocorrelation function of the integrated light. Recently, the solar cycle is also observed in travel-time measurements of p-mode wavepackets for multiple skips [1]. In this work, we first construct a forward model to explain the variation in travel-time measurements with solar activity. A simplified model is constructed by considering axisymmetric averages of the magnetic activity associated with perturbations in the near-surface wave-speed. The perturbations are constructed by longitudinally averaging synoptic magnetograms from SDO/HMI and the SOHO/MDI. The maximum correlation between observed and modeled travel-time shifts is as high as 0.92 for some skips, much less for others. Subsequently, we setup an inverse problem to invert for the latitudinal distribution of solar activity from travel-time observations. This work is a first step towards the goal of retrieving stellar butterfly diagrams from asteroseismic observables.

References

[1] V. Vasilyev, L. Gizon, 2023, submitted.

Resolution of reconstruction from discrete Radon transform data

MS59 1
Fri Sep 8
1:30 pm
2:00 pm
VG2.103

A. Katsevich

In this talk we overview recent results on the analysis of resolution of reconstruction from discrete Radon transform data. We call our approach Local Resolution Analysis, or LRA. LRA yields simple formulas describing the reconstruction from discrete data in a neighborhood of the singularities of f in a variety of settings. We call these formulas the Discrete Transition Behavior (DTB). The DTB function provides the most direct, fully quantitative link between the data sampling rate and resolution. This link is now established for a wide range of integral transforms, conormal distributions f, and reconstruction operators. Recently the LRA was generalized to the reconstruction of objects with rough edges. Numerical experiments demonstrate that the DTB functions are highly accurate even for objects with fractal boundaries.

MS03 1
Mon Sep 4
2:30 pm
3:00 pm
VG2.103

Random tree Besov priors for detail detection

H. Kekkonen, M. Lassas, S. Siltanen

Besov priors are well fitted for imaging since smooth functions with few local irregularities have a sparse expansion in the wavelet basis which is encouraged by the prior. The edge preservation of Besov priors can be enhanced by introducing a new random variable T that takes values in the space of 'trees', and which is chosen so that the realizations have jumps only on a small set. The density of the tree, and so the size of the set of jumps, is controlled by a hyperparameter. In this talk I will show how this hyperparameter can be optimized for the data and what the optimal values tell us about behaviour of the signal or image.

MS35
Mon Sep 4
5:00 pm
5:30 pm
VG2.105

Edge preserving Random Tree Besov Priors

H. Kekkonen, M. Lassas, E. Saksman, S. Siltanen

Gaussian process priors are often used in practice due to their fast computational properties. The smoothness of the resulting estimates, however, is not well suited for modelling functions with sharp changes. We propose a new prior that has same kind of good edge-preserving properties than total variation or Mumford-Shah but correspond to a well-defined infinite dimensional random variable. This is done by introducing a new random variable T that takes values in the space of 'trees', and which is chosen so that the realisations have jumps only on a small set.

CT07
Thu Sep 7
5:00 pm
5:30 pm
VG1.105

Maximum marginal likelihood estimation of regularisation parameters in Plug & Play Bayesian estimation: Application to non-blind and semi-blind image deconvolution

C. Kemajou Mbakam, M. Pereyra, J.-F. Giovannelli

Bayesian Plug & Play (PnP) priors are widely acknowledged as a powerful framework for solving a variety of inverse problems in imaging. This Bayesian PnP framework has made tremendous advances in recent years, resulting in state-of-the-art methods. Although PnP methods have been distinguished by their ability to regularize Bayesian inverse problems through a denoising algorithm, setting the amount of regularity enforced by the prior, determined by the noise level parameter of the denoiser, has been an issue for several reasons. This talk aims to present an empirical Bayesian extension of an existing Plug & Play (PnP) Bayesian inference method. The main novelty of this work is that we estimate the regularisation parameter directly from the observed data by maximum marginal likelihood estimation (MMLE). However, noticing that the MMLE problem is computationally and analytically intractable, we incorporate a Markov kernel within a stochastic approximation proximal gradient scheme to address this difficulty. The resulting method calibrates a regularisation parameter by MMLE while generating samples asymptotically distributed according to the empirical Bayes (pseudo-) posterior distribution of interest. Additionally, the proposed method can estimate other unknown parameters of the model using MMLE; such as the noise level of the observation model, and the parameters of the forward operator simultaneously. The proposed method has been demonstrated with a range of non-blind and semi-blind image deconvolution problems, as well as compared to state-of-the-art methods.

Scalable moment relaxations for graph-structured problems with values in a manifold: An optimal transport approach

MS10 3
Fri Sep 8
3:00 pm
3:30 pm
VG1.103

R. Kenis, E. Laude, P. Patrinos

In this paper we consider a moment relaxation for large-scale nonsmooth optimization problems with graphical structure and manifold constraints. In the context of probabilistic inference this can be interpreted as MAP-inference in a continuous graphical model. In contrast to classical moment relaxations for global polynomial optimization we exploit the partially separable structure of the optimization problem and leverage Kantorovich-Rubinstein duality for optimal transport to decouple the problem. The proposed formulation is obtained via a dual subspace approximation which allows us to tackle possibly nonpolynomial optimization problems with manifold constraints and geodesic coupling terms. We show that the duality gap vanishes in the limit by proving that a Lipschitz continuous dual multiplier on a unit sphere can be approximated as closely as desired in terms of a Lipschitz continuous polynomial. This is closely related to spherical harmonics and the eigenfunctions of the Laplace-Beltrami operator. The formulation is applied to manifold-valued imaging problems with total variation regularization and graph-based SLAM. In imaging tasks our approach achieves small duality gaps for a moderate degree. In graph-based SLAM our approach often finds solutions which after refinement with a local method are near the ground truth solution.

SGD for select inverse problems in Banach spaces

MS13 2
Fri Sep 8
5:30 pm
6:00 pm
VG0.111

Z. Kereta, B. Jin

In this work we present a mathematical framework and analysis for SGD in Banach spaces for select linear and non-linear inverse problems. Analysis in the Banach space setting presents unique challenges, requiring novel mathematical tools. This is achieved by combining insights from Hilbert space theory with approaches from modern optimisation. The developed theory and algorithms open doors for a wide range of applications, and we present some future challenges and directions.

An Abstract Framework for Stochastic Elliptic Inverse Problems.

MS02 2
Tue Sep 5
5:00 pm
5:30 pm
VG1.102

A. Khan

Motivated by the necessity to identify stochastic parameters in a wide range of stochastic partial differential equations, this talk will focus on an abstract inversion framework for stochastic inverse problems. The stochastic inverse problem will be posed as a convex stochastic optimization problem. The essential properties of the solution maps and the solvability of the inverse problem will be discussed. Convergence rates for the stochastic inverse problem without requiring the so-called smallness condition will be presented. We will discuss an application of the abstract framework to estimate stochastic Lamé parameters in the system of linear elasticity. We will present numerical results to show the feasibility and efficacy of the developed framework.

MS14 3
Tue Sep 5
1:30 pm
2:00 pm
VG1.104

Inverse Problems for Generalized Subdiffusion Equations

N. Kinash

The talk focuses on the theoretical investigation of the inverse problem for the Pennes' bioheat wave equation. Uniqueness and existence are the main questions under consideration.

MS02 1
Tue Sep 5
2:30 pm
3:00 pm
VG1.102

Convergence Nestorov acceleration for linear ill-posed problems

S. Kindermann

We show that Nesterov acceleration is an optimal-order iterative regularization method for linear ill-posed problems provided that a parameter is chosen accordingly to the smoothness of the solution. The central result is a representation of the iteration residual polynomials via Gegenbauer polynomials. This also explains the observed semi-saturation effect of Nesterov iteration.

MS51 1
Thu Sep 7
2:30 pm
3:00 pm
VG1.108

Feynman's inverse problem - an inverse problem for water waves

A. Kirkeby, M. Karamehmedović

We analyse an inverse problem for water waves proposed by Richard Feynman in the BBC documentary "Fun to imagine". We show how the presence of both gravity and capillary waves makes water an excellent medium for the propagation of information.

CT07
Thu Sep 7
4:00 pm
4:30 pm
VG1.105

Accelerating MCMC for imaging science by using an implicit Langevin algorithm

T. Klatzer, K. Zygalakis, P. Dobson, M. Pereyra, Y. Altmann

In this work, we present a highly efficient gradient-based Markov chain Monte Carlo methodology to perform Bayesian computation in imaging problems. Like previous Monte Carlo approaches, the proposed method is derived from a discretisation of a Langevin diffusion. However, instead of a conventional explicit discretisation like Euler-Maruyama, here we use an implicit discretisation based on the theta-method. In particular, the proposed sampling algorithm requires to solve an optimization problem in each step. In the case of a log-concave posterior, this optimisation problem is strongly convex and thus can be solved efficiently, leading to effective step sizes that are significantly larger than traditional methods permit. We can show that even for these large step sizes the corresponding Markov Chain has low bias while also preserving the posterior variance. We demonstrate the proposed methodology on a range of problems including non-blind image deconvolution and denoising. Comparisons with state-of-the-art MCMC methods confirm that the Markov chains generated with our method exhibit significantly faster convergence speeds, and produce lower mean square estimation errors at equal computational budget.

MS29 1
Mon Sep 4
1:30 pm
2:00 pm
VG3.104

Interior transmission eigenvalue trajectories

A. Kleefeld, L. Pieronek

Complex-valued eigenvalue trajectories parametrized by a constant index of refraction are investigated for the interior transmission problem. Several properties are derived for the unit disk such as that the only intersection points with the real axis are Dirichlet eigenvalues of the Laplacian. For general sufficiently smooth scatterers in two dimensions the only trajectorial limit points are shown to be Dirichlet eigenvalues of the Laplacian as the refractive index tends to infinity. Additionally, numerical results for several scatterers are presented which give rise to an underlying one-to-one correspondence between these two eigenvalue families which is finally stated as a conjecture.

Globally Convergent Convexification Method for Coefficient Inverse Problems for Three Equations

CT06
Thu Sep 7
2:00 pm
2:30 pm
VG2.107

M. Klibanov

Three Coefficient Inverse Problems (CIP) will be considered. Respectively, three versions of the globally convergent convexification numerical method will be presented. Global convergence theorems will be outlined and numerical results will be presented. Results outlined below are the first ones for each considered CIP. These CIPs are:

1. CIP for the radiative transport equation with euclidian propagation of particles [1].

2. CIP for the Riemannian radiative transport equation. In this case, particles propagate along geodesic lines between their scattering events [2].

3. Travel Time Tomography Problem in the 3-d case [3]. This is a CIP for the eikonal equation in the 3-d case. First numerical results in 3-d for this CIP will be presented,

References

[1] M.V. Klibanov, J. Li, L.H. Nguyen, Z. Yang, Convexification numerical method for a coefficient inverse problem for the radiative transport equation, SIAM J. Imaging Sciences, 16;35-63, 2023.

[2] M.V. Klibanov, J. Li, L.H. Nguyen, V.G. Romanov, Z. Yang, Convexification numerical method for a coefficient inverse problem for the Riemannian radiative transfer equation, arxiv: 2212.12593, 2022.

[3] M.V. Klibanov, J. Li, W. Zhang, Numerical solution of the 3-D travel time tomography problem, Journal of Computational Physics, 476:111910, 2023. published online https://doi.org/10.1016/j.jcp.2023.111910.

Some Inverse Problems for Parabolic Equations

CT01
Wed Sep 6
9:00 am
9:30 am
VG2.104

M. Klibanov

Two types of new results of the presenter will be discussed:

1. Holder and Lipschitz stability estimates for coefficient inverse problem and inverse source problem with the final overdetermination [1]. The solution of the parabolic equation is known at $t = 0$ and $t = T$. Both Dirichlet and Neumann boundary conditions are known either on part of the boundary or on the entire boundary. A new Carleman estimate for the parabolic operator is the key here. Unlike standard Carleman estimates in this one, the Carleman Weight Function is independent on t. The Holder stability estimate is in the case of incomplete boundary data and the Lipshitz stability is in the case of complete boundary data. Both results and the methodology are significantly different from previous ones.

2. Stability estimates and uniquness theorems for some inverse problems for the Mean Field Games system [2]. These results are also new. The Mean Field Games system is a system of two parabolic equations, which was originally proposed by J.-M. Lasry and P.-L. Lions in 2006-2007 and became quite popular nowadays due to a number of very exciting applications. The main challenge here is that the time t is running in two opposite directions in these equations. Therefore, the Volterra-like property of conventional systems of parabolic PDEs is not kept here.

References

[1] M. V. Klibanov, Stability estimates for some parabolic inverse problems with the final overdetermination via a new Carleman estimate, arxiv: 2301.09735, 2023.

[2] M. V. Klibanov, Yu. V. Aveboukh, Stability and uniqueness of two inverse problems for the Mean Field Games system, in preparation.

MS02 1
Tue Sep 5
3:00 pm
3:30 pm
VG1.102

Analysis of the discrepancy principle for Tikhonov regularization under low order source conditions

C. Klinkhammer, R. Plato

We study the application of Tikhonov regularization to ill-posed nonlinear operator equations. The objective of this work is to prove low order convergence rates for the discrepancy principle under low order source conditions of logarithmic type. We work within the framework of Hilbert scales and extend existing studies on this subject to the oversmoothing case. The latter means that the exact solution of the treated operator equation does not belong to the domain of definition of the penalty term. As a consequence, the Tikhonov functional fails to have a finite value.

MS49 2
Tue Sep 5
5:00 pm
5:30 pm
VG3.102

Parameter identification in magnetization models for large ensembles of magnetic nanoparticles

H. Albers, T. Kluth

Magnetic particle imaging (MPI) is a tracer based imaging modality which exploits the magnetization behavior of magnetic nanoparticles (MNPs) to obtain spatially distributed concentration images from voltage measurements. Proper modeling, which is still an unsolved problem in MPI, relies on magnetization dynamics of individual nanoparticles which typically include Neel and Brownian magnetic moment rotation dynamics. In the context of MPI large ensembles of MNPs and their magnetization behavior need to be considered. Taking into account Neel/Brownian rotation, the ensembles magnetization behavior can be described by a Fokker-Planck equation, i.e., a linear parabolic PDE which models the temporal evolution of the probability that the magnetic moment of a nanoparticle has a certain orientation. The resulting behavior is strongly influenced by time-dependent parameters in the PDE. In this talk we discuss the physical modeling as well as time-dependent parameter identification problems related to the magnetization dynamics based on a Fokker-Planck equation.

MS50 1
Fri Sep 8
1:30 pm
2:00 pm
VG1.105

Deep learning MR image reconstruction and task-based evaluation

F. Knoll, J. Kim, M. Vornehm, V. Saksena, Z. Tan, B. Kainz

The inverse problem of reconstructing MR images u from Fourier (k-) space data f takes the form of the optimization problem:

$$\min \|Au - f\|_2^2 + \lambda \mathcal{R}(u).$$

$A = \mathcal{F}_\Omega C$ is the forward operator that describes the MR encoding process. It consists of a Fourier transform $\mathcal{F}_\Omega$ that maps from image space to Fourier (k-) space coefficients at the coordinates Ω and a diagonal matrix C that contains the sensitivity profiles of the receiver coils of the MR system. $\mathcal{R}$ is a regularizer that separates between true image content and artifacts introduced by an accelerated acquisition. It has been demonstrated that deep learning methods that map the image reconstruction optimization problem onto unrolled neural networks and learn a regularizer from training data [1] achieve state of the art performance in public research challenges [2].

In this work, we will present an update on the performance of learned image reconstruction for a range of clinically relevant applications and discuss the issue of missing-, as well as artificially hallucinated fine-detail image features [3]. We will present results for cardiac, oncological and neuroimaging applications, and will also introduce a novel task-based evaluation for the quality of the reconstructed images using the fastMRI+ dataset [4].

References

[1] K. Hammernik, T. Klatzer, E. Kobler, M. P. Recht, D. K. Sodickson, T. Pock, F. Knoll. Learning a Variational Network for Reconstruction of Accelerated MRI Data, Magnetic Resonance in Medicine 79: 3055-3071, 2018. https://doi.org/10.1002/mrm.26977

[2] M. J. Muckley, B. Riemenschneider, A. Radmanesh, S. Kim, G. Jeong, J. Ko, Y. Jun, H. Shin, D. Hwang, M. Mostapha, S. Arberet, D. Nickel, Z. Ramzi, P. Ciuciu, J.-L. Starck, J. Teuwen, D. Karkalousos, C. Zhang, A. Sriram, Z. Huang, N. Yakubova, Y. W. Lui, F. Knoll. Results of the 2020 fastMRI Challenge for Machine Learning MR Image Reconstruction, IEEE Transactions on Medical Imaging 40: 2306-2317, 2021. https://doi.org/10.1109/TMI.2021.3075856

[3] A. Radmanesh, M. J. Muckley, T. Murrell, E. Lindsey, A. Sriram, F. Knoll, D. K. Sodickson, Y.W. Lui. Exploring the Acceleration Limits of Deep Learning Variational Network-based Two-dimensional Brain MRI, Radiology: Artificial Intelligence 4, 2022. https://doi.org/10.1148/ryai.210313

[4] R. Zhao, B. Yaman, Y. Zhang, R. Stewart, A. Dixon, F. Knoll, Z. Huang, Y. W. Lui, M. S. Hansen, M. P. Lungren. fastMRI+: Clinical Pathology Annotations for Knee and Brain Fully Sampled Multi-Coil MRI Data, Scientific Data 2022 9: 1-6, 2022. https://doi.org/10.1038/s41597-022-01255-z

Mathematical Methods in Parallel MRI

MS50 2
Fri Sep 8
5:30 pm
6:00 pm
VG1.105

B. Kocurov

Magnetic Resonance Imaging (MRI) is an important technique in medical imaging. In the subfield of Parallel MRI, multiple receive coils are used to reconstruct tomographic images with fewer data acquisition steps compared to ordinary MRI. In this talk we will take a deeper look into the mathematical background of some of the prominent reconstruction methods. We will show that, in the course of these methods, implicit assumptions on the structure of the signals and the sensitivity profiles that are associated to the receive coils are made. In order to get a better understanding of the methods at hand and possible improvements, we aim to make these assumptions explicit.

Learning Spatio-Temporal Regularization Parameter-Maps for Total Variation-Minimization Reconstruction in Dynamic Cardiac MRI

MS50 1
Fri Sep 8
3:00 pm
3:30 pm
VG1.105

A. Kofler, F. Altekrüger, F. A. Ba, C. Kolbitsch, E. Papoutsellis, D. Schote, C. Sirotenko, F. F. Zimmermann, K. Papafitsoros

In dynamic cardiac Magnetic Resonance Imaging (MRI), one is interested in the assessment of the cardiac function based on a series of images which show the beating heart. Because the measurements typically take place during a breathhold of the patients, it is desirable to accelerate the scan by undersampling the data which yields an ill-posed inverse problem which requires the use of regularization methods. A prominent and successful example of regularization method is the well-known total variation (TV)-minimization approach which imposes sparsity of the image in its gradient domain. Thereby, the choice of the regularization parameter which balances between the data-fidelity term and the TV-term plays a crucial role. Moreover, having only a scalar regularization parameter which globally dictates the strength of the regularization seems to be sub-optimal for various reasons. Intuitively speaking, the strength of the TV-term should be locally dependent based on the content of the image. However, obtaining entire regularization parameter-maps for dynamic problems can be a challenging task. In this work, we propose a simple yet efficient approach for estimating patient-dependent spatio-temporal regularization parameter-maps for dynamic MRI based on TV-minimization. The overall approach is based on recent developments on algorithm unrolling using deep Neural Networks (NNs). A first NN estimates a spatio-temporal regularization parameter-map from an input image which is then fixed and used to formulate a reconstruction problem which a second network - an unrolled scheme using the primal dual hybrid gradient method - approximately solves. The approach combines NNs with a well-established model-based variational method and yields an entirely interpretable and convergent reconstruction scheme which can be used to improve over TV with merely scalar regularization parameters.

MS21 2
Tue Sep 5
4:30 pm
5:00 pm
VG2.103

Monitoring of hemorrhagic stroke using Electrical Impedance Tomography

V. Kolehmainen

In this talk, we present recent progress in development of electrical impedance tomography (EIT) based bedside monitoring of hemorrhagic stroke. We present the practical setup and pipeline for this novel application of EIT and the CT prior informed image reconstruction method we have developed for it. Feasibility of the approach is studied with simulated data from anatomically highly accurate simulation models and experimental phantom data from a laboratory setup.

MS54 1
Mon Sep 4
1:30 pm
2:00 pm
VG1.101

Unique continuation for the momentum ray transform

J. Ilmavirta, P.-Z. Kow, S. K. Sahoo

We will explain the relation between momentum ray transform and the fractional Laplacian. As a consequence of unique continuation property of the fractional Laplacian, one can discuss similar properties for momentum ray transform (of integer and fractional order). In addition, we will also explain the relation between the weighted ray transform and the cone transform, which appeared in different imaging approaches (for example, Compton camera).

This talk is prepared based on the work [1].

References

[1] J. Ilmavirta, P.-Z. Kow, S. K. Sahoo. Unique continuation for the momentum ray transform, arXiv: 2304.00327, 2023.

MS18 3
Tue Sep 5
2:30 pm
3:00 pm
VG1.103

An inverse problem related to fractional wave equation

P.-Z. Kow

In this talk, we will focus in an inverse problem for the fractional wave equation with a potential, which can be regarded as a special case of the peridynamics which models the nonlocal elasticity theory. We will discuss the issues of uniqueness and stability estimate in the determination of the potential by the exterior Dirichlet-to-Neumann map. This talk is prepared based on the work https://doi.org/10.1137/21M1444941

Bayesian hypothesis testing in statistical inverse problems

MS05 3
Thu Sep 7
4:00 pm
4:30 pm
VG2.102

R. Kretschmann, F. Werner

In many inverse problems, one is not primarily interested in the whole solution $u^\dagger$, but in specific features of it that can be described by a family of linear functionals of $u^\dagger$. We perform statistical inference for such features by means of hypothesis testing.

This problem has previously been treated by multiscale methods based upon unbiased estimates of those functionals [1]. Constructing hypothesis tests using unbiased estimators, however, has two severe drawbacks: Firstly, unbiased estimators only exist for sufficiently smooth linear functionals, and secondly, they suffer from a huge variance due to the ill-posedness of the problem, so that the corresponding tests have bad detection properties. We overcome both of these issues by considering the problem from a Bayesian point of view, assigning a prior distribution to $u^\dagger$, and using the resulting posterior distribution to define Bayesian maximum a posteriori (MAP) tests.

The existence of a hypothesis test with maximal power among a class of tests with prescribed level has recently been shown for all linear functionals of interest under certain a priori assumptions on $u^\dagger$ [2]. We study Bayesian MAP tests bases upon Gaussian priors both analytically and numerically for linear inverse problems and compare them with unregularized as well as optimal regularized hypothesis tests.

References

[1] K. Proksch, F. Werner, A. Munk. Multiscale scanning in inverse problems. Ann. Statist. 46(6B): 3569–3602. 2018. https://doi.org/10.1214/17-AOS1669

[2] R. Kretschmann, D. Wachsmuth, F. Werner. Optimal regularized hypothesis testing in statistical inverse problems. Preprint, 2022. https://doi.org/10.48550/arXiv.2212.12897

UCP and counterexamples to UCP involving generalized ray transforms

MS18 3
Tue Sep 5
2:00 pm
2:30 pm
VG1.103

V. Krishnan

We study generalized Radon-type transforms involving functions and symmetric tensor fields. We show in some instances that unique continuation principle for such transforms holds and we also give explicit counterexamples where such principle does not hold.

Inverse problems and deep learning in epidemiology and social processes

CT14
Fri Sep 8
4:30 pm
5:00 pm
VG2.106

O. Krivorotko, S. Kabanikhin, V. Petrakova, N. Zyatkov

Mathematical modeling of infectious propagation is strongly connected with social and economic processes. The different types of mathematical models (time-series, differential, agent-based and mean-field games ones) are investigated to formulate adequate models. The parameters (contagiousness, probability of progression of severe disease, mortality, asymptomatic carriers, probability of testing, and others) of models are, as a rule, unknown and should be estimated by solving inverse problems. Inverse problems are ill-posed, i.e. its solutions are unstable and/or non-unique due to incomplete and noisy input data (epidemiological statistics, socio-economic characteristics, etc.). Therefore we use regularization ideas and special technique to achieve the appropriate estimation of the model parameters.

The first step in construction of the mathematical model of epidemiology and social processes propagation consists in data processing using machine learning methods. It helps to fix key characteristics of both processes. For detailed inverse problem data time-series, differential (ordinary or partial equations to account for migration), agent-based models are combined to describe epidemiology situation in a considered region with influence of social processes [1, 2]. Otherwise, mean field approach is used for optimal control of epidemiology and social processes that consists in combination of Kolmogorov-Fokker-Plank (KFP) equation for propagation of the density of representative agent for considered epidemiological status and Hamilton-Jacobi-Bellman (HJB) equation for the optimal control strategy [3]. In [3] it was showed that an incorrect assessment of current social processes in the population leads to significant errors in predicting morbidity. The search for a correct description of the socio-epidemiological situation in mathematical terms leads to the formulation of the inverse mean field problem, where, according to epidemiological statistics and the rate of increase in the number of infected, factors affecting the development of the incidence (for example, antiviral restrictions) can be estimated [5].

The second step based on sensitivity-based identifiability analysis with using Bayesian approach, Monte-Carlo method, and singular value decomposition [4]. It provides the sequence of sensitivity parameters from the more sensitive to the less ones and reduces the boundaries of variation of the unknown parameters for further development of the regularization algorithm.

The inverse problems consist in (1) identification of less sensitive epidemic parameters for models based on differential equations and after that (2) identification of more sensitive epidemic parameters for agent-based models using known approximation of other parameters and processes data. Inverse problems are formulated as a least-squares minimization problem that solved by combination of global (Tree-Structured Parzen Estimator, tensor optimization, differential evolution) and gradient type optimization methods with a priory information about inverse problem solution.

Deep neural and generative adversarial networks for data processing and forecasting of time-series data as well as alternative approach for the direct and inverse problem solutions are applied and investigated. The key features of epidemiological and social processes and Wasserstein metrics are used for construction neural networks.

The numerical results are demonstrated the effectiveness of combination models and approaches to the COVID-19 propagation in different regions using socio-economic processes and optimal control programs of epidemic propagation in different economics.

The work is supported by the Mathematical Center in Akademgorodok under the agreement No. 075-15-2022-281 with the Ministry of Science and Higher Education of the Russian Federation.

References

[1] O. Krivorotko, M. Sosnovskaia, I. Vashchenko, C. Kerr, D. Lesnic. Agent-based modeling of COVID-19 outbreaks for New York state and UK: parameter identification algorithm. Infectious Disease Modelling. 7: 30-44, 2022.

[2] O.I. Krivorotko, N.Y. Zyatkov. Data-driven regularization of inverse problem for SEIR-HCD model of COVID-19 propagation in Novosibirsk region. Eurasian Journal of Mathematical and Computer Applications. 10(1): 51-68, 2022.

[3] V. Petrakova, O. Krivorotko. Mean field game for modeling of COVID-19 spread. Journal of Mathematical Analysis and Application. 514: 126271, 2022.

[4] O.I. Krivorotko, S.I. Kabanikhin, M.I. Sosnovskaya, D.V. Andornaya. Sensitivity and identifiability analysis of COVID-19 pandemic models. Vavilovskii Zhurnal Genetiki i Selektsiithis. 25(1): 82-91, 2021.

[5] L. Ding, W. W., S. Osher et al. A Mean Field Game Inverse Problem. Journal of Scientific Computing. 92:7, 2021.

Fractional anisotropic Calderon problem on Riemannian manifolds

MS18 2
Mon Sep 4
5:30 pm
6:00 pm
VG1.103

K. Krupchyk

We shall discuss some recent progress on the fractional anisotropic Calderon problem on closed Riemannian manifolds of dimensions two and higher. Specifically, we show that the knowledge of the local source-to-solution map for the fractional Laplacian, given on an arbitrary small open nonempty a priori known subset of a smooth closed Riemannian manifold, determines the Riemannian manifold up to an isometry. This can be viewed as a nonlocal analog of the anisotropic Calderon problem in the setting of closed Riemannian manifolds, which is wide open in dimensions three and higher. This is joint work with Ali Feizmohammadi, Tuhin Ghosh, and Gunther Uhlmann.

Inverse problems for nonlinear elliptic PDE

MS46 1
Thu Sep 7
5:30 pm
6:00 pm
VG1.104

K. Krupchyk

We shall discuss some recent progress for inverse boundary problems for nonlinear elliptic PDE. Our focus will be on inverse problems for isotropic quasilinear conductivity equations, as well as nonlinear Schrodinger and magnetic Schrodinger equations. In particular, we shall see that the presence of a nonlinearity may actually help, allowing one to solve inverse problems in situations where the corresponding linear counterpart is open. This talk is based on joint works with Catalin Carstea, Ali Feizmohammadi, Yavar Kian, and Gunther Uhlmann.

On modeling and regularization of piezoelectric inverse problems using all-at-once and reduced approaches

CT06
Thu Sep 7
2:30 pm
3:00 pm
VG2.107

R. Kuess

Piezoelectric materials are an essential component for a wide range of electrical devices. Consequently, the range of possible applications for piezoelectric materials is expansive, encompassing, for example, electronic toothbrushes and microphones, as well as ultrasound imaging and sonar devices.

Simplified, the behaviour in the small signal range can be described by a linearly coupled PDE system for mechanical displacement and electrical potential, which can then be extended by a non-linear PDE system to consider piezoelectric material in high signal range. Since many applications require high precision and also due to the transition to lead-free piezoceramics, a consistent and reproducible characterization of the material parameter set is of very high importance to properly determine the material properties, as the material data provided by the manufacturers often deviate significantly from the real data and are difficult and expensive to measure.

Therefore, this talk will focus on the parameter identification problem for the piezoelectric partial differential equation based on a measured and simulated quantity of the sample. Hence, we will derive the forward operator of this inverse problem generally. Then we will consider this inverse problem using regularization techniques based on all-at-once and reduced iterative methods, and further discuss the connection between the adjoint operators of the all-at-once approach and the adjoint differential equations of the reduced approach. Since several applications exhibit nonlinear material behaviour, the all-at-once approach is of particular interest, especially with respect to computational aspects. Thus, modeling, analysis and the solution of these inverse problems in these different settings by fitting simulated data is the main focus. Finally, numerical examples are provided.

MS47 2
Tue Sep 5
5:00 pm
5:30 pm
VG3.101

Gamma ray imaging with bidirectional Compton cameras

L. Kuger, M. Burger

For in-situ gamma ray spectrometry, Compton cameras are an efficient imaging tool that operate without collimation and therefore attain large sensitivities. Conventionally, Compton cameras are built with separated scattering and absorbing layers. This setup allows detector materials to be tailored to maximize sensitivity and have good energetic or spatial resolution, but often sacrifices the camera's ability to produce spatially resolved images in the whole 4π field of view resulting in a de facto collimation. We propose the mathematical model of a Compton camera whose detectors are all considered to both scatter and absorb the incoming gamma rays. Since the measurements of the camera do not give any information about the direction of a coincidence of scattering and absorption, we talk of a bidirectional Compton camera. The additional uncertainty is reflected in the operator describing the forward model, which is the weighted sum of two conical Radon transforms. We demonstrate the ability of the system to efficiently image gamma radiation by numerical results on simulated and measured data.

MS43 2
Mon Sep 4
4:30 pm
5:00 pm
VG1.108

Practical gamma ray imaging with monolithic scintillation detector Compton cameras

L. Kuger, M. Burger

Compton cameras are stationary, uncollimated gamma ray imaging devices that use the Compton effect to reconstruct a spatially resolved activity distribution. Due to the missing collimation, the cameras exhibit high sensitivities, particularly so for setups with large detectors in close distance of each other. This allows reconstruction in relatively low-count regimes and hence a flexible application in areas of low activity. For cameras with spatially non-resolved detectors, the size of the detectors however results in large angular uncertainty and distorted measurements due to multiple scattering contributions in the data. In this talk, we address the design and corresponding modeling approaches of Compton cameras with such monolithic, spatially non-resolved scintillation detectors. Numerical results on measured data support the theoretical considerations.

MS41 1
Fri Sep 8
1:30 pm
2:00 pm
VG3.101

Geodesic X-ray tomography on manifolds of low regularity

A. K. Kykkänen

Geodesic X-ray tomography arises in geomathematics as the linearized travel time problem of planets. Planets have non-smooth geometry as the sound speed is generally non-smooth, can have jump discontinuities and other extreme behavior. In this talk we consider the question: How non-smooth can Riemannian geometry be for the X-ray transform of scalar functions (and tensor fields) to remain injective? We prove that the X-ray transform is (solenoidally) injective on Lipschitz functions (tensor fields) when the Riemannian geometry is simple $C^{1,1}$. The class $C^{1,1}$ is the natural lower bound on regularity to have a well-defined X-ray transform. Our proofs are based on energy estimates derived from a Pestov identity, which lives on the non-smooth unit sphere bundle of the manifold. The talk is based on joint work with Joonas Ilmavirta.

An Inverse Problem for Nonlinear Fractional Magnetic Schrodinger Equation

MS18 2
Mon Sep 4
4:30 pm
5:00 pm
VG1.103

R.-Y. Lai

The study of nonlinear equations arises in many physical phenomena and is an active direction in the field of inverse problems. In this talk, we will discuss inverse problems for the fractional magnetic Schrodinger equation with nonlinear potential and address the crucial techniques that are applied to reconstruct the unknown coefficient from measurements.

Evolving surfaces driven by stochastic PDEs

MS09
Fri Sep 8
2:00 pm
2:30 pm
VG1.102

A. Lang

Motivated by evolving shapes such as moving cells, we construct examples of evolving stochastic surfaces by transformation of solutions to stochastic PDEs on spheres. We focus on the stochastic heat equation and its approximation to understand the transformation and simulation methods for the surfaces.

Surface finite element approximation of Gaussian random fields on Riemannian manifolds

MS04 1
Tue Sep 5
1:30 pm
2:00 pm
VG2.102

A. Lang

Whittle-Matérn Gaussian random fields are popular tools in spatial statistics. Interpreting them as solutions to specific stochastic PDEs allow to generalize them from fields on all of $\mathbb{R}^d$ to bounded domains and manifolds. In this talk we focus on Riemannian manifolds and efficient approximations of Gaussian random fields based on surface finite element methods.

Deep learning for phase retrieval from Fresnel diffraction patterns

MS59 2
Fri Sep 8
4:30 pm
5:00 pm
VG2.103

M. Langer, **K. Mom**, **B. Sixou**

We present our recent developments in phase retrieval from propagation-based X-ray phase contrast images using deep learning-based approaches. Previously, deep convolutional neural networks had been used as post-processing step to a linear phase retrieval algorithm [1]. In a first approach, we investigated the use of deep convolutional neural networks to directly retrieve phase and amplitude from a propagation distance series of phase contrast images [2]. Due to a structure that seems well adapted to the properties of the phase contrast images, taking into account features at several scales and connecting the corresponding feature maps, we chose the mixed-scale dense network (MS-DN) [3] architecture as network structure. We developed a transfer learning approach where the network is trained on simulated phase contrast images generated from projections of random objects with simple geometric shape.

We showed that the use of a simple pre-processing to transform the input to the image domain improved results, providing some support to the hypothesis that including knowledge of the image formation process in the network improves reconstruction quality. Some work has been done in this direction using generative adversarial networks by introducing a model of the image formation in a CycleGAN network [4].

Going one step further, information on how to solve the phase retrieval problem can be introduced into the neural network, algorithm unrolling being one such approach [5]. In algorithm unrolling, parts of an iterative algorithm, usually the regularization part, are replaced by neural networks. The networks learn the steps of the chosen iterative algorithm. These networks can then be applied in a sequential fashion, making the run-time application very efficient, moving the calculation load from the iterative reconstruction to the off-line training of the networks.

Based on this idea, we proposed the Deep Gauss-Newton network (DGN) [6]. Gauss-Newton type algorithms have been successfully used for phase retrieval from Fresnel diffraction patterns [7]. Inspired by this, we developed an unrolling-type algorithm based on a Gauss-Newton iteration. Both the regularization and the inverse Hessian are replaced by neural networks. The same network is used for each iteration, making the method very economical in terms of network weights. An initial reconstruction is not required; the algorithm can be initialized at zero. It can retrieve simultaneously the phase and attenuation sorption from one single diffraction pattern. We applied the DGN to both simulated and experimental data, for which it substantially improved the reconstruction error and the resolution compared both to the standard iterative algorithm and the MSDN-based method.

Future work includes extension of the algorithms to tomographic and time-resolved imaging, as well as to other imaging problems. Code for both algorithms will be made available through the PyPhase package [8] in a future release.

References

[1] C. Bai, M. Zhou, J. Min, S. Dand, X. Yu, P. Zhang, T. Peng, B. Yao. Robust contrast-transfer-function phase retrieval via flexible deep learning networks, Opt. Lett. 44 (21), 5141-5144, 2019.

[2] K. Mom, B. Sixou, M. Langer. Mixed scale dense convolutional networks for x-ray phase contrast imaging, Appl. Opt. 61, 2497-2505, 2022.

[3] D. M. Pelt, J. A. Sethian, A mixed-scale dense convolutional neural network for image analysis, Proc. Natl.402 Acad. Sci. USA 115, 254-259, 2018.

[4] Y. Zhang, M. A. Noack, P. Vagovic, K. Fezzaa, F. Garcia-Moreno, T. Ritschel, P. Villanueva-Perez. PhaseGAN: a deep-learning phase-retrieval approach for unpaired datasets, Opt. Express 29, 19593-19604, 2021.

[5] V. Monga, Y. Li, Y. C. Eldar. Algorithm unrolling: Interpretable, efficient deep learning for signal and image processing, IEEE Signal Proc. Mag. 38, 18-44, 2021.

[6] K. Mom, M. Langer, B. Sixou. Deep Gauss-Newton for phase retrieval, Opt. Lett. 48, 1136-1139, 2023.

[7] S. Maretzke, M. Bartels, M. Krenkel, T. Salditt, T. Hohage. Regularized newton methods for X-ray phase contrast and general imaging problems, Opt. Express 24, 6490-6506, 2016.

[8] M. Langer, Y. Zhang, D. Figueirinhas, J.-B. Forien, K. Mom, C. Mouton, R. Mokso, P. Villanueva-Perez. PyPhase - a Python package for X-ray phase imaging, J. Synch. Radiat. 28, 1261-1266, 2021.

Mapping properties of neural networks and inverse problems

MS34 1
Mon Sep 4
2:30 pm
3:00 pm
VG3.103

M. Lassas, M. Puthawala, I. Dokmanić, M. de Hoop

We will consider mapping properties of neural networks, in particular, injectivity of neural networks, universal approximation property of neural networks and the properties which the ranges of neural networks need to have. Also, we study approximation of probability measures using neural networks composed of invertible flows and injective layer and applications of these results in inverse problems.

Inverse problems for non-linear hyperbolic equations and many-to-one scattering relations

MS46 1
Thu Sep 7
5:00 pm
5:30 pm
VG1.104

M. Lassas

In the talk we give an overview on inverse problems for Lorentzian manifolds. We also discuss how inverse problems for partial differential equations can be solved using non-linear interaction of solutions. In the talk we concentrate on the geometric tools used to solve these problems, for instance to the k-to-1 scattering relation associated to the k-th order interactions and the observation time functions on Lorentzian manifolds.

Bayesian computation with Plug & Play priors for inverse problems in imaging

MS17
Tue Sep 5
4:30 pm
5:00 pm
VG1.104

R. Laumont, V. De bortoli, A. Almansa, J. Delon, A. Durmus, M. Pereyra

This presentation is devoted to the study of Plug & Play (PnP) methods applied to inverse problems encountered in image restoration. Since the work of Venkatakrishnan et al. in 2013 [1], PnP methods are often applied for image restoration in a Bayesian context. These methods aim at computing Minimum Mean Square Error (MMSE) or Maximum A Posteriori (MAP) for inverse problems in imaging by combining an explicit likelihood and an implicit prior defined by a denoising algorithm. In the literature, PnP methods differ mainly in the iterative scheme used for both optimization and sampling. In the case of optimization algorithms, recent works guarantee the convergence to a fixed point of a certain operator, fixed point which is not necessarily the MAP. In the case of sampling algorithms in the literature, there is no evidence of convergence. Moreover, there are still important open questions concerning the correct definition of the underlying Bayesian models or the computed estimators, as well as their regularity properties, necessary to ensure the stability of the numerical scheme. The aim of this thesis is to develop simple but efficient restoration methods while answering some of these questions. The existence and nature of MAP and MMSE estimators for PnP prior is therefore a first line of study. Three methods with convergence results are then presented, PnP-SGD for MAP estimation and PnP-ULA and PPnP-ULA for sampling. A particular interest is given to denoisers encoded by deep neural networks. The efficiency of these methods is demonstrated on classical image restoration problems such as denoising, deblurring or interpolation. In addition to allowing the estimation of MMSE, sampling makes possible the quantification of uncertainties, which is crucial in domains such as biomedical imaging. [2] and [3] are the papers related to this talk.

References

[1] S. Venkatakrishnan, V. Singanallur, C. Bouman, B. Wohlberg. Plug-and-play priors for model based reconstruction, IEEE Global Conference on Signal and Information Processing, 2013. DOI: 10.1109/GlobalSIP.2013.6737048.

[2] R. Laumont, V. De Bortoli, A. Almansa, J. Delon, A. Durmus, M, Pereyra. Bayesian imaging using Plug & Play priors: when Langevin meets Tweedie, SIAM Journal on Imaging Sciences 15(2): 701-737, 2022.

[3] R. Laumont, V. De Bortoli, A. Almansa, J. Delon, A. Durmus, M. Pereyra. On Maximum a Posteriori Estimation with Plug & Play Priors and Stochastic Gradient Descent, Journal of Mathematical Imaging and Vision 65: 140-163, 2023.

MS58 2
Tue Sep 5
5:00 pm
5:30 pm
VG2.104

Shape optimization approach for sharp-interface reconstructions in time-domain full waveform inversion.

A. Laurain

Velocity models presenting sharp interfaces are frequently encountered in seismic imaging, for instance for imaging the subsurface of the Earth in the presence of salt bodies. In order to mitigate the oversmoothing of classical regularization strategies such as the Tikhonov regularization, we propose a shape optimization approach for sharp-interface reconstructions in time-domain full waveform inversion. Using regularity results for the wave equation with discontinuous coefficients, we show the shape differentiability of the cost functional measuring the misfit between observed and predicted data, for shapes with low regularity. We propose a numerical approach based on the obtained distributed shape derivative and present numerical tests supporting our methodology.

MS19 1
Tue Sep 5
3:00 pm
3:30 pm
VG3.103

Theoretical and numerical off-the-grid curve reconstruction

B. Laville, L. Blanc-Féraud, G. Aubert

Recent years have seen the development of super-resolution variational optimisation optimisation in measure spaces. These so-called off-the-grid approaches offer both theoretical (uniqueness, reconstruction guarantees) and numerical results, with very convincing results in biomedical imaging. However, the gridless variational optimisation is formulated for reconstruction of point sources, which is not always suitable for biomedical imaging applications: more realistic biological structures such as curves should also be reconstructed, to represent blood vessels or filaments for instance.

We propose a new strategy for the reconstruction of curves in an image through an off-the-grid variational framework, inspired by the reconstruction of spikes in the literature. We introduce a new functional CROC on the space of 2-dimensional Radon measures with finite divergence denoted V. Our main contribution lies in the sharp characterisation of the extreme points of the unit ball of the V -norm: there are exactly measures supported on 1-rectifiable oriented simple Lipschitz curves, thus enabling a precise characterisation of our functional minimisers and further opening the avenue for the algorithmic implementation.

MS28 2
Tue Sep 5
4:00 pm
4:30 pm
VG1.108

Gradient descent-based algorithms for inverse problems in variable exponent Lebesgue spaces

M. Lazzaretti, Z. Kereta, L. Calatroni, C. Estatico

Variable exponent Lebesgue spaces $\ell^{(p_n)}$ have been recently proved to be the appropriate functional framework to enforce pixel-adaptive regularisation in signal and image processing applications (see [1]), combined with gradient descent (GD) or proximal GD strategies. Compared to standard Hilbert or Euclidean settings, however, the application of these algorithms in the Banach setting of $\ell^{(p_n)}$ is not straightforward due to the lack of a closed-form expression and the non-separability property of the underlying norm. We propose the use of the associated separable modular function [2, 3], instead of the norm, to define algorithms based on GD in $\ell^{(p_n)}$ and consider a stochastic GD [3, 4] to reduce the per-iteration cost of iterative schemes, used to solve linear inverse real-world image reconstruction problems.

References

[1] B. Bonino, C. Estatico, and M. Lazzaretti. Dual descent regularization algorithms in variable exponent Lebesgue spaces for imaging, Numer. Algorithms 92(6), 2023.

[2] M. Lazzaretti, L. Calatroni, and C. Estatico. Modular-proximal gradient algorithms in variable exponent Lebesgue spaces, SIAM J. Sci. Compu. 44(6), 2022.

[3] M. Lazzaretti, Z. Kereta, L. Calatroni, and C. Estatico. Stochastic gradient descent for linear inverse problems in variable exponent Lebesgue spaces, 2023. [https://arxiv.org/abs/2303.09182]

[4] Z. Kereta, and B. Jin. On the convergence of stochastic gradient descent for linear inverse problems in Banach spaces, SIAM J. Imaging Sci. (in press), 2023.

Advancements and New Questions in Analysing the Geometry of Molecular Conformations in Cryo-EM

MS26 2
Thu Sep 7
2:30 pm
3:00 pm
VG3.102

R. R. Lederman

Cryo-Electron Microscopy (cryo-EM) is an imaging technology revolutionizing structural biology. One of the great promises of cryo-EM is to study mixtures of conformations of molecules. We will discuss recent advancements in the analysis of continuous heterogeneity - the continuum of conformations in flexible macromolecule. We will discuss some of the mathematical and technical questions arising from these recent algorithms.

Advances in object characterisation for metal detection inverse problems

MS14 3
Tue Sep 5
2:30 pm
3:00 pm
VG1.104

P. D. Ledger, W. R. B. Lionheart, J. Elgy

The location and identification of hidden conducting threat objects using metal detection is an important yet difficult task. Applications include security screening at transport hubs and finding landmines and unexploded ordnance in areas of former conflict. Based on an asymptotic expansion of the perturbed magnetic field, we have derived an economical object description called a magnetic polarizability tensor (MPT), which is a function of the object's size, shape, material properties and the exciting frequency [1]. The MPT provides the object characterisation in the leading order term of the asymptotic expansion of the perturbed magnetic field as the object size tends to 0 and we have extended this to a complete asymptotic expansion with improved object characterisation provided by generalised MPTs expressed in terms of tensorial and multi-indices [2].

To compute object characterisations, we employ a hp-finite element method, accelerated by an adaptive reduced order model and scaling results [3], to efficiently compute a large dictionary spectral signature characterisations of realistic threat and non-threat objects relevant for security screening [4]. To accurately capture small skin depths and realistic in-homogeneous objects with thin material layers, this involves including thin layers of prismatic boundary layers, which we have shown are in close agreement with measurements [5]. In this talk, we review our latest developments and discuss possible classification strategies [6].

References

References

[1] P. D. Ledger, W. R. B. Lionheart. The spectral properties of the magnetic polarizability tensor for metallic object characterisation. Mathematical Methods in the Applied Sciences, 43:78-113, 2020.

[2] P.D. Ledger, W.R.B. Lionheart. Properties of generalized magnetic polarizability tensors. Mathematical Methods in the Applied Sciences, To appear 2023. DOI:10.1002/mma.8856

[3] B. A. Wilson, P. D. Ledger. Efficient computation of the magnetic polarizability tensor spectral signature using proper orthogonal decomposition. International Journal for Numerical Methods in Engineering, 122:1940-1963, 2021.

[4] P. D. Ledger, B. A. Wilson, A. A. S. Amad, W. R. B. Lionheart. Identification of metallic objects using spectral magnetic polarizability tensor signatures: Object characterisation and invariants. International Journal for Numerical Methods in Engineering, 122:3941-3984, 2021.

[5] J. Elgy, P.D. Ledger, J.L. Davidson, T. Ozdeger, A.J. Peyton, Computations and measurements of the magnetic polarizability tensor characterisation of highly conducting and magnetic objects, submitted 2023.

[6] B. A. Wilson, P. D. Ledger, and W. R. B. Lionheart. Identification of metallic objects using spectral magnetic polarizability tensor signatures: Object classification. International Journal for Numerical Methods in Engineering 123: 2076-2111, 2022.

MS08 1
Fri Sep 8
2:30 pm
3:00 pm
VG2.102

Spectral theory of surface plasmons in the nonlocal hydrodynamic Drude model

H. Lee, M. Ruiz, S. Yu

We study surface plasmons, which are collective oscillations of electrons at metal-dielectric interfaces that can be excited by light. The local Drude model, which is the standard way to describe surface plasmons, ignores the spatial and quantum variations of the electron gas. These variations matter at the nanoscale and can change how metallic nanostructures interact with light. We use integral operator methods to investigate how the nonlocal hydrodynamic Drude model (HDM), which accounts for these variations, affects the spectral properties of surface plasmons in general shapes with smooth boundaries.

CT13
Fri Sep 8
4:00 pm
4:30 pm
VG2.105

Joint Born Inversion of Acoustic and Electromagnetic Wave fields

A. V. de Wit, T. van Leeuwen, F. Lucka, D. J. Verschuur, K. W. A. van Dongen

Imaging by inversion of acoustic or electromagnetic wave fields have applications in a wide variety of areas, such as non-destructive testing, biomedical applications, and geophysical exploration. However, each modality suffers from its own application specific limitations with respect to resolution and sensitivity. To exploit the advantages of both imaging modalities, methods to combine them include image fusion, usage of spatial priors and application of joint or multi-physics inversion methods. In this work, a joint inversion algorithm based on structural similarity is presented. In particular, a joint Born inversion (BI) algorithm has been developed and tested successfully. With standard BI, an error functional based on the L2-norm of the mismatch between the measured and modeled wave field is minimized iteratively. To accomplish joint BI, we extend the standard error functional with an additional penalty term based on the L2-norm of the difference between the gradients of the acoustic and electromagnetic contrasts.

Marked length spectrum rigidity for Anosov surfaces

MS52 3
Tue Sep 5
1:30 pm
2:00 pm
VG1.105

T. Lefeuvre

On a closed Riemannian manifold, the marked length spectrum rigidity problem consists in recovering the metric from the knowledge of the lengths of its closed geodesics (marked by the free homotopy classes of the manifold). I will present a solution to this problem for Anosov surfaces namely, surfaces with uniformly hyperbolic geodesic flow (in particular, all negatively-curved surfaces are Anosov). This generalizes to the Anosov setting the celebrated rigidity results by Croke and Otal from the 90s.

Scanning biological tissues using thermal-waves

MS14 1
Mon Sep 4
1:30 pm
2:00 pm
VG1.104

D. Lesnic

Many materials in nature possess properties that are unknown and difficult to measure directly. In such a situation, inverse modelling offers a viable alternative where one is trying to infer those unknown properties from appropriate measurements of the main dependent variable(s) governing the physical process under investigation. Our investigation is driven by the fact that knowledge of the properties of biological tissues is essential in monitoring any abnormalities that may be forming and have a major impact on organs malfunctioning. Therefore, these disorders must be detected and treated early to save lives and improve the general health. Within the framework of thermal therapies, e.g. hyperthermia or cryoablation, the knowledge of the tissue temperature and its properties, as well as the blood perfusion rate are of utmost importance. Motivated by such a significant biomedical application, this study investigates the reconstruction of biological properties in the thermal-wave hyperbolic model of bio-heat transfer.

The support of the EPSRC grant EP/W000873/1 on “Transient Tomography for Defect Detection” is acknowledged.

Regularized, pretrained and subspace-restricted Deep Image Prior for CT reconstruction

MS21 2
Tue Sep 5
4:00 pm
4:30 pm
VG2.103

R. Barbano, J. Antorán, J. Leuschner, B. Jin, J. M. Hernández-Lobato, Z. Kereta, D. O. Baguer, M. Schmidt, A. Denker, A. Hauptmann, P. Maaß

Computed tomography (CT) is an important tool in both medicine and industry. By now, a great variety of deep learning (DL) techniques has been developed for inverse imaging tasks including CT reconstruction. In constrast to most DL approaches, the deep image prior (DIP) is an unsupervised framework that does not rely on a large training dataset, but only on the single degraded observation. The central observation with DIP is that the early-stopped optimization an untrained networks can lead to favorable solutions, thus acting as an implicit prior.

We extend the DIP in several ways. First, we add an explicit prior in the form of a total variation regularization term, which can stabilize and improve the reconstruction. Second, we pretrain on a post-processing task with easy-to-generate synthetic data, which induces prior information, learned from the synthetic image class and the operator-specific degradation, into the subsequent unsupervised DIP optimization. This two-stage procedure of supervised pretraining and unsupervised fine-tuning is called the educated DIP (EDIP) and often requires a significantly shorter optimization time in the fine-tuning stage compared to untrained DIP. Finally, we experiment with restricting the parameter space in the fine-tuning stage of EDIP. Using an affine linear subspace, which is expanded around the pretraining parameters with a sparsified basis obtained from many checkpoints saved during the pretraining, both overfitting behaviour can be reduced and second order optimization methods become feasible, enabling more stable and faster reconstruction.

MS59 1
Fri Sep 8
2:30 pm
3:00 pm
VG2.103

Learned post-processing approaches for nano-CT reconstruction

T. Lütjen, F. Schönfeld, A. Oberacker, M. Schmidt, J. Leuschner, T. Kluth, A. Wald

X-ray computed tomography on the nano-meter scale is a challenging imaging task. Tiny perturbations, such as environmental vibrations, technology imprecision or a thermal drift over time, lead to considerable deviations in the measured projections for nano-CT. Reconstruction algorithms must take into account the presence of these deviations in order to avoid strong artifacts. We study different learned post-processing approaches for nano-CT reconstruction on simulated datasets featuring relative object shifts and rotations. The initial reconstruction is provided by a classical method (FBP, Kaczmarz) or a deviation-aware method (Dremel method, RESESOP-Kaczmarz). Neural networks are then trained supervisedly to post-process such initial reconstructions. We consider (i) a directly trained U-Net post-processing, and (ii) conditional normalizing flows, which learn an invertible mapping between a simple random distribution and the image reconstruction space, conditioned on the initial reconstruction. Normalizing flows do not only yield a reconstruction, but also an estimate of the posterior density. As a simple indicator of reconstruction uncertainty one may evaluate the pixel-wise standard deviation over samples from the estimated posterior.

MS12 1
Mon Sep 4
1:30 pm
2:00 pm
VG2.102

Parameter-Robust Preconditioning for Oseen Iteration Applied to Navier-Stokes Control Problems

S. Leveque, J. Pearson

Optimal control problems with PDEs as constraints arise very often in scientific and industrial problems. Due to the difficulties arising in their numerical solution, researchers have put a great effort into devising robust solvers for this class of problems. An example of a highly challenging problem attracting significant attention is the (distributed) control of incompressible viscous fluid flow problems. In this case, the physics may be described, for very viscous flow, by the (linear) incompressible Stokes equations, or, in case the convection of the fluid plays a non-negligible role in the physics, by the (non-linear) incompressible Navier-Stokes equations. In particular, as the PDEs given in the constraints are non-linear, in order to obtain a solution of Navier-Stokes control problems one has to iteratively solve linearizations of the problems until a prescribed tolerance on the non-linear residual is achieved.

In this talk, we present novel, fast, and parameter-robust preconditioned iterative methods for the solution of the distributed time-dependent Navier-Stokes control problems with Crank-Nicolson discretization in time. The key ingredients of the solver are a saddle-point type approximation for the linear systems, an inner iteration for the $(1,1)$-block accelerated by a generalization of the preconditioner for convection-diffusion control derived in [2], and an approximation to the Schur complement based on a potent commutator argument applied to an appropriate block matrix. The flexibility of the commutator argument, which is a generalization of the technique derived in [1], allows one to alternatively apply a backward Euler scheme in time, as well as to solve the stationary Navier-Stokes control problem. We show the effectiveness and robustness of our approach through a range of numerical experiments.

This talk is based on the work in [3].

References

[1] D. Kay, D. Loghin, A.J. Wathen. A Preconditioner for the Steady-State Navier-Stokes Equations, SIAM Journal on Scientific Computing 24: 237-256, 2002.

[2] S. Leveque, J.W. Pearson. Fast Iterative Solver for the Optimal Control of Time-Dependent PDEs with Crank-Nicolson Discretization in Time, Numerical Linear Algebra with Applications 29: e2419, 2022.

[3] S. Leveque, J.W. Pearson. Parameter-Robust Preconditioning for Oseen Iteration Applied to Stationary and Instationary Navier-Stokes Control, SIAM Journal on Scientific Computing 44: B694-B722, 2022.

Hopf lemma for fractional diffusion equations and application to inverse problem

MS55 2
Mon Sep 4
4:30 pm
5:00 pm
VG3.101

D. Jiang, Z. Li

In this talk, we will discuss an inverse problem of determining the spatially dependent source term and the Robin boundary coefficient in a time-fractional diffusion equation, with the aid of extra measurement data at a subdomain near the accessible boundary. Firstly, the spatially varying source is uniquely determined in view of the unique continuation principle and Duhamel principle for the fractional diffusion equation. The Hopf lemma for a homogeneous time-fractional diffusion equation is proved and then used to prove the uniqueness of recovering the Robin boundary coefficient. Numerically, based on the theoretical uniqueness result, we apply the classical Tikhonov regularization method to transform the inverse problem into a minimization problem, which is solved by an iterative thresholding algorithm. Finally, several numerical examples are presented to show the accuracy and effectiveness of the proposed algorithm.

UNLIMITED: The UNiversal Lepskii-Inspired MInimax Tuning mEthoD

MS05 2
Thu Sep 7
3:00 pm
3:30 pm
VG2.102

H. Li, F. Werner

In this talk we consider statistical linear inverse problems in separable Hilbert spaces. They arise in applications spanning from astronomy over medical imaging to engineering. We study the (ordered) filter-based regularization methods, including e.g. spectral cutoff, Tikhonov, iterated Tikhonov, Landweber, and Showalter. The proper choice of regularization parameter is always crucial, and often relies on the (unknown) structure assumptions of the true signal. Aiming at a fully automatic procedure, we investigate a specific a posteriori parameter choice rule, which we call UNiversal Lepskii-Inspired MInimax Tuning method (UNLIMITED). We show that the UNLIMTED rule leads to adaptively minimax optimal rates over various smoothness function classes in mildly and severely ill-posed problems. In particular, our results reveal that the “common sense” that one typically loses a log-factor for Lepskii-type methods is actually wrong! In addition, the empirical performance of UNLIMITED is examined in simulations.

MS19 1
Tue Sep 5
1:30 pm
2:00 pm
VG3.103

Stability and super-resolution of MUSIC and ESPRIT for multi-snapshot spectral estimation

W. Li

We study the spectral estimation problem of estimating the locations of a fixed number of point sources given multiple snapshots of Fourier measurements collected by a uniform array of sensors. We prove novel stability bounds for MUSIC and ESPRIT as a function of the noise standard deviation, number of snapshots, source amplitudes, and support. When the point sources are located in several clumps, we provide explicit upper bounds for MUSIC and ESPRIT in terms of a Super-Resolution Factor (SRF). We also derive a new Cramér-Rao lower bound for the clumps model, and as a result, implies that ESPRIT is comparable to that of the optimal unbiased estimator(s) in terms of the dependence on noise, number of snapshots and SRF. As a byproduct of our analysis, we discover several fundamental differences between the single-snapshot and multi-snapshot problems.

MS33 1
Wed Sep 6
10:30 am
11:00 am
VG1.105

Scalable Bayesian uncertainty quantification with learned convex regularisers

T. I. Liaudat, M. Betcke, J. D. McEwen, M. Pereyra

The last decade brought us substantial progress in computational imaging techniques for current and next-generation interferometric telescopes, such as the SKA. Imaging methods have exploited sparsity and more recent deep learning architectures with remarkable results. Despite good reconstruction quality, obtaining reliable uncertainty quantification (UQ) remains a common pitfall of most imaging methods. The UQ problem can be addressed by reformulating the inverse problem in the Bayesian framework. The posterior probability density function provides a comprehensive understanding of the uncertainties. However, computing the posterior in high-dimensional settings is an extremely challenging task. Posterior probabilities are often computed with sampling techniques, but these cannot yet cope with the high-dimensional settings from radio imaging.

This work proposes a method to address uncertainty quantification in radio-interferometric imaging with data-driven (learned) priors for very high-dimensional settings. Our model uses an analytic physically motivated model for the likelihood and exploits a data-driven prior learned from data. The proposed prior can encode complex information learned implicitly from training data and improves results from handcrafted priors (e.g., wavelet-based sparsity-promoting priors). We exploit recent advances in neural-network-based convex regularisers for the prior that allow us to ensure the log-concavity of the posterior while still being expressive. We leverage probability concentration phenomena of log-concave posterior functions that let us obtain information about the posterior avoiding the use of sampling techniques. Our method only requires the maximum-a-posteriori (MAP) estimation and evaluations of the likelihood and prior potentials. We rely on convex optimisation methods to compute the MAP estimation, which are known to be much faster and better scale with dimension than sampling strategies. The proposed method allows us to compute local credible intervals, i.e., Bayesian error bars, and perform hypothesis testing of structure on the reconstructed image. We demonstrate our method by reconstructing simulated radio-interferometric images and carrying out fast and scalable uncertainty quantification.

Phaseless sampling of the short-time Fourier transform

MS22 1
Tue Sep 5
2:30 pm
3:00 pm
VG1.101

L. Liehr

We discuss recent advances in phaseless sampling of the short-time Fourier transform (STFT). The main focus of the talk lies in the question if phaseless samples of the STFT contain enough information to recover signals belonging to infinite-dimensional function spaces. It turns out, that this problem differs from ordinary sampling in a rather fundamental and subtle way: if the sampling set is a lattice then uniqueness is unachievable, independent of the choice of the window function and the density of the lattice. Based on this discretization barrier, we present possible ways to still achieve unique recoverability from samples: lattice-uniqueness is possible if the signal class gets restricted to certain proper subspaces of $L^2(\mathbb{R})$, such as the class of compactly-supported functions or shift-invariant spaces. Finally, we highlight that sampling on so-called square-root lattices achieves uniqueness in $L^2(\mathbb{R})$.

Inverse problem for the minimal surface equation and nonlinear CGO calculus in dimension 2

MS46 2
Fri Sep 8
2:00 pm
2:30 pm
VG1.104

T. Liimatainen

We present our recent results regarding inverse problems for the minimal surface equation. Applications of the result include generalized boundary rigidity problem and AdS/CFT correspondence in physics. Minimal surfaces are solutions to a quasilinear elliptic equation and we determine the minimal surface up to an isometry from the corresponding Dirichlet-to-Neumann map in dimension 2. For this purpose we develop a nonlinear calculus for complex geometric optics solutions (CGOs) to handle numerous correction terms that appear in our analysis. We expect the calculus to be applicable to inverse problems for other nonlinear elliptic equations in dimension 2. The talk is based on joint works with Catalin Carstea, Matti Lassas and Leo Tzou.

Numerical computation of Laplacian eigenvalues based on the layer potential formulation

MS08 1
Fri Sep 8
3:00 pm
3:30 pm
VG2.102

M. Lim, J. Hong

In this talk, we will present a numerical method that allows for the Laplacian eigenvalues of a planar, simply connected domain by only using the coefficients of the conformal mapping of the domain. We formulate the eigenvalue problems using the layer potential characterization and geometric density basis functions, resulting in an infinite dimensional matrix, where geometric density basis functions are associated with the conformal mapping of the domain. We will discuss how to compute the eigenvalues by using this infinite-dimensional matrix. Additionally, we will provide some convergence analysis for this approach based on the Gohberg-Sigal theory for operator-valued functions.

Inverse source problems for nonlinear equations

MS46 2
Fri Sep 8
1:30 pm
2:00 pm
VG1.104

Y.-H. Lin

In this talk, we perform inverse source problems for nonlinear equations. Unlike linear differential equations, which always have gauge invariance. We investigate how the gauge symmetry could be broken for several nonlinear and nonlocal equations, which leads to unique determination results for certain equations.

MS20 1
Thu Sep 7
1:30 pm
2:00 pm
VG3.104

Determining a nonlinear hyperbolic system with unknown sources and nonlinearity

Y.-H. Lin

This talk is devoted to some inverse boundary problems associated with a time-dependent semilinear hyperbolic equation, where both nonlinearity and sources (including initial displacement and initial velocity) are unknown. It is shown in several generic scenarios that one can uniquely determine the nonlinearity and/or the sources by using passive or active boundary observations. In order to exploit the nonlinearity and the sources simultaneously, we develop a new technique, which combines the observability for linear wave equations and an approximation property with higher order linearization for the semilinear hyperbolic equation

MS51 1
Thu Sep 7
2:00 pm
2:30 pm
VG1.108

Fourier method for inverse source problem using correlation of passive measurements

K. Linder-Steinlein, M. Karamehmedović, F. Triki

We consider the inverse source problem for a Cauchy wave equation with passive cross-correlation data. We propose to consider the cross-correlation as a wave equation itself and reconstruct the cross-correlation in the support of the source for the original Cauchy wave equation. Having access to the cross-correlation in the support of the source, we use a Fourier method to reconstruct the source of the original Cauchy wave equation. We show the inverse source problem is ill-posed and suffer from non-uniqueness when the mean of the source is zero, and provide a uniqueness result and stability estimate in case of non-zero mean.

MS54 3
Tue Sep 5
4:30 pm
5:00 pm
VG1.105

Rich tomography reconstruction problems in applications.

W. Lionheart

Rich tomography refers generally to problems in which the image has more than just a scalar per voxel, and often the measurement is more than one scalar per source and detector pair. In this talk I will give a number of examples of real problems where the data collection systems exist and I will review their mathematical formulation, what is known and what is yet to be determined about the reconstruction problem (as well as sufficiency of data, range characterization and stability,

Small Angle X-ray Scattering (SAXS) tomography is an example where a diffraction pattern is measured for each ray, and the inverse problem is to determine the 'reciprocal space map' a function of three variables at each point.

Several techniques involve the imaging of strain in a crystalline or polycrystalline material. I will show the formulation of the problem where the measurement uses neutrons and electrons. In polycrystalline materials the texture, or distribution of crystal orientations over a given scale, is often an 'nuisance variable' but can be of interest in its own right. I will suggest some possible mathematical challenges.

Finally the imaging of magnetic fields is a vector tomography problem and I will contrast the method using polarimetric tomography with neutrons and also a method using electron tomography.

A Mathematical Theory of Computational Resolution Limit and Super-resolution

MS19 1
Tue Sep 5
2:00 pm
2:30 pm
VG3.103

P. Liu, H. Ammari

Due to the physical nature of wave propagation and diffraction, there is a fundamental diffraction barrier in optical imaging systems which is called the diffraction limit or resolution limit. Rayleigh investigated this problem and formulated the well-known Rayleigh limit. However, the Rayleigh limit is empirical and only considers the resolving ability of the human visual system. On the other hand, resolving sources separated below the Rayleigh limit to achieve so-called "super-resolution" has been demonstrated in many numerical experiments.

In this talk, we will propose a new concept "computational resolution limit" which reveals the fundamental limits in superresolving the number and locations of point sources from a data-processing point of view. We will quantitatively characterize the computational resolution limits by the signal-to-noise ratio, the sparsity of sources, and the cutoff frequency of the imaging system. As a direct consequence, it is demonstrated that l_0 optimization achieves the optimal order resolution in solving super-resolution problems. For the case of resolving two point sources, the resolution estimate is improved to an exact formula, which answers the long-standing question of diffraction limit in a general circumstance. We will also propose an optimal algorithm to distinguish images generated by single or multiple point sources. Generalization of our results to the imaging of positive sources and imaging in multi-dimensional spaces will be briefly discussed as well.

Inverse scattering problems with incomplete data

MS55 1
Mon Sep 4
3:00 pm
3:30 pm
VG3.101

X. Liu

Inverse scattering problems aim to determine unknown scatterers with wave fields measured around the scatterers. However, from the practical point of views, we have only limited information, e.g., limited aperture data phaseless data and sparse data. In this talk, we introduce some data retrieval techniques and the applications in the inverse scattering problems. The theoretical and numerical methods for inverse scattering problems with multi-frequency spase measurements will also be mentioned.

Acceleration strategies for Magnetic Resonance Spin Tomography in Time-Domain (MR-STAT) reconstructions

MS50 1
Fri Sep 8
2:30 pm
3:00 pm
VG1.105

H. Liu, O. van der Heide, M. Stefano, V. Edwin, F. Miha, C. A. T. van den Berg, A. Sbrizzi

Magnetic Resonance Spin Tomography in Time-Domain (MR-STAT) is an emerging quantitative magnetic resonance imaging technique which aims at obtaining multi-parametric tissue parameter maps (T1, T2, proton density, etc) from short scans. It describes the relationship between the spatial-domain tissue parameters and the time-domain measured signal by using a comprehensive, volumetric forward model. The MR-STAT reconstruction is cast as a large-scale, ODE constrained, nonlinear inversion problem, which is very challenging in terms of both computing time and memory.

In this presentation, I'll talk about recent progresses about the acceleration strategies for MR-STAT reconstructions, for example, using a neural network model for the solution of the underlying differential equation model, applying alternating direction method of multipliers (ADMM) etc.

MS12 1
Mon Sep 4
2:30 pm
3:00 pm
VG2.102

An Accelerated Level-Set Method for Inverse Scattering Problems

L. Audibert, H. Haddar, X. Liu

We propose a rapid and robust iterative algorithm to solve inverse acoustic scattering problems formulated as a PDE constrained shape optimization problem. We use a level-set method to represent the obstacle geometry and propose a new scheme for updating the geometry based on an adaptation of accelerated gradient descent methods. The resulting algorithm aims at reducing the number of iterations and improving the accuracy of reconstructions. To cope with regularization issues, we propose a smoothing to the shape gradient using a single layer potential associated with ik where k is the wave number. Numerical experiments are given for several data types (full aperture, backscattering, phaseless, multiple frequencies) and show that our method outperforms a nonaccelerated approach in terms of convergence speed, accuracy, and sensitivity to initial guesses.

MS57 2
Mon Sep 4
4:00 pm
4:30 pm
VG3.102

A mathematical theory of resolution limits for dynamic super-resolution in particle tracking problems

P. Liu, H. Ammari

Particle tracking in a live cell environment is concerned with reconstructing the trajectories, locations, or velocities of the targeting particles, which holds the promise of revealing important new biological insights. The standard approach of particle tracking consists of two steps: first reconstructing statically the source locations in each time step, and second applying tracking techniques to obtain the trajectories and velocities. In contrast to the standard approach, the dynamic reconstruction seeks to simultaneously recover the source locations and velocities from all frames, which enjoys certain advantages. In this talk, we will present a rigorous mathematical analysis for the resolution limit of reconstructing source number, locations, and velocities by general dynamical reconstruction in particle tracking problems, by which we demonstrate the possibility of achieving super-resolution for dynamic reconstruction. We show that when the location-velocity pairs of the particles are separated beyond certain distances (the resolution limits), the number of particles and the location-velocity pair can be stably recovered. The resolution limits are related to the cut-off frequency of the imaging system, signal-to-noise ratio, and the sparsity of the source. By these estimates, we also derive a stability result for a sparsity-promoting dynamic reconstruction. In addition, we further show that the reconstruction of velocities has a better resolution limit which improves constantly as the particles move. The result is derived from a crucial observation that the inherent cut-off frequency for the velocity recovery can be viewed as the cut-off frequency of the imaging system multiplied by the total observation time, which may lead to a better resolution limit than the one for each diffraction-limited frame. In addition, we propose super-resolution algorithms for recovering the number and values of the velocities in the tracking problem and demonstrate theoretically or numerically their super-resolution capability.

A Parameter Identification Algorithm for Gaussian Mixture Models

MS19 3
Wed Sep 6
9:30 am
10:00 am
VG3.103

X. Liu, H. Zhang

In this talk, we consider the problem of learning the parameters from the Fourier measurements of the one-dimensional Gaussian mixture models(GMM). Unlike most algorithms requires the number of Gaussians a prior, our method only need to know the number of different variances as prior information. We also illustrate that for stably recovering all the components under certain noise level, a separation condition for the variances is necessary. Our method can be generalized into high dimensional cases.

Damage detection by guided ultrasonic waves and uncertainty quantification

MS10 2
Thu Sep 7
5:30 pm
6:00 pm
VG1.103

D. Lorenz, N. K. Bellam Muralidhar, C. Gräßle, N. Rauter, A. Mikhaylenko, R. Lammering

New materials like fibre metal laminates (FML) call for new methods when it comes to structural health monitoring (SHM). In this talk we describe an approach to SHM in FML based on guided ultrasonic waves that travel through plates as lamb waves. By the controlled emission of such waves and the measurement of the displacement at a few position, we aim to detect if a damage in the material is present. We approach this inverse problem by an analytical model of the forward propoagation and a simple damage model that is (nonlinearly) parameterized by a small number of parameters. To identify the damage parameters we employ Bayesian methods (namely a Markov Chain Monte-Carlo Metropolis-Hastings method and the ensemble Kalman filter). To make these computationally tractable, we use parametric model reduction to speed up the forward evaluations of the model.

Quadratic regularization of optimal transport problems

MS45 1
Tue Sep 5
5:30 pm
6:00 pm
VG0.111

D. Lorenz, H. Mahler, P. Manns, C. Meyer

In this talk we consider regularization of optimal transport problems with quadratic terms. We use the Kantorovich for of optimal transport and add a quadratic regularizer, which forces the transport plan to be a square integrable function instead of a general measure. We derive the dual problem and show strong duality and existence of primal and dual solutions to the regularized problem. Then we derive two algorithms to solve the dual problem of the regularized problem: A Gauss-Seidel method and a semismooth quasi-Newton method and investigate both methods numerically. Our experiments show that the methods perform well even for small regularization parameters. Quadratic regularization is of interest since the resulting optimal transport plans are sparse, i.e. they have a small support (which is not the case for the often used entropic regularization where the optimal transport plan always has full measure). Finally we briefly sketch an extension of the results to the more general case of regularization with so-called Young functions which unifies the entropic and the quadratic regularization.

CT02
Wed Sep 6
10:30 am
11:00 am
VG2.105

Convergence analysis of optimization-by-continuation algorithms

I. Loris

We discuss several iterative optimization algorithms for the minimization of a cost function consisting of a linear combination of up to three convex terms with at least one differentiable and a second one prox-simple. Such optimization problems frequently occur in the numerical solution of inverse problems (data misfit term plus penalty or constraint term).

We present several new results on the convergence of proximal-gradient-like algorithms in the context of a optimization-by-continuation strategy. The algorithms special feature lies in their ability to approximate, in a single iteration run, the minimizers of the cost function for many different values of the parameters determining the relative weight of the three terms in the cost function (penalty parameters). As a special case, one recovers a generalization of the primal-dual algorithm of Chambolle and Pock.

MS30 1
Wed Sep 6
10:00 am
10:30 am
VG2.103

Inverse problems for the graph Laplacian

E. Blåsten, H. Isozaki, M. Lassas, J. Lu

We study the discrete version of Gel'fand's inverse spectral problem, formulated as follows for a finite weighted graph and the graph Laplacian on it. Suppose we are given a subset B of vertices and the spectral data $(\lambda_j, \phi_j|_B)$, where λ_j are the eigenvalues of the graph Laplacian and $\phi_j|_B$ are the values of the corresponding eigenfunctions on B. We consider if these data uniquely determine the graph structure and the weights. In general, this problem is not uniquely solvable without assumptions on the graph or the set B due to counterexamples. We introduce a so-called Two-Points Condition on graphs (with respect to B), and prove that the inverse spectral problem is uniquely solvable under this condition. We also consider inverse problems for random walks on finite graphs. We show that under the Two-Points Condition, the graph structure and the transition matrix of the random walk can be uniquely recovered from the distributions of the first passing times on B.

CT09
Thu Sep 7
4:30 pm
5:00 pm
VG2.107

Photoacoustic and Ultrasonic Tomography for Breast Imaging

F. Lucka

New high-resolution, three-dimensional imaging techniques are being developed that probe the breast without delivering harmful radiation. In particular, photoacoustic tomography (PAT) and ultrasound tomography (UST) promise to give access to high-quality images of tissue parameters with important diagnostic value. However, the involved inverse problems are very challenging from an experimental, mathematical and computational perspective. In this talk, we want to give an overview of these challenges and illustrate them with data from an ongoing clinical feasibility study that uses a prototype scanner for combined PAT and UST.

Regularization by Randomization: The Case of Partially Separable Optimization

MS10 1
Thu Sep 7
2:00 pm
2:30 pm
VG1.103

R. Luke

We present a Markov-chain analysis of blockwise-stochastic algorithms for solving partially block-separable optimization problems. Our main contributions to the extensive literature on these methods are statements about the Markov operators and distributions behind the iterates of stochastic algorithms, and in particular the regularity of Markov operators and rates of convergence of the distributions of the corresponding Markov chains. This provides a detailed characterization of the moments of the sequences beyond just the expected behavior. This also serves as a case study of how randomization restores favorable properties to algorithms that iterations of only partial information destroys. We demonstrate this on stochastic blockwise implementations of the forward-backward and Douglas-Rachford algorithms for nonconvex (and, as a special case, convex), nonsmooth optimization.

Bayesian MRI reconstruction with joint uncertainty estimation using diffusion priors

MS33 1
Wed Sep 6
9:30 am
10:00 am
VG1.105

G. Luo, M. Blumenthal, M. Heide, M. Uecker

The application of generative models in MRI reconstruction is shifting researchers' attention from the unrolled reconstruction networks to the probabilistic methods which can be used for unsupervised medical image reconstruction [1-4]. We formulate the image reconstruction problem from the perspective of Bayesian inference, which enables efficient sampling from the learned posterior probability distributions [1-2]. Different from conventional deep learning-based MRI reconstruction techniques, samples are drawn from the posterior distribution given the measured k-space using the Markov chain Monte Carlo (MCMC) method. Because the generative model can be learned from an image database independently from the forward operator, the same pre-trained models can be applied to k-space acquired with different sampling schemes or receive coils. Here, we present additional results in terms of the uncertainty of reconstruction, the transferability of learned information, and the comparison using data from the fastMRI challenge.

References

[1] G. Luo, M. Heide, M. Uecker. Using data-driven Markov chains for MRI reconstruction with Joint Uncertainty Estimation. Proc. Intl. Soc. Mag. Reson. Med. 30: 0298.

[2] G. Luo, M. Blumenthal, M. Heide, M. Uecker. Bayesian MRI reconstruction with joint uncertainty estimation using diffusion models. Magn. Reson. Med. 90: 295- 311, 2023.

[3] A. Jalal, M. Arvinte, G. Daras, E. Price, A. Dimakis, J. Tamir. Robust Compressed Sensing MRI with Deep Generative Priors. Neural Information Processing Systems 34: 14938-14954, 2021.

[4] H. Chung, C. Ye. Score-based diffusion models for accelerated MRI, Medical Image Analysis 80: 102479, 2022.

How to sample from a posterior like you sample from a prior

MS33 2
Thu Sep 7
2:30 pm
3:00 pm
VG1.105

B. Maboudi Afkham, M. Chung, J. Chung

The importance of quantifying uncertainties is rising in many applications of inverse problems. One way to estimate uncertainties is to explore the posterior distribution, e.g. in the context of Bayesian inverse problems. Standard approaches in exploring the posterior, e.g. the Markov Chain Monte Carlo (MCMC) methods, are often inefficient for large-scale and non-linear inverse problems.

In this work, we propose a method that exploits data to construct accelerated sampling from the posterior distributions for goal-oriented inverse problems. We use variational encoder-decoder (VED) to approximate the mapping that relates a measurement vector to the posterior distribution. The output of the VED network is an approximation of the true distribution and can estimate its moment, e.g. using Monte-Carlo methods. This enables real-time uncertainty quantification. The proposed method showcases a promising approach for large-scale inverse problems.

MS14 1
Mon Sep 4
2:30 pm
3:00 pm
VG1.104

Uniqueness of determining a space-dependent source for inverse source problems in thermoelasticity

F. Maes, K. Van Bockstal

A thermoelastic system describes the interaction between the changes in the shape of an object $\mathbf{u}(\mathbf{x}, t)$ and the fluctuation in the temperature $\theta(\mathbf{x}, t)$. We consider an isotropic thermoelastic system of type-III which links the elastic and thermal behaviors of an isotropic material occupying a bounded domain $\Omega \subset \mathbb{R}^d$ with Lipschitz continuous boundary. In this contribution, we will study and discuss uniqueness results for solutions to several inverse source problems (ISPs). Our main assumption is that either the heat source h or load source $\mathbf{p}$ can be decomposed as a product of a given time-dependent and an unknown space-dependent function. The main goal is to find the spatial component given some measurement of the function(s) $\mathbf{u}(\mathbf{x}, t)$ and/or $\theta(\mathbf{x}, t)$.

More specifically, the first ISP under consideration deals with the determination of the spatial component $\mathbf{f}(\mathbf{x})$ of the load source $\mathbf{p}(\mathbf{x}, t) = g(t)\mathbf{f}(\mathbf{x})$ from the final in time measurement $\mathbf{u}(\mathbf{x}, T)$, or from the time-average measurement $\int_0^T \mathbf{u}(\mathbf{x}, t)\,\mathrm{d}t$, where T denotes the final time. The second ISP concerns finding $f(\mathbf{x})$ in the heat source $h(\mathbf{x}, t) = g(t)f(\mathbf{x})$ from the time-average measurement $\int_0^T \theta(\mathbf{x}, t)\,\mathrm{d}t$. The uniqueness results are formulated under suitable assumptions on the temporal component $g(t)$ and its derivative. Some examples will be provided showing the necessity of these (sign) conditions on g. The results holds for (homogeneous) Dirichlet boundary conditions on $\mathbf{u}$ and θ as well as in the case a (homogeneous) Neumann boundary condition for θ is used. Finally, the in last ISP, we discuss the problem of finding both $\mathbf{f}$ and f simultaneously when a combination of different measurements is available.

The presented work is based on joint work with Dr. Karel Van Bockstal [1].

References

[1] F. Maes, K. Van Bockstal. Uniqueness for inverse source problems of determining a space-dependent source in thermoeleastic systems, J. Inverse Ill-Posed Probl. 30(6): 845-856, 2022.

MS02 2
Tue Sep 5
4:30 pm
5:00 pm
VG1.102

Iterative regularization methods for non-linear ill-posed operator equations in Banach spaces

P. Mahale

In this talk, we will introduce few simplified iterative regularization methods, in a Banach space setting, to obtain stable approximate solution of nonlinear ill-posed operator equation. We will discuss convergence analysis of these methods under suitable non linearity conditions. Numerical examples will be demonstrated to show applicability of these methods to practical problems.

Optimizing electrode positions in electrical impedance tomography for head imaging

MS23 2
Wed Sep 6
10:00 am
10:30 am
VG1.103

R. R. Maity, N. Hyvönen, A. Hannukainen, A. Vavilov

Electrical impedance tomography is an imaging modality for deducing information about the conductivity inside a physical body from boundary measurements of current and voltage by a finite number of contact electrodes. This work applies techniques of Bayesian experimental design to the linearized forward model of impedance tomography in order to select optimal positions for the available electrodes. The aim is to place the electrodes so that the conditional probability distribution of the (discretized) conductivity given the electrode measurements is as localized as possible in the sense of the A- or D-optimality criterion of Bayesian experimental design. The focus is on difference imaging of a human head under the assumption that an MRI or CT image of the patient in question is available. The algorithm is developed in the computational framework introduced in [1].

References

[1] V. Candiani, A. Hannukainen, N. Hyvönen. Computational framework for applying electrical impedance tomography to head imaging. SIAM J. Sci. Comput. 41 (2019), no. 5, B1034-B1060. https://doi.org/10.1137/19M1245098

Learned iterative model-based approaches in quantitative photoacoustic tomography

MS34 2
Mon Sep 4
4:00 pm
4:30 pm
VG3.103

A. Manninen, A. Hauptmann, F. Lucka

Quantitative photoacoustic tomography (QPAT) is an upsurging imaging modality which can provide high-resolution tissue images based on optical absorption. Classical reconstruction methods rely on sufficient prior information to overcome noisy and imperfect data. As these methods utilise computationally expensive forward models, the computation becomes slow, delimiting the possibilities of QPAT in time-critical applications. As an alternative approach, deep learning-based reconstruction methods have been proposed to allow fast computation of accurate reconstructions. In our work, we adopt the model-based learned iterative approach to solve the nonlinear optical problem of QPAT. In the learned iterative model-based approach, the forward operator and its derivative are iteratively evaluated to compute an update step direction, which is then fed to the network. The learning task is formulated as greedy, requiring iterate-wise optimality, as well as in an end-to-end manner, where all updating networks are trained jointly. We formulated these training schemes and evaluated the performances when the step direction was computed with gradient descent and with the Gauss-Newton method.

Time domain analysis of body resonant-modes for classical waves

MS57 1
Mon Sep 4
3:00 pm
3:30 pm
VG3.102

A. Mantile, A. Posilicano

We consider the wave propagation in the time domain in the presence of small inhomogeneities having high contrast with respect to a homogeneous background. This can be interpreted as a reduced scalar-model for the interaction of an electromagnetic wave with dielectric nanoparticles with high refractive indices. Such composite systems are known to exhibit a transition towards a resonant regime where an enhancement of the scattered wave can be observed at specific incoming frequencies, commonly referred to as body resonances. The asymptotic analysis of the stationary scattering problem, in the high-index nanoparticles regime, recently provided accurate estimates of the resonant frequencies and useful point-scatterer expansions for the solution in the far-field approximation. A key role in this analysis is played by the Newton operator related to the inhomogeneity support, whose eigenvalues identify the inverse resonant energies. We point out that a characterization of such singular frequencies in a proper sense spectral requires the spectral analysis of the Hamiltonian associated to the time-dependent problem. Here we focus on this problem by introducing the scale-dependent Hamiltonian of the time-evolution equation. In this framework, we consider the spectral profile with a particular focus on the generalized spectrum close to the branch-cut. We show that, in this region, the resonances are located in small neighbourhoods of the eigenvalues of the inverse Newton operator and provide accurate estimates for their imaginary parts. In particular, this allows a complete computation of the time-propagator in the asymptotic regime, providing in this way the full asymptotic expansion of the time-domain solution.

CT03
Wed Sep 6
9:30 am
10:00 am
VG2.107

Microlocal Analysis of Multistatic Synthetic Aperture Radar Imaging

D. McMahon, C. Nolan

We consider Synthetic Aperture Radar (SAR) in which scattered waves, simultaneously emitted from a pair of stationary emitters, are measured along a flight track traversed by an aircraft. A linearized mathematical model of scattering is obtained using a Fourier integral operator. This model can then be used to form an image of the ground terrain using backprojection together with a carefully designed data acquisition geometry.

The data is composed of two parts, corresponding to the received signals from each emitter. A backprojection operator can be easily chosen that correctly reconstructs the singularities in the wave speed using just one emitter. One would expect this to lead to a reasonable image of the terrain. However, we expect that application of this backprojection operator to the data from the other emitter will lead to unwanted artifacts in the image. We analyse the operators associated with this situation, and use microlocal analysis to determine configurations of flight path and emitter locations so that we may mitigate the artifacts associated to such "cross talk" between the two emitters.

CT09
Thu Sep 7
4:00 pm
4:30 pm
VG2.107

Diffraction Tomography: Elastic parameters reconstructions

B. Mejri, O. Scherzer

In this talk, we introduce an elastic imaging method where elastic properties (i.e. mass density and Lamé parameters) of a weakly scatterer are reconstructed from full-field data of scattered waves. We linearise the inverse scattering problem under consideration using Born's, Rytov's or Kirchhoff's approximation. Primarily, one appeal to the Fourier diffraction theorem developed in our previous work [1] for the pressure-pressure mode (i.e. generating Pressure incident plane waves and measuring the Pressure part of the scattered data). Then, we reconstruct the inverse Fourier transform of the pressure-pressure scattering potential using the inverse *nonequispaced discrete Fourier transform* for 2D transmission acquisition experiments. Finally, we quantify the elastic parameter distributions with different plane wave excitations.

References

[1] B. Mejri, O. Scherzer. A new inversion scheme for elastic diffraction tomography. arXiv:2212.02798, 2022.

Efficient Bayesian computation for low-photon imaging problems

MS35
Mon Sep 4
4:00 pm
4:30 pm
VG2.105

S. Melidonis, P. Dobson, Y. Altmann, M. Pereyra, K. C. Zygalakis

This talk presents a new and highly efficient MCMC methodology to perform Bayesian inference in low-photon imaging problems, with particular attention to situations involving observation noise processes that deviate significantly from Gaussian noise, such as binomial, geometric and low-intensity Poisson noise. These problems are challenging for many reasons. From an inferential viewpoint, low photon numbers lead to severe identifiability issues, poor stability and high uncertainty about the solution. Moreover, low-photon models often exhibit poor regularity properties that make efficient Bayesian computation difficult; e.g., hard non-negativity constraints, non-smooth priors, and log-likelihood terms with exploding gradients. More precisely, the lack of suitable regularity properties hinders the use of state-of-the-art Monte Carlo methods based on numerical approximations of the Langevin stochastic differential equation (SDE) or other similar dynamics, as both the continuous-time process and its numerical approximations behave poorly. We address this difficulty by proposing an MCMC methodology based on a reflected and regularised Langevin SDE, which is shown to be well-posed and exponentially ergodic under mild and easily verifiable conditions. This then allows us to derive four reflected proximal Langevin MCMC algorithms to perform Bayesian computation in low-photon imaging problems. The proposed approach is illustrated with a range of experiments related to image deblurring, denoising, and inpainting under binomial, geometric and Poisson noise.

Gradient Methods for Blind Ptychography

MS22 1
Tue Sep 5
1:30 pm
2:00 pm
VG1.101

O. Melnyk

Ptychography is an imaging technique, the goal of which is to reconstruct the object of interest from a set of diffraction patterns obtained by illuminating its small regions. When the distribution of light within the region is known, the recovery of the object from ptychographic measurements becomes a special case of the phase retrieval problem. In the other case, also known as blind ptychography, the recovery of both the object and the distribution is necessary.

One of the well-known reconstruction methods for blind ptychography is extended Ptychographic Iterative Engine. Despite its popularity, there was no known analysis of its performance. Based on the fact that it is a stochastic gradient descent method, we derive its convergence guarantees if the step sizes are chosen sufficiently small. The second considered method is a generalization of the Amplitude Flow algorithm for phase retrieval, a gradient descent scheme for the minimization of the amplitude-based squared loss. By applying an alternating minimization procedure, the blind ptychography is reduced to phase retrieval subproblems, which can be solved by performing a few steps of Amplitude Flow. The resulting procedure converges to a critical point at a sublinear rate.

Prolate eigensystem and its application in Born inverse scattering

MS29 2
Mon Sep 4
4:30 pm
5:00 pm
VG3.104

S. Meng

This talk is concerned with the generalized prolate spheroidal wave functions/eigenvalues (in short prolate eigensystem) and their application in two dimensional Born inverse medium scattering problems. The prolate eigenfunctions are eigenfunctions of a Fourier integral operator; they remarkably extend analytically to the whole space, are doubly orthogonal, and are complete in the class of band-limited functions. We first establish a Picard criterion for reconstructing the contrast using the prolate eigensystem, where the reconstruction formula can also be understood in the viewpoint of data processing and analytic extrapolation. Another salient feature associated with the generalized prolate spheroidal wave functions is that the prolate basis for a disk is also a basis for a Sturm-Liouville differential operator. With the help of Sturm-Liouville theory, we estimate the L^2 approximation error for a spectral cutoff approximation of H^s functions, $0 < s \leqslant 1$. This yields a spectral cutoff regularization strategy for noisy data and an explicit stability estimate for contrast in H^s $(0 < s \leqslant 1)$ in the full aperture case. In the limited-aperture and multi-frequency cases, we also obtain spectral cutoff regularization strategies for noisy data and stability estimates for a class of contrast. Numerical examples are currently being investigated and a few preliminary examples are provided to illustrate the application of prolate eigensystem in inverse scattering problems.

MS06 4
Fri Sep 8
3:00 pm
3:30 pm
VG3.103

Single Mode Multi-frequency Factorization Method for the Inverse Source Problem in Acoustic Waveguides

S. Meng

This talk discusses the inverse source problem with a single propagating mode at multiple frequencies in an acoustic waveguide. The goal is to provide both theoretical justifications and efficient algorithms for imaging extended sources using the sampling methods. In contrast to the existing far/near field operator based on the integral over the space variable in the sampling methods, a multi-frequency far-field operator is introduced based on the integral over the frequency variable. This far-field operator is defined in a way to incorporate the possibly non-linear dispersion relation, a unique feature in waveguides. The factorization method is deployed to establish a rigorous characterization of the range support which is the support of source in the direction of wave propagation. A related factorization-based sampling method is also discussed. These sampling methods are shown to be capable of imaging the range support of the source. Numerical examples are provided to illustrate the performance of the sampling methods, including an example to image a complete sound-soft block.

CT06
Thu Sep 7
1:30 pm
2:00 pm
VG2.107

L^1-data fitting for Inverse Problems with subexponentially-tailed data

K. Meth, F. Werner

Outgoing from [1] and [2] we analyze variational regularization with L^1 data fidelity. We investigate discrete models with regular data in the sense that the tails decay subexponentiallly. Therefore, error bounds are provided and numerical simulations of convergence rates are presented.

References

[1] T. Hohage, F. Werner, Convergence rates for inverse problems with impulsive noise, SIAM J. Numer. Anal., 52: 1203-1221, 2014.

[2] C.König, F. Werner, T. Hohage, Convergence rates for exponentially ill-posed inverse problems with impulsive noise, SIAM J. Numer. Anal., 54: 341-360, 2016.

Recursive Update of Linearization Model Error for Conductivity Reconstruction from ICDI

CT08
Thu Sep 7
5:00 pm
5:30 pm
VG2.105

P. Mi, Y. Dong, B. Jin

Conductivity Reconstruction serves as one of the most critical tasks of medical imaging, while approaches concerning interior current density information (ICDI) have drawn a lot of attention recently. However, they face challenges due to the nonlinearity between the conductivity and the interior current density and the high contrast of the conductivity. In this work, we propose a novel Bayesian framework to tackle these difficulties. We incorporate and iteratively update the model error introduced by linearization in the framework, and we also reform the linearization operator recursively to obtain better approximation. Numerical implementation shows that our method outperforms other approaches in terms of both relative errors of estimates and Kullback-Leibler divergence between distributions.

Non-unique Inversions in Earth Sciences - an Underestimated Pitfall?

MS44 1
Mon Sep 4
3:00 pm
3:30 pm
VG2.104

V. Michel

Earth exploration is in many cases connected to inverse problems, since often regions of interest cannot be accessed sufficiently. This is the case for the recovery of structures in the Earth's interior. However, it is also present in the investigation of processes at the Earth's surface, e.g. if a sufficient global or regional coverage is required or if remote areas are of interest.

Many of these problems are associated to an instability of the inverse problems, which is why a variety of regularization methods for their stabilization has been developed so far. However, a notable number of the problems is also ill-posed because of a non-unique solution. Phantom anomalies and other artefacts might be possible consequences. In some cases, the mathematical structure of the underlying null spaces is entirely understood (e.g. for a certain class of Fredholm integral equations of the first kind). In other cases, such a theory is still missing. Nevertheless, also for mathematically well described cases, numerical methods often ignore what can be visible and what can be invisible in available data.

The purpose of this talk is to create some more sensitivity regarding the challenges of inverse problems with non-unique solutions.

References

[1] S. Leweke, V. Michel, R. Telschow. On the non-uniqueness of gravitational and magnetic field data inversion (survey article), in: Handbook of Mathematical Geodesy (W. Freeden, M.Z. Nashed, eds.), Birkhäuser, Basel, 883-919, 2018.

[2] V. Michel. Geomathematics - Modelling and Solving Mathematical Problems in Geodesy and Geophysics. Cambridge University Press, Cambridge, 2022.

[3] V. Michel, A.S. Fokas. A unified approach to various techniques for the non-uniqueness of the inverse gravimetric problem and wavelet-based methods, Inverse Problems 24: 25pp, 2008.

[4] V. Michel, S. Orzlowski. On the null space of a class of Fredholm integral equations of the first kind, Journal of Inverse and Ill-Posed Problems 24: 687-710, 2016.

CT04
Thu Sep 7
2:30 pm
3:00 pm
VG2.104

Logarithmic stability and instability estimates for random inverse source problems

P. R. Mickan, T. Hohage

We study the inverse source problem to determine the strength of a random acoustic source from correlation data. More precisely, the data of the inverse problems are correlations of random time-harmonic acoustic waves measured on a surface surrounding a region of random, uncorrelated sources. Such a model is used in experimental aeroacoustics to determine the strength of sound sources [1]. Uniqueness has been previously established [1,2]. In this talk we report on logarithmic stability results and logarithmic convergence rates for the Tikhonov regularisation applied to the inverse source problem by establishing a variational source condition under Sobolev type smoothness assumption. We also present logarithmic instability estimates using an entropy argument. Furthermore, we will show numerical experiments supporting our theoretical results.

References

[1] T. Hohage, H.-G. Raumer, C. Spehr. Uniqueness of an inverse source problem in experimental aeroacoustics. Inverse Problems, 36(7):075012, 2020.

[2] A. J. Devaney. The inverse problem for random sources. Journal of Mathematical Physics, 20(8):1687-1691, 1979.

MS34 2
Mon Sep 4
4:30 pm
5:00 pm
VG3.103

Autocorrelation analysis for cryo-EM with sparsifying priors

O. Mickelin

Cryo-electron microscopy is a non-linear inverse problem that aims to reconstruct 3-D molecular structures from randomly oriented tomographic projection images, taken at extremely low signal-to-noise-ratio.

This talk presents new results for using the method of moments to reconstruct sparse molecular structures. We prove that molecular structures modeled as sparse sums of Gaussians can be uniquely recovered from the autocorrelations of the images, which significantly lowers the sample complexity of the problem compared to previous results. Moreover, we provide practical reconstruction algorithms inspired by crystallographic phase retrieval.

The full reconstruction pipeline includes estimating autocorrelations from projection images, using rotation-invariant principal component analysis made possible by recent improvements to approximation algorithms into the Fourier-Bessel basis.

MS37 1
Thu Sep 7
2:00 pm
2:30 pm
VG1.102

Improving our Understanding of Jupiter's and Saturn's Interior Structure

B. Militzer

Traditionally models for the interior structure of giant planets are constrained by spacecraft measurements that fly by a planet at close range and measure its gravitational field with high precision. Still with increasing depth, it becomes more and more difficult with such measurements to uniquely determine what type of layers exist in a giant planet. This is especially true for the cores of giant planets that harbor valuable information on how the planet formed and what the early solar system looked like. Measurements of normal modes on the other hand offer an alternate potentially powerful approach to probing much deeper into a giant planet. While such dynamic measurements are very challenging, a number of such observations have already been reported. Here we review ring seismological measurements of spiral density waves in Saturn's rings, radial velocity measurements of Jupiter's atmosphere as well as a recent analysis of time dependent variations in Jupiter's gravity field. We then compare results from these measurements with predictions from models for the interiors of Jupiter and Saturn that were constrained by gravity measurements alone. We conclude by discussing Jupiter's dilute core and a recent study that explains how Saturn's ring formed.

Super-localisation of a point-like emitter in a resonant environment : correction of the mirage effect

MS19 3
Wed Sep 6
10:00 am
10:30 am
VG3.103

P. Millien

In this paper, we show that it is possible to overcome one of the fundamental limitations of super-resolution microscopy techniques: the necessity to be in an optically homogeneous environment. Using recent modal approximation results we show as a proof of concept that it is possible to recover the position of a single point-like emitter in a known resonant environment from far-field measurements with a precision two orders of magnitude below the classical Rayleigh limit. The procedure does not involve solving any partial differential equation, is computationally light (optimisation in $\mathbb{R}^d$ with d of the order of 10) and therefore suited for the recovery of a very large number of single emitters.

Solving Cauchy problems using semi-discretization techniques and BIE

MS16 2
Thu Sep 7
4:30 pm
5:00 pm
VG0.111

L. Mindrinos

In this work we present a two-step method for the numerical solution of parabolic and hyperbolic Cauchy problems. Both problems are formulated in 2D and the proposed method is considered for the direct and the corresponding inverse problem. The main idea is to combine a semi-discretization with respect to the time variable with THE boundary integral equation method for the spatial variables. The time discretization reduces the problem to a sequence of elliptic stationary problems. The solution is represented using a single-layer ansatz and then we end up solving iteratively for the unknown boundary density functions. We solve the discretized problem on the boundary of the medium with the collocation method. Classical quadrature rules are applied for handling the kernel singularities. We present numerical results for different linear PDEs.

This is a joint work with R. Chapko (Ivan Franko University of Lviv, Ukraine) and B. T. Johansson (Linköping University, Sweden).

Mode identification in rapidly-rotating stars: paving the way to inverse methods

MS38 2
Tue Sep 5
4:00 pm
4:30 pm
VG2.105

G. M. Mirouh

Asteroseismology has opened a window on the internal physics of thousands of stars, by relating pulsations of stars to their internal physics. Mode identification, namely the process of associating a measured oscillation frequency to the corresponding mode geometry and properties, is the preliminary step of the seismic analysis. In upper main-sequence stars, that often rotate rapidly, this identification is challenging and largely incomplete, as modes assume complex geometries and frequencies shift under the combined influence of the Coriolis force and centrifugal flattening.

In this contribution, I will describe the various classes of mode geometries that emerge in rapidly rotating stars and their differences with slow rotators. After discussing how their frequencies and periods relate with structural quantities, allowing us to derive constraints on the stellar evolution, I will discuss the approaches developed towards inversion methods.

MS54 2
Mon Sep 4
5:00 pm
5:30 pm
VG1.101

Inversion of a restricted transverse ray transform on symmetric m-tensor fields in $\mathbb{R}^3$

R. K. Mishra, **C. Thakkar**

In this work, we study a restricted transverse ray transform on symmetric m-tensor fields in $\mathbb{R}^3$ and provide an explicit inversion algorithm to recover the unknown m-tensor field. We restrict the transverse ray transform to all lines passing through a fixed curve γ satisfying the Kirillov-Tuy condition. This restricted data is used to find the weighted Radon transform of components of the unknown tensor field, which we use to recover components of the tensor field explicitly.

MS59 2
Fri Sep 8
5:00 pm
5:30 pm
VG2.103

Time resolved and multi-resolution tomographic reconstruction strategies in practice.

R. Mokso, **V. Nikitin**

A collimated X-ray beam is the trademark of synchrotron X-ray sources and comes with certain benefits for tomography, namely the simplicity of parallel beam tomographic reconstruction. Building on this a number of new approaches emerges to reconstruct a 3D volume from truncated X-ray projections. I will mainly consider here truncation in the time domain. One specificity of imaging at synchrotron instruments is that individual angular projections are acquired on a sub-ms time-frame and the entire tomographic dataset in a fraction of a second [1,2]. This enables time resolved studies of dynamic processes at the micrometer spatial and sub-second temporal resolution. Despite this fast acquisition the sample is often evolving at a faster rate, giving rise to motion artefact in the reconstructed volume. One possible approach to reconstruct an artifact-free 3D volume from (in the traditional sense) inconsistent projections is to use the concept of compressed sensing in the way that data in the temporal direction is represented by a linear combination of appropriate basis functions [3]. In our approach we perform L1 norm minimization for the gradient in both spatial and temporal variables. The optimal choice of basis functions is case specific and is the matter of further investigation.

Multiresolution acquisition is an attractive tomographic approach, but comes with it's own challenges. I will discuss an approach to merge high and low resolution datasets of the same sample [4] for the extension of the reconstructed volume.

References

[1] R. Mokso, D.A. Schwyn, S.M. Walker et al. Four-dimensional in vivo X-ray microscopy with projection guided gating, Scientific Reports 5 (1), 8727, 2015.

[2] F. Garcia-Moreno et al. Using X-ray tomoscopy to explore the dynamics of foaming metal, Nature Communications. 10(1), 3762, 2019.

[3] V. Nikitin, M. Carlsson, F. Andersson, R. Mokso. Four-dimensional tomographic reconstruction by time domain decomposition, IEEE Transaction on Computational Imaging 5(3), 409, 2019.

[4] L. Varga, R. Mokso. Iterative High Resolution Tomography from Combined High-Low Resolution Sinogram Pairs, Proceedings of International Workshop on Combinatorial Image Analysis, 150-163, 2018.

Implicit regularization via re-parametrization

MS10 4
Fri Sep 8
5:00 pm
5:30 pm
VG1.103

C. Molinari

Recently, the success of optimization is related to re- and over-parametrization, that are widely used - for instance - in neural networks applications. However, there is still an open question of how to find systematically what is the inductive bias hidden behind the model for a particular optimization scheme. The goal of this talk is taking a step in this direction, studying extensively many reparametrization used in the state of the art and providing a common structure to analyze the problem in a unified way. We show that gradient descent on the objective function for many reparametrization is equivalent to mirror descent on the original problem. The mirror function depends on the reparametrization and introduces an inductive bias, which plays the role of the regularizer. Our theoretical results provide asymptotic behavior and convergence results.

Mapping properties and functional relations for the hyperbolic X-ray transform

MS56 1
Mon Sep 4
3:00 pm
3:30 pm
VG2.106

F. S. Monard, N. Eptaminitakis, Y. Zou

I will discuss recent results on the range characterization of the X-ray transform on the hyperbolic disk, along with functional relations with distinguished differential operators, and mapping properties in adapted scales of Sobolev spaces.

This is based on joint work with Nikolaos Eptaminitakis (Leibniz University Hannover) and Yuzhou Zou (Northwestern).

Target Signatures for Thin Surfaces

MS06 1
Wed Sep 6
10:00 am
10:30 am
VG0.110

P. Monk

In 1994, just within the 30 years mentioned in the title of this minisymposium, Colton and Kirsch proposed a set of target signatures for imperfectly conducting obstacles at fixed frequency [1]. These are characterized by using the far field equation. Today there are many families of target signatures including transmission eigenvalues, Steklov eigenvalues and modified transmission eigenvalues. All of these relate to scattering by a target of non-zero volume, and they can all be determined from scattering data using appropriate modifications of the far field equation [2].

In this presentation I will continue by describing recently developments target signatures for screens. Screen are open surfaces, and hence have no volume. A typical example is a resistive screen modeled using transmission conditions across the screen. The goal is to design target signatures that are computable from scattering data in order to detect changes in the material properties of the screen. This target signature is characterized by a mixed Steklov eigenvalue problem for a domain whose boundary contains the screen.

Following [3], I shall show that the corresponding eigenvalues can be determined from an appropriately modified far field equation. Numerical experiments using the classical linear sampling method are presented to support our theoretical results.

References

[1] D.L. Colton, A. Kirsch. Target signatures for imperfectly conducting obstacles at fixed frequency. Quart. J. Mech. Appl. Math. 47:1–15, 1994.

[2] D.L. Colton, F. Cakoni, H. Haddar. Inverse Scattering Theory and Transmission Eigenvalues, 2nd edition, CBMS-NSF, Regional Conference Series in Applied Mathematics, SIAM Publications, 98, 2022.

[3] F. Cakoni, P. Monk, Y. Zhang. Target signatures for thin surfaces. Inverse Probl. 38, 025011, 28 pp, 2021. doi: 10.1088/1361-6420/ac4154

MS29 1
Mon Sep 4
2:30 pm
3:00 pm
VG3.104

Computation of transmission eigenvalues in singular configurations using a corner perfectly matched layer

A.-S. Bonnet-Ben Dhia, L. Chesnel, F. Monteghetti

In scattering, transmission eigenvalues are complex wavenumbers at which there exists an incident field that produces a vanishingly-small scattered far field. These eigenvalues solve the interior transmission eigenvalue problem (ITEP), which is a non-selfadjoint eigenvalue problem formulated on the support of the scatterer. In this work, we consider the discretization of the ITEP in two-dimensional cases where the difference between the parameters of the scatterer and that of the background medium changes sign at some point O on the boundary of the scatterer. This sign change implies the existence of strongly-oscillating singularities localized around O, which prevent H^1-conforming finite element discretizations from approximating transmission eigenvalues, even when the corresponding modes are in H^1. In this talk we will demonstrate how transmission eigenvalues can be approximated by solving a modified ITEP; the modification consists in applying a suitable perfectly matched layer in a neighborhood of O, whose job is intuitively to tame strongly-oscillating singularities without inducing spurious reflections.

MS59 1
Fri Sep 8
3:00 pm
3:30 pm
VG2.103

X-ray phase and dark-field retrieval from propagation-based images, via the Fokker-Planck Equation

K. S. Morgan, T. Leatham, M. Beltran, J. Ahlers, S. Alloo, M. Kitchen, K. Pavlov, D. Paganin

Conventional x-ray imaging, which measures the intensity of the transmitted x-ray wavefield, is extremely useful when imaging strongly-attenuating samples like bone, but of limited use when imaging weakly-attenuating samples like the lungs or brain. In recent years, it has been seen that the phase of the transmitted x-ray wavefield contains useful information about these weakly-attenuating samples, however it is not possible to directly measure x-ray phase. This necessitates the use of mathematical models that relate the observed x-ray intensity, which is measurable, to the x-ray phase. These models can then be solved to retrieve how the sample has changed the x-ray phase; the inverse problem of phase retrieval. A widely adopted example is the use of the Transport of Intensity Equation (TIE) to retrieve x-ray phase from an intensity image collected some distance downstream of the sample, a distance at which sample-induced phase variations have resulted in self-interference of the wave and changed the local observed intensity [1]. The use of a single-exposure ‘propagation-based’ set-up like this, where no optics (gratings, crystals etc.) are required, makes for a robust and simple x-ray imaging set-up, which is also compatible with time-sequence imaging.

In this talk, we present an extension to the TIE, the X-ray Fokker-Planck Equation [2, 3], and associated novel retrieval algorithms for extracting x-ray phase and dark-field [5-7] from propagation-based images.

The TIE describes how x-ray intensity evolves with propagation from the sample to a downstream camera, for a wavefield with given phase and intensity. The X-ray Fokker-Planck Equation adds an additional term that incorporates how dark-field effects from the sample will be seen in the observed intensity [2,3]. X-ray dark-field effects are present when the sample contains microstructures that are not directly resolved, but which scatter the wavefield in such a way as to locally reduce image contrast. Examples of dark-field-inducing microstructure include powders, carbon fibres and the air sacs in the lungs. Until very recently [4], it was considered that crystals or gratings were required optical elements in the experimental set-up in order to capture a dark-field image.

Using the X-ray Fokker-Planck Equation, we have derived several novel algorithms that allow dark-field retrieval from propagation-based images. Because phase and dark-field effects evolve differently with propagation, images captured at two different sample-to-detector distances allow the separation and retrieval of dark-field images and phase images [5]. Alternatively, dark-field and phase images can be retrieved by looking at sample-induced changes in a patterned illumination via a Fokker-Planck approach, either using a single short exposure [6], or by scanning the pattern across the sample to access the full spatial resolution of the detector [7]. Incorporating dark-field effects in the TIE not only allows a dark-field image to be extracted from propagation-based images, but also increases the potential spatial resolution of the retrieved phase image. These propagation-based Fokker-Planck approaches are best suited to small samples (e.g. under 10 cm), so may provide avenues for fast and simple phase and dark-field micro/nano-tomography.

References

[1] D. Paganin, S. C. Mayo, T. E. Gureyev, P. R. Miller, S. W. Wilkins. Simultaneous phase and amplitude extraction from a single defocused image of a homogeneous object, Journal of Microscopy 206(1): 33-40, 2002.

[2] K. S. Morgan, D. M. Paganin. Applying the Fokker-Planck equation to grating-based x-ray phase and dark-field imaging, Scientific Reports 9(1): 17465, 2019.

[3] D.M. Paganin, K. S. Morgan. X-ray Fokker-Planck equation for paraxial imaging, Scientific Reports, 9(1): 17537, 2019.

[4] T.E. Gureyev, D.M. Paganin, B. Arhatari, S. T. Taba, S. Lewis, P. C. Brennan, H. M. Quiney. Dark-field signal extraction in propagation-based phase-contrast imaging, Physics in Medicine & Biology, 65(21): 215029, 2020.

[5] T. A. Leatham, D. M. Paganin, K. S. Morgan. X-ray dark-field and phase retrieval without optics, via the Fokker-Planck equation, IEEE Transactions on Medical Imaging (in press), 2023.

[6] M. A. Beltran, D. M. Paganin, M. K. Croughan, K. S. Morgan. Fast implicit diffusive dark-field retrieval for single-exposure, single-mask x-ray imaging, Optica, 10(4): 422-429, 2023.

[7] S. J. Alloo, K. S. Morgan, D. M. Paganin, K. M. Pavlov. Multimodal intrinsic speckle-tracking (MIST) to extract images of rapidly-varying diffuse X-ray dark-field, Scientific Reports, 13(1): 5424, 2023.

Exact Parameter Identification in PET Pharmacokinetic Modeling Using the Irreversible Two Tissue Compartment Model

CT10
Fri Sep 8
1:30 pm
2:00 pm
VG3.102

E. Morina, M. Holler, G. Schramm

In this talk we consider the identifiability of metabolic parameters from multi-compartment measurement data in quantitative positron emission tomography (PET) imaging, a non-invasive clinical technique that images the distribution of a radio tracer in-vivo.

We discuss how, for the frequently used two-tissue compartment model and under reasonable assumptions, it is possible to uniquely identify metabolic tissue parameters from standard PET measurements, without the need of additional concentration measurements from blood samples. The core assumption requirements for this result are that

PET measurements are available at sufficiently many time points, and that the arterial tracer concentration is parametrized by a polyexponential, an approach that is commonly used in practice. Our analytic identifiability result, which holds in the idealized, noiseless scenario, indicates that costly concentration measurements from blood samples in quantitative PET imaging can be avoided in principle. The connection to noisy measurement data is made via a consistency result in Tikhonov regularization theory, showing that exact reconstruction is maintained in the vanishing noise limit.

We further present numerical experiments with a regularization approach based on the Iteratively Regularized Gauss-Newton Method (IRGNM) supporting these analytic results in an application example.

MS26 2
Thu Sep 7
3:00 pm
3:30 pm
VG3.102

Optimal transport: a promising tool for cryo-electron microscopy

A. Moscovich

Optimal transport is a branch of mathematics whose central problem is minimizing the cost of transporting a given source distribution to a target distribution. The Wasserstein metric is defined to be the cost of a minimizing transport plan. For mass distributions in Euclidean space, the Wasserstein metric is closely related to physical motion, making it a natural choice for many of the core problems in cryo-electron microscopy.

Historically, computational bottlenecks have limited the applicability of optimal transport for image processing and volumetric processing. However, recent advances in computational optimal transport have yielded fast approximation schemes that can be readily used for the analysis of high-resolution images and volumetric arrays.

In this talk, we will present the optimal transportation problem and some of its key properties. Then we will discuss several promising applications to cryo-electron microscopy, including particle picking, class averaging and continuous heterogeneity analysis.

MS39
Mon Sep 4
3:00 pm
3:30 pm
VG2.105

Causality and Consistency in Bayesian Inference Paradigms

K. Mosegaard

Bayesian inference paradigms are regarded as powerful tools for solution of inverse problems. However, Bayesian formulations suffer from a number of difficulties that are often overlooked.

The well known, but mostly neglected, difficulty is connected to the use of conditional probability densities. Borel, and later Kolmogorov's (1933/1956), found that the traditional definition of probability densities is incomplete: In different parameterizations it leads to different, conditional probability measures. This inconsistency is generally neglected in the scientific literature, and therefore threatens the objectivity of Bayesian inversion, Bayes Factor computations, and trans-dimensional inversion. We will show that this problem is much more serious than usually assumed.

Additional inconsistencies in Bayesian inference are found in the so-called hierarchical methods where so-called hyper-parameters are used as variables to control the uncertainties. We will see that these methods violate causality, and analyze how this challenges the validity of Bayesian computations.

The Lippmann-Schwinger Lanczos algorithm for inverse scattering.

MS06 2
Thu Sep 7
2:00 pm
2:30 pm
VG3.103

J. Baker, E. Cherkaev, V. Druskin, S. Moskow, M. Zaslavsky

We combine data-driven reduced order models with the Lippmann- Schwinger integral equation to produce a direct nonlinear inversion method. The ROM is viewed as a Galerkin projection and is sparse due to Lanczos orthogonalization. Embedding into the continuous problem, a data-driven internal solution is produced. This internal solution is then used in the Lippmann-Schwinger equation, in a direct or iterative framework. The approach also allows us to process more general transfer functions, i.e., to remove the main limitation of the earlier versions of the ROM based inversion algorithms. We describe how the generation of internal solutions simplifies in the time domain, and show how Lanczos orthogonalization in the spectral domain relates to time stepping. We give examples of its use given mono static data, targeting synthetic aperture radar.

Efficient adversarial regularization for inverse problems

MS45 1
Tue Sep 5
4:00 pm
4:30 pm
VG0.111

S. Mukherjee, M. Carioni, O. Öktem, C.-B. Schönlieb

We propose a new optimal transport-based approach for learning end-to-end reconstruction operators using unpaired training data for ill-posed inverse problems. The key idea behind the proposed method is to minimize a weighted combination of the expected distortion in the measurement space and the Wasserstein-1 distance between the distributions of the reconstruction and the ground truth. The regularizer is parametrized by a deep neural network and learned simultaneously with an unrolled reconstruction operator in an adversarial training framework. The variational problem is then initialized with the output of the reconstruction network and solved iteratively till convergence. Notably, it takes significantly fewer iterations to converge as compared to variational methods, thanks to the excellent initialization obtained via the unrolled reconstruction operator. The resulting approach combines the computational efficiency of end-to-end unrolled reconstruction with the well-posedness and noise-stability guarantees of the variational setting. We demonstrate with the example of image reconstruction in X-ray computed tomography (CT) that our approach outperforms state-of-the-art unsupervised methods and that it outperforms or is at least on par with state-of-the-art supervised data-driven CT reconstruction approaches.

Provably Convergent Plug-and-Play Quasi-Newton Methods

MS24 1
Thu Sep 7
3:00 pm
3:30 pm
VG1.101

H. Y. Tan, S. Mukherjee, J. Tang, C.-B. Schönlieb

Plug-and-Play (PnP) methods are a class of efficient data-driven methods for solving imaging inverse problems, wherein one incorporates an off-the-shelf denoiser inside iterative optimization schemes such as proximal gradient descent and ADMM. PnP methods have been shown to yield excellent reconstruction performance and are also supported by convergence guarantees. However, existing provable PnP methods impose heavy restrictions on the denoiser (such as nonexpansiveness) or the fidelity term (such as strict convexity). In this work, we propose a provable PnP method that imposes relatively light conditions based on proximal denoisers and introduce a quasi-Newton step to greatly accelerate convergence. By specially parameterizing the deep denoiser as a gradient step, we further characterize the fixed points of the resulting quasi-Newton PnP algorithm.

MS57 2
Mon Sep 4
4:30 pm
5:00 pm
VG3.102

Heat Generation Using Lorentzian Nanoparticles. The Full Maxwell System

A. Mukherjee, M. Sini

We analyze and quantify the amount of heat generated by a nanoparticle, injected in a background medium, while excited by incident electromagnetic waves. These nanoparticles are dispersive with electric permittivity following the Lorentz model. The purpose is to determine the quantity of heat generated extremely close to the nanoparticle (at a distance proportional to the radius of the nanoparticle). We show that by exciting the medium with incident frequencies close to the Plasmonic or Dielectric resonant frequencies, we can generate any desired amount of heat close to the injected nanoparticle while the amount of heat decreases away from it. These results offer a wide range of potential applications in the areas of photo-thermal therapy, drug delivery, and material science, to cite a few. To do so, we employ time-domain integral equations and asymptotic analysis techniques to study the corresponding mathematical model for heat generation. This model is given by the heat equation where the body source term comes from the modulus of the electric field generated by the used incident electromagnetic field. Therefore, we first analyze the dominant term of this electric field by studying the full Maxwell scattering problem in the presence of Plasmonic or All-dielectric nanoparticles. As a second step, we analyze the propagation of this dominant electric field in the estimation of the heat potential. For both the electromagnetic and parabolic models, the presence of the nanoparticles is translated into the appearance of large scales in the contrasts for the heat-conductivity (for the parabolic model) and the permittivity (for the full Maxwell system) between the nanoparticle and its surrounding.

MS13 2
Fri Sep 8
5:00 pm
5:30 pm
VG0.111

Learning Linear Operators

N. Mücke

We consider the problem of learning a linear operator θ between two Hilbert spaces from empirical observations, which we interpret as least squares regression in infinite dimensions. We show that this goal can be reformulated as an inverse problem for θ with the undesirable feature that its forward operator is generally non-compact (even if θ is assumed to be compact or of p-Schatten class). However, we prove that, in terms of spectral properties and regularisation theory, this inverse problem is equivalent to the known compact inverse problem associated with scalar response regression. Our framework allows for the elegant derivation of dimension-free rates for generic learning algorithms under Hölder-type source conditions. The proofs rely on the combination of techniques from kernel regression with recent results on concentration of measure for sub-exponential Hilbertian random variables. The obtained rates hold for a variety of practically-relevant scenarios in functional regression as well as nonlinear regression with operator-valued kernels and match those of classical kernel regression with scalar response.

MS05 3
Thu Sep 7
5:30 pm
6:00 pm
VG2.102

Learning Linear Operators

N. Mücke

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Quantitative passive imaging in helioseismology

MS37 2
Thu Sep 7
5:30 pm
6:00 pm
VG1.102

B. Müller

In helioseismology one studies cross-correlations of line-of-sight velocities at the solar surface in order to invert for parameters in the solar interior. In the frequency domain the cross-correlation data takes the form $C(\boldsymbol{r_1}, \boldsymbol{r_2}, \omega) = \psi(\boldsymbol{r_1}, \omega)^* \psi(\boldsymbol{r_2}, \omega)$ with freqeuency ω and two points $\boldsymbol{r_1}, \boldsymbol{r_2}$ on the solar surface. This data set is of immense size and unfeasible to store, such that it is in need of an apriori averaging in space in frequency. Helioseismic holography is a physically motivated averaging scheme, which is based on backpropagation of surface fluctuations [1]. In this talk we show that the traditional holograms can be understood as the first step of an iterative inversion procedure [2]. This way we can extend traditional helioseismic holography to a full quantitative regularization method, which has two main advantages compared to traditional helioseismic inversions: By changing the order of backpropagation and local correlation we can use the whole cross-correlation data implicitly by avoiding the computation explicitly. Furthermore the iterative setup allows us to tackle nonlinear problems, which are only rarely studied in helioseismology. We validate iterative helioseismic holography on synthetics of large-scale axisymmetric flows like solar differential rotation and meridional flows. Finally we show some interesting future applications of iterative helioseismic holography which can not be studied with traditional helioseismology so far.

References

[1] C. Lindsey, D. Braun. Helioseismic Holography, Astrophysical Journal 485(2), p.895-903, 1997. doi:10.1086/304445

[2] T. Hohage, H. Raumer, C. Spehr. Uniqueness of an inverse source problem in experimental aeroacoustics, Inverse Problems 36(7), 2020. doi:10.1088/1361-6420/ab8484

Properties of solutions for anisotropic viscoelastic systems

MS18 2
Mon Sep 4
5:00 pm
5:30 pm
VG1.103

M. de Hoop, M. Kimura, C.-L. Lin, G. Nakamura

In this talk I will consider two kinds of anisotropic viscoelastic systems. One is an anisotropic viscoelastic systems which is described as an integro-differential system (ID system) and the other is the so-called extended Maxwell model (EM system) which is schematically described using springs and dashpots. There is a relation between them but they are different systems. I will discuss about their relation and the large time behavior of their solutions. Further, for the EM system, I will discuss about a generation of semigroup and the limiting amplitude principle. The method of proof for the ID system is an energy estimate, and that for the EM system is mainly based on several resolvent estimates. The limiting amplitude principle could be useful for setting up the inverse problem when the measurements may use a sequence of several different time harmonic inputs such as the magnetic resonance elastography.

This is a joint work with Maarten de Hoop, Ching-Lung Lin for the EM system and also including Masato Kimura for the EM system.

MS28 2
Tue Sep 5
5:00 pm
5:30 pm
VG1.108

Proximal point algorithm in spaces with semidefinite inner product

E. Naldi, E. Chenchene, D. A. Lorenz, J. Marquardt

We introduce proximal point algorithms in spaces with semidefinite inner products. We focus our attention in particular on products induced by self-adjoint positive semidefinite linear operators defined on Hilbert spaces. We show convergence for the algorithm under suitable conditions and we investigate applications for splitting methods. As first application, we devise new schemes for finding minimizers of the sum of many convex lower semicontinuous functions and show some applications of these new schemes to congested transport and distributed optimization in the context of Support Vector Machines, investigating their behavior. Finally, we analyze the convergence of the proximal point algorithm letting vary the (semidefinite) metric at each iteration. We discuss applications of this analysis to the primal-dual Douglas-Rachford scheme, investigating adaptive stepsizes for the method.

MS23 2
Wed Sep 6
10:30 am
11:00 am
VG1.103

Immersed boundary method for electrical impedance tomography in the frame of electrocardiography

J. Dardé, N. Nasr, L. Weynans

EIT is a non-invasive imaging technique that aims, to reconstruct the electrical conductivity distribution inside a domain by imposing electrical currents on the boundary of this domain, and measuring the resulting voltages on the same boundary. It has several applications in the medical field, in particular in lung monitoring and stroke detection. Mathematically, the problem, known as Calderón's problem or inverse conductivity problem, is a severely ill-posed inverse problem. In practical experiments, the currents are driven inside the body of interest through a collection of surface electrodes, no current being driven between the electrodes. For each current pattern, the potential differences between the electrodes are measured. This practical setting is accurately modeled by the Complete Electrode Model (CEM). It takes into account the shape of the electrodes as well as the shunting effect, that is the thin resistive layer that appears at the interface between the electrodes and the object during the measurements. The CEM is known to correctly predict experimental data, and therefore is widely used in the numerical resolution of both direct and inverse problems related to EIT. The CEM is as follows :

Find the potentials $u \in H^1(\Omega)$ and $U \in \mathbb{R}^M_\diamond$ such that,

$$\begin{cases} \nabla \cdot (\sigma \nabla u) &= 0 \text{ in } \Omega \\ u + z_m \sigma \partial_\nu u &= U_m \text{ on } E_m, \\ \sigma \partial_\nu u &= 0 \text{ on } \partial\Omega \backslash \overline{E}, \\ \displaystyle\int_{E_m} \sigma \partial_\nu u \, ds &= I_m, \end{cases}$$

with E_m the mth electrode , z_m the associated contact impedance, $I \in \mathbb{R}^M_\diamond$ the current pattern. Where

$$\mathbb{R}^M_\diamond = \left\{ I \in \mathbb{R}^M, \sum_{k=1}^{M} I_k = 0 \right\}.$$

We propose an immersed boundary method (IBM) for the numerical resolution of the CEM in Electrical Impedance Tomography, that we use as a main ingredient in the resolution of inverse problems in medical imaging. Such method allows to use a Cartesian mesh without accurate discretization of the boundary, which is useful in situations where the boundary is complicated and/or changing. We prove the convergence of our method, and illustrate its efficiency with two dimensional direct and inverse problems.

References

[1] J. Dardé, N. Nasr, L. Weynans. Immersed boundary method for the complete electrode model in electrical impedance tomography. 2022.

[2] M. Cisternino, L. Weynans. A parallel second order Cartesian method for elliptic interface problems. Addison Wesley, Massachusetts, 2nd ed.

Diffraction tomography for a generalized incident beam wave

MS16 1
Thu Sep 7
2:00 pm
2:30 pm
VG0.111

N. Naujoks

The mathematical imaging problem of diffraction tomography is an inverse scattering technique used to find the material properties of an object. Here, the object is exposed to a certain form of radiation and the scattered wave is recorded. In conventional diffraction tomography, the incident wave is assumed to be a monochromatic plane wave arriving from a fixed direction of propagation. However, this plane wave excitation does not necessarily correspond to measurement setups used in practice: There, the size of the emitting device is limited and therefore cannot produce plane waves. Besides, it is common to emit focused beams to achieve a better resolution in the far field. In this talk, I will present our recent results that allow diffraction tomography to be applied to these realistic illumination scenarios. We use a new forward model, that incorporates individually generated incident fields. Based on this, a new reconstruction algorithm is developed.

Operator Learning Meets Inverse Problems

MS05 2
Thu Sep 7
2:30 pm
3:00 pm
VG2.102

N. H. Nelsen, M. V. de Hoop, N. B. Kovachki, A. M. Stuart

This talk introduces two connections between operator learning and inverse problems. The first involves framing the supervised learning of a linear operator between function spaces as a Bayesian inverse problem. The resulting analysis of this inverse problem establishes posterior contraction rates and generalization error bounds in the large data limit. These results provide practical insights on how to reduce sample complexity. The second connection is about solving inverse problems with operator learning. This work focuses on the inverse problem of electrical impedance tomography (EIT). Classical methods for EIT tend to be iterative (hence slow) or lack sufficient accuracy. Instead, a new type of neural operator is trained to directly map the data (the Neumann-to-Dirichlet boundary map, a linear operator) to the unknown parameter of the inverse problem (the conductivity, a function). Theory based on emulating the D-bar method for direct EIT shows that the EIT solution map is well-approximated by the proposed architecture. Numerical evidence supports the findings in both settings.

MS10 2
Thu Sep 7
4:30 pm
5:00 pm
VG1.103

Accelerated Griffin-Lim algorithm: A fast and provably convergent numerical method for phase retrieval

R. Nenov, D.-K. Nguyen, R. I. Bot, P. Balazs

The recovery of a signal from the magnitudes of its transformation, like the Fourier transform, is known as the phase retrieval problem and is of big relevance in various fields of engineering and applied physics. The Griffin-Lim algorithm is a staple method commonly used for the phase retrieval problem, which is based on alternating projections. In this talk, we introduce and motivate a fast inertial/momentum modification of the Griffin-Lim Algorithm for the phase retrieval problem and we present a convergence guarantee for the new algorithm.

MS37 2
Thu Sep 7
5:00 pm
5:30 pm
VG1.102

Frequency-Difference Backprojection of Earthquakes

J. C. Neo, W. Fan, Y. Huang, D. R. Dowling

Backprojection has proven useful in imaging large earthquake rupture processes. The method is generally robust and requires relatively simple assumptions about the fault geometry or the Earth velocity model. It can be applied in both the time and frequency domain. Backprojection images are often obtained from records filtered in a narrow frequency band, limiting its ability to uncover the whole rupture process. Here, we develop and apply a novel frequency-difference backprojection (FDBP) technique to image large earthquakes, which imitates frequencies below the bandwidth of the signal. The new approach originates from frequency-difference beamforming, which was initially designed to locate acoustic sources. Our method stacks the phase-difference of frequency pairs, given by the autoproduct, and is less affected by scattering and -time errors from 3-D Earth structures. It can potentially locate sources more accurately, albeit with lower resolution. We validated the FDBP algorithm with synthetic tests and benchmarked it against conventional backprojection. We successfully applied the method to the 2015 M7.8 Gorkha earthquake, and tested two stacking approaches - Band Width Averaged Autoproduct and its counterpart (BWAP and non-BWAP). The FDBP method shows promise in resolving complex earthquake rupture processes in tectonically complex regions.

MS47 2
Tue Sep 5
5:30 pm
6:00 pm
VG3.101

A hybrid algorithm for material decomposition in multi-energy CT

L. Neumann, M. Haltmeier, T. Prohaszka

The aim of multi-energy CT is to reconstruct the distribution of a known set of substances inside a sample by performing CT measurements at different energies. The measurements can be achieved either by using different tube voltages at the source or by means of energy sensitive detectors (e.g. photon counting detectors). In any case the energy dependent absorption of the materials under consideration is used to distinguish the substances in the sample which leads to a nonlinear reconstruction problem. The majority of reconstruction algorithms can be divided into those performing the material decomposition in the sinogram domain and those decomposing the image after inversion of the Radon transform for each energy bin. Both types of algorithms can be implemented very efficiently but also suffer from specific artefacts. More recently one-step algorithms performing decomposition and inversion in one pass have become an active research area. While they eliminate most of the problems of two-step approaches, they are usually computationally costy because they are iterative in nature and the relative similarity of absorption coefficients often leads to poor convergence. We present a method that combines preconditioning in the sinogram domain and an efficient numerical method for the nonlinear problem with a simple and thus fast iteration for the linear part of the problem. Our hybrid method does not suffer from systematic problems like beam hardening or difficulties with not perfectly aligned images for different energy bins. It is iterative but convergence is fast and the computational cost of each iteration is modest.

Learning Sparsifying Regularisers

MS24 2
Thu Sep 7
4:00 pm
4:30 pm
VG1.101

S. Neumayer

Solving inverse problems is possible, for example, by using variational models. First, we discuss a convex regularizer based on a one-hidden-layer neural network with (almost) free-form activation functions. Our numerical experiments have shown that this simple architecture already achieves state-of-the-art performance in the convex regime. This is very different from the non-convex case, where more complex models usually result in better performance. Inspired by this observation, we discuss an extension of our approach within the convex non-convex framework. Here, the regularizer can be non-convex, but the overall objective has to remain convex. This maintains the nice optimization properties while allowing to significantly boost the performance. Our numerical results show that this convex-energy-based approach is indeed able to outperform the popular BM3D denoiser on the BSD68 test set for various noise scales.

Deep Learning Methods for Partial Differential Equations and Related Parameter Identification Problems

MS51 1
Thu Sep 7
1:30 pm
2:00 pm
VG1.108

D. Nganyu Tanyu, J. Ning, T. Freudenberg, N. Heilenkötter, A. Rademacher, U. Iben, P. Maass

Recent years have witnessed a growth in mathematics for deep learning–which seeks a deeper understanding of the concepts of deep learning with mathematics, and explores how to make it more robust–and deep learning for mathematics, where deep learning algorithms are used to solve problems in mathematics. The latter has popularised the field of scientific machine learning where deep learning is applied to problems in scientific computing. Specifically, more and more neural network architectures have been developed to solve specific classes of partial differential equations (PDEs). Such methods exploit properties that are inherent to PDEs and thus solve the PDEs better than classical feed-forward neural networks, recurrent neural networks, and convolutional neural networks. This has had a great impact in the area of mathematical modeling where parametric PDEs are widely used to model most natural and physical processes arising in science and engineering, In this work, we review such methods and extend them for parametric studies as well as for solving the related inverse problems. We equally proceed to show their relevance in some industrial applications

MS32 1
Wed Sep 6
10:30 am
11:00 am
VG1.104

Bi-level iterative regularization for inverse problems in nonlinear PDEs

T. Nguyen

We investigate the ill-posed inverse problem of recovering spatially dependent parameters in nonlinear evolution PDEs from linear measurements. We propose a bi-level Landweber scheme, where the upper-level parameter reconstruction embeds a lower-level state approximation. This can be seen as combining the classical reduced setting and the newer all-at-once setting, allowing us to, respectively, utilize well-definedness of the parameter-to-state map, and to bypass having to solve nonlinear PDEs. Using this, we derive stopping rules for lower- and upper-level iterations and convergence of the bi-level method.

MS47 3
Wed Sep 6
9:00 am
9:30 am
VG3.101

Analytic and Deep learning-based Inversions in Circular Compton Scattering Tomography

M. K. Nguyen, C. Tarpau, J. Cebeiro, I. Ayad

Circular Compton scattering tomography (CCST) where a fixed radiation source and a number of regularly spaced detectors are positioned on a fixed circular frame is recently proposed [1]. It has multiple advantages such as compact and motion-free system, possibility of combination with classic fan-beam CT (computed tomography) as a bi-imaging system, capacity of scanning both small and large objects.

In the case where the detectors are collimated to split up scattered photons coming from two opposite sides of the source-detector segment, the modelling of CCST's data acquisition leads to a Radon transform on a family of arcs of circles passing through a fixed point (the point source). The analytical inversion of this Radon transform is derived from Cormack's earlier works.

In the case of non-collimated detectors, the corresponding Radon transform is defined on a specific family of double circular arcs and named DCART (double circular arc Radon transform). The exact inverse formula for this new Radon transform on pair of circles is not available presently. Recently, deep learning-based techniques appear as promising alternatives to solve the ill-posed inverse problems in CT reconstruction from limited-angle and sparse-view projection data. In our work we propose a neural network architecture acting on both image and data domains. The particularity of this architecture lies in its capability to map the projection (Radon domain) to image domain at different scales of the data while extracting important image features used at reconstruction. The obtained results suggest that removing the collimator at detectors in CCST is feasible thanks to deep learning-based techniques.

Another way to by-pass the collimator at detectors is to design a CST with a single detector rotating around a fixed source. The corresponding Radon transform and its inverse are established in [2,3] but the CST is no longer a motion-free system.

References

[1] C. Tarpau, J. Cebeiro, M. A. Morvidone, M. K. Nguyen. A new concept of Compton scattering tomography and the development of the corresponding circular Radon transform, IEEE Transactions on Radiation and Plasma Medical Sciences (IEEE-TRPMS) 4.4: 433-440, 2020. https://doi.org/10.1109/TRPMS.2019.2943555

[2] C. Tarpau, J. Cebeiro, M. K. Nguyen, G. Rollet, M. A. Morvidone. Analytic inversion of a Radon transform on double circular arcs with applications in Compton Scattering Tomography, IEEE Transactions on Computational Imaging (IEEE-TCI) 6: 958-967, 2020. https://doi.org/10.1109/TCI.2020.2999672

[3] J. Cebeiro, C. Tarpau, M. A. Morvidone, D. Rubio, M. K. Nguyen, On a three-dimensional Compton scattering tomography system with fixed source, Inverse Problems, Special issue on Modern Challenges in Imaging 37: 054001, 2021. https://doi.org/10.1088/1361-6420/abf0f0.

Regularized Radon - Nikodym differentiation and some of its applications

MS07 1
Fri Sep 8
1:30 pm
2:00 pm
VG1.101

D. H. Nguyen, S. Pereverzyev, W. Zellinger

We discuss the problem of estimation of Radon-Nikodym derivatives. This problem appears in various applications, such as covariate shift adaptation, likelihood-ratio testing, mutual information, and conditional probability estimation. To address the above problem, we employ the general regularization scheme in reproducing kernel Hilbert spaces. The convergence rate of the corresponding regularized learning algorithm is established by taking into account both the smoothness of the derivative and the capacity of the space in which it is estimated. It is done in terms of general source conditions and the regularized Christoffel functions. The theoretical results are illustrated by numerical simulations.

Fast convex optimization via closed-loop time scaling of gradient dynamics

MS10 1
Thu Sep 7
2:30 pm
3:00 pm
VG1.103

H. Attouch, R. I. Bot, D.-K. Nguyen

In a Hilbert setting, for convex differentiable optimization, we develop a general framework for adaptive accelerated gradient methods. They are based on damped inertial dynamics where the coefficients are designed in a closed-loop way. Specifically, the damping is a feedback control of the velocity, or of the gradient of the objective function. For this, we develop a closed-loop version of the time scaling and averaging technique introduced by the authors. We thus obtain autonomous inertial dynamics which involve vanishing viscous damping and implicit Hessian driven damping. By simply using the convergence rates for the continuous steepest descent and Jensen's inequality, without the need for further Lyapunov analysis, we show that the trajectories have several remarkable properties at once: they ensure fast convergence of values, fast convergence of the gradients towards zero, and they converge to optimal solutions. Our approach leads to parallel algorithmic results, that we study in the case of proximal algorithms. These are among the very first general results of this type obtained using autonomous dynamics.

References

[1] H. Attouch, R.I. Bot, D.-K. Nguyen. Fast convex optimization via time scale and averaging of the steepest descent, arXiv:2208.08260, 2022

[2] H. Attouch, R.I. Bot, D.-K. Nguyen. Fast convex optimization via closed-loop time scaling of gradient dynamics, arXiv:2301.00701, 2023

How many Neurons do we need? A refined Analysis.

MS03 2
Mon Sep 4
5:30 pm
6:00 pm
VG2.103

M. Nguyen, N. Mücke

We present new results for random feature approximation in kernel methods and discuss the connection to generalization properties of two-layer neural networks in the NTK regime. Here, we aim at improving the results of Nitanda and Suzuki [1] in various directions. More precisely, we aim at overcoming the saturation effect appearing in Nitanda and Suzuki [1] by providing fast rates of convergence for smooth objectives. On our way, we also precisely keep track of the number of hidden neurons required for generalization.

References

[1] A. Nitanda, T. Suzuki. Functional Gradient Boosting for Learning Residual-like Networks with Statistical Guarantees. Proceedings of the Twenty Third International Conference on Artificial Intelligence and Statistics. 108: 2981–2991. 2020.

MS34 1
Mon Sep 4
3:00 pm
3:30 pm
VG3.103

Data-driven regularization theory of invertible ResNets for solving inverse problems

J. Nickel, C. Arndt, T. Kluth, S. Dittmer, A. Denker, M. Iske, N. Heilenkötter, P. Maass

Data-driven solution techniques for inverse problems, typically based on specific learning strategies, exhibit remarkable performance in image reconstruction tasks. These learning-based reconstruction strategies often follow a two-step scheme. First, one uses a given dataset to train the reconstruction scheme, which one often parametrizes via a neural network. Second, the reconstruction scheme is applied to a new measurement to obtain a reconstruction. We follow these steps but specifically parametrize the reconstruction scheme with invertible residual networks (iResNets). We demonstrate that the invertibility opens the door to new investigations into the influence of the training and the architecture on the resulting reconstruction scheme. To be more precise, we analyze the effect of different iResNet architectures, loss functions, and prior distributions on the trained network. The investigations reveal a formal link to the regularization theory of linear inverse problems for shallow network architectures and connections to MAP estimation with Gaussian noise models. Moreover, we analytically optimize the parameters of specific classes of architectures in the context of Bayesian inversion, revealing the influence of the prior and noise distribution on the solution.

CT04
Thu Sep 7
1:30 pm
2:00 pm
VG2.104

Weighted sparsity regularization for estimating the source term in the potential equation

O. L. Elvetun, B. F. Nielsen

We investigate the possibility for using boundary measurements to recover a sparse source term $f(x)$ in the potential equation. This work is motivated by the observation that standard methods typically suggest that internal sinks and sources are located close to the boundary and hence fail to produce adequate results. That is, the large null space of the associated forward operator is not “correctly handled” by the classical regularization techniques.

Provided that weighted sparsity regularization is used, we derive criteria which assure that several sinks ($f(x) < 0$) and sources ($f(x) > 0$) can be identified. Furthermore, we present two cases for which these criteria always are fulfilled: a) well-separated sources and sinks, and b) many sources or sinks located at the boundary plus one interior source/sink. Our approach is such that the linearity of the associated forward operator is preserved in the discrete formulation. The theory is therefore conveniently developed in terms of Euclidean spaces, and it can be applied to a wide range of problems. In particular, it can be applied to both isotropic and anisotropic cases. We present a series of numerical experiments.

This work extends the results presented at the ”Symposium on Inverse Problems” in Potsdam in September 2022: The theory for the single source case is generalized to the several sources and sinks situation, we do not employ any box constraints and the analysis is carried out for the potential equation instead of focusing on the screened Poisson equation or the Helmholtz equation.

A phase-field approach to shape optimization of acoustic waves in dissipative media

MS49 2
Tue Sep 5
4:00 pm
4:30 pm
VG3.102

V. Nikolic

In this talk, we will discuss the problem of finding the optimal shape of a system of acoustic lenses in a dissipative medium. The problem is tackled by introducing a phase-field formulation through diffuse interfaces between the lenses and the surrounding fluid. The resulting formulation is shown to be well-posed and we rigorously derive first-order optimality conditions for this problem. Additionally, a relation between the diffuse interface problem and a perimeter-regularized sharp interface shape optimization problem can be established via the Γ-limit of the reduced objective.

Efficient high-dimensional Bayesian multi-fidelity inverse analysis for expensive legacy solvers

MS11
Wed Sep 6
9:00 am
9:30 am
VG1.108

J. Nitzler, W. A. Wall, P.-S. Koutsourelakis

Bayesian inverse analysis can be computationally burdensome when dealing with large scale numerical models dependent on high-dimensional stochastic input, and especially when model derivatives are unavailable, as is the case for many high-fidelity legacy codes. To overcome these limitations, we introduce a novel approach called Bayesian multi-fidelity inverse analysis (BMFIA), which utilizes computationally inexpensive lower fidelity models to construct a multi-fidelity likelihood function. This function can be learned robustly, and potentially adaptively, from a few high-fidelity simulations (100-300). Our approach incorporates in the resulting, multi-fidelity posterior the epistemic uncertainty stemming from the limited high-fidelity data and the information loss caused by the multi-fidelity approximation. BMFIA can handle non-linear dependencies between low- and high-fidelity models. In particular, when the former are differentiable the solution of high-dimensional problems can be achieved while maintaining the high-fidelity accuracy by the multi-fidelity likelihood. Bayesian inference is performed using state-of the-art sampling-based or variational methods which require solely evaluations of the lower-fidelity model. We demonstrate the applicability of BMFIA to large-scale biomechanical and coupled multi-physics problems.

Transparent scatterers and transmission eigenvalues of infinite multiplicity

MS29 3
Tue Sep 5
2:30 pm
3:00 pm
VG3.104

R. Novikov, P. G. Grinevich

We give a short review of old and recent results on scatterers with transmission eigenvalues of infinite multiplicity, including transparent scatterers. Our examples include potentials from the Schwartz class and multipoint potentials of Bethe - Peierls type.

References

[1] P.G. Grinevich, R.G. Novikov. Russian Mathematical Surveys 77:1021-1028, 2022. https://doi.org/10.4213/rm10080e

CT03
Wed Sep 6
10:00 am
10:30 am
VG2.107

An inverse problem for the Riemannian minimal surface equation

J. Nurminen

In this work we study an inverse problem for the Riemannian minimal surface equation, which is a quasilinear elliptic PDE. Consider a Riemannian manifold (M, g) where $M = \mathbb{R}^n$ and the metric is a so called conformally transversally anisotropic metric i.e. $g = c(\hat{g} \oplus e)$, where $\hat{g}$ is a metric on $\mathbb{R}^{n-1}$. Let $u \colon \Omega \subset \mathbb{R}^{n-1} \to \mathbb{R}$ be a smooth function that satisfies the minimal surface equation. Assume that we can make boundary measurements on the graph of u, that is we know the Dirichlet-to-Neumann (DN) map which maps the boundary value $u|_{\partial\Omega} = f$ to the normal derivative $\partial_\nu u|_{\partial\Omega} = \hat{g}^{ij}\partial_{x_i} u \nu_j|_{\partial\Omega}$. The Dirichlet data f is the height of minimal surface on the boundary. The normal derivative $\partial_\nu u|_{\partial\Omega}$ can be thought of as tension on the boundary caused by the minimal surface. In this talk we show that if we have knowledge of two DN maps corresponding to two different metrics in the same conformal class, then we can deduce that the metrics have the same Taylor series up to a constant multiplier.

This work connects some aspects of two previous articles, that is [1] and [2]. We use the technique of higher order linearization (see for example [3]) that has received increasing attention lately.

References

[1] J. Nurminen. An inverse problem for the minimal surface equation. Nonlinear Anal. 227,113163:19. 2023

[2] C. I. Cârstea, M. Lassas, T. Liimatainen, L. Oksanen. An inverse problems for the riemannian minimal surface equation, arXiv: 2203.09262:1-18. 2022

[3] M. Lassas, T. Liimatainen, Y.-H. Lin, M. Salo. Inverse problems for elliptic equations with power type nonlinearities. J. Math. Pures Appl. (9) 145: 44- 82. 2021

MS46 2
Fri Sep 8
3:30 pm
4:00 pm
VG1.104

Determining Lorentzian manifold from non-linear wave observation at a single point

M. Nursultanov

Our research demonstrates that it is possible to determine the Lorenzian manifold by measuring the source-to-solution map for the semilinear wave equation at a single point. (Joint work with Lauri Oksanen and Leo Tzou).

MS59 1
Fri Sep 8
2:00 pm
2:30 pm
VG2.103

Deep Learning for Reconstruction in Nano CT

A. Oberacker, A. Wald, B. Hahn-Rigaud, T. Kluth, J. Leuschner, M. Schmidt, T. Schuster

Tomographic X-ray imaging on the nano-scale is an important tool to visualise the structure of materials such as alloys or biological tissue. Due to the small scale on which the data acquisition takes place, small perturbances caused by the environment become significant and cause a motion of the object relative to the scanner during the scan.

An iterative reconstruction method called RESESOP-Kaczmarz was introduced in [1] which requires the motion to be estimated. However, since the motion is hard to estimate and its incorporation into the reconstruction process strongly increases the numerical effort, we investigate a learned version of RESESOP-Kaczmarz. Imaging data was programmatically simulated to train a deep network which unrolls the iterative image reconstruction of the original algorithm. The network therefore learns the back-projected image after a fixed number of iterations.

References

[1] S. E. Blanke et al. Inverse problems with inexact forward operator: iterative regularization and application in dynamic imaging, Inverse Problems 36 124001, 2020.

Automatic Differentiation of Fixed-Point Algorithms for Structured Non-smooth Optimization

MS25 1
Mon Sep 4
1:30 pm
2:00 pm
VG0.111

P. Ochs

A large class of non-smooth practical optimization problems can be written as minimization of a sum of smooth and partly smooth functions. We consider structured non-smooth optimization problems which also depend on a parameter vector and study the problem of differentiating its solution mapping with respect to the parameter which has far reaching applications in sensitivity analysis and parameter learning. We show that under partial smoothness and other mild assumptions, Automatic Differentiation (AD) of the sequence generated by proximal splitting algorithms converges to the derivative of the solution mapping. For a variant of automatic differentiation, which we call Fixed-Point Automatic Differentiation (FPAD), we remedy the memory overhead problem of the Reverse Mode AD and moreover provide faster convergence theoretically. We numerically illustrate the convergence and convergence rates of AD and FPAD on Lasso and Group Lasso problems and demonstrate the working of FPAD on prototypical practical image denoising problem by learning the regularization term.

PAC-Bayesian Learning of Optimization Algorithms

MS10 2
Thu Sep 7
4:00 pm
4:30 pm
VG1.103

P. Ochs

The change of paradigm from purely model driven to data driven (learning based) approaches has tremendously altered the picture in many applications in Machine Learning, Computer Vision, Signal Processing, Inverse Problems, Statistics and so on. There is no need to mention the significant boost in performance for many specific applications, thanks to the advent of large scale Deep Learning. In this talk, we open the area of optimization algorithms for this data driven paradigm, for which theoretical guarantees are indispensable. The expectations about an optimization algorithm are clearly beyond empirical evidence, as there may be a whole processing pipeline depending on a reliable output of the optimization algorithm, and application domains of algorithms can vary significantly. While there is already a vast literature on ”learning to optimize”, there is no theoretical guarantees associated with these algorithms that meet these expectations from an optimization point of view. We develop the first framework to learn optimization algorithms with provable generalization guarantees to certain classes of optimization problems, while the learning based backbone enables the algorithms’ functioning far beyond the limitations of classical (deterministic) worst case bounds. Our results rely on PAC-Bayes bounds for general, unbounded loss-functions based on exponential families. We learn optimization algorithms with provable generalization guarantees (PAC-bounds) and explicit trade-off between a high probability of convergence and a high convergence speed.

MS32 1
Wed Sep 6
9:00 am
9:30 am
VG1.104

Spacetime finite element methods for inverse and control problems subject to the wave equation

L. Oksanen, S. Alexakis, A. Feizmohammadi

There is a well-known duality between inverse initial source problems and control problems for the wave equation, and analysis of both these boils down to the so-called observability estimates. I will present recent results on numerical analysis of these problems. The inverse initial source problem gives a model for the acoustic step of Photoacoustic tomography.

MS52 1
Mon Sep 4
1:30 pm
2:00 pm
VG1.105

Inverse problem for Yang-Mills-Higgs fields

L. Oksanen, X. Chen, M. Lassas, G. Paternain

We show that the Yang-Mills potential and Higgs field are uniquely determined (up to the natural gauge) from source-to-solution type data associated with the classical Yang-Mills-Higgs equations in the Minkowski space. We impose natural non-degeneracy conditions on the representation for the Higgs field and on the Lie algebra of the structure group which are satisfied for the case of the Standard Model. Our approach exploits non-linear interaction of waves to recover a broken non-abelian light ray transform of the Yang-Mills field and a weighted integral transform of the Higgs field.

MS56 1
Mon Sep 4
2:00 pm
2:30 pm
VG2.106

A 1-Wasserstein framework for forward-peaked diffusive transport

G. Bal, B. Palacios

In this talk, I will present a framework to study inverse problems involving forward-peaked diffusive transport. More specifically, we will study Fokker-Planck approximations to highly forward-peaked scattering and the accuracy of its respective approximations via Fermi pencil-beams, in a metric based on the 1-Wasserstein distance. We argue that metrics of this kind are suitable for analyzing the stability of related inverse problems, for instance, in inverse transport, microscopy, and off-axis laser detection. This is joint work with Guillaume Bal.

CT11
Fri Sep 8
1:30 pm
2:00 pm
VG1.108

Extension and convergence of sixth order Jarratt-type method

S. Panathale Bheemaiah

A sixth order convergence of Jarratt-type method for solving nonlinear equations is considered. Weaker assumptions on the derivative of the involved operator is made, contrary to the earlier studies. The convergence analysis does not depend on the Taylor series expansion and this increases the applicability of the proposed method. Numerical examples and Basins of attractions of the method are provided in this study.

References

[1] I.K. Argyros , S. Hilout. On the local convergence of fast two-step Newton-like methods for solving nonlinear equations: Journal of Computational and Applied Mathematics 245:1-9, 2013.

[2] A. Cordero , M.A. Hernández-Verón , N. Romero , J.R. Torregrosa. Semilocal convergence by using recurrence relations for a fifth-order method in Banach spaces: Journal of computational and applied mathematics,volume(273):205-213, 2015.

[3] S. George , I.K. Argyros , P. Jidesh , M. Mahapatra, M. Saeed. Convergence Analysis of a Fifth-Order Iterative Method Using Recurrence Relations and Conditions on the First Derivative: Mediterranean Journal of Mathematics,volume(18):1-12, 2021.

[4] P. Jarratt. Some fourth order multipoint iterative methods for solving equations: Mathematics of computation, Vol(20):434-437, 1966.

[5] H. Ren. On the local convergence of a deformed Newton's method under Argyros-type condition, Journal of Mathematical Analysis and Applications, 321(1):396-404. 2006.

[6] S. Singh, D.K. Gupta, E. Martínez , J.L. Hueso. Semilocal convergence analysis of an iteration of order five using recurrence relations in Banach spaces: Mediterranean Journal of Mathematics. volume(13):4219-4235, 2016.

Learning data-driven priors for image reconstruction: From bilevel optimisation to neural network-based unrolled schemes

MS25 1
Mon Sep 4
2:00 pm
2:30 pm
VG0.111

K. Papafitsoros, A. Kofler, F. Altekrüger, F. Antarou Ba, C. Kolbitsch, E. Papoutsellis, D. Schote, C. Sirotenko, F. Zimmermann

Combining classical model-based variational methods for image reconstruction with deep learning techniques has attracted a significant amount of attention during the last years. The aim is to combine the interpretability and the reconstruction guarantees of a model-based method with the flexibility and the state-of-the-art reconstruction performance that the deep neural networks are capable of achieving. We introduce a general novel image reconstruction approach that achieves such a combination which we motivate by recent developments in deeply learned algorithm unrolling and data-driven regularisation as well as by bilevel optimisation schemes for regularisation parameter estimation. We consider a network consisting of two parts: The first part uses a highly expressive deep convolutional neural network (CNN) to estimate a spatially varying (and temporally varying for dynamic problems) regularisation parameter for a classical variational problem (e.g. Total Variation). The resulting parameter is fed to the second sub-network which unrolls a finite number of iterations of a method which solves the variational problem (e.g. PDHG). The overall network is then trained end-to-end in a supervised fashion. This results to an entirely interpretable algorithm since the "black-box" nature of the CNN is placed entirely on the regularisation parameter and not to the image itself. We prove consistency of the unrolled scheme by showing that, as the number of unrolled iterations tends to infinity, the unrolled energy functional used for the supervised learning Γ-converges to the corresponding functional that incorporates the exact solution map of the TV-minimization problem. We also provide a series of numerical examples that show the applicability of our approach: dynamic MRI reconstruction, quantitative MRI reconstruction, low-dose CT and dynamic image denoising.

On the identification of small anomaly via MUSIC algorithm without background information

MS08 1
Fri Sep 8
1:30 pm
2:00 pm
VG2.102

W.-K. Park

MUltiple SIgnal Classification (MUSIC) is a promising non-iterative technique for identifying small anomaly in microwave imaging. For a successful application, accurate values of permittivity, permeability, and conductivity of the background must be known. If one of these values is unknown, inaccurate location will inevitably retrieved by using the MUSIC. To explain this phenomenon, we investigate the structure of the imaging function of MUSIC by establishing a relationship with an infinite series of the Bessel functions

of integer order, antenna arrangement, and applied values of permittivity, permeability, and conductivity. The revealed structure explains the theoretical reason why inaccurate location of anomaly is retrieved. Simulation results with synthetic data are illustrated to support the theoretical result.

References

[1] W.-K. Park. Application of MUSIC algorithm in real-world microwave imaging of unknown anomalies from scattering matrix, Mech. Syst. Signal Proc. 153: Article No. 107501, 2021.

[2] R. Solimene, G. Ruvio, A. Dell'Aversano, A. Cuccaro, Max J. Ammann, R. Pierri. Detecting point-like sources of unknown frequency spectra, Prog. Electromagn. Res. B 50: 347-364, 2013.

MS16 1
Thu Sep 7
3:00 pm
3:30 pm
VG0.111

Uncertainty-aware blob detection in astronomical imaging

F. Parzer, P. Jethwa, A. Boecker, M. Alfaro-Cuello, O. Scherzer, G. van de Ven

Blob detection, i. e. detection of blob-like shapes in an image, is a common problem in astronomy. A difficulty arises when the image of interest has to be recovered from noisy measurements, and thus comes with uncertainties. Formulating the reconstruction of the image as a Bayesian inverse problem, we propose an uncertainty-aware version of the classic Laplacian-of-Gaussians method for blob detection. It combines ideas from scale-space theory, statistics and variational regularization to identify salient blobs in uncertain images. The proposed method is illustrated on a problem from stellar dynamics: the identification of components in a stellar distribution recovered from integrated-light spectra. This talk is based on our recent preprint [1].

References

[1] F. Parzer, P. Jethwa, A. Boecker, M. Alfaro-Cuello, O. Scherzer, G. van de Ven. Uncertainty-Aware Blob Detection with an Application to Integrated-Light Stellar Population Recoveries, arXiv:2208.05881, 2022.

MS36 2
Thu Sep 7
4:30 pm
5:00 pm
VG3.101

Directional regularization with the Core Imaging Library for limited-angle CT in the Helsinki Tomography Challenge 2022

E. Pasca, J. Jørgensen, E. Papoutsellis, L. Murgatroyd, G. Fardell

The Core Imaging Library (CIL) is a software for Computed Tomography (CT) and other inverse problems. It provides processing algorithms for CT data and tools to write optimisation problems with near math syntax. Last year the Finnish Inverse Problems Society organized the "Helsinki Tomography Challenge 2022" (HTC2022) - an open competition for researchers to submit reconstruction algorithms for a challenging series of real-data limited-angle computed tomography problems. The HTC2022 provided the perfect grounds to test the capabilities of CIL in limited angle CT.

The algorithm we submitted consists of multiple stages: first, pre-processing including beam-hardening correction and data normalization; second a purpose-built directional regularization method exploiting prior knowledge of the scanned object; and finally, a multi-Otsu segmentation method. The algorithm was fully implemented using the optimization prototyping capabilities of CIL and its performance assessed and optimized on the provided training data ahead of submission. The algorithm performed well on limited-angle data down to an angular range of 50 degrees, and in the competition was beaten only by two machine learning based strategies involving generation of very large sets of synthetic training data.

In the spirit of open science, all the data sets are available from the challenge website, https://fips.fi/HTC2022.php, and the submitted algorithm code from https://github.com/TomographicImaging/CIL-HTC2022-Algo2.

Imbalanced data sets in a magnetic resonance imaging case study of preterm neonates: a strategy for identifying informative variables

MS07 2
Fri Sep 8
4:00 pm
4:30 pm
VG1.101

S. Pereverzyev Jr.

Background and objective: Variable selection is the process of identifying relevant data characteristics (features, biomarkers) that are predictive of future outcomes. There is an arsenal of methods addressing the variable selection problem, but the available techniques may not work on the so-called imbalanced data sets containing mainly examples of the same outcome. Retrospective clinical data often exhibit such imbalanceness. This is the case for neuroimaging data derived from the magnetic resonance images of prematurely born infants used in attempt to identify prognostic biomarkers of their possible neurodevelopmental delays, which is the main objective of the present study. Methods: The variable selection algorithm used in our study scores the combinations of variables according to the performance of prediction functions involving these variables. The considered functions are constructed by kernel ridge regression with various input variables as regressors. As regression kernels we used universal Gaussian kernels and the kernels adjusted for underlying data manifolds. The prediction functions have been trained using data that were randomly extracted from available clinical data sets. The prediction performance has been measured in terms of area under the Receiver Operating Characteristic Curve, and maximum performance exhibited by prediction functions has been averaged over simulations. The resultant average value is then assigned as the performance index associated with the considered combination of input variables. The variables allowing the largest index value are selected as the informative ones. Results: The proposed variable selection strategy has been applied to two retrospective clinical datasets containing data of preterm infants who received magnetic resonance imaging of the brain at the term equivalent age and at around 12 months corrected age with the developmental evaluation. The first dataset contains data of 94 infants, with 13 of them being later classified as delayed in motor skills. The second set contains data of 95 infants, with 7 of them being later classified as cognitively delayed. The application of the proposed strategy clearly indicates 2 metabolite ratios and 6 diffusion tensor imaging parameters as being predictive of motor outcome, as well as 2 metabolite ratios and 2 diffusion tensor imaging parameters as being predictive of cognitive outcome. Conclusion: The proposed strategy demonstrates its ability to extract the meaningful variables from the imbalanced clinical datasets. The application of the strategy provides independent evidence supporting several previous studies separately suggesting different biomarkers. The application also shows that the predictor involving several informative variables can exhibit better performance than single variable predictors.

On the Regularized Functional Regression

MS39
Mon Sep 4
1:30 pm
2:00 pm
VG2.105

S. Pereverzyev

Functional Regression (FR) involves data consisting of a sample of functions taken from some population. Most work in FR is based on a variant of the functional linear model first introduced by Ramsay and Dalzell in 1991. A more general form of polynomial functional regression has been introduced only quite recently by Yao and Müller (2010), with quadratic functional regression as the most prominent case. A crucial issue in constructing FR models is the need to combine information both across and within observed functions, which Ramsay and Silverman (1997) called replication and regularization, respectively. In this talk we are going to present a general approach for the analysis of regularized polynomial functional regression of arbitrary order and indicate the possibility for using here a technique that has been recently developed in the context of supervised learning. Moreover, we are going to describe of how multiple penalty regularization can be used in the context of FR and demonstrate an advantage of such use. Finally, we briefly discuss the application of FR in stenosis detection.

Joint research with S. Pereverzyev Jr. (Uni. Med. Innsbruck), A. Pilipenko (IMATH, Kiev) and V.Yu. Semenov (DELTA SPE, Kiev) supported by the consortium of Horizon-2020 project AMMODIT and the Austrian National Science Foundation (FWF).

MS05 1
Wed Sep 6
9:00 am
9:30 am
VG2.102

Aggregation by the Linear Functional Strategy in Regularized Domain Adaptation

S. Pereverzyev

In this talk we are going to discuss the problem of hyperparameters tuning in the context of learning from different domains known also as domain adaptation. The domain adaptation scenario arises when one studies two input-output relationships governed by probabilistic laws with respect to different probability measures, and uses the data drawn from one of them to minimize the expected prediction risk over the other measure.

The problem of domain adaptation has been tackled by many approaches, and most domain adaptation algorithms depend on the so-called hyperparameters that change the performance of the algorithm and need to be tuned. Usually, algorithm performance variation can be attributed to just a few hyperparameters, such as a regularization parameter in kernel ridge regression, or batch size and number of iterations in stochastic gradient descent training.

In spite of its importance, the question of selecting these parameters has not been much studied in the context of domain adaptation. In this talk, we are going to shed light on this issue. In particular, we discuss how a regularization of the Radon-Nikodym differentiation can be employed in hyperparameters tuning. Theoretical results will be illustrated by application to stenosis detection in different types of arteries.

The talk is based on the recent joint work [1] performed within COMET-Module project S3AI funded by the Austrian Research Promotion Agency (FFG).

References

[1] E.R. Gizewski, L. Mayer, B.A. Moser, D.H. Nguyen, S. Pereverzyev Jr., S.V. Pereverzyev, N. Shepeleva, W. Zellinger. On a regularization of unsupervised domain adaptation in RKHS. Appl. Comput. Harmon. Anal. 57: 201-227, 2022.

MS19 2
Tue Sep 5
5:30 pm
6:00 pm
VG3.103

Approximate inverse scattering via convex programming

G. Alberti, R. Petit, M. Santacesaria

In this work, we propose to apply and adapt known results on convex variational methods for inverse problems to the inverse scattering problem. We rely on approximations to circumvent its nonlinearity, and discuss recovery guarantees and numerical methods.

Machine Learning Techniques applied to Compton Cameras

MS43 2
Mon Sep 4
5:00 pm
5:30 pm
VG1.108

S. Petrak, K. Hölzer

Compton cameras have a long tradition in γ-ray astronomy and increasingly find new applications in radiation protection and nuclear safety. We have built three prototypes of Compton cameras to assist the decommissioning process of safely removing a nuclear facility from service and reducing residual radioactivity to permissible levels. In this talk, the inverse problem of Compton cameras is addressed with two techniques, one based on a Bayesian framework, and another graph-based approach that makes full use of the discrete nature of ionizing radiation interactions with matter. We have implemented a new physics concept in our Compton cameras whereby we no longer label radiation detectors according to their function as either scattering or absorbing detectors but rather characterize them by their materials, most importantly their effective atomic number Z_{eff}. As essentially no detector exists that would exclusively absorb radiation, we propose to record coincidence events between all pairs of detectors in which at least one detector material has $Z_{\text{eff}} > 30$. This new trigger condition includes coincidences of detector pairs where both materials have $Z_{\text{eff}} > 30$ which would traditionally be labeled absorbing detectors and would normally not be recorded by a Compton camera. These changes in the electronics setup of our Compton cameras yield an enlarged data sample available for subsequent inversion treatment.

We will present experimental results obtained with the relevance vector machine and a graph heuristic used for assigning coincidence events to emission points. The measurements were carried out at the radiation laboratory of the University of Applied Sciences Zittau/Görlitz. We gratefully acknowledge financial support by the Federal Ministry of Education and Research (BMBF) through the FORKA program under Grant No. 15S9431A-D.

Probing solar turbulent viscosity with inertial modes

MS38 2
Tue Sep 5
5:30 pm
6:00 pm
VG2.105

J. Philidet, L. Gizon

Solar inertial modes offer new possibilities to probe the solar interior down to the tachocline, and can be used to constrain such properties as the differential rotation or the spectrum of turbulent energy throughout the convection zone. Linear analysis enables us to compute the discrete eigenfrequencies of these modes [1,2]. However, because the inertial modes overlap in the frequency domain, especially for high azimuthal order m, this is not enough: it is necessary to model the power spectral density in the whole inertial frequency range, which can be done by modelling the stochastic source of excitation of the modes by turbulent vorticity.

In this presentation, I will show how this can be achieved in a 2D spherical setting, based on the formalism by [3]. I will then describe how this formalism can be used to relate changes in turbulent properties, with a focus on the turbulent viscosity, to their effects on the whole inertial range power spectral density (forward problem), as well as discuss the corresponding inverse problem.

References

[1] L. Gizon, D. Fournier, M. Albekioni. Effect of latitudinal differential rotation on solar Rossby waves: Critical layers, eigenfunctions, and momentum fluxes in the equatorial β plane, Astron. Astrophys 642: A178, 2020.

[2] Y. Bekki, R.H. Cameron, L. Gizon. Theory of solar oscillations in the inertial frequency range: Linear modes of the convection zone. Astron. Astrophys 662: A16, 2022.

[3] J. Philidet, and L. Gizon. Interaction of solar inertial modes with turbulent convection, A 2D model for the excitation of linearly stable modes. Astron. Astrophys 673: A124, 2023.

MS32 1
Wed Sep 6
9:30 am
10:00 am
VG1.104

Mathematical challenges in Full Waveform inversion

L. Pieronek

Full Waveform inversion (FWI) is a state-of-the-art geophysical imaging method that exploits seismic measurements to reconstruct shallow earth parameters. Mathematically, this translates into a non-linear inverse problem where the seismic measurements are modeled as solutions to a time-dependent wave-type system and the searched-for parameters are (some of) the coefficients. In order for numerical solution to be successful, both the parameter and measurement spaces need to be selected carefully: For instance, the reconstruction of sharp material interfaces requires non-smooth parameter spaces which are numerically difficult to cope with. Further, to minimize artifacts and spurious reconstructions, the resulting non-linear objective functional should be as convex as possible, which thus constraints the choice of compatible metrics for the seismic measurements. In this talk, we present novel ideas and solutions regarding these challenges in FWI.

MS45 1
Tue Sep 5
4:30 pm
5:00 pm
VG0.111

Data Driven Gradient Flows

J.-F. Pietschmann, M. Schlottbom

We present a framework enabling variational data assimilation for gradient flows in general metric spaces, based on the minimizing movement (or Jordan-Kinderlehrer-Otto) approximation scheme. After discussing stability properties in the most general case, we specialise to the space of probability measures endowed with the Wasserstein distance. This setting covers many non-linear partial differential equations (PDEs), such as the porous medium equation or general drift-diffusion-aggregation equations, which can be treated by our methods independent of their respective properties (such as finite speed of propagation or blow-up). We then focus on the numerical implementation of our approach using an primal-dual algorithm. The strength of our approach lies in the fact that by simply changing the driving functional, a wide range of PDEs can be treated without the need to adopt the numerical scheme. We conclude by presenting detailed numerical examples.

MS02 2
Tue Sep 5
4:00 pm
4:30 pm
VG1.102

New results for variational regularization with oversmoothing penalty term in Banach spaces

B. Hofmann, C. Klinkhammer, R. Plato

In this talk on variational regularization for ill-posed nonlinear problems, we discuss the impact of utilizing an oversmoothing penalty term. This means that the searched-for solution of the considered nonlinear operator equation does not belong to the domain of definition of the penalty functional. In the past years, such variational regularization has been investigated comprehensively in Hilbert scales. Our present results extents those results to Banach scales. This new study includes convergence rates results for a priori and a posteriori choices of the regularization parameter, both for Hölder-type smoothness and low order-type smoothness. An illustrative example intends to indicate the specific characteristics of non-reflexive Banach spaces.

Super-resolved Lasso

MS19 2
Tue Sep 5
5:00 pm
5:30 pm
VG3.103

C. Poon

The behaviour of sparse regularization using the Lasso method is well understood when dealing with discretized linear models. However, the behaviour of Lasso is poor when dealing with models with very large parameter spaces and exact localisation of the sparse support is often not possible due to discretization (gridding) issues. We introduced a new optimization problem known as the super-resolved Lasso, by considering a higher order expansion of the continuous operator, we show that we can precisely recover the support when the 'true' signal lies up to a fraction off the grid. This is joint work with Gabriel Peyre.

An off-the-grid approach to multi-compartment magnetic fingerprinting

MS03 2
Mon Sep 4
5:00 pm
5:30 pm
VG2.103

C. Poon

We propose a off-the-grid numerical approach to separate multiple tissue compartments in image voxels and to estimate quantitatively their nuclear magnetic resonance (NMR) properties and mixture fractions, given magnetic resonance fingerprinting (MRF) measurements. One of the challenge is that fine-grid discretisation of the multi-dimensional NMR properties creates large and highly coherent MRF dictionaries that can challenge scalability and precision of the numerical methods for sparse approximation. To overcome this issues, we propose an off-the-grid approach equipped with an extended notion of the sparse group lasso regularisation for sparse approximation using continuous Bloch response models. Through numerical experiments on simulated and in-vivo healthy brain MRF data, we demonstrate the effectiveness of the proposed scheme compared to baseline multi-compartment MRF methods.

This is joint work with Mohammad Golbabaee.

Inverse wave scattering in the time domain

MS57 1
Mon Sep 4
1:30 pm
2:00 pm
VG3.102

A. Mantile, A. Posilicano

Let $\Delta_\Lambda \leqslant \lambda_\Lambda$ be a semi-bounded self-adjoint realization of the Laplace operator with boundary conditions (Dirichlet, Neumann, semi-transparent) assigned on the Lipschitz boundary of a bounded obstacle Ω. Let u_f^Λ and u_f^0 denote the solutions of the wave equations corresponding to Δ_Λ and to the free Laplacian Δ respectively, with a source term f concentrated at time $t = 0$ (a pulse). We show that for any fixed $\lambda > \lambda_\Lambda \geqslant 0$ and any fixed $B \subset\subset \mathbb{R}^n \backslash \overline{\Omega}$, the obstacle Ω can be reconstructed by the scattering data operator

$$F_\lambda^\Lambda f(x) := \int_0^\infty e^{-\sqrt{\lambda}\,t}\big(u_f^\Lambda(t,x) - u_f^0(t,x)\big)\,dt\,, \qquad x \in B\,,\ f \in L^2(\mathbb{R}^n)\,,\ \mathrm{supp}(f) \subset B\,.$$

A similar result holds for point scatterers; in this case, the locations of the of scatterers are determined by an analog of F_λ^Λ acting in a finite dimensional space.

MS06 1
Wed Sep 6
10:30 am
11:00 am
VG0.110

Learning Dynamical Models and Model Components from Observations

R. Potthast

Dynamical models are the basis for forecasting in important application regimes such as weather or climate forecasting. Numerical models are based on a combination of PDEs from fluid flow, simulation of electromagnetic radiation and microphysics. For synchronization of such systems with reality data assimilation methods are used. These methods combine observations with short range forecasts into so-called analysis of components of the earth system, e.g. the atmosphere, land or the ocean. This is repeated for global atmospheric models every three hours, for high-resolution atmospheric models every hour, for ocean forecasting once per day. In climate science monthly means are assimilated for seasonal or decadal forecasting. The cycled run of short range forecasts and assimilation steps is known as data assimilation cycle. Observations include radiative transfer codes for microwave or infrared measurements, leading to integral-equation type observation operators as the basis of high-resolution global or regional data assimilation.

Here, we will address the task to learn dynamical models or model components iteratively which running such a data assimilation cycle. To this end we will employ either iterated Tikhonov regularization or its more elaborate version, the Kalman filter. We will demonstrate that model learning can be carried out very efficiently based on a particular representation of the model based on a sufficiently large variety of observations to be exploited in each step of the assimilation cycle. Examples from popular academic models such as the Lorenz 63 or 96 systems and more real-word systems will be demonstrated.

MS25 2
Mon Sep 4
5:00 pm
5:30 pm
VG0.110

Speckle noise removal via learned variational models

S. Cuomo, M. De Rosa, S. Izzo, M. Pragliola, F. Piccialli

In this talk, we address the image denoising problem in presence of speckle degradation typically arising in ultra-sound images. Variational methods and Convolutional Neural Networks (CNNs) are considered well-established methods for specific noise types, such as Gaussian and Poisson noise. Nonetheless, the advances achieved by these two classes of strategies are limited when tackling the de-speckle problem. In fact, variational methods for speckle removal typically amounts to solve a non-convex functional with the related issues from the convergence viewpoint; on the other hand, the lack of large datasets of noise-free ultra-sound images has not allowed the extension of the state-of-the-art CNN denoiser methods to the case of speckle degradation. Here, we aim at combining the classical variational methods with the predictive properties of CNNs by considering a weighted total variation regularized model; the local weights are obtained as the output of a statistically inspired neural network that is trained on a small and composite dataset of natural and synthetic images. The resulting non-convex variational model, which is minimized by means of the Alternating Direction Method of Multipliers (ADMM) is proven to converge to a stationary point. Numerical tests show the effectiveness of our approach for the denoising of natural and satellite images.

Adaptive estimation of $\alpha-$generalized random fields for statistical linear inverse problems with repeated measurements

CT10
Fri Sep 8
2:30 pm
3:00 pm
VG3.102

M. Pricop-Jeckstadt

In this talk we study an adaptive two-step estimation method for statistical linear inverse problems with repeated measurements for smoothness classes expressed as $\alpha-$generalized random fields [1]. In a first step, the minimum fractional singularity order α is estimated, and in the second step the penalized least squares estimator with smoothness estimated in the first step is studied [2]. Rates of convergence for both the process smoothness and the penalized estimator are proven and illustrated through numerical simulations.

References

[1] M. D. Ruiz-Medina, J. M. Angulo, V. V. Anh. Fractional generalized random fields on bounded domains. Stochastic Anal. Appl. 21: 465–492, 2005.

[2] S. Golovkine, N. Klutchnikoff, V. Patilea. Learning the smoothness of noisy curves with application to online curve estimation. Electron. J. Stat. 16: 1485–1560, 2022.

Augmented total variation regularization in imaging inverse problems

MS16 2
Thu Sep 7
5:30 pm
6:00 pm
VG0.111

N. E. Protonotarios, C.-B. Schönlieb, N. Dikaios, A. Charalambopoulos

Total variation (TV) regularization has been extensively employed in inverse problems in imaging. In this talk, we propose a new method of TV regularization for medical image reconstruction, which extends standard regularization approaches. Our novel method may be conceived as an augmented version of typical TV regularization. Within this approach, a new monitoring variable, $\omega(x)$, is introduced via an additional term in the minimization functional. The integration in this term is performed with respect to the TV measure, corresponding to the deviation of the image, $u(x)$. The dual function $\omega(x)$ is the integrand of the additional term, and its smoothing nature compensates, when necessary, for the abruptness of the TV measure of the image. It is within this dual variable that the regularity is imposed via the minimization process itself. The main purpose of the dual variable is to control the behavior of $u(x)$, especially regarding its discontinuity properties. Our preliminary results indicate the fast convergence rate of our method, thus highlighting its promising potential. This research is partially supported by the Horizon Europe project SEPTON, under grant agreement 101094901.

Imaging molecular wave functions with photoemission orbital tomography: Recent developments

MS15 2
Mon Sep 4
5:30 pm
6:00 pm
VG1.102

P. Puschnig

This contribution will concentrate on three recent applications of photoemission orbital tomography (POT). First, results of an on-surface synthesized molecular layer will be presented, show-casing how the imaging of molecular orbitals using POT sheds light on surface chemical reactions. Second, it will be demonstrated how POT can be generalized to extended two-dimensional systems. On the example of a strongly-hybridising molecular overlayer on a Cu(110) surface, deep insights into the complicated interplay of bulk states, surface states, and molecular orbitals can be gained from the orbital imaging. Finally, experimental and theoretical results for monolayer graphene will be presented. Here, the photon energy dependence of photoemission intensities indicate limitations of the plane-wave final state approximation which is at the heart of POT. Validated by real-time time-dependent density functional calculations, we develop a simple and intuitive model which accounts for final state scattering, which should allow for the inversion of experimental data to real-space orbital images, thereby going beyond the plane-wave paradigm of POT.

MS30 2
Thu Sep 7
1:30 pm
2:00 pm
VG2.103

Deep Invertible Approximation of Topologically Rich Maps between Manifolds

M. Puthawala, M. Lassas, I. Dokmanic, P. Pankka, M. de Hoop

How can we design neural networks that allow for stable universal approximation of maps between topologically interesting manifolds? In this talk, we will provide the surprisingly simple answer. By exploiting the topological parallels between locally bilipschitz maps, covering spaces, and local homeomorphisms as well as universal approximation arguments from machine learning, we find that a novel network of the form $p \circ \mathcal{E}$, where $\mathcal{E}$ is a smooth embedding and p a fixed coordinate projection, are universal approximators of local diffeomorphisms between compact smooth submanifolds embedded in $\mathbb{R}^n$. We emphasize the case when the map to be learned changes topology. Further, we find that by constraining the projection p, multivalued inversions of our networks can be computed without sacrificing universality. As an application of the problem, we show that the question of learning a group invariant function where the group action is unknown can be naturally reduced to the question of learning local diffeomorphisms when the group action is continuous, finite, and has constant-sized orbits. In this context the novel inversion result permits us to recover orbits of the group action.

MS47 1
Tue Sep 5
2:00 pm
2:30 pm
VG3.101

Motion detection in diffraction tomography

M. Quellmalz, P. Elbau, O. Scherzer, G. Steidl

We study the mathematical imaging problem of optical diffraction tomography (ODT) for the scenario of a rigid particle rotating in a trap created by acoustic or optical forces. Under the influence of the inhomogeneous forces, the particle carries out a time-dependent smooth, but irregular motion. The rotation axis is not fixed, but continuously undergoes some variations, and the rotation angles are not equally spaced, which is in contrast to standard tomographic reconstruction assumptions. Once the time-dependent motion parameters are known, the particle's scattering potential can be reconstructed based on the Fourier diffraction theorem, considering it is compatible with making the first order Born or Rytov approximation.

The aim of this presentation is twofold: We first need to detect the motion parameters from the tomographic data by detecting common circles in the Fourier-transformed data. This can be seen as analogue to method of common lines from cryogenic electron microscopy (cryo-EM), which is based on the assumption that the assumption that the light travels along straight lines. Then we can reconstruct the scattering potential of the object utilizing non-uniform Fourier methods.

References

[1] M. Quellmalz, P. Elbau, O. Scherzer, G. Steidl. Motion Detection in Diffraction Tomography by Common Circle Methods 2022. https://arxiv.org/abs/2209.08086

Microlocal properties and injectivity for Ellipsoidal and hyperbolic Radon transforms

MS47 1
Tue Sep 5
1:30 pm
2:00 pm
VG3.101

J. Webber, S. Holman, E. T. Quinto

We present novel microlocal results for generalized ellipsoid and hyperboloid Radon transforms in Euclidean Space and we apply our results to Ultrasound Reflection Tomography (URT). We introduce a new Radon transform, R, which integrates compactly supported distributions over ellipsoids and hyperboloids with centers on a smooth nypersurface, S in $\mathbb{R}^n$. R is shown to be a Fourier Integral Operator and in our main theorem we prove that R satisfies the Bolker condition if and only if the support of the function is in a connected set that is not intersected by any plane tangent to S. In this case, backprojection type reconstruction operators such as the normal operator R^*R do not add artifacts to the reconstruction.

We apply our results to a cylindrical geometry that could be used in URT. We prove injectivity results and investigate the visible singularities in this modality. In addition, we present reconstructions of image phantoms in two dimensions that illustrate our microlocal theory.

Non-conventional shape optimization methods for solving shape inverse problems

MS58 1
Tue Sep 5
2:30 pm
3:00 pm
VG2.104

J. F. T. Rabago, L. Afraites, A. Hadri

We propose non-conventional shape optimization approaches for the resolution of shape inverse problems inspired by non-destructive testing and evaluation. Our main objective is to improve the detection of the concave parts or regions of the unknown inclusion/obstacle/boundary through two different strategies and under shape optimization settings. Firstly, we will introduce the so-called alternating direction method of multipliers or ADMM in shape optimization framework to solve a boundary inverse problem for the Laplacian with Dirichlet condition using a single boundary measurement. Secondly, we will consider a similar problem, but with the Robin condition, and demonstrate how we can effectively detect a void with concavities using several pairs of Cauchy data. We will illustrate the effectiveness of the proposed schemes by testing them to some shape detection problems with pronounced concavities and under noisy data. Examples are given in two and three dimensions.

Numerical solution to inverse source problems for a parabolic equation with nonlocal conditions

MS14 3
Tue Sep 5
2:00 pm
2:30 pm
VG1.104

A. Rahimov, K. Aida-zade

In the report, we consider an inverse problem for a parabolic equation with unknown coefficient depending from only one independent variable: space or time variable.

We consider the following problem of determining unknown coefficient $C_0(x)$ of the linear parabolic equation:

$$\begin{aligned}&\tfrac{\partial v(x,t)}{\partial t} = a_0 \tfrac{\partial^2 v(x,t)}{\partial x^2} + a_1 \tfrac{\partial v(x,t)}{\partial x} + a_2 v(x,t) + \\ &+ f(x,t) + F(x,t), \qquad (x,t) \in \Omega = \{(x,t) : 0 < x < l,\ 0 < t \leqslant T\},\end{aligned}$$

under conditions:

$$k_1 v(x,0) + \int_0^T e^{k\tau} v(x,\tau)\, d\tau = \varphi_0(x), \quad v(x,T) = \varphi_T(x), \quad x \in [0, l],$$

$$v(0,t) = \psi_0(t), \quad v(l,t) = \psi_1(t), \quad t \in [0, T],$$

and where $F(x,t) = B_0(x,t)\, C_0(x)$ and $k,\ k_1 \neq 0$ are constants.

Two cases are considered. In the first case, the known coefficients $a_i,\ i = 0, ..., 2$ are functions of x, i.e. $a_i = a_i(x)$. The functions $a_0(x) > 0$, $a_1(x)$, $a_2(x)$, $\varphi_0(x)$, $\varphi_T(x)$, $f(x,t)$, $B_0(x,t)$, $\psi_0(t)$, $\psi_1(t)$ are given and satisfy all the conditions of existence and uniqueness of the functions $v(x,t)$, $C_0(x)$, which are the solutions to the problem.

We propose a numerical method of solution to the problem, which is based on the use of the method of lines. The initial problem is reduced to the parametric inverse problems with respect to ordinary differential equations. Then, we propose a non-iterative method based on using a special representation of the solutions to the obtained problems [1, 2]. Some of the results of the carried out numerical experiments are given. The obtained results show the efficiency of the proposed approach.

In the second case, similar approaches to numerical solution to the problem of identifying $C_0(t)$ in case $F(x,t) = B(x,t)\, C_0(t)$ are proposed. In this case, the known coefficients $a_i,\ i = 0, ..., 2$ are functions of t, and instead of the first conditions, we use the following ones:

$$\int_0^l e^{k\xi} v(\xi,t)\, d\xi = \psi(t), \quad t \in [0, T],$$

$$v(x,0) = \varphi_0(x), \quad x \in [0, l].$$

References

[1] K.R. Aida-zade, A.B. Rahimov. An approach to numerical solution of some inverse problems for parabolic equations, Inverse Probl. Sci. Eng. 22: 96-111, 2014.

[2] K.R. Aida-zade, A.B. Rahimov. On recovering space or time-dependent source functions for a parabolic equation with nonlocal conditions, Appl. Math. Comp. 419, 2022.

CT05
Thu Sep 7
3:00 pm
3:30 pm
VG2.105

Multi-Penalty TV Regularisation for Image Denoising: A Study

K. Raik

A common method for image denoising would be through TV regularisation, i.e.,

$$\frac{1}{2}\|k * x - y^\delta\|^2 + \alpha\, \mathrm{TV}(x) \to \min_x,$$

with $k = \mathrm{id}$ and $\alpha > 0$ as the parameter determining the trade-off between the accuracy and computational stability of your solution. The noise level $\|y - y^\delta\| \leqslant \delta$ is usually unknown, and therefore in this talk, I have opted to present a numerical study of the performance of several heuristic (i.e., noise-level free) parameter choice rules for total variation regularisation, both isotropic and anisotropic, with a focus on image denoising.

This is a prelude, however, to the more ominous multi-parameter choice problem [2] through the example of semiblind deconvolution [1], in which one only has an approximation k_η of a blurring kernel k, with $\|k - k^\eta\| \leqslant \eta$ (and η is known, thus the expression "semi"-blind). The functional we would like to minimise would then be

$$\frac{1}{2}\|k * x - y^\delta\|^2 + \alpha\, \mathrm{TV}(x) + \beta\|k - k^\eta\|^2 \to \min_{x,k}.$$

To quote a famous science-fiction film: ”now there are two of them” (α and β, that is).

References

[1] A. Buccini, M. Donatelli, R. Ramlau, A Semiblind Regularization Algorithm for Inverse Problems with Application to Image Deblurring, SIAM Journal on Scientific Computing, 2018. https://epubs.siam.org/doi/10.1137/16M1101830.

[2] M. Fornasier, V. Naumova, S. V. Pereverzyev, Parameter Choice Strategies for Multipenalty Regularization, SIAM Journal on Numerical Analysis, 2014. https://epubs.siam.org/doi/10.1137/130930248.

Inverse problems, unique continuation and the fractional Laplacian

MS54 2
Mon Sep 4
5:30 pm
6:00 pm
VG1.101

J. Railo

The Calderón problem is a famous nonlinear model inverse problem: Do voltage and current measurements on the boundary of an object determine its electric conductivity uniquely? X-ray computed tomography is a famous linear model inverse problem studied via Radon transforms. We discuss how the fractional Laplacians pop up in the analysis of Radon transforms. We then discuss recent results on the unique continuation of the fractional Laplacians and the related Caffarelli-Silvestre extension problem for L^p functions. We explain some of the implications to the analysis of Radon transforms with partial data and its further generalizations. Finally, we discuss the role of unique continuation in recent mathematical studies of the Calderón problem to nonlocal equations.

Stability estimates for the inverse fractional conductivity problem

MS53
Wed Sep 6
10:00 am
10:30 am
VG3.104

J. Railo

We study the stability of an inverse problem for the fractional conductivity equation on bounded smooth domains. We obtain a logarithmic stability estimate for the inverse problem under suitable a priori bounds on the globally defined conductivities. The argument has three main ingredients: 1. the logarithmic stability of the related inverse problem for the fractional Schrödinger equation by Rüland and Salo; 2. the Lipschitz stability of the exterior determination problem; 3. utilizing and identifying nonlocal analogies of Alessandrini's work on the stability of the classical Calderón problem. The main contribution of the article is the resolution of the technical difficulties related to the last mentioned step. Furthermore, we show the optimality of the logarithmic stability estimates, following the earlier works by Mandache on the instability of the inverse conductivity problem, and by Rüland and Salo on the analogous problem for the fractional Schrödinger equation.

Fixed angle inverse scattering for velocity

MS20 2
Thu Sep 7
4:00 pm
4:30 pm
VG3.104

R. Rakesh

An inhomogeneous acoustic medium is probed by a plane wave and the resultant time dependent wave is measured on the boundary of a ball enclosing the inhomogeneous part of the medium. We describe our partial results about the recovery of the velocity of the medium from the boundary measurement. This is a formally determined inverse problem for the wave equation, consisting of the recovery of a non-constant coefficient of the principal part of the operator from the boundary measurement.

CT13 Fri Sep 8 5:30 pm 6:00 pm VG2.105

Detection of geophysical structures using optical flow methodologies for potential data

J. A. Ramoz León, E. Fregoso Becerra, A. Palafox González

The subsurface exploration, as part of the development of the human being's environment, focuses on the location of water and mineral deposits, oil, gas, geological structures, among others. Geophysical methods provide information about natural resources, besides information of structures generated by human beings, namely archaeological structures, from the analysis of their physical properties, density of a source body for instance.

The Euler's homogeneity equation for geophysical potential data is given by:

$$(x-x_0)\frac{\partial T}{\partial x}+(y-y_0)\frac{\partial T}{\partial y}+(z-z_0)\frac{\partial T}{\partial z}=n(B-T),$$

where (x_0, y_0, z_0) refers to the top of a source object, (x, y, z) refers to the position of the observed potential field T, n is the structural index, which depends on the source geometry, and B is the regional value of the total field [1].

The inverse problem we are interested in, consists in locating a set of points (x_0, y_0, z_0) on the top of the source, from observed potential field data. In the classical Euler deconvolution strategy, this is achieved by solving Euler's homogeneity equation shown above. However, this strategy has an opportunity area in estimating the vertical component z_0 of the points composing the top of the source. This limitation is amplified when multiple source objects are present.

In the area of image processing, in particular in optical flow, the movement of pixels between two frames is analyzed. The spatial and temporal displacements are assumed to follow the Lambertian assumption: the pixels intensity remains after displacement. This assumption results in a differential equation very similar to the Euler's homogeneity equation: the Optical Flow equation:

$$\nabla T = 0,$$

where ∇ indicates spatial-temporal derivatives. There exist methodological similarities between standard Euler deconvolution method, and standard Optical Flow methods such as Lucas-Kanade. Thus, our hypothesis is that the improving methods applicable to Optical Flow, such as Horn and Schunck method [2], will benefit analogously to the Euler deconvolution method. By reformulating the Euler deconvolution strategy to be similar to the Horn and Schunck method, the position of the top of the source is estimated by minimizing the energy functional:

$$E_{HSED}(u,v,w)=\int\int\int (T_x u+T_y v+T_z w-n(B-T))^2+\Big(\lambda_u(u_x^2+u_y^2+u_z^2) + \lambda_v(v_x^2+v_y^2+v_z^2)+\lambda_w(w_x^2+w_y^2+w_z^2)\Big)d_x d_y d_z,$$

where u,v and w are the unknowns, λ_u, λ_v and λ_w are regularization parameters and the sub-indices indicate partial derivation. It is noticed that the first term in the integral corresponds to Euler's equation, meanwhile regularization terms impose smoothness on the source position reconstruction.

In this work it will be shown the results obtained after applying the methodology to synthetic 3D subsurface models. We present evidence that the horizontal location of the sources provided by Horn and Schunck based formulation is comparable to results obtained by standard Euler deconvolution strategy, with the advantage that the depth of the top of the subsurface's source is properly estimated.

References

[1] D.T . Thompsom., A new technique for making computer-assisted depth estimates from magnetic data.", Vol 47. 1982.

[2] Berthold K.P. Horn, Brian G. Schunck . "Determining Optical Flow", Artificial Intelligence Laboratory, Massachusetts Institute of Technology, Cam bridge, MA 02139, 1981.

Multi-window STFT phase retrieval

MS22 2
Tue Sep 5
5:30 pm
6:00 pm
VG1.101

M. Rathmair

We consider the problem of recovering a function $f \in L^2(\mathbb{R})$ (up to a multiplicative phase factor) from phase-less samples of its short-time Fourier transform $V_g f$, where

$$V_g f(x,y) = \int_{\mathbb{R}} f(t)\overline{g(t-x)}e^{-2\pi i y t}\,dt,$$

with $g \in L^2(\mathbb{R})$ a window function. Recently established dicretization barriers state that in general f is not uniquely determined given $|V_g f(\Lambda)| := \{|V_g f(\lambda)|, \lambda \in \Lambda\}$ if $\Lambda \subseteq \mathbb{R}^2$ is a lattice (irrespectively of the choice of the window g and the density of the lattice Λ). We show that these discretization barriers can be overcome by employing multiple window functions. More precisely, we prove that

$$\{|V_{g_1} f(\Lambda)|, |V_{g_2} f(\Lambda)|, |V_{g_3} f(\Lambda)|, |V_{g_4} f(\Lambda)|\}$$

uniquely determines $f \sim e^{i\theta} f$ when $g_1, \dots, g_4$ are suitably chosen windows provided that Λ has sufficient density.

Joint work with Philipp Grohs and Lukas Liehr.

Convex regularization in statistical inverse learning problems

MS07 1
Fri Sep 8
3:00 pm
3:30 pm
VG1.101

L. Ratti, T. A. Bubba, M. Burger, T. Helin

We consider a problem at the crossroad between inverse problems and statistical learning: namely, the estimation of an unknown function from noisy and indirect measurements, which are only evaluated at randomly distributed design points. This occurs in many contexts in modern science and engineering, where massive data sets arise in large-scale problems from poorly controllable experimental conditions. When tackling this task, a common ground between inverse problems and statistical learning is represented by regularization theory, although with slightly different perspectives. In this talk, I will present a unified approach, leading to convergence estimates of the regularized solution to the ground truth, both as the noise on the data reduces and as the number of evaluation points increases. I will mainly focus on a class of convex, p-homogeneous regularization functionals (p being between 1 and 2), which allow moving from the classical Tikhonov regularization towards sparsity-promoting techniques. Particular attention is given to the case of Besov norm regularization, which represents a case of interest for wavelet-based regularization. The most prominent application I will discuss is X-ray tomography with randomly sampled angular views. I will finally sketch some connections with recent extensions of our approach, including a more general family of sparsifying transforms and dynamical inverse problems.

MS25 2
Mon Sep 4
4:00 pm
4:30 pm
VG0.110

Learning a sparsity-promoting regularizer for linear inverse problems

L. Ratti, G. S. Alberti, E. De Vito, T. Helin, M. Lassas, M. Santacesaria

Variational regularization is a well-established technique to tackle instability in inverse problems, and it requires solving a minimization problem in which a mismatch functional is endowed with a suitable regularization term. The choice of such a functional is a crucial task, and it usually relies on theoretical suggestions as well as a priori information on the desired solution. A promising approach to this task is provided by data-driven strategies, based on statistical learning: supposing that the exact solution and the measurements are distributed according to a joint probability distribution, which is partially known thanks to a training sample, we can take advantage of this statistical model to design regularization operators. In this talk, I will present a hybrid approach, which first assumes that the desired regularizer belongs to a class of operators (suitably described by a set of parameters) and then learns the optimal one within the class. In the context of linear inverse problems, I will first briefly recap the main results obtained for the family of generalized Tikhonov regularizers: a characterization of the optimal regularizer, and two learning-based techniques to approximate it, with guaranteed error estimates. Then, I will focus on a class of sparsity-promotion regularizers, which essentially leads to the task of learning a sparsifying transform for the considered data. Also in this case, it is possible to deduce theoretical error bounds between the optimal regularizer and its supervised-learning approximation as the size of the training sample grows.

CT05
Thu Sep 7
2:30 pm
3:00 pm
VG2.105

Choice of the regularization parameter in case of over- or under-estimated noise level of data

T. Raus

We consider an operator equation

$$Au = f_*, \quad f_* \in R(A),$$

where $A \in L(H, F)$ is the linear continuous operator between real Hilbert spaces H and F. We assume that instead of the exact right-hand side f_* we have only an approximation $f \in F$ with supposed noise level δ. To get the regularized solution we consider Tikhonov method $u_\alpha = (\alpha I + A^* A)^{-1} A^* f$, where $\alpha > 0$ is the regularization parameter.

In article [1] is shown that at least one local minimum point m_k of the quasioptimality criterion function

$$\psi_Q(\alpha) = \alpha \left\| du_\alpha / d\alpha \right\| = \alpha^{-1} \left\| A^*(Au_{2,\alpha} - f) \right\|, \quad u_{2,\alpha} = (\alpha I + A^* A)^{-1}(\alpha u_\alpha + A^* f),$$

is always a good regularization parameter. We will use this fact to choose proper regularization parameter in case of a possible over- or underestimation of the noise level.

If the actual noise level $\|f - f_*\|$ can be less than δ, then we propose the following rule.

Rule 1. Let $c > 1$ and the parameter $\alpha(\delta)$ is choosen according to the modified discrepancy principle or monotone error rule (see [2]). For the regularization parameter choose smallest local minimum point $m_k \leqslant \alpha(\delta)$ of the quasioptimality criterion function for which holds

$$\max_{\alpha, \alpha', m_k \leqslant \alpha' < \alpha \leqslant \alpha(\delta)} \frac{\psi_Q(\alpha')}{\psi_Q(\alpha)} \leqslant c. \qquad (1)$$

If such local minimum point does not exist, then choose $\alpha(\delta)$.

If the actual noise level can be both larger or smaller than δ then we propose the following rule.

Rule 2. Let $c > 1$ and the parameter $\alpha(\delta)$ is chosen according to the balancing principle (see [2]). If there exists local minimum point $m_{k_0} > \alpha(\delta)$ for which $\psi_Q(\alpha(\delta)) > c\psi_Q(m_{k_0})$, then choose m_{k_0} for the regularization parameter. Otherwise, choose smallest local minimum point $m_k \leqslant \alpha(\delta)$ for which holds inequality (1). If such local minimum point does not exist, then choose $\alpha(\delta)$.

References

[1] T. Raus, U. Hämarik. Heuristic parameter choice in Tikhonov method from minimizers of the quasi-optimality function. In: Hofmann, Bernd, Leitao, Antonio, Zubelli, Jorge P. (Ed.). New Trends in Parameter Identification for Mathematical Models (1-18). Birkhäuser De Gruyter:227 - 244, 2018.

[2] T. Raus, U. Hämarik. About the Balancing Principle for Choice of the Regularization Parameter. Numerical Functional Analysis and Optimization, 30:9-10, 951 - 970, 2008.

Bayesian estimation in a multidimensional diffusion model with high frequency data

MS04 1
Tue Sep 5
3:00 pm
3:30 pm
VG2.102

M. Hoffmann, K. Ray

We consider a multidimensional diffusion model describing a particle moving in an insulated inhomogeneous medium under Brownian dynamics. We study Bayesian inference based on discrete high-frequency observations of the particle's location. Bayesian posteriors (and their posterior means) based on suitable Gaussian priors are shown to estimate the diffusivity function of the medium at the minimax optimal rate over Holder smoothness classes in any dimension. We also show that certain penalized least squares estimators are minimax optimal for estimating the diffusivity.

Inversion methods in asteroseismology

MS38 1
Tue Sep 5
2:00 pm
2:30 pm
VG2.105

D. R. Reese

In this talk, I will review the different kernel-based inversion techniques that have been used in asteroseismology. In particular, I will describe regularised least-squares (RLS) as well as optimally localised averages (OLA) type inversions. These have been applied to rotation and structural profiles as well as to integrated quantities such as the total kinetic rotation energy, the mean density, the acoustic radius, and various evolutionary phase and convective region indicators. I will also briefly show how inverse techniques can lead to more subtle constraints such as inequalities on rotational splittings if one makes certain assumptions on the rotation profile.

On uncertainty quantification for nonlinear inverse problems

MS51 2
Thu Sep 7
5:30 pm
6:00 pm
VG1.108

K. Ren

We study some uncertainty quantification problems in nonlinear inverse coefficient problems for PDEs. We are interested in characterizing the impact of unknown parameters in the PDE models on the reconstructed coefficients. We argue that, unlike the situation in forward problems, uncertainty propagation in inverse problems is influenced by both the forward model and the inversion method used in the reconstructions. For ill-conditioned problems, errors in reconstructions can sometimes dominate the uncertainty caused by the unknown parameters in the model. Based on such observations, we will propose methods that quantify uncertainties more accurately than a generic method by compensating for the errors due to the reconstruction algorithms.

MS56 2
Mon Sep 4
4:30 pm
5:00 pm
VG2.106

Quantitative reconstructions in inverse transport problems

K. Ren

In many practical applications of inverse problems, the data measured contain unknown normalization constants due to the unknown strength of the illumination sources. In such cases, it is usually impossible to quantitatively reconstruct the coefficients of interest. We show, mainly computationally, that one can actually have quantitative reconstructions for some inverse transport problems where redundancy in data helps us to eliminate the unknown normalization constant encoded in the illumination sources.

MS28 2
Tue Sep 5
4:30 pm
5:00 pm
VG1.108

Multiscale hierarchical decomposition methods for images corrupted by multiplicative noise

J. Barnett, W. Li, E. Resmerita, L. Vese

Recovering images corrupted by multiplicative noise is a well known challenging task. Motivated by the success of multiscale hierarchical decomposition methods (MHDM) in image processing, we adapt a variety of both classical and new multiplicative noise removing models to the MHDM form. We discuss well-definedness and convergence of the proposed methods. Through comprehensive numerical experiments and comparisons, we qualitatively and quantitatively evaluate the validity of the considered models. By construction, these multiplicative multiscale hierarchical decomposition methods have the added benefit of recovering many scales of an image, which can provide features of interest beyond image restoration.

MS58 1
Tue Sep 5
1:30 pm
2:00 pm
VG2.104

Isogeometric Shape Optimization of Periodic Structures in Three Dimensions

H. Harbrecht, M. Multerer, R. von Rickenbach

The optimal design of medical and dental implants, or lightweight structures in aeronautics can be modelled by a periodic structure with an empty, but a-priorily unknown inclusion. Homogenisation of this periodic scaffold structure, i.e., a material containing periodically arranged, identical copies of a cavity, leads to a macroscopic equation involving an effective material tensor $\mathbf{A}_0(\Omega) \in \mathbb{R}^{d\times d}_{\text{sym}}$.

This effective tensor is determined by a microscopic problem, defined on the d-dimensional, periodic unit cell $Y := [-\frac{1}{2}, \frac{1}{2}]^d$, containing the void $\Omega \subset Y$. The solutions of the respective cell problems

$$\begin{cases} \Delta w_i = 0 & \text{in } Y\setminus\overline{\Omega}, \\ \partial_{\boldsymbol{n}} w_i = -\langle \boldsymbol{n}, \boldsymbol{e}_i\rangle & \text{on } \partial\Omega, \end{cases} \qquad i = 1, \ldots, d,$$

define the coefficients of the effective tensor by

$$a_{i,j}(\Omega) = \int_{Y\setminus\overline{\Omega}} \big\langle \boldsymbol{e}_i + \nabla w_i,\ \boldsymbol{e}_j + \nabla w_j \big\rangle \,\mathrm{d}\boldsymbol{y}.$$

Therefore, effective material tensor on the macroscopic scale is given by the solution of a problem on the microscopic scale.

Considering a sought material tensor $\mathbf{B} \in \mathbb{R}^{d\times d}_{\text{sym}}$, which expresses desired material properties, we may ask the following question: Can we find a cavity Ω such that the effective tensor is as close to $\mathbf{B}$ as possible? In other terms, we want to minimise the tracking type functional

$$J(\Omega) := \frac{1}{2}\left\|\mathbf{A}_0(\Omega) - \mathbf{B}\right\|_F^2.$$

In [2], formulae for the shape gradient of the functional $J(\Omega)$ have been derived and numerical examples in two dimensions were presented, whereas in [3], integral equations were used to obtain numerical results in three dimensions. These examples include simply connected cavities and also more complex cavities of genus greater than zero. The calculations were performed with the isogeometric C++ library BEMBEL [1].

References

[1] J. Dölz, H. Harbrecht, S. Kurz, M. Multerer, S. Schöps, F. Wolf. Bembel: The fast isogeometric boundary element C++ library for Laplace, Helmholtz, and electric wave equation, SoftwareX, 11: 100476, 2020.

[2] M. Dambrine, H. Harbrecht. Shape optimization for composite materials and scaffold structures, Multiscale Modeling & Simulation, 18: 1136–1152, 2020.

[3] H. Harbrecht, M. Multerer, R. von Rickenbach. Isogeometric shape optimization of periodic structures in three dimensions, Computer Methods in Applied Mechanics and Engineering, 391: 114552, 2022.

Deep learning to tackle model inexactness and motion in Compton Scattering Tomography

MS47 1
Tue Sep 5
2:30 pm
3:00 pm
VG3.101

G. Rigaud, D. Frank

Modelling the Compton scattering effect leads to many challenges such as non-linearity of the forward model, multiple scattering and high level of noise for moving targets. While the non-linearity is addressed by a necessary linear approximation of the first-order scattering with respect to the sought-for electron density, the multiple-order scattering stands for a substantial and unavoidable part of the spectral data which is difficult to handle due to highly complex forward models. However, the smoothness properties of the operators modelling the different scattering orders suggests that differential operators can be used to reduce the level of multiple scattering. Last but not least, the stochastic nature of the Compton effect may involve a large measurement noise, in particular when the object under study is subject to motion, and therefore time must be taken into account. To tackle these different issues, we discuss in this talk a Bayesian method based on the generalized Golub-Kahan bidiagonalization and explore the possibilities to mimic and improve the stochastic approach with deep neural networks.

On Approximation for Multi-Source Domain Adaptation in the Space of Copulas

MS07 2
Fri Sep 8
4:30 pm
5:00 pm
VG1.101

P. Roy, B. Moser, W. Zellinger, S. Saminger-Platz

The set of d-copulas ($d \geqslant 2$), denoted by $\mathcal{C}_d$ is a compact subspace of $(\Xi(\mathbb{I}^d), d_\infty)$, the space of all continuous functions with domain $\mathbb{I}^d$; where $\mathbb{I}$ is the unit interval, $d_\infty(f_1, f_2) = \sup_{u\in\mathbb{I}^d}|f_1(\mathbf{u}) - f_2(\mathbf{u})|$ and the function $C : \mathbb{I}^d \to \mathbb{I}$ is a d-copula if, and only if, the following conditions hold:

(i) $C(u_1, .., u_d) = 0$ whenever $u_j = 0$ for at least one index $j \in \{1, ..., d\}$,

(ii) when all the arguments of C are equal to 1, but possibly for the j-th one, then

$$C(1,..,1,u_j,1,..,1) = u_j$$

(iii) C is d-increasing i.e., $\forall\ ]\mathbf{a},\mathbf{b}] \subseteq \mathbb{I}^d, V_C(]\mathbf{a},\mathbf{b}]) := \sum_{\mathbf{v}\in \text{ver}(]\mathbf{a},\mathbf{b}])} \text{sign}(\mathbf{v})C(\mathbf{v}) \geqslant 0$ where $\text{sign}(\mathbf{v}) = 1$, if $v_j = a_j$ for an even number of indices, and $\text{sign}(\mathbf{v}) = -1$, if $v_j = a_j$ for an odd number of indices.

Note that every copula $C \in \mathcal{C}_d$ induces a d-fold stochastic measure μ_C on $(\mathbb{I}^d, \mathcal{B}(\mathbb{I})^d)$ defined on the rectangles $R =]\mathbf{a},\mathbf{b}]$ contained in $\mathbb{I}^d$, by

$$\mu_C(R) := V_C(]\mathbf{a},\mathbf{b}]).$$

We will focus on specific copulas whose support is possibly a fractal set and discuss the uniform convergence of empirical copulas induced by orbits of the so-called chaos game (a Markov process induced by transformation matrices $\mathcal{T}$, compare [4]). We aim at learning, i.e., approximating an unknown function f (see also [5]), from random samples based on the examples of patterns, namely the so-called chaos game. Further details on copulas can be found in the monographs [1,2,3].

In this talk, we will first investigate the problem of learning in a relevant function space for an individual domain with the chaos game representation. Within this framework, we further formulate the problem of domain adaptation with multiple sources [6], where we discuss the method of aggregating the already obtained approximated functions in each domain to derive a function with a small error with respect to the target domain.

Acknowledgement:

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References

[1] F. Durante, C. Sempi. Principles of copula theory. CRC Press, 2016.

[2] R. B. Nelsen. An introduction to copulas. Springer Series in Statistics. Springer, second edition, 2006.

[3] C. Alsina, M. J. Frank, B. Schweizer. Associative functions. Triangular norms and copulas.World Scientific Publishing Co. Pte. Ltd.,2006.

[4] W. Trutschnig, J.F. Sanchez. Copulas with continuous, strictly increasing singular conditional distribution functions. J. Math. Anal. Appl. 410(2): 1014-1027, 2014.

[5] F. Cucker, S. Smale. On the mathematical foundations of learning. Bull. Amer. Math. Soc. (N.S.) 39(1): 1-49, 2002.

[6] Y. Mansour, M. Mohri, A. Rostamizadeh. Domain adaptation with multiple sources. Advances in neural information processing systems 21, 2008.

MS06 2
Thu Sep 7
1:30 pm
2:00 pm
VG3.103

Nonlinearity parameter imaging in the frequency domain

B. Kaltenbacher, W. Rundell

Nonlinear parameter tomography is a technique for enhancing ultrasound imaging and amounts to identifying the spatially varying coefficient $\eta = \eta(x)$ in the Westervelt equation $p_{tt} - c^2\triangle p - b\triangle p_t = \eta(p^2)_{tt} + h$ in a domain $(0,T)\times\Omega$. Here p is the acoustic pressure, c the speed of sound, b the diffusivity of sound, and h the excitation. Observations consist of pressure measurements on some manifold Σ immersed in the acoustic domain Ω.

Our imaging goal is to show unique recovery when $\eta(x)$ is a finite set $\{a_i\chi(D_i)\}_i$ and where each D_i is starlike with respect to its centroid.

Assuming periodic excitations of the form $h(x,t) = Ae^{i\omega t}$ for some fixed frequency ω one can convert this to an infinite system of coupled linear Helmholtz equations. We will give both uniqueness and reconstructions results and note that this work was inspired by a previous paper of one author and Rainer Kress.

The Recovery of Coefficients in Wave Equations from Time-trace Data

MS32 2
Thu Sep 7
2:30 pm
3:00 pm
VG1.104

B. Kaltenbacher, W. Rundell

The Westervelt equation is a common formulation used in nonlinear optics and several of its coefficients are meaningful as imaging parameters of physical consequence. We look at the recovery of some of these from both an analytic and a reconstruction perspective.

Designing an algorithm for low-dose Poisson phase retrieval

CT12
Fri Sep 8
1:30 pm
2:00 pm
VG2.104

B. Diederichs, F. Filbir, P. Römer

Many experiments in the field of optical imaging are modelled as phase retrieval problems. Motivated by imaging experiments with biological specimens that need to be measured using a preferably low dose of illumination particles, we consider phase retrieval systems with small Poisson noisy measurements. In this talk, we discuss how to formulate a suitable optimization problem. We study reasonable loss functions adapted to the Poisson distribution, optimized for low-dose data. As a solver, we apply gradient descent algorithms with Wirtinger derivatives. For the proposed loss functions, we analyze the convergence of the respective Wirtinger flow type algorithms to stationary points. We present numerical reconstructions from phase retrieval measurements in a low-dose regime to corroborate our theoretical observations.

Geometric regularization in three-dimensional inverse obstacle scattering

CT02
Wed Sep 6
9:30 am
10:00 am
VG2.105

J. Rönsch, H. Schumacher, M. Wardetzky, T. Hohage

We study the classical inverse problem to determine the shape of a three-dimensional scattering obstacle from measurements of scattered waves or their far-field patterns. Previous research on this subject has mostly assumed the object to be star-shaped and imposed a Sobolev penalty on the radial function or has defined the penalty term in some other ad-hoc manner which is not invariant under coordinate transformations.

For the case of curves in $\mathbb{R}^2$, reference [1] suggests to use the bending energy as regularisation functional and proposes Tikhonov regularization and regularized Newton methods on a shape manifold. The case of surfaces in $\mathbb{R}^3$ is considerably more demanding. First, a suitable space (manifold) of shapes is not obvious. The second problem is to find a stabilizing functional for generalised Tikhonov regularisation which on the one hand should be bending-sensitive and on the other hand prevent the surface from self-intersections during the reconstruction.

The tangent-point energy is a parametrization-invariant and repulsive surface energy that is constructed as the double integral over a power of the tangent point radius with respect to two points on the surface, i.e. the smallest radius of a sphere being tangent to the first point and intersecting the other. The finiteness of this energy also provides $C^{1,\alpha}$ Hölder regularity of the surfaces.[2] Using this energy as the stabilising functional, we choose general surfaces of Sobolev-Slobodeckij reguality, which are naturally connected to this energy.

The proposed approach works for surfaces of arbitrary (known) topology. In numerical examples we demonstrate that the flexibility of our approach in handling rather general shapes.

References

[1] J Eckhardt, R Hiptmair, T Hohage, H Schumacher, M Wardetzky. Elastic energy regularization for inverse obstacle scattering problems. 2019

[2] P. Strzlecki, H. von der Mosel. Tangent-point repulsive potentials for a class of smooth m-dimensional sets in $\mathbb{R}^n$. Part 1: Smoothing and self-avoidance effects. 2011

MS54 2
Mon Sep 4
4:00 pm
4:30 pm
VG1.101

Inversion of the momenta X-ray transform of symmetric tensor fields in the plane

K. Sadiq

The X-ray transform of symmetric tensor fields recovers the tensor field only up to a potential field. In 1994, V. Sharafutdinov showed that augmenting the X-ray data with several momentum-ray transforms establishes uniqueness, with a most recent work showing stability of the inversion. In this talk, I will present a different approach to stably reconstruct symmetric tensor fields compactly supported in the plane.

The method is based on the extension of Bukhgeim's theory to a system of A-analytic maps.

This is joint work with H. Fujiwara, D. Omogbhe and A. Tamasan.

MS16 2
Thu Sep 7
4:00 pm
4:30 pm
VG0.111

Source Reconstruction from Partial Boundary Data in Radiative Transport

K. Sadiq

This talk concerns the source reconstruction problem in a transport problem through an absorbing and scattering medium from boundary measurement data on an arc of the boundary. The method, specific to two dimensional domains, relies on Bukgheim's theory of A-analytic maps and it is joint work with A. Tamasan (UCF) and H. Fujiwara (Kyoto U).

MS33 1
Wed Sep 6
10:00 am
10:30 am
VG1.105

Utilizing variational autoencoders in the Bayesian inverse problem of photoacoustic tomography

T. Sahlström, T. Tarvainen

Photoacoustic tomography (PAT) is an imaging modality based on the photoacoustic effect. In the inverse problem of PAT, an initial pressure distribution induced by absorption of an externally introduced light is estimated from measured photoacoustic data. In the recent years, utilisation of machine learning in the inverse problem of PAT has gained significant interest. However, many of these machine learning-based methods do not provide information regarding the uncertainty of the reconstructed image.

In this work, we proposed a machine learning-based framework for the Bayesian inverse problem of PAT. The approach is based on the variational autoencoder (VAE) and the recently proposed uncertainty quantification variational autoencoder (UQ-VAE). In the

VAE and UQ-VAE, an approximation of the true underlying posterior distribution is estimated by minimizing a divergence between the true and estimated posterior distributions using a neural network. The approach is evaluated using numerical simulations both in full and limited view measurement geometries with multiple levels of measurement noise.

The linearized Calderon problem for polyharmonic operators

MS54 1
Mon Sep 4
2:00 pm
2:30 pm
VG1.101

S. K. Sahoo, M. Salo

The density of products of solutions to several types of partial differential equations, such as elliptic, parabolic, and hyperbolic equations, plays a significant role in solving various inverse problems, dating back to Calderon's fundamental work. In this talk, we will discuss some density properties of solutions to polyharmonic operators on the space of symmetric tensor fields. These density questions are closely related to the linearized Calderon problem for polyharmonic operators. This is joint work with Mikko Salo.

Tomographic Reconstruction in X-ray Near-field Diffractive Imaging: from Laboratory μCT to Synchrotron Nano-Imaging

MS59 2
Fri Sep 8
5:30 pm
6:00 pm
VG2.103

T. Salditt

X-rays can provide information about the structure of matter, on multiple length scales from bulk materials to nanoscale devices, from organs to organelle, from the organism to macromolecule. Due to the widespread lack of suitable lenses, the majority of investigations are rather indirect - apart from classical shadow radiography perhaps. While diffraction problems have been solved since long, the modern era has brought about lensless coherent imaging with X-rays, down to the nanoscale. How can we address and implement optimized tomography solutions for phase contrast inhouse and synchrotron data, taking into account partial coherence, propagation and cone beam geometry? We show how solutions and algorithms of mathematics of inverse problems [1-3] help us to meet the challenges of phase retrieval, tomographic reconstruction, and more generally image processing of bulky data. We also include illustrative bioimaging projects such as mapping the human brain [4,6] of fighting infectious diseases [6]. References:

References

[1] T. Salditt, A. Egner, R. D. Luke (Eds.) Nanoscale Photonic Imaging Springer Nature, TAP, 134, Open Access Book, 2020.

[2] L. M. Lohse, A.-L. Robisch, M. Töpperwien, S. Maretzke, M. Krenkel, J. Hagemann, T. Salditt A phase-retrieval toolbox for X-ray holography and tomography Journal of Synchrotron Radiation, 27, 3, 2020.

[3] S. Huhn, L.M. Lohse, J. Lucht, T. Salditt. Fast algorithms for nonlinear and constrained phase retrieval in near-field X-ray holography based on Tikhonov regularization - arXiv preprint arXiv:2205.01099, 2022.

[4] M. Eckermann, B. Schmitzer, F. van der Meer, J. Franz, O. Hansen, C. Stadelmann, T. Salditt. Three-dimensional virtual histology of the human hippocampus based on phase-contrast computed tomography Proc. Natl. Acad. Sci., 118, 48, e2113835118, 2021.

[5] M. Eckermann, J. Frohn, M. Reichardt, M. Osterhoff, M. Sprung, F. Westermeier, A.Tzankov, C. Werlein, M. Kuehnel, D. Jonigk, T. Salditt. 3d Virtual Patho-Histology of Lung Tissue from Covid-19 Patients based on Phase Contrast X-ray Tomography, eLife, 9:e60408, 2020.

[6] M. Reichardt, P.M. Jensen, V.A. Dahl, A.B. Dahl, M. Ackermann, H. Shah, F. Länger, C. Werlein, M.P. Kuehnel, D. Jonigk, T. Salditt. 3D virtual histopathology of cardiac tissue from Covid-19 patients based on phase-contrast X-ray tomography, eLife, 10:e71359, 2021.

MS34 1
Mon Sep 4
1:30 pm
2:00 pm
VG3.103

Continuous generative models for nonlinear inverse problems

M. Santacesaria, G. S. Alberti, J. Hertrich, S. Sciutto

Generative models are a large class of deep learning architectures, trained to describe a subset of a high dimensional space with a small number of parameters. Popular models include variational autoencoders, generative adversarial networks, normalizing flows and, more recently, score-based diffusion models. In the context of inverse problems, generative models can be used to model prior information on the unknown with a higher level of accuracy than classical regularization methods.

In this talk we will present a new data-driven approach to solve inverse problems based on generative models. Taking inspiration from well-known convolutional architectures, we construct and explicitly characterize a class of injective generative models defined on infinite dimensional functions spaces. The construction is based on wavelet multi resolution analysis: one of the key theoretical novelties is the generalization of the strided convolution between discrete signals to an infinite dimensional setting. After an off-line training of the generative model, the proposed reconstruction method consists in an iterative scheme in the low-dimensional latent space. The main advantages are the faster iterations and the reduced ill-posedness, which is shown with new Lipschitz stability estimates. We also present numerical simulations validating the theoretical findings for linear and nonlinear inverse problems such as electrical impedance tomography.

MS30 1
Wed Sep 6
10:30 am
11:00 am
VG2.103

Inverse problems on manifolds via graph-based semi-supervised learning

D. Sanz-Alonso, R. Yang

In this talk I will introduce graphical representations of stochastic partial differential equations with the goals of approximating Matérn Gaussian fields on manifolds and generalizing the Matérn model to abstract point clouds. I will show that these graph-based prior models can give optimal posterior contraction in semi-supervised learning, and illustrate their use in various inverse problems on manifolds.

MS09
Fri Sep 8
3:00 pm
3:30 pm
VG1.102

Advantages of locality in random field representations for shape uncertainty quantification

L. Scarabosio, W. van Harten

We consider the solution to an elliptic partial differential equation on a domain which is subject to uncertain changes in its shape.

When representing uncertain shape variations, using localized basis functions can be appealing from a modeling point of view, as they offer more geometrical flexibility compared to globally supported basis functions. In this talk, we will see that locality of basis functions can also be convenient in terms of approximation properties with respect to the uncertain parameter. Extending ideas from [1,2], it is indeed possible to prove, using pointwise summability bounds, that sparse polynomial approximations to the parameter-to-solution map may converge faster if localized functions are used in the shape representation. We will also see that this approximability result goes beyond shape uncertainty, and it applies in fact to many other parameter-to-solution maps, as long as they are smooth and have some given sparsity properties.

References

[1] M. Bachmayr, A. Cohen, G. Migliorati. Sparse polynomial approximation of parametric elliptic PDEs. Part I: affine coefficients, ESAIM: Mathematical Modelling and Numerical Analysis 51(1): 321-339, 2017.

[2] M. Bachmayr, A. Cohen, R. DeVore, G. Migliorati, Sparse polynomial approximation of parametric elliptic PDEs. Part II: lognormal coefficients, ESAIM: Mathematical Modelling and Numerical Analysis 51(1): 341-363, 2017

Numerical Linear Algebra Networks for Solving Linear Inverse Problems

MS10 1
Thu Sep 7
1:30 pm
2:00 pm
VG1.103

<u>O. Scherzer</u>

We consider solving a probably ill-conditioned linear operator equation, where the operator is not modeled, but given indirectly via training samples. The method de- and encoding is very useful for such applications and will be analyzed from a point of regularization theory. This analysis in particular shows that preprocessing of the image data is required, which is implemented by linear algebra networks.

Photoacoustic imaging in acoustic attenuating media

MS49 1
Tue Sep 5
1:30 pm
2:00 pm
VG3.102

<u>O. Scherzer</u>, P. Elbau, C. Shi

Acoustic attenuation describes the loss of energies of propagating waves. This effect is inherently frequency dependent. Typical attenuation models are derived phenomenologically and experimentally without the use of conservation principles. Because of these general strategy a zoo of models has been developed over decades.

Photoacoustic imaging is a hybrid imaging technique where the object of interest is excited by a laser and the acoustic response of the medium is measured outside of the object. From this the ability of the medium to convert laser excitation into acoustic waves is computationally reconstructed. For photoacoustics, which is a linear inverse problem, we will determine its spectral values, and we shall see that there are two kind of attenuating models, resulting in mildly and severely inverse photoacoustic problems.

A primal dual projection algorithm for efficient constraint preconditioning

MS12 2
Mon Sep 4
5:00 pm
5:30 pm
VG2.102

<u>A. Schiela</u>, M. Weiser, M. Stöcklein

We consider a linear iterative solver for large scale linearly constrained quadratic minimization problems that arise, for example, in optimization with partial differential equations (PDEs). By a primal-dual projection (PDP) iteration, which can be interpreted and analysed as a gradient method on a quotient space, the given problem can be solved by computing sulutions for a sequence of constrained surrogate problems, projections onto the feasible subspaces, and Lagrange multiplier updates. As a major application we consider a class of optimization problems with PDEs, where PDP can be applied together with a projected cg method using a block triangular constraint preconditioner. Numerical experiments show reliable and competitive performance for an optimal control problem in elasticity.

MS42 Tue Sep 5 4:30 pm 5:00 pm VG3.104

Reconstructing anisotropic conductivities on manifolds

H. A. Schlüter

We study the problem of recovering an electrical anisotropic conductivity from interior power density measurements on a two-dimensional Riemannian manifold. This problem arises in Acousto-Electric Tomography and is motivated by the geometric Calderón problem of recovering the metric from the Dirichlet-to-Neumann map. In contrast to the geometric Calderón problem, we consider a conductive Riemannian manifold and treat the conductivity and metric separately. Assuming that the metric is known, for two-dimensional Riemannian manifolds with genus zero, we highlight in this talk that under certain assumptions on the power density data it is possible to recover the conductivity uniquely and constructively from the data. We illustrate our findings with a numerical experiment and comment on how added noise on the manifold affects the reconstructed conductivity.

MS41 1 Fri Sep 8 2:00 pm 2:30 pm VG3.101

Invariance of the elastic wave equation in the context of Finsler geometry

H. A. Schlüter

In this talk we address the Euclidean elastic wave equation under change of variables and extend this to Riemannian geometry. This is inspired by previous research that has concerned the principal behavior of the Euclidean elastic wave equation under coordinate transformations. Further research has concerned how the density normalized stiffness tensor gives rise to a Finsler metric. With this in mind we will touch upon what one can say about the density and stiffness tensor fields that give rise to the same Finsler metric. In this context we will talk about how this will affect the full elastic wave equation and not only the principal behavior.

MS47 1 Tue Sep 5 3:00 pm 3:30 pm VG3.101

Diffusion based regularization for multi-energy CT with limited data

B. Hahn-Rigaud, G. Rigaud, R. Schmähl

As shown by the rise of data-driven and learning techniques, the use of specific features in datasets is essential to build satisfactory solutions to ill-posed inverse problems suffering limitations, sparsity and large level of noise. The well-known total-variation regularization has become a standard approach due to producing good results without any a priori knowledge. Providing additional information, it is possible to improve the reconstruction using forward/backward diffusions. An example is the so-called Perona-Malik functional which is based on a priori on the global contrast. Such a construction of regularizers is particularly relevant with machine learning techniques in which a database can provide natural features and informations such as contrast and edges. We propose to study this approach and to validate its potential on multi-energy CT (computerized tomography) subject to limitations such as sparsitiy and limited angles.

Regularized matching pursuits with a learning add-on for geoscientific inverse problems

MS44 1
Mon Sep 4
2:30 pm
3:00 pm
VG2.104

N. Schneider

We consider challenging inverse problems from the geosciences: the downward continuation of satellite data for the approximation of the gravitational potential as well as the travel time tomography using earthquake data to model the interior of the Earth. Thus, we are able to monitor certain influences on the system Earth, in particular the mass transport of the Earth or its interior anomalies.

For the approximation of these linear(ized) inverse problems, different basis systems can be utilized. Traditionally, we a-priori either choose a global, e.g. spherical harmonics on the sphere or polynomials on the ball, or a local one, e.g. radial basis functions and wavelets or finite elements.

The Learning Inverse Problem Matching Pursuits (LIPMPs), however, have the unique characteristic to enable the combination of global and local trial functions for the approximation of inverse problems. The latter is obtained iteratively from an intentionally overcomplete set of trial functions, the dictionary, such that the Tikhonov functional is reduced. Moreover, the learning add-on allows the dictionary to be infinite such that an a-priori choice of a finite number of trial functions is negligible. Further, it increases the efficiency of the methods.

In this talk, we give details on the LIPMPs and show some current numerical results.

Reconstructing Molecular Flexibility in Cryogenic Electron Microscopy

MS26 3
Thu Sep 7
5:00 pm
5:30 pm
VG3.102

J. Schwab, D. Kimanius, S. Scheres

Cryogenic electron microscopy (cryo-EM) is a powerful technique to obtain the 3D structure of macromolecules from thousands of noisy projection images. Since these macromolecules are flexible by nature, the areas where a protein moves yields in a local drop of resolution in the reconstruction. We propose a method named dynamight, that represents the molecule with gaussian basis functions and estimates deformation fields for every experimental image. We further use the estimated deformations to better resolve the flexible regions in the reconstruction using a filtered backprojection algorithm along curved lines. We present results on real data showing that we obtain improved 3D reconstruction

Traction force microscopy - a testbed for solving the inverse problem of elasticity

MS49 1
Tue Sep 5
3:00 pm
3:30 pm
VG3.102

U. Schwarz

During the last three decades, the new field of mechanobiology has demonstrated that mechanical forces play a key role for the decision making of biological cells. The standard way to estimate cell forces is traction force microscopy on soft elastic substrates, whose deformations can be tracked with fiducial marker beads. To infer the corresponding cell forces, one can either solve the inverse problem of elasticity, which usually is done in Fourier space, or calculate strain and stress tensors directly from the deformation data. In both cases, some type of regularization is required to deal with experimental noise.

Here we discuss recent developments in this field, including microparticle traction force microscopy and machine learning approaches.

MS23 1
Tue Sep 5
4:30 pm
5:00 pm
VG1.103

Far field operator splitting and completion for inhomogeneous medium scattering

L. Schätzle

We consider scattering of time-harmonic acoustic waves by an ensemble of compactly supported penetrable scattering objects in 2D. These scattering objects are illuminated by an incident plane wave. The resulting total wave is the superposition of incident and scattered wave and solves a scattering problem for the Helmholtz equation. For guaranteeing uniqueness, the scattered wave must fulfill the Sommerfeld radiation condition at infinity.

In our consideration, measurements of the total wave are replaced by the corresponding far field operator. This operator contains all information about the scattered wave far away from the scattering objects for all possible illumination directions.

We are interested in two inverse problems. On the one hand, given a limited observation of this far field operator, we want to determine its missing part, which we refer to as operator completion problem. 'Limited observation' in this context means, that we do not have access to measurements for all illumination directions or that we cannot measure in all observation directions around the scattering objects. On the other hand, given the far field operator for the ensemble of scattering objects, we want to determine the far field operators of the individual scattering objects. This is what we refer to as operator splitting problem. Multiple reflection effects cause, in contrast to the first problem, the nonlinearity of this second problem.

We characterize spaces containing the individual, for the two problems relevant components of the far field operator. Operators in these spaces turn out to have a low rank and sparsity properties with respect to some known modulated Fourier frame. Furthermore, this rank and frame can be determined under knowledge of the locations and sizes of the scatterer's components.

In my talk I will suggest two reformulations of the inverse problems, a least squares norm formulation and a $l^1 \times l^1$-norm minimization, and appropriate algorithms for solving these formulations numerically. Moreover, I will present stability results for these reconstructions and support them by numerical experiments.

MS25 1
Mon Sep 4
2:30 pm
3:00 pm
VG0.111

Learned proximal operators in accelerated unfolded methods with pseudodifferential operators

A. Sebastiani, T. A. Bubba, L. Ratti, S. Mukherjee

In recent years, hybrid reconstruction frameworks has been proposed by unfolding iterative methods and learning a suitable pseudodifferential correction on the part that can provably not be handled by model-based methods. In particular, the inner hyperameters of the method are estimated by using supervised learning techniques.

In this talk, I will present a variant of this approach, where an accelerated iterative algorithm is unfolded and the proximal operator is replaced by a learned operators, as in the PnP framework. The numerical experiments on limited-angle CT achieve promising results.

Recent developments on integral equation approaches for Electrical Impedance Tomography

MS14 2
Mon Sep 4
4:30 pm
5:00 pm
VG1.104

C. Sebu

The talk is focused on recent developments of reconstruction algorithms that can be used to approximate admittivity distributions in Electrical Impedance Tomography. The algorithms are non-iterative and are based on linearized integral equation formulations [1,2] which have been extended to reconstruct the conductivity and/or permittivity distributions of two and three-dimensional domains from boundary measurements of both low and high-frequency alternating input currents and induced potentials [3]. The linearized approaches rely on the solutions to the Laplace equation on a disk and a hemispherical domain subject to appropriate idealized Neumann boundary conditions corresponding to applied spatial varying trigonometric current patterns. Reconstructions from noisy simulated data are obtained from single-time, time-difference and multiple-times data. Moreover, a proposed design of a prototype for a novel integrated circuit based electrical impedance mammographic system embedded in a brassiere will be presented.

References

[1] C. Hähnlein, K. Schilcher, C. Sebu, H. Spiesberger. Conductivity imaging with interior potential measurements, Inverse Problems in Science and Engineering 19(5): 729-750, 2011.

[2] K-H. Georgi, C. Hähnlein, K. Schilcher, C. Sebu, H. Spiesberger. Conductivity Reconstructions Using Real Data from a New Planar Electrical Impedance Device, Inverse Problems in Science and Engineering, Inverse Problems in Science and Engineering 21(5): 801-822, 2013.

[3] C. Sebu, A. Amaira, J. Curmi. A linearized integral equation reconstruction method of admittivity distributions using Electrical Impedance Tomography, Engineering Analysis with Boundary Elements 150: 103-110, 2023.

Parameter estimation for boundary conditions in ice sheet models

MS04 2
Tue Sep 5
4:00 pm
4:30 pm
VG2.102

F. Seizilles

In this work, we are interested in the non-linear inverse problem which consists in retrieving the basal drag factor, an important parameter for scientists who want to understand the dynamics of ice sheets in the Antarctic. This drag factor takes the form of a Robin boundary condition at the bottom of the ice sheet in our PDE problem, and varies spatially along the boundary. Due to the thickness of the ice, the drag cannot be measured directly, and the only data available to us is the velocity of the ice at the surface.

We present a computational routine to estimate posterior densities of parameters for this Robin boundary condition.

A new family of modified interior transmission eigenvalues for a fluid-solid interaction

MS29 1
Mon Sep 4
2:00 pm
2:30 pm
VG3.104

P. Monk, V. Selgas

We study a new family of modified interior transmission eigenvalues for the interaction of a bounded elastic body (the target) embedded in an unbounded compressible inviscid fluid (the acoustic medium). This problem is modelled with the elastodynamic and acoustic equations in the time-harmonic regime, and the interaction of the two media is represented through the dynamic and kinematic boundary conditions; these are are two transmission conditions posed on the wet boundary that represent the equilibrium of forces, and the equality of the normal displacements of the solid and the fluid, respectively.

For such a model problem, we propose a new family of modified interior transmission eigenvalues (mITP eigenvalues), which depends on a tunable parameter γ that can help increase the sensitivity of the eigenvalues to changes in the scatterer. We analyze the distribution of the mITP eigenvalues on the complex plane, in particular we show that they are real valued, and that they either fill the whole real line or define a discrete subset with no finite accumulation point. We also justify theoretically that they can be approximated from measurements of the far field pattern corresponding to incident plane waves by solving a collection of modified far field equations. Furthermore, for a suitable choice of the parameter γ, our theory is more complete: it includes a proof of the discreteness of the mTIP eigenvalues, an upper bound for them, and a physical interpretation of the largest of them via a Courant min-max principle.

We finally provide numerical results for synthetic data to give an insight of the expected perfomance of the mITP eigenvalues if used as target signatures in applications.

References

[1] F. Cakoni, D. Colton, S. Meng, P. Monk. Stekloff eigenvalues in inverse scattering, SIAM J. Appl. Math. 76(4): 1737-1763, 2016.

[2] S. Cogar, D. Colton, S. Meng, P. Monk. Modified transmission eigenvalues in inverse scattering theory, Inverse Probl. 33(12): 125002, 2017.

[3] M. Levitin, P. Monk, V. Selgas,.Impedance eigenvalues in linear elasticity, SIAM J. on Appl. Math. 81(6), 2021.

[4] P. Monk, V. Selgas. Modified transmission eigenvalues for inverse scattering in a fluid-solid interaction problem, Research in the Mathematical Sciences 9(3), 2022.

MS57 2
Mon Sep 4
5:00 pm
5:30 pm
VG3.102

Lipschitz stability for some inverse problems for a hyperbolic PDE with space and time dependent coefficients

V. P. Krishnan, S. Senapati, R. Rakesh

We study stability aspects for the determination of space and time-dependent lower order perturbations of the wave operator in three space dimensions with point sources. The problems under consideration here are formally determined and we establish Lipschitz stability results for these problems. The main tool in our analysis is a modified version of Bukgheĭm-Klibanov method based on Carleman estimates.

References

[1] V. P. Krishnan, S. Senapati, Rakesh. Stability for a formally determined inverse problem for a hyperbolic PDE with space and time dependent coefficients, SIAM J. Math. Anal. 53, no. 6, 6822-6846, 2021.

[2] V. P. Krishnan, S. Senapati, Rakesh. Point sources and stability for an inverse problem for a hyperbolic PDE with space and time dependent coefficients, J. Differential Equations 342, 622-665, 2023.

MS54 3
Tue Sep 5
4:00 pm
4:30 pm
VG1.105

The Calderón problem for space-time fractional parabolic operators with variable coefficients

A. Banerjee, S. Senapati

We study an inverse problem for variable coefficient fractional parabolic operators of the form $(\partial_t - \operatorname{div}(A(x)\nabla_x))^s + q(x,t)$ for $s \in (0,1)$ and show the unique recovery of q from exterior measured data. Similar to the fractional elliptic case, we use Runge type approximation argument which is obtained via a global weak unique continuation property. The proof of such a unique continuation result involves a new Carleman estimate for the associated variable coefficient extension operator. In the latter part of the work, we prove analogous unique determination results for fractional parabolic operators with drift.

References

[1] A. Banerjee, S. Senapati. The Calderón problem for space-time fractional parabolic operators with variable coefficients, arXiv: 2205.12509, 2022.

Edge-preserving inversion with heavy-tailed Bayesian neural networks priors

MS17
Tue Sep 5
5:00 pm
5:30 pm
VG1.104

A. Senchukova, F. Uribe, J. de Wiljes, L. Roininen

We study Bayesian inverse problems where the unknown target function is piecewise constant. Priors based on neural networks with heavy-tailed-distributed weights/biases have been employed due to their discretization-independent property and ability to capture discontinuities. We aim at developing neural network priors whose parameters are drawn from Student's t distributions. The idea is to parameterize the unknown function using a neural network which sets a finite-dimensional inference framework. This requires finding the posterior distribution of the weights/biases of the network representation. The resulting posterior is, however, high-dimensional and multimodal which makes it difficult to characterize using traditional sampling algorithms. Therefore, we explore data assimilation techniques to sample the posterior distribution more effectively. As a numerical example, we consider a simple signal deconvolution to illustrate the properties of the prior.

Inverse problem of determining time-dependent diffusion coefficient in the time-fractional heat equation

MS14 2
Mon Sep 4
5:00 pm
5:30 pm
VG1.104

D. Serikbaev

Let $\mathcal{H}$ be a separable Hilbert space and let $\mathcal{L}$ be operator with a discrete spectrum on $\mathcal{H}$. For

$$\begin{cases} \mathcal{D}_t^\alpha u(t) + a(t)\mathcal{L}u(t) = f(t) \text{ in } \mathcal{H},\ 0 < t \leqslant T, \\ u(0) = h \text{ in } \mathcal{H}, \end{cases} \tag{1}$$

we study

Coefficient inverse problem: Given $f(t), h$ and $E(t)$, find a pair of functions $\{a(t), u(t)\}$ satisfying the problem (1) and the additional condition

$$F[u(t)] = E(t),\ t \in [0,T],$$

where F is the linear bounded functional.

As for this kind of inverse problem for parabolic equation, see [1]. Under suitable restrictions on the given data, we prove the existence, uniqueness and continuous dependence of the solution on the data.

References

[1] Z. Zhang. An undetermined time-dependent coefficient in a fractional diffusion equation, Inverse Problems and Imaging. 11: 875-900, 2017.

MS06 4
Fri Sep 8
2:30 pm
3:00 pm
VG3.103

Revisiting the Hybrid method for the inverse scattering transmission problem

P. Serranho, J. Paixão

In this talk we will address the numerical solution of the time-harmonic inverse scattering problem for an obstacle with transmission conditions and with given far-field data. To this end we will revisit the ideas of the hybrid method [1,2,3,4,5] that combines the framework of the Kirsch-Kress decomposition method and the iterative Newton-type method.

Instead of linearizing all the equations at once as in [6,7], we will explore the possibility of in a first ill-posed step reconstructing the scattered exterior field and the interior field by imposing the far-field condition and one of the boundary conditions and then in a second step linearizing on the second boundary condition in order to update the approximation of the boundary of the obstacle. The first and second steps are then iterated until some stopping criteria is achieved.

References

[1] R. Kress, P. Serranho. A hybrid method for two-dimensional crack reconstruction, Inverse Probl. 21 (2): 773–784, 2005.

[2] P. Serranho. A hybrid method for inverse scattering for shape and impedance, Inverse Probl. 22 (2): 663–680, 2006.

[3] R. Kress, P. Serranho. A hybrid method for sound-hard obstacle reconstruction, J. Comput. Appl. Math. 204 (2): 418–427, 2007.

[4] P. Serranho. A hybrid method for inverse scattering for Sound-soft obstacles in $\mathbb{R}^3$. Inverse Problems and Imaging. 1(4): 691–712, 2007.

[5] O. Ivanyshyn, R. Kress, P. Serranho. Huygens' principle and iterative methods in inverse obstacle scattering. Adv. Comput. Math. 33 (4): 413–429, 2010.

[6] A. Altundag, R. Kress. An iterative method for a two-dimensional inverse scattering problem for a dielectric. J. Inverse Ill-Posed Probl. 20 (4): 575–590, 2012.

[7] A. Altundag. Inverse obstacle scattering with conductive boundary condition for a coated dielectric cylinder. J. Concr. Appl. Math. 13 ,(1–2): 11–22, 2015.

MS31 1
Fri Sep 8
2:30 pm
3:00 pm
VG3.104

An Intensity-based Inversion Method for Quasi-Static Optical Coherence Elastography

E. Sherina, L. Krainz, S. Hubmer, W. Drexler, O. Scherzer

We consider optical coherence elastography, which is an emerging research field but still lacking precision and reproducibility. Elastography as an imaging modality aims at mapping of the biomechanical properties of a given sample. This problem is widely used in Medicine, in particular for the non-invasive identification of malignant formations inside the human skin or tissue biopsies during surgeries. In term of diagnostics accuracy, one is interested in quantitative values mapped on top of the visualisation of the sample rather then only qualitative images.

In this work, we discuss a general intensity-based approach to the inverse problem of quasi-static elastography, under any deformation model. From a pair of tomographic scans obtained by an imaging modality of choice, e.g. as X-ray, ultrasound, magnetic resonance, optical imaging or other, we aim to recover one or a set of unknown material parameters describing the sample. This approach has been briefly introduced in [1], under the name of intensity-based inversion method, and applied for recovery of the Young's modulus of a set of samples imaged with Optical Coherence Tomography. Here, we mainly focus on investigating the intensity-based inversion approach in the Inverse Problems framework.

Furthermore, we illustrate the performance of the inversion method on twelve silicone elastomer phantoms with inclusions of varying size and stiffness.

References

[1] L. Krainz, E. Sherina, S. Hubmer, M. Liu, W. Drexler, O. Scherzer. Quantitative Optical Coherence Elastography: A Novel Intensity-Based Inversion Method Versus Strain-Based Reconstructions. IEEE J. Sel. Topics Quantum Electron. 29(4): 1-16, 2023. DOI: 10.1109/JSTQE.2022.3225108.

Multi-stage Deep Learning Artifact Reduction for Computed Tomography

MS59 2
Fri Sep 8
4:00 pm
4:30 pm
VG2.103

J. Shi, D. Pelt, J. Batenburg

Computed Tomography (CT) is a challenging inverse problem that involves reconstructing images from projection data. The CT pipeline typically comprises three stages: 1) acquisition of projection images, 2) transposition of projection images into sinogram images, and 3) computation of reconstruction images. In practice, the projection images are often corrupted, resulting in various imaging artifacts such as noise, zinger artifacts, and ring artifacts in the reconstructed images. Although recent deep learning-based methods have shown promise in reducing noise through post-processing of CT images, they struggle to effectively address globally distributed artifacts along with noise.

Classical artifact reduction methods, on the other hand, have demonstrated success in reducing globally distributed artifacts by targeting individual types of artifacts before the reconstruction stage. These methods operate in the natural domain where the artifacts are most prominent. Inspired by that, we propose to reduce artifacts in all projection, sinogram, and reconstruction stages with deep learning. This approach enables accurate reduction of globally distributed artifacts along with noise, leading to improved CT image quality. Experiments on both simulated and real-world datasets validate the effectiveness of our proposed approach.

Fast Principal Component Analysis for Cryo-EM Images

MS26 3
Thu Sep 7
4:30 pm
5:00 pm
VG3.102

N. Marshall, O. Mickelin, Y. Shi, A. Singer

Principal component analysis (PCA) plays an important role in the analysis of cryo-EM images for various tasks such as classification, denoising, compression, and ab-initio modeling. We introduce a fast method for estimating a compressed representation of the 2-D covariance matrix of noisy cryo-electron microscopy projection images that enables fast PCA computation. Our method is based on a new algorithm for expanding images in the Fourier-Bessel basis (the harmonics on the disk), which provides a convenient way to handle the effect of the contrast transfer functions. For N images of size L by L, our method has much lower time and space complexities compared to the previous work. We demonstrate our approach on synthetic and experimental data and show acceleration by factors of up to two orders of magnitude.

Some aspects of the spectrum of the Neumann-Poincaré operator

MS08 2
Fri Sep 8
4:30 pm
5:00 pm
VG2.102

S. Shipman

I will discuss some applications of the spectrum of the Neumann-Poincaré operator.

MS21 1
Tue Sep 5
2:00 pm
2:30 pm
VG2.103

Fractal priors for imaging using random wavelet trees

S. Siltanen

A novel Bayesian prior distribution family is introduced, based on wavelet transforms.The priors correspond to well-defined infinite-dimensional random variables and can be approximated by finite-dimensional models. The non-zero wavelet coefficients are chosen in a systematic way so that prior draws have a specific fractal behaviour. This paves the way for new types of signal and image processing methods that can either promote certain fractal properties in the underlying data, or serve as smart "fingerprints" for measured object types. Realisations of the new priors take values in Besov spaces and have singularities only on a small set with a certain Hausdorff dimension. We also introduce an efficient algorithm for calculating the MAP estimator in the denoising problem.

MS58 1
Tue Sep 5
2:00 pm
2:30 pm
VG2.104

Stokes Traction Method: A Numerical Approach to Volume Constrained Shape Optimization Problems

J. S. H. Simon

Numerically solving shape optimization problems usually takes advantage of the Zolesio-Hadamard form, which writes the shape derivative of the objective function into a boundary integral of the product of the shape grdient and the deformation field. Intuitively, one can choose the deformation field to take the form of the negative of the shape gradient, evaluated on the free boundary, as a gradient descent direction. However, such choice may cause instabilities and oscillations on the free boundary. This issue is a motivation for extending the deformation field to the computational domain in a smooth manner, this method is known as the traction method [1]. In this talk, solenoidal extensions to solve shape optimization problems with volume constraints will be considered. In particular, the deformation field will be extended to the computational domain by solving an incompressible Stokes equations with a Robin data defined as the negative of the shape gradient and the viscosity constant assumed to be sufficiently small. We apply such method to a vorticity maximization problem for the Navier–Stokes equations and compare with it the augmented Lagrangian method used by C. Dapogny et al. [2].

References

[1] H. Azegami, K. Takeuchi. A smoothing method for shape optimization: traction method using the Robin condition, Int J Comput Methods. 3(1): 21–33, 2006.

[2] C. Dapogny, P. Frey, F. Omnès, Y. Privat. Geometrical shape optimization in fluid mechanics using FreeFem++, Struct Multidisciplinary Opt 58(6):2761-2788, 2018.

MS37 1
Thu Sep 7
2:30 pm
3:00 pm
VG1.102

Full-Waveform Inversion and Reverse-Time Migration in Earthquake and Exploration Seismology

F. J. Simons, Q. Liu, Z. Zhang, Z. Liu, E. Bachmann, A. L. Burky, C. Cui, J. C. E. Irving, J. Tromp

In this presentation I will gather an overview of various inverse problems that have arisen in the context of (passive) terrestrial imaging–including but not limited to earthquakes, that is. At the smallest scale, I will discuss a source-encoded crosstalk-free Laplace-domain elastic Full Waveform Inversion (FWI) method that uses time- domain solvers, which cuts down drastically on computation time even for very data rich environments. This technique has been used in medical ultrasound, but also at the scale of the globe, and is now actively being developed for applications in the oil industry. At the regional scale, I will discuss full-waveform centroid moment tensor (CMT) inversion of passive seismic data acquired at the reservoir scale, for a field application in Tajikistan. At the largest scale, I will show how receiver function techniques are being supplemented by new technology to image mantle transition zone (MTZ) discontinuities in three-dimensional (3-D) heterogeneous background Earth models, and I will show new seismic evidence for a 1000 km mid-mantle discontinuity under the Pacific obtained by imaging via full-waveform reverse-time migration of precursors to surface-reflected seismic body waves, and its interpretation.

Efficient Parameter Estimation of Sampled Random Fields

MS44 2
Mon Sep 4
4:00 pm
4:30 pm
VG2.104

F. J. Simons, A. P. Guillaumin, A. M. Sykulski, S. C. Olhede

Describing and classifying the statistical structure of topography and bathymetry is of much interest across the geophysical sciences. Oceanographers are interested in the roughness of seafloor bathymetry as a parameter that can be linked to internal-wave generation and mixing of ocean currents. Tectonicists are searching for ways to link the shape and fracturing of the ocean floor to build detailed models of the evolution of the ocean basins in a plate-tectonic context. Geomorphologists are building time-dependent models of the surface that benefit from sparsely parameterized representations whose evolution can be described by differential equations. Geophysicists seek access to parameterized forms for the spectral shape of topographic or bathymetric loading at various (sub)surface interfaces in order to use the joint structure of topography and gravity for inversions for the effective elastic thickness of the lithosphere. A unified geostatistical framework involves the Matérn process, a theoretically well justified parameterized form for the spectral-domain covariance of Gaussian processes. We provide a computationally and statistically efficient method for estimating the parameters of a stochastic covariance model observed on a regular spatial grid in any number of dimensions. Our proposed method makes important corrections to the well-known Whittle likelihood to account for large sources of bias caused by boundary effects and aliasing. We generalise the approach to flexibly allow for significant volumes of missing data including those with lower-dimensional substructure, and for irregular sampling boundaries. We provide detailed implementation guidelines which maintains the computational scalability of Fourier and Whittle-based methods for large data sets.

Phase retrieval and phaseless inverse scattering with background information

CT02
Wed Sep 6
10:00 am
10:30 am
VG2.105

T. Hohage, R. Novikov, V. Sivkin

We consider the problem of finding a compactly supported potential in the multidimensional Schrodinger equation from its differential scattering cross section (squared modulus of the scattering amplitude) at fixed energy. In the Born approximation this problem simplifies to the phase retrieval problem of reconstructing the potential from the absolute value of its Fourier transform on a ball. To compensate for the missing phase information we use the method of a priori known background scatterers. In particular, we propose an iterative scheme for finding the potential from measurements of a single differential scattering cross section corresponding to the sum of the unknown potential and a known background potential, which is sufficiently disjoint. If this condition is relaxed, then we give similar results for finding the potential from additional monochromatic measurements of the differential scattering cross section of the unknown potential without the background potential. The performance of the proposed algorithms is demonstrated in numerical examples. This talk is based on the work

Hohage, Novikov, Sivkin, preprint 2022, hal-03806616

MS32 2
Thu Sep 7
2:00 pm
2:30 pm
VG1.104

Identification of the electric potential of the time-fractional Schrödinger équation by boundary measurement

É. Soccorsi

This talk deals with the inverse problem of identifying the real valued electric potential of the time-fractional Schrödinger equation, by boundary observation of its solution. Its main purpose is to establish that the Dirichlet-to-Neumann map computed at one fixed arbitrary time uniquely determines the time-independent potential.

MS14 2
Mon Sep 4
5:30 pm
6:00 pm
VG1.104

Determining an Iwatsuka Hamiltonian through quantum velocity measurement

É. Soccorsi

The main purpose of this talk is to explain how quantum currents induced by either the classical or the time-fractional Schrödinger equation, associated with an Iwatsuka Hamiltonian, uniquely determine the magnetic potential.

MS10 4
Fri Sep 8
4:00 pm
4:30 pm
VG1.103

Phase retrieval from overexposed PSFs: theory and practice

O. A. Soloviev

In industrial applications, phase retrieval algorithms can be used to obtain information on optical system misalignment. Because of the specific wavelengths used, often the input data for such algorithms are affected by a high level of noise and quantized with a low bit resolution, and the traditional methods fail to restore the phase accurately. The restoration accuracy can be increased with the presented method of phase retrieval from a (single) overexposed measurement of a point-spread function. We demonstrate that under certain conditions, any projection-based phase retrieval method can be adjusted to accept the input data with the saturated pixels. The modification uses a concept of the clipped set which is able to represent and restore the information lost due to overexposure correctly. With moderate levels of overexposure, the phase restoration accuracy is increased due to the improved signal-to-noise ratio of the PSF. The presentation describes the concept of a clipped set and the procedure of calculating the projection on it and demonstrates the application on the simulated and experimental data.

MS25 2
Mon Sep 4
5:30 pm
6:00 pm
VG0.110

Bayesian sparse optimization for dictionary learning

A. Bocchinfuso, D. Calvetti, E. Somersalo

Dictionary learning methods have been used in recent years to solve inverse problems without using the forward model in the traditional optimization algorithms. When the dictionaries are large, and a sparse representation of the data in terms of the atoms is desired, computationally efficient sparse optimization algorithms are needed. Furthermore, reduced dictionaries can represent the data only up to a model reduction error, and Bayesian methods for estimating modeling errors turn out to be useful in this context. In this talk, the ideas of using Bayesian hierarchical models and modeling error methods are discussed.

Edge-preserving inversion with α-stable priors

MS21 2
Tue Sep 5
5:00 pm
5:30 pm
VG2.103

J. Suuronen, T. Soto, N. Chada, L. Roininen

The α-stable distributions are a family of heavy-tailed and infinitely divisible distributions that are well-suited to edge-preserving inversion in the context of discretization of infinite-dimensional continuous-time statistical inverse problems. In this talk we discuss some of the technical issues arising from the application of such priors.

Imaging valence and excited states of fullerenes in momentum space

MS15 1
Mon Sep 4
1:30 pm
2:00 pm
VG1.102

B. Stadtmüller, M. Aeschlimann

One of the key milestones in advancing the performance of molecular electronic and photonic devices is to gain a comprehensive understanding of the electronic properties and rich excited state dynamics of this class of materials. In this context, momentum-resolved photoemission in combination with photoemission orbital tomography (POT) has been established as a powerful tool to study the band structure of molecular films and to reveal the degree of localization of molecular valence orbitals by their characteristic emission pattern in momentum space.

In this contribution, we exploit these capabilities of POT to study the valence and excited states of fullerenes grown on noble metal surfaces. For the most prototypical fullerene, the buckyball C_{60}, we will show that the valence states show signatures of an atomic crystal-like band structure with delocalized π- and localized σ-orbitals [1]. This observation differ significantly from our results for thin films of the endohedral fullerene $Sc_3N@C_{80}$, where the valence states are strongly localized on the carbon cage of the molecules.

Finally, we provide a first insight into the momentum space signatures of the excited state dynamics of C_{60} thin films obtained by time-resolved two-photon momentum microscopy. For an optical excitation with 3.1 eV photons, we are able to identify three characteristic emission patterns even in the small momentum space range accessible by our experiment. These signatures are discussed in the context of the recently proposed charge transfer and Frenkel exciton character of these states [2].

References

[1] N. Haag, D. Lüftner, F. Haag, J. Seidel, L. Kelly, G. Zamborlini, M. Jugovac, V. Feyer, M. Aeschlimann, P. Puschnig, M. Cinchetti, B. Stadtmüller. Signatures of an atomic crystal in the band structure of a C60 thin film, Phys. Rev. B 101, 2020.

[2] B. Stadtmüller, S. Emmerich, D. Jungkenn, N. Haag, M. Rollinger, S. Eich, M. Maniraj, M. Aeschlimann, M. Cinchetti, S. Mathias. Strong modification of the transport level alignment in organic materials after optical excitation, Nat. Commun. 10, 2019.

MS13 2
Fri Sep 8
4:00 pm
4:30 pm
VG0.111

From inexact optimization to learning via gradient concentration

B. Stankewitz, **N. Mücke**, **L. Rosasco**

Optimization in machine learning typically deals with the minimization of empirical objectives defined by training data. The ultimate goal of learning, however, is to minimize the error on future data (test error), for which the training data provides only partial information. In this view, the optimization problems that are practically feasible are based on inexact quantities that are stochastic in nature. In this paper, we show how probabilistic results, specifically gradient concentration, can be combined with results from inexact optimization to derive sharp test error guarantees. By considering unconstrained objectives, we highlight the implicit regularization properties of optimization for learning.

MS05 1
Wed Sep 6
10:00 am
10:30 am
VG2.102

Early stopping for L^2-boosting in high-dimensional linear models

B. Stankewitz

We consider L^2-boosting in a sparse high-dimensional linear model via orthogonal matching pursuit (OMP). For this greedy, nonlinear subspace selection procedure, we analyze a data-driven early stopping time τ, which is sequential in the sense that its computation is based on the first τ iterations only. Our approach is substantially less costly than established model selection criteria, which require the computation of the full boosting path.

We prove that sequential early stopping preserves statistical optimality in this setting in terms of a general oracle inequality for the empirical risk and recently established optimal convergence rates for the population risk. The proofs include a subtle ω-pointwise analysis of a stochastic bias-variance trade-off, which is induced by the greedy optimization procedure at the core of OMP. Simulation studies show that, at a significantly reduced computational cost, these types of methods match or even exceed the performance of other state of the art algorithms such as the cross-validated Lasso or model selection via a high-dimensional Akaike criterion based on the full boosting path.

MS52 1
Mon Sep 4
2:00 pm
2:30 pm
VG1.105

The Lorentzian scattering rigidity problem and rigidity of stationary metrics

P. Stefanov

We study scattering rigidity in Lorentzian geometry: recovery of a Lorentzian metric from the scattering relation $\mathcal{S}$ known on a lateral boundary. We show that, under a non-conjugacy assumption, every defining function $r(x, y)$ of the submanifold of pairs of boundary points which can be connected by a lightlike geodesic plays the role of the boundary distance function in the Riemannian case in the following sense. Its linearization is the light ray transform of tensor fields of order two which are the perturbations of the metric. Next, we study scattering rigidity of stationary metrics in time-space cylinders and show that it can be reduced to boundary rigidity of magnetic systems on the base; a problem studied previously. This implies several scattering rigidity results for stationary metrics.

Weakly nonlinear geometric optics and inverse problems for hyperbolic nonlinear PDEs

MS46 1
Thu Sep 7
4:00 pm
4:30 pm
VG1.104

P. Stefanov

We review recent results by the presenter, Antônio Sá Barreto, and Nikolas Eptaminitakis about inverse problems for the semilinear wave equation and the quasilinear Westervelt wave equation modeling nonlinear acoustic. We study them in a regime in which the solutions are not "small" so that we can linearize; when the nonlinear effects are strong and correspond to the observed phyisical effects. We show that a propagating high frequency pulse recovers the nonlinearity uniquely by recovering its X-ray transform, and we will show numerical simulations.

The inverse spectral problem for a spherically symmetric refractive index using modified transmission eigenvalues

MS29 2
Mon Sep 4
5:30 pm
6:00 pm
VG3.104

D. Gintides, N. Pallikarakis, K. Stratouras

In recent years, the classic transmission eigenvalue problem has risen in importance in inverse scattering theory. In this work, we discuss the introduction of a modification that corresponds to an artificial metamaterial background [1] and pose the inverse problem for determining a spherically symmetric refractive index from these modified eigenvalues. We show that uniqueness can be established under some assumptions for the magnitude of a fixed wavenumber and the unknown refractive index [2].

References

[1] D. Gintides, N. Pallikarakis, K. Stratouras. On the modified transmission eigenvalue problem with an artificial metamaterial background, Res. Math. Sci. 8, 2021.

[2] D. Gintides, N. Pallikarakis, K. Stratouras. Uniqueness of a spherically symmetric refractive index from modified transmission eigenvalues, Inverse Problems 38, 2022.

Concentration analysis of multivariate elliptic diffusions

MS04 1
Tue Sep 5
2:00 pm
2:30 pm
VG2.102

C. Aeckerle-Willems, C. Strauch, L. Trottner

We prove concentration inequalities and associated PAC bounds for continuous- and discrete-time additive functionals for possibly unbounded functions of multivariate, nonreversible diffusion processes. Our analysis relies on an approach via the Poisson equation, which allows us to consider a very broad class of subexponentially ergodic processes. These results add to existing concentration inequalities for additive functionals of diffusion processes which have so far been only available for either bounded functions or for unbounded functions of processes from a significantly smaller class. We demonstrate the usefulness of the results by applying them in the context of high-dimensional drift estimation and Langevin MCMC for moderately heavy-tailed target densities.

One-step estimation of spectral optical parameters in quantitative photoacoustic tomography

CT09
Thu Sep 7
5:00 pm
5:30 pm
VG2.107

M. Suhonen, A. Pulkkinen, T. Tarvainen

In quantitative photoacoustic tomography, information about a target tissue is obtained by estimating its optical parameters. In this work, we propose a one-step methodology for estimating spectral optical parameters directly from photoacoustic time-series data. This is carried out by representing the optical parameters with their spectral models and by combining the models of light and ultrasound propagation. The inverse problem is approached in the framework of Bayesian inverse problems. Concentrations of four chromophores, two scattering related parameters, and the Grüneisen parameter are estimated simultaneously. The methodology is evaluated using numerical simulations.

MS56 2
Mon Sep 4
4:00 pm
4:30 pm
VG2.106

Reconstruction of the doping profile in Vlasov-Poisson

W. Sun, R.-y. Lai, Q. Li

In this talk we show how the singular decomposition method can be applied to recover the doping profile in the Vlasov-Poisson equation.

MS44 2
Mon Sep 4
5:00 pm
5:30 pm
VG2.104

Transdimensional joint inversion of gravity and surface wave phase velocities

W. Szwillus

A fundamental choice for any geophysical inversion is the parametrization of the subsurface. Voxels and coefficients of basis functions (i.e., spherical harmonics) often are a natural choice, especially since they can simplify forward calculations. An alternative approach is to use a finite collection of discrete anomalies, which leads to transdimensional (TD) techniques, when considered through a Bayesian lens. The most popular form of TD inversion uses a variable number of Voronoi cells as spatial representation. The TD approach addresses the issues of non-uniqueness and lack of resolution in a special way: Instead of smoothing or damping the solutions, the spatial structure of the model is controlled by weighing the number of elements against the achieved data fit. This gives it an intrinsic adaptive behaviour, useful for heterogeneous data coverage. Furthermore, geophysical sensitivity often changes with depth, which TD approaches can also adapt to. In a joint inversion context for several properties (like seismic velocities and densities), spatial coupling between different sought parameters is automatically guaranteed.

In this contribution I will present some examples for using TD inversions on global gravity and surface wave data to simultaneously determine the velocity and density structure within the Earth's mantle.

CT04
Thu Sep 7
2:00 pm
2:30 pm
VG2.104

Lipschitz stability for inverse source problems of waves on Lorentzian manifolds

H. Takase

We consider an inverse problem of the wave equation on a Lorentzian manifold, a type of semi-Riemannian manifold. This kind of equation is obtained by linearizing the Einstein equation and is known as the equation satisfied by gravitational waves. In this talk, we prove a global Lipschitz stability for the inverse source problem of determining a source term in the equation. Sobolev spaces on manifolds, semigeodesic coordinates, and Carleman estimates, which are important tools in geometric analysis, will also be discussed.

Bayesian modelling and inference for radiation source localisation

MS43 1
Mon Sep 4
2:00 pm
2:30 pm
VG1.108

C. Tarpau, M. Fang, Y. Altmann, A. Di Fulvio, M. Pereyra, K. Zygalakis

In this work, we study a Compton Imager, made of an array of scintillation crystals. This imaging system differs from a more classical Compton camera since the sensor array acts simultaneously as a set of scatterers and absorbers. From the recorded data, the objective is to localize the positions of point-like sources responsible for the emission of the measured radiation. The inverse problem is formulated within a Bayesian framework, and a Markov chain Monte Carlo method is investigated to infer the source locations.

Utilising Monte Carlo method for light transport in the inverse problem of quantitative photoacoustic tomography

MS05 2
Thu Sep 7
1:30 pm
2:00 pm
VG2.102

T. Tarvainen, N. Hänninen, A. Pulkkinen, S. Arridge

We study the inverse problem of quantitative photoacoustic tomography in a situation where the forward operator is stochastic. In the approach, Monte Carlo method for light transport is used to simulate light propagation in the imaged target. Monte Carlo method is based on random sampling of photon paths as they propagate in the medium. In the inverse problem, MAP estimates for absorption and scattering are computed, and the reliability of the estimates is evaluated. Now, due to the stochastic nature of the forward operator, also the search direction of the optimization algorithm for solving the MAP estimates is stochastic. An adaptive approach for controlling the number of simulated photons during the iteration is studied.

Imaging molecular wave functions with photoemission orbital tomography: An introduction

MS15 1
Mon Sep 4
2:00 pm
2:30 pm
VG1.102

F. S. Tautz

The photoemission orbital tomography (POT) technique, a variant of angle-resolved photoemission spectroscopy, has been very useful in the characterization of the electronic properties of molecular films. It is a combined experimental and theoretical approach that is based on the interpretation of the photoelectron angular distribution in terms of a one-electron initial state. This includes the unambiguous assignment of emissions to specific molecular orbitals, their reconstruction to real space orbitals in two and three dimensions, the deconvolution of complex spectra into individual orbital contributions beyond the limits of energy resolution, the extraction of detailed geometric information such as molecular orientations, twists and bends, the precise description of the charge balance and transfer at interface, and the detection of momentum-selective hybridization with the substrate, to name only a few examples. In its simplest form, POT relies on the plane-wave approximation for the final state. While this works surprisingly well in many cases, this approximation does have its limitations, most notably for small molecules and with respect to the photon-energy dependence of the photoemission intensity. Regarding the latter, a straightforward extension of the plane wave final state leads to a much-improved description while preserving the simple and intuitive connection between the photoelectron distribution and the initial state.

MS47 2
Tue Sep 5
4:30 pm
5:00 pm
VG3.101

Optimal parameter design for spectral CT

F. Terzioglu, G. Bal, E. Sidky

Spectral CT is an x-ray transmission imaging technique that uses the energy dependence of x-ray photon attenuation to determine elemental composition of an object of interest. Mathematically, forward spectral CT measurements are modeled by a nonlinear integral transform for which no analytical inversion is available. In this talk, I will present some of our recent results on the global uniqueness and the stability of spectral CT reconstructions. These analyses are useful for designing optimal scan parameters, which will be demonstrated using numerical simulations. This is joint work with G. Bal and E. Sidky.

MS43 1
Mon Sep 4
3:00 pm
3:30 pm
VG1.108

Exact inversion of an integral transform arising in passive detection of gamma-ray sources with a Compton camera

F. Terzioglu

This talk addresses the overdetermined problem of inverting the n-dimensional cone (or Compton) transform that integrates a function over conical surfaces in $\mathbb{R}^n$. The study of the cone transform originates from Compton camera imaging, a nuclear imaging method for the passive detection of gamma-ray sources. We present a new identity relating the n-dimensional cone and Radon transforms through spherical convolutions with arbitrary weight functions. This relationship leads to various inversion formulas in n-dimensions under a mild assumption on the geometry of detectors. We present two such formulas along with the results of their numerical implementation using synthetic phantoms.

MS51 1
Thu Sep 7
3:00 pm
3:30 pm
VG1.108

Inference in Stochastic Differential Equations using the Laplace Appromixation

U. H. Thygesen

We consider the problem of estimation of solutions to systems of coupled stochastic differential equations, as well as underlying system parameters, based on discrete-time measurements. We concentrate on the case where transition densities are not available in closed form, and focus on the technique of the Laplace approximation for integrating out unobserved state variables in a Bayesian setting. We demonstrate that the direct approach of inserting sufficiently many time points with unobserved states performs well, when the noise is additive. A pitfall arises when the noise intensity in the state equation depends on state variables, i.e., when the noise is not additive: In this case, maximizing the posterior density over unobserved states does not lead to useful state estimates (i.e., they are not consistent in the fine-time limit). This problem can be overcome by focusing in stead on the minimum-energy realization of the noise process which is consistent with data, which provides a connection to calculus of variations. We demonstrate the theory with numerical examples.

Stochastic optimization for high-resolution refinement in cryo-EM

MS26 3
Thu Sep 7
4:00 pm
4:30 pm
VG3.102

B. Toader, M. A. Brubaker, R. R. Lederman

Cryo-EM reconstruction with traditional iterative algorithms is often split into two separate stages: ab initio, where an initial estimation of the volume and the pose variables are estimated, and high-resolution refinement, where a high-resolution volume is obtained using local optimization. While state-of-the-art results for high-resolution refinement are obtained using the Expectation-Maximization algorithm, this requires marginalization over the pose variables for all the 2D particle images at each iteration. In contrast, ab initio reconstruction is often performed using a variation of the stochastic gradient descent algorithm, which only uses a subset of the data at each iteration. In this talk, we present an approach that has the potential to enable the use of stochastic optimization algorithms for high-resolution refinement with improved running time. We present an analysis related to the conditioning of the problem that motivates our approach and show preliminary numerical results.

Scattering of electromagnetic waves by small obstacles

MS57 2
Mon Sep 4
5:30 pm
6:00 pm
VG3.102

S. Tordeux

We develop fast, accurate and efficient numerical methods for solving the time harmonic scattering problem of electromagnetic waves in 3D by a multitude of obstacles for low and medium frequencies. Taking into account a large number of heterogeneities can be costly in terms of computation time and memory usage, particularly in the construction process of the matrix. We consider a multi-scale diffraction problem in low-frequency regimes in which the characteristic length of the obstacles is small compared to the incident wavelength. We use the matched asymptotic expansion method which allows for the model reduction. Two types of approximations are distinguished : near-field or quasi-static approximations that descibe the phenomenon at the microscopic scale and far-field approximations that describe the phenomenon at a long distance. In the latter one, small obstacles are no longer considered as geometric constraintsand can be modelled by equivalent point-sources which are interpreted in terms of electromagnetic multipoles.

References

[1] J. Labat, V. Péron, S. Tordeux. Equivalent multipolar point-source modeling of small spheres for fast and accurate electromagnetic wave scattering computations, Wave Motion 92: 102409, 2020.

Inverse scattering problems for semi-linear wave equations on manifolds

MS46 2
Fri Sep 8
2:30 pm
3:00 pm
VG1.104

T. Tyni, S. Alexakis, H. Isozaki, M. Lassas

We discuss some recent results on inverse scattering problems for semi-linear wave equations. The inverse scattering problem is formulated on a Lorentzian manifold equipped with a Minkowski type infinity. We show that a scattering functional, which roughly speaking maps measurements of solutions of a semi-linear wave equation at the past infinity to the future infinity, determines the manifold, the conformal class of the metric, and the nonlinear potential function up to a gauge. The main tools we employ are a Penrose-type conformal compactification of the Lorentzian manifold, reduction of the scattering problem to the study of the source-to-solution operator, and the use of higher order linearization method to exploit the nonlinearity of the wave equation.

This is a joint work with S. Alexakis, H. Isozaki, and M. Lassas.

MS36 2
Thu Sep 7
5:30 pm
6:00 pm
VG3.101

Limited-Angle Tomography Reconstruction via Deep Learning on Synthetic Data

T. Germer, J. Robine, S. Konietzny, S. Harmeling, T. Uelwer

Computed tomography (CT) has become an essential part of modern science. A CT scanner consists of an X-ray source that is spun around an object of interest. On the opposite end of the X-ray source a detector captures X-rays that are not absorbed by the object. The reconstruction of an image is a linear inverse problem which is usually solved by the filtered back projection algorithm. However, when the number of measurements is too small the reconstruction problem is highly ill-posed. This is for example the case when the X-ray source is not spun completely around the object, but rather irradiates the object only from a limited angle. To tackle this problem, we present a deep neural network that performs limited-angle tomography reconstruction. The model is trained on a large amount of carefully-crafted synthetic data. Our approach won the first place in the Helsinki Tomography Challenge 2022.

MS18 1
Mon Sep 4
2:00 pm
2:30 pm
VG1.103

Nonlocality Helps

G. Uhlmann

We give several examples of solutions inverse problems involving lon-range interactions whosecorresponding local problem is not solved.

MS14 1
Mon Sep 4
2:00 pm
2:30 pm
VG1.104

Identification of the time-dependent part of a heat source in thermoelasticity

K. Van Bockstal, L. Marin

The isotropic thermoelasticity system of type-III, describing the mechanical and thermal behaviours of a body occupying a bounded domain with a Lipschitz boundary, is considered. The displacement vector and either the normal heat flux or the temperature are prescribed on the boundary.

This talk deals with the theoretical and numerical reconstruction of a time-dependent heat source from the knowledge of an additional weighted integral measurement of the temperature in the framework mentioned above. Firstly, it is proved that the measurement type depends on the available thermal boundary condition, expressed by different conditions on the associated weight function. Secondly, for both thermal boundary conditions, the existence of a unique weak solution for exact data is proved, which is achieved by employing Rothe's method. This approach has the advantage of including a time-discrete numerical scheme for computations. Hence, for each of the two inverse source problems considered in this talk, a numerical algorithm that builds upon a decoupling technique is proposed, and the convergence of these numerical schemes is proved for exact data. Furthermore, the uniqueness of a solution is obtained by using an energy estimate. Finally, using the finite element method, the numerical results obtained for various numerical examples with noisy measurements are presented to validate the convergence and stability of the proposed algorithms. The noisy data are regularised using the nonlinear least-squares method; hence, they can be used as input for the proposed numerical scheme.

The results presented in this talk are published in [1].

References

[1] K. Van Bockstal, L. Marin. Finite element method for the reconstruction of a time-dependent heat source in isotropic thermoelasticity systems of type-III, Zeitschrift für angewandte Mathematik und Physik 73, 2022.

Reconstruction of anisotropic stiffness tensors using algebraic geometry

MS41 1
Fri Sep 8
3:00 pm
3:30 pm
VG3.101

M. de Hoop, J. Ilmavirta, M. Lassas, A. Varilly-Alvarado

Stiffness tensors serve as a fingerprint of a material. We describe how to harness anisotropy, using standard tools from algebraic geometry (e.g., generic geometric integrality, upper-semicontinuity of some standard functions, and Gröbner bases) to uniquely reconstruct the stiffness tensor of a general anisotropic material from an analytically small neighborhood of its corresponding slowness surface.

Quantitative Parameter Reconstruction from Optical Coherence Tomographic Data

MS16 2
Thu Sep 7
5:00 pm
5:30 pm
VG0.111

L. Veselka, W. Drexler, P. Elbau, L. Krainz

Optical Coherence Tomography (OCT), an imaging modality based on the interferometric measurement of back-scattered light, is known for its high-resolution images of biological tissues and its versatility in medical imaging. Especially in its main field of application, ophthalmology, the continuously increasing interest in OCT, aside from improving image quality, has driven the need for quantitative information, like optical properties, for a better medical diagnosis. In this talk, we discuss the quantification of the refractive index, an optical property which describes the change of wavelength between different materials, from OCT data. The presented method is based on a Gaussian beam forward model, resembling the strongly focused laser light typically used within an OCT setup. Samples with layered structure are considered, meaning that the refractive index as a function of depth is well approximated by a piece-wise constant function. For the reconstruction, a layer-by-layer method is presented where in every step the refractive index is obtained via a discretized L^2-minimization. The applicability of the proposed method is then verified by reconstructing refractive indices of layered media from both simulated and experimental OCT data.

Passive Gamma Emission Tomography (PGET) of spent nuclear fuel

MS43 1
Mon Sep 4
1:30 pm
2:00 pm
VG1.108

R. Virta, T. A. Bubba, M. Moring, S. Siltanen, T. Honkamaa, P. Dendooven

The world's first deep underground repository for spent nuclear fuel will soon start operations in Eurajoki, Finland. Disposal tunnels have been excavated 430 meters below the ground surface in bedrock, and the spent nuclear fuel will be placed in deposition holes in copper canisters. After the fuel is disposed of, it will be practically unreachable

[1]. For safeguarding nuclear material, all fuel items need to be reliably verified prior to disposal in the geological repository. Fuel assembly integrity is investigated to make sure all nuclear material stays in peaceful use.

Passive Gamma Emission Tomography (PGET) is a non-destructive assay method that allows for accurate 2D slice images of the fuel assembly to be reconstructed. Fuel assembly types we have studied are rectangular or hexagonal objects, about 4 meters long and about 15 cm in diameter, consisting of a bunch of 63-126 individual fuel rods in a fixed geometric arrangement. Spent nuclear fuel emits gamma-rays at a very high rate and with specific energies, providing a method to verify the presence of fuel rods in the assemblies. Gamma emission data is collected with the torus-shaped PGET device which has two highly collimated CdZnTe gamma detector banks that rotate a full 360 degree around the fuel assembly, which is placed in the central hole of the device. Gamma-rays are significantly attenuated in the fuel material, and thus the attenuation map of the object is reconstructed simultaneously with the activity map. The mathematical approach to this unique inverse problem is described in another presentation in this minisymposium, while the context of the method and the measurements are presented in more detail in this contribution [2,3].

During 2017-2022, over 100 spent nuclear fuel assemblies have been measured at the Finnish nuclear power plants with the PGET method [3,4]. The imaged fuel has had a range of characteristics and 10 different geometrical types. The measurement campaigns have concentrated on refining the measurement parameters for improving detection of possible empty rod positions. Data acquisition gamma energy windows have been fine-tuned, different sets of angles out of the full 360 angle data have been used in the reconstructions and different methods for quantitatively investigating the image quality have been developed. Even the use of less abundant but higher-energy and higher-penetrating gamma-rays were investigated to improve the detection of missing rods in the central parts of the fuel.

The PGET method has shown to detect individual missing rods with high confidence and has even demonstrated the ability to reproduce intra-rod activity differences. We have also shown that the method is able to distinguish activity differences in the axial direction of the fuel, which we show with a set of axial measurements conducted over a fuel assembly with partial-length fuel rods.

A variety of results from the measurement campaigns will be presented, illustrating the usability of the method for safeguards purposes in the Finnish context.

References

[1] www.posiva.fi

[2] R. Backholm, T. A. Bubba, C. Bélanger-Champagne, T. Helin, P. Dendooven, S. Siltanen. Simultaneous reconstruction of emission and attenuation in passive gamma emission tomography of spent nuclear fuel, Inv. Probl. Imag. 14: 317-337, 2020.

[3] P. Dendooven, T.A. Bubba. Gamma ray emission imaging in the medical and nuclear safeguards fields, Lecture Notes in Physics 1005: 245-295, 2022.

[4] R. Virta, R. Backholm, T. A. Bubba, T. Helin, M. Moring, S.Siltanen, P. Dendooven, T. Honkamaa. Fuel rod classification from Passive Gamma Emission Tomography (PGET) of spent nuclear fuel assemblies, ESARDA Bulletin 61: 10-21, 2020.

[5] R. Virta, T. A. Bubba, M. Moring, S. Siltanen, T. Honkamaa, P. Dendooven. Improved Passive Gamma Emission Tomography image quality in the central region of spent nuclear fuel, Scientific Reports 12: 12473, 2022.

Optimal learning of high-dimensional classification problems using deep neural networks

MS21 2
Tue Sep 5
5:30 pm
6:00 pm
VG2.103

F. Voigtlaender

We study the problem of learning classification functions from noiseless training samples, under the assumption that the decision boundary is of a certain regularity. We establish universal lower bounds for this estimation problem, for general classes of continuous decision boundaries. For the class of locally Barron-regular decision boundaries, we find that the optimal estimation rates are essentially independent of the underlying dimension and can be realized by empirical risk minimization methods over a suitable class of deep neural networks. These results are based on novel estimates of the L^1 and L^∞ entropies of the class of Barron-regular functions.

This is joint work with Philipp Petersen (University of Vienna).

Principal component analysis in infinite dimensions

MS13 2
Fri Sep 8
4:30 pm
5:00 pm
VG0.111

M. Wahl

In high-dimensional settings, principal component analysis (PCA) reveals some unexpected phenomena, ranging from eigenvector inconsistency to eigenvalue (upward) bias. While such high-dimensional phenomena are now well understood in the spiked covariance model, the goal of this talk is to present some extensions for the case of PCA in infinite dimensions. As an application, we present bounds for the prediction error of spectral regularization estimators in the overparametrized regime.

Reconstruction of active forces in actomyosin droplets

MS05 3
Thu Sep 7
5:00 pm
5:30 pm
VG2.102

A. Wald, E. Klass

Many processes in cells are driven by the interaction of multiple proteins, for example cell contraction, division or migration. Two important types of proteins are actin filaments and myosin motors. Myosin is able to bind to and move along actin filaments with its two ends, leading to the formation of a dynamic actomyosin network, in which stresses are generated and patterns may form. Droplets containing an actomyosin network serve as a strongly simplified model for a cell, which are used to study elemental mechanisms. We are interested in determining the parameters that characterize this active matter, i.e., active forces that cause the dynamics of an actomyosin network, represented by the flow inside the actomyosin droplet, as well as the local viscosity. This leads to a (deterministic) parameter identification problem for the Stokes equation, where the viscosity inside the droplet can be estimated by means of statistical approaches.

New approaches for reconstruction in dynamic nano-CT imaging

MS40
Tue Sep 5
2:30 pm
3:00 pm
VG2.107

A. Wald, B. Ehlers, A. Oberacker, B. Hahn-Rigaud, T. Salditt, J. Lucht

Tomographic X-ray imaging on the nano-scale is an important tool to visualize the structure of materials such as alloys or biological tissue. Due to the small scale on which the data acquisition takes place, small perturbances caused by the environment become significant and cause a motion of the object relative to the scanner during the scan. Since this motion is hard to estimate and its incorporation into the reconstruction process strongly increases the numerical effort, we aim at a different approach for a stable reconstruction: We interpret the object motion as a modelling inexactness in comparison to the model in the static case. This inexactness is estimated and included in an iterative regularization scheme called sequential subspace optimization. Data-driven techniques are investigated to estimate the modelling error and to improve the obtained reconstructions.

MS57 1
Mon Sep 4
2:00 pm
2:30 pm
VG3.102

A new approach to an inverse source problem for the wave equation

M. Sini, H. Wang

Consider an inverse problem of reconstructing a source term from boundary measurements for the wave equation. We propose a novel approach to recover the unknown source through measuring the wave fields after injecting small particles, enjoying a high contrast, into the medium. For this purpose, we first derive the asymptotic expansion of the wave field, based on the time-domain Lippmann-Schwinger equation. The dominant term in the asymptotic expansion is expressed as an infinite series in terms of the eigenvalues of the Newtonian operator (for the pure Laplacian). Such expansions are useful under a certain scale between the size of the particles and their contrast. Second, we observe that the relevant eigenvalues appearing in the expansion have non-zero averaged eigenfunctions. By introducing a Riesz basis, we reconstruct the wave field, generated before injecting the particles, on the center of the particles. Finally, from these last fields, we reconstruct the source term. A significant advantage of our approach is that we only need the measurements for a single point away from the support of the source.

MS53
Wed Sep 6
9:30 am
10:00 am
VG3.104

Refined instability estimates for two inverse problems

J.-N. Wang

Many inverse problems are known to be ill-posed. The ill-posedness can be manifested by an instability estimate of exponential type, first derived by Mandache. Inspired by Mandache's idea, in this talk, I would like to refinements of the instability estimates for two inverse problems, including the inverse inclusion problem and the inverse scattering problem. The aim is to derive explicitly the dependence of the instability estimates on key parameters.

The first topic of this talk is to show how the instability depends on the depth of the hidden inclusion and the conductivity of the background medium. The second topic is to justify the optimality of increasing stability in determining the near-field of a radiating solution of the Helmholtz equation from the far-field pattern.

MS46 1
Thu Sep 7
4:30 pm
5:00 pm
VG1.104

Identification of nonlinear effects in X-ray tomography

Y. Wang

Due to beam-hardening effects, metal objects in X-ray CT often produce streaking artefacts which cause degradation in image reconstruction. It is known that the nature of the phenomena is nonlinear. An outstanding inverse problem is to identify the nonlinearity which is crucial for reduction of the artefacts. In this talk, we show how to use microlocal techniques to extract information of the nonlinearity from the artefacts. An interesting aspect of our analysis is to explore the connection of the artefacts and the geometry of metal objects.

Laplace priors and spatial inhomogeneity in Bayesian inverse problems

MS04 2
Tue Sep 5
5:00 pm
5:30 pm
VG2.102

S. Wang, S. Agapiou

Spatially inhomogeneous functions, which may be smooth in some regions and rough in other regions, are modelled naturally in a Bayesian manner using so-called Besov priors which are given by random wavelet expansions with Laplace-distributed coefficients. This talk considers frequentist theoretical guarantees for Bayes methods with Besov priors, in the setting of non-linear inverse problems with Gaussian white noise. Our results are first derived under a general local Lipschitz assumption on the forward map. We then verify the assumption for two non-linear inverse problems arising from elliptic partial differential equations. We also discuss novel convergence rate results for penalized least squares estimators with ℓ_1 wavelet penalty, which have a natural interpretation as maximum a posteriori (MAP) estimators. The true parameter is assumed to belong to some spatially inhomogeneous Besov class. In a setting with direct observations, we complement these upper bounds with a lower bound on the rate of contraction for arbitrary Gaussian priors. Consequently, while Laplace priors can achieve minimax-optimal rates over spatially inhomogeneous classes, Gaussian priors are limited to a (by a polynomial factor) slower contraction rate. This gives information-theoretical justification for the intuition that Laplace priors are more compatible with ℓ_1 regularity structure in the underlying parameter.

Hybrid Inverse Problems for Nonlinear Elasticity

MS31 1
Fri Sep 8
1:30 pm
2:00 pm
VG3.104

A. Waters, H. Carrillo-Lincopi

We consider the Saint-Venant model in 2 dimensions for nonlinear elasticity. Under the hypothesis the fluid is incompressible, we recover the displaced field and the Lame parameter μ from power density measurements. A stability estimate is shown to hold for small displacement fields, under some natural hypotheses on the direction of the displacement. The techniques introduced show the difficulties of using hybrid imaging techniques for non-linear inverse problems.

On a cylindrical scanning modality in three-dimensional Compton scatter tomography

MS47 3
Wed Sep 6
9:30 am
10:00 am
VG3.101

J. Webber

We present injectivity and microlocal analyses of a new generalized Radon transform, R, which has applications to a novel scanner design in 3-D Compton Scattering Tomography (CST), which we also introduce here. Using Fourier decomposition and Volterra equation theory, we prove that R is injective and show that the image solution is unique. Using microlocal analysis, we prove that R satisfies the Bolker condition (sometimes called the “Bolker assumption”), and we investigate the edge detection capabilities of R. This has important implications regarding the stability of inversion and the amplification of measurement noise. This paper provides the theoretical groundwork for 3-D CST using the proposed scanner design.

MS19 2
Tue Sep 5
4:30 pm
5:00 pm
VG3.103

Vectorized Hankel Lift: A Convex Approach for Blind Super-Resolution of Point Sources

K. Wei

Blind super-resolution is the problem of estimating high-resolution information about a signal from its low-resolution measurements when the point spread functions (PSFs) are unknown. It is a common problem in many scientific and engineering research areas, such as machine learning, signal processing, and computer vision. Blind super-resolution can be cast as a low-rank matrix recovery problem by exploiting the inherent simplicity of the signal and the low-dimensional structure of the PSFs.

In this talk, we will discuss the low-rank matrix recovery problem for blind super-resolution of point sources. The target matrices associated with these problems are not only low rank but also highly structured. Convex approaches are proposed for the corresponding low-rank matrix recovery problems. Theoretical guarantees are established showing that near-optimal sample complexity is sufficient for successful recovery.

MS28 1
Tue Sep 5
2:00 pm
2:30 pm
VG1.108

A Bregman-Kaczmarz method for nonlinear systems of equations

M. Winkler

We propose a new randomized method for solving systems of nonlinear equations, which can find sparse solutions or solutions under certain simple constraints. The scheme only takes gradients of component functions and uses exact or relaxed Bregman projections onto the solution space of a Newton equation. As such, it generalizes the Sparse Kaczmarz method which finds sparse solutions to linear equations, as well as the nonlinear Kaczmarz method, which performs euclidean projections. The relaxed Bregman projection is achieved by using the step size from the nonlinear Kaczmarz method. Local convergence is established for systems with full rank Jacobian under the local tangential cone condition. We show examples in which the proposed method outperforms similar methods with the same memory requirements.

MS01
Wed Sep 6
10:30 am
11:00 am
VG1.102

Deceptive performance of artificial neural networks in semantic segmentation tasks on the example of lung delineation

M. Wittig

The presentation focuses on a critical analysis of the performance of artificial neural networks (ANNs) in the context of semantic segmentation of organs as reported in scientific reports. In recent years, extensive research has been performed on combining loss functions and developing non-trainable layers for ANNs in order to optimize the boundary regions of semantic segmentation. These boundaries are particularly crucial for various segmentation tasks such as the detection of water retention in the lungs for COVID-19 diagnosis, the localization of organs at risk in radiotherapy treatment planning or the identification of white matter hyperintensities in the brain. With the U-Net, Ronneberger et al. have designed a powerful network architecture for any type of segmentation task. With a reported IOU (intersection over union) of 92% and 77.5% for the datasets used in the original work, respectively, it was far superior to the follow-up network. On this basis, U-Net was used for many segmentation tasks in the following years. In the field of semantic organ segmentation, the U-Net and U-Net-like artificial neural networks achieved very high accuracies. Since then, the reported accuracy has hardly improved. However, the underlying calculation of accuracy is misleading, as the improvements in recent years have been aimed at improving boundary regions, but these are usually unfavourably proportionate to the inner area.Hence, improvements in boundary segmentation accuracy has only a marginal impact on the overall accuracy. To illustrate this, we will look at the reported performance and improvements of artificial neural networks in both single-task and multi-task applications, using lung segmentation as an example. Typical evaluation methods, specifically Dice coefficient or Hausdorff distance, will be presented with current values and improvements. An overview of new evaluation methods and a discussion of the current way of reporting will also be addressed.

Multiscale hierarchical decomposition methods for ill-posed problems

MS10 3
Fri Sep 8
2:30 pm
3:00 pm
VG1.103

T. Wolf, E. Resmerita, S. Kindermann

The Multiscale Hierarchical Decomposition Method (MHDM) is a popular method originating from mathematical imaging. In its original context, it is very well suited to recover fine details of solutions to denoising and deblurring problems. The main idea is to iteratively solve a ROF minimization problem. In every iteration, the data for the ROF functional will be the residual from the previous step, and the approximation to the true data will consist of the sum of all minimizers up to that step. Thus, one obtains iterates that represent a decomposition of the ground truth into multiple levels of detail at different scales. We consider the method in a more general framework, by replacing the total variation seminorm in the ROF functional by more general penalty terms in appropriate settings. We expand existing convergence results for the residual of the iterates in the case when some classes of convex and nonconvex penalties are employed. Moreover, we propose a necessary and sufficient condition under which the iterates of the MHDM agree with Tikhonov regularizers corresponding to suitable regularization parameters. We discuss the results on several examples, including 1- and 2-dimensional TV-denoising.

Combined EEG/MEG source analysis for reconstructing the epileptogenic zone in focal epilepsy

CT04
Thu Sep 7
3:00 pm
3:30 pm
VG2.104

C. H. Wolters, F. Neugebauer, S. Pursiainen, M. Burger, J. Wellmer, S. Rampp

MEG and EEG source analysis is frequently used in presurgical evaluation of pharmacoresistant epilepsy patients. The localization quality depends, among other aspects, on the selected inverse and forward approaches and their respective parameter choices. In my talk, I will present new forward and inverse approaches and their application for the identification of the epileptogenic zone in focal epilepsy. The forward approaches are based on the finite element method (FEM). The inverse approaches contain beamforming, hierarchical Bayesian modeling (HBM) and standard dipole scanning techniques. I will discuss advantages and disadvantages of those approaches and compare their performance in a retrospective evaluation study with patients of focal epilepsy.

References

[1] Neugebauer, F., Antonakakis, M., Unnwongse, K., Parpaley, Y., Wellmer, J., Rampp, S., Wolters, C.H., Validating EEG, MEG and Combined MEG and EEG Beamforming for an Estimation of the Epileptogenic Zone in Focal Cortical Dysplasia. Brain Sci:114, 2022. https://doi.org/10.3390/brainsci12010114.

[2] Aydin, Ü., Rampp, S., Wollbrink, A., Kugel, H., Cho, J.-H., Knösche, T.R.,Grova, C., Wellmer, J., Wolters, C.H., Zoomed MRI guided by combined EEG/MEG source analysis: A multimodal approach for optimizing presurgical epilepsy work-up and its application in a multi-focal epilepsy patient case study, Brain Topography, 30(4):417-433, 2017. https://doi.org/10.1007/s10548-017-0568-9.

CT08
Thu Sep 7
4:00 pm
4:30 pm
VG2.105

On Adaptive confidence Ellipsoids for sparse high dimensional linear models

X. Xie

In high-dimensional linear models the problem of constructing adaptive confidence sets for the full parameter is known to be generally impossible. We propose re-weighted loss functions under which constructing fully adaptive confidence sets for the parameter is shown to be possible. We give necessary and sufficient conditions on the loss functions for which adaptive confidence sets exist, and exhibit a concrete rate-optimal procedure for construction of such confidence sets.

MS45 1
Tue Sep 5
5:00 pm
5:30 pm
VG0.111

The quadratic Wasserstein metric for inverse data matching

B. Engquist, K. Ren, Y. Yang

This work characterizes, analytically and numerically, two major effects of the quadratic Wasserstein (W_2) distance as the measure of data discrepancy in computational solutions of inverse problems. First, we show, in the infinite-dimensional setup, that the W_2 distance has a smoothing effect on the inversion process, making it robust against high-frequency noise in the data but leading to a reduced resolution for the reconstructed objects at a given noise level. Second, we demonstrate that, for some finite-dimensional problems, the W_2 distance leads to optimization problems that have better convexity than the classical L^2 and $\dot{H}^{-1}$ distances, making it a more preferred distance to use when solving such inverse matching problems. This talk is based on the work [1].

References

[1] B. Engquist, K. Ren, Y. Yang. The quadratic Wasserstein metric for inverse data matching, Inverse Problems 36(5): 055001, 2020.

MS39
Mon Sep 4
2:30 pm
3:00 pm
VG2.105

Stability and Generalization for Stochastic Gradient Methods

Y. Ying

Stochastic gradient methods (SGMs) have become the workhorse of machine learning (ML) due to their incremental nature with a computationally cheap update. In this talk, I will first discuss the close interaction between statistical generalization and computational optimization for SGMs in the framework of statistical learning theory (SLT). The core concept for this study is algorithmic stability which characterizes how the output of an ML algorithm changes upon a small perturbation of the training data. Our theoretical studies have led to new insights into understanding the generalization of overparameterized neural networks trained by SGD. Then, I will describe how this interaction framework can be used to derive lower bounds for the convergence of existing methods in the task of maximizing the AUC score which further inspires a new direction for designing efficient AUC optimization algorithms.

Quantum computing algorithms for inverse problems on graphs

MS30 1
Wed Sep 6
9:30 am
10:00 am
VG2.103

J. Ilmavirta, M. Lassas, J. Lu, L. Oksanen, L. Ylinen

Quantum computing is a technology that utilizes quantum mechanical phenomena to do computation faster than is believed to be possible with classical computers. It is a rapidly developing and interdisciplinary field comprising of physics, computer science, and mathematics. It is predicted that in the future quantum computers will enable scientists to solve problems outside the capabilities of classical computers in many fields such as molecular simulations in drug discovery and complex combinatorics problems.

In this talk, we consider a quantum algorithm for an inverse travel time problem on a graph. This problem is a discrete version of the inverse travel time problem encountered in seismic and medical imaging and the boundary rigidity problem studied in Riemannian geometry. We also consider the computational complexity of the inverse problem, and show that the quantum algorithm has a quadratic improvement in computational cost when compared to the standard classical algorithm.

Calibration-Based Probabilistic Error Bounds for Inverse Problems in Imaging

MS33 2
Thu Sep 7
1:30 pm
2:00 pm
VG1.105

M. Zach, A. Habring, M. Holler, D. Narnhofer, T. Pock

Traditional hand-crafted regularizers, such as the total variation, have a profound history in the context of inverse problems. Typically, they are accompanied by a geometrical interpretation and experts are familiar with (artifacts in) the resulting reconstructions. Modern, learned regularizers can hardly be interpreted in this way, thus it is important to supply uncertainty maps or error bounds in addition to any reconstruction. In this talk, we give an overview of calibration-based methods that provide 1) pixel-wise probabilistic error bounds or 2) probabilistic confidence with respect to entire structures in the reconstruction. We show results on the clinically highly relevant problem of undersampled magnetic resonance reconstruction.

Noise Estimation via Tractable Diffusion

MS25 2
Mon Sep 4
4:30 pm
5:00 pm
VG0.110

M. Zach, T. Pock, E. Kobler, A. Chambolle

Diffusion models have recently received significant interest in the imaging sciences. After achieving impressive results in image generation, focus has shifted towards finding ways to exploit the encoded prior knowledge in classical inverse problems. In this talk, we highlight another intriguing viewpoint: Instead of focusing on image reconstruction, we propose to use tractable diffusion models which also allow to estimate the noise in an image. In particular, we utilize a fields-of-experts-type model with Gaussian mixture experts that admits an analytic expression for a normalized density under diffusion, and can be trained with empirical Bayes. The normalized model can be used for noise estimation of a given image by maximizing it w.r.t. diffusion time, and simultaneously gives a Bayesian least-squares estimator for the clean image. We show results on denoising problems and propose possible applications to more involved inverse problems.

MS09
Fri Sep 8
2:30 pm
3:00 pm
VG1.102

Multilevel domain UQ in computational electromagnetics

J. Zech, R. Aylwin, C. Jerez-Hanckes, C. Schwab

In this talk, we focus on the numerical approximation of time-harmonic electromagnetic fields for the Maxwell lossy cavity problem on uncertain domains. To deal with the different problem geometries, a shape parametrization framework that maps physical domains to a fixed polyhedral nominal domain is adopted. We discuss multilevel Monte Carlo sampling and multilevel sparse-grid quadrature for computing the expectation of the solutions with respect to uncertain domain ensembles. In addition, we analyze sparse-grid interpolation to compute surrogates of the domain-to-solution mappings. A rigorous fully discrete error analysis is provided, and we prove that dimension-independent algebraic convergence is achieved.

MS07 2
Fri Sep 8
5:30 pm
6:00 pm
VG1.101

Parameter choice in distance-regularized domain adaptation

W. Zellinger, S. V. Pereverzyev

We address the unsolved algorithm design problem of choosing a justified regularization parameter in unsupervised domain adaptation, the problem of learning from unlabeled data using labeled data from a different distribution. Our approach starts with the observation that the widely-used method of minimizing the source error, penalized by a distance measure between source and target feature representations, shares characteristics with penalized regularization methods. This observation allows us to extend Lepskii's balancing principle, and it's related error bound, to unsupervised domain adaptation. This talk is partially based on [1].

References

[1] W. Zellinger, N. Shepeleva, M.-C. Dinu, H. Eghbal-zadeh, H. D. Nguyen, B. Nessler, S. V. Pereverzyev, B. Moser. The balancing principle for parameter choice in distance-regularized domain adaptation. Advances in Neural Information Processing Systems (NeurIPS) 34, 2021.

MS03 1
Mon Sep 4
2:00 pm
2:30 pm
VG2.103

Regularization for learning from unlabeled data using related labeled data

W. Zellinger, S. V. Pereverzyev

We consider the problem of learning from unlabeled target datasets using related labeled source datasets, e.g. learning from an image-dataset from a target medical patient using expert-annotated datasets from related source patients. This problem is complicated by (a) missing target labels, e.g. no target expert-annotations of a tumor, and, (b) possible differences in the source and target data generating distributions, e.g. caused by medical patents' human variations. The major three methods for this problem, are special cases of multiple or cascade regularization methods, i.e., methods involving simultaneously more than one regularization. This talk is based on [1-3] and reviews non-asymptotic (w.r.t. dataset size) error bounds of the major three methods.

References

[1] W. Zellinger, N. Shepeleva, M.-C. Dinu, H. Eghbal-zadeh, H. D. Nguyen, B. Nessler, S. V. Pereverzyev, B. Moser. The balancing principle for parameter choice in distance-regularized domain adaptation. Advances in Neural Information Processing Systems (NeurIPS). 34: 20798–20811, 2021.

[2] E.R. Gizewski, L. Mayer, B. Moser, D.H. Nguyen, S. Pereverzyev Jr, S.V. Pereverzyev, N. Shepeleva, and W. Zellinger. On a regularization of unsupervised domain adaptation in RKHS. Appl. Comput. Harmon. Anal. 57: 201–227. 2022. https://doi.org/10.1016/j.acha.2021.12.002

[3] M. Holzleitner, S.V. Pereverzyev, W. Zellinger. Domain Generalization by Functional Regression. arXiv preprint arXiv:2302.04724 (2023). https://doi.org/10.48550/arXiv.2302.04724

Lipschitz Stability of Recovering the Conductivity from Internal Current Densities

CT02
Wed Sep 6
9:00 am
9:30 am
VG2.105

L. Qiu, S. Zheng

We investigates the inverse problem of reconstructing the electrical conductivity of an object in hybrid imaging methods. These techniques have been developed in recent years to produce clearer images than those produced by electrical impedance tomography. We focus on the inverse problem arising in the quantitative step of many hybrid imaging techniques. The problem is formulated as recovering the isotropic conductivity of an object given internal current densities generated by applying different boundary conditions to the electrostatic equation. We will present two specific examples of these techniques, current density impedance imaging and magneto-acousto-electric tomography, to illustrate the different boundary conditions that can be used. We provide a local Lipschitz stability for the general inverse problem in both full and partial data cases.

Imaging with two-photon absorption optics

MS56 2
Mon Sep 4
5:00 pm
5:30 pm
VG2.106

Y. Zhong

In this talk, we briefly talk about the inverse boundary/medium problems with the semi-linear transport model which has a natural application in two-photon absorption optics. For the inverse boundary problem, we adopted the usual linearization technique and prove the uniqueness of reconstruction. For the inverse medium problems, we consider the problem from photoacoustic imaging specifically in static and time-dependent settings and prove the uniqueness of the reconstruction for the absorption coefficients.

Imaging with two-photon absorption optics

MS55 2
Mon Sep 4
4:00 pm
4:30 pm
VG3.101

Y. Zhong

In this talk, we briefly talk about the inverse boundary/medium problems with the semi-linear transport model which naturally rises from two-photon absorption optics. The model can be formally derived from a paraxial setting of a nonlinear absorption wave model. For the related inverse problems, we consider two cases. For the inverse boundary problem, we adopted the usual linearization technique and prove the uniqueness of reconstruction. For the inverse medium problems, we consider the problem from photoacoustic imaging specifically in static and time-dependent settings and prove the uniqueness of the reconstruction for the absorption coefficients.

Inverse Problems for Some Nonlinear Schrodinger Equations

MS20 2
Thu Sep 7
4:30 pm
5:00 pm
VG3.104

T. Zhou

In this talk, I will demonstrate the higher order linearization approach to solve several inverse boundary value problems for nonlinear PDEs, modeling for example nonlinear optics, including nonlinear magnetic Schrodinger equation and its fractional version. Considering partial data problems, the problem will be reduced to solving for the coefficient functions from their integrals against multiple linear solutions that vanish on part of the boundary. We will focus our discussion on choices of linear solutions and some microlocal anlaysis tools and ideas in proving injectivity of the coefficient function from its integral transforms such as the FBI transform.

MS55 1
Mon Sep 4
1:30 pm
2:00 pm
VG3.101

An Inverse Problem for Nonlinear Time-dependent Schrodinger Equations with Partial Data

T. Zhou

In this talk, I will present some recent results on solving inverse boundary value problems for nonlinear PDEs, especially for a time-dependent Schrodinger equation with time-dependent potentials with partial boundary Dirichlet-to-Neumann map. After a higher order linearization step, the problem will be reduced to implementing special geometrical optics (GO) solutions to prove the uniqueness and stability of the reconstruction. This is a joint work with my PhD student Xuezhu Lu and Prof. Ru-Yu Lai.

MS13 1
Fri Sep 8
1:30 pm
2:00 pm
VG0.111

Beating the Saturation of the Stochastic Gradient Descent for Linear Inverse Problems

B. Jin, Z. Zhou, J. Zou

Stochastic gradient descent (SGD) is a promising method for solving large-scale inverse problems, due to its excellent scalability with respect to data size. The current mathematical theory in the lens of regularization theory predicts that SGD with a polynomially decaying stepsize schedule may suffer from an undesirable saturation phenomenon, i.e., the convergence rate does not further improve with the solution regularity index when it is beyond a certain range. In this talk, I will present our recent results on beating this saturation phenomenon:

(i) By using a small initial step size. We derive a refined convergence rate analysis of SGD, which shows that saturation does not occur if the initial stepsize of the schedule is sufficiently small.

(ii) By using Stochastic variance reduced gradient (SVRG), a popular variance reduction technique for SGD. We prove that, with a suitable constant step size schedule, SVRG can achieve an optimal convergence rate in terms of the noise level (under suitable regularity conditions), which means the saturation does not occur.

MS56 1
Mon Sep 4
2:30 pm
3:00 pm
VG2.106

Recovery of coefficients in nonlinear transport equations

H. Zhou

In this talk, we will discuss the determination of coefficients in time-dependent nonlinear transport equations. We consider both cases of time-independent and time-dependent coefficients. The talk is based on joint work with Ru-Yu Lai and Gunther Uhlmann.

MS18 1
Mon Sep 4
2:30 pm
3:00 pm
VG1.103

Fractional p-Calderón problems

P. Zimmermann

The main purpose of this talk is to discuss two different nonlocal variants of the p-Calderón problem.

In the first model the nonlocal operator under consideration is a weighted fractional p-Laplacian and, similarly as for the p-Laplacian in dimensions $n \geqslant 3$, it is an open problem, whether it satisfies a unique continuation principle (UCP). However, it will be explained that the variational structure of the problem is still sufficiently nice that one can explicitly reconstruct the weight $\sigma(x,y)$ on the diagonal $D = \{(x,x) : x \in W\}$ of the measurement set W. This reconstruction formula establishes a global uniqueness result for separable, real analytic coefficients [1].

In the second model, we consider the (anisotropic) fractional p-biharmonic operator, which naturally appears in the variational characterization of the optimal fractional Poincaré constant in Bessel potential spaces $H^{s,p}$. In contrast to the one above, this operator satisfies the UCP and so heuristically corresponds to the p-Laplacian in dimension $n = 2$. Finally, we explain how this can be used to establish a global uniqueness result of the related inverse problem under a monotonicity condition [2].

References

[1] M. Kar, Y. Lin, and P. Zimmermann. Determining coefficients for a fractional p-Laplace equation from exterior measurements, arXiv:2212.03057, 2022.

[2] M. Kar, J. Railo, and P. Zimmermann. The fractional p-biharmonic systems: optimal Poincaré constants, unique continuation and inverse problems, arXiv:2208.09528, 2022.

X-ray mapping properties and degenerately elliptic operators

MS52 2
Mon Sep 4
5:00 pm
5:30 pm
VG1.105

<u>Y. Zou</u>, F. Monard, R. K. Mishra

We discuss recent results regarding C^∞-isomorphism properties of weighted normal operators of the X-ray transform on manifolds with boundary, in joint work [1] with Francois Monard and Rohit Kumar Mishra. The crux of the result depends on understanding the Singular Value Decomposition of weighted X-ray transforms/backprojection operators, which itself can be obtained via intertwining with certain degenerately elliptic differential operators. We also discuss recent work [2] with Francois Monard on developing tools to study such degenerately elliptic operators even further. Such tools include a scale of Sobolev spaces which take into account behavior up to the boundary, as well as generalizations of Dirichlet and Neumann traces called boundary triplets associated to degenerately elliptic operators which pick out the first and second most singular terms of a function near the boundary.

References

[1] R. Mishra, F. Monard, Y. Zou. The C^∞-isomorphism property for a class of singularly-weighted X-ray transforms. Inverse Problems 39: 024001, 2023. https://doi.org/10.1088/1361-6420/aca8cb

[2] F. Monard, Y. Zou. Boundary triples for a family of degenerate elliptic operators of Keldysh type, arXiv: 2302.08133, 2023.

Travel Time Tomography in Transversely Isotropic Elasticity via Microlocal Analysis

MS41 2
Fri Sep 8
4:30 pm
5:00 pm
VG3.101

<u>Y. Zou</u>

We will discuss recent results of the author regarding the travel time tomography problem in the context of transversely isotropic elasticity. The works build on previous works regarding X-ray and (elastic) travel time tomography and boundary rigidity problems studied by de Hoop, Stefanov, Uhlmann, Vasy, et al., which reduce the inverse problems to the microlocal analysis of certain operators obtained from a pseudolinearization argument. We will discuss the additional analytic complications in this situation, due to the degenerating ellipticity of certain key operators obtained in the pseudolinearization argument, as well as the machinery developed to tackle these additional complications.

Poster Presentations

Inverse Level-Set Problems for Capturing Calving Fronts

Wed Sep 6
12:15 pm
ZHG Foyer

D. Abele, A. Humbert

Capturing the calving front motion is critical for simulations of ice sheets and ice shelves. Multiple physical processes - besides calving also melting and the forward movement of the ice - need to be understood to accurately model the front. Calving is particularly challenging due to its discontinuous nature and modelers require more tools to examine it.

A common technique for capturing the front in ice simulations is the Level-set method. The front is represented implicitly by the zero isoline of a function. The movement of the front is described by an advection equation, where the velocity field is a combination of ice velocity and frontal ablation rate.

To improve understanding of these processes, we are developing methods to estimate parameters of calving laws based on inverse Level-Set problems. The regularization is chosen so it can handle discontinuous parameters or calving laws to fit discontinuous front positions due to large calving events. The input for the inverse problem is formed by observational data from satellite images that is often sparse. The methods will be applied to large scale models of the Antarctic Ice Sheet.

Reduced Order Methods for Linear Gaussian Bayesian Inverse Problems on separable Hilbert Spaces

Wed Sep 6
12:15 pm
ZHG Foyer

G. Carere, H. C. Lie

In Bayesian inverse problems, the computation of the posterior distribution can be computationally demanding, especially in many-query settings such as filtering, where a new posterior distribution must be computed many times. In this work we consider some computationally efficient approximations of the posterior distribution for linear Gaussian inverse problems defined on separable Hilbert spaces. We measure the quality of these approximations using the Kullback-Leibler divergence of the approximate posterior with respect to the true posterior and investigate their optimality properties. The approximation method exploits low dimensional behaviour of the update from prior to posterior, originating from a combination of prior smoothing, forward smoothing, measurement error and limited number of observations, analogous to the results of Spantini et al. [1] for finite dimensional parameter spaces. Since the data is only informative on a low dimensional subspace of the parameter space, the approximation class we consider for the posterior covariance consists of suitable low rank updates of the prior. In the Hilbert space setting, care must be taken when inverting covariance operators. We address this challenge by using the Feldman-Hajek theorem for Gaussian measures.

References

[1] A. Spantini, A. Solonen, T. Cui, J. Martin, L. Tenorio, Y. Marzouk. Optimal Low-Rank Approximations of Bayesian Linear Inverse Problems. SIAM J. on Sci. Comp. 37, no. 6: A2451-87, 2015

Wed Sep 6
12:15 pm
ZHG Foyer

Investigation of the effects of Cowling approximation on adiabatic wave propagation in helioseismology

H. Barucq, L. Chabat, F. Faucher, D. Fournier, H. Pham

Helioseismology investigates the interior structures and the dynamics of the Sun from oscillations observed on its visible surface. Ignoring flow and rotation, time-harmonic adiabatic waves in a self-gravitating Sun in Eulerian-Lagrangian description are described by the Lagrangian displacement ξ and the gravitational potential perturbation δ_ϕ which satisfy Galbrun's equation [1] coupled with a Poisson equation. In most works, perturbation to gravitational potential δ_ϕ is neglected under Cowling's approximation [3]. However, this approximation is known to shift the eigenvalues of the forward operator for low-order harmonic modes [4]. Here, we study the effects of this approximation on numerical solutions and discuss its implication for the inverse problem. Removing Cowling's approximation allows us to accurately simulate waves for low-degree modes, and help us better characterize the deep interior of the Sun.

The investigation is carried out for a Sun with minimum activity, called quiet Sun, whose background coefficients are given by the radially symmetric standard solar model Model S in the interior, with a choice of extension beyond the surface to include the presence of atmosphere cf [5]. Radial symmetry is exploited to decouple the problem on each spherical harmonic mode ℓ to give a system of ordinary differential equations in radial variable. This extends previous work [1] which employed Cowling approximation. The modal system is resolved by using the Hybridizable Discontinuous Galerkin method (HDG). For purpose of validation, the equations are coupled with free-surface boundary condition which is adapted for low-frequency modes and is commonly employed in helioseismology cf. [6]. Since eigenvalues are poles of Green's tensor, the magnitude of the latter as a function of frequency peaks around an eigenvalue. As preliminary results, we compare the location where the Green's tensor peaks to the values of eigenvalues computed by the GYRE code [2], between which we find a good agreement.

References

[1] H. Barucq, F. Faucher, D. Fournier, L. Gizon, H. Pham. Efficient computation of modal Green's kernels for vectorial equations in helioseismology under spherical symmetry, 2021.

[2] RHD Townsend, SA Teitler. GYRE: an open-source stellar oscillation code based on a new Magnus Multiple Shooting scheme, Monthly Notices of the Royal Astronomical Society:3406-3418, 2013.

[3] Thomas G Cowling. The non-radial oscillations of polytropic stars, Monthly Notices of the Royal Astronomical Society:367, 1941.

[4] J. Christensen-Dalsgaard. Lecture notes on stellar oscillations, 2014.

[5] J. Christensen-Dalsgaard. Introductory report : Solar Oscillations, Liege International Astrophysical Colloquia:155-207, 1984.

[6] W. Unno,Y. Osaki, H. Ando, H. Shibahashi. Nonradial oscillations of stars, Tokyo: University of Tokyo Press, 1979.

Wed Sep 6
12:15 pm
ZHG Foyer

Compensating motion and model inexactness in nano-CT

B. Ehlers, A. Wald

In Nano CT imaging the scale is so small that we have unwanted and unknown movement of the scanned object relativ to the tomograph, for example due to vibrations of the measuring apparatus. Not incorporating these movements in the radon operator leads to artefact due to the model inexactness. Reconstructing the rigid body motion of the object is possible due to the structure of the range of the Radon operator. The range of a Radon operator which includes the movement is different from one that does not. This can be used to extract the motion, correct the radon operator, correct the data or to estimate the operator error for use in a scheme called sequential subspace optimisation. We will focus on the error estimation for this regularisation method.

GAN-based motion correction in MRI

Wed Sep 6
12:15 pm
ZHG Foyer

M. S. Feinler, B. Hahn

Magnetic Resonance Imaging allows high resolution data acquisition with the downside of motion sensitivity due to relatively long acquisition times. Even during the acquisition of a single 2D slice, motion can severely corrupt the image. Retrospective motion correction strategies do not interfere during acquisition time but operate on the motion affected data. In most applications, the trajectories are cartesian like in the HASTE sequence. These classical sampling schemes show no or only marginal temporal redundancy by the sensitivity encoding (SENSE) that multiple receiver coils provide. Hence, in practice, residual based optimizations will fail to produce motion artifact free images. In recent years, Generative Adversarial Networks (GANs) have gained interest for motion compensation. Albeit the performance is visually appealing, it cannot be guaranteed that small details of diagnostic relevance are predicted correctly, even if large parts of the image are in fact motion artifact free. To this end we propose a learned iterative procedure to substantiate the reconstructions and achieve data consistency. We show that, dependent on the complexity of deformations, even small details which have initially been erased by GANs can be recovered.

Iterated Arnoldi-Tikhonov method

Wed Sep 6
12:15 pm
ZHG Foyer

D. Bianchi, M. Donatelli, D. Furchì, L. Reichel

When solving an ill-posed linear operator equation, most of the analysis does not take the discretization error into account. This paper contributes to address this gap. Building upon the analysis presented in [1], we extend the study to the iterated framework. Firstly, we demonstrate a saturation result for the Arnoldi-Tikhonov solution method outlined in [2]. Subsequently, we extend the analysis to the iterated Arnoldi-Tikhonov method, providing a parameter choice rule, which produces higher-quality computed solutions compared to the standard Arnoldi-Tikhonov method. Theoretical results are supported by relevant computed examples.

References

[1] A. Neubauer. An a posteriori parameter choice for Tikhonov regularization in the presence of modeling error. Appl. Numer. Math., 4 1986.

[2] R. Ramlau, L. Reichel. Error estimates for Arnoldi-Tikhonov regularization for ill-posed operator equations. IOP Publishing, Inverse Problems 35, 2019.

Edge-Preserving Tomographic Reconstruction with Uncertain View Angles

Wed Sep 6
12:15 pm
ZHG Foyer

P. C. Hansen, J. M. Bardsley, Y. Dong, N. A. B. Riis, F. Uribe

In computed tomography, data consist of measurements of the attenuation of X-rays passing through an object. The goal is to reconstruct an image of the linear attenuation coefficient of the object's interior. For each position of the X-ray source, characterized by its angle with respect to a fixed coordinate system, one measures a set of data referred to as a view. A common assumption is that these view angles are known - but in some applications, they are known with imprecision.

We present a Bayesian inference approach to solving the joint inverse problem for the image and the view angles, while also providing uncertainty estimates. For the image, we impose a Laplace difference prior enabling the representation of sharp edges in the image; this prior has connections to total variation regularization. For the view angles, we use a von Mises prior which is a 2π-periodic continuous probability distribution.

Numerical results show that our algorithm can jointly identify the image and the view angles, while also providing uncertainty estimates of both. We demonstrate our method with simulations of a 2D X-ray computed tomography problems using fan beam configurations.

References

[1] N. A. B. Riis, Y. Dong, P. C. Hansen, Computed tomography reconstruction with uncertain view angles by iteratively updated model discrepancy, J. Math. Imag., 63,:133-143, 2021. doi 10.1007/s10851-020-00972-7.

[2] N. A. B. Riis, Y. Dong, P. C. Hansen, Computed tomography with view angle estimation using uncertainty quantification, Inverse Problems, 37: 065007, 2021. doi 10.1088/1361-6420/abf5ba.

[3] F. Uribe, J. M. Bardsley, Y. Dong, P. C. Hansen, N. A. B. Riis, A hybrid Gibbs sampler for edge-preserving tomographic reconstruction with uncertain angles, SIAM/ASA J. Uncertain. Quantif., 10:1293-1320, 2022. doi 10.1137/21M1412268.

Wed Sep 6
12:15 pm
ZHG Foyer

Geodesic slice sampling on the sphere

M. Hasenpflug, M. Habeck, S. Kodgirwar, D. Rudolf

We introduce a geodesic slice sampler on the Euclidean sphere (in arbitrary but fixed dimension) that can be used for approximate sampling from distributions that have a density with respect to the corresponding surface measure. Such distributions occur e.g. in the modelling of directional data or shapes. We provide some mild conditions which ensure that the geodesic slice sampler is reversible with respect to the distribution of interest. Moreover, if the density is bounded, then we obtain a uniform ergodicity convergence result. Finally, we illustrate the performance of the geodesic slice sampler on the sphere with numerical experiments.

Wed Sep 6
12:15 pm
ZHG Foyer

Measurement and analysis strategies for EUV pump-probe spectroscopic imaging

G. S. M. Jansen, H. Strauch, T. Hohage, S. Mathias

Interference-based measurement methods allow the extraction of phase differences of electromagnetic waves, thus adding phase information to an intensity-based measurement. In holography, the encoded phase information allows the reconstruction of the complete wavefront, which has powerful applications in imaging. Similarly, Fourier-transform spectroscopy allows spectral information to be extracted from pulse delay-dependent interference measurements. Recently, it was demonstrated that the combination of these interferometric measurements might enable hyperspectral imaging in the extreme ultraviolet (EUV). However, to obtain full spectral information, normally long reference-probe delay scans are required, resulting in long measurement times and large amounts of data.

We aim to address this challenge by implementing a combination of Fourier transform spectroscopy and Fourier transform holography: Two phase-locked EUV pulses are imaged to separate reference and probe positions on the sample plane, which leads to both spectral and spatial information to be encoded in the far-field diffraction pattern. This interferometric approach provides an opportunity to reduce sampling requirements, as a suitable reconstruction algorithm can implement prior knowledge on the spatial domain to constrain the spectral domain (and vice versa). As typical for diffraction microscopy, the measurement data are proportional to the amplitude of the Fourier transform, meaning that although the forward model is nonlinear, it can be efficiently implemented. From simulations and analysis of the forward model, we will discuss ways to adapt both measurement and analysis to facilitate efficient acquisition of multidimensional pump-probe spectroscopy data.

Dual-grid parameter choice method for total variation regularised image deblurring

Wed Sep 6
12:15 pm
ZHG Foyer

Y. Dong, M. Juvonen, M. Lassas, I. Pohjola, S. Siltanen

We present a new parameter choice method for total variation (TV) deblurring of images. The method is based on a dual-grid computation of the solution.

Instead of a single grid we have 2 grids with different discretisation. The first grid is the same were the measurement is given. The origin of the second grid is shifted half a pixel width both horizontally and vertically. Note that the underlying true image is the same for both grids. Assume that the pixel size is much smaller than a typical constant valued area in an image. The premise of the study is that when solving the TV regularised noisy deblurring problem with a large enough parameter the solutions on both grids will converge to the same image.The proposed algorithm looks for the smallest parameter with which convergence can be numerically detected.

The method has been tested on both simulated and real image data. Preliminary computational experiments suggest that an optimal parameter can be chosen by monitoring the difference of the TV seminorms of the dual-grid solutions while changing the regularisation parameter size.

Reconstruction of active forces generated by actomyosin networks

Wed Sep 6
12:15 pm
ZHG Foyer

E. Klass, A. Wald

Biological Cells rely on the interaction of multiple proteins to perform various forms of movement such as cell contraction, division, and migration. In particular, the proteins actin is able to create long branching filament structures which the protein myosin can bind to and slide along on, thereby creating so-called acto-myosin networks. These networks produce mechanical stress resulting in movement of the cell itself, and its interior.

We depict the physical process of the flow inside of cells generated by acto-myosin networks using a 2-dimensional droplet model using the Stokes equation for incompressible Newtonian fluids for non-constant viscosities. Here we add a Neumann boundary condition where the normal component of the velocity field on the boundary of the droplet vanishes to represent that no fluid can flow in or out of the domain. Further, we add a Robyn-type or slip boundary condition to model the interaction with surrounding fluids. We choose a non-constant viscosity to portray the acto-myosin network.

We aim to reconstruct the active forces inside of the droplet from noisy measurements of the velocity field. This results a (deterministic) parameter identification problem for the Stokes equation.

Wed Sep 6
12:15 pm
ZHG Foyer

Revealing Functional Substructure of Retinal Ganglion Cell Receptive Fields Using Tomography-Based Stimulation

S. Krüppel, T. Gollisch

Retinal ganglion cells (RGCs) are the output cells of the retina and perform various computations on the visual signals that are detected by the retina's photoreceptors. Here, nonlinearities in an RGC's receptive field - the subset of all photoreceptors that (indirectly) connect to a given RGC - play an essential role. Many RGC types are spatially nonlinear, that is they integrate signals from different areas of their receptive field nonlinearly. This spatial nonlinearity is mediated via so-called subunits which in turn are considered to be linear and thought to correspond to those cells that provide direct excitatory input to RGCs, the retinal bipolar cells. In order to understand RGC responses to the finely structured natural images animals encounter, knowledge of the subunits is critical. In addition, large-scale electrophysiological studies of RGCs are relatively simple, but the same cannot be said about bipolar cells. Efforts have therefore been made to infer the subunits of a given RGC from recordings of the RGC's activity to visual stimuli presented to the retina. Yet, methods to quickly and consistently infer how many subunits compose an RGC's receptive field and where they are located are rare. The problem is made more difficult by additional nonlinearities in the system, the unknown shapes of the nonlinearities, and potential interactions between subunits. Our approach is to flash a bar with a preferred-contrast center and sidebands of non-preferred contrast in the receptive field of an RGC at various positions and angles. If the bar width is similar to the expected subunit size, the responses of the RGC should, for a given angle and varying position, roughly correspond to a projection of the subunit layout along the bar's orientation. Borrowing from tomography, we can thus compose a sinogram out of all responses of an RGC and reconstruct the subunit layout using, e.g., filtered back-projection. In simulations of RGCs with various subunit layouts, we find that those RGC responses that are generated by excitation of a specific subunit are well confined to a small region in the sinogram. This often allows successful reconstruction of the subunit layout, but reconstruction quality of realistic layouts is limited by nonlinearities not accounted for by filtered back-projection. We also performed multi-electrode array recordings from isolated primate retinas where our approach revealed substructure in many RGC receptive fields as well. Altogether, our tomographic subunit detection method is a promising candidate to quickly and reliably infer substructure in the receptive field of an RGC, thereby laying foundations to better predict responses to natural images and indirect large-scale bipolar cell studies.

Acknowledgements: This work was supported by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation)–project IDs 154113120 (SFB 889, project C01); 432680300 (SFB 1456, project B05)–and by the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (grant agreement number 724822).

Wed Sep 6
12:15 pm
ZHG Foyer

Non-stationary hyperspectral unmixing with learnt regularization

J. M. Lascar

In astrophysics or remote sensing, spectro-imagers can record cubes of data called hyperspectral images, with two spatial dimensions and a third dimension of energy. Often, the observed data are a mixture of several emitting sources. Thus, the task of source separation is key to perform detailed studies of the underlying physical components.

Most source separation algorithms assume a stationary mixing model, i.e. a sum of spectra, one per component, each multiplied by an amplitude map. But in many cases, this assumption is erroneous, since the spectral shape of each component varies spatially due to physical properties. Our algorithm's goal is to achieve non-stationary source separation, obtaining for each component a cube with varying spectral shape. This is an ill-posed inverse problem, thus in need of regularization.

For spectral regularization, we use a generative model learned on auto-encoders, which constrains the spectra to interpretable shapes in a semi-supervised scheme. This was combined with a spatial regularization scheme, via a sparse modelling of the generative model's latent parameters. The optimization was achieved in an algorithm of alternating proximal gradient descent. It was tested for the case study of X-ray astrophysics spectro-imagery, for which results will be shown on realistic simulated data. To our knowledge, this is the first method to extend sparse blind source separation to the non-stationary case.

Phase retrieval beyond the homogeneous object approximation in X-ray holographic imaging

Wed Sep 6
12:15 pm
ZHG Foyer

J. Lucht, L. M. Lohse, S. Huhn, T. Salditt

X-ray near field in-line holographic imaging using highly coherent synchrotron radiation offers spatial resolution down to the nanometer scale. Combined with tomographic methods it allows high resolution three-dimensional imaging with wide applicability in life, natural and material sciences. Using X-ray phase contrast enables the study of samples that show little to no conventional absorption based contrast, for example soft tissue. Since the phase cannot be directly measured, it has to be retrieved from the measured diffraction patterns by solving an ill-posed inverse problem.

To solve this phase problem, one common approximation for X-ray Fresnel holography is the so-called homogeneous or single material object approximation. It restricts the phase shift and absorption part of the object's refractive index to be proportional. Hence, the number of unknowns of the inverse problem can be reduced from two, phase shift and absorption, to one while also imposing restrictions on the sample to satisfy this approximation. Multi material samples naturally violate this assumption and hence reconstructions with homogeneous object assumption show artifacts. To resolve this incompatibility we present a reconstruction method which relaxes the homogeneous object assumption based on linearization of the Fresnel diffraction for weak objects, known as contrast transfer function (CTF), that is also popular in electron microscopy. We demonstrate that reconstruction quality can be significantly improved if physical priors are imposed on the reconstruction with tools of constrained optimization. Furthermore, we discuss the stability and experimental design for the proposed method.

Microlocal Analysis of Multistatic Synthetic Aperture Radar Imaging

Wed Sep 6
12:15 pm
ZHG Foyer

D. McMahon, C. Nolan

We consider Synthetic Aperture Radar (SAR) in which scattered waves, simultaneously emitted from a pair of stationary emitters, are measured along a flight track traversed by an aircraft. A linearized mathematical model of scattering is obtained using a Fourier integral operator. This model can then be used to form an image of the ground terrain using backprojection together with a carefully designed data acquisition geometry.

The data is composed of two parts, corresponding to the received signals from each emitter. A backprojection operator can be easily chosen that correctly reconstructs the singularities in the wave speed using just one emitter. One would expect this to lead to a reasonable image of the terrain. However, we expect that application of this backprojection operator to the data from the other emitter will lead to unwanted artifacts in the image. We analyse the operators associated with this situation, and use microlocal analysis to determine configurations of flight path and emitter locations so that we may mitigate the artifacts associated to such "cross talk" between the two emitters.

Wed Sep 6
12:15 pm
ZHG Foyer

Adaptive Method for Bayesian EEG/MEG Source Localization to Support Treatment of Focal Epilepsy

J. Lahtinen, A. Koulouri, T. Erdbrügger, C. H. Wolters, S. Pursiainen

Non-invasive electrophysiological brain stimulation techniques such as tES and TMS can provide a potential alternative treatment for drug-resistant focal epileptic patients, when a surgical operation to remove the pathological tissue is not feasible. Choosing an appropriate stimulation montage is possible only if the location of the epileptogenic zone (EZ) is known sufficiently. Easiest for the patient is if EZ is localized non-invasively based on EEG/MEG measurements. Non-invasive EEG/MEG source localization, nevertheless, poses a challenging inverse problem the solution of which can be highly sensitive to selected model parameters [1,2].

We introduce a new standardized and adaptive Bayesian method which we show to (1) reconstruct focal sources accurately and (2) to perform robustly with respect to inherent model uncertainties. Our approach follows a hierarchical posterior distribution in which the model related free-parameters are automatically tuned as described in [3,4]. As we have shown previously, the present scheme allows us to obtain sparse vectors to represent the neural activity distribution. In particular, the solution is a pair (x, γ) which is obtained via an iterative algorithm that maximizes the posterior for x and the hyperparameter γ alternatingly while applying the standardization on each step.

We demonstrate through simulation that our approach localizes a focal epileptic zone for synthetic interictal EEG data. These simulation results are complemented with results obtained with experimental data comparing the source localization outcome to a reference zone designated by specialists. As comparison techniques we use Standardized Shrinking LORETA-FOCUSS (SSLOFO) and Standardized low-resolution brain electromagnetic tomography (sLORETA) which have been used successfully in localization of EZ both with ictal and interictal presurgical data [5,6,7]. Our results suggest that the proposed approach localizes EZ within 1 cm accuracy. We suggest that the reconstructions obtained are more focal compared to those obtained with sLORETA, consequently, making the localization less open to interpretation.

References

[1] M. B. H. Hall, et al. An evaluation of kurtosis beamforming in magnetoencephalography to localize the epileptogenic zone in drug resistant epilepsy patients. Clinical Neurophysiology. 129: 1221-1229, 2018.

[2] F. Neugebauer, et al. Validating EEG, MEG and combined MEG and EEG beamforming for an estimation of the epileptogenic zone in focal cortical dysplasia. Brain Sciences. 12: 114, 2022.

[3] A. Rezaei, et al. Parametrizing the conditionally Gaussian prior model for source localization with reference to the P20/N20 component of median nerve SEP/SEF. Brain Sciences. 10: 934, 2020.

[4] J. Lahtinen, et al. Conditionally Exponential Prior in Focal Near-and Far-Field EEG Source Localization via Randomized Multiresolution Scanning (RAMUS). Journal of Mathematical Imaging and Vision. 64:

587-608, 2022.

[5] A. J. R. Leal, et al. Analysis of the dynamics and origin of epileptic activity in patients with tuberous sclerosis evaluated for surgery of epilepsy. Clinical Neurophysiology. 119: 853-861, 2008.

[6] K. L. de Gooijer-van de Groep, et al. Inverse modeling in magnetic source imaging: comparison of MUSIC, SAM (g2), and sLORETA to interictal intracranial EEG. Human brain mapping. 34: 2032-2044, 2013.

[7] A. Coito, et al. Interictal epileptogenic zone localization in patients with focal epilepsy using electric source imaging and directed functional connectivity from low-density EEG. Epilepsia open. 4: 281-292, 2019.

EIT reconstruction using virtual X-rays and machine learning

Wed Sep 6
12:15 pm
ZHG Foyer

S. I. Rautio

The mathematical model of electrical impedance tomography (EIT) is the inverse conductivity problem introduced by Calderón. The aim is to recover the conductivity σ from the knowledge of the Dirichlet-to-Neumann map Λ_σ. It is a nonlinear and ill-posed inverse problem.

We introduce a new reconstruction algorithm for EIT, 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 DN map. 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 learn the nonlinear deconvolution-like operation. Finally, we can compute a reconstruction of the conductivity using the inverse Radon transform. We demonstrate the method with simulated data examples.

Combining Non-Data-Adaptive Transforms For OCT Image Denoising By Iterative Basis Pursuit

Wed Sep 6
12:15 pm
ZHG Foyer

R. Razavi, H. Rabbani, G. Plonka

Optical Coherence Tomography (OCT) images, as well as a majority of medical images, are imposed to speckle noise while capturing. Since the quality of these images is crucial for detecting any abnormalities, we develop an improved denoising algorithm that is particularly appropriate for OCT images. The essential idea is to combine two non-data-adaptive transform-based denoising methods that are capable to preserve different important structures appearing in OCT images while providing a very good denoising performance. Based on our numerical experiments, the most appropriate non-data-adaptive transforms for denoising and feature extraction are the Discrete Cosine Transform (DCT) (capturing local patterns) and the Dual-Tree Complex Wavelet Transform (DTCWT) (capturing piecewise smooth image features). These two transforms are combined using the Dual Basis Pursuit Denoising (DBPD) algorithm. Further improvement of the denoising procedure is achieved by total variation (TV) regularization and by employing an iterative algorithm based on DBPD.

Microlocal analysis of inverse scattering problems

Wed Sep 6
12:15 pm
ZHG Foyer

G. Samelsohn

Microlocal analysis has recently been shown to provide deep insight into the transformation of singularities and the origin of certain artifacts for a variety of tomographic imaging problems with limited data (X-ray CT, electron microscopy, SAR imaging, etc.). In this work, we report on an even more close relation between microlocal analysis and some inverse scattering problems. In particular, a new algorithm [1] proposed for tomographic imaging of impenetrable (e.g., perfectly conducting) scatterers is considered. The boundary value problem is converted into a volume integral equation, with a singular double-layer potential. Fourier-Radon inversion of the resulting far-field pattern is then applied to compute an indicator function. No approximations are made in the construction of the forward model and derivation of the inversion algorithm. Instead, some elementary facts of the microlocal analysis, in particular the pseudo-locality of the corresponding operator, are used to recover the support of the scattering potential, and therefore, the shape of the obstacle. Generalizations of this approach to tomographic imaging of the impedance-type and penetrable objects are also discussed.

References

[1] G. Samelsohn. Tomographic imaging of perfectly conducting objects. J. Opt. Soc. Am. A 40, 229-236: 2023.

Wed Sep 6
12:15 pm
ZHG Foyer

Dynamic Computerized Tomography using Inexact Models and Data-driven Motion Detection

G. Sarnighausen, A. Wald

Reconstructing a dynamic object with affine motion in computerized tomography leads to motion artefacts if the motion is not taken into account. The iterative RESESOP-Kaczmarz method can - under certain conditions - reconstruct dynamic objects at different time points even if the exact motion is unknown. However, the method is very time consuming. In order to speed the reconstruction process up and obtain better results, the following three steps are used:

1. RESESOP-Kacmarz with only a few iterations is implemented to reconstruct the object at different timepoints.
2. The motion is estimated via deep learning.
3. The estimated motion is integrated into the reconstruction process, allowing to use dynamic filtered backprojection.

Wed Sep 6
12:15 pm
ZHG Foyer

Gibbsian Polar Slice Sampling

P. Schär, M. Habeck, D. Rudolf

Polar slice sampling [2] is a Markov chain approach for approximate sampling of distributions that is difficult, if not impossible, to implement efficiently, but behaves provably well with respect to the dimension. By updating the directional and radial components of chain iterates separately, we obtain a family of samplers that mimic polar slice sampling, and yet can be implemented efficiently. Numerical experiments for a variety of settings indicate that our proposed algorithm significantly outperforms the two most closely related approaches, elliptical slice sampling [3] and hit-and-run uniform slice sampling [4]. We prove the well-definedness and convergence of our methods under suitable assumptions on the target distribution.

References

[1] P. Schär, M. Habeck, D. Rudolf. Gibbsian Polar Slice Sampling. arXiv preprint arXiv:2302.03945, 2023.

[2] G. O. Roberts, J. S. Rosenthal. The Polar Slice Sampler. Stochastic Models 18(2):257-280, 2002.

[3] I. Murray, R. Adams, D. MacKay. Elliptical Slice Sampling. Journal of Machine Learning Research 9:541-548, 2010.

[4] D. MacKay. Information Theory, Inference and Learning Algorithms, Cambridge University Press, 2003.

Hybrid knowledge and data-driven approaches for DOT reconstruction in medical imaging

Wed Sep 6
12:15 pm
ZHG Foyer

A. Serianni

Diffuse Optical Tomography (DOT) is an emerging medical imaging technique which employs NIR light to estimate the spatial distribution of optical coefficients in biological tissues for diagnostic purposes, in a non-invasive and non-ionizing manner. NIR light undergoes multiple scattering throughout the tissue, making DOT reconstruction a severely ill-conditioned problem [1]. In this contribution, we present our research in adopting hybrid knowledge-driven/data-driven approaches which combine the use of well-known physical models with deep learning techniques integrating the collected data. Our main idea is to leverage neural networks to solve PDE-constrained inverse problems of the form

$$\theta^* = \arg\min_{\theta} \mathcal{L}(y, \tilde{y}) \tag{1}$$

where $\mathcal{L}$ is a loss function which typically contains a discrepancy measure (or data fidelity) term as well as prior information on the solution. In the context of inverse problems like (1), one seeks the optimal set of physical parameters θ, given the set of observations y. Moreover, $\tilde{y}$ is the computable approximation of y, which may be both obtained from a neural network and in a classic way via the resolution of a PDE with given input coefficients. The idea underlying our approach is to exploit Graph Neural Networks (GNNs) as a fast forward model that solves PDEs: after an appropriate construction of the graph on the spatial domain of the PDE, the message passing framework allows to directly learn the kernel of the network which approximates the PDE solution [2]. Due to the severe ill-conditioning of the reconstruction problem, we also learn a prior over the space of solutions using an auto-decoder type network which maps the latent code to the estimated physics parameter that is passed to the GNN to finally obtain the prediction.

References

[1] A. Benfenati, G. Bisazza, P. Causin. A Learned SVD approach for Inverse Problem Regularization in Diffuse Optical Tomography, arXiv preprint arXiv:2111.13401, 2021.

[2] Q. Zhao, D.B. Lindell, G. Wetzstein. Learning to Solve PDE-constrained Inverse Problems with Graph Networks, arXiv preprint arXiv:2206.00711, 2022.

Reconstruction of the potential in a hyperbolic equation in dimension 3

Wed Sep 6
12:15 pm
ZHG Foyer

F. N. Sylla, M. Ngom, M. Ndiaye, D. Seck

In this paper, we consider the wave equation $\partial_{tt}v(x,t) - \Delta v(x,t) + p(x)v(x,t) = 0$ in $B \times (0,T)$, where B is the unit ball in $\mathbb{R}^3$ and, $T > 0$. We are interested in the inverse problem of identifying the potential $p(x)$ from the Cauchy data $(f, \partial_n v)$ where f is all possible functions on the boundary $\partial B \times (0,T)$ and $\partial_n v$ the measurements of the normal derivative of the solution of the wave on $\partial B \times (0,T)$ associated to f.

Using spherical harmonics tools and an explicit formula for the Dirichlet-to-Neumann map Λ_p which associates to all f the measurements $\partial_n v$ in a unit ball in dimension 3, we determine an explicit expression for the potential $p(x)$ on the domain edge. We present theoretically and numerically an example.

Wed Sep 6
12:15 pm
ZHG Foyer

Frequentist Ensemble Kalman Filter

M. Tienstra, S. Reich

We are interested in the Tikhonov type regularization of statistical inverse problems. The main challenge is the choice of the regularization parameter. Hierarchical Bayesian methods and Bayesian model selection give us theoretical understanding of how the regularization parameters depend on the data. One popular way to solve statistical inverse problems is using the Ensemble Kalman filter (EnKF). We formulate a frequentist version of the continuous time EnKF, which brings us to the well known bias and variance tradeoff of our estimator dependent upon the regularization parameter. From here we can reformulate the choice of regularization parameter as a choice of stopping time dependent on estimation of the residuals. We are not only interested in recovering a point estimator, as in the case of optimization, but in the ability to correctly estimate the spread of the posterior. We numerically and theoretically explore this through the infinite dimensional linear inverse problem, and a non-linear inverse problem arising from the Schrödinger equation. This is joint work with Prof. Dr. Sebastian Reich. This research has been partially funded by the Deutsche Forschungsgemeinschaft (DFG)- Project-ID 318763901 - SFB1294.

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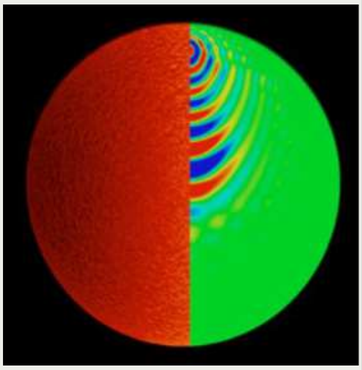

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