Computational Imaging: Theory, Algorithms, and Learning

Session program

Dolomites Research Week on Approximation and Applications 2026 (DRWAA26)

31.08-04.09.2026, Bressanone (BZ), Italy

Organizers: Tatiana Alessandra Bubba, Wolfgang Erb and Chiara Razzetta

Last update: August 28, 2026

List of participants

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Schedule

	Mon. 31th	Tue. 1st	Wed. 2nd	Thu. 3rd	Fri. 4th
9:00 – 10:00					
10:30 – 12:30		Guidetti Palumbo Perracchione		Elefante Erb	
16:00 – 18:00		Bubba Weinmann		Campi Razzetta	

List of contributions

Tatiana Alessandra Bubba: *Sparse dynamic tomography through multiscale representation systems* 2

Cristina Campi: *Identifiability in Compartmental Modeling of [18F]FDOPA Kinetics in the Cerebellum* 3

Giacomo Elefante: *hp-adaptive trees for graph signal approximation* 4

Wolfgang Erb: *Morphological imaging based on max-min operations* 5

Alessia Guidetti: *Adaptive group-sparse regularization for Poisson linear inverse problems* 6

Barbara Palumbo: *Inverse Problems in Probability Spaces* 7

Emma Perracchione: *Greedy Optimal Sampling via Variably Scaled Kernels for Solar Inverse Problems (GOSSIP)* 8

Chiara Razzetta: *A Wasserstein Weisfeiler–Lehman Kernel Framework for Multimodal Brain Connectome Analysis* 9

Andreas Weinmann: *MPI Reconstruction Using a Debye Magnetization Model* 10

Sparse dynamic tomography through multiscale representation systems

Tatiana Alessandra Bubba
Dipartimento di Matematica e Informatica, Università degli Studi di Ferrara, Ferrara, Italy

Abstract: Multiscale representation systems, such as shearlets, excel at capturing complex directional features in multi-dimensional signals like images and video sequences. When applied to ill-posed imaging inverse problems, these representations provide powerful sparsity-promoting priors that outperform traditional systems, such as separable wavelets, in preserving sharp spatio-temporal boundaries and moving interfaces. In this talk, I present a motion-aware variational regularization approach tailored for dynamic tomography using cylindrical shearlets, a novel multiscale directional system designed specifically for spatio-temporal data. By modeling nonstationary targets as joint spatio-temporal objects, the proposed strategy efficiently couples static time-frame data fidelity with cylindrical shearlet regularization. After briefly touching upon the theoretical foundations of this framework, I demonstrate on both simulated and measured data that our method provides a robust, highly efficient strategy for reconstructing moving objects from sparse dynamic data.

Identifiability in Compartmental Modeling of [18F]FDOPA Kinetics in the Cerebellum

Cristina Campi
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Abstract: [18F]FDOPA PET is widely used to study presynaptic dopaminergic function, with the cerebellum commonly used as a reference region. Its kinetics are typically described by a two-tissue compartmental model accounting for FDOPA and its peripheral metabolite 3-OMFD, following Huang et al. (1991). Despite its relative simplicity, this model raises open questions concerning parameter identifiability, since the two sub-systems share similar transport kinetics and are driven by strongly correlated plasma inputs, making parameter estimation potentially ill-conditioned.

This work aims to investigate the structural and practical identifiability of the cerebellar FDOPA compartmental model, and to study the numerical issues involved in its estimation, including the sensitivity of the parameters to the input function (arterial vs. image-derived) and to the sampling schedule. We plan to compare the full model with simplified formulations to assess the trade-off between model flexibility and identifiability.

hp-adaptive trees for graph signal approximation

Giacomo Elefante
Università della Svizzera Italiana, Lugano, Switzerland

Abstract: Tree-encoded partitionings of graphs are key tools for decomposing and approximating graph signals, enabling wavelet-type structures like graph wedgelets. Standard top-down tree constructions, such as fixed hierarchical partitioning or adaptive greedy splitting, typically rely on constant local approximations. Despite being fast, in order to achieve high accuracy, it requires a large number of domain decompositions. To improve efficiency while maintaining accuracy, we introduce optimization strategies based on *hp*-refinements, combining domain decompositions with higher-degree polynomial approximations. We model this refinement process as a binary knapsack problem to extract an optimal, low-complexity subtree from the full partitioning tree while preserving the total error bound. Additionally, we present an a-posteriori strategy that prunes the partitioning tree by optimizing polynomial degrees across subdomains. To make polynomial bases accessible for general or high-dimensional graphs, we embed local graph patches into low-dimensional Euclidean spaces.

Morphological imaging based on max-min operations

Wolfgang Erb
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Abstract: We build and study a conceptual bridge between morphological imaging and max-min sampling operators. This connection will allow us to obtain new insights into the interrelations between continuous and discrete morphological processes, and the convergence behavior of discrete morphological transformations. To this end, we introduce and analyze non-linear sampling operators based on the arithmetic operations of the max-min algebra. These new sampling operators can be interpreted as approximate morphological operations relying on the function values on a chosen sampling grid and a specific kernel. We investigate the convergence behavior of these operators, alongside with the respective properties of their morphological operations as dilation, erosion, opening and closing. In the two-dimensional setting, we show how these morphological sampling operators can be effectively applied to various image processing tasks, such as upscaling, denoising, or segmentation.

This is joint work with İsmail Aslan, Department of Mathematics, Hacettepe University, Turkey

Adaptive group-sparse regularization for Poisson linear inverse problems

Alessia Guidetti
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Abstract: Poisson inverse problems arise in many scientific imaging applications where measurements correspond to photon counts. In many such settings, the unknown variables are organized into groups, and only a subset of these groups is expected to be active, leading to structured sparsity. In this work, we propose a group-sparse regularization approach for Poisson inverse problems with a linear forward operator. Unlike classical Group Lasso theory developed for Gaussian models or canonical generalized linear models, we focus on physically motivated inverse problems where counting noise is intrinsically coupled with a signal-formation process that depends linearly on the unknown parameters. We formulate the reconstruction problem as a convex variational problem, combining a quadratic approximation of the Kullback–Leibler divergence [1] with an ℓ_1/ℓ_2 mixed-norm penalty to promote group sparsity. We show that the resulting estimator, called the Poisson Re-weighted Adaptive Group Lasso (PRAGL), achieves model selection consistency. We apply this method to image reconstruction from data acquired by the Spectrometer/Telescope for Imaging X-rays (STIX) [2] onboard the ESA Solar Orbiter mission, which observes X-ray emission from solar flares produced by hot plasma. The measurements are Poisson-distributed and depend linearly on the plasma distribution, while physical considerations suggest that only a few temperature components are active [3], naturally motivating a group-sparse regularization approach. Numerical experiments on simulated and real STIX data show that our method identifies the active temperature groups and yields stable, physically meaningful reconstructions.

References

[1] S. Guastavino and F. Benvenuto, A consistent and numerically efficient variable selection method for sparse Poisson regression with applications to learning and signal recovery. Statistics and Computing (2019).

[2] S. Krucker, et al. The spectrometer/telescope for imaging X-rays (STIX). Astronomy & Astrophysics (2020) 642.

[3] A. Caspi, A.Y. Shih, J.M. McTiernan, and S. Krucker, Hard X-Ray imaging of individual spectral components in solar flares. The Astrophysical Journal Letters (2015) 811.

Inverse Problems in Probability Spaces

Barbara Palumbo
Dipartimento di Matematica, Università degli Studi di Genova, Genova, Italy

Abstract: In this presentation we introduce the study of inverse problems in probability spaces. Starting from operators defined between Hilbert spaces, we show how the inverse problem can be reformulated within spaces of probability measures. This framework provides a unified approach that covers three classical framework: the deterministic setting, where both the solution and the noise are modeled as Dirac measures; the frequentist setting, where the solution is deterministic while the noise is modeled as a random variable; and the Bayesian setting, where both the solution and the noise are treated as random variables. We begin by introducing the notions of well-posedness, ill-posedness, and generalized inverses within this probabilistic framework, and then turn to regularization methods. In particular, we extend Tikhonov regularization theory to probability spaces and establish convergence rates generalizing the classical deterministic results, analyzing rates both with respect to weak convergence and with respect to the Wasserstein metric. Finally, we show that incorporating additional structural information on the noise can lead to improved convergence rates, highlighting the advantages of the probabilistic framework for the analysis of inverse problems.

Greedy Optimal Sampling via Variably Scaled Kernels for Solar Inverse Problems (GOSSIP)

Emma Perracchione
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Abstract: We present a framework for solving inverse problems in solar physics using adaptive kernel-based methods. This approach combines Variably Scaled Kernels (VSKs) with greedy sampling strategies, enabling efficient reconstruction of solar phenomena from sparse, noisy data. VSKs adapt the shape of basis functions using spatially varying scale functions, enhancing resolution in areas with rapid variations while simplifying smoother regions. The greedy algorithm features an automatic stopping criterion based on Stein's Unbiased Risk Estimate (SURE), balancing approximation accuracy with model complexity without needing the true solution. Theoretical analysis confirms convergence rates and error bounds for the greedy VSK approximation. Numerical tests on STIX flare data show that this method achieves comparable or superior accuracy to leading approaches while reducing computational costs.

A Wasserstein Weisfeiler–Lehman Kernel Framework for Multimodal Brain Connectome Analysis

Chiara Razzetta
AOM - IRCCS Ospedale Policlinico San Martino, Genova, Italy

Abstract: Multimodal neuroimaging poses a genuine computational-imaging problem: structural (DTI) and functional (fMRI) connectivity capture complementary aspects of brain organization, yet standard multilayer-network approaches fuse them through an externally fixed interlayer coupling, leaving the two modalities analytically separable. We present a graph-kernel framework that instead encodes each subject as a single attributed graph, with DTI defining the propagation topology and fMRI supplying the node attributes to be propagated. Multi-scale node embeddings are obtained via Weisfeiler–Lehman-style neighbourhood averaging along the structural scaffold, and inter-subject similarity is measured by the Wasserstein distance between the resulting point clouds, yielding a positive-definite kernel with no interlayer parameter to estimate. On a synthetic cohort of 600 subjects built from six independently-seeded structural templates the kernel achieves balanced accuracy 0.807 ± 0.033 ($p < 0.001$) under nested cross-validation, outperforming five internal ablations and two independent graph-classification baselines. The embedding shift induced by structural propagation is unevenly distributed across resting-state networks, concentrated in Visual and Default-mode regions, and correlates in a coherent, monotone order with four independent clinical variables not used to build the kernel, providing region- and biomarker-level interpretability as a direct byproduct of the kernel computation. We discuss the theoretical role of optimal transport in this construction, algorithmic aspects of the propagation operator, and the learning pipeline (nested calibration of kernel bandwidth, depth, and SVM regularization), and outline ongoing validation on real neuroimaging data.

MPI Reconstruction Using a Debye Magnetization Model

Andreas Weinmann
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Abstract: Magnetic Particle Imaging is an emerging imaging modality which uses the non-linear magnetization behavior of superparamagnetic nanoparticles as a tracer. The basic Langevin magnetization model is simple and can capture most of the relation between the measured signal and the particle distribution although it does not model any relaxation effects. The Debye magnetization model accounts for such effects by modeling also the delay in the alignment of the nanoparticles to the magnetic field. By incorporating the Debye model into our reconstruction method we obtain improved reconstruction results in relevant scenarios. We provide examples showing the results of our reconstruction algorithm based on the Debye model.