Computational Methods in Medical Imaging (CEMI)

Session program

Dolomites Research Week on Approximation and Applications 2025 (DRWAA25)

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Organizers: Cristina Campi and Wolfgang Erb

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List of participants

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- Sara Sommariva, Università di Genova, sara.sommariva@unige.it
- Andreas Weinmann, Darmstadt University of Applied Sciences, andreas.weinmann@h-da.de

Schedule

	Mon. 8th	Tue. 9th	Wed. 10th	Thu. 11th	Fri. 12th
9:00 – 10:00					
10:30 – 12:30		Campi Erb		Benvenuto Palumbo März	
16:00 – 18:00	Gazzola Sommariva Karimnejad Esfahani	Pedemonte Gapyak			

List of contributions

Federico Benvenuto: *Risk-based estimation of hyperparameters for computational techniques: an application to pipeline algorithms of the DHEAL-COM project* 2

Cristina Campi: *Compartmental model for FDG consumption in cancer metabolism* . . 3

Wolfgang Erb: *Morphological image processing with max-min sampling operators* 4

Vladyslav Gapyak: *Model-Based Reconstructions in Magnetic Particle Imaging* 5

Silvia Gazzola: *New flexible and inexact Krylov solvers for inverse problems* 6

Thomas März: *Higher Order Variational Techniques for Model-Based Reconstruction in Magnetic Particle Imaging* 7

Barbara Palumbo: *Convergence rates for Tikhonov regularization on compact sets: application to neural network* 8

Daniele Pedemonte: *Neural radiance fields as a regularization approach to inverse volume rendering* 9

Sara Sommariva: *Statistical approaches for identifying differences in brain functional connectivity graphs.* 10

Risk-based estimation of hyperparameters for computational techniques: an application to pipeline algorithms of the DHEAL-COM project

Federico Benvenuto
Dipartimento di Matematica, Università di Genova, Genova, Italy

Abstract: This work addresses the recovery of unknown signals from noisy observations using regularization. Traditional parameter-choice methods such as GCV and UPRE often select parameters that are too small, leading to overfitting, especially with limited data or high noise. To address this, the authors propose a strategy based on a lower bound for the predictive risk, assuming knowledge of the data norm. The method introduces a function balancing data fidelity and regularization, whose minimizer yields a reliable estimate of the optimal parameter. We prove that this method avoids overfitting, ensures stability across noise realizations, and depends only on the signal-to-noise ratio (SNR), without requiring the true solution. Three practical strategies are presented, depending on whether the SNR is known or must be estimated. The approach is intended for integration into the DHEAL-COM project's WP4 data-processing pipelines, enabling robust and adaptive computational workflows in proximity medicine applications.

Compartmental model for FDG consumption in cancer metabolism

Cristina Campi
Dipartimento di Matematica, Università di Genova, Genova, Italy
IRCCS Ospedale Policlinico San Martino, Genova, Italy

Abstract: In this talk I will present how computational method for the creation of parametric maps from dynamic Positron Emission Tomography (PET) data can have an effect on the diagnostic interpretation of PET images and the localization accuracy of tumoral lesions. We test the software tool on 13 subjects, and we studied how the estimated K values change using different acquisition window. In particular, we look what happens in a tumoral region, considered as the volume with a "standardized uptake value" (SUV) higher than the 40% of the maximum value is the lesion. The time-resolved Patlak analysis based on progressively delaying the starting point, documented the existence of a significant amount of releasing voxels, i.e., with consistently negative K values. The findings suggest that extending the analysis of FDG uptake across the time domain could enhance the informational value of PET/CT imaging, for assessing and monitoring therapy effectiveness.

Morphological image processing with max-min sampling operators

Ismail Aslan, Wolfgang Erb
University of Padova, Padova, Germany

Abstract: As part of the PRIN 2022 CEMI project on Computational Methods in Medical Imaging, I will present joint work with Ismail Aslan (Hacettepe University) on max–min sampling operators. These operators generalize classical linear sampling operators in Euclidean spaces by replacing addition and multiplication with the maximum and minimum operations. This modification makes the operators non-linear, positive, and monotone. These features make them, on the one hand, more complex and mathematically challenging, but on the other hand also particularly well suited for image processing, as they are able to preserve the edge structure of images.

The action of max–min operators on images closely parallels fundamental operations from morphological image analysis, such as dilation and erosion. In this talk, we will present approximation-theoretic results for these operators, including convergence properties under suitable smoothness assumptions on the underlying function. From an applied perspective, we will demonstrate how max–min operators can be adapted to realize dilation, erosion, opening, and closing in the context of morphological image analysis, and how these operations can serve as effective preprocessing tools for biomedical image denoising and edge detection.

Model-Based Reconstructions in Magnetic Particle Imaging

Vladyslav Gapyak
University of Applied Sciences Darmstadt, Darmstadt, Germany

Abstract: Magnetic Particle Imaging (MPI) is a novel medical imaging modality that allows to visualize the spatio-temporal distribution of magnetic nanoparticles injected into the body. Applications of the modality range from early cancer detection to real-time cardiovascular monitoring. The reconstruction of the particle distributions is presently obtained by inversion of a measured system matrix which is obtained via a time-consuming calibration. To avoid time-consuming calibrations, and to advance this modality, model-based solutions to the image reconstruction problems are of interest. Recently, a method based on Chebyshev polynomials was proposed for multi-dimensional MPI; this method strongly depends on the choice of sinusoidal scanning trajectories. In this talk, we describe our two-stage algorithm based on a reconstruction formula, which is able to reconstruct the signal independently of the choice of the scanning trajectory. We demonstrate the performance of our method on real 2D MPI data.

New flexible and inexact Krylov solvers for inverse problems

Silvia Gazzola
Dipartimento di Matematica, Università di Pisa, Pisa, Italy

Abstract: This talk introduces a new class of algorithms for solving large-scale linear inverse problems based on new flexible and inexact Golub-Kahan factorizations. The proposed methods iteratively compute regularized solutions by approximating a solution to (re)weighted least squares problems via projection onto adaptively generated subspaces, where the constraint subspaces are formally equipped with iteration-dependent preconditioners or inexactness. Although this framework is particularly suited for handling general data fidelity functionals, e.g., those expressed in the p-norm, its use is also discussed in the context of problems with unmatched transposes. The new solvers offer a flexible and inexact Krylov subspace alternative to other existing Krylov-based approaches. Numerical experiments in imaging applications, such as deblurring and computed tomography, highlight the effectiveness and competitiveness of the proposed methods with respect other popular methods.

Higher Order Variational Techniques for Model-Based Reconstruction in Magnetic Particle Imaging

Vladyslav Gapyak, Thomas März and Andreas Weinmann
University of Applied Sciences Darmstadt, Darmstadt, Germany

Abstract: In computational imaging, variational reconstruction techniques commonly use mathematical models to describe the underlying physics. Magnetic Particle Imaging (MPI), the application considered here, is an imaging modality which exploits the non-linear magnetization behavior of super-paramagnetic nano-particles to applied magnetic fields. MPI has gained significant research interest over the last 15 years. Current multivariate MPI image reconstruction typically relies on a system matrix. However, acquiring this matrix through calibration is both time-consuming and requires extensive storage. Model-based approaches, conversely, use mathematical models of the signal generation and recording process to exploit inherent structures. Here, we present an MPI image reconstruction algorithm which works in two main steps: first, we reconstruct the MPI Core Operator's components in the core-stage. This is a data approximation problem, formulated variationally. Second, in the deconvolution-stage we robustly solve a deconvolution problem, using the output from the core-stage as data, to produce the final reconstructed image. We provide examples to showcase the results of our algorithm.

Convergence rates for Tikhonov regularization on compact sets: application to neural network

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Abstract: In this presentation, we introduce a novel regularization method for ill-posed inverse problems, based on a sequence of compact sets that becomes dense in the solution space. This approach is inspired by selection methods and the classical Ritz method. The key idea is to approximate the solution within an increasing family of compact subsets by minimizing the classical Tikhonov functional over each set. We analyze the convergence rates of the method and show that, if the compact sets become dense sufficiently fast, we recover the classical convergence rates of Tikhonov regularization. Moreover, in the linear case, we obtain optimal convergence rates under standard source conditions. Finally, we apply this framework to neural networks, which are employed in a novel way within inverse problems as a tool to parametrize the solution by leveraging the powerful technique of 'positional encoding'. This leads to a new perspective on how neural networks can contribute to the regularization of ill-posed problems.

Neural radiance fields as a regularization approach to inverse volume rendering

Daniele Pedemonte
Dipartimento di Matematica, Università di Genova, Genova, Italy

Abstract: Inverse volume rendering poses a significant challenge in reconstructing density and color functions from real-world observations, particularly due to the non injectivity of the problem. This study addresses this issue by introducing a unique criterion to ensure a well-defined solution. We explore the connection between classical regularization, specifically the Selection method, and modern neural network approaches. Our methodology integrates minimum support regularization with a novel technique to achieve sharper density estimates, complemented by a georeferencing pipeline that aligns reconstructed point clouds with planar cartographic data.

Statistical approaches for identifying differences in brain functional connectivity graphs.

Sara Sommariva
Dipartimento di Matematica, Università di Genova, Genova, Italy

Abstract: Functional connectivity (FC) analysis of electroencephalography (EEG) data characterizes statistical dependencies between spatially distinct brain regions, and comparative analysis of FC graphs can reveal group-level alterations in neural organization associated to brain disorders such as Dementia with Lewy Body (Carini et al., submitted). In this talk, I will present two statistical strategies for such comparisons. The first approach leverages classical statistical tools (Zalesky et al., 2010) to identify connected subgraphs that show significant between-group differences from adjacency matrices derived from frequency-domain FC metrics. The second approach is a novel neighbour selection approach based on conditional functional graphical regression models. The performance of both approaches are discussed using simulated and experimental EEG time-series.

References

L. Carini et al., Network based statistics shows that rem sleep behavior disorder and visual hallucinations increase functional connectivity in early dementia with Lewy bodies. Submitted to npj Parkinson's Disease

A. Zalesky et al., Network-based statistic: identifying differences in brain networks., 2010, NeuroImage