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Minisymposia Presentations Abstracts

MS1 Inverse scattering and electrical impedance tomography

Organizers:
Nuutti Hyvönen (*Aalto University*)
Roland Griesmaier (*Karlsruhe Institute of Technology*)

MS1-1 - Tuesday, 05 at 13:30 Room P (Palazzina B - Building B, floor 0)

A MUSIC scheme for impedance imaging using multiple AC frequencies
We investigate a multifrequency impedance imaging technique that has recently been suggested for mammography screenings. This MUSIC type technique uses boundary voltages generated by time harmonic (AC) boundary currents with the same spatial distribution but different driving frequencies. We prove that the method will always find a single small focal lesion in two or three space dimensions. Concerning the two dimensional case we also discuss the potential of the method to find and separate multiple inclusions.

- Martin Hanke (*Johannes Gutenberg-Universität Mainz*)

Detecting indefinite inclusions using the Complete Electrode Model
I will consider the detection of indefinite inclusions in electrical impedance tomography. Thus, there are both more and less conductive inhomogeneities, compared to a reference conductivity, and I seek to approximate the support of these inhomogeneities. I will use the Complete Electrode Model as an approximation to the exact monotonicity method in the continuum setting, and show that asymptotically, as noise and model errors decay, the exact outer shape of the inclusions is reconstructed.

- Henrik Garde (*Aalborg University*)
  Stratos Staboulis (*Eniram Oy*)

Monotonicity-based inverse scattering
This work extends monotonicity-based methods in inverse problems to the case of the Helmholtz (or stationary Schrödinger) equation for fixed non-resonance frequency and real-valued scattering coefficient function. We show a new monotonicity relation between the scattering coefficient and the local Neumann-Dirichlet operator that holds up to finitely many eigenvalues. Combining this with the method of localized potentials, we derive a new local uniqueness result, and a constructive monotonicity-based characterization of scatterers from partial boundary data.

- Bastian Harrach (*Goethe-Universität Frankfurt am Main*)
  Valter Pohjola (*University of Jyväskylä*)
  Mikko Salo (*University of Jyväskylä*)

Multifrequency inverse source problems and a generalization of Prony's method
We consider a multifrequency inverse source problem for time-harmonic acoustic or electromagnetic waves. Assuming that far field measurements of the wave radiated by a collection of compactly supported sources are available across a whole frequency band but only at a few observation directions, we develop a non-iterative reconstruction scheme to locate

the support of the sources. The method produces a union of convex polygons that approximate the positions and the geometry of well-separated source components.

- Roland Griesmaier (*Karlsruhe Institute of Technology*)
  Christian Schmiedecke (*Universität Würzburg*)

MS1-2 - **Tuesday, 05 at 16:00** Room P (Palazzina B - Building B, floor 0)

On identifiable spectra related to shapes and material properties
We shall discuss how one can identify (artificial) transmission eigenvalues in the Born approximation regime. The application of the linear sampling method to identifying these frequencies from farfield data gives a way to construct spectra associated with images that have nice properties in terms of invariant representations.

- Houssem Haddar (*INRIA & Ecole Polytechnique*)

A spectral method to detect perfect invisibility in waveguides
We consider the propagation of waves in a waveguide with a localized defect. We propose a spectral approach to compute, for a given setting (geometry, material properties,...), frequencies for which there is an incident field such that the associated scattered field is null at infinity. In such a situation, the defect can not be identified from measurements made with devices located far from it. In other words it is invisible to the incident field.

- Lucas Chesnel (*Inria/Ecole Polytechnique*)

Exterior approach for finding defects in the wave equation
We focus on the reconstruction of defects, characterized by a Dirichlet condition, in a medium governed by the wave equation, from a single Cauchy boundary measurement. Our approach relies on the coupling of a non-standard level set method and a new version of the quasi-reversibility method adapted to the wave equation. We present several numerical results to illustrate the efficiency of the method. This is a joint work with Laurent Bourgeois and Dmitry Ponomarev.

- Jeremi Darde (*Universite Paul Sabatier*)

On the separation of potential fields as an inverse source problem in geomagnetism
The main challenge with geomagnetic satellite data is the separation into its different contributions. Here, we focus on separating the core magnetic field from the crustal magnetic field by modeling both contributions as potential fields generated on spheres of different radii. Under the assumption that there is a layer of zero conductivity between the two spheres and that the magnetization on the outer sphere is locally supported, we show that the two contributions can be distinguished uniquely from knowledge of the overall magnetic field on a third exterior sphere (satellite orbit). Additionally, we provide an approach to approximating the Fourier coefficients of either contribution.'

- Christian Gerhards (*University of Vienna*)

MS2 Interpolation and Approximation Methods in Imaging

Organizers:
Alessandra De Rossi (*University of Torino*)
Costanza Conti (*University of Firenze*)
Francesco Dell'Accio (*University of Calabria*)

MS2-1 - **Tuesday, 05 at 13:30** Room 2 (Redenti, floor 1)

Patch-based dictionary learning for sparse image approximation
We propose a new regularization method for sparse representation and denoising of seismic data. Our approach is based on a sparse data representation in a learned dictionary and a similarity measure for image patches that is evaluated using the Laplacian matrix of a graph. We propose dictionary learning algorithms based on clustering and singular value decomposition. We also consider a similarity measure for the local geometric structures of the data.

- Gerlind Plonka (*University of Goettingen*)

Adaptive filtering in Magnetic Particle Imaging via Lissajous sampling
Polynomial interpolation and approximation methods on sampling points along Lissajous curves using Chebyshev series is an effective way for a fast image reconstruction in Magnetic Particle Imaging (MPI). We introduce Lissajous sampling and classical filtering techniques in one and several dimensions. We then present an adaptive spectral filtering process for the reduction of the Gibbs phenomenon and for an improved approximation of the underlying function or image. In this adaptive filtering technique, the spectral filter depends on the distance of a spatial point to the nearest discontinuity. We show the effectiveness of this filtering approach in theory, in numerical simulations as well as in the application in Magnetic Particle Imaging.

- Stefano De Marchi (*University of Padova*)
  Wolfgang Erb (*University of Hawaii at Manoa*)
  Francesco Marchetti (*University of Padova*)

Performance bounds for co-/sparse box constrained signal recovery

The recovery of structured signals from few linear measurements is a central point in both compressed sensing (CS) and discrete tomography. In CS the signal structure is described by means of a low complexity model like e.g. co-/sparsity. The CS theory shows that any signal/image can be undersampled at a rate dependent on its intrinsic complexity. Moreover, in such undersampling regimes the signal can be recovered by sparsity promoting convex regularisation like e.g. l1- or total variation (TV-) minimization. Precise relations between many low complexity measures and the sufficient number of random measurements are known for many sparsity promoting norms. However, a precise estimate of the undersampling rate for the TV seminorm is still lacking. We address this issue by: a) providing dual certificates for testing uniqueness of a given cosparse signal with bounded signal values, b) approximating the undersampling rates via the statistical dimension of the TV descent cone and c) showing empirically that the provided rates also hold for tomographic measurements.

Jan Kuske (*Heidelberg University*)
- Stefania Petra (*University of Heidelberg*)

Near-best quartic C^2 spline quasi-interpolation for volume data reconstruction

We present a new approach to reconstruct volume data by non-discrete models. As a model, we use a family of "near-best" spline quasi-interpolants based on trivariate C^2 quartic box splines and obtained by minimizing an upper bound of their infinity norm. We show the uniqueness of the problem solution, that we explicitly give, we discuss the optimal approximation properties of our model and we present some numerical tests and applications with real world volume data.

Domingo Barrera (*Department of Applied Mathematics, University of Granada*)
Catterina Dagnino (*University of Torino*)
María José Ibáñez (*Department of Applied Mathematics, University of Granada*)
Paola Lamberti (*University of Torino*)
- Sara Remogna (*University of Torino*)

MS2-2 - **Tuesday, 05 at 16:00** Room 2 (Redenti, floor 1)

Image reconstruction from scattered data by kernel methods

A novel method for the reconstruction of images from a finite set of Radon data is presented. The method is based on kernel approximation techniques, so that we can deal with data collected at arbitrary scattered locations. In particular, applications to missing data scenarios and greedy-based sparse selection of data will be discussed.

- Gabriele Santin (*University of Stuttgart*)

Landmark-based image registration using radial kernels

Topology preservation is a necessary condition to be satisfied, especially for landmark-based image registration. Here, we focus on two different families of radial kernels, known as Gneiting and Matérn kernels. So, taking a number of landmarks, we analyze topology preservation and registration properties of these two families of kernels. Finally, we show some results considering test examples and real applications.

- Roberto Cavoretto (*University of Torino*)
Alessandra De Rossi (*University of Torino*)
Hanli Qiao (*University of Torino*)

RBF methods for edge detection

Edge detection is a widely used tool for identifying abrupt changes or discontinuities in a signal/digital image. It is well-known that Radial Basis Functions (RBFs) are a powerful tool in data interpolation/approximation. We discuss their use in edge detection and propose new techniques based on variably scaled kernels and on the identification of the local maxima of the absolute values of the interpolation coefficients. Some numerical examples illustrate the effectiveness of the proposed techniques.

Lucia Romani (*University of Milano-Bicocca*)
- Milvia Rossini (*University of Milano-Bicocca*)
Daniela Schenone (*University of Milano-Bicocca*)

On a regularized approach for the method of fundamental solution

The method of fundamental solution is a boundary meshless method recently adopted in the framework of non-invasive neuroimaging techniques. The method approximates the solution of a BVP by a linear combination of fundamental solutions of the governing PDE. A crucial feature of the method is the placement of the fictitious boundary to avoid the singularities of fundamental solutions. In this paper we report on our experiences with a regularized MFS method in the neuroimaging context.

Guido Ala (*University of Palermo*)
Gregory Fasshauer (*Colorado School of Mines*)
Elisa Francomano (*University of Palermo*)
Salvatore Ganci (*Worldenergy SA, Greenconnector*)
Michael McCourt (*SigOPT, San Francisco*)
- Marta Paliaga (*University of Palermo*)

MS2-3 - **Wednesday, 06 at 13:00** Room 2 (Redenti, floor 1)

On Shannon sampling operators in Imaging

A natural application of Shannon sampling operators is imaging. We can represent a discrete image as a continuous function using generalized Shannon sampling series. Many image resizing (resampling) algorithms use such type of representation. We consider sampling operators with kernels, mostly bandlimited, defined as Fourier' transform of certain window function. We study approximation properties of such sampling operators and show some applications of the sampling operators in image superresolution algorithms.

- Gert Tamberg (*Tallinn University of Technology*)

Numerical methods for Mellin integral equations with applications in Imaging Science

The talk is devoted to the study of suitable Nystrom Methods, based on global polynomial approximation, for boundary integral equations of second kind. An application to the planar radiosity equation will be given. This approach represents a first step in the study of the spatial radiosity equation, which relates the brightness at points of a surface to the reflectivity and emissivity at such points, and also to the geometric shape of the surface.

Donatella Occorsio (*University of Basilicata*)
- Maria Grazia Russo (*University of Basilicata*)

Approximation results for prototyping

The aim of this talk is to provide approximation results that, using sampling type operators and digital image processing algorithms, provide concrete applications both in the medical and engineering fields. In particular it will be shown how some of these results could be useful for the prototyping of dental arches starting by cone beam CT-images.

- Gianluca Vinti (*University of Perugia*)

Hexagonal Shepard method for scattered data interpolation

Lagrange interpolation of functions by quadratic polynomials on nodes which are vertices of a triangulation has been recently studied and local six-tuples of vertices which assure the uniqueness and the optimal-order of the interpolation polynomial are known. Following Little's idea and theoretical results on the approximation order and accuracy of the triangular Shepard method, we introduce an hexagonal Shepard operator with quadratic precision and cubic approximation order for scattered data approximation without least square fit.

Francesco Dell'Accio (*University of Calabria*)
- Filomena Di Tommaso (*University of Calabria*)

MS2-4 - **Wednesday, 06 at 15:30** Room 2 (Redenti, floor 1)

Object separation in videos by means of adaptive PCA

PCA is a classical method to learn common information of a sequence of images. Especially in video analysis, this requires the computation of the (thin) SVD of large matrices. We present a method, based on an efficient SVD computation for augmented matrices, that allows to adapt the number of relevant singular vectors while analyzing a sequence of images. This technique allows the detection of moving elements in surveillance videos with varying background.

- Tomas Sauer (*University of Passau*)

Subdivision-based deformable models for extracting volumetric structures from biomedical images

An important challenge in biomedical imaging is the characterization of volumetric structures. In a clinical context, the delineation of organs such as lungs and kidneys allows for better 3D visualization and hence facilitates preoperative steps. In a biological context, microscopic images often contain hundreds of cells for which an automatized or semi-automatized cell segmentation is necessary because the manual delineation of each cell would otherwise be overly time consuming. 3D deformable models are powerful tools for the extraction of volumetric structures from biomedical images. They consist in flexible surfaces that are deformed from an initial user-provided configuration toward the boundary of the object to be delineated. The deformation can be driven manually, by interactively modifying the control points of the model, or automatically by minimizing suitable energy functionals. In this talk we describe the surface of a 3D deformable model by the limit surface obtained by applying a suitably defined subdivision scheme to an initial coarse triangular mesh. The benefits provided by the considered subdivision scheme are related to i) its efficiency to characterize 3D biomedical structures with sphere-like topology; ii) its applicability to an initial mesh with very few vertices; iii) its discrete nature that leads to an easy implementation. Finally, it allows for a friendly user interaction whenever some manual editing of the model is desired. Application examples of extraction of volumetric structures from real 3D biomedical images are illustrated.

Anaïs Badoual (*EPFL, Lausanne*)
- Lucia Romani (*University of Milano-Bicocca*)

Daniel Schmitter (*EPFL, Lausanne*)
Michael Unser (*EPFL, Lausanne*)

Mathematical methods of ptychographical imaging

In ptychographical imaging a set of far-field diffraction patterns of a sample is used to reconstruct it. Those patterns are obtained by illuminating small parts of the sample and shifting this illumination such that in the end the whole sample will be covered. We will introduce this technique, point out its (mathematical) challenges, and present methods how to tackle them. This is joint work with Frank Filbir (HMGU), Rayan Saab (UCSD), and Christian Schroer (DESY).

Frank Filbir (*Helmholtz Center Munich*)
Rayan Saab (*University of California, San Diego*)
Christian Schroer (*DESY*)
- Nada Sissouno (*University of Munich & Helmholtz Zentrum München*)

Multiple MRA and image processing

Unlike standard wavelet techniques, a multiple multiresolution analysis (MMRA) makes use of filterbanks based on level-varying scaling matrices and low-pass/high-pass filters chosen from finite given sets. This approach allows for a better detection of directional singularities in images, especially when sets of anisotropic scaling matrices are employed. We present a general construction of orthogonal MMRAs and examples of their application to some image processing problems specifically requiring compression and detection capabilities of the processing system.

- Mariantonia Cotronei (*University of Reggio Calabria*)

MS3 Applications of Imaging Modalities beyond the Visible Spectrum

Organizers:
Max Gunzburger (*Florida State University*)
Tesfaye G-Michael (*Naval Surface Warfare Center, Panama City*)
Janet Peterson (*Florida State University*)

MS3-1 - **Tuesday, 05 at 13:30** Matemates (Matemates, floor 0)

Coherence in Synthetic Aperture Sonar Imaging

Coherence of synthetic aperture sonar (SAS) data is a fundamental property that allows all manner of data exploitation and information extraction. Its understanding is crucial to maximizing the utility of SAS data, particularly in change-map generation for coherent change detection (CCD). This presentation will discuss the property of coherence as it relates to a variety of SAS CCD and exploitation techniques, as well as what factors influence it, and its quality in detecting obscured objects.

- Tesfaye G-Michael (*Naval Surface Warfare Center, Panama City*)

Automated repeat-pass processing of synthetic aperture sonar imagery

Autonomous Underwater Vehicles (AUV) equipped with advanced Aided Inertial Navigation Systems (AINS) and Synthetic Aperture Sonar (SAS) have over the last decade been increasingly used for detailed seabed surveying. This high-precision imagery has spurred development of repeat-pass processing methods, as the detection of seafloor changes over time is relevant for many applications, including mine hunting, infrastructure inspection and environmental monitoring. The main repeat-pass challenges are temporal decorrelation due to geophysical processes and biological activities, baseline decorrelation due to differences in sensing geometries and data co-registration requirements. We present techniques to mitigate these challenges, applied on HISAS imagery from HUGIN AUVs.

- Oivind Midtgaard (*Norwegian Defence Research Establishment (FFI)*)
Torstein Saebo (*Norwegian Defense Research Establishment (FFI)*)

Generative Acoustic Imaging Models with Applications

Adapting representations from a source domain to instances from a new target domain is an important problem in machine learning. In this work, the method of unsupervised domain adaptation in the context of mine countermeasure and automated target recognition is presented, where we have labeled data only from the source domain. Motivated by incremental learning, we create intermediate representations of data between the two domains and utilize this information to create new datasets.

- Jason C. Isaacs (*Naval Surface Weapons Center - Panama City*)

A statistics-based approach to image registration

We describe a technique for the registration of images that relies on a statistical confidence measure. While an extensive literature exists on the problem of image registration, few of the current approaches include a well-defined measure of the confidence associated with the solution. Having a confidence measure is critical for many autonomous applications, where erroneous registration solutions can have a significant impact. Our method utilizes a cross-correlation based registration algorithm to determine the "best" among a class of candidate solutions. A statistical test is used to identify which other solutions are not significantly worse than the best solution. This allows for the construction of confidence regions.

Katherine Simonson (*Sandia National Laboratories*)
- J. Derek Tucker (*Sandia National Laboratories*)

MS3-2 - **Tuesday, 05 at 16:00** Matemates (Matemates, floor 0)

Parallel Regularized k-means Clustering in Image Analysis and Compression

Clustering techniques provide an unsupervised approach for extracting information from images in color space representation, which is useful in applications including image analysis, quantization, and compression. We present our algorithm for parallel computation of a regularized k-means, which takes advantage of modern computing hardware to efficiently produce clusters while adaptively choosing the number of clusters which is not known a priori. This is advantageous when the optimal partitioning of the space is not known. We discuss the properties of clusters produced by the algorithm and examples drawn from imaging applications.

- Benjamin McLaughlin (*NSWC-PCD*)

Autonomous Naval Mine Countermeasures - single vehicle adaptive behaviours
Autonomous underwater vehicles are now commonly used for wide-area survey and exploration missions mine countermeasures. CMRE is developing environmentally adaptive vehicle behaviours which exploit synthetic aperture sonar (SAS) imagery to ensure that area exploration for target detection is properly executed. We describe the construction of an in-mission vehicle world model from SAS images and the use of this situational awareness to drive adaptive behaviours. Finally, simulation results from the CMRE exploration algorithm are presented.

- Samantha Dugelay (*NATO STO Centre for Maritime Research and Experimentation (CMRE)*)
  Giorgio Urso (*CMRE*)

A Deep Learning Approach to Modeling Expected Entropy Reduction in Imaging Sonar
Planning sonar measurements for the purpose of target recognition and classification is very useful in many maritime applications. The performance of an imaging sonar depends on the target features, the relative distance and pose to the target, and other conditions such as operating frequency, environmental conditions, and beamwidth. Information obtained from sonar images is directional, meaning that both the relative distance and orientation play an important role in determining the amount of uncertainty in target detection and classification. In this paper we propose an information-driven approach, where we learn an information value function (IVF) from image training datasets based on the expected entropy reduction (EER) concept. Although sonar images can be analyzed via signal processing algorithms, including convolutional neural networks, the dimensionality of the image pixels and of the features extracted makes deriving the EER from the sonar model intractable. Therefore, this paper presents an approach for representing the sonar expected performance as an EER function that is learned from sonar data. The target features are represented by random variables and extracted from images by training a convolutional AlexNet. The imaging sonar and automatic target recognition (ATR) are modeled by a graphical model learned from a training database of labeled sonar images. Then, the EER function is learned from the actual entropy reduction evaluated from the graphical model and the training database, also containing the target features and classification ground truth. Given a prior image of a target, the learned EER function allows one to compute the imaging sonar expected performance for images that are not yet available, as a function of the sonar relative distance and orientation.

- Silvia Ferrari (*Cornell University*)

Clustering approaches to feature change detection
Identifying meaningful changes between two multi-temporal images is a problem with application in many types of sensing modalities and visual monitoring. This presentation examines the usage of k-means clustering in color space to detect changes to an image collected by synthetic aperture sonar system in the form of new objects added to the scene. For simple images with a limited number of colors, new objects can be detected by examining the change between the optimal number of clusters for the original and modified images.

Tesfaye G-Michael (*Naval Surface Warfare Center, Panama City*)
- Max Gunzburger (*Florida State University*)
  Janet Peterson (*Florida State University*)

MS4 Graph Techniques for Image Processing

Organizers:
Yifei Lou (*University of Texas at Dallas*)
Jing Qin (*Montana State University*)

MS4-1 - **Tuesday, 05 at 13:30** Room H (Palazzina B - Building B, floor 0)

Graph Regularized EEG Source Imaging with In-Class Consistency and Out-Class Discrimination
Electroencephalography (EEG) has become one of the most popular brain imaging tools. We develop a graph Laplacian-based model for discriminative EEG brain source imaging that takes into account the label information (happiness, sadness, surprise, etc). In addition, we also incorporate some regularization terms, such as L1 norm, total variation, and nuclear norm (low rank) to further improve the results. Simulated experiments show the effectiveness of the proposed framework.

- Yifei Lou (*University of Texas at Dallas*)

A Graph Framework for Manifold-Valued Data
In this talk, we present a framework for processing discrete manifold-valued data, for which the underlying (sampling) topology is modeled by a graph. We introduce the notion of a manifold-valued derivative on a graph and based on this

exemplarily deduce a family of manifold-valued graph p-Laplace operators. We discuss a simple numerical scheme to compute a solution to corresponding parabolic PDEs and apply this algorithm to different manifold-valued data in denoising and inpainting applications.

Ronny Bergmann (*Technische Universität Chemnitz*)
- Daniel Tenbrinck (*University of Münster*)

An Auction Dynamics Approach to Data Classification
We reinterpret the semi-supervised data classification problem using an auction dynamics framework (inspired by real life auctions) in which elements of the data set make bids to the class of their choice. This leads to a novel forward and reverse auction method for data classification that readily incorporates volume/class size constraints into an accurate and efficient algorithm requiring remarkably little training/labeled data. We prove that the algorithm is unconditionally stable.

- Ekaterina Rapinchuk (*Michigan State University*)

Cut Pursuit: A Working Set Strategy to Find Piecewise Constant Functions on Graphs
Problems regularized by the total variation on a general weighted graph produce piecewise constant solutions with a small number of constant connected components. We propose a working-set strategy which exploits this structure by recursively splitting the connected components of a candidate solution using graph cuts. This method exhibits a significant speed-up over state-of-the-art algorithms when regularizing ill-posed, ill-conditioned, large-scale inverse problems, notably involving functions with a separable non-smooth part.

- Loic Landrieu (*Institut géographique national*)

MS4-2 - **Tuesday, 05 at 16:00** Room H (Palazzina B - Building B, floor 0)

EEG Source Imaging based on Spatial and Temporal Graph Structures
To better retrieve task related discriminative source patches, we propose a novel EEG source imaging model based on spatial and temporal graph structures. In particular, graph fractional-order total variation (gFOTV) is used to enhance spatial smoothness, and the label information of brain state is enclosed in a temporal graph regularization term to guarantee intra-class consistency of estimated sources. Numerical experiments have shown that our method localizes source extents more effectively than the benchmark methods.

- Jing Qin (*Montana State University*)

Interpolation on High Dimensional Point Cloud
Interpolation on high dimensional point cloud provides a fundamental model in many data analysis and machine learning problems. In this talk, we will present some PDE based methods to do interpolation on point cloud. Applications in image processing and data analysis are shown to demonstrate the performance of our methods.

- Zuoqiang Shi (*Tsinghua University*)

On the Front Propagation on Weighted Graphs With Applications in Image Processing and High-Dimensional Data
In this talk, we propose an adaptation of PDE-based level set method for nonmonotonic front propagation on weighted graphs. A new formulation of the level set equation on weighted graphs considering both time-dependent and stationary versions of this equation in the case of signed velocities is proposed. This formulation leads to an efficient algorithm that generalized the fast marching to graphs with signed velocities. We propose to use this method for image processing and for high-dimensional data classification.

Xavier Desquesnes (*Université d'Orléans*)
- Abderrahim Elmoataz (*University of Caen Normandie, CNRS*)

Learning Binary Neural Networks
Neural networks have become the workhorse for modern image processing and analysis, among many other areas. For deployment of neural networks onto low-power consumer electronics, the networks must be sufficiently compact and energy efficient. In this talk, I will describe principled ways of training neural networks toward sparse connections and discrete (as low as binary) weights.

- Ju Sun (*Stanford University*)

Xiaoxia Sun (*Johns Hopkins*)

MS5 Learning and adaptive approaches in image processing

Organizers:
Kostas Papafitsoros (*Weierstrass Institute Berlin*)
Michael Hintermüller (*Humboldt University and Weierstrass Institute Berlin*)

MS5-1 - **Tuesday, 05 at 13:30** Room M (Palazzina B - Building B, floor 0)

A physical-oriented reconstruction method for quantitative magnetic resonance imaging

In this talk, we will introduce a novel method for quantitative MRI which asks for precise estimation of the parameters e.g. T1, T2 and so on. The proposed approach respects the physical law characterized by Bloch equations as the recently developed method magnetic resonance fingerprinting (MRF). However, in comparison with MRF, the new method does not rely on the discretization size in the dictionary, and shows much higher accuracy for the estimated parameters.

- Guozhi Dong (*Humboldt University Berlin*)
  Michael Hintermüller (*Humboldt University and Weierstrass Institute Berlin*)
  Kostas Papafitsoros (*Weierstrass Institute Berlin*)

A Variational Model for Brain Tumor Segmentation: Deep Learning Based Parameter Optimization
We present a new variational model for saliency detection in images and its application to brain tumor segmentation. Incorporating a saliency term to a classical Total Variation based restoration functional this model is able to discriminate what is relevant (salient) from the background, resulting into a non-convex and non-smooth problem. To optimize the parameters of the proposed energy functional we introduce a Deep Learning framework using available knowledge from the specific application.

- Adrián Martín (*Universitat Pompeu Fabra*)
  Ivan Ramirez (*Universidad Rey Juan Carlos*)
  Emanuele Schiavi (*Universidad Rey Juan Carlos*)

Analytical solutions of quadratic variational coupling models of arbitrary order
We discuss a model for quadratic variational denoising that approximates smoothness terms of arbitrary order by a coupling of the solution and auxiliary variables such that a system of partial differential equations of second order is obtained. We show that the model maintains a continuous as well as discrete integrability property between coupling variables. In the discrete setting an algorithm is presented that yields the desired solution analytically and refrains from calculating any auxiliary variables.

- Aaron Wewior (*Saarland University*)

Bilevel optimization and some "parameter learning" applications in image processing
This talk addresses opportunities as well as challenges connected to bilevel approaches in image restoration or blind deconvolution. While a major advantage is a monolithic optimization framework favoring leader-follower principles, some of the main challenges are related to non-smoothness, non- convexity, lack of constraint qualification as well as the design of efficient solution algorithms. Particular applications highlighted in this talk comprise distributed regularization parameter choice rules as well as topics in multiframe blind deconvolution.

- Michael Hintermüller (*Humboldt University and Weierstrass Institute Berlin*)

MS5-2 - **Tuesday, 05 at 16:00** Room M (Palazzina B - Building B, floor 0)

Deep regularization for medical image analysis
Recent advances have shown that learning regularization is a powerful tool to obtain customized regularizers for many low-level vision applications. In this presentation, we show our latest results on extending the Fields of Experts regularization model by deepening this structure using a series of convolutional and deconvolutional operators. The aim is to regularize not only low-level features but also mid- to high-level features to increase the reconstruction performance for medical imaging.

  Kerstin Hammernik (*Graz University of Technology*)
  Teresa Klatzer (*Graz University of Technology*)
- Erich Kobler (*Graz University of Technology*)
  Thomas Pock (*Graz University of Technology*)

Joint reconstruction and segmentation from undersampled MRI data
Magnetic resonance imaging often deals with fast acquisition techniques and incomplete measurements, posing challenges in the reconstruction and further analysis of the data (e.g. segmentation). We propose a method to jointly reconstruct and segment undersampled MRI data. Our model consists of a total variationregularisedreconstruction and a Chan-Vese based segmentation. We develop an algorithm based on a splitting approach that solves efficiently the two minimisation subproblems. We present results for synthetic and real data.

- Veronica Corona (*University of Cambridge*)

Learning a sampling pattern for MRI
Taking measurements in MRI is a time-consuming procedure, so ideally one would take few samples and still recover a useable image. We consider the problem of learning a suitable sampling pattern for a class of objects that are similar. Given a training set consisting of pairs of clean images and MRI measurements, a bilevel optimisation problem can be formulated and studied, whose solution is a sparse sampling pattern that gives rise to good reconstructions.

- Ferdia Sherry (*University of Cambridge*)

Structural adaptation for noise reduction in magnetic resonance imaging
Structural adaptation is a technique from nonparametric statistics that enables the reduction of noise in data, e.g., from medical imaging applications, without blurring the structural borders that are given by tissue borders. In this talk, I will present the general principles of this approach as well as its application to specific magnetic resonance imaging modalities and demonstrate, how it can be used for improved inference from the acquired data.

- Karsten Tabelow (*Weiestrass Institute Berlin*)

MS6 Time-dependent problems in imaging

Organizers:
Thomas Schuster (*Saarland University*)
Anne Wald (*Saarland University*)

MS6-1 - Tuesday, 05 at 13:30 Room L (Palazzina B - Building B, floor 0)

On dynamic photoacoustic imaging with optical flow constraints
In photoacoustic imaging, as in many high resolution modalities, the major bottle neck is the acquisition time of finely spatially sampled data. In particular for imaging of dynamical processes, this results in incomplete data. In this talk we are going to discuss different aspects of variational methods for photoacoustic imaging using spatio-temporal regularization via optical flow constraint which allow us maintaining good quality of the reconstruction from severely subsampled/compressed dynamic data.

Simon Arridge (*University College London*)
- Marta Betcke (*University College London*)

Ben Cox (*Department of Medical Physics, University College London*)
Nam Huynh (-)
Felix Lucka (*CWI & UCL*)
Bolin Pan (*University College London*)
Beard Paul (*UCL*)
Edward Zhang (*UCL*)

Dynamic inverse problems for wave equations
We endow the inhomogeneous wave equation with time-dependent parameters and consider the task of reconstructing these parameters from the wave field. This dynamic inverse problem is more involved compared to static parameters. We give existence and uniqueness results for the equation and compute the Fréchet derivative of the solution operator, for which we also show ill-posedness. These results motivate the numerical reconstruction using regularized Newton-like methods.

- Thies Gerken (*University of Bremen*)

Algorithms for motion compensation
Motion compensation represents an important time-dependent problem in tomography. Most modalities record the data sequentially, e.g. in computerized tomography, measurements are taken while the X-ray source rotates around the specimen. Temporal changes of the object therefore lead to undersampled and/or inconsistent measurements. Consequently, suitable models and algorithms have to be developed in order to provide artefact free images. In this talk, we present recent advances in this field and their application to different imaging modalities.

- Bernadette Hahn (*University of Würzburg*)

Reconstruction and Decomposition of Dynamic and Undersampled MR Data
In many clinical applications the tracking of fast dynamics in 4D MR data is of major interest. Due to time restrictions in the MR measurement process in this context it is reasonable to make use of undersampled data. In this talk we discuss variational methods for spatial temporal reconstruction from such MR data, which decompose the image sequence into different characteristic components such as background, motion and inhomogeneities.

- Meike Kinzel (*University of Münster*)

MS6-2 - Tuesday, 05 at 16:00 Room L (Palazzina B - Building B, floor 0)

A reconstruction method for multi-modal imaging
In this work we consider the inverse problem of reconstructing the optical properties of a dielectric medium from measurements from the multi-modal Photoacoustic and Optical Coherence Tomography (PAT/OCT) setup. We reformulate the inverse problem as a Fredholm type integral equation for the Grüneisen parameter (space dependent) to be solved with a Galerkin type method. This is a joint work with P. Elbau and O. Scherzer.

- Leonidas Mindrinos (*Computational Science Center, University of Vienna*)

Numerical treatment of inverse heat transfer problems
Time-dependent problems are often modeled via parabolic differential equations. Possibly, the most prominent example for such an equation is the classical linear heat equation that describes the distribution of heat (or temperature) in a given region over time. We discuss extensions of this classical equation to nonlinear PDEs in 1D. Furthermore, we will address the associated inverse heat transfer problems and their relevance in industrial applications. Finally, numerical studies will be presented.

- Dimitri Rothermel (*Saarland University*)

All-at-once versus reduced version of Landweber-Kaczmarz for parameter identification in time dependent problems

A large number of inverse problems in applications ranging from engineering via economics to systems biology can be formulated as a state space system with a finite or infinite dimensional parameter that is supposed to be identified from additional continuous or discrete observations. In this talk we will compare reduced and all-at-once versions of Landweber-Kaczmarz iteration for a reformulation of the problem as a system resulting from splitting the time line into subintervals.

- Tram Thi Ngoc Nguyen (*Alpen-Adria-Universität Klagenfurt*)

Regularizing sequential subspace optimization for the identification of the stored energy of a hyperelastic structure

We consider the nonlinear dynamic inverse problem of identifying the stored energy function of hyperelastic materials from surface sensor measurements. In connection with the detection of damages in structures consisting of such materials this task is highly interesting since all mechanical properties are hidden in the stored energy function. This problem has already been solved using the attenuated Landweber method. Since this process is extremely time-consuming, we use sequential subspace optimiziation as a regularization technique.

- Rebecca Klein (*Saarland University*)

MS7 Limited data problems in imaging

Organizers:
Bernadette Hahn (*University of Würzburg*)
Gaël Rigaud (*Saarland University*)
Jürgen Frikel (*OTH Regensburg*)

MS7-1 - Tuesday, 05 at 13:30 Room I (Palazzina B - Building B, floor 0)

A Complete Characterization of Artifacts in Arbitrary Limited Data Tomography Problems

We will describe our characterization of artifacts in limited data X-ray tomography reconstructions with arbitrary data. We provide estimates of the strength of the added artifacts in some cases, and we illustrate our results using standard and non-standard limited data tomography problems with real and simulated data. The work is based on a microlocal analysis of the X-ray transform and backprojection, and it can be applied to a range of limited data problems.

Leise Borg (*University of Copenhagen*)
Jürgen Frikel (*OTH Regensburg*)
Jakob Jorgensen (*University of Manchester*)
- Todd Quinto (*Tufts University*)

Challenges in learning-based MR image reconstruction

Learning-based reconstruction approaches require a suitable network architecture, training data, and a loss function, to measure the similarity between the reconstructed image and a reference image during training. In this talk, we give an overview of our current developments using variational networks for accelerated MR image reconstruction and discuss several challenges that are encountered during learning, focusing on how the design of the loss function influences reconstruction quality.

- Kerstin Hammernik (*Graz University of Technology*)
Teresa Klatzer (*Graz University of Technology*)
Florian Knoll (*New York University*)
Erich Kobler (*Graz University of Technology*)
Thomas Pock (*Graz University of Technology*)
Michael P Recht (*New York University School of Medicine*)
Daniel Sodickson (*New York University*)

Iterative image reconstruction for limited angular range scanning in digital breast tomosynthesis

Our work on iterative image-reconstruction applied to Digital Breast Tomosynthesis is split in two efforts: identifying optimization-based algorithms that provide useful images with few iterations, and developing image quality metrics that guide the parameter settings of the image-reconstruction algorithms. We prototype many optimization-based approaches, involving total-variation, using the Chambolle-Pock primal-dual algorithm. We also present image quality metrics tailored to the task of tumor/mass classification, and discuss the difference in image properties with respect to scan-angle.

Xiaochuan Pan (*University of Chicago*)
Ingrid Reiser (*University of Chicago*)
Sean Rose (*University of Chicago*)
- Emil Sidky (*University of Chicago*)

Machine learning for imaging problems with limited data

In recent years, machine learning has proved to be successful in several imaging fields. In this talk, different approaches for applying machine learning to challenging imaging problems involving limited data will be discussed. For example, in low-dose tomography problems, neural networks can be used to improve reconstruction quality, enabling analysis of new types of samples. Results will be shown for various problems, and important practical considerations, e.g. computational requirements, will be discussed.

- Allard Hendriksen (*CWI*)
  Daniel Pelt (*CWI*)

MS7-2 - **Tuesday, 05 at 16:00** Room I (Palazzina B - Building B, floor 0)

On limited data issues in Compton scattering imaging
Compton imaging is a nascent concept arising from the current development of high-sensitive energy detectors and based on the Compton effect, i.e. the scattering of a photon by an electron. Such detectors are able to collect incoming photons in terms of energy. It follows applications exploiting the scattering radiation to image the electron density of the studied medium. This presentation introduces potential 3D modalities in Compton imaging as well as the corresponding limited data issues.

- Gaël Rigaud (*Saarland University*)

A new reconstruction strategy for compressed sensing photoacoustic tomography
Compressed sensing is a promising approach for significantly reducing the number of measurements in photoacoustic tomography (or other limited data imaging problems) while preserving its high spatial resolution. In this talk we present a new sparse recovery framework for recovering the photoacoustic source from compressive measurements. Results with simulated as well as experimental data are given. (Joint work with Linh Nguyen, Michael Sandbichler, Thomas Berer, Johannes Bauer-Marschallinger, Peter Burgholzer)

Thomas Berger (*RECENDT Research Center for Non Destructive Testing GmbH*)
- Markus Haltmeier (*University Innsbruck*)
  Linh Nguyen (*University of Idaho*)

Reconstructions from incomplete tomographic data in PAT
In this talk, we will investigate a reconstruction problem that arises in limited data photoacoustic tomography with a flat observation surface. In the first part of this talk, we will explain which singularities of the original object can be reliably reconstructed and why artifacts can be generated when applying the classical FBP-type reconstruction operators to limited data. We will also provide precise characterizations of added artifacts and explain how they can be reduced. In the second part of this talk, we will present a stable reconstruction method, which is based on sparsity assumptions in the wavelet domain. In particular, we will present an easy to implement numerical algorithm for that problem. This is based on a joint work with Eric Todd Quinto (Tufts University) and Markus Haltmeier (University of Innsbruck).

- Jürgen Frikel (*OTH Regensburg*)

Algorithms for dynamic tomography with limited data
Examples of tomographic imaging of moving objects: recovering the structure of blood vessels using injected contrast agent, and analysing penetration of fluid into porous media. There is often a need to keep the data collection as short as possible and to reduce the radiation dose. One can do this by taking fewer projection images and shortening exposures, leading to scarce-angle tomography with noisy data. Different approaches are compared: optical flow, shearlet sparsity, and Kalman filtering.

- Samuli Siltanen (*University of Helsinki*)

MS8 Krylov Methods in Imaging: Inverse Problems, Data Assimilation, and Uncertainty Quantification

Organizers:
Arvind Saibaba (*North Carolina State University*)
Julianne Chung (*Virginia Tech*)
Eric de Sturler (*Virginia Tech*)

MS8-1 - **Tuesday, 05 at 13:30** Room E (Palazzina A - Building A, floor 2)

Analysis of bidiagonalization-based regularization methods for inverse problems with general noise setting
Golub-Kahan iterative bidiagonalization represents the core algorithm in regularization of large linear noise-polluted inverse problems. Regularization is here achieved via projection on a sequence of Krylov subspaces dominated by low-frequency vectors. Here we consider a general noise setting and analyze regularization effect of bidiagonalization-based methods LSQR, LSMR, and CRAIG, by relating their residuals with propagated noise. We discuss validity of our results in image deblurring problems. Influence of the loss of orthogonality is considered.

- Iveta Hnetynkova (*Charles University, Faculty of Mathematics and Physics*)

Flexible Krylov methods for l_p-regularization

We consider flexible Krylov methods for efficiently computing regularized solutions to large-scale linear inverse problems with a p-norm penalization term, for p>=1. To handle general (non-square) l_p-regularized least-squares problems, we introduce a flexible Golub-Kahan approach and exploit it within a Krylov-Tikhonov hybrid framework. The key benefits of our approach are that efficient projection methods replace inner-outer schemes and expensive regularization parameter selection techniques can be avoided. Theoretical insights and numerical results from image deblurring are provided.

- Julianne Chung (*Virginia Tech*)

  Silvia Gazzola (*University of Bath*)

Incorporating Known Information into a Krylov Subspace Iteration

In this talk, we explore some practical strategies of incorporating outside information into a Krylov subspace method for image reconstruction, focusing mainly on augmented Krylov subspace methods. Many variants of these methods have been been proposed by different authors for the improvement of the reconstruction and acceleration of the semiconvergence, particularly in the case where one augments with known sharp edge features and jumps. However, what can one do in a more practical setting, where one may not know where any of these features are? We discuss here some new methods and ideas moving towards answering this question.

- Kirk Soodhalter (*Trinity College Dublin*)

Krylov Recycling for Sequences of Shifted Systems Arising in Image Restoration

Edge-preserving image restoration is often posed as (a sequence of) optimization problems. Thus, the single biggest computational bottleneck to image recovery is the solution of a sequence of large-scale linear systems with multiple, non-identity shifts. In this talk, we present new, computationally efficient Krylov recycling methods designed to significantly reduce the costs of solving these sequences of shifted systems. We illustrate the advantage of our methods on several examples.

Eric de Sturler (*Virginia Tech*)

- Misha Kilmer (*Tufts University*)

  Meghan O'Connell (*Mathworks*)

MS8-2 - **Tuesday, 05 at 16:00** Room E (Palazzina A - Building A, floor 2)

Krylov, Bayes and L2 magic.

The success of the compressed sensing algorithms is based on the observation that if the underlying image is known to be sparse, or nearly black, a good approximation can be found as the minimizer of the ell-1 norm. Bayesian hypermodels using conditionally Gaussian priors provide a competitive alternative, in particular when combined with Krylov subspace iterative solvers. We address both computational and theoretical aspects of the proposed iterative algorithms.

- Daniela Calvetti (*Case Western Reserve University*)

  Erkki Somersalo (*Case Western Reserve University*)

  Alexander Strang (*Case Western Reserve University*)

Adaptative preconditioning for TV regularization

Krylov subspace methods are powerful iterative regularization tools for large-scale linear inverse problems, such as those arising in image deblurring and computed tomography. We exploit a flexible version of some Krylov subspace methods, which uses adaptive preconditioning to promote TV-like regularization in the solution. Numerical experiments and comparisons with other well-known methods for the computation of large-scale solutions are presented.

Silvia Gazzola (*University of Bath*)

- Malena Sabate Landman (*University of Bath*)

Regularization parameter convergence for hybrid RSVD methods

Tikhonov regularization for projected solutions of large-scale ill-posed problems is considered. Traditionally hybrid LSQR iterative methods are used to find the solution on a subspace that inherits the ill-conditioning of the original problem and regularization is imposed at the subspace level. Modern techniques employ a randomized singular value decomposition (RSVD) to find the subspace for the solution. Through the connection with the truncated singular value decomposition we prove parameter convergence for the hybrid RSVD approaches.

Anthony Helmstetter (*Arizona State University*)

- Rosemary Renaut (*Arizona State University*)

  Saeed Vatankhah (*University of Tehran*)

Truncation and Recycling Methods for Lanczos Bidiagonalization and Hybrid Regularization

Krylov methods for inverse problems have the nice property that regularization can be decided dynamically. However, this typically requires that the entire Krylov space is kept in memory, which is problematic for large problems that do not converge quickly. We propose strategies for truncating the search space while maintaining the possibility of dynamic regularization (for various regularization methods). In addition, these strategies have advantages if a sequence of related regularized solves is required.

Julianne Chung (*Virginia Tech*)

- Eric de Sturler (*Virginia Tech*)

MS9 Innovative models and algorithms for astronomical imaging

Organizers:
Silvia Tozza (*INdAM/Dept. Mathematics, University of Rome "La Sapienza"*)
Marco Castellano (*INAF Osservatorio Astronomico di Roma*)
Maurizio Falcone (*Dipartimento di Matematica, Università di Roma "La Sapienza"*)
Adriano Fontana (*INAF Osservatorio Astronomico di Roma*)

MS9-1 - **Tuesday, 05 at 13:30** Room D (Palazzina A - Building A, floor 1)

Astronomical imaging in the era of cosmological surveys and giant telescopes: challenges and opportunities
The next generation of astronomical imaging instruments will present at the same time incredible scientific opportunities and technical challenges. I will highlight forthcoming developments in the field of astronomical imaging and how they will yield huge amount of data to be processed with unprecedented precision. I will discuss the need for a multidisciplinary approach in the development of new image analysis algorithms and promising ways for attaining crucial improvements in the field.

- Marco Castellano (*INAF Osservatorio Astronomico di Roma*)

Blind Deconvolution of galaxy survey images
Removing the aberrations introduced by the Point Spread Function (PSF) is a fundamental aspect of astronomical image processing. The presence of noise in observed images makes deconvolution a nontrivial task that necessitates the use of regularisation. This task is particularly difficult when the PSF varies spatially as is the case for big surveys such as LSST or Euclid surveys. It becomes a fantastic challenge when the PSF field is unknown. The first step is therefore to estimate accurately the PSF field. In practice, isolated stars provide a measurement of the PSF at a given location in the telescope field of view. Thus we propose an algorithm to recover the PSF field, using the measurements available at few these locations. This amounts to solving an inverse problem that we regularize using both matrix factorization and a sparsity. Then we show that, for these new surveys providing images containing thousand of galaxies, the deconvolution regularisation problem can be considered from a completely new perspective. In fact, one can assume that galaxies belong to a low-rank dimensional space. This work introduces the use of the low-rank matrix approximation as a regularisation prior for galaxy image deconvolution and compares its performance with a standard sparse regularisation technique. This new approach leads to a natural way to handle a space variant PSF. Deconvolution is performed using a Python code that implements a primal-dual splitting algorithm. The data set considered is a sample of 10 000 space-based galaxy images convolved with a known spatially varying Euclid-like PSF and including various levels of Gaussian additive noise. Performance is assessed by examining the deconvolved galaxy image pixels and shapes. The results demonstrate that the low-rank method performs as a well as sparsity for small samples of galaxies and outperforms sparsity for larger samples.

- Samuel Farrens (*CEA*)
  Morgan Schmitz (*CEA*)
  Jean-Luc Starck (*Service d'Astrophysique, CEA Saclay*)

Application of machine learning algorithm, based on clustering analysis, to detection and deblending of astronomical sources
I will present the application of clustering algorithms (DBSCAN and DENCLUE) to the detection and the deblending of confused sources, both for Optical/CCD and gamma-ray astronomical images. I will also show how to use the features extracted from these algorithms with supervised ensemble classification algorithms.

- Andrea Tramacere (*ISDC Data Center for Astrophysics, University of Geneve*)

An Inverse diffraction method for de-saturation of Extreme Ultraviolet images of solar eruptive events
Saturation affects a significant rate of images recorded by the Atmospheric Imaging Assembly (AIA) on the Solar Dynamics Observatory (SDO), a solar satellite launched by NASA on February 2010. This talk shows an automatic, inverse-problems-based procedure for the recovery of information in the saturation region based on a correlation/inversion analysis of the diffraction pattern associated to the telescope observations. An assessment of its reliability will be performed against images recorded from different eruptive events.

- Anna Maria Massone (*CNR - SPIN*)

MS9-2 - **Tuesday, 05 at 16:00** Room D (Palazzina A - Building A, floor 1)

Separation and Extraction of Structural Components in Astronomical Images
Modern high-resolution images display extreme intensity variations on all spatial scales. They reveal very complex blends of compact sources, omnipresent filamentary structures, background molecular clouds, and instrumental noise. These structural components appear quite dissimilar in various wavebands with different angular resolutions, which further complicates the problem of automated detection and measurements of filaments and compact sources. It is very beneficial to flatten images and separate the structural components before their extraction.

- Alexander Menshchikov (*DAp, IRFU, CEA Saclay, Paris*)

An approximate nonnegative matrix factorization algorithm for astronomical imaging
The angular differential imaging (ADI) improves contrast in the astronomical imaging.An example is direct imaging of exoplanet in camera fed by Extreme Adaptive Optics. The subtraction of the main dazzling object to observe the faint companion was improved using Principal Component Analysis (PCA). It factorizes the positive astronomical frames into positive and negative components. On the contrary, the Nonnegative Matrix Factorization (NMF) uses only positive components, mimicking the actual composition of the long exposure images.

- Carmelo Arcidiacono (*INAF Osservatorio Astronomico di Bologna*)

Accurate wavefront reconstruction for real-time AO with pyramid wavefront sensors
Pyramid wavefront sensors are planned to be included on large earthbound telescopes currently under development. These rely on real-time adaptive optics systems to compensate for atmospheric perturbations. Using our mathematical analysis of the pyramid sensor model, we present several algorithms for a high-quality and high-speed wavefront correction including gradient-based methods and approaches based on the inversion of the Finite Hilbert transform, and we take into account data disconnectivity induced by telescope spider legs.

- Victoria Hutterer (*Industrial Mathematics Institute Johannes Kepler University, Linz*)

Reconstruction of hard X-ray images of solar flares by means of compressed sensing
This talk shows that compressed sensing realized by means of regularized deconvolution and the Finite Isotropic Wavelet Transform is effective and reliable in hard X-ray solar imaging. Specifically, this image reconstruction approach is applied against both synthetic data mimicking the Spectrometer/Telescope Imaging X-rays (STIX) measurements and experimental observations provided by the Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI). The performances of the method are compared with the results provided by standard visibility-based reconstruction methods.

Miguel Duval Poo (*Dipartimento di matematica, University of Genoa*)
Anna Maria Massone (*CNR - SPIN*)
- Michele Piana (*Dept. Mathematics, University of Genoa*)

MS10 Advanced optimization methods for image processing

Organizers:
Marco Prato (*University of Modena and Reggio Emilia*)
Ignace Loris (*Université Libre de Bruxelles*)

MS10-1 - **Tuesday, 05 at 13:30** Room G (Palazzina A - Building A, floor 0)

Inexact forward-backward and primal-dual methods for applied inverse problems
Most recent variational methods consist of bricks of very different computational complexity. A particular instance are parts containing a costly (e.g. imaging) operator whose evaluation is limited to a small number, and often is the crucial time factor in a practical setup. We use (accelerated) inexact forward-backward splittings and (accelerated) inexact primal-dual methods to separate these limiting parts from easier ones to provide the best possible result within a small budget of operator evaluations.

Antonin Chambolle (*Ecole Polytechnique*)
- Julian Rasch (*Westfälische Wilhelms-Universität Münster*)

Non-smooth non-convex Bregman minimization: unification and new algorithms
We propose a unifying algorithm for non-smooth non-convex optimization. The algorithm approximates the objective function by a convex model function and finds an approximate Bregman proximal point of the convex model. We prove convergence to a stationary point under weak assumptions on the growth of the model function error. Special instances of the algorithm with Euclidean distance are, e.g., Gradient Descent, Forward–Backward Splitting, ProxDescent. Applications include non-linear inverse problems in image processing and machine learning.

Jalal Fadili (*Université Caen*)
- Peter Ochs (*Saarland University*)

A block coordinate proximal algorithm for N-th order tensor decomposition
We are interested here in one of the most popular tensor factorization namely the Canonical Polyadic Decomposition (CPD) for N-th order tensors. It consists in decomposing a tensor into a minimal sum of rank-one terms, the number of rank-one tensors being the tensor rank (possibly unknown). The tensor satisfies a multi-linear property with respect to its loading factors. The objective of this work is to recover the loading factors that define the observed tensor modeled by the CP model. The large size of the observations as well as possible perturbations and the lack of knowledge of the actual tensor rank make the CPD inverse problem often difficult to solve. We thus propose to formulate the CP problem as an optimization problem to be solved, the criterion to be minimized gathering a data fidelity term involving the observed tensor and the unknow loading factors and penalizations acting individually on the loading factors (possibly favoring sparsity and ensuring nonnegativity). Then, based on a block coordinate variable metric forward-backward (BC-VMFB) method, we proposed a new penalized nonnegative N-th order CPD algorithm. It consists in four main steps : i) a gradient step in the forward stage, ii) a proximal step in the backward stage, iii) a preconditioning step (“variable metric”), and iv) a

block arrangement ("Block Coordinate") of the unknown (latent) variables that will be generally swept according to a random or cyclic rule . The efficiency (flexibility, robustness and speed) of the proposed algorithm is not only demonstrated through synthetic third and fourth order tensor decomposition but also on real 3D fluorescence spectroscopy data (water monitoring experiment).

- Caroline Chaux (*Aix-Marseille Université*)
  Sylvain Maire (*Aix-Marseille Université*)
  Nadège Thirion-Moreau (*Aix-Marseille Université*)
  Xuan Vu (*Aix-Marseille Université*)

TV-based Poisson image restoration by IRLS and gradient projection methods
We consider optimization problems modeling image restoration from Poisson data. The objective function is the generalized Kullback-Leibler (KL) divergence plus a TV regularizer; nonnegativity and photon-flux conservation constraints are imposed. We propose an iterative procedure where quadratic problems, obtained by classical approximation of KL and iteratively reweighted least-squares (IRLS) approximation of TV, are solved inexactly by a two-phase gradient projection method. A convergence proof of our procedure and numerical experiments showing its effectiveness are presented.

- Daniela di Serafino (*University of Campania "L. Vanvitelli"*)
  Germana Landi (*University of Bologna*)
  Marco Viola (*University of Rome "La Sapienza"*)

MS10-2 - **Tuesday, 05 at 16:00** Room G (Palazzina A - Building A, floor 0)

A variational Bayesian approach for image restoration with Poisson-Gaussian noise
In this talk, a methodology is investigated for signal recovery in the presence of mixed Poisson-Gaussian noise. Existing strategies for solving inverse problems often define the estimate as a minimizer of an appropriate cost function. Several algorithms have been proposed to tackle the problem of restoration for signals corrupted with non-Gaussian noise by using minimization approaches. In these approaches, the regularization parameter allows a tradeo to be performed between fidelity to the observations and the prior information. The problem of selecting the regularization parameter remains an open issue especially in situations where the images are acquired under poor conditions i.e. when the noise level is very high. To address the shortcomings of these methods, one can adopt the Bayesian framework. In particular, Bayesian estimation methods based on Markov Chain Monte Carlo (MCMC) sampling algorithms have been recently extended to inverse problems involving non-Gaussian noise. However, despite good estimation performance that has been obtained, such methods remain computationally expensive for large scale problems. Another alternative approach which is explored here is to rely on variational Bayesian approximation (VBA). Instead of simulating from the true posterior distribution, VBA approaches aim at approximating the intractable true posterior distribution with a tractable one from which the posterior mean can be easily computed. These methods can lead generally to a relatively low computational complexity when compared with sampling based algorithms. In this work, we propose such a VBA estimation approach for signals degraded by an arbitrary linear operator and corrupted with non-Gaussian noise. One of the main advantages of the proposed method is that it allows us to jointly estimate the original signal and the required regularization parameter from the observed data by providing good approximations of the Minimum Mean Square Estimator (MMSE) for the problem of interest. While using VBA, the main diculty arising in the non-Gaussian case is that the involved likelihood and the prior density may have a complicated form and are not necessarily conjugate. To address this problem, a majorization technique is adopted providing a tractable VBA solution for non-conjugate distributions. Our approach allows us to employ a wide class of a priori distributions accounting for the possible sparsity of the target signal after some appropriate linear transformation. It can be easily applied to several non Gaussian likelihoods that have been widely used. In particular, experiments in the case of images corrupted by Poisson Gaussian noise showcase the good performance of our approach compared with methods using the discrepancy principle for estimating the regularization parameter. Moreover, we propose variants of our method leading to a significant reduction of the computational cost while maintaining a satisfactory restoration quality.

Emilie Chouzenoux (*Université Paris-Est Marne-la-Vallée*)
Yosra Marnissi (*Université Paris-Est Marne-la-Vallée*)
- Jean-Christophe Pesquet (*Université Paris-Saclay*)
  Yuling Zheng (*IBM Research China*)

Proximity operator of a sum of functions: Application to image segmentation
Proximal splitting algorithms are of main interest in a large number of image processing applications. The main advantage of this class of algorithms is to make possible to split a criterion in a sum of functions easier to handle with (e.g. split differentiable and non-smooth functions). However, the larger the splitting, the slower the convergence. In this work, we show how to compute the proximity operator of a sum of two functions, for a certain type of functions operating on objects having a graph structure. The gain provided by avoiding unnecessary splitting is illustrated on image segmentation.

Laurent Condat (*Université Grenoble Alpes*)
- Nelly Pustelnik (*CNRS, Laboratoire de Physique de l'ENS de Lyon*)

Fast algorithms for nonlocal myriad filtering
The contribution of this talkis two-fold. First, we introduce a generalized myriad filter, which is a method to compute the joint maximum likelihood estimator of the location and the scale parameter of the Cauchy distribution. Estimating only the

location parameter is known as myriad filter. We propose an efficient algorithm to compute the generalized myriad filter and prove its convergence. Special cases of this algorithm result in the classical myriad filtering, respective an algorithm for estimating only the scale parameter. Based on an asymptotic analysis, we develop a second, even faster generalized myriad filtering technique. Second, we use our new approaches within a nonlocal, fully unsupervised method to denoise images corrupted by Cauchy noise. Special attention is paid to the determination of similar patches in noisy images. Numerical examples demonstrate the excellent performance of our algorithms which have moreover the advantage to be robust with respect to the parameter choice.

Friederike Laus (*Technische Universität Kaiserslautern*)
Fabien Pierre (*Université de Lorraine*)
- Gabriele Steidl (*University of Kaiserslautern*)

A fast algorithm for non-convex optimization in highly under-sampled MRI
This talk concerns a fast and efficient method for the reconstruction of Magnetic Resonance Images (MRI) from severely under-sampled data. Reduced sampled acquisitions are employed in MRI when fast imaging is essential to improve patient care and reduce the costs. The aim is to reconstruct MR images from highly under-sampled data in order to reduce the amount of acquired data without degrading the reconstructed images. Following the Compressed Sensing theory, the problem is mathematically modeled as a constrained minimization with a family of non-convex regularizing objective functions and a least squares data fit constraint. The proposed algorithm is based on an iterative scheme where the non-convex problem is substituted by a sequence of convex approximations by a re-weighting scheme. Moreover the penalization parameter is automatically updated through an adaptive procedure. Each convex problem is solved by a Forward-Backward procedure, where the Backward step is solved by a Split-Bregman strategy. A very efficient iterative algorithm, based on a new matrix splitting method, is introduced for the solution of the inner linear systems of the Backward steps. The results on synthetic phantoms and real images show that the algorithm is very well performing and computationally efficient when compared to the most efficient methods present in the literature.

Damiana Lazzaro (*Dept. Mathematics, University of Bologna*)
Elena Loli Piccolomini (*Dept. Computer Science and Engineering, University of Bologna*)
- Fabiana Zama (*Dept. Mathematics, University of Bologna*)

MS11 Computational Imaging for Micro- and Nano-structures in Materials Science

Organizers:
Brendt Wohlberg (*Los Alamos National Laboratory*)
Jeff Simmons (*Air Force Research Laboratory*)

MS11-1 - Tuesday, 05 at 13:30 Room C (Palazzina A - Building A, floor 1)

3D Computational Phase Microscopy
Computational imaging involves the joint design of imaging system hardware and software, optimizing across the entire pipeline from acquisition to reconstruction. We describe new methods for computational phase microscopy in the optical and X-ray regimes. We use computational illumination and detection, combined with simple hardware modifications and advanced image reconstruction algorithms to achieve fast, robust imaging of 3D refractive index. Algorithms are based on large-scale nonlinear non-convex optimization procedures for phase retrieval, with appropriate priors.

- Laura Waller (*University of California, Berkeley*)

SLADS: Fast Dynamic Sampling using Machine Learning
In traditional imaging applications, pixels are sampled in raster order. However, it can be argued that such an approach is optimally bad since each new measure pixel gives the least new information. In this talk, we present SLADS (a Supervised Learning Approach to Dynamic Sampling) a method for fast greedy selection of pixels which minimizes the reconstruction distortion for 2D image sampling. SLADS is based on the goal of selecting the pixel at each step that most reduces the absolute reconstruction error. By doing this, we can dramatically reduce the number of samples required to reconstruct an image. A key innovation of SLADS is that it uses machine learning methods to estimate the expected reduction in distortion (ERD) so that the algorithm is very fast. This makes SLADS practical for implementation on real image scanning systems. We present results of SLADS' application in the problems of synchrotron imaging, scanning electron microscopy, and confocal microscopy, and show how it can be used to reduce scan time and radiation dosage.

- Charles Bouman (*Purdue University*)

Sparse Sampling in Scanning Electron Microscopes
Sparse sampling is a design paradigm for electron microscopes that may be advantageous for some applications. To collect large data sets quickly, we pioneered sparse sampling in SEM. Here, we describe using image content to implement meander scan in SEM to avoid time-wasting 'carriage return' dynamics. We also describe a beam dynamic model extracted directly from meander scan images enabling sparse meander sampling, which further reduces collection time. Extension to multi-beam SEM is discussed.

- Kurt Larson (*Sandia National Laboratories, US Department of Energy*)

Denoising of Scanning Transmission Electron Microscopy Images for Materials Structure Characterization
The atomic structure of materials with a large number of positional and chemical degrees of freedom can be extremely difficult to estimate. However, much of the experimental data available to materials scientists is necessarily photon limited. In this talk, we will describe novel image recovery algorithms for photon-limited electron microscopy images of material structures that exhibit low-dimensional geometry related to the underlying atomic structure of the material.

Jie Feng (*University of Wisconsin-Madison*)
Willem Marais (*University of Wisconsin-Madison*)
Paul Voyles (*University of Wisconsin-Madison*)
• Rebecca Willett (*University of Wisconsin, Madison*)

MS11-2 - **Tuesday, 05 at 16:00** Room C (Palazzina A - Building A, floor 1)

Physics-based Regularization for Denoising Polycrystalline Material Images
The classical Markov Random Field (MRF), used extensively in Image Processing was actually derived from the Ising and Potts models used for describing magnetic phase transitions in materials at the atomic scale. This work upgrades the regularizer from the Potts model to the modern Phase Field Model, which quantitatively describes material structure formation, in order to provide a quantitative physics-based regularizer for solving ill-posed problems in microscopy. Examples of phase field regularized denoising are given.

Charles Bouman (*Purdue University*)
Jeffrey Rickman (*Materials Science and Engineering/Physics; Lehigh University*)
• Jeff Simmons (*Air Force Research Laboratory*)
Amirkoshyar Ziabari (*Electrical and Computer Engineering; Purdue University*)

Convolutional sparse coding based regularizers for tomographic inverse problems
Regularized/model-based inversion techniques have emerged as a vital tool in improving tomographic reconstruction quality for microscopic applications. In this talk, we will present an algorithm for integrating data-driven regularizers based on convolutional sparse representations into the tomographic reconstruction framework. We will present results of using these techniques on scientific tomography data sets and compare them to the traditional regularizers used in these applications.

• Singanallur Venkatakrishnan (*Oak Ridge National Laboratory*)
Brendt Wohlberg (*Los Alamos National Laboratory*)

Incorporating Physical Constraints and Regularization in Min-cut/Max-flow Graph Partitioning for Segmentation and Clustering in Materials Imaging
Engineering materials are heterogeneous mixtures at the microscale. Often the properties of the material have a strong dependence on features which have been obscured by phase transformations. Reconstruction of the prior structure is ill-posed, as the forward transformation is one-to-many. Here we present a graph partitioning approach to incorporate physically motivated priors in stochastic image reconstruction. The approach will be demonstrated on recovery of pre-transformation microstructures as well as segmentation and clustering in materials microscopy.

Alexander Brust (*The Ohio State University*)
• Stephen Niezgoda (*The Ohio State University*)
Eric Payton (*Air Force Research Laboratory*)

Regularized Image Reconstruction for Nonlinear Diffractive Imaging
Multiple scattering of light as it passes through an object is a fundamental problem that limits the performance of current material imaging systems. From the perspective of imaging inverse problems, multiple scattering leads to nonlinear forward models that generally lead to intractable optimization problems. In this talk, we will discuss recent advances for designing optimization schemes that can account for multiple scattering while also accommodating model-based priors for imaging.

• Ulugbek Kamilov (*Washington University in St. Louis*)
Hassan Mansour (*Mitsubishi Electric Research Laboratories (MERL)*)
Brendt Wohlberg (*Los Alamos National Laboratory*)

MS12 New directions in hybrid data tomography

Organizers:
Kim Knudsen (*Technical University of Denmark*)
Cong Shi (*Georg-August-Universität Göttingen*)

MS12-1 - **Tuesday, 05 at 13:30** Room F (Palazzina A - Building A, floor 2)

Some results on convergence rates for the density matrix reconstruction
Over the past few years, the research group from Prof. Claus Ropers developed a novel implementation of Ultrafast Transmission Electron Microscopy ("UTEM"). The instrument employs a "pump-probe" scheme, in which two laser pulses

are coupled into the column of a transmission electron microscope (TEM). Mathematically, The problem is to reconstruct the quantum state of free-electron ensembles in terms of their density matrix, from the measurements of the final quantum state. This is an inverse problem. In this talk we will introduce our results about the uniqueness and convergence rates for the reconstruction of the density matrix. This is a joint work with Thorsten Hohage and Claus Ropers.

- Cong Shi (*Georg-August-Universität Göttingen*)

Acousto-electric tomography based on complete electrode model for isotropic and anisotropic tissues

Acousto-electric tomography (AET) is a hybrid data imaging method. Most work in the litterature considers the EIT model with either Dirichlet or pure Neuman boundary conditions. However, complete electrode model (CEM) is a more practical model which is rarely discussed in the literature of AET. The present work is to develop a more practical imaging methodology, either iterative or explicit, for AET and based on CEM. Both isotropic and anisotropic tissues are considered.

- Changyou Li (*Northwestern Plytechnical University*)

Dynamical super-resolution with applications to ultrafast ultrasound

Recently there has been a successful development in ultrasound imaging, increasing significantly the sampling rate and therefore enhancing this imaging's capacities. In particular, for vessel imaging, the use of microbubble tracking allows us to super-resolve blood vessels, and by estimating the particles' speeds inside them, it is possible to calculate the vessels' diameters. In this context, we model the obtained signal with ultrafast ultrasound, giving a precise formula for the respective PSF and providing reasonable approximations to it. Additionally, we model the microbubble tracking problem, formulating it in terms of a sparse spike recovery problem in the phase space (the position and velocity space), that allows us to obtain simultaneously the speed of the microbubbles and their location. This leads to an L1 minimization algorithm for point source tracking, that promises to be faster than current alternatives.

- Francisco Romero (*ETH Zurich*)

Lamé Parameters Estimation from Static Displacement Field Measurements in the Framework of Nonlinear Inverse Problems

Quantitative Elastography is an imaging modality mapping biomechanical parameters of tissues. The problem of estimating Lamé parameters from full internal static displacement field measurements is formulated as a nonlinear operator equation. The Fréchet derivative and the adjoint of the nonlinear operator are derived. The main theoretical result is the verification of a nonlinearity condition guaranteeing convergence of iterative regularization methods. Furthermore, numerical examples for recovery of the Lamé parameters from simulated displacement data are presented.

Simon Hubmer (*Johannes Kepler University Linz*)
Andreas Neubauer (*Johannes Kepler University Linz*)
Otmar Scherzer (*Computational Science Center, University of Vienna*)

- Ekaterina Sherina (*Technical University of Denmark*)

MS12-2 - **Tuesday, 05 at 16:00** Room F (Palazzina A - Building A, floor 2)

Why does stochastic gradient descent work for inverse problems ?

Stochastic gradient descent uses one data sample per iteration, and is straightforward to implement. It is the workhorse for many large-scale optimization problems, especially in training deep neural networks. Numerical experiments indicate that it is also very promising for solving large-scale inverse problems. However, the theoretical understanding of the method remains very limited. In this talk, I will discuss its property from the perspective of regularization theory, and aims at explaining the excellent practical performance.

- Bangti Jin (*University College London*)

Non-zero constraints in quantitative coupled physics imaging

The reconstruction in quantitative coupled physics imaging often requires that the solutions of certain PDEs, e.g. the conductivity equation, the Helmholtz equation or Maxwell's equations, satisfy certain non-zero constraints, such as the absence of critical points. From the mathematical point of view, it is then interesting to see whether one can construct suitable boundary values (the illuminations used to probe the object), possibly independently of the unknown coefficients, in such a way that the corresponding solutions satisfy the required properties. In this talk, I will discuss several techniques used for this aim, as well as some negative results.

- Giovanni S. Alberti (*University of Genoa*)

Quantitative reconstructions by combining photoacoustic and optical coherence tomography

Reconstructions from photoacoustic imaging data run into the problem that there are too many physical parameters involved (optical absorption and scattering coefficients and the thermodynamic Grüneisen parameter) to be able to recover them uniquely. We want to show how additional measurements from an optical coherence tomography experiment can improve the situation and help to get a full quantitative reconstruction. Such a combined measurement could then be used as an acquisition method for an elastography setup.

- Peter Elbau (*University of Vienna*)

Spectral properties of the forward operator in photo-acoustic tomography

Photo-acoustic tomography (PAT) exploits an interaction between electromagnetic and acoustic phenomena. Accordingly, a standard forward model underlying PAT involves an elliptic PDE with internal data coupled with a hyperbolic initial-boundary problem. For both component problems one can formulate a forward operator that maps a feature of the sample (light absorption, diffusivity) to internal or boundary data. We investigate spectral properties of the composition of the two forward operators, exploring the interplay between the component operators.

- Mirza Karamehmedović (*Technical University of Denmark*)

MS13 Optimization for Imaging and Big Data

Organizers:
Margherita Porcelli (*University of Firenze*)
Francesco Rinaldi (*University of Padova*)

MS13-1 - **Tuesday, 05 at 13:30** Main room - aula magna - SP.I.S.A. (SP.I.S.A., floor 0)

An Active-Set Approach for Minimization over the Simplex and the l1-Ball
In this talk, we describe a new active-set algorithmic framework for minimizing a function over the simplex. The method is quite general and encompasses different strategies. We first analyze the convergence of the framework. Then, we explain how to adapt it in order to handle the problem of minimizing a function over the l1-ball. Finally, we report numerical experiments on different classes of instances.

Andrea Cristofari (*University of Rome "La Sapienza"*)
Marianna De Santis (*University of Rome "La Sapienza"*)
Stefano Lucidi (*University of Rome "La Sapienza"*)
- Francesco Rinaldi (*University of Padova*)

Beyond the worst case convergence analysis of the forward-backward algorithm
The forward-backward splitting algorithm is nowadays one of the most popular iterative procedures to solve convex minimization problems arising in machine learning and inverse problems. The worst case convergence rate on the function values is well-known to be O(1/n). However, in practice, the forward-backward algorithm is often much faster. The goal of this talk is to discuss that under suitable geometric assumptions, often satisfied in practice, the convergence rates of forward-backward algorithm are much faster.

Guillaume Garrigos (*Ecole Normale Supérieure, CNRS*)
Lorenzo Rosasco (*University of Genoa, Istituto Italiano di Tecnologia; Massachusetts Institute of Technology*)
- Silvia Villa (*Politecnico di Milano*)

Continuous modularity function for detecting leading communities in networks
Maximizing the discrete modularity function allows to locate relevant communities in networks. This combinatorial optimization problem is known to be NP-hard. We introduce a continuous function f and we show that its global maximum on the ℓ^∞-sphere coincides with the maximum of the original discrete modularity function. Thus we propose a community detection strategy based on f and we show extensive numerical comparisons with standard matrix-based approaches.

- Francesco Tudisco (*University of Strathclyde*)

Distributed learning in large scale networks: from GPS-denied localization to MAP inference in a graphical model
Big Data can elicit greater insight, but storage or computational limitations – or even privacy concerns – challenge learning from massive data sets. Distributed algorithms fit such problems just right: they work on partial data and fuse intermediate results with local neighborhoods, over a distributed network of computing nodes. In this talk we will take a trip starting on GPS-denied localization as a motivation and culminating on a general distributed MAP inference algorithm for graphical models.

João Gomes (*Institute for Systems and Robotics (ISR/IST), LARSyS, Instituto Superior Técnico, Universidade de Lisboa*)
- Claudia Soares (*LARSyS, Instituto Superior Técnico*)
João Xavier (*Institute for Systems and Robotics (ISR/IST), LARSyS, Instituto Superior Técnico, Universidade de Lisboa*)

MS13-2 - **Tuesday, 05 at 16:00** Main room - aula magna - SP.I.S.A. (SP.I.S.A., floor 0)

Exact spectral-like gradient method for distributed optimization
We consider unconstrained distributed optimization problems where N agents constitute an arbitrary connected network and collaboratively minimize the sum of their local convex cost functions. In this setting, we develop distributed gradient methods where agents' step-sizes are designed according to the rules akin to those in spectral gradient methods. The proposed method converges to the exact solution of the aggregate loss function. Numerical performance of the proposed distributed methods is illustrated on several application examples.

- Nataša Krejić (*University of Novi Sad*)

Douglas-Rachford iterations for TV - TGV - and constrained TGV - Denoising
We propose different versions of the TGV denoising method, which have several advantages over the classical one: Switching from penalties to constraints and changing the variables allows for simple universal parameter choice methods

and leads to finite duality gaps. We use the Douglas-Rachford method to solve these variational problems. We solve the large linear subproblems inexactly by the preconditioned conjugate gradient method and develop effective preconditioners.

Birgit Komander (*Technische Universität Braunschweig*)
Dirk Lorenz (*Technische Universität Braunschweig*)
• Lena Vestweber (*Technische Universität Braunschweig*)

Optimization in inverse problems via iterative regularization

In the context of linear inverse problems, we propose and study a general iterative regularization method allowing to consider large classes of regularizers and data-fit terms. We are particularly motivated by dealing with non-smooth data-fit terms, such like a Kullback-Liebler divergence, or an L1 distance. We treat these problems by designing an algorithm, based on a primal-dual diagonal descent method, designed to solve hierarchical optimization problems. The key point of our approach is that, in presence of noise, the number of iterations of our algorithm acts as a regularization parameter. In practice this means that the algorithm must be stopped after a certain number of iterations. This is what is called regularization by early stopping, an approach which gained in popularity in statistical learning. Our main results establishes convergence and stability of our algorithm, and are illustrated by experiments on image denoising, comparing our approach with a more classical Tikhonov regularization method.

• Guillaume Garrigos (*Ecole Normale Supérieure, CNRS*)
Lorenzo Rosasco (*University of Genoa, Istituto Italiano di Tecnologia; Massachusetts Institute of Technology*)
Silvia Villa (*Politecnico di Milano*)

Stochastic Approximation Method with Second Order Search Direction

Application of second-order- like search directions in the Stochastic Approximation framework is discussed together with convergence conditions. We consider strictly convex problems in noisy environment and assume that only noisy values for the objective function and the gradient are available, as well as some approximate Hessian value. Under the zero mean assumption on noise a convergence analysis is presented for methods that use some approximate second-order direction. We prove that there exists a level of inexactness, governed by the usual gain sequence in SA methods, that does not interfere with the convergence and hence derive the set of convergence conditions that are applicable to a number of search directions. These directions include the so called mini-batch subsampled Hessian in statistical learning and similar directions.

Nataša Krejić (*University of Novi Sad*)
• Natasa Krklec Jerinkic (*University of Novi Sad*)
Zoran Ovcin (*Faculty of Technical Sciences, University of Novi Sad*)

MS14 Denoising in Photography and Video

Organizers:
Stacey Levine (*Duquesne University*)
Marcelo Bertalmío (*University Pompeu Fabra*)

MS14-1 - **Tuesday, 05 at 13:30** Room A (Palazzina A - Building A, floor 0)

A Tour of Denoising: Form, Function, and Applications

Image denoising has reached impressive heights in performance and quality, almost as good as it can ever get. There are tens of thousands of papers on this topic and their scope is so vast and approaches so diverse, that putting them in some order is difficult. I will speak about why we should still care deeply about this topic, what we can say about this general class of functions, and what makes them so special.

• Peyman Milanfar (*Google Research*)

Camera Noise and Noise Perception in Motion Pictures

Noise in digital video can clearly reduce the perceived quality of video sequences captured in low-light conditions. As real camera noise is very different from the usually assumed AWGN, we discuss the characteristics of real camera noise and analyze it in a motion-picture camera workflow. Additionally, we present new results on the visual perception of spatiotemporal noise. The results can be used to optimize denoising methods for real camera noise and high visual quality.

• Tamara Seybold (*Technische Universität München*)

Benchmarking denoising algorithms with real photographs

Image denoising techniques are traditionally evaluated on images corrupted by synthesized i.i.d. Gaussian noise. We aim to obviate this unrealistic setting with a methodology for benchmarking denoising techniques on real photographs. Based on pairs of images with different ISO values and appropriately adjusted exposure times, we obtain ground truth by carefully post-processing the nearly noise-free low-ISO image. Our Darmstadt Noise Dataset (DND) enables the realistic evaluation of denoising techniques and yields several interesting insights.

• Stefan Roth (*Technische Universität Darmstadt*)

How to Improve Your Denoising Result Without Changing Your Denoising Algorithm
In this talk we will review some recent approaches for improving denoising results, in the particular case of photographic images. This includes denoising a transformed version of the image rather than processing the image data directly, ensuring the image follows the noise model assumed by the denoising algorithm, and optimizing the parameters of the denoising method according to visual appearance, not to image quality metrics.

Thomas Batard (*Technische Universität Kaiserslautern*)
Marcelo Bertalmío (*University Pompeu Fabra*)
Gabriela Ghimpeteanu (*Universitat Pompeu Fabra*)
- Stacey Levine (*Duquesne University*)

MS14-2 - **Tuesday, 05 at 16:00** Room A (Palazzina A - Building A, floor 0)

Toward efficient and flexible CNN-based solutions for denoising in photography
The talk begins with the disign of denoising CNN (DnCNN) model by incorporating residual learning and batch normalization. Then, we introduce several methods for better tradeoff between denoising accuracy and efficiency, including dilated filtering, sub-images, and the incorporation of wavelets. Furthermore, a fexible denoising CNN (FFDNet) is presented to handle Gaussian denoising with any or even spatially variant noise levels. Finally, several remarks are provided to develop CNNs for denoising in real photography.

Pengju Liu (*Harbin Institute of Technology*)
Kai Zhang (*The Hong Kong Polytechnic University*)
Lei Zhang (*Hong Kong Polytechnic University*)
- Wangmeng Zuo (*Harbin Institute of Technology*)

Restoration of noisy and compressed video sequences
A new method for denoising video sequences is presented. The method is able to deal with poor quality sequences affected by both noise and compression, as for example mobile phone videos recorded in low light conditions. This algorithm takes advantage of self similarity and redundancy of adjacent frames and uses motion compensation by regularized optical flow methods, which permits robust patch comparison in a spatio-temporal volume.

- Toni Buades (*Universitat de les Illes Balears*)

Modeling and removal of correlated noise: towards effective approximate models
We provide an overview of the modeling and removal of correlated noise (including crosstalk and fixed pattern) in the context of transform-domain filters, and introduce a method for both the exact computation and effective approximations of the noise spectrum in nonlocal collaborative transforms. Extensive experiments support the proposed method over earlier crude approximations used by filters such as BM3D. We conclude with a discussion on how these models interplay with signal-dependent observations and variance stabilization.

Lucio Azzari (*Tampere University of Technology*)
Alessandro Foi (*Tampere University of Technology*)
- Ymir Mäkinen (*Tampere University of Technology*)

High-Dimensional Mixture Models For Unsupervised Image Denoising
I will address the problem of patch-based image denoising through the unsupervised learning of a high-dimensional mixture model on the noisy patches. To overcome the curse of dimensionality, our model adopts a parsimonious modeling which assumes that the patches live in group-specific subspaces of low dimensionalities. This yields a numerically stable blind denoising algorithm that demonstrates state-of-the-art performance, both when the noise level is known and unknown. Joint work with Charles Bouveyron and Antoine Houdard.

- Julie Delon (*Université Paris Descartes*)

MS15 Nonlinear Diffusion: Models, Extensions and Algorithms

Organizers:
Ke Chen (*University of Liverpool*)
Joachim Weickert (*Saarland University*)
Xue-Cheng Tai (*Hong Kong Baptist University*)

MS15-1 - **Tuesday, 05 at 13:30** Room B (Palazzina A - Building A, floor 1)

Efficient solution of Euler elastica models
In this talk, we will present some new approaches in using operator splitting methods to get fast numerical algorithms for the minimization of Elastica energy for functions. The algorithms are fast and robust and nearly parameter free. Application to image restoration, segmentation, especially our recent efforts in adding convexity shape priori into geometry models, will be explained in details. Numerical experiments will be given to show the applications of the algorithms for real challenging applications.

- Xue-Cheng Tai (*Hong Kong Baptist University*)

Efficient Methods for Edge-weighted Colorization Models with Sphere Constraints
Alternating minimization algorithms are developed to solve variational models for image colorization based on chromaticity and brightness color system. The proposed methods are based on operator splitting, augmented Lagrangian and alternating direction method for multipliers. Some analytic results as well as numerical results will be presented.

- Sung-ha Kang (*Georgia Institute of Technology*)
  Maryam Yashtini (*Gerogetown University*)
  Wei Zhu (*University of Alabama*)

Generalized image osmosis filtering with applications
We introduce a generalized image osmosis model, enhancing the quality of the reconstructed image in the shadow removal problem by means of directional diffusion weights. Analogies with the second order linear and nonlinear diffusion inpainting equations (e.g. Harmonic, AMLE, Total Variation) acting on the shadow boundaries are further shown. Numerical details of efficient implementations for the model are provided, as well as applications to real images and to cultural heritage conservation challenges.

  Luca Calatroni (*CMAP, École Polytechnique CNRS*)
  Marco Caliari (*University of Verona*)
- Simone Parisotto (*University of Cambridge*)
  Carola-Bibiane Schönlieb (*University of Cambridge*)

An Image Reconstruction Model Regularized by Edge-preserving Diffusion and Smoothing for Limited-angle Computed Tomography
Conventional reconstruction algorithms for Limited-angle computed tomography introduce blurring and streak artifacts. We propose a reconstruction model that incorporates two regularization terms which play the role of edge-preserving diffusion and smoothing along the x-direction and y-direction respectively. Our model is based on the observation that through the image edges are blurred along the y-direction, they are visible along the x-direction, which is a global view of the theoretical results given by Quinto et al.

  Hongwei Li (*Capital Normal University of Beijing*)
  Jinqiu Xu (*Capital Normal University, Beijing*)
- Prof Peng Zhang (*Capital Normal University of Beijing*)
  Yunsong Zhao (*Capital Normal University, Beijing*)

MS15-2 - **Tuesday, 05 at 16:00** Room B (Palazzina A - Building A, floor 1)

Spectral analysis of nonlinear flows
We will examine flows through a nonlinear eigenvalue perspective. First we will show how gradient descent can reveal the eigen-structure of the initial condition, with a somewhat similar intuition as in the linear case. We will then discuss preliminary findings related to eigenfunctions of anisotropic diffusion.

- Gilboa Guy (*Electrical Engineering Department, Technion*)

Fractional order variational models for image restoration and other problems
Commonly used fractional order variational models in imaging involve minimization of regularizers of fractional order between 1 and 2, resulting in fractional partial differential equations of order between 2 and 4. They are particularly more advantageous in representing smooth images than high order integer derivatives based regularizers both in theory and in practice. This talk will review such works and present some recent progresses in the topic.

- Ke Chen (*University of Liverpool*)

Keeping Backward Diffusion Under Control: Discrete Analysis and Numerics
Nonlinear diffusion is a well-established tool for image denoising and enhancement. Whereas traditionally, nonnegative diffusivities are considered, it has been observed since long that backward diffusion plays a pivotal role for e.g. edge enhancement, provoking interest in diffusivities that even admit negative values. Then, the inherent instability of backward diffusion must be controlled. We discuss recent approaches to this problem, including nonstandard spatial discretisations, adaptive time-stepping schemes and special boundary conditions.

- Martin Welk (*Private University for Health Sciences, Medical Informatics and Technology (UMIT)*)

Partial Differential Equations and Image Segmentation in Medical Imaging
We study a partial differential equation model that can be applied to perform image segmentation. We use a geometric differential operator including a forcing term. We study the existence and uniqueness of solutions, the shape of some radial solutions and we show that under a suitable choice of the forcing term the geometric equation has non trivial asymptotic states. We present an application of the model to the segmentation of vessels in CT scans

- Luis Alvarez (*Universidad de Las Palmas de Gran Canaria*)
  Jesús Ildefonso Díaz (*Departamento de Matemática Aplicada. Universidad Complutense de Madrid*)

MS16 Topological Image Analysis: Methods, Algorithms, Applications

Organizers:
Patrizio Frosini (*University of Bologna*)
Massimo Ferri (*University of Bologna*)
Claudia Landi (*University of Modena and Reggio Emilia*)

MS16-1 - Wednesday, 06 at 09:30 Room P (Palazzina B - Building B, floor 0)

Methods, Algorithms and Applications in Topological Image Analysis
This talk will provide an introduction to the topics of this minisymposium. An overview of recent research in computational topology for image and shape analysis will be given, with focus on activities carried out by the Bologna group. This includes discrete Morse theory, persistent homology, Reeb graphs.

- Claudia Landi (*University of Modena and Reggio Emilia*)

Functional data analysis using a topological summary statistic: an application to brain cancer imaging
We introduce a novel summary statistic derived from topological data analysis, the smooth Euler characteristic transform (SECT), with well-defined inner-product structure that can be used in a wide range of functional and nonparametric modeling approaches. We show that the topological quantification of tumor MRIs are better predictors of clinical outcomes in glioblastoma multiforme (GBM) patients. SECT features alone explain more of the variance in patient survival than gene expression, volumetric, and morphometric features.

- Andrew X. Chen (*Department of Systems Biology at Columbia University*)
  Anthea Monod (*Columbia University*)

Discrete Morse theory for image analysis
Discrete Morse theory has been used in various works of image analysis. In this talk, we will describe a recent study on how to reconstruct a geometric graph from its noisy sample using Discrete Morse theory. Theoretical results can be applied for reconstructing road networks from their noisy images in 2D. In three dimensions, we explore its application to reconstructing neurons, porous bones, and other fillamentary structures from their images. Joint work with: Jiayuan Wang and Yusu Wang

- Tamal Krishna Dey (*The Ohio State University*)

Spectral geometry of shapes under topological alterations and its application to shape matching
We introduce a robust formulation of the shape correspondence problem under missing geometry and topological alterations with the language of functional maps. Using perturbation analysis, we show how removal of shape parts changes the Laplace-Beltrami eigenfunctions, and exploit it as a prior on the spectral representation of the correspondence. Our approach operates completely in the spectral domain, allowing to analyze shapes with constant complexity independent of their size, and yielding unprecedented results on challenging benchmarks.

- Luca Cosmo (*Ca' Foscari University of Venice*)
  Emanuele Rodolà (*University of Rome "La Sapienza", Dip. di Informatica*)

MS16-2 - Wednesday, 06 at 13:00 Room P (Palazzina B - Building B, floor 0)

Persistent entropy: a statistical tool for separating topological features from noise
Persistent homology studies the evolution of k-holes along a "filtration". The persistence barcode encodes birth and death times of k-holes along such filtration. k-Holes with short lifetimes are “topological noise”, and those with long lifetimes are “topological features” associated to the filtration. Persistent entropy is defined as the Shannon entropy of the persistence barcode. We will present properties of persistent entropy and derive a method for separating noise from features given a persistent barcode.

- Rocío Gonzalez-Diaz (*Universidad de Sevilla*)

Local persistent homology of metric-measure spaces in image analysis
Imaging data are frequently represented as point clouds or probability measures on surfaces, volumes or other metric spaces. We discuss how local persistent homology may be used to quantify the shape of such data in a robust, stable and often interpretable manner. We illustrate the method with an application to analysis of quantitative trait loci for plant morphology.

- Washington Mio (*Florida State University*)

Computing persistent homology of images with(out) discrete Morse theory
I present new methods for computing persistent homology for multidimensional image data. These methods are tailored for efficient handling of large – counted in billions of voxels and beyond – images, such as those produced by modern MicroCT scanners. First, a brief review of existing methods will be given, then new techniques will be described, including a parallel, streaming implementation. Finally, to describe limitations of current methods, we discuss worst-case bounds for topological complicatedness of images.

- Hubert Wagner (*IST Austria*)

Efficient computation of multipersistent homology and applications to data analysis and visualization
In this talk, we will focus on computational tools for the analysis of large size datasets equipped with multiple scalar values. We will consider multi-persistent homology, an extension of persistent homology motivated by the need to analyze

properties of data characterized by several parameters. We will present a new approach to multi-persistent homology computation based on reducing the input complex through the definition of a discrete gradient field inspired by discrete Morse theory.

Leila De Floriani (*University of Maryland*)
- Federico Iuricich (*City University of New York*)

MS16-3 - Wednesday, 06 at 15:30 Room P (Palazzina B - Building B, floor 0)

Topological Analysis of Biomedical Images
Topological Data Analysis (TDA) extracts and analyzes the underlying topological structures of data. Recent years has witnessed much progress, including efficient algorithms for persistence diagrams and effective kernel methods. Applying such tools in practice is exciting yet still nontrivial. In this presentation, we will describe our use of topological features for the analysis of various biomedical images, highlighting promises and limitations of the currently available methods.

Chao Chen (*City University of New York*)
- Federico Iuricich (*City University of New York*)

Polygonal meshes of superpixels for image over-segmentation based on topological skeletons
We consider the problem of splitting an image into a small number of convex polygons with vertices at subpixel resolution. Edges of resulting superpixels can have any direction and should adhere well to object boundaries. We introduce a Convex Constrained Mesh that accepts any straight line segments (or a straight-line graph based on a topological persistence) and outputs a complete mesh of convex polygons without small angles and with approximation guarantees for the given lines.

- Vitaliy Kurlin (*University of Liverpool*)

Similarity assessment for the analysis and understanding of 3D shapes: from geometry to topology with an eye to semantics
In this talk, we will give an overview of the methods developed at CNR-IMATI to support reasoning on the similarity among 3D digital objects. Geometry, structure and semantics are compared and analysed adopting a topological approach where important shape features are modelled, wherever possible, as critical points of real functions, following the Morse theory as mathematical context. Examples of complex and realistic scenarios will be discussed, with perspectives on future challenges.

Silvia Biasotti (*IMATI-CNR*)
Bianca Falcidieno (*IMATI-CNR*)
- Michela Spagnuolo (*IMATI-CNR*)

Topological analytics for large-scale scientific data
This talk presents the application of a discrete topological framework for the representation and analysis of large-scale scientific data. The inherent robustness of the approach allows addressing effectively the high complexity of the feature extraction and tracking of high-resolution scientific data. This approach has enabled the successful analysis of several massively parallel simulations including turbulent hydrodynamic instabilities, porous material under stress, energy transport of eddies in ocean data, and lifted flames for clean energy production.

- Valerio Pascucci (*University of Utah*)

MS17 Discrete-to-continuum graphical methods for large-data clustering, classification and segmentation

Organizers:
Matthew Thorpe (*University of Cambridge*)
Luca Calatroni (*CMAP, École Polytechnique CNRS*)
Daniel Tenbrinck (*University of Münster*)

MS17-1 - Wednesday, 06 at 09:30 Room M (Palazzina B - Building B, floor 0)

Scaling Results in Lp Regularised Semi-Supervised Learning
The semi-supervised learning problem is to assign labels to a dataset given a small number of training labels. We consider random geometric graphs and a Lp finite difference regulariser. In the talk I will discuss the asymptotic behaviour when the number of unlabelled data points increases whilst the number of training labels remains fixed. We show a delicate interplay between the regularizing nature of the functionals considered and the nonlocality inherent to the graph constructions.

- Matthew Thorpe (*University of Cambridge*)

Discrete to continuum limit of the graph Ginzburg-Landau functional
The graph Ginzburg-Landau functional has been extensively used for data clustering, classification, and image segmentation problems in recent years. In this talk we will look at the discrete to continuum Gamma limit of the functional on a regular graph and discuss interesting variations of the functional.

- Yves van Gennip (*University of Nottingham*)

Gromov-Hausdorff limit of Wasserstein spaces on point clouds
Many analytical and geometrical notions at the continuum level can be analyzed by interpreting them in Wasserstein spaces, hence it is natural to do the same at the sample level. The relevant question is when are these notions stable as the sample size grows to infinity? The main result can be used to establish a variety of consistency results for evolutions of gradient flow type that are relevant to tasks like manifold learning and clustering.

- Garcia Trillos Nicolas (*Brown University*)

Large data and zero noise limits of graph-based semi-supervised learning algorithms
Graph-based approaches to semi-supervised classification typically employ a graph Laplacian L constructed from the unlabelled data to provide clustering information. We consider Bayesian approaches wherein the prior is defined in terms of L; choice of data model then leads to probit and Bayesian level set algorithms. We investigate large data limits of these algorithms from both optimization and probabilistic points of view, and observe a common necessary condition for the limiting algorithms to be meaningful.

- Matt Dunlop (*Caltech*)

MS18 Functional neuroimaging methods for experimental data

Organizers:
Anna Maria Massone (*CNR - SPIN*)

MS18-1 - Wednesday, 06 at 09:30 Room 2 (Redenti, floor 1)

Image processing for the investigation of glucose metabolism in patients of ALS
In this talk we will present a generalization of the Hough transform to special classes of curves with the aim of recognizing complicated profiles in images. We show how a curve with degree 6 can be successfully used to recognize the spinal cord profile in Computed Tomography images and how these anatomical information can be combined with functional data provided by FDG-PET to measure the spinal marrow metabolism in patients affected by Amyotrophic Lateral Sclerosis.

- Cristina Campi (*University of Padoa*)
  Anna Maria Massone (*CNR - SPIN*)

Predicting brain atrophy progression from the healthy brain connectome
Alzheimer's Disease (AD) is caused by an accumulation of pathogenic proteins, which spread in the brain in disease-specific patterns. We can learn the underlying spreading mechanisms using Network Propagation Models, which attempt to explain disease progression in terms of spatial propagation through brain networks. By using DTI data of healthy subjects and AV45-PET data of AD patients we can predict patterns of amyloid deposition and reveal which mechanisms best explain AD.

- Sara Garbarino (*Universite de la Cote d'Azur and INRIA Sophia Antipolis*)

Conductivity models for functional neuroimaging
Electro- and magneto-encephalography provide measurements of brain activity at high time resolution. Their interpretation is intricate because they mix various sources of activity. This talk establishes the models required for extracting brain source activity from EEG and MEG data. To represent the geometry and conductivity of tissues, and compute the forward problems, boundary element methods have been developpped and implemented in opensource software. This is of particular interest for multimodal validation of source localization results.

- Maureen Clerc (*INRIA Sophia Antipolis-Méditerranée*)

Brain imaging from MEG data: an unsupervised clustering approach for source space reduction
When estimating functional connectivity from magnetoencephalographic (MEG) signals, regions of interest (ROIs) are typically defined based on standard anatomical parcellations, which are not informed by the limited spatial resolution of MEG. In this talk, we present an unsupervised clustering approach to divide and downsize the cortical source-space into ROIs based on the forward operator. By explicitly taking into account the MEG spatial resolution, the algorithm produces ROIs with a lower cross-talk compared to anatomical parcellations.

Lauri Parkkonen (*Aalto University*)
Narayan Puthanmadam Subramaniyam (*Aalto University*)
- Sara Sommariva (*Aalto University*)

MS19 Brain imaging: from neurosignals to functional brain mapping

Organizers:
Erkki Somersalo (*Case Western Reserve University*)
Francesca Pitolli (*Dept. of Basic and Applied Sciences for Engineering, University of Rome "La Sapienza"*)

MS19-1 - **Wednesday, 06 at 09:30** Matemates (Matemates, floor 0)

Novel instrumentation and analysis approaches for brain imaging
Human brain activity can be monitored with high temporal resolution by recording the weak magnetic fields produced by electrically active neurons. This technique, magnetoencephalography (MEG), is currently undergoing a renaissance due to the advent of novel sensors that can be placed much closer to the brain as well as due to advanced signal analysis techniques e.g. to study functional connectivity between brain regions and to provide neurofeedback. I will discuss how MEG is changing.

- Lauri Parkkonen (*Aalto University*)

Bayesian M/EEG brain mapping in the time and frequency domain
Magneto- and Electro-Encephalography (M/EEG) record the most direct consequences of brain activity with one-millisecond resolution. Functional brain mapping from M/EEG data requires to solve the corresponding inverse problem. In this talk, we describe the application of a recently proposed class of Monte Carlo Samplers for Bayesian estimation of multiple dipolar sources. The same method can be used either in the time domain (for stimulus induced responses) or in the frequency domain (for studying oscillatory activity).

Gianvittorio Luria (*University of Genoa*)
Michele Piana (*Dept. Mathematics, University of Genoa*)
Sara Sommariva (*Aalto University*)
- Alberto Sorrentino (*University of Genoa*)

"Hierarchical Bayesian Uncertainty Quantification for EEG/MEG Source Reconstruction"
We examine Hierachical Bayesian approaches to solve the under-determined and severely ill-posed inverse problem of EEG/MEG source reconstruction. For Laplacian scale mixture models, we show how a combination of Markov Chain Monte-Carlo methods and convex optimization techniques can be used to explore the different modes of the posterior distribution and thereby quantify the inherent uncertainty and ambiguity of such ill-posed inference procedures. Joint work with Yousra Bekhti, Joseph Salmon and Alexandre Gramfort.

- Felix Lucka (*CWI & UCL*)

Phase Synchronization in MEG/EEG: methodological considerations and empirical evidence
Synchronization of active neuronal groups has been proven to have causal consequences for neuronal communication. Magnetoencephalography is an ideal tool to study brain synchronization thanks to its non-invasiveness coupled to exquisite temporal and good spatial resolutions. This talk will address methods to detect linear and nonlinear frequency specific phase synchronization in MEG/EEG. The relevance of the proposed approaches to the underlying brain communication mechanisms will be discussed in covert visuospatial attention MEG data.

- Laura Marzetti (*Università degli Studi G. d'Annunzio Chieti e Pescara*)

MS20 Advances in Reconstruction Methods for Electrical Impedance Tomography

Organizers:
Melody Alsaker (*Gonzaga University*)
Samuli Siltanen (*University of Helsinki*)

MS20-1 - **Wednesday, 06 at 09:30** Room H (Palazzina B - Building B, floor 0)

Nonlinear D-bar Reconstructions of 2D Human EIT Data with an Optimized Spatial Prior
In recent years, advances in D-bar reconstruction methods for 2D EIT have resulted in a priori methods, wherein prior spatial information is included in the D-bar equations. These methods have been demonstrated to produce improved spatial resolution in reconstructions of computer-simulated EIT data. In this talk, we present the first human data reconstructions computed using a priori D-bar techniques, including still and moving images of human tidal breathing and a comparison with standard D-bar reconstructions.

- Melody Alsaker (*Gonzaga University*)
Jennifer Mueller (*Colorado State University*)
Rashmi Murthy (*Colorado State University*)

Bayesian approximation of continuous boundary data for EIT
Several direct computational methods (e.g. Layer Stripping, D-bar Method) for reconstructing electric conductivity distributions from current-voltage boundary measurements assume idealized continuous boundary data, while in reality the data consist of measurements from a fixed set of contact electrodes. The passage from discrete measurements to continuous boundary data contributes to the ill-posedness of the EIT inverse problems. In this talk, we propose a computational method rooted in the Bayesian paradigm to estimate continuous data from measurements.

- Sumanth Reddy Nakkireddy (*Case Western Reserve University*)

D-bar methods appliedto functionalpulmonary imaging: methods and clinical results
While clinical images can provide detailed information to physicians for diagnosis or monitoring, the derivation of concise measures is also of clinical importance. In this talk, several such measures for pulmonary assessment derived from EIT images are presented. Functional difference images computed by the D-bar method were used to compute surrogate measures of spirometry output and ventilation-perfusion ratios. Results are shown on data collected on pediatric patients with lung disease.

- Jennifer Mueller (*Colorado State University*)

Electrical impedance tomography imaging via the Radon transform
Here we show how Electrical Impedance Tomography can be used to efficiently detect interior jumps of the conductivity. Analysis of the complex geometrical optics solutions makes it possible to exploit an underlying complex principal type structure of the problem. We show that the leading term in a Neumann series is an invertible generalized Radon transform of the conductivity. Numerical simulation indicate that this approach effectively for detects inclusions within inclusions via EIT.

Allan Greenleaf (*University of Rochester*)
- Matti Lassas (*University of Helsinki*)

Matteo Santacesaria (*University of Helsinki*)
Samuli Siltanen (*University of Helsinki*)
Gunther Uhlmann (*University of Washington*)

MS20-2 - **Wednesday, 06 at 13:00** Room H (Palazzina B - Building B, floor 0)

Acousto-Electric Tomography with limited data
Acousto-Electric Tomography (AET) is a recently proposed technology for tomography that makes use of both ultrasonic waves and electric fields simultaneously to recover the conductivity distribution in a body. In this talk the basic reconstruction problem of AET will be considered. We will discuss some recent numerical and theoretical results regarding the stability of the problem in case of limited boundary data. The analysis is based on SVD analysis of the linearized problem.

- Kim Knudsen (*Technical University of Denmark*)

Robust Absolute EIT Imaging in 2D
Electrical Impedance Tomography (EIT) uses harmless surface electrical measurements to image the interior conductivity/permittivity of an object. The EIT problem is a severely ill-posed nonlinear inverse problem requiring carefully designed algorithms for robust image reconstruction. Recovering "absolute/static" EIT images is particularly challenging and often thought impossible. No simulated guess solutions are required for the "Matrix D-bar Method" making it remarkably robust to incorrect electrode locations and boundary shape. Absolute reconstructions from experimental data are presented.

- Sarah Hamilton (*Marquette University*)

Improving direct reconstructions from partial-boundary data in electrical impedance tomography
Electrical Impedance Tomography is a highly nonlinear inverse problem requiring carefully designed reconstruction procedures to ensure reliable image generation. D-bar methods are based on rigorous mathematical analysis and provide robust direct reconstructions by using a low-pass filtering of the associated nonlinear Fourier data. Similarly to low-pass filtering of linear Fourier data, only using low frequencies in the image recovery process results in blurred images. In this work we present several techniques to improve image quality.

- Andreas Hauptmann (*University College London*)

Reconstruction of a piecewise constant conductivity on a polygonal partition via shape optimization in EIT
In this talk we present a new iterative reconstruction algorithm that allows the recovery of a piecewise constant conductivity on an unknown triangular partition. This is formulated as a minimization problem for an appropriate cost functional, which is solved using some shape optimization techniques, such as the shape derivative of the functional. We will discuss numerical test cases from simulated data to show the reliability of the method as well as related theoretical issues.

- Matteo Santacesaria (*University of Helsinki*)

MS20-3 - **Wednesday, 06 at 15:30** Room H (Palazzina B - Building B, floor 0)

Contrast enhancement in EIT imaging of the brain
We propose a statistical learning approach to enhance contrast in EIT imaging of the brain. The conductivity is modelled as a combination of two unknowns, spatially distributed background and the skull layer. The discrepancy between the forward models with and without the skull layer is treated as a modelling error which is handled by the Bayesian approximation error approach. The approach is evaluated with simulations and phantom data.

Jari Kaipio (*The University of Auckland*)
- Ville Kolehmainen (*University of Eastern Finland*)

Antti Nissinen (*University of Eastern Finland*)
Marko Vauhkonen (*University of Eastern Finland*)

Generalized linearization techniques and smoothened complete electrode model
The forward problem of electrical impedance tomography is often linearized with respect to the conductivity and the resulting linear inverse problem is regarded as a subproblem in an iterative algorithm or as a reconstruction method as such. We introduce and numerically test a novel, accurate linearization technique based on the logarithm of the Neumann-to-Dirichlet operator. A smoothened contact conductance model is also proposed for electrode measurements, leading to improved regularity for the complete electrode model.

- Nuutti Hyvönen (*Aalto University*)

Image reconstruction in rotational EIT with limited boundary access
Rotational EIT has been proposed to increase accuracy of reconstructions through added independent measurements in multiple rotational positions around the sample. However, the benefit of conventional electrode configurations are limited to small amount of rotational positions. This talk presents the of use small number of electrodes and large number of rotational measurement position measurements to get comparable results. Furthermore, the limited EIT boundary access allows space for simultaneous attachment of other measurement modalities.

Edite Figueiras (*International Iberian Nanotechnology Laboratory*)
Jari Hyttinen (*Tampere University of Technology*)
- Olli Koskela (*Tampere University of Technology*)
Mari Lehti-Polojärvi (*Tampere University of Technology*)
Aku Seppänen (*University of Eastern Finland*)

The Use of the Approximation Error Method and Bayesian Inference to Introduce Anatomical and Physiological Prior Information into D-bar Algorithms
In Electrical impedance tomography, it was shown that the use of prior information and the Approximation Error Method improves the spatial resolution using the Gauss-Newton method. However, the D-bar method's approach to solve the inverse problem makes difficult to include statistical priors in the algorithm. In this work a method of correcting the data based on Bayesian techniques to incorporate statistical priors in the D-bar algorithm is proposed. Results are shown on experimental tank data.

- Talles Santos (*Polytechnic School of University of São Paulo*)

MS21 Recent mathematical advances in phase retrieval and computational imaging

Organizers:
Mahdi Soltanolkotabi (*University of Southern California*)
Tamir Bendory (*Princeton University*)

MS21-1 - Wednesday, 06 at 09:30 Room I (Palazzina B - Building B, floor 0)

Denoising with spherically uniform neural layers
A generative adversarial network (GAN) parameterizes an approximation to a given class of images. In practice, GAN-based models describe real-world image classes much more effectively than conventional wavelet-based models. Image processing with a GAN amounts to solving a non-convex optimization problem, and first-order methods tend to perform well. We introduce a model for neural layers that is amenable to analysis and suggests the use of certain activation functions. Joint work with Soledad Villar (NYU).

- Dustin Mixon (*Department of Mathematics, Ohio State University*)

Fast Phase Retrieval from Windowed Fourier Measurements via Wigner Distribution Deconvolution + Angular Synchronization
We will discuss phase retrieval from STFT magnitude measurements of a vector x based on a two step approach: First, a modified Wigner distribution deconvolution approach is used to solve for a portion of the lifted rank-one signal xx*. Second, an angular synchronization approach is used to recover x from the known portion of xx*. In addition to being computationally efficient the proposed method also gives insight into the design of good window/probe functions.

- Mark Iwen (*Department of Mathematics, Michigan State University*)
Sami Merhi (*Michigan State University*)
Michael Perlmutter (*Michigan State University*)

Nonconvex Sparse Blind Deconvolution: Geometry and Efficient Methods
Sparse blind deconvolution arises in a variety of imaging problems, including deblurring and motif-finding in microscopy data. Inspired by these applications, we study the short-and-sparse variant of this problem, in which the goal is to recover a short filter and a (random) sparse spike train from their convolution. We describe theory for methods based on nonconvex optimization over the sphere, which guarantee that we can efficiently produce the ground truth, up to symmetry.

Han-Wen Kuo (*Columbia University*)
- John Wright (*Department of Electrical Engineering, Columbia University*)
Yuqian Zhang (*Columbia University*)

Invariants for cryo-EM and multireference alignment
In this talk, the invariants of the cryo-EM problem will be introduced. We will start by discussing the group invariants of the simplified model of multireference alignment and show how these invariants can also be used for the 2D classification problem in cryo-EM. Then, it will be shown how by similar principles we construct an ab initio model from the cryo-EM images, without estimating the viewing directions, using low-order moments.

- Tamir Bendory (*Princeton University*)

MS21-2 - **Wednesday, 06 at 13:00** Room I (Palazzina B - Building B, floor 0)

Phase retrieval by alternating projections for random Gaussian measurements
Non-convex heuristics have been used to solve phase retrieval problems for decades, but only recently have convergence guarantees been obtained for some non-convex algorithms, mostly in the case where the sensing vectors are random. Algorithms for which such guarantees were established typically have a particular form: they consist in finding a good initial point, then doing a gradient descent over a well-chosen non-convex objective function, which does not encompass most algorithms actually used in applications. In this talk, I will explain how to obtain identical convergence guarantees for an algorithm closer to practice, by replacing the gradient descent with the very classic alternating projections method, and discuss the issues that arise when trying to further extend these results to the precise methods used in applications.

- Irene Waldspurger (*CEREMADE (Université Paris-Dauphine)*)

Phase retrieval with structured measurements
The problem of phase retrieval arises in various fields of science and engineering. In this talk we review several modern methods for treating the phase retrieval problem with structured measurements. In particular, we focus on methods to render the 1D Fourier phase retrieval unique by adding redundancy into the Fourier measurements. We then consider techniques for designing an optimal measurement matrix for phase retrieval based on maximizing the mutual information.

- Yonina Eldar (*Department of EE, Technion, Israel Institute of Technology, Haifa*)

Phase Retrieval Without Small-Ball Probability Assumptions
It is well known that many classes of random embeddings (e.g., Bernoulli matrices) do not allow for recovery from phaseless measurements. In this talk will discuss that there is still a large class of signals that can be reconstructed uniquely, namely "non-peaky" ones. We will discuss stability and uniqueness as well as a uniform recovery guarantee for the PhaseLift algorithm. In all of these cases, the number of measurements m approaches the information-theoretic lower bound.

- Felix Krahmer (*Technical University of Munich, Department of Mathematics*)
  Yi-Kai Liu (*National Institute of Standards and Technology*)

What are heuristic phase retrieval algorithms and why you should care
The phase retrieval problems that arise in X-ray crystallography are hard. The best known algorithms have time complexity that grows exponentially with problem size. Given the importance of the application, over the years heuristic algorithms have evolved to the point where solutions of structures up to thousands of atoms are within reach. Applied mathematicians have given these algorithms the cold shoulder because they do not guarantee solutions. On the other hand, they have not come up with algorithms that do. This talk aims to rehabilitate, for an audience of mathematicians, the heuristic algorithms used in crystallography. I will discuss a modern variant that has a 100% empirical success rate and is best described as a dynamical system that, thanks to ergodicity, manages to perform an exhaustive search. As in statistical mechanics, ergodicity is enabled by chaotic behavior and represents a strong departure from more disciplined modes of search (e.g. on trees). My take-away message will be that rather run from these algorithms mathematicians should try to understand them.

- Veit Elser (*Department of Physics, Cornell University*)

MS22 Mapping problems in imaging, graphics and vision

Organizers:
Ronald Lui (*Chinese University of Hong Kong*)
Ke Chen (*University of Liverpool*)

MS22-1 - **Wednesday, 06 at 09:30** Room L (Palazzina B - Building B, floor 0)

A fast solver for locally rigid image registration
We introduce a fast solver for registration problems that include image-based local rigidity constraints. Such problems arise in many applications, and the constraints are useful for incorporating prior knowledge about expected solutions for these typically ill-posed problems. Locally rigid registration can be posed as a nonlinear optimization which is nonlinear in two blocks of variables: one set of large dimension representing the nonlinear motion on the unconstrained portion of the domain and the other set of small dimension representing the rigid motion parameters on the constrained regions of the image. We propose a fast solver based on a Gauss-Newton framework that includes a tailored linear solver for improved efficiency. The linearized subproblems for the search direction are solved iteratively using our Linearize and Project (LAP) approach. Specifically, we eliminate the set of variables associated with the rigid motion and iteratively compute an update

of the nonlinear motion parameters. We show numerical examples that demonstrate the effectiveness of our approach both regarding iterations and time-to-solution.

- James Herring (*Emory University*)

A new constrained image registration model to avoid folding
Searching for a variational image registration model suitable for large and smooth deformation field with low computing time and no mesh folding is still a challenge. In this talk, a new constrained image registration model to avoid folding is presented. Furthermore, a fast solver is provided for numerical implementation of the new model. Numerical experiments are illustrated to show the good performance of our new model according to the registration quality.

Ke Chen (*University of Liverpool*)
- Jin Zhang (*Liao-Cheng University*)

Medical image analysis based on artificial intelligence and its clinical application
A new deep learning algorithm is proposed by introducing new concepts such as rotation invariance and split dropout. We discuss the problems in medical image analysis from such aspects as image segmentation, image registration and pattern recognition, establish a series of new mathematical models and design a new algorithm on the basis of geometrical analysis. By correlating the research results, we develop a set of applied, credible system to treat with medical image. The system succeeded in being widely used in 12 renowned hospitals such as Beijing 301 hospital in China and saving lives.

- Dexing Kong (*Zhejiang University*)

Longitudinal MRI brain analysis on image manifold
Longitudinal image analysis plays an important role in depicting the development of the brain structure, where image regression and interpolation are two commonly used techniques. In this paper, we develop an efficient model and approach based on a path regression on the image manifold instead of the geodesic one to avoid the complexity of the geodesic computing. Concretely, first we model the deformation by diffeomorphism, and then a large deformation is represented by a path on the orbit of the diffeomorphism group action. This path is obtained by compositing several small deformations, which can be well approximated by its linearization. Second, we introduce some intermediate images as constraints to the model, which guide to form the best fitting path. Thirdly, we propose an approximated quadratic model by local linearization method, where a closed form is deduced for the solution. It actually speeds up the algorithm. Finally, we evaluate the proposed model and algorithm on a synthetic data and a really longitudinal MRI data and the results show that our proposed method outperforms several state-of-the-art method.

- Shi-hui Ying (*Shanghai University*)

MS22-2 - Wednesday, 06 at 13:00 Room L (Palazzina B - Building B, floor 0)

Non-isometric shape matching via conformal Laplace-Beltrami Basis Pursuit
Surface registration is one of the most fundamental problems in geometry processing. Many approaches have been developed to compute such maps in cases where the shapes are nearly isometric. However, it is a much more challenging task to compute correspondence for shapes which are intrinsically less similar. In this talk, I will discuss a variational model to adaptively compute the Laplace-Beltrami (LB) eigensytem of two non-isometric shapes via conformal deformations.

Rongjie Lai (*Rensselaer Polytechnic Institute*)
- Stephan Schonsheck (*Rensselaer Polytechnic Institute (RPI)*)

On a new multigrid algorithm for image segmentation
Global and selective image segmentation are very important applications of image processing techniques. The latter is of particular importance in medical imaging. We introduce a new convex selective segmentation model which achieves results which could not previously be attained. We also introduce a new multigrid framework for solving this model, and a whole class of segmentation models with O(N) complexity.

Ke Chen (*University of Liverpool*)
- Mike Roberts (*University of Liverpool*)

Parametrising flat-foldable surfaces with incomplete data
We propose a novel way of computing surface folding maps via solving PDEs. This framework is a generalisation to the existing quasiconformal methods but allows manipulation of the geometry of folding. Moreover, the crucial quantity that characterises the geometry occurs as the coefficient of the equation, namely the Beltrami coefficient. This allows us to solve an inverse problem of parametrising the folded surface when only partial data and the folding geometry are given.

Ronald Lui (*Chinese University of Hong Kong*)
- Di Qiu (*The Chinese University of Hong Kong*)

Surface mapping using Teichmuller theory
Surface mapping plays a fundamental role in engineering field and medicine. Teichmuller theory offers a powerful means to compute diffeomorphisms between surfaces with the least angle distortion, namely the Teichmuller mapping. The Teichmuller mapping has deep connections with holomorphic quadratic differentials. In this talk, we introduce the way to construct the basis of the space of all holomorphic quadratic differentials, and to produce the Teichmuller mapping.

- Xianfeng Gu (*State University of New York at Stony Brook*)

MS22-3 - **Wednesday, 06 at 15:30** Room L (Palazzina B - Building B, floor 0)

Variational Diffeomorphic Models for Image Registration
Image registration is to find a transformation to map the corresponding image data. But in large deformation registration problems, it is very difficult to obtain a solution that has no folding. Lam and Lui (2014) has used Beltrami coefficient to control the transformation and avoid the twist. In this talk, I will propose novel diffeomorphic models based quasi-conformal theory for image registration. Numerical experiments demonstrate that the proposed models can get accurate and diffeomorphic transformations.

Ke Chen (*University of Liverpool*)
- Daoping Zhang (*University of Liverpool*)

Fuzzy based energy model for Segmentation of images using hybrid image data
Segmentation of images having intensity inhomogeneity and texture is always challenging. A region based model is proposed for segmentation of images having intensity inhomogeneity and texture. The model uses local hybrid image data combined with fuzzy membership function, which helps the model to achieve global minimum. No re-initialization is not required. Due to the use of local intensity information of the hybrid image, the model works well in images having intensity inhomogeneity. For segmentation of texture images, the proposed model is combined with extended structure tensor (EST). The model works well in images having clutter background, and images having maximum, minimum or average intensity background.

- Noor Badshah (*University of Engineering and Technology Peshawar*)

Topology Preserving Image Segmentation by Beltrami Signature of Images
A new approach using the Beltrami repre- sentation of a shape for topology preserving image seg- mentation is proposed. Using the proposed model, the target object can be segmented from the input image by a region of user prescribed topology. Given a target image I, a template image J is constructed and then deformed with respect to the Beltrami representation. The deformation on J is designed such that the topology of the segmented region is preserved as which the object interior in J. The topology preserving property of the deformation is guaranteed by imposing only one constraint on the Beltrami representation, which is easy to be handled. Introducing the Beltrami representation also allows large deformations on the topological prior J, so that it can be a very simple image, such as an image of disks, torus, disjoint disks, etc. Hence, prior shape information of I is unnecessary for the proposed model. Additionally, the proposed model can be easily incorporated with selective segmentation, in which landmark constraints can be imposed interactively to meet any practical need (e.g. medical imaging). High accuracy and stability of the proposed model to deal with different segmentation tasks are validated by nu- merical experiments on both artificial and real images.

- Hei Long Chan (*The Chinese University of Hong Kong*)

Sobolev Gradient and Segmentation of Vector Valued Texture Images
In this paper, we propose a method for minimization of segmentation model for vector-valued texture images. The texture in the image will be smoothed by using L0 gradient norm and then the vector valued image segmentation model will be minimized through sobolev gradient for fast convergence. The better performance of the method will observed from the experimental results. Results of the proposed method are compared with L^2 gradients.

- Fahim Ullah (*University of Engineering and Technology Peshawar*)

MS23 Multi-Modality/Multi-Spectral Imaging and Structural Priors

Organizers:
Matthias J. Ehrhardt (*University of Cambridge*)
Simon Arridge (*University College London*)

MS23-1 - **Wednesday, 06 at 09:30** Room F (Palazzina A - Building A, floor 2)

Edge Aligning Image Regularizations
This talk will give an overview of different strategies for image regularizations that encourage edges in multiple channels to coincide. The position and direction of such edges can either be predetermined by a guidance image or estimated during the reconstruction of multiple channels. For the latter I will present an iterative strategy based on Bregman distances as well as collaborative total variation and total generalized variation type penalties.

- Michael Moeller (*University of Siegen*)

Incorporating feature space classification in multi-spectral image reconstruction
Analysis of medical images often proceeds by applying classification approaches from machine vision, under the assumption that the images have been robustly reconstructed. In the case of strongly ill-posed inverse problems the reconstruction process can lead to considerable artefact in the images which can degrade this classification step. In this talk we present an approach that applies classification algorithms within iterative reconstruction algorithms. Results are presented for some non-linear tomography problems.

- Simon Arridge (*University College London*)

Coupled regularization with multiple data discrepancies

We consider a class of regularization methods for inverse problems where a coupled regularization is employed for the simultaneous reconstruction of data from multiple sources. This is motivated by applications where one aims to exploit correlations of different data channels for the ill-posed inversion. We consider a rather general setting and derive stability and convergence results. In particular, we show how parameter choice strategies adapted to the interplay of different discrepancies improve convergence rates.

- Martin Holler (*École Polytechnique, Université Paris Saclay*)
  Richard Huber (*University of Graz*)
  Florian Knoll (*New York University*)

Magnetic particle imaging using prior information from MRI

Magnetic particle imaging (MPI) is a new tracer-based imaging modality to image blood flow without using harmful radiation. Since MPI does not provide anatomical information, e.g. from biological tissue, it is combined with MRI. In this talk we present a model-based approach for MPI reconstruction to improve reconstruction quality. We use total least squares to compensate for modeling errors and a TV-term to incorporate the MRI information.

- Christine Bathke (*Center for Industrial Mathematics (ZeTem), University of Bremen*)

MS23-2 - **Wednesday, 06 at 13:00** Room F (Palazzina A - Building A, floor 2)

Unbiased joint reconstruction in multi-modal biomedical imaging

This talk discusses reconstruction strategies for multi-modal imaging based on Bregman iterations, in particular taking into account joint edge information. We demonstrate that such methods robustly achieve similar results as state-of-the art methods by solving sequences of convex problems and thus avoiding problems with local minima. Moreover, the iterative schemes naturally decrease the bias, thus leading better quantitative results. We discuss these issues in applications to PET-MR and undersampled MR with different weighting and also comment on computational aspects.

- Martin Burger (*University of Muenster*)

Multimodal Sparse Reconstruction Via Learning Cross-Modality Maps

We introduce a framework to reconstruct undersampled signals with the aid of correlated signals. The correlated signals can arise from a different modality and, thus, need not be similar to the target signals and can have different representations. Our framework has two elements: L1-L1 minimization theory, which allows reconstructing undersampled signals with the aid of similar (same modality) signals, and an approach to learn mappings between modalities. Guarantees are obtained via statistical learning theory.

- Joao Mota (*Heriot-Watt University*)

Faster image reconstruction by stochastic optimization

Image reconstruction with convex anatomical priors can be performed by the Primal-Dual Hybrid Gradient (PDHG) algorithm (Chambolle and Pock, 2011). For many imaging modalities, e.g. PET, the problem has a special saddle point structure which is usually not exploited. We propose a stochastic extension of the PDHG which randomly selects subsets of the data in each iteration. Numerical results on clinical PET data show a significant speed-up by this technique.

- Matthias J. Ehrhardt (*University of Cambridge*)

MS24 Data-driven approaches in imaging science

Organizers:
Jae Kyu Choi (*Institute of Natural Sciences, Shanghai Jiao Tong University*)
Chenglong Bao (*Yau Mathematical Sciences Center, Tsinghua University*)

MS24-1 - **Wednesday, 06 at 09:30** Room G (Palazzina A - Building A, floor 0)

Algorithmic Self-Calibration in Computational Imaging

Computational imaging jointly designs optical hardware and computational software to develop methods with new capabilities or simpler hardware than existing methods. Such efficient imaging systems are often sensitive to model mismatch errors (e.g. misalignment, aberrations), requiring careful calibration to remove artifacts. We describe new methods that correct for experimental errors algorithmically, within the inverse problem itself, via joint optimization. This removes the need for time-consuming and delicate calibration routines, resulting in robust and user-friendly setups.

Michael Chen (*UC Berkeley*)
Regina Eckert (*UC Berkeley*)
Zachary Phillips (*UC Berkeley*)
- Laura Waller (*University of California, Berkeley*)
  Li Hao Yeh (*UC Berkeley*)

Wafer Defect Detection Algorithm Using Deep Learning Algorithms

Since 1990, many mathematicians studied the image processing based on partial differential equations and variational methods. Using TV(total variation) and some optimization techniques, there were a lot of improvement in image processing areas. Until deep learning methods coming out, those were the state of art methods in these areas. But once using deep learning techniques, it turns out that in almost every areas in image processing fields, deep learning is the one of the best method. I will explain and compare the some results for Wafer defect detection using the traditional image enhancement methods and deep learning methods. Also I will explain a little bit about the networks of deep learning which we are using for detecting the defect.

- Myung Joo Kang (*Department of Mathematical Sciences, Seoul National University*)

Deep Learning for Inverse Wave Scattering Problems

In this talk, we introduce our novel deep learning approaches called "deep convolutional framelets" for inverse wave scattering problems originated from diffuse optical tomography, ultrasound imaging, wave scattering, etc. In particular, inspired by the recent discovery that a deep convolutional neural network is closely related to the Hankel matrix decomposition, we provide a unified deep learning approach for addressing inverse scattering problems that lead to low-rank Hankel matrix and associated deep convolutional neural networks.

- Jong Chul Ye (*Department of Bio and Brain Engineering, Korea Advanced Institute of Science and Technology*)
  Jaejun Yoo (*KAIST*)
  Yeo Hun Yoon (*KAIST*)

Computational models for Coherence retrieval

Coherence retrieval is important in optical systems. Mathematically, it is a generalization of phase retrieval problem. In this talk, we will show the error caused by the traditional method for coherence retrieval. Furthermore, a robust trace regularization method is proposed to achieve more robust results.

- Chenglong Bao (*Yau Mathematical Sciences Center, Tsinghua University*)

MS24-2 - Wednesday, 06 at 13:00 Room G (Palazzina A - Building A, floor 0)

Partial Differential Equations in Manifold Learning

Manifold provides a powerful tool to model high dimensional data. PDEs on the manifold can help us to reveal the intrinsic structure of the manifold. In this talk, we will discuss the relation between PDEs and some machine learning problem. Several models and algorithms are proposed.

- Zuoqiang Shi (*Tsinghua University*)

Machine Learning for Seismic Data Processing

In this talk, we would like to present how machine learning (including SVR and deep learning) can work for seismic data denoising and inversion from training data sets. We introduce deep learning method to seismic noise attenuation without knowing the noise variance (blind denoising). The training set is obtained by partitioning the data from SEG open data and some denoised field data into small patches. Numerical results are provided with comparisons to traditional methods and state-of-the-art methods, showing deep learning method achieve good performance.

- Jianwei Ma (*Department of Mathematics, Center of Geophysics, Harbin Institute of Technology*)

Operator Norm Optimization for Structural Changes in Cryo-EM Imaging

When taking Cryo-EM images of 3D protein structures, we obtain extremely noisy 2D images. Moreover, it is possible for the same proteins to have different forms under certain circumstances. We want to discuss how to describe such different forms of the same proteins by the unknown covariance matrix representing 3D conformational changes. Since we are most interest in the major deviation in the change, we look for the first principal component via operator norm optimization.

- Yunho Kim (*Department of Mathematical Sciences, Ulsan National Institute of Science and Technology*)

Exploiting Low-Quality Visual Data using Deep Networks

While many sophisticated models are developed for visual information processing, very few pay attention to their usability in the presence of data quality degradations. Most successful models are trained and evaluated on high quality visual datasets. On the other hand, the data source often cannot be assured of high quality in practical scenarios. For example, video surveillance systems have to rely on cameras of very limited definitions, due to the prohibitive costs of installing high-definition cameras all around, leading to the practical need to recognize objects reliably from very low resolution images. Other quality factors, such as occlusion, motion blur, missing data and bad weather conditions, are also ubiquitous in the wild. The seminar will present a comprehensive and in-depth review, on the recent advances in the robust sensing, processing and understanding of low-quality visual data, using deep learning methods. I will mainly show how the image/video restoration and the visual recognition could be jointly optimized as one pipeline. Such an end-to-end optimization consistently achieves the superior performance over the traditional multi-stage pipelines. I will also demonstrate how our proposed approach largely improves a number of real-world applications.

- Zhangyang Wang (*Department of Computer Science and Engineering, Texas A&M University (TAMU)*)

MS24-3 - Wednesday, 06 at 15:30 Room G (Palazzina A - Building A, floor 0)

Learned Experts' Assessment-Based Reconstruction Network ("LEARN") for Sparse-Data CT

To perform sparse-data CT, the iterative reconstruction commonly uses regularizers in the CS framework. In this paper, inspired by the idea of deep learning, we unfold a state-of-the-art "fields of experts" based iterative reconstruction scheme up to a number of iterations for data-driven training, construct a Learned Experts' Assessment-based Reconstruction Network ("LEARN") for sparse-data CT, and demonstrate the feasibility and merits of LEARN network. The experimental results produces a superior performance to several state-of-the-art methods.

Hu Chen (*Sichuan University*)
Yunjin Chen (*ULSee Inc.*)
Peixi Liao (*The Sixth People's Hospital of Chengdu*)
Yang Lv (*Shanghai United Imaging Healthcare Co., Ltd*)
Huaiqiang Sun (*West China Hospital of Sichuan University*)
Ge Wang (*Rensselaer Polytechnic Institute*)
Weihua Zhang (*Sichuan University*)
- Yi Zhang (*School of Computer Science, Sichuan University*)

An Edge Driven Wavelet Frame Model for Image Restoration
Wavelet frame systems are known to be effective in capturing singularities from degraded images. In this talk, we introduce a new edge driven wavelet frame model for image restoration by approximating images as piecewise smooth functions. With an implicit representation of singularity sets, the proposed model inflicts different strength of regularization on smooth region and singularities. Our model is robust to both image approximation and singularity estimation. The implicit formulation also enables to provide a rigorous connection between the discrete model and the continuous variational model.

- Jae Kyu Choi (*Institute of Natural Sciences, Shanghai Jiao Tong University*)
Bin Dong (*Peking University*)
Xiaoqun Zhang (*Institute of Natural Sciences, School of Mathematical Sciences, and MOE-LSC, Shanghai Jiao Tong University*)

MS25 Bilinear and quadratic problems in imaging

Organizers:
Felix Krahmer (*Technical University of Munich, Department of Mathematics*)
Kristian Bredies (*Universität Graz*)

MS25-1 - **Wednesday, 06 at 15:30** Room D (Palazzina A - Building A, floor 1)

Regularization of bilinear and quadratic inverse problems by tensorial lifting
Considering the question: how non-linear may a non-linear operator be in order to extend the linear regularization theory, we introduce the class of dilinear and diconvex mappings. Using tensorial liftings, we generalize the concept of subgradients and Bregman distances from convex analysis to establish convergence rates under similar assumptions than in the linear setting. Finally, we apply our results to the deautoconvolution problem to derive satisfiable source conditions and numerically provable convergence rates.

- Robert Beinert (*University of Graz*)

Nonconvex methods for nanoscale, 3D phaseless imaging
This talk focuses on nonconvex gradient-based methods (a.k.a. Wirtinger Flows) for solving phase retrieval problems. I will introduce new accelerated variants of Wirtinger Flow that is able to escape low-quality local optima and achieve state of the art reconstruction results with less computational effort. I will also discuss applications in imaging of integrated circuits, demonstrating the ability of Wirtinger Flows to reconstruct nano-scale features in the presence of noise and device mis-alignments.

- Mahdi Soltanolkotabi (*University of Southern California*)

Calibrationless Reconstruction Methods in Magnetic Resonance Imaging
Magnetic Resonance Imaging (MRI) is a powerful tomographic imaging technique based on sampling of Fourier data in a series of measurements. To reduce the number of measurements, parallel imaging utilizes data from multiple receive coils which each produces a signal modulated by a different spatial sensitivity profile. We will discuss robust algorithms for parallel imaging that avoid explicit calibration of the sensitivities by formulating reconstruction as a non-linear inverse problem.

H. Christian M. Holme (*University Medical Center Göttingen*)
Sebastian Rosenzweig (*University Medical Center Göttingen*)
- Martin Uecker (*University Medical Center Göttingen*)

Blind Demixing and Deconvolution at Near-Optimal Rate
In this talk we consider simultaneous blind deconvolution of r signals from their noisy superposition, a problem also referred to as blind demixing and deconvolution. We will show that recovery of the unknown functions is possible using convex programming, if the number of measurements is close to the degrees of freedom.

Peter Jung (*Technical University of Berlin*)
Felix Krahmer (*Technical University of Munich, Department of Mathematics*)
- Dominik Stoeger (*Technical University of Munich*)

MS26 New trends in inpainting

Organizers:
Yann Gousseau (*Telecom ParisTech*)
Simon Masnou (*Université Lyon 1*)

MS26-1 - Wednesday, 06 at 09:30 Room E (Palazzina A - Building A, floor 2)

Sparse Inpainting with Anisotropic Integrodifferential Operators
Many PDE-based inpainting methods use sophisticated higher-order differential operators to bridge large gaps and to recover structures with low curvature. They require fairly advanced numerical methods, while the inpainting process is still fairly slow. We show that one can achieve results of competitive quality by the limiting case of a widely ignored anisotropic diffusion operator involving Gaussian convolution. It offers favourable shape reconstruction properties for sparse data, while allowing simple and efficient numerical algorithms.

- Joachim Weickert (*Saarland University*)

Image Completion by CNN with Global and Local Consistency
We present a novel approach for image completion that results in images that are both locally and globally consistent. In the popular adversarial network scheme, we train an image completion network as well as two—global and local—context discriminator networks. The image completion network is trained to fill-in the missing regions in the input image to fool the discriminators, which are in turn trained to distinguish real images from completed ones.

- Hiroshi Ishikawa (*Waseda University*)

Higher-order total directional variation with imaging applications
The talk will be devoted to a new class of higher-order anisotropic total variation regularizers, with applications to image denoising and to digital elevation maps reconstruction. Our model can mix isotropic and anisotropic regularization at various derivation orders, which helps recovering the intrinsic structure of images and surfaces. I will describe a primal-dual approach for the numerical implementation of the model. The talk will be illustrated with various numerical examples.

Simon Masnou (*Université Lyon 1*)
- Simone Parisotto (*University of Cambridge*)

Carola-Bibiane Schönlieb (*University of Cambridge*)

Motion Consistent Video Inpainting
We propose a fast and automatic inpainting technique that works under many challenging conditions such as moving camera, dynamic scenes or long occlusion.By using optical flow in many stages of the algorithm, our method has the capability of preserving the spatio-temporal coherency as well as reconstructing moving objects within a long temporal occlusion. It compares favorably with previous works while radically reducing the computation time.

- Le Thuc Trinh (*Telecom ParisTech and University Lyon 2*)

MS27 Color Imaging Meets Geometry

Organizers:
Gabriele Steidl (*University of Kaiserslautern*)
Edoardo Provenzi (*Université de Bordeaux*)

MS27-1 - Wednesday, 06 at 09:30 Room C (Palazzina A - Building A, floor 1)

Resnikoff's geometrical framework for the space of perceived colors and locality of vision
In 1974, H. L. Resnkikoff published an inspiring paper about the use of differential geometry to study, among other things, the intrinsic shape of the space of perceived colors and the Riemannian metrics on it. The mathematical techniques that he used is shared with modern theories of theoretical physics, which are far from being a common background for scientists in color vision and processing. Due to this, Resnikoff's paper remained unnoticed for decades. In this talk, some insights about how to update Resnikoff's ideas will be given and discussed in relationship with a modern theory of color spaces.

- Edoardo Provenzi (*Université de Bordeaux*)

Colorisation of LiDAR point cloud
Most recent mobile mapping systems (MMS) capture 3D lidar point cloud together with HD optical images. In this talk, we will present a method to add color information to each lidar point. First, each lidar point is projected onto each color

image. By comparing the depth of a point in one image with the ones of its neighbors in the same image, a visibility coefficient is automatically estimated for each point in each point of view/image. It provides a confidence index to the color of the corresponding pixel. Each point is thus associated to a list of color candidates and their index of confidence. The final color for each point is computed from spatial regularization on the point cloud domain.

- Aurélie Bugeau (*LaBRI / University of Bordeaux*)
  Aujol Jean-Francois (*University of Bordeaux*)
  Bredif Mathieu (*IGN*)
  Biasutti Pierre (*LaBRI / IMB / University of Bordeaux*)

Exemplar-based face colorization using image morphing

Colorization of gray-scale images relies on prior color information. Exemplar-based methods use a color image as source of such information. Then the colors of the source image are transferred to the gray-scale target image. In the literature, this transfer is mainly guided by texture descriptors. Face images usually contain few texture so that the common approaches frequently fail. In this work, we propose a new method taking the geometric structure of the images rather their texture into account such that it is more reliable for faces. Our approach is based on image morphing and relies on the YUV color space. First, a correspondence mapping between the luminance Y channel of the color source image and the gray-scale target image is computed. This mapping is based on the time discrete metamorphosis model suggested by Berkels, Effland and Rumpf. We provide a new finite difference approach for the numerical computation of the mapping. Then, the chrominance U,V channels of the source image are transferred via this correspondence map to the target image. A possible postprocessing step by a variational model is developed to further improve the results. To keep the contrast special attention is paid to make the postprocessing unbiased. Our numerical experiments show that our morphing based approach clearly outperforms state-of-the-art methods.

- Fabien Pierre (*Université de Lorraine*)

A geometric model of brightness perception and its application to color images correction

Retinex-based formulations aim at modeling the color perception of an image, and some of them can geometrically be viewed as the averaging of perceptual distances between image pixels. In this talk, I will present a generalization of these distances by considering the parallel transport map associated to a covariant derivative, and from which derives a new variational model for contrast enhancement. I will show some results for well-chosen covariant derivatives that encode brightness perception phenomena.

- Thomas Batard (*Technische Universität Kaiserslautern*)
  Marcelo Bertalmío (*University Pompeu Fabra*)

MS28 Diffeomorphic Image Registration: Numerics, Applications, and Theory

Organizers:
Andreas Mang (*Department of Mathematics, University of Houston*)
George Biros (*Institute for Computational Engineering and Sciences, University of Texas at Austin*)

MS28-1 - **Wednesday, 06 at 09:30** Main room - aula magna - SP.I.S.A. (SP.I.S.A., floor 0)

Modelling and complexity issues on large deformations for shape ensembles

As pointed out by D'arcy Thomspon in his celebrated "Theory of Transformations" (Growth and Forms, 1917), the structure of a collection of shapes can be more easily understood if one considers that "simple" transformations can usually morph one shape into another. Its mathematical translation into the idea of action of groups of transformations on various "deformable" objects has initiated a rich theoretical and computational framework connecting numerous branches of mathematics fueled by applications in medical imaging, computational anatomy and computational medicine. However, there are still challenging issues to address theoretically and computationally the more difficult *pattern theoretic* question of the "understanding" of the relations between a collection of shapes through the use and the selection of a descriptive language for deformations as pioneered by Ulf Grenander. We will discuss in this talk some of these issues as well as some of our attempts in that direction.

- Alain Trouvé (*Centre de Mathématiques et Leurs Applications*)

Optimal transport for diffeomorphic registration

In this talk, we propose the use of optimal transport for diffeomorphic registration of embedded surfaces and other sparse data. We also propose an extension to the space of images. This type of global similarity measures between data relies on the use of an embedding of data to a space of measures and the use of the entropic regularization of a generalization of the Wasserstein metric. This method can be generalized to many inverse problems.

- François-Xavier Vialard (*University Paris-Dauphine*)

A Lagrangian Framework for Fast and Flexible Diffeomorphic Image Registration

We present efficient solvers for diffeomorphic registration problems in the framework of Large Deformations Diffeomorphic Metric Mappings (LDDMM). We use an optimal control formulation in which the (stationary or instationary) velocity field of a hyperbolic PDE needs to be chosen in order to minimize the distance between the final state of the system (the transformed/transported template image) and the observation (the reference image). Our formulation is widely applicable as it allows solving mass- and intensity-preserving registration problems.

- Lars Ruthotto (*Department of Mathematics and Computer Science, Emory University*)

Statistically-constrained Robust Diffeomorphic Registration

We present a novel framework to construct statistical deformation models for diffeomorphisms, aiming to improve the robustness of deformable registration in the presence of pathologies. We model the high-dimensional velocity field as a collection of local velocity fields. For each local field, we learn a low-dimensional representation using principal component analysis. Dependencies across local transformations are captured through canonical correlation analysis. We showcase the improved robustness of the proposed method using simulated brain lesion images as well as real brain images with pathologies.

Christos Davatzikos (*University of Pennsylvania*)
- Aristeidis Sotiras (*University of Pennsylvania*)

Ke Zeng (*University of Pennsylvania*)

MS28-2 - **Wednesday, 06 at 15:30** Main room - aula magna - SP.I.S.A. (SP.I.S.A., floor 0)

Non-parametric registration of medical image data using Schatten-q-Norms

One keytask in modern medical imaging is image registration. It is the task of spatially aligning two or more images. A major problem is the similarity of images. To measure similarity, so-called distance measures are applied. We present a novel measure using Schatten-q-Quasinorms which are based on Singular Value Decompositions of a matrix of the images' gradients. The theoretical background is discussed and promising results are presented.

- Kai Brehmer (*Institute of Mathematics and Image Computing, University of Lübeck*)

Jan Modersitzki (*University of Luebeck*)
Benjamin Wacker (*University of Lübeck*)

Machine Learning Approaches for Deformable Image Registration

Deformable image registration is a key technology for image analysis. Traditionally, approaches for deformable image registration have focused on well-defined mathematical models that allow inferring spatial deformations between image pairs via optimization. However, most recently a number of approaches have been proposed that replace optimization by training appropriate regression models from data. This talk will discuss some of these recent developments.

- Marc Niethammer (*University of North Carolina at Chapel Hill*)

GPU Based Geodesics of Image Time Series

We investigate the interpolation of image time series using the metamorphosis model of a manifold of images. Based on a variational time discretization, discrete geodesic paths in this space of images are computed. The space discretization is based on finite elements spanned by tensor product cubic B-splines. An efficient implementation is obtained by utilizing a proper combination of GPU and CPU computation. Numerical results of the approach on optical coherence tomography image series are shown.

- Benjamin Berkels (*RWTH Aachen University*)

Michael Buchner (*Institute for Numerical Simulation, University of Bonn*)
Alexander Effland (*Universität Bonn*)
Martin Rumpf (*University of Bonn*)

CLAIRE: A parallel solver for constrained large deformation diffeomorphic image registration

We present CLAIRE, a parallel solver for constrained large deformation diffeomorphic image registration in three dimensions. Our contributions are the following: (i) We present an improved implementation of our memory-distributed, globalized, preconditioned Newton–Krylov solver. (ii) We present effective techniques to precondition the reduced space Hessian. (iii) We study numerical accuracy, rate of convergence, time-to-solution, inversion quality, and scalability of our solver. We use a PDE-constrained formulation for diffeomorphic image registration. The PDE constraints are the transport equations for the image intensities. The control variable is the velocity field. The discretization of the optimality system leads to high-dimensional, ill-conditioned, multiphysics systems that are challenging to solve in an efficient way. Our code is implemented in C/C++ and uses the message passing interface (MPI) library for parallelism. We study the performance of our solver for multi-subject registration problems in neuroimaging. We will see that our solver is competitive in terms of time-to-solution and registration quality. We will see that we can solve problems on clinical images (50 million unknowns) in less than two minutes on a workstation with 40 cores. If we use 512 MPI tasks we can reduce the runtime to under 2 seconds, paving the way to tackle real-time applications.

George Biros (*Institute for Computational Engineering and Sciences, University of Texas at Austin*)
Amir Gholami (*UC Berkeley*)
- Andreas Mang (*Department of Mathematics, University of Houston*)

MS29 Geometry and Learning in 3D Shape Analysis

Organizers:
Ronald Lui (*Chinese University of Hong Kong*)
Rongjie Lai (*Rensselaer Polytechnic Institute*)

MS29-1 - **Wednesday, 06 at 09:30** Room A (Palazzina A - Building A, floor 0)

Learning Geometry
We will review the problem of face geometric structure reconstruction from a single image, planar shape matching, and the dimensionality of facial expressions all from the point of view of deep learning. Geometry - which is in a sense understanding the problem at hand by finding its invariants will be shown to be related in some specific cases to deep learning. In this talk we will try to unify learning and understanding by empirically understanding deep learning.

- Ron Kimmel (*Technion - Israel Institute of Technology*)

Geometric Interpretation to GAN model
Generative Adversary Network (GAN) converts a fixed distribution in the latent space to the data distribution in the image space, which can be interpreted using optimal mass transportation framework and governed by Monge-Ampere equation. In turn, L2 optimal transportation has close relation with convex geometry. In this talk, we expose this relation and give a geometric method for Wasserstein-GAN. Furthermore, we explain the following questions: Does a deep neural network learn a function or a probability measure ? Does the neural networks really memorize the samples or learn ? Why neural networks are easily fooled ?

- Xianfeng Gu (*State University of New York at Stony Brook*)

Tradeoffs between speed and accuracy in inverse problems
Solving a linear system of the type Ax + n = y with many more unknowns than equations is a fundamental ingredient in a plethora of applications. The classical approach to this inverse problem is by formulating an optimization problem consisting a data fidelity term and a signal prior, and minimizing it using an iterative algorithm. Imagine we have a wonderful iterative algorithm but real-time limitations allows only to execute five iterations thereof. Will it achieve the best accuracy within this budget? Imagine another setting in which an iterative algorithm pursues a certain data model, which is known to be accurate only to a certain amount. Can this knowledge be used to design faster iterations? In this talk, I will try to answer these questions by showing how the introduction of controlled inaccuracy can significantly increase the convergence speed of iterative algorithms used to solve various inverse problems. I will also elucidate connections to deep learning an provide a theoretical justification of the very successful LISTA networks. Examples of applications in computational imaging and audio processing will be provided.

- Alexander Bronstein (*Technion - Israel Institute of Technology*)

The Geometry of Synchronization Problems and Learning Group Actions
We develop a geometric framework, based on the classical theory of fibre bundles, to characterize the cohomological nature of a large class of *synchronization-type problems* in the context of graph inference and combinatorial optimization. We identify each synchronization problem in topological group G on connected graph Γ with a flat principal G-bundle over Γ, thus establishing a classification result for synchronization problems using the representation variety of the fundamental group of Γ into G. We then develop a twisted Hodge theory on flat vector bundles associated with these flat principal G-bundles, and provide a geometric realization of the *graph connection Laplacian* as the lowest-degree Hodge Laplacian in the twisted de Rham-Hodge cochain complex. Motivated by these geometric intuitions, we propose to study the problem of *learning group actions* — partitioning a collection of objects based on the local synchronizability of pairwise correspondence relations — and provide a heuristic synchronization-based algorithm for solving this type of problems. We demonstrate the efficacy of this algorithm on simulated and real datasets.

- Tingrao Gao (*The University of Chicago*)

MS30 Imaging, Modeling, Visualization and Biomedical Computing

Organizers:
Cristian Linte (*Biomedical Engineering and Center for Imaging Science, Rochester Institute of Technology*)
Suzanne Shontz (*University of Kansas*)

MS30-1 - **Thursday, 07 at 14:00** Matemates (Matemates, floor 0)

High-order Curvilinear Tetrahedral Meshes of the Cardiac Anatomy
Heart models and meshes are used in computational simulations of cardiovascular surgeries and cardiac arrhythmias. There are numerous challenges in generating high-quality meshes of cardiac anatomies; these are due to the complex geometry of the heart, its high curvature, and its motion. In this talk, we present our method for generation of high-order curvilinear tetrahedral meshes and apply our method to the generation of high-quality, high-order meshes of the 3D myocardium geometry.

Cristian Linte (*Biomedical Engineering and Center for Imaging Science, Rochester Institute of Technology*)
Niels Otani (*Rochester Institute of Technology*)

- Suzanne Shontz (*University of Kansas*)
  Mike Stees (*University of Kansas*)

Mesh Adaptation-aided Image Segmentation
Image segmentation plays a crucial role in many applications where the identification of an object or of a portion of an image is relevant. Several approaches are available in the literature to set fast and reliable algorithms. We focus on a method based on the minimization of the Ambrosio-Tortorelli (AT) energy functional, customized in an image segmentation framework. To improve the efficiency of the method, we enrich the plain AT algorithm with anisotropic mesh adaptation.

  Alberto Silvio Chiappa (*Politecnico di Milano*)
  Stefano Micheletti (*MOX, Politecnico di Milano*)
  Riccardo Peli (*Politecnico di Milano*)
- Simona Perotto (*MOX, Politecnico di Milano*)

Coupling Brain-Tumor Biophysical Models and Diffeomorphic Image Registration
We present the SIBIA framework for joint image registration and biophysical inversion. Given an atlas brain MRI and a cancer patient MRI, we invert for patient-specific tumor growth parameters. We couple diffeomorphic image registration between atlas and patient with a reaction-diffusion tumor model. We derive Picard iterative solver schemes for the PDE-constrained optimization formulation of the coupled problem. Several tests for synthetic and clinical datasets assess the performance and convergence in different usage scenarios.

  George Biros (*Institute for Computational Engineering and Sciences, University of Texas at Austin*)
  Christos Davatzikos (*University of Pennsylvania*)
  Amir Gholami (*UC Berkeley*)
  Andreas Mang (*Department of Mathematics, University of Houston*)
- Miriam Mehl (*Universitat Stuttgart*)
  Klaudius Scheufele (*University of Stuttgart*)

Patient-specific reconstruction and CFD analysis of coronary stented arteries
The interplay between the struts of bioresorbable stents and the hemodynamics has a major role in the therapy success. A quantitative analysis of this requires an accurate patient-specific reconstruction of the geometry of the arteries and of the stent. We present the experience of the Emory Core Lab based on Optical Coherence Tomographies and Angiographies. We will illustrate also the registering procedure to guide the reconstruction with the undeployed geometry and CFD results.

- Alessandro Veneziani (*Emory University*)

MS30-2 - Thursday, 07 at 16:30 Matemates (Matemates, floor 0)

Medical Imaging and Visualization: Enabling Computer-assisted Diagnosis and Therapy
Computer-aided diagnosis and therapy has evolved in response to the need for techniques that can assist clinicians identify conditions, plan treatments, and deliver therapy while reducing human error and achieving more accurate and precise disease diagnosis or treatment. However, despite the efforts of the academic research community to develop state-of-the-art algorithms and high performance techniques, their footprint often hampers their clinical use. Currently, the main challenge is not the lack of techniques for medical image analysis, and computing, but rather the lack of clinically feasible solutions that leverage the already developed techniques, as well as the clear demonstration of the potential clinical use and impact of these tools. This lecture will provide a few examples that demonstrate the implementation and evaluation of different image computing and navigation tools and illustrate their use across several clinical applications.

- Cristian Linte (*Biomedical Engineering and Center for Imaging Science, Rochester Institute of Technology*)

Segmentation of Biomedical Images - Algorithms and Applications
The computational segmentation of biomedical images is very challenging, and it is usually tackled using, for example, deformable models, statistical, geometrical and physical modelling, and/or artificial classifiers. Examples of applications include the segmentation of: skin lesions, lungs, heart, brain, ear, and related structures, just to name a few. In this lecture, algorithms of biomedical image segmentation that we have developed will be presented, and examples of their use in real cases discussed.

- João Manuel R. S. Tavares (*Faculty of Engineering of the University of Porto*)

High-resolution MRI-based heart models for image-guided electrophysiology procedures
Scar-related arrhythmia is a major cause of sudden cardiac death worldwide. Image-based computational models for electrophysiology can help us understand and predict such arrhythmias. Our broad goal is to enable novel non-invasive technologies by combining advanced imaging methods that efficiently probe the biophysical MR signal with computer modelling to accurately predict abnormal propagation of electrical wave through the heart. Specifically, this talk summarizes our recent efforts focused on developing a preclinical in vivo experimental-theoretical framework and on testing it in a swine model of chronic infarct. All animals underwent MR study for infarct scar imaging, followed by either X-ray guided electro-anatomical mapping or real time MRI-guided electrophysiology study. For infarct scar imaging, we employed our custom-developed T1-mapping MR method (1x1x5mm spatial resolution). We used the MR images as input to a robust fuzzy-logic algorithm, and segmented the infarcted area into unexcitable dense fibrosis zones and slow conducting peri-infarct zones (i.e., mixture of viable and non-viable myocytes forming arrhythmia substrate). Using these segmented

images, we further built high-fidelity 3D predictive heart models, integrating the three zones: healthy myocardium, dense fibrosis and peri-infarct into computational meshes (1mm element size). Finally, we investigated the accuracy of model predictions by comparing the simulated and measured isochronal maps (i.e., depolarization time maps). Overall, results showed that our predictive T1-based heart models are sufficiently accurate; the mean absolute error between the simulated and measured depolarization times was small (10ms in average). Future work will focus on refining the spatial resolution of the current T1 imaging method, on simulating arrhythmia inducibility and guiding the RF ablation procedure by the image-based models.

- Mihaela Pop (*University of Toronto*)

Augmented Reality for Cardiac Interventions
Many intra-cardiac interventions employ minimally invasive approaches, where instrumentation is introduced into the chambers via the vascular system or heart wall. One such procedure involves the trans-apical repair of a mitral-valve leaflet. Using Augmented Reality, we demonstrate dramatically increased performance over the standard of care, reducing total navigation time and total tool path lengths by factors of 4 and 5 respectively, as well as a significantly decreasing dangerous incursions of the instrument within the heart.

- Terry M. Peters (*Robarts Research Institute/Western University*)

MS31 Variational Approaches for Regularizing Nonlinear Geometric Data

Organizers:
Martin Storath (*Universität Heidelberg*)
Martin Holler (*École Polytechnique, Université Paris Saclay*)
Andreas Weinmann (*Hochschule Darmstadt*)

MS31-1 - **Wednesday, 06 at 13:00** Room M (Palazzina B - Building B, floor 0)

Metamorphosis and Schild's Ladder for One-Dimensional Shapes with Applications to the Classification of Cardiac Stem Cells
Advances in deformable template matching has allowed us to investigate various different biological phenomena, from computational anatomy to kinematics. However, there is still more to be explored in what is capable by these models. In particular, the theory of metamorphosis, proposed by Younes, Trouve, and Miller, can be used to assess the similarity between two shapes by solving a variational problem that mixes the deforming of the domain and the modulating of the range of the shape template. This captures more modes of variation than the other pure deformation models, and can be used as a metric to define a Riemannian space of shapes, allowing for additional insights about shape similiarity. In this talk, I will discuss the foundations of metamorphosis in the one dimensional case, as well as provide two additional insights. The first is theory that allows us to solve for one of the variables in the alternating minimization in closed form. The second is a construction of Schild's ladder in the metamorphosis metric space, allowing us to perform parallel transport and adequately compare tangent vectors in the shape space. Additionally, I will show that by using these insights on the shape space of heart cell action potentials, one can suggest the phenotype (atrial vs ventricular) of a newly differentiated heart muscle cell, as well as determine whether a heart cell has a modification that makes it more/less susceptible to a given drug treatment.

Giann Gorospe (*Johns Hopkins University*)
- Rene Vidal (*Johns Hopkins University*)

Averaging positive-definite matrices
The problem of averaging symmetric positive-definite (SPD) matrices arises for example in medical imaging (denoising and segmentation tasks in Diffusion Tensor Imaging), mechanics (elasticity tensor computation), and in video tracking and radar detection tasks. We will review recent advances in iterative methods that converge to the SPD geometric mean (namely the least-squares mean in the sense of the so-called affine-invariant metric), and in methods that approach it using limited resources.

- Pierre-Antoine Absil (*University of Louvain*)
Kyle Gallivan (*Florida State University*)
Julien Hendrickx (*UCLouvain*)
Estelle Massart (*UCLouvain*)
Yuan Xinru (*Florida State University*)

Curvature Regularization on Manifolds
Euler's elastica energy (the mean squared acceleration) of parameterized curves may serve as a regularization for fitting or approximating temporal data. We study the case of data in a Riemannian manifold, as is relevant for various applications such as keyframe interpolation in computer graphics or interpolation in the space of images, equipped with an appropriate Riemannian metric. The analysis of the energy and its discretization hold some surprises fundamentally different from the Euclidean setting.

Heeren Behrend (*University of Bonn*)

Martin Rumpf (*University of Bonn*)
- Benedikt Wirth (*Universität Münster*)

Unsupervised Label Learning on Manifolds by Spatially Regularized Geometric Assignment
We present a novel approach combining unsupervised computation of manifold-valued prototypes and their spatially regularized assignment to given manifold-valued data. Both processes evolve dynamically through coupled flows. The separate representation of prototypes and assignment enables the application to various manifold data models. As a case study, we apply our approach to unsupervised learning on the positive definite matrix manifold. Joint work with Matthias Zisler, Freddie Åström, Stefania Petra and Christoph Schnörr.

- Artjom Zern (*Universität Heidelberg*)

MS31-2 - **Wednesday, 06 at 15:30** Room M (Palazzina B - Building B, floor 0)

A variational approach for Multi-Angle TIRF Microscopy
Multi-Angle Total Internal Reflection Fluorescence (MA-TIRF) microscopy is a recent technique which provides depth information. Its axial resolution is typically 20 nm, but the lateral resolution is unfortunately not as good. We investigate the combination of MA-TIRF and single molecule emission microscopy techniques, so as to remove that shortcoming. This yields an inverse problem where the measurements combine partial Laplace and convolution operations. We present a gridless total-variation minimization approach, with theoretical and numerical results.

- Vincent Duval (*INRIA*)

Variational approximation of data in manifolds using Geometric Finite Elements
We study the discretization of maps from a Euclidean domain into a smooth Riemannian manifold minimizing an elliptic energy. The discretization is given by a finite-dimensional approximation of the set of functions, such that the target manifold is neither embedded nor approximated. In particular, we discuss two constructions, namely geodesic and projection-based finite elements. Both have the properties needed for an error analysis comparable to standard Euclidean finite elements.

- Hanne Hardering (*TU Dresden*)

Edge-Parallel Inference with Graphical Models Using Wasserstein Messages and Geometric Assignment
A novel approach is introduced to Maximum A Posteriori inference based on discrete graphical models. The given discrete objective function is smoothly approximated using regularized local Wasserstein distances in order to couple assignment measures across edges of the underlying graph. This approximation is restricted to the assignment manifold and optimized by a multiplicative update combining (i) geometric integration of the resulting Riemannian gradient flow and (ii) rounding to integral solutions that represent valid labelings.

- Ruben Hühnerbein (*Universität Heidelberg*)

Total generalized variation for manifold-valued data
The total generalized variation (TGV) functional provides a convex model for piecewise smooth vector-space data and is amongst the most successful regularization functionals for variational image reconstruction. In this talk, we introduce the notion of second-order TGV regularization for manifold-valued data. We provide an axiomatic approach to formalize reasonable generalizations of TGV to this setting and present concrete instances that fulfill the proposed axioms. We prove well-posedness results and present numerical algorithms and experimental results.

Kristian Bredies (*Universität Graz*)
- Martin Holler (*École Polytechnique, Université Paris Saclay*)

Martin Storath (*Universität Heidelberg*)
Andreas Weinmann (*Hochschule Darmstadt*)

MS31-3 - **Thursday, 07 at 09:30** Room F (Palazzina A - Building A, floor 2)

Geodesic Interpolation in the Space of Images
In the metamorphosis approach the space of images is considered as a Riemannian manifold. In this talk, we focus on the computation of time discrete geodesics defined as minimizers of time discrete path energies. Here, images are either considered as square-integrable intensity functions or regarded as a superposition of sparse signals convoluted with structure classifying learned kernels. In the first case, the Gamma-convergence of the time discrete model to the time continuous model is discussed.

Benjamin Berkels (*RWTH Aachen University*)
- Alexander Effland (*Universität Bonn*)

Erich Kobler (*Graz University of Technology*)
Thomas Pock (*Graz University of Technology*)
Martin Rumpf (*University of Bonn*)

Functional-Analytic Questions in Measure-Valued Variational Problems
We develop a general mathematical framework for variational problems where the unknown function assumes values in the space of probability measures on some metric space. We study suitable weak and strong topologies and define a total variation seminorm for functions taking values in a Banach space. For a class of variational problems based on this formulation, we prove existence and point out connections to the Kantorovich-Rubinstein norm and optimal transport.

- Thomas Vogt (*Universität Lübeck*)

Nonlocal inpainting of manifold-valued data on finite weighted graphs
When dealing with manifold-valued data one faces the same challenging processing tasks as, e.g., in classical imaging. In this talk we consider image inpainting for manifold-valued data in which missing information have to be filled in suitably. We present a generalization of the graph infinity-Laplacian to manifold-valued data based on the min-max characterization of the local discrete Lipschitz constant. We derive a numerical scheme to solve the obtained manifold-valued infinity-Laplace equation and inpaint missing data.

- Ronny Bergmann (*Technische Universität Chemnitz*)
  Daniel Tenbrinck (*University of Münster*)

Curvature Regularization with Adaptive Discretization of Measures
Curvature regularization of image level lines is a powerful tool in image processing. Using so-called functional lifting, this can be achieved by specific convex functionals in a higher-dimensional space. The functional requires a subtle discretization of a Radon measure to fulfill a compatibility condition and to give reasonable results. Additionally, the resulting high computational costs have to be managed. We present an adaptive discretization and give some results for image segmentation for 2D- and 3D-images.

- Ulrich Hartleif (*Universität Münster*)

MS32 Nonlinear Spectral Theory and Applications (part 1)

Organizers:
Aujol Jean-Francois (*University of Bordeaux*)
Gilboa Guy (*Electrical Engineering Department, Technion*)

MS32-1 - **Wednesday, 06 at 13:00** Room C (Palazzina A - Building A, floor 1)

Introductory words and recent trends in nonlinear spectral processing
This talk will first present the main topics covered in this minisymposium. Then an overview of current active research in nonlinear spectral processing will be given, with focus on activities in my lab. This includes spectral representations of non-convex functionals, 1-Laplacian theory and applications and new numerical methods to solve nonlinear eigenvalue problems.

- Gilboa Guy (*Electrical Engineering Department, Technion*)

Nonlinear Spectral Image Decomposition and its Application to Segmentation
Reliable and automated segmentation of objects of different scales is a key problem in the field of medical imaging. Recently, new theory and algorithms for nonlinear eigenvalue problems via spectral decompositions have been developed and shown to result in promising segmentation results. In this talk, we compare different data-terms for TV-based segmentation and evaluate how informative the resulting spectral response function is. The analysis is supported by segmentation results of simulated and experimental cell data.

- Zeune Leonie (*University of Twente*)

Nonlinear spectral methods in machine learning
I will give an overview of our work on nonlinar eigenproblems ranging from exact relaxations of combinatorial problems as nonlinear eigenproblems to our recent work on Perron-Frobenius theory of multi-homogeneous mappings related to spectral problems of tensors and hypergraphs. This also leads to a nonlinear spectral method with which one can train a certain neural network globally optimal with a linear convergence rate.

- Hein Matthias (*University of Tuebingen*)

Spectral total-variation local scale signatures for image manipulation and fusion
We present a method to isolate and differentiate objects of different contrasts, sizes and structures in complex, multi-scaled sensor imagery. The analysis is based on scale and spatial information of spectral TV bands, referred to as spectral local scale signatures. We use dimensionality reduction to extract highly contrasted objects in thermal and medical images for image fusion; as well as groups of objects of similar features in images of repetitive structures for image manipulation.

- Hait Ester (*Technion*)

MS33 Advances in reconstruction algorithms for computed tomography

Organizers:
Gunay Dogan (*Theiss Research, NIST*)
Harbir Antil (*George Mason University*)
Elena Loli Piccolomini (*Dept. Computer Science and Engineering, University of Bologna*)

Samuli Siltanen (*University of Helsinki*)

MS33-1 - **Thursday, 07 at 14:00** Room D (Palazzina A - Building A, floor 1)

3D reconstruction of human trabecular bone using sparse X-ray tomography
X-ray tomography is a reliable tool for determining density and three-dimensional (3D) structure of trabecuale bone . However, traditional reconstruction methods such as FDK require dense angular sampling in data acquisition phase leading to long measurement times. Acquiring less data using greater angular steps is an obvious way for speeding up the process. However, computing 3D reconstruction from such a sparsely sampled dataset is very sensitive to measurement noise and modelling errors. An automatic regularization method is proposed for robust reconstruction, based on enforcing sparsity in the three-dimensional shearlet transform domain. The inputs of the algorithm are the projection data and *a priori* known expected degree of sparsity, denoted $0 < \mathscr{C}\_pr \leq 1$. The number $\mathscr{C}\_pr$ can be calibrated from a few dense-angle reconstructions and fixed. The morphology of the trabeculae bone is then analyzed using standard metrics. The proposed method is shown to outperform the baseline algorithm (FDK) in the case of sparsely collected data.

- Zenith Purisha (*University of Helsinki*)
  Samuli Siltanen (*University of Helsinki*)

A nonsmooth approach for sparse dynamic tomography based on shearlets
Tomographic imaging offers many challenges when it comes to sparse dynamic tomography. Due to the loss of information in the data and the ongoing motion, this problem calls for regularization. To reconstruct a moving 2D object, we propose a 3D variational formulation based on 3D shearlets, where the third-dimension accounts for the motion in time. Results on both simulated and real data show that better reconstructions are achieved when motion is considered.

- Tatiana Bubba (*University of Helsinki*)

Algorithm-enabled multi-spectral X-ray tomography
In multispectral (or photon-counting) computed tomography (MCT), accurate image reconstruction remains challenging because the appropriate data model in MCT is highly non-linear. In the presentation, our recent work will be reported on non-convex optimization-based image reconstruction (OBIR) approach to directly solving adequately the non-linear data model in MCT. Following the derivation of the OBIR approach, its effectiveness will first be demonstrated for image reconstruction in the standard MCT. Subsequently, a study will be carried out to reveal that the OBIR approach can be exploited for enabling MCT with partial scanning configurations yet involving no or minimum hardware modification to standard CT, thus lowering hardware cost, enhancing scanning flexibility, and reducing imaging dose/time. Numerical studies are carried out for demonstration of enabled image reconstruction for partial scanning configurations of practical significance with varying scanning angular range and/or x-ray illumination coverage in MCT imaging.

- Xiaochuan Pan (*University of Chicago*)

Evaluating tomographic reconstruction methods in applications
Digital Breast tomosynthesis is a recent clinical application of sparse data tomographic reconstruction. Quality control procedures are crucial for the evaluation of system performance and they aim to anticipate the outcome of the clinical validation. Challenges in a general definition of evaluation methods resides in the differences between vendors, in acquisition as well as in the choice of reconstruction methods. The main approaches for image evaluation endorsed by the medical physics community are illustrated.

- Sara Vecchio (*IMS Company, Bologna*)

MS33-2 - **Thursday, 07 at 16:30** Room D (Palazzina A - Building A, floor 1)

Fast iterative model based methods from reduced sampling in 3D X-rays CT
The reconstruction of X-Ray Ct images from low sampled data is of great interest in different applications, such as medicine or engineering. We follow a regularization approach with a smoothed differentiable Total Variation function . The problem is challenging for its very large size and because a good reconstruction is required in a very short time. We propose to use a gradient projection method, accelerated by exploiting a scaling strategy and generalized Barzilai-Borwein rules.

- Elena Loli Piccolomini (*Dept. Computer Science and Engineering, University of Bologna*)

A Novel Convex Relaxation for Non-binary Discrete Tomography
We present a novel convex relaxation and a corresponding inference algorithm for the non-binary discrete tomography problem, that is, reconstructing discrete-valued images from few linear measurements. In contrast to state of the art approaches that split the problem into a continuous reconstruction problem for the linear measurement constraints and a discrete labeling problem to enforce discrete-valued reconstructions, we propose a joint formulation that addresses both problems simultaneously, resulting in a tighter convex relaxation. For this purpose a constrained graphical model is set up and evaluated using a novel relaxation optimized by dual decomposition. We evaluate our approach experimentally and show superior solutions both mathematically (tighter relaxation) and experimentally in comparison to previously proposed relaxations.

- Jan Kuske (*Heidelberg University*)
  Stefania Petra (*University of Heidelberg*)
  Paul Sowoboda (*Institute of Science and Technology (IST) Austria, Klosterneuburg*)

How microlocal analysis can inform algorithm development

In limited data tomography, some data are missing. Because of the missing data, certain features of the object might be invisible from the data, and algorithms might create streaks are independent of the object. I will explain the artifacts and use microlocal analysis to explain how to suppress them while keeping most of the visible features of the object. I will provide reconstructions from real and simulated data that illustrate the theory.

Leise Borg (*University of Copenhagen*)
Jürgen Frikel (*OTH Regensburg*)
Jakob Jorgensen (*University of Manchester*)
- Todd Quinto (*Tufts University*)

Iterative methods for spectral breast tomosynthesis

We consider a multimaterial polyenergetic digital breast tomosynthesis model taking into account the polyenergetic nature of the x-ray beam and the various materials composing the object. The multimaterial polyenergetic model requires solving a large-scale, nonlinear inverse problem which is much less susceptible to beam hardening artifacts than the typically used linear monoenergetic model. We formulate the image reconstruction process as a nonlinear least squares problem and regularized iterative techniques are considered for its solution.

- Germana Landi (*University of Bologna*)
Elena Loli Piccolomini (*Dept. Computer Science and Engineering, University of Bologna*)

MS33-3 - **Friday, 08 at 09:30** Room A (Palazzina A - Building A, floor 0)

Iterative reconstruction combining attenuation and Compton scattering for few-view X-ray tomography systems

X-ray computed tomography systems typically measure attenuation along straight-line paths, with off-angle Compton-scattered photons treated as noise. We seek to improve reconstructions for few-view systems by fusing attenuation data with scatter measurements, as the broken-ray paths of scattered photons provide additional geometric views. We demonstrate a nonlinear Landweber algorithm for fusing attenuation and scatter data, yielding improved reconstructions on experimental data. Results also show benefit from optimizing weighting of attenuation vs. scatter data during reconstruction.

- Brian Tracey (*Tufts University*)

Learned iterative reconstruction for CT

Deep learning has shown tremendous success in several fields of science such as image and natural language processing. In this talk we demonstrate how these advancements can be extended to Image Reconstruction by embedding the forward operator inside a classical Convolutional Neural Network. We demonstrate some such Learned Iterative Reconstruction schemes and give state of the art results from Computed Tomography.

- Jonas Adler (*KTH Royal Institute of Technology*)
Ozan Öktem (*KTH - Royal Institute of Technology*)

Limited-data x-ray CT for underwater pipeline inspection using shearlet-based regularization

In this talk we consider inspection of underwater oil pipelines via fan-beam X-ray CT where, due to restrictions in the measurement device, the beam cannot illuminate the full area to be reconstructed. Moreover, it is desirable to use only a small number of projections to save measurement cost. We use microlocal analysis to determine a favorable scanning geometry, and propose a reconstruction method based on compactly supported shearlets with a weighted sparsity penalty.

Yiqiu Dong (*Technical University of Denmark*)
Jacob Frøsig (*FORCE Technology*)
Per Christian Hansen (*Technical University of Denmark*)
- Nicolai André Brogaard Riis (*Technical University of Denmark*)

Exploiting structural similarities in multi-energy tomographic reconstructions

One limitation of computed tomography is that no bijective relation exists between the composition of the material and the greyscale value in the reconstruction. More information on the material composition can be obtained by performing multiple scans using different X-ray energies, which in turn leads to technical issues with aligning the projections from different energies. We propose a technique based on structural similarities, which allows reconstructing the object at multiple energies without projection alignment. Additionally, we will introduce the openly available tomographic datasets from the University of Helsinki, including multi-energy CT data.

- Alexander Meaney (*University of Helsinki*)

MS33-4 - **Friday, 08 at 14:00** Room A (Palazzina A - Building A, floor 0)

On CT forward operator approximation and applications to limited data CT

Limited data CT techniques are getting increasing interest in many fields, given their advantages in acquisition time, exposure to radiations and device design. However, the object reconstruction process, in simulations as well as in real world situations, requires to estimate in some way the forward operator, that models the acquisition geometry. The talk will deal with one such approximation technique and how its vectorization impacts on the overall time and quality of the reconstruction.

Tatiana Bubba (*University of Helsinki*)
- Gaetano Zanghirati (*University of Ferrara*)

Preconditioning for spectral tomography
In this talk, we use a linearization technique to transform the nonlinear matrix equation corresponding that models spectral computed tomography (CT) into an optimization problem that is based on a weighted least squares term and nonnegative bound constraints. To solve this optimization problem, we propose a new preconditioner that can reduce the condition number significantly, and with this preconditioner, we implement FISTA with projections to achieve remarkable improvements on convergence speed and image quality.

Martin Andersen (*Technical University of Denmark*)
• Yunyi Hu (*Emory University*)
James Nagy (*Emory University*)

Quasi-3D iterative reconstruction
Slice-based visualization is a common analysis tool for 3D tomographic reconstructions. Conventionally, this requires a full volume, whereas a quasi-3D approach is to only reconstruct those slices that are currently of interest. Direct algorithms such as FBP and FDK are local in that they can reconstruct arbitrary slices efficiently. In contrast, iterative algorithms are harder to restrict to slices. We discuss approaches to tackle this problem, which is closely related to region of interest tomography.

Joost Batenburg (*CWI, Amsterdam*)
• Jan-Willem Buurlage (*Centrum Wiskunde & Informatica*)
Holger Kohr (*Thermo Fisher Scientific*)
Willem Jan Palenstijn (*Centrum Wiskunde & Informatica, Amsterdam*)

AIR Tools II – a MATLAB toolbox of algebraic iterative reconstruction methods for CT
AIR Tools II is a much expanded and improved modular implementation of the AIR Tools toolbox from 2012. It offers many easy-to-use SIRT, ART and column-action reconstruction methods in a consistent framework complete with a range of stopping criteria, relaxation parameter selection strategies and numerous test problems. Major new features and use cases are demonstrated, including application to large-scale real data by interfacing to external GPU-accelerated implementations of forward and back-projection operations.

Per Christian Hansen (*Technical University of Denmark*)
• Jakob Jorgensen (*University of Manchester*)

MS34 Numerical Linear Algebra techniques for Image Restoration and Reconstruction

Organizers:
Caterina Fenu (*University of Cagliari*)
Marco Donatelli (*University of Insubria*)

MS34-1 - **Wednesday, 06 at 13:00** Room E (Palazzina A - Building A, floor 2)

IR Tools MATLAB Package for Large-Scale Inverse Problems: Introduction to Basic Capabilities
In this talk we describe and demonstrate basic capabilities of a new MATLAB software package that consists of state-of-the-art iterative methods to solve large scale discretizations of inverse problems. The package allows users to easily experiment with different iterative methods and regularization strategies with very little programming effort. The package includes several test problems and examples to illustrate how the iterative methods can be used on a variety of large-scale inverse problems.

Silvia Gazzola (*University of Bath*)
Per Christian Hansen (*Technical University of Denmark*)
• James Nagy (*Emory University*)

IR Tools MATLAB Package for Large-Scale Inverse Problems: Constrained Krylov Subspace Solvers
In this talk we describe details of new state-of-the-art Krylov subspace iterative solvers that are implemented in our MATLAB software package IR Tools. In particular, we describe hybrid Krylov-subspace-based regularization approaches that combine matrix factorization methods with iterative solvers. The methods are very efficient for large scale problems, and can also incorporate methods to automatically estimate regularization parameters. We also show how the approaches can be adapted to enforce sparsity and nonnegativity.

• Silvia Gazzola (*University of Bath*)
Per Christian Hansen (*Technical University of Denmark*)
James Nagy (*Emory University*)

Multigrid iterative regularization for image deblurring
Recent numerical methods for image deblurring decompose nonlinear problems into simpler subproblems and usually require an inner linear regularization. We combine a simple linear iterative regularization method with soft-thresholding framelet denoising in a multigrid scheme. The coarsening strategy of the proposed multigrid method allows to achieve fast computations at each coarser level independently of the blurring operator. Projecting every iteration in a closed and convex set, we prove that it is a regularization method.

Alessandro Buccini (*Kent State University*)
- Marco Donatelli (*University of Insubria*)

Unmatched Projector/Backprojector Pairs: Perturbation and Convergence Analysis
Software for algebraic iterative reconstruction methods often uses different discretization methods for the projection and the backprojection. Consequently, the two matrices that represent these operations are not each other's transpose; they form an unmatched projector/backprojector pair. We study the influence of such an unmatched pair on the reconstruction problem through perturbation bounds and convergence analysis for the iterative methods, and we give numerical examples that illustrate our results. This is joint work with Tommy Elfving.

Tommy Elfving (*Linköping University*)
- Per Christian Hansen (*Technical University of Denmark*)

MS34-2 - **Wednesday, 06 at 15:30** Room E (Palazzina A - Building A, floor 2)

Point Spread Function Reconstruction and Blind Deconvolution from Adaptive Optics Data of Extremely Large Telescopes
In the upcoming generation of Extremely Large Telescopes, the impact of the turbulent atmosphere is corrected by Adaptive Optics systems. Even after correction the quality of astronomical images is degraded, e.g., due to time delay coming from measurement/correction processes resulting in a blur in images. We present an approach for the reconstruction of the directional dependent PSF using, e.g., atmospheric tomography. Finally, a blind deconvolution algorithm for the improvement of the scientific image is used.

- Ronny Ramlau (*Kepler University Linz and Johann Radon Institute*)

An ℓ^2-ℓ^q regularization method for large discrete ill-posed problems
Regularization replaces the original ill-posed problem by the minimization problem with a fidelity and a regularization term. The use of a p-norm for the fidelity term, and a q-norm for the regularization term, has received considerable attention. The trade-off between these terms is determined by a parameter. In this talk we discuss how this parameter can be determined using the discrepancy principle. We conside $p = 2$ and $0 < q \leq 2$, observe that $0 < q < 1$ induces a non-convex problem.

- Alessandro Buccini (*Kent State University*)

Lothar Reichel (*Kent State University*)

Minimization of the GCV function for Tikhonov Regularization
Tikhonov regularization is commonly used for the solution of linear discrete ill-posed problems with error-contaminated data. A regularization parameter, that determines the quality of the computed solution, has to be chosen. One of the most popular approaches to choosing this parameter is to minimize the Generalized Cross Validation (GCV) function. We will present two fairly inexpensive ways to determine upper and lower bounds for the numerator and denominator of the GCV function for large matrices.

- Caterina Fenu (*University of Cagliari*)

Lothar Reichel (*Kent State University*)
Giuseppe Rodriguez (*University of Cagliari*)
Hassane Sadok (*Université du Littoral Côte d'Opale*)

Improving sharpness in geophysical imaging by TV-based regularization
Applied geophysics techniques for non destructive soil surveying include low frequency electromagnetic (EM) induction data processing. A nonlinear model is often required to correctly simulate the physical system in the presence of strong conductors. We will present a regularized Gauss-Newton algorithm aimed at processing the full complex signal detected by last generation devices, and incorporating a nonlinear regularizing term based on total variation, which may improve the sharpness of the reconstruction for 2D /3D domains.

Gian Piero Deidda (*University of Cagliari*)
Patricia Diaz De Alba (*University of Cagliari*)
Caterina Fenu (*University of Cagliari*)
- Giuseppe Rodriguez (*University of Cagliari*)

Giulio Vignoli (*University of Cagliari*)

MS35 Optimal Transport and Patch based Methods for Color Image Editing

Organizers:
Nicolas Papadakis (*CNRS, Institut de Mathématiques de Bordeaux*)
Rabin Julien (*CNRS, Normandie Univ.*)

MS35-1 - **Wednesday, 06 at 13:00** Main room - aula magna - SP.I.S.A. (SP.I.S.A., floor 0)

Inverse problems using regularized optimal transport for computer graphics

The geometry of optimal transport provides a useful way to compare and interpolate histograms. Recent work on entropic regularization makes optimal transport computationally affordable and easy to implement. This talk presents Wasserstein Barycentric Projection and Wasserstein Dictionary Learning as an optimization over parameters within the entropic optimal transport framework. I will show numerous applications in computer graphics, for processing colors, geometry, images and material reflectances.

- Nicolas Bonneel (*CNRS/LIRIS*)

Image and Video Unsupervised Style Transfer by Adaptive Patch Sampling
First, a new patch-based method for exemplar-based image style transfer is presented. It is based on an adaptive partition that captures the style of the example image and preserves the structure of the source image. Then, an extension to video is also proposed ensuring spatially and temporally consistent stylized videos. Results show that out method is visually plausible while being very competitive in memory and computation time.

- Neus Sabater (*Technicolor Research & Innovation*)

Semi-Discrete Optimal Transport in Patch Space for Enriching Gaussian Textures
A bilevel texture model is proposed, based on a local transform of a Gaussian random field. The core of this method relies on the optimal transport of a continuous Gaussian distribution towards the discrete exemplar patch distribution. The synthesis then simply consists in a fast post-processing of a Gaussian texture sample, boiling down to an improved nearest-neighbor patch matching, while offering theoretical guarantees on statistical compliancy.

- Arthur Leclaire (*CMLA, ENS Cachan*)

Generalized Optimal Transport for Manifold-Valued Images.
We introduce optimal transport-type distances for manifold- valued images. To do so we lift the initial data to measures on the product space of image domain and signal space, where they are compared using a transport cost that combines spatial distance and signal discrepancy. Applying recent 'unbalanced' optimal transport models leads to more natural results. We illustrate the benefit of the lifting with examples for interpolation of color images and classification of handwritten digits.

- Friederike Laus (*Technische Universität Kaiserslautern*)

MS36 Computational Methods for Large-Scale Machine Learning in Imaging

Organizers:
Matthias Chung (*Virginia Tech*)
Lars Ruthotto (*Department of Mathematics and Computer Science, Emory University*)

MS36-1 - Wednesday, 06 at 13:00 Room A (Palazzina A - Building A, floor 0)

Randomized Newton and quasi-Newton methods for large linear least squares problems
We describe a randomized Newton and randomized quasi-Newton approaches to efficiently solve large linear least-squares problems where the very large data sets present a significant computational burden. In our proposed framework, stochasticity is introduced to overcome these computational limitations, and probability distributions that can exploit structure and/or sparsity are considered. Our results show, that randomized Newton iterates, in contrast to randomized quasi-Newton iterates, may not converge to the desired least-squares solution.

Julianne Chung (*Virginia Tech*)
- Matthias Chung (*Virginia Tech*)

David Kozak (*Colorado School of Mines*)
J. Tanner Slagel (*Virginia Tech*)
Luis Tenorio (*Colorado School of Mines*)

End-to-end learning of CNN features in in discrete optimization models for motion and stereo
For many years, discrete optimization models such as conditional random fields (CRFs) have defined the state-of-the-art for classical correspondence problems such as motion and stereo. One of the most important ingredients in those models is the choice of the feature transform that is used to compute the similarity between images patches. For a long time, hand crafted features such as the celebrated scale invariant feature transform (SIFT) defined the state-of-the-art. Triggered by the recent success of convolutional neural networks (CNNs), it is quite natural to learn such a feature transform from data. In this talk, I will show how to efficiently learn such CNN features from data using an end-to-end learning approach. It turns out that our learned models yields state-of-the-art results on a number of established benchmark databases.

Patrick Knöbelreiter (*Graz University of Technology*)
Gottfried Munda (*Graz University of Technology*)
- Thomas Pock (*Graz University of Technology*)

Christian Reinbacher (*Amazon*)
Alexander Shekhovtsov (*TU Prague*)

Memory-Optimal Deep Neural Networks
In this talk, we will be concerned with the question, how well a function, which for instance encodes a classification task, can be approximated by a neural network with sparse connectivity. We will derive a fundamental lower bound on the sparsity of a neural network independent on the learning algorithm, and also demonstrate how networks can be constructed which attain this bound, leading to memory-optimal deep neural networks.

Helmut Bölcskei (*ETH Zürich*)
Philipp Grohs (*Universität Wien*)
• Gitta Kutyniok (*Technische Universität Berlin*)
Philipp Petersen (*Technische Universität Berlin*)

A Batch-Incremental Video Background Estimation Model Using Weighted Low-Rank Approximation of Matrices
Principal component pursuit (PCP) is a state-of-the-art approach to background estimation problems. Due to their higher computational cost, PCP algorithms, such as robust principal component analysis (RPCA) and its variants, are not feasible in processing high definition videos. To avoid the curse of dimensionality in those algorithms, several methods have been proposed to solve the background estimation problem incrementally. We build a batch-incremental background estimation model by using a special weighted low-rank approximation of matrices. Through experiments with real and synthetic video sequences, we demonstrate that our model is superior to the existing state-of-the-art background estimation algorithms such as GRASTA, ReProCS, incPCP, and GFL.

• Aritra Dutta (*KAUST*)
Xin Li (*University of Central Florida*)
Peter Richtarik (*KAUST and University of Edinburgh*)

MS36-2 - Wednesday, 06 at 15:30 Room A (Palazzina A - Building A, floor 0)

Unpacking Image Models from Neural Nets
Generative Adversarial Networks can be used to form sophisticated and accurate models for natural images. However, these models are buried inside a neural network, and can only be accessed in very limited ways. In this talk, we explore methods to "unpack" image models from neural networks, and use them to form complex image priors and perform difficult image classification tasks.

Tom Goldstein (*University of Maryland*)
• Sohil Shah (*University of Maryland*)

PDE-based Algorithms for Convolution Neural Networks
This talk presents a new framework for image classification that exploits the relationship between the training of deep Convolution Neural Networks (CNNs) to the problem of optimally controlling a system of nonlinear partial differential equations (PDEs). This new interpretation leads to a variational model for CNNs, which provides new theoretical insight into CNNs and new approaches for designing learning algorithms. We exemplify the myriad benefits of the continuous network in three ways. First, we show how to scale deep CNNs across image resolutions using multigrid methods. Second, we show how to scale the depth of deep CNNS in a shallow-to-deep manner to gradually increase the flexibility of the classifier. Third, we analyze the stability of CNNs and present stable variants that are also reversible (i.e., information can be propagated from input to output layer and vice versa), which in combination allows training arbitrarily deep networks with limited computational resources.

• Eldad Haber (*University of British Columbia*)
Lars Ruthotto (*Department of Mathematics and Computer Science, Emory University*)

Maximum Principle Based Algorithms for Deep Learning
We discuss the dynamical systems approach to deep learning, in which training is recast as a control problem and this allows us to formulate necessary optimality conditions using the Pontryagin's maximum principle (PMP). Modifications of the method of successive approximations is then used to solve the PMP, giving rise to alternative training algorithms for deep learning. Rigorous error estimates are established and applications to training non-traditional networks are explored.

• Qianxiao Li (*Institute of High Performance Computing*)

Mass effect in glioblastomas
Glioblastoma is a form of primary brain cancer. Mass effect is a clinical term of art to indicate clearly visible mechanical deformations due to the presence of the tumor. In many cases such effect is absent but when it is present it seems to correlate with the tumor aggressiveness (but not always). In this talk I will present a framework for quantitatively characterizing mass effect and a set of inverse problems and algorithms that can be used to analyze clinical datasets.

• George Biros (*Institute for Computational Engineering and Sciences, University of Texas at Austin*)
Amir Gholami (*UC Berkeley*)
Naveen Himthani (*UT Austin*)
James Levitt (*UT Austin*)
Andreas Mang (*Department of Mathematics, University of Houston*)
Sameer Tharakan (*UT Austin*)

MS37 Sparse-based techniques in variational image processing

Organizers:
Serena Morigi (*Dept. Mathematics, University of Bologna*)
Ivan Selesnick (*New York University*)
Alessandro Lanza (*Dept. Mathematics, University of Bologna*)

MS37-1 - Wednesday, 06 at 13:00 Room B (Palazzina A - Building A, floor 1)

Alternating structure-adapted proximal gradient descent (ASAP) for nonconvex nonsmooth regularised problems with smooth coupling terms. Applications in imaging problems
There is an increasing interest in block regularized nonconvex nonsmooth optimization. We introduce an approach that effectively exploits the structure of the problem and enables complex application-dependent regularization to be used. The proposed ASAP algorithm enjoys simple explicit updates. Global convergence to a critical point is proved using the Kurdyka-Lojasiewicz property. We also prove that a large class of useful objective functions satisfy this property. Applications of ASAP to various imaging problems are presented.

- Mila Nikolova (*CMLA - CNRS ENS Cachan, University Paris-Saclay*)
  Pauline Tan (*CMLA, École normale supérieure Paris-Saclay*)

Class-adapted and Scene-Adapted Regularization for Imaging Inverse Problems
I will discuss our recent work on patch-based models that are adapted to specific image classes, or even specific scenes. We illustrate their use beyond image denoising, in more general inverse problems, such as inpainting, deblurring, and hyperspectral super-resolution, using the recently introduced plug-and-play-ADMM approach. We discuss conditions for convergence of the resulting algorithm. This is joint work with José Bioucas-Dias and Afonso Teodoro

- Mário Figueiredo (*Instituto de Telecomunicações and IST, University of Lisboa*)

Nonconvex regularization of numerical differentiation of noisy images
We consider the problem of differentiating a multivariable function specified by noisy data. We regularize the differentiation process by formulating it as an inverse problem with an integration operator as the forward model. Total-variation regularization avoids the noise amplification of finite-difference methods, while allowing for discontinuous solutions. Nonconvex generalizations of total variation, on the other hand, can lessen contrast loss and more faithfully preserve the geometry of image contours. We use an alternating directions, method of multipliers algorithm to provide greater efficiency, allowing rapid differentiation of images with millions of pixels. We apply our differentiation method to the phase wrapping problem of synthetic aperture radar interferometry.

- Rick Chartrand (*Descartes Labs*)

Robust and stable region-of-interest tomographic reconstruction by sparsity-inducing convex optimization
We propose an improved framework for region-of-interest computed tomography in the situation of noisy projection data. Under the assumption of a robust width prior that generalizes sparsity norms and measurement models used in compressed sensing, we derive performance guarantees by establishing error bounds for robust and stable recovery. Our reconstruction algorithm is guaranteed to satisfy predetermined fidelity and consistency tolerances while controlling the reconstruction error. It performs very competitively with respect to state-of-the-art methods.

- Demetrio Labate (*University of Houston*)

MS37-2 - Wednesday, 06 at 15:30 Room B (Palazzina A - Building A, floor 1)

Convex Envelopes for Least Squares Low Rank Approximation
The best low rank approximation of a given matrix can be found through singular value decomposition. However due to the non-convexity of the problem incorporation of any additional priors is difficult. In this talk we show how to compute convex envelopes of a class of objective functions useful for low rank approximation. We derive efficient algorithms for evaluating the envelope and its proximal operator which enables large scale optimization in general convex frameworks.

- Carl Olsson (*Chalmers University of Technology*)

Exact continuous relaxations for the l0-regularized least-squares criteria
Several continuous non-convex relaxations of the l0 pseudo-norm have been proposed over the past. In this talk, considering the l0-regularized least-squares minimization problem (l2-l0), I will present theoretical results which allow to compare such relaxations from the perspective of their fidelity to the initial l2-l0 problem. I will exhibit necessary and sufficient conditions on separable penalties approximating the l0 pseudo-norm which ensure that the associated regularized least-squares functional preserves the global minimizers of the initial one and do not add new local minimizers. From these conditions, we get a class of penalties said to be exact regarding to their properties concerning the relaxed functional.

- Emmanuel Soubies (*EPFL, Biomedical Imaging Group, Lausanne VD*)

On regularization/convexification of functionals including an l2-misfit term
A common technique for solving ill-posed inverse problems is to include some sparsity/low-rank constraint, and pose it as a convex optimization problem, as is done e.g. in compressive sensing. The corresponding functional to be minimized often includes an l2 data fidelity term plus a convex term forcing sparsity. However, for many applications a non-convex

term would be more suitable, although this is usually discarded since it leads to issues with algorithm convergence, local minima etc. I will introduce a new transform to (partially) convexify non-convex functionals of the above type. In some settings this leads to a convex problem, and in more complicated scenarios we can prove that the modified functional shares minima with the original functional, as well as give concrete conditions implying that a given stationary point is indeed the sought global minima.

- Marcus Carlsson (*Lund University*)

Sparsity-inducing Non-convex Regularization for Convex Image Processing
It is well known that, in general, nonconvex regularizers hold the potential for promoting sparsity more effectively than convex regularizers. To avoid the intrinsic difficulties related to nonconvex optimization, we present a new Convex Non-Convex variational model based on a more general parametric nonconvex regularizer which is applicable to a greater variety of image processing problems than prior CNC methods.. We derive the convexity conditions and related theoretical aspects of the CNC non-separable model.

Alessandro Lanza (*Dept. Mathematics, University of Bologna*)
Serena Morigi (*Dept. Mathematics, University of Bologna*)
- Ivan Selesnick (*New York University*)
Fiorella Sgallari (*Dept. Mathematics, University of Bologna*)

MS38 Geometry-driven anisotropic approaches for imaging problems

Organizers:
Luca Calatroni (*CMAP, École Polytechnique CNRS*)
Dario Prandi (*CNRS - L2S, CentraleSupélec*)
Valentina Franceschi (*INRIA Paris*)

MS38-1 - Wednesday, 06 at 15:30 Room I (Palazzina B - Building B, floor 0)

Cortical-inspired functional lifting for image inpainting
We present a mathematical model for the human primary visual cortex V1 and its applications to image processing, based on the sub-Riemannian Citti-Petitot-Sarti model. In this model the primary visual cortex is represented as the bundle $PT\mathbb{R}^2$ of directions of the plane, where each point corresponds to a neuron with both spatial location and local orientation preferences, endowed with a sub-Riemannian structure. Several new numerical and theoretical results will be discussed.

- Dario Prandi (*CNRS - L2S, CentraleSupélec*)

Computation of Curvature Penalized Shortest Paths via the Fast Marching Algorithm
Motivated by applications to motion planning and image segmentation, we consider paths models with a data-driven cost and a curvature penalization, such as the Euler/Mumford elasticas or the Reeds-Shepp car. Our strategy for computing paths of minimal energy involves a dimension lifting in $R^d x S^{d-1}$, d=2,3, and a strongly anisotropic approximation of the singular metric underlying the model. The relevant eikonal equation is then numerically solved by a variant of the Fast-Marching algorithm.

- Jean-Marie Mirebeau (*Université Paris-Sud - CNRS - Université Paris-Saclay*)

Anisotropic multiphase mean curvature flows with mobilities
The talk will be devoted to phase field approximations of multiphase mean curvature flows which can incorporate anisotropic surface tensions and mobility coefficients. The model we propose is well suited for both purposes of asymptotic analysis and derivation of a robust numerical scheme. Several numerical examples will be provided, related either to physics or imaging.

- Simon Masnou (*Université Lyon 1*)

A function space framework for structural total variation regularization with applications in inverse problems
We introduce a function space setting for a class of structural total variation (TV) regularization methods in inverse problems, where the regularizer is defined via a relaxation framework. We show equivalence of the Tikhonov regularization problem to a saddle-point problem where no knowledge of an explicit formulation of the regularization functional is needed. We provide numerical examples, solving the saddle-point problem for weighted-TV denoising and MR-guided PET reconstruction.

Michael Hintermüller (*Humboldt University and Weierstrass Institute Berlin*)
Martin Holler (*École Polytechnique, Université Paris Saclay*)
- Kostas Papafitsoros (*Weierstrass Institute Berlin*)

MS39 Nonlinear Spectral Theory and Applications (part 2)

Organizers:

Aujol Jean-Francois (*University of Bordeaux*)
Gilboa Guy (*Electrical Engineering Department, Technion*)

MS39-1 - **Wednesday, 06 at 15:30** Room C (Palazzina A - Building A, floor 1)

Theoretical analysis of flows estimating eigenfunctions of one-homogeneous functionals
Nonlinear eigenfunctions, induced by subgradients of one-homogeneous functionals (such as the 1-Laplacian), have shown to be instrumental in segmentation, clustering and image decomposition. We present a class of flows for finding such eigenfunctions, generalizing a method recently suggested by Nossek-Gilboa. We analyze the flows on grids and graphs in the time-continuous and time-discrete settings. Several examples are provided showing how such flows can be used on images and graphs.

- Aujol Jean-Francois (*University of Bordeaux*)

Continuum limit of total variation defined on geometric graphs
Motivated by applications in machine learning we consider the notion of total variation defined on graphs over data clouds. Graphs are used to leverage the geometry of a ground-truth distribution, as well as to incorporate "must link" and "can not link" constraints on the data. We study the variational limit of the graph total variation as the number of data points goes to infinity and the parameters used to construct the graphs are scaled appropriately.

- Garcia Trillos Nicolas (*Brown University*)

Bias reduction in variational regularization
We present a two-step method to reduce bias in variational methods. After solving the standard variational problem, the idea is to perform a consecutive debiasing step minimizing the data fidelity on an appropriate model subspace. It is defined by Bregman distances using the subgradient appearing in the optimality condition of the variational method. This leads to a decomposition of the overall bias into two parts, model and method bias, of which we tackle the latter.

- Camille Sutour (*University Paris Descartes*)

MS40 Recent Advances in Convolutional Sparse Representations

Organizers:
Giacomo Boracchi (*Politecnico di Milano*)
Alessandro Foi (*Tampere University of Technology*)
Brendt Wohlberg (*Los Alamos National Laboratory*)

MS40-1 - **Friday, 08 at 09:30** Room F (Palazzina A - Building A, floor 2)

Online Convolutional Dictionary Learning for Multimodal Imaging
Computational imaging methods that can exploit multiple modalities have the potential to enhance traditional sensing systems. We propose a new method that reconstructs multimodal images from their linear measurements by exploiting redundancies across different modalities. Our method combines a convolutional group-sparse representation of images with total variation regularization. We develop an online algorithm that enables the unsupervised learning of convolutional dictionaries on large-scale datasets. We illustrate the benefit of our approach for joint intensity-depth imaging.

Kévin Degraux (*Université catholique de Louvain*)
- Ulugbek Kamilov (*Washington University in St. Louis*)

From convolutional analysis operator learning (CAOL) to convolutional neural network (CNN)
The recent global approach can learn convolutional operators without storing many overlapping patches. We propose 1) a new CAOL framework in the global approach, and 2) a new convergent Block Proximal Gradient method using Majorizer (BPG-M) to solve block multi-nonconvex problems. Numerical experiments show acceleration of CAOL via BPG-M and the effectiveness of tight-frame filters learned via CAOL for sparse-view CT reconstruction. Finally, we illustrate mathematical models for CNN via CAOL.

- Il Yong Chun (*University of Michigan*)

Jeffrey A. Fessler (*University of Michigan*)

Greedy and learned approaches for convolutional sparse coding
We propose a convolutional recurrent sparse auto-encoder model. The model consists of a sparse encoder, which is a convolutional extension of the learned ISTA (LISTA) method, and a linear convolutional decoder. Our strategy offers a simple method for learning a task-driven sparse convolutional dictionary (CD), and producing an approximate convolutional sparse code (CSC) over the learned dictionary. We trained the model to minimize reconstruction loss via gradient decent with back-propagation and have achieved competitive results to KSVD image denoising and to leading CSC methods in image inpainting requiring only a small fraction of their run-time.

- Raja Giryes (*Tel Aviv University*)

Convolutional Sparse Coding vs Aggregation of Independent Estimates
Convolutional sparse coding (CSC) is a way to compute translation-invariant sparse representations by solving a global optimization problem. Although CSC has lately attracted increasing interest, it is not clear whether it can outperform classical techniques, such as cycle spinning, in image denoising. Our thorough comparisons show that estimates computed via CSC exhibit lower bias, but suffer from larger variance when the representations are not extremely sparse, which seriously impairs the CSC-based denoising of natural images.

Giacomo Boracchi (*Politecnico di Milano*)
- Diego Carrera (*Politecnico di Milano*)
Alessandro Foi (*Tampere University of Technology*)
Brendt Wohlberg (*Los Alamos National Laboratory*)

MS41 Framelets, Optimization, and Image Processing

Organizers:
Xiaosheng Zhuang (*City University of Hong Kong*)
Lixin Shen (*Syracuse University*)
Bin Han (*University of Alberta*)
Yan-Ran Li (*Shenzhen Univeristy*)

MS41-1 - **Thursday, 07 at 09:30** Room I (Palazzina B - Building B, floor 0)

Moreau Enhanced TV for Image Restoration
In this talk, we will introduce a sparsity-prompting function that is formed by L1 norm and its Moreau envelope. We will present the properties of this function and show its applications in signal and image processing.

- Lixin Shen (*Syracuse University*)

Multiplicative Noise Removal with A Non-Convex Optimization Model
In this talk, we introduce a variational restoration model for multiplicative noise reduction. Different from popular existing models which focus on pursuing convexity, the proposed sparsity-aware model may be nonconvex depending on the conditions of the parameters of the model for achieving the optimal denoising performance. An algorithm for finding a critical point of the objective function of the model is developed. Experimental results show that the proposed method can remarkably outperform several state-of-art methods.

- Jian Lu (*Shenzhen University*)

Noncovex Frame-based Methods for Image Restoration
Since digital images are usually sparse in the wavelet frame domain, some nonconvex minimization models based on wavelet frame have been proposed and sparse approximations have been widely used in image restoration in recent years. Some proximal alternating iterative hard thresholding methods are proposed in this talk to solve the nonconvex model based on wavelet frame to restore degraded image. We will perform the test on image denoising and image deconvolution.

- Yi Shen (*Zhejiang Sci-Tech Univeristy*)

Digital Affine Shear Filter Banks with 2-Layer Structure and Their Applications in Image/Video Processing
This work introduces an affine shear tight frame with 2 layers of high-pass framelets. The frame is generated by two set of generators which are meat to cover the inner and outer layers of high-pass bands in order to capture edge and texture features respectively. A characterization is given of the frame being a tight frame. A low redundancy fast transform is implemented, and tested on image/video denoising and inpainting tasks.

- Zhihua Che (*City University of Hong Kong*)

MS41-2 - **Thursday, 07 at 14:00** Room I (Palazzina B - Building B, floor 0)

Parallel Magnetic Resonance Imaging by 3-D Regularization
Parallel magnetic resonance imaging (pMRI) is a technique to accelerate the magnetic resonance imaging process. The problem of reconstructing an image from the collected pMRI data is ill-posed. Regularization on multi-coil images by tight-frame systems is proposed to reduce the aliasing artifacts on reconstructed images. Numerical experiments for in-silico and in-vivo data sets are provided to demonstrate the superiority of the 3-D regularization model and the efficiency of our proposed algorithm for pMRI reconstruction.

- Yan-Ran Li (*Shenzhen Univeristy*)

The Convex Geometry of Learning Single-hidden-layer Neural Networks
The work initiates the study of the geometry of learning single-hidden-layer neural networks. Deep learning is a machine learning technique based on modeling data using neural networks of many layers and has achieved great success in many practical applications. The geometry of the optimizations arising in deep learning plays an important role in deciding the trainability of deep neural networks. Understanding such a geometry for "shallow" networks with a single hidden layer is a necessary first step toward more thorough investigations. In this work, learning a one-hidden-layer neural network from

training data is formulated as a convex program in the space of measures. This convex program is a generalization of l1 minimization that promotes sparsity in finite-dimensional spaces. A sufficient condition for successful recovery of ground truth network parameters using the proposed convex programs is derived.

- Gongguo Tang (*Colorado School of Mines*)

Framelets on Graphs with Applications in Multiscale Data Analysis
In this talk, we discuss the characterizations, construction, and applications of tight framelets on graphs. Fast algorithmic realizations and numerical examples will be shown.

- Xiaosheng Zhuang (*City University of Hong Kong*)

Medical Image Analysis and Its Applications
Medical images provide functional and structural clinical information. Its crucial and urgent to find solutions on enhancing quality of medical images and extracting disease-related information. This report tries to take breast cancer as an example to illustrate basic theories and techniques in medical image analysis and Radiomics. Recent studies and progress in high dimensional reconstruction of complicated medical data, feature extraction, feature reduction, and machine learning are also discussed.

- Yao Lu (*Sun Yat-sen University*)

Kernel-based Approximation Methods for Generalized Interpolations: A Deterministic or Stochastic Problem?
In this talk, we solve a deterministically generalized interpolation problem by a stochastic approach. We introduce a kernel-based probability measure on a Banach space by a covariance kernel which is defined on the dual space of the Banach space. The kernel-based probability measure provides a numerical tool to construct and analyze the kernel-based estimators conditioned on non-noise data or noisy data including algorithms and error analysis. Same as meshfree methods, we can also obtain the kernel-based approximate solutions of elliptic partial differential equations by the kernel-based probability measure.

- Qi Ye (*South China Normal University*)

MS41-3 - **Thursday, 07 at 16:30** Room I (Palazzina B - Building B, floor 0)

MS42 Low dimensional structures in imaging science

Organizers:
Wenjing Liao (*Georgia Institute of Technology*)
Haizhao Yang (*Duke University*)
Zhizhen Zhao (*University of Illinois Urbana-Champaign*)

MS42-1 - **Thursday, 07 at 09:30** Room M (Palazzina B - Building B, floor 0)

Using invariant features for multi-reference alignment and multi-segment reconstruction
We focus on an alignment-free method to estimate the underlying signal from a large number of noisy randomly shifted observations. Specifically, we recover the signal from the sample estimates of the invariant moments. We introduce a spectral method to recover the phase of the signal from the bispectrum matrix. The invariant moments approach is also applied to multi-segment reconstruction to recover a signal from noisy segments with unknown positions of the observation windows.

- Zhizhen Zhao (*University of Illinois Urbana-Champaign*)

Model stability of low complexity priors
A now standard method for recovering the unknown signal is to solve a convex optimization problem that enforces some prior knowledge about its structure. I will deliver a review of recent advances in the field where the regularization prior promotes solutions conforming to some notion of simplicity/low-complexity. Our aim is to provide a unified treatment of all these regularizations under a single umbrella, namely the theory of partial smoothness.

- Samuel Vaiter (*IMB, Université de Bourgogne*)

What's happening in provable dictionary learning?
Given massive amounts of data, is it possible to learn a sparsifying basis? This dictionary learning problem has witnessed intensive algorithmic developments and empirical successes over the past two decades. In contrast, only recently has theoretical understanding on dictionary learning surfaced. In this talk, I will summarize the recent theoretical progress, and highlight the surprising role that nonconvex optimization plays in provable and practical dictionary learning, and beyond.

Qing Qu (*Columbia University*)
- Ju Sun (*Stanford University*)

John Wright (*Department of Electrical Engineering, Columbia University*)

A tale of two bases: local-nonlocal regularization on image patches with convolution framelets
We propose an image representation scheme combining the local and nonlocal characterization of patches in an image. Our representation scheme is shown to be equivalent to a tight frame constructed from convolving local bases (e.g. wavelet

frames, discrete cosine transforms, etc.) with nonlocal bases (e.g. spectral basis induced by nonlinear dimension reduction on patches), and we call the resulting frame elements convolution framelets. Insight gained from analyzing the proposed representation leads to a novel interpretation of a recent high-performance patch-based image inpainting algorithm using Point Integral Method (PIM) and Low Dimension Manifold Model (LDMM). In particular, we show that LDMM is a weighted ℓ_2-regularization on the coefficients obtained by decomposing images into linear combinations of convolution framelets; we extend the original LDMM to a reweighted version that yields further improved inpainting results. Our framework can be potentially generalized to interpret more complex image processing algorithms.

• Tingrao Gao (*The University of Chicago*)

MS42-2 - Thursday, 07 at 14:00 Room M (Palazzina B - Building B, floor 0)

Composition-aware spectroscopic tomography

We combine confocal microscopy and imaging spectroscopy to determine spatial morphology and chemical composition of a target in three spatial dimensions from backscattered light. We assume the target comprises few chemical species with known spectra and develop conditions on the spectra and number of measurements for unique image recovery. Images are formed by solving a regularized least squares problem using an iterative algorithm. Simulations illustrate imaging of cellular phantoms and sub-wavelength targets from noisy measurements.

Rohit Bhargava (*University of Illinois at Urbana-Champaign*)
• Yoram Bresler (*University of Illinois at Urbana-Champaign*)
P. Scott Carney (*Dept. of ECE, University of Illinois at Urbana-Champaign*)
Luke Pfister (*Dept. of ECE, University of Illinois at Urbana-Champaign*)

Multiscale vector quantization

We present a novel quantization algorithm based on building and adaptively pruning a partition on the data space. The proposed method has connections with decision trees, wavelet representation and can be contrasted to classic quantization schemes such as k-means. The performance of the algorithms are analyzed in a general statistical learning framework where data are assumed to be sample according to un unknown distribution. In particular, the obtained error estimates depend on the geometric properties of the support of the distribution and cover the special case where the latter is a manifold. Joint work with Enrico Cecini (Universita' di Genova) and Ernesto De Vito (Universita' di Genova)

• Lorenzo Rosasco (*University of Genoa, Istituto Italiano di Tecnologia; Massachusetts Institute of Technology*)

Steerable graph-Laplacian filters for image-valued manifolds

We consider the problem of filtering a set of images lying on a low dimensional manifold, under the assumption that the in-plane rotation of each image is irrelevant. We derive the steerable graph Laplacian on the image-manifold, which accounts for all planar rotations of all images, and show how to use it for image filtering while exploiting all images and their rotations simultaneously. We demonstrate our approach for the denoising of cryo-electron microscopy image datasets.

• Boris Landa (*Tel Aviv University*)
Yoel Shkolnisky (*Tel Aviv University*)

Regularization by invariant multiscale statistics

I will talk about a new approach to linear ill-posed inverse problems with data-driven regularization. Instead of learning a stable inverse, unrolling standard algorithms into neural nets, or learning projectors for iterative schemes, we still compute the solution as a minimizer of a regularized cost functional, albeit non-convex. Our regularizer promotes "correct" conditional statistics in some feature space. As feature transform we choose the non-linear multiscale scattering transform—a complex convolutional network which discards the phase and thus exposes spectral correlations otherwise hidden beneath the phase fluctuations. We need scale separation in order to guarantee stability to deformations. For a given realization, the feature-space representation is linearly estimated from a reconstruction in a stable subspace and it represents the unstable part of the signal. We demonstrate that our approach stably recovers the missing spectrum in super-resolution and tomography.

• Ivan Dokmanic (*University of Illinois at Urbana–Champaign*)

MS42-3 - Thursday, 07 at 16:30 Room M (Palazzina B - Building B, floor 0)

Super-resolution, subspace methods and conditioning of Vandermonde matrices

We consider the spectral estimation problem of finding point-like frequencies of a signal from its noisy samples in the time domain. I will present some subspace methods, in particular, MUSIC, ESPRIT and the matrix pencil method. These methods are well known for their super-resolution phenomenon – the capability of resolving closely spaced frequencies. We will give a theoretical guarantee of the resolution limit of these subspace methods through a sharp bound on the conditioning of Vandermondes matrices with nodes on the unit circle.

• Wenjing Liao (*Georgia Institute of Technology*)

An analysis of the BLASSO method for the multi-dimensional super-resolution problem

This talk is concerned with the super-resolution problem for positive spikes in arbitrary dimensions. More precisely, I will discuss the issue of support recovery for the so-called BLASSO method. While super-resolution is of paramount importance in overcoming the limitations of many imaging devices, its theoretical analysis is still lacking beyond the

1-dimensional case. The reason is that in the 2-dimensional case and beyond, the relative positions of the spikes enter the picture, and one needs to account for these different geometrical con

figurations. After presenting an algorithmic description of the limit of the associated dual problems as the spikes cluster around a given point, I will present a detailed analysis of the support stability and super-resolution effect in the case of a pair of spikes.

Gabriel Peyré (*ENS Paris*)
• Clarice Poon (*University of Cambridge*)

Spectral super-resolution via projected gradient descent
We consider reconstructing a spectrally sparse signal with super-resolution from its partial revealed entries. By utilizing the low-rank structure of the Hankel matrix, we develop a computationally efficient algorithm for this problem. The algorithm is a projected gradient descent for a non-convex functional. We prove that O(r2log(n)) observed entries are sufficient for our algorithm to achieve the successful recovery of a spectrally sparse signal. Our algorithm is competitive with other state-of-the-art spectral compressed sensing algorithms.

• Jian-Feng Cai (*Hong Kong University of Science and Technology*)
Tianming Wang (*University of Iowa*)
Ke Wei (*Fudan University*)

PET-MRI Joint Reconstruction by Joint Sparsity Based Tight Frame Regularization
Recent technical advances lead to the coupling of PET and MRI scanners, enabling to acquire functional and anatomical data simultaneously. In this talk, we propose a tight frame based PET-MRI joint reconstruction model via the joint sparsity of tight frame coefficients. In addition, a non-convex balanced approach is adopted to take the different regularities of PET and MRI images into account. To solve the nonconvex and nonsmooth model, a proximal alternating minimization algorithm is proposed, and the global convergence is present based on Kurdyka-Lojasiewicz property. Finally, the numerical experiments show that the our proposed models achieve better performance over the existing PET-MRI joint reconstruction models.

Chenglong Bao (*Yau Mathematical Sciences Center, Tsinghua University*)
• Jae Kyu Choi (*Institute of Natural Sciences, Shanghai Jiao Tong University*)
Xiaoqun Zhang (*Institute of Natural Sciences, School of Mathematical Sciences, and MOE-LSC, Shanghai Jiao Tong University*)

MS43 Variational Image Segmentation: Methods and Applications

Organizers:
Jack Spencer (*University of Liverpool*)

MS43-1 - **Thursday, 07 at 09:30** Room H (Palazzina B - Building B, floor 0)

Interactive Variational Segmentation in Medical Imaging
In this talk we introduce new variational methods for two-phase segmentation, focussing on medical imaging. The approaches we discuss concern the effective incorporation of user interactivity to segmentation and contouring, with respect to convex relaxation formulations and minimal path methods. We also present associated applications, such as organ contouring for radiotherapy planning and volume computation of abdominal aortic aneurysms, considering examples from multiple modalities in both 2D and 3D.

Ke Chen (*University of Liverpool*)
• Jack Spencer (*University of Liverpool*)

Joint CT Reconstruction and Segmentation with Discriminative Dictionary Learning
In this talk, I will introduce a new algorithm for Computed Tomography that simultaneously computes a reconstruction and a corresponding segmentation. Our algorithm uses learned dictionaries for both the reconstruction and the segmentation, constructed via discriminative dictionary learning using a set of corresponding images and segmentations. Numerical simulations demonstrate that our method provides better results than the other simultaneous reconstruction and segmentation methods or dictionary-based methods, especially when there are not sufficient projections.

• Yiqiu Dong (*Technical University of Denmark*)
Per Christian Hansen (*Technical University of Denmark*)
Hans Martin Kjer (*Technical University of Denmark*)

Variational Approaches to Medical Image Segmentation
Two variational approaches for brain MRI tissue segmentation and tumor extraction are considered. Specifically, I will introduce the multinomial level-set approach for multi-region image segmentation which is based on replacing the traditional regularized Heaviside function with the multinomial logistic regression (Softmax) classifier. I will then present a machine-learning paradigm called the Atlas of Classifiers (AoC) that allows a statistical summary of annotated training datasets taking into account both the imaging data and the corresponding labels.

- Tammy Riklin Raviv (*Ben-Gurion University*)

Minimal Paths and Geodesic Metrics for Image Segmentation and Tubular Structure Extraction
We solve two drawbacks of the classical minimal path models. Firstly, the curvature term was removed in the model in order to transform the problem into finding distance map associated to a source point. We reintroduce the curvature term to the Eikonal PDE framework to find curvature regularised minimal paths. Moreover, in the context of segmentation, existing metrics depend only on object boundary information. We propose a new Finsler metric involving the region-based similarity/dissimilarity measure.

- Da Chen (*University Paris Dauphine, PSL Research University; Centre Hospitalier National d'Ophtalmologie des Quinze-Vingts, Paris, France*)
  Laurent D. Cohen (*University Paris Dauphine, PSL Research University*)

MS44 3D Image Depth/Texture/Reflectivity Tracking, Modelling and Reconstruction

Organizers:
Catherine Higham (*University of Glasgow*)
Roderick Murray-Smith (*University of Glasgow*)

MS44-1 - Thursday, 07 at 09:30 Room P (Palazzina B - Building B, floor 0)

Real-time Depth Prediction with Sensor Fusion.
Single-photon sensors combined with eye-safe, high repetition rate, pulsed laser sources enable a solution for many applications when conventional imaging with a multi-pixel sensor is not possible or otherwise expensive such as three-dimensional ranging. The temporal response of single-photon LIDAR results in a surface-to-surface resolution at the millimetre scale. However the requirement of high resolution reconstructions in real time can result in very sparse low photon counts. Here we investigate fusing data from a single photon sensor with other low cost image (RGB/infra-red) information in a deep learning framework to predict depth at high resolution in milliseconds.

Catherine Higham (*University of Glasgow*)
- Roderick Murray-Smith (*University of Glasgow*)

Mathematical Imaging Methods for Mitosis Analysis in Live-Cell Phase Contrast Microscopy.
In this talk, we present MitosisAnalyser, a framework for automated mitosis detection and cell tracking in time-lapse phase contrast microscopy images. In cancer research, live-cell imaging experiments constitute a key part in chemotherapy drug development, where abnormal mitotic behaviour is a key indicator of successful treatment. Derived from mathematical concepts like the circular Hough transform and variational segmentation methods, we present our holistic and automated imaging pipeline and show results for real data while validating them.

Martin Burger (*University of Muenster*)
- Joana Grah (*The Alan Turing Institute*)
  Jenny Harrington (*Cancer Research UK Cambridge Institute*)
  Siang B. Koh (*Massachusetts General Hospital Cancer Center, Boston*)
  Jeremy A. Pike (*University of Birmingham*)
  Stefanie Reichelt (*Cancer Research UK Cambridge Institute*)
  Carola-Bibiane Schönlieb (*University of Cambridge*)
  Alexander Schreiner (*PerkinElmer, Hamburg*)

Imaging Behind Walls.
We will discuss recent advances in the use of optics to image behind walls. This is typically achieved by imaging and post-processing the return signals (light echoes) reflected from multiple surfaces, thus circumventing the obstacle or wall. The challenge therefore lies on the one hand in actually detecting the very weak return signals and on the other, in efficiently processing this data to retrieve target information for incoherent, multiple- scattered light. We will discuss the state of the art and show recent results demonstrating how deep learning can both simplify the detection hardware and achieve simultaneous location and identification of a person hidden behind a wall.

Alessandro Boccolini (*Heriot Watt University*)
Daniel Buschek (*University of Munich*)
- Piergiorgio Caramazza (*University of Glasgow*)
  Daniele Faccio (*Heriot Watt University*)
  Robert Henderson (*University of Edinburgh*)
  Catherine Higham (*University of Glasgow*)
  Matthias Hullin (*University of Bonn*)
  Roderick Murray-Smith (*University of Glasgow*)

Photoacoustic Tomography Reconstruction from Sparse Data using Ray Tracing.
In this talk we show the use of high frequency asymptotic approximation to the solution of the wave equation in photoacoustic tomography (PAT). We consider ray tracing, a technique that involves solving the wave equation along

the trajectories of a Hamiltonian system. We evaluate the quality of the ray tracing solutions to both the forward and inverse problem against a full wave solution obtained using a k-space method implemented in k-Wave Toolbox [1]. The major benefit of ray tracing approach versus the full wave solution is that the solution along each ray can be obtained independently and at a much lower cost than the full solution. [1] B. E. Treeby and B. T. Cox, k-wave: Matlab toolbox for the simulation and reconstruction of photoacoustic wave fields, Journal of biomedical optics, 15 (2010), pp. 021314–021314.

Marta Betcke (*University College London*)
- Francesc Rullan (*University College London*)

MS45 Mathematical techniques for bad visibility restoration

Organizers:
Javier Vazquez-Corral (*Information and Communication Technologies Department, Universitat Pompeu Fabra*)

MS45-1 - **Thursday, 07 at 09:30** Room L (Palazzina B - Building B, floor 0)

Variational image dehazing
We will introduce two different variational methods for haze removal. The first method extends a perception-inspired variational framework in two ways: i) replacing the grey-world hypothesis by an estimation of the mean of the clean image, ii) adding a set of new terms to the energy functional for maximizing the inter-channel contrast. The second method extends the previous approach by including the computation of saturation maps, to avoid the overenhancement of near-by objects.

- Javier Vazquez-Corral (*Information and Communication Technologies Department, Universitat Pompeu Fabra*)

Markov Random Field for combined defogging and stereo reconstruction
Stereo reconstruction serves many outdoor applications, and thus sometimes faces difficulties with foggy weather. However, fog provides depth cues for far away objects. By taking advantages of both stereo and fog cues, stereo reconstruction in fog can be improved. We propose a Markov Random Field model for this problem. The proposed model is tested on synthetic images and it shows that improved results can be achieved on both stereo reconstruction and visibility restoration.

Laurent Caraffa (*IGN*)
- Jean-Philippe Tarel (*Researcher. COSYS/LEPSiS , IFSTTAR*)

Spectral Edge Image Fusion
The goal of Spectral Edge Image Fusion is to map a low-dimensional guide image so that its gradient structure matches that present in a higher dimensional image of the same scene with the additional constraint that the 'colour' aspect of the guide is approximately preserved. Applications of spectral edge fusion include mapping RGB+NIR to RGB and visualising remote sensing data.

- Graham Finlayson (*School of Computing Sciences, University of East Anglia, Norwich Research Park*)

On the use of sparse reconstruction for the restoration of areas obscured by thick clouds in satellite image time series
Multispectral spaceborne sensors are characterized by a short revisit time and by additional spectral bands with respect to natural images. Exploiting the resulting high dimensionality of satellite image time series, sparse reconstruction algorithms can be exploited to synthetically reconstruct the areas obscured by thick clouds in a given acquisition, if enough cloud-free images are available on the same area.

- Daniele Cerra (*German Aerospace Center (DLR), Remote Sensing Technology Institute, Photogrammetry and Image Analysis, Oberpfaffenhofen*)

MS46 Randomized Numerical Linear Algebra for Imaging Science

Organizers:
N. Benjamin Erichson (*University of Washington*)
Steven L. Brunton (*University of Washington*)
J. Nathan Kutz (*Univeristy of Washington*)

MS46-1 - **Thursday, 07 at 09:30** Matemates (Matemates, floor 0)

Random Sampling Strategies for Learning High-Dimensional Time-Dependent Observations
We study the problem of learning high-dimensional dynamics from under-sampled data. In particular, we leverage the sparse structure of the governing equations along with recent results from random sampling theory to develop several methods for recovering dynamical systems. Using results from compressive sensing, we show that the strategies lead to exact recovery, which is stable to the sparse structure of the governing equations and robust to noise in the estimation of the velocity. Computational results validate each of the sampling strategies and highlight potential applications.

- Giang Tran (*University of Waterloo*)

Subsampling Large Datasets via Random Mixing
We will discuss a topic at the intersection of two big trends from the past decade: the fast Johnson-Lindenstrauss Transform for compressing data, and machine learning applied to big data sets. Suppose we wish to analyze a large data set, and in particular, group the items into clusters. When the data set is so large that this is computationally infeasible, a simple idea is to randomly throw away some of the data until it is feasible again. Of course, this will negatively affect the accuracy of the clustering. This talk is about one of the better ways to "throw away data" that minimizes the loss in accuracy by randomly mixing the dataset. Our method is particularly well-suited for streaming data, i.e., a data source of such volume that we can never store all of it. We may also discuss extensions to randomized Nyström methods.

- Stephen Becker (*University of Colorado Boulder*)

Randomized Nonnegative Matrix Factorizations
Nonnegative matrix factorization (NMF) is a powerful tool for image processing. However, the emergence of high-resolution images has severely challenged our ability to compute this fundamental decomposition using deterministic algorithms. We present a randomized hierarchical alternating least squares (HALS) algorithm to compute the NMF. By deriving a smaller matrix from the nonnegative input data, a more efficient nonnegative decomposition can be computed. Our algorithm scales to big data applications while attaining a near-optimal factorization, i.e., the algorithm scales with the target rank of the data rather than the ambient dimension of measurement space.

- N. Benjamin Erichson (*University of Washington*)

Recovery of Structured Nonlinear Dynamics from Under-sampled Measurements
Extracting information from stationary and dynamic data is an important task for data-based analysis. One way is to learn the function that generates the data, from limited or noisy samples. The form of that the equation takes may not be known a priori, so additional conditions, such as sparsity, smoothness, and randomness, are used to supplement the learning. In this talk, we detail several approaches using different assumptions on either the data or the generating function, and provide both numerical and theoretical results.

- Hayden Schaeffer (*Carnegie Mellon University*)

MS47 Splines in Imaging

Organizers:
Carolina Beccari (*Dept. Mathematics, University of Bologna*)
Virginie Uhlmann (*EPFL, Lausanne*)
Michael Unser (*EPFL, Lausanne*)

MS47-1 - **Thursday, 07 at 09:30** Room G (Palazzina A - Building A, floor 0)

Optimality of splines for the resolution of linear inverse problems with Tikhonov or total-variation regularization
We present two representer theorems that provide the parametric form of the solution(s) of generic linear inverse problems with Tikhonov (p=2) vs. total-variation (p=1) regularization. Remarkably, the solutions in both cases are generalized splines that are tied to the underlying regularization operator L. For p=2, the knots are fixed with basis functions that are smoothed versions of the measurement operator. In the total variation scenario, the solutions are nonuniform L-splines with adaptive (and fewer) knots.

Gupta Harshit (*EPFL, Lausanne*)
Fageot Julien (*EPFL, Lausanne*)
- Michael Unser (*EPFL, Lausanne*)

Sparse Approximation for Few View Tomographic Reconstruction
Tomographic imaging from limited projections is an ill-posed problem and reconstruction algorithms rely on regularization, often sparsity-based, to improve the quality of imaging. We present a spline framework for consistent discretization in tomographic reconstruction and demonstrate its advantages for sparse approximation. Our experiments provide comparisons with commonly-used techniques such as total variation based tomographic reconstruction.

- Alireza Entezari (*Department of Computer & Information Science & Engineering, University of Florida, Gainesville*)
Elham Sakhaee (*University of Florida*)
Kai Zhang (*University of Florida*)

Recovery of piecewise smooth signals on manifolds using structured low-rank methods
We introduce a continuous domain framework for the recovery of points on a surface, which is represented as the zero-level set of a bandlimited function. We show that the exponential maps of the points satisfy some annihilation relations. The annihilation conditions are used to derive sampling conditions, and to develop kernel low-rank algorithms that will be used to recover free breathing and ungated cardiac MRI data from highly undersampled measurements.

- Mathews Jacob (*Department of Electrical and Computer Engineering, University of Iowa*)

Hermite-like representation of images in terms of samples with local tangents
The aim of this talk is to discuss the construction of minimally supported basis functions for Hermite interpolation on a three directional mesh of the plane. Our model relies on three directional Box-splines and gets advantage from the deep relationship between Hermite and Bézier representation of piecewise bivariate polynomials. Starting by the simpler but analogous univariate case, we will show how the use of Greens' function allows us to unreveil all theoretical properties of the new bivariate Hermite basis functions. The proposed model meets practical requirements such as invariance to affine transformations and good approximation properties.One of its great advantages is its non tensor-product structure which avoids the use of mixed derivatives and makes it suitable to Hermite-like representation of images in terms of samples with local tangents.

- Costanza Conti (*University of Firenze*)
Lucia Romani (*University of Milano-Bicocca*)
Michael Unser (*EPFL, Lausanne*)

MS47-2 - Thursday, 07 at 14:00 Room G (Palazzina A - Building A, floor 0)

Statistical optimality of Hermite splines for the reconstruction of self-similar signals
Hermite splines are commonly used for interpolating data when samples of the derivative are available, in a scheme called Hermite interpolation. Assuming a suitable statistical model, we demonstrate that this method is optimal for reconstructing random signals in Papoulis' generalized sampling framework. More precisely, we show the equivalence between cubic Hermite interpolation and the linear minimum mean-square error (LMMSE) estimation of a second-order Lévy process.

- Virginie Uhlmann (*EPFL, Lausanne*)

The Role of Discretization in X-Ray CT Reconstruction
Discretization—representing a continuous-time function or operation with a discrete-time one—is unavoidable in solving inverse problems. In X-ray computed tomography (CT) reconstruction, the classical algorithm handles discretization "at the end". Modern approaches discretize "in the middle" or "at the beginning". In this talk, I will show how the latter provides algorithms that are mathematically rigorous and implementable. I will also discuss the choice of the basis function among pixels, B-splines, box splines, Kaiser-Bessel windows, and sincs.

- Michael McCann (*EPFL*)

Subdivision-based Active Contours
In this talk we present a new family of active contours by exploiting subdivision schemes. Depending on the choice of the mask, such models have the ability to reproduce trigonometric or polynomial curves. They can also be designed to be interpolating, a property that is useful in user-interactive applications. Such active contours are robust in the presence of noise and to the initialization. We illustrate their use for the segmentation of bioimages.

- Anaïs Badoual (*EPFL, Lausanne*)

Sparse Approximation of Images by Adaptive Thinning
We propose an adaptive algorithm for sparse image approximation, termed "adaptive thinning" (AT). The algorithm AT works with recursive removals of pixels from the target image, where the image is approximated by linear splines over anisotropic Delaunay triangulations. We discuss both computational and theoretical aspects of AT. The good performance of AT is finally supported by numerical examples and comparisons.

- Armin Iske (*Dept. Mathematics, University of Hamburg*)

MS47-3 - Thursday, 07 at 16:30 Room G (Palazzina A - Building A, floor 0)

Applications of nonstationary wavelet filters in image processing
We present a study concerning the construction, the properties and the applications in image processing of a family of nonstationary biorthogonal wavelet filterbanks. Such a family is generated by a class of functions satisfying level-dependent refinement equations and includes cardinal polynomial B-splines. Nonstationarity offers a greater flexibility and a better adaptation to the local image content, allowing for a more focused scale-space analysis and thus providing better results when compared to classical biorthogonal B-spline filters.

- Vittoria Bruni (*Dept. of Basic and Applied Sciences for Engineering, University of Rome "La Sapienza"*)
Mariantonia Cotronei (*University of Reggio Calabria*)
Francesca Pitolli (*Dept. of Basic and Applied Sciences for Engineering, University of Rome "La Sapienza"*)

Acceleration of B-spline based nonrigid image registration
In nonrigid image registration, B-splines are used extensively for interpolation and transformation. We propose efficient multi-dimensional algorithms for the B-spline interpolation and transformation functions and their derivatives. The algorithms are based on recursive formulations and implemented using template metaprogramming. Compared to reference implementations, we obtain an acceleration factor of 4 for interpolation and a factor of 18 for transformation. When used within a registration algorithm, total computation time reduces by a factor 1.5 to 3.5.

Wyke Huizinga (*Biomedical Imaging Group Rotterdam, Erasmus MC*)
- Stefan Klein (*Biomedical Imaging Group Rotterdam, Erasmus MC*)
Dirk Poot (*Biomedical Imaging Group Rotterdam, Erasmus MC*)
Marius Staring (*Division of Image Processing (LKEB), Dept. of Radiology, Leiden University Medical Center*)

High-dimensional and accurate MRF dictionary-based fitting with spline interpolation

Magnetic resonance fingerprinting methods quantify multiple MR parameters by matching the measured signal to a precomputed 5-dimensional dictionary in which each parameter is a dimension. Generating high-precision maps requires dense grids in each dimension, which is prohibitively expensive in memory and computation time. We propose B-spline interpolation of the dictionary to reduce the dictionary size and to enable efficient nonlinear least-squares fitting by gradient-based optimization methods. The method is shown to substantially reduce fitting error.

Stefan Klein (*Biomedical Imaging Group Rotterdam, Erasmus MC*)
Dirk Poot (*Biomedical Imaging Group Rotterdam, Erasmus MC*)
• Willem van Valenberg (*Quantitative Imaging Group, Delft University of Technology, Biomedical Imaging Group Rotterdam, Erasmus MC*)
Lucas van Vliet (*Quantitative Imaging Group, Delft University of Technology*)
Frans Vos (*Quantitative Imaging Group, Delft University of Technology, Radiology, Academic Medical Center, Amsterdam*)

DTHB3D_Reg: Dynamic Truncated Hierarchical B-Spline Based 3D Nonrigid Image Registration

We present a robust approach to perform 3D nonrigid image registration suitable for large deformation and develop a software named DTHB3D_Reg. The optimum spatial transformation, defined using truncated hierarchical B-splines, is obtained through the minimization of an energy functional. An adaptive strategy carries out refinement only in the regions with large deformation. The proposed method is demonstrated on medical images to show robustness on topology change as compared to other image registration methods.

Cosmin Anitescu (*University of Weimar*)
Yue Jia (*Northwestern Polytechnical University*)
• Aishwarya Pawar (*Department of Mechanical Engineering, Carnagie Mellon University, Pittsburgh*)
Timon Rabczuk (*University of Weimar*)
Jessica Zhang (*Department of Mechanical Engineering, Carnagie Mellon University, Pittsburgh*)

MS48 Recent Advances in Mathematical Morphology: Algebraic and PDE-based Approaches

Organizers:
Martin Welk (*Private University for Health Sciences, Medical Informatics and Technology (UMIT)*)
Michael Breuss (*Brandenburg University of Technology*)

MS48-1 - **Thursday, 07 at 09:30** Room D (Palazzina A - Building A, floor 1)

Discretization of Morphology-type PDEs and Active Contours on Graphs

We present advances on extending morphology PDEs and active contours to arbitrary graphs by developing difference schemes and geometric approximations of gradient and curvature, with theoretical results on their convergence in probability and asymptotic error bounds. We also use finite elements to generalize active contour models on graphs and reduce the problem from a PDE to a sparse nonlinear system. For both approaches we provide experimental results for image segmentation and graph clustering.

Kimon Drakopoulos (*University of Southern California*)
Nikos Kolotouros (*University of Pennsylvania*)
• Petros Maragos (*National Technical University of Athens*)
Christos Sakaridis (*ETH Zürich*)

Mathematical morphology for multispectral images

The processing of multispectral images is a challenging task due to the fact that the pixel content is vectorial and the definition of an order is difficult. A new geometrical framework based on double hypersimplices and the Loewner ordering is illustrated to define the two fundamental operations dilation and erosion for multispectral images. These are the two main building blocks of mathematical morphology to define higher morphological operations such as top hats, gradients, and the morphological Laplacian. Numerical results are given to show the advantages and shortcomings of the new proposed approach.

• Andreas Kleefeld (*Forschungszentrum Jülich GmbH*)

Morphological operators on ultrametric spaces

Hierarchical representations are ubiquitous in morphological image processing and are mathematically modeled as ultrametric spaces. In this talk, morphological operators for functions defined on ultrametric spaces are considered. The notion of ultrametric structuring function is introduced. Then, using as fundamental ingredient the convolution in the (max,min)-algebra, the multi-scale ultrametric dilation and erosion are defined and their semigroup properties are stated.

• Jesús Angulo (*Center for Mathematical Morphology, Départ. de Mathématiques et Systèmes, MINES ParisTech*)

Operator-algebraic approach to image processing of matrix fields
Matrix valued images, so-called matrix fields, represent a data type frequently encountered, for instance, in medical imaging and engineering sciences. For symmetric matrices the Loewner order may be utilised to establish many useful morphological operations for these fields, both order- and PDE-based. This talk is about the basic mathematical background of the framework and its extension to non-symmetric matrices, such as rotation matrices. Numerical results will indicate the potential of the proposed approach.

- Bernhard Burgeth (*Saarland University, Saarbrücken*)

MS49 Image Restoration, Enhancement and Related Algorithms

Organizers:
Weihong Guo (*Case Western Reserve University*)
Ke Chen (*University of Liverpool*)
Xue-Cheng Tai (*Hong Kong Baptist University*)
Guohui Song (*Clarkson University*)

MS49-1 - **Thursday, 07 at 09:30** Room E (Palazzina A - Building A, floor 2)

Sparse-data Based 3D Surface Reconstruction for Cartoon and Map
A model combining the first-order and the second-order variational regularizations for the purpose of 3D surface reconstruction based on 2D sparse data is proposed. The model includes a hybrid fidelity constraint which allows the initial conditions to be switched flexibly between vectors and elevations. A numerical algorithm based on the augmented Lagrangian method is also proposed. The numer ical expriments are presented, showing its excellent performance both in designing cartoon characters, as well as in recovering oriented mountain surfaces. This talk is based on joint works with Bin Wu and Talal Rahman.

- Xue-Cheng Tai (*Hong Kong Baptist University*)

Infimal Convolution of Oscillation Total Generalized Variation for the Recovery of images with structured texture
We propose a new type of regularization functional called oscillation total generalized variation (TGV) which is able to represent structured textures with oscillatory character. The infimal convolution of oscillation TGV associated with different directions is studied as a regularizer for variational imaging problems. We discuss analytical properties of these functionals, discretization and algorithmic realization. Finally, numerical experiments are presented that show the advantages of the model in terms of texture preservation and reconstruction.

- Kristian Bredies (*Universität Graz*)
  Yiming Gao (*Nanjing University of Science and Technology,*)

A Distributed Dictionary Learning Algorithm and its Applications
Dictionary learning has shown its great performances in image processing and computer vision. Modern learning tasks have to deal with large amount of data and thus put a high requirement on the efficiency of optimization algorithms. We propose a novel distributed algorithm for structured dictionary learning. Specifically, we leverage the existing alternating scheme with atom re-allocation followed by consensus updates. We also address to maintain the manifold structure of the dictionary atoms which is usually omitted by existing methods. Furthermore, advantages of the proposed algorithm are demonstrated for various applications.

- Weihong Guo (*Case Western Reserve University*)
  Yue Zhang (*Case Western Reserve University*)

Variational Models for Joint Subsampling and Reconstruction of Turbulence-degraded Images
Turbulence-degraded image frames are distorted by both turbulent deformations and space-time-varying blurs. To suppress these effects, we propose a multi-frame reconstruction scheme to recover a latent image from the observed image sequence. Commonly used approaches are based on registering each frame to a reference image, by which geometric turbulent deformations can be estimated and a sharp image can be restored. A major challenge is that a fine reference image is usually unavailable, as every turbulence-degraded frames are distorted. A high-quality reference image is crucial for the accurate extraction of geometric deformations and fusion of frames. Besides, it is unlikely that all frames from the image sequence are useful, and thus frame selection is necessary. In this work, we propose a variational model for joint subsampling of frames and extraction of a reference image. A fine reference image extracted from a suitable choice of subsample are simultaneously obtained by iteratively reducing an energy functional. The energy consists of a fidelity term measuring the discrepancy between the reference image and the subsampled frames, as well as a quality measure for each frame. Different choices of fidelity and quality terms are explored. By carefully selecting suitable frames and extracting the reference image, the quality of the reconstructed image can be significantly improved. Extensive experiments have been carried out, which demonstrate the efficacy of our proposed model.

- Chun Pong Lau (*The Chinese University of Hong Kong*)
  Ronald Lui (*Chinese University of Hong Kong*)

MS49-2 - **Friday, 08 at 09:30** Room E (Palazzina A - Building A, floor 2)

Fast multilevel algorithms for nonlinear optimization in image processing
Solving effectively nonlinear optimization is a key step in image processing, especially in variational modeling. While gradient descent methods and augmented Lagrangian methods operating on a single mesh level are popularly used, developing fast and optimal multilevel methods are of great importance. This talk extends previous works on multilevel methods for image restoration to image segmentation where there is a further scope to explore in acceleration beyond $O(N \ln N)$ complexity.

Ke Chen (*University of Liverpool*)
- Abdul Jumaat (*University of Liverpool*)

Variational Phase Retrieval with globally convergent preconditioned Proximal Algorithm
We reformate a general phase retrieval (PR) problem to explicitly contain a Lipchitz differentiable term. The model can be efficiently solved via Partially Preconditioned Proximal Alternating Linearized Minimization (P3ALM). Thanks to the Lipchitz term, we prove the global convergence of P3ALM. We conduct experiments on a variety of PR sampling schemes to show the effectiveness of the proposed method. Finally, some empirical observations are drawn to better characterize the PR problems.

- Yifei Lou (*University of Texas at Dallas*)

A Multigrid Approach for Multi Scale Total Variation Models
We propose a novel multi-grid method for solving total variation models. This type of models arises frequently in image processing tasks such as de-noising and segmentation. It is usually proposed as minimizing a nonlinear functional containing a total variation term, and the computational domain is either rectangle in 2D or rectangular cuboid in 3D. A usual multi-level decomposition of the domain is performed over the whole domain. The resulted subdomains are marked by four colors (in 2D case) in the interlacing formation, such that subdomains of the same color are non-overlapping. At each level, the solution for the minimizer of the nonlinear functional is updated in parallel on the subdomains of the same color, while the solution on each subdomain is updated by the same constant. This process is carried out in a Gauss-Seidel manner over the four colors for a few iterations. Unlike the usually multi-grid method that loops over all levels in V-cycle or W-cycles, the proposed approach sequentially updates the solution from coarsest level to finest, and repeat the procedure until convergence. The numerical tests demonstrate the linear scalability of the proposed algorithm and shows a potential for improvement in parallel computing.

- Ke Yin (*Huazhong Univeristy of Science and Technology*)

MS49-3 - **Friday, 08 at 14:00** Room E (Palazzina A - Building A, floor 2)

Super-Resolution of Multispectral Multiresolution Images
I will present our recent work on super-resolution of multiband images with multiresolution bands (e.g., Sentinel-2, MODIS). We address this imaging inverse problem by adopting scene-adapted non-local patch/tensor-based variational regularization. The inference is carried out under the convex or the plug-and-play frameworks. The effectiveness of the proposed approach will be documented in a series of experiments with simulated and real data.

Jose Bioucas-Dias (*Universidade de Lisboa, Instituto Superior Técnico (IST), Instituto de Telecomunicações (IT)*)
- Mário Figueiredo (*Instituto de Telecomunicações and IST, University of Lisboa*)

The SparseFI Algorithms for Resolution Enhancement of Optical Remote Sensing Images
Data provided by most Earth observation satellites possess either high spatial or high spectral resolution. A high spatial resolution allows for accurate geometric analysis and rich spectral information is necessary for thematic interpretation. Therefore, remote sensing applications usually require both. The required solutions are sophisticated data fusion techniques that increase the spatial resolution of the images while introducing negligible spectral distortion. In this talk, a bunch of sparse image fusion (SparseFI) algorithms will be introduced.

- Claas Grohnfeldt (*Technical University of Munich (TUM)*)
Xiaoxiang Zhu (*Technical University of Munich (TUM) & German Aerospace Center (DLR)*)

Fusion of Multispectral and Panchromatic Image: a Review of Classical Approaches and New Developments
Pansharpening refers to the fusion of a monochrome image acquired by a broadband panchromatic instrument with a fine spatial resolution, and a multispectral image with a high spectral resolution. In this paper, we will focus on the classical pansharpening and, in particular, on methods belonging to the component substitution and the multi-resolution analysis classes. The optimization of these two main families of pansharpening techniques will be addressed.

Luciano Alparone (*University of Florence*)
Jocelyn Chanussot (*Grenoble Institute of Technology*)
- Andrea Garzelli (*University of Siena*)
Gemine Vivone (*University of Salemo*)

Producible Kernel Hilbert Space and Heaviside Functions in Image Enhancement
In this talk, we first present an iterative scheme to solve single image super-resolution problems. It recovers a high quality high-resolution image from solely one low-resolution image without using a training data set. We solve the problem from image intensity function estimation perspective and assume the image contains smooth and edge components. We model

the smooth components of an image using a thin-plate reproducing kernel Hilbert space (RKHS) and the edges using approximated Heaviside functions. The proposed method is applied to image patches, aiming to reduce computation and storage. In addition, we also extend the proposed framework to the fusion of panchromatic and multispectral images. Visual and quantitative comparisons with some competitive approaches show the effectiveness of the proposed framework.

- Liang-Jian Deng (*University of Electronic Science and Technology of China*)

MS49-4 - Friday, 08 at 16:30 Room E (Palazzina A - Building A, floor 2)

Second Order Approximation of the MRI Signal for Single Shot Parameter Assessment

Abstract: Most current methods of Magnetic Resonance Imaging (MRI) reconstruction interpret raw signal values as samples of the Fourier transform of the object. Although this is computationally convenient, it neglects relaxation and off-resonance evolution in phase. A more accurate model, known as Parameter Assessment by Recovery from Signal Encoding (PARSE), takes the time evolution of the signal into consideration. In this talk, we propose using a second-order approximation of the original PARSE model.

- Rodrigo Platte (*Arizona State University*)

Convex Blind Image Deconvolution with Inverse Filtering

Blind image deconvolution is the process of estimating both the original image and the blur kernel from the degraded image with only partial or no information about degradation and the imaging system. It is a bilinear ill-posed inverse problem corresponding to the direct problem of convolution. Regularization methods are used to handle the ill-posedness of blind deconvolution and get meaningful solutions. In this paper, we investigate a convex regularized inverse filtering method for blind deconvolution of images. We assume that the support region of the blur object is known, as has been done in a few existing works. By studying the inverse filters of signal and image restoration problems, we observe the oscillation structure of the inverse filters. Inspired by the oscillation structure of the inverse filters, we propose to use the star norm to regularize the inverse filter. Meanwhile, we use the total variation to regularize the resulting image obtained by convolving the inverse filter with the degraded image. The proposed minimization model is shown to be convex. We employ the first-order primal-dual method for the solution of the proposed minimization model. Numerical examples for blind image restoration are given to show that the proposed method outperforms some existing methods in terms of peak signal-to-noise ratio (PSNR), structural similarity (SSIM), visual quality and time consumption. This is a joint work with Xiao-Guang Lv and Fang Li.

- Tieyong Zeng (*Department of Mathematics, The Chinese University of Hong Kong, Shatin, N.T.*)

Half-quadratic Adaptive TV^p to the Image Restoration Problem

Keeping structures in the restoration problem is very important via coupling the local information of the image with the proposed model. In this paper we propose a local self-adaptive ℓ^p-regularization model for $p \in (0,2)$ based on the total variation scheme, where the choice of p depends on the local structures described by the eigenvalues of the structure tensor. Since the proposed model as the classic ℓ^p problem unifies two classes of optimization problems such as the nonconvex and nonsmooth problem when $p \in (0,1)$, and the convex and smooth problem when $p \in (1,2)$, it is generally challenging to find a ready algorithmic framework to solve it. Here we propose a new and robust numerical method via coupling with the half-quadratic scheme and the alternating direction method of multipliers(ADMM). The convergence of the proposed algorithm is established and the numerical experiments illustrate the possible advantages of the proposed model and numerical methods over some existing variational-based models and methods.

Ke Chen (*University of Liverpool*)
Hui Li (*Henan University*)
- Zhi-Feng Pang (*Hunan University*)

Phase Retrieval from Local Measurements: Deterministic Measurement Constructions and Efficient Recovery Algorithms

Certain imaging applications such as x-ray crystallography require the recovery of a signal from magnitude-only measurements. This is a challenging inverse problem since the phase encapsulates a significant amount of structure in the underlying signal. In this talk, we discuss a recently introduced algorithm for solving the discrete phase retrieval problem from deterministic local measurements. Theoretical recovery guarantees as well as numerical results demonstrating the method's speed, accuracy and robustness will be provided.

Mark Iwen (*Department of Mathematics, Michigan State University*)
Brian Preskitt (*University of California, San Diego*)
Rayan Saab (*University of California, San Diego*)
- Aditya Viswanathan (*University of Michigan - Dearborn*)

MS50 Analysis, Optimization, and Applications of Machine Learning in Imaging

Organizers:

Michael Moeller (*University of Siegen*)
Gitta Kutyniok (*Technische Universität Berlin*)

MS50-1 - **Thursday, 07 at 09:30** Room C (Palazzina A - Building A, floor 1)

Global Optimality in Matrix, Tensor Factorization, and Deep Learning
The past few years have seen a dramatic increase in the performance of recognition systems thanks to the introduction of deep networks for representation learning. However, the mathematical reasons for this success remain elusive. A key issue is that the neural network training problem is non-convex, hence optimization algorithms may not return a global minima. Building on ideas from convex relaxations of matrix factorizations, this work proposes a general framework which allows for the analysis of a wide range of non-convex factorization problems – including matrix factorization, tensor factorization, and deep neural network training. The talk will describe sufficient conditions under which a local minimum of the non-convex optimization problem is a global minimum and show that if the size of the factorized variables is large enough then from any initialization it is possible to find a global minimizer using a local descent algorithm. Joint work with Ben Haeffele.

Benjamin Haeffele (*Johns Hopkins University*)
- Rene Vidal (*Johns Hopkins University*)

Texture modeling with scattering transform
We study how to model the texture as a stationary and ergodic random process. The texture is assumed to be homogenous in two-dimensional space, i.e. stationary under translation, and is ergodic in sense that the statistics do not differ considerably from one single realisation to another. These statistical properties fit well the classical microcanonical modeling framework, resulting in a maximum entropy process satisfying a pre-defined set of statistics. The main challenge is to define this set of statistics so as to capture the non-Gaussianarity of the underlying random process, in particular when the texture has long-range dependency and complex geometry such as vorticity solutions two-dimensional Navier-Stokes equation. One common way to evaluate the model is to synthesis texture of similar visual quality and variability. We use the scattering transform to capture the geometric correlations in the space beyond second order statistics. The basic idea is to model progressively the Gaussian and non-Gaussian part of the random process through a cascade of convolutional and non-linear transforms. When the random process is a Gaussian process, we use the l_2 moments of the 1st order scattering coefficients to approximate its covariance structure. We evaluate the Gaussian model by standard metrics in power spectrum estimation. The use of the Gabor wavelets in 1st order scattering also extracts the non-Gaussian statistics. The non-linear modulus operator is then applied to introduce the correlations between across scales and angles. We then build a second order model with PCA to capture these non-Gaussian correlations by the 2nd order scattering coefficients. We will present results on the synthesis texture of Turbulence and Brodatz texture dataset.

- Sixin Zhang (*Ecole Normale Supérieure Paris*)

Learning for Compressed Sensing CT Reconstruction
In this talk, we present our latest work on learning reconstructions of low-dose computed tomography data. We focus on two methods to decrease the radiation dose: x-ray tube current reduction, reducing the signal-to-noise ratio, and x-ray beam interruption, which undersamples data and results in images with aliasing artifacts. Our reconstruction results using trainable variational networks enable higher radiation dose reductions and/or increase the image quality for a given dose.

Baiyu Chen (*New York University*)
Kerstin Hammernik (*Graz University of Technology*)
Teresa Klatzer (*Graz University of Technology*)
Florian Knoll (*New York University*)
- Erich Kobler (*Graz University of Technology*)
Matthew Muckley (*New York University*)
Ricardo Otazo (*New York University*)
Thomas Pock (*Graz University of Technology*)
Daniel Sodickson (*New York University*)

Deep inversion: convolutional neural networks meet neuroscience

- Christoph Brune (*University of Twente*)

MS50-2 - **Thursday, 07 at 14:00** Room C (Palazzina A - Building A, floor 1)

Breaking the Curse of Dimensionality with Convex Neural Networks
We consider neural networks with a single hidden layer and non-decreasing positively homogeneous activation functions like the rectified linear units, and study the statistical and computational properties in a high-dimensional set-up, where the number of hidden units grow unbounded. While these networks are provably adaptive to low-dimensional structures, they require an efficient solver for the non-convex subproblem of addition of a new unit.

- Francis Bach (*Departement d'Informatique de l'Ecole Normale Superieure Centre de Recherche INRIA de Paris*)

Prediction Methods for training Generative Image Models
Adversarial neural networks solve many important problems in image science, and can be used to build sophisticated image models and priors. However, these models are notoriously difficult to train. These difficulties come from the fact that optimal weights for adversarial nets correspond to saddle points, and not minimizers, of the loss function. The alternating stochastic gradient methods typically used for such problems do not reliably converge to saddle points, and

when convergence does happen it is often highly sensitive to learning rates. We propose a simple modification of stochastic gradient descent that stabilizes adversarial networks. We show, both in theory and practice, that the proposed method reliably converges to saddle points. This makes adversarial networks less likely to "collapse", and enables faster training with larger learning rates.

- Tom Goldstein (*University of Maryland*)
  Abhay Kumar (*University of Maryland*)
  Sohil Shah (*University of Maryland*)
  Zheng Xu (*University of Maryland*)

An Optimal Control Framework for Efficient Training of Deep Neural Networks

We present a new mathematical framework that simplifies designing, training, and analyzing deep neural networks. It is based on the interpretation of deep learning as a dynamic optimal control problem. The deep learning problem can thus be cast as a continuous problem and can also be interpreted as a dynamic inverse problem (comparable to, e.g., electromagnetic imaging, optical flow) or optimal control problems (similar to, e.g., optimal mass transport or path-planning). We exemplify how the understanding of the underlying dynamical systems helps design, analyze, and train deep neural networks. The talk focusses on ways to ensure the stability of the dynamics in both the continuous and discrete setting to obtain a well-posed learning problem that allows effective, iterative solution. Throughout the talk, we will illustrate the impact of stability and discretization on the performance of both stochastic and deterministic iterative optimization algorithms.

  Eldad Haber (*University of British Columbia*)
- Lars Ruthotto (*Department of Mathematics and Computer Science, Emory University*)

Are neural networks convergent regularisation methods?

We propose a generic Fejér-monotonicity result for neural network architectures with added constraints. This result can be interpreted as a first step towards establishing an analogy between neural network architectures and convergent, iterative regularisation methods, and therefore help to stabilise the neural network architectures. We apply our result to architectures such as variational networks and the learned iterative soft-thresholding algorithm (LISTA) and demonstrate how the theory dictates additional constraints for the learning of the network parameters. This is joint work with Thomas Pock and Peter Maaß.

- Martin Benning (*University of Cambridge*)

MS50-3 - Thursday, 07 at 16:30 Room C (Palazzina A - Building A, floor 1)

Fast Learning and Inference for Computational Imaging

I'll describe a general framework for rapidly learning image processing operators, applying them, and inverting them. We developed the first application of this approach in 2016: the Rapid and Accurate Image Super Resolution (RAISR) method for fast and high quality image upscaling, using a trained set of filters. I will detail this work first, which has since been used in a number of products at Google including the Pixel 2 phones. Then, I will describe a broad generalization of RAISR, a more powerful trainable image-adaptive filtering framework that is still easy to train, computationally efficient, and useful for a wide range of problems in computational photography and imaging. I will illustrate applications to a variety of operations which may appear in a camera pipeline and elsewhere, including denoising, demosaicing, and stylization. Finally, I will describe how such a framework can also be used to solve various other inverse problems very efficiently.

  Ignacio Garcia-Dorado (*Google Research*)
  Pascal Getreuer (*Google Research*)
  John Isidoro (*Google Research*)
- Peyman Milanfar (*Google Research*)
  Yaniv Romano (*Technion - Israel Institute of Technology*)

Unraveling the mysteries of stochastic gradient descent on deep networks

We show that stochastic gradient descent (SGD) performs variational inference, it minimizes an average potential over the posterior distribution on weights with an entropic regularization term. For deep networks, this potential is different from the original loss used to compute gradients due to highly non-isotropic mini-batch gradient noise. Most likely trajectories of SGD in this case are not Brownian motion near critical points, they are closed loops in the weight space. Joint work with Stefano Soatto.

- Pratik Chaudhari (*University of California, Los Angeles, UCLA*)

Proximal Backpropagation

We propose proximal backpropagation (ProxProp) as a novel algorithm that takes implicit instead of explicit gradient steps to update the network parameters during neural network training. ProxProp is developed from a general point of view on the backpropagation algorithm. Specifically, we show that backpropagation of a prediction error is equivalent to sequential gradient descent steps on a quadratic penalty energy. We conclude by analyzing theoretical properties of ProxProp and demonstrate promising numerical results.

- Thomas Frerix (*Technical University of Munich*)
  Thomas Möllenhoff (*Technical University of Munich*)

A shearlet-based deep learning approach to limited-angle tomography
In computed tomography (CT), one of the key issues is the limited angle problem. Traditional imaging methodologies are not capable of reconstructing the complete image satisfactorily. In this talk, we will present a deep learning approach to this problem using shearlets as a sparsifying transform.

- Gitta Kutyniok (*Technische Universität Berlin*)
  Maximilian März (*Technische Universität Berlin*)
  Wojciech Samek (*Fraunhofer Institute for Telecommunications–Heinrich Hertz Institute*)
  Vignesh Srinivasan (*Fraunhofer Institute for Telecommunications–Heinrich Hertz Institute*)

MS51 Algorithms for Single Particle Reconstruction in Cryo-Electron Microscopy (cryo-EM).

Organizers:
Roy Lederman (*Yale University*)
Joakim Andén (*Flatiron Institute*)

MS51-1 - Thursday, 07 at 09:30 Main room - aula magna - SP.I.S.A. (SP.I.S.A., floor 0)

Overview of computational challenges in cryo-EM analysis
Single-particle cryo-electron microscopy (cryo-EM) has recently joined X-ray crystallography and NMR spectroscopy as a high-resolution structural method for biological macromolecules (Nobel Prize in Chemistry 2017). The speaker will give an overview of the computational challenges in cryo-EM analysis and how he and others are trying to face them, focusing on 3D ab-initio modeling and the heterogeneity problem of determining structural variability.

- Amit Singer (*Princeton University*)

Atomic resolution single particle Cryo-EM
Improvements in the DQE of direct electron detectors combined with their ability to operate in movie mode, have created unique opportunities for the development of computational strategies in single-particle cryo-EM. By harnessing the time-resolved information contained in movie frames, we developed methods to account for local variations in defocus and beam-induced drift, and implemented a data-driven dose compensation scheme that allowed us to overcome fundamental resolution barriers inherent to imaging biological samples using high-energy electrons.

- Alberto Bartesaghi (*CCR/NCI/NIH*)

Viewing direction estimation for molecules with rotational symmetry
We present an algorithm for determining the three-dimensional structure of molecules that possess rotational point group symmetry. Our algorithm utilizes the fact that, every two images of any such molecule share many common-lines, and that each image has several self common lines. This in turn enables a maximum-likelihood type based approach, in which all possible pairwise viewing directions are considered, thus enabling a high detection rate even in a noisy setting.

- Gabi Pragier (*Tel Aviv University*)

Fast Algorithms for CryoEM Reconstruction
Image reconstruction in cryo-electron microscopy gives rise to a non-convex optimization problem and the raw data is noisy. Existing methods are generally based on some version of the expectation-maximization method to solve a maximum-likelihood problem. We propose recursion in frequency as a way to mitigate the difficulties associated with the non-convexity of the optimization task. We will also present a collection of algorithms intended to accelerate the reconstruction.

- Marina Spivak (*Flatiron Institute*)

MS51-2 - Thursday, 07 at 14:00 Main room - aula magna - SP.I.S.A. (SP.I.S.A., floor 0)

Resolution measures in Electron Microscopy reconstructions
In this talk we will review the different definitions of resolution use in Electron Microscopy. We will explore its statistical distributions and the conditions under which these are analytically determined. As will be seen, strong statements about resolution must be taken with care. We will also explore the relationship between the particle size, the number of images required to achieve a given resolution and the image formation physics.

- Carlos Oscar Sorzano (*Centro Nacional Biotecnología*)

Hyper-molecules for continuous heterogeneity in Cryo-EM
While other methods for structure determination, such as x-ray crystallography and nuclear magnetic resonance (NMR), measure ensembles of molecules together, cryo-EM produces measurements of individual molecules. Therefore, cryo-EM could potentially be used to study mixtures of different conformations of molecules. Indeed, current algorithms have been very successful at analyzing homogeneous samples, and can recover some distinct conformations mixed in solutions, but, the determination of multiple conformations, and in particular, continuums of similar conformations (continuous heterogeneity), remains one of the open problems in cryo-EM. We introduce "hyper-molecules," a formulation for truly

continuously heterogeneous molecules and a Bayesian framework which we use to recover continuums of conformations with multiple degrees of freedom from cryo-EM data. http://roy.lederman.name/cryo-em

- Roy Lederman (*Yale University*)

Manifold denoising for cryo-EM data sets
A key challenge in processing cryo-EM images is the overwhelming level of noise in them. We present an algorithm for denoising cryo-EM image sets, by exploiting the geometrical property that all underlying (unknown) clean images lie on a manifold of lower dimensionality. Each image is denoised by projecting it onto this (unknown) low-dimensional manifold. We show that all the quantities required to compute this projection can be estimated using only the two-dimensional images.

Boris Landa (*Tel Aviv University*)
- Yoel Shkolnisky (*Tel Aviv University*)

MS51-3 - **Thursday, 07 at 16:30** Main room - aula magna - SP.I.S.A. (SP.I.S.A., floor 0)

Parameter estimation in heterogeneous mixtures
Particles imaged in cryo-electron microscopy (cryo-EM) often exhibit a number of different three-dimensional structures. In some cases it is important to estimate the ratio of samples from each structure in order to better understand the biological meaning of the sructures. We present a noval was to estimate this ratio, and give bounds on the error of the estimate.

- Yariv Aizenbud (*Tel Aviv University*)
Boris Landa (*Tel Aviv University*)
Yoel Shkolnisky (*Tel Aviv University*)

3D ab initio modeling in cryo-EM by autocorrelation analysis
Many algorithms for reconstruction of 3D structure from cryo-EM data require ab-initio models for initialization. There is also a general need for validation methods in the absence of ground truth. We present a procedure to quickly obtain low resolution ab-initio models using Kam's autocorrelation method, which can be used for both purposes. This procedure sidesteps the need to estimate particle orientations and is guaranteed to recover the true structure in the absence of noise.

Tamir Bendory (*Princeton University*)
Nicolas Boumal (*Princeton University*)
Joe Kileel (*Princeton University*)
- Eitan Levin (*Princeton University*)
Amit Singer (*Princeton University*)

Resolving cryo-EM heterogeneity with low-rank methods
A single biological molecule typically exhibits multiple structural configurations, each with a different function. Cryo-electron microscopy can capture this variability since different structures yield different projection images. We discuss methods for characterizing this variability which exploit the fact that it is often well-approximated by a low-rank model. This property allows us to draw on methods from matrix completion and singular value shrinkage. We demonstrate the utility and efficiency of the proposed methods on experimental datasets.

- Joakim Andén (*Flatiron Institute*)

MS52 A Denoiser Can Do Much More Than Just... Denoising

Organizers:
Yaniv Romano (*Technion - Israel Institute of Technology*)
Peyman Milanfar (*Google Research*)
Michael Elad (*The Technion - Israel Institute of Technology*)

MS52-1 - **Thursday, 07 at 09:30** Room A (Palazzina A - Building A, floor 0)

Regularization by Denoising (RED): New and surprising uses of an old problem
Image denoising has reached impressive heights in performance and quality – almost as good as it can ever get. This talk is about the many other things one can do with a good denoiser besides using it for its intended purpose. Of particular interest is how to use denoisers in the regularization of any inverse problem. We propose an explicit image-adaptive regularization functional that makes the overall objective functional clear and well-defined. Remarkably, the resulting regularizer is convex. With complete flexibility to choose the iterative optimization procedure for minimizing this functional, RED is capable of incorporating any image denoising algorithm as a regularizer, treat general inverse problems very effectively, and is guaranteed to converge to the globally optimal result. I will show examples of applications, including tone-mapping, deblurring, and super-resolution.

Michael Elad (*The Technion - Israel Institute of Technology*)
- Peyman Milanfar (*Google Research*)
Yaniv Romano (*Technion - Israel Institute of Technology*)

Fast Algorithms for Regularization-by-Denoising
Regularization-by-denoising (RED) is an image recovery framework recently proposed by Romano, Elad, and Milanfar that allows arbitrary denoiser subroutines to be used with arbitrary convex optimization algorithms to solve a wide range of image recovery problems. We provide new interpretations and new algorithmic solutions to RED, and demonstrate our methods on cardiac imaging via parallel MRI.

Edward Reehorst (*The Ohio State University*)
Adam Rich (*The Ohio State University, United States*)
Ahmad Rizwan (*The Ohio State University*)
• Phil Schniter (*The Ohio State University*)

Image Restoration by Iterative Denoising and Backward Projections
Inverse problems appear in many image processing applications and are usually addressed by designing task-specific algorithms. The recently proposed Plug-and-Play (P&P) framework allows solving general inverse problems by leveraging the impressive capabilities of existing denoising techniques. However, P&P often requires a burdensome parameter tuning. We propose an alternative method for solving inverse problems using denoising algorithms that require less parameter tuning. We demonstrate its competitiveness with task-specific techniques and P&P for image inpainting and deblurring.

• Raja Giryes (*Tel Aviv University*)
Tom Tirer (*Tel Aviv University*)

Divide and Conquer: Class-adapted Denoisers for Imaging Inverse Problems
I will discuss our recent work on patch-based models that are adapted to specific image classes, or even specific scenes. These models take the form of minimum mean squared error (MMSE) patch-based denoisers, using Gaussian mixture priors. We illustrate their use beyond image denoising, in more general inverse problems, such as inpainting, deblurring, and hyperspectral super-resolution, using the recently introduced plug-and-play approach.

Jose Bioucas-Dias (*Universidade de Lisboa, Instituto Superior Técnico (IST), Instituto de Telecomunicações (IT)*)
• Mário Figueiredo (*Instituto de Telecomunicações and IST, University of Lisboa*)
Afonso M. Teodoro (*Technical University of Lisbon*)

MS52-2 - **Thursday, 07 at 14:00** Room A (Palazzina A - Building A, floor 0)

Learning to Mean-Shift in O(1) for Bayesian Image Restoration
Finding strong oracle priors is an important topic in image restoration. In this talk, I will show how denoising autoencoders (DAEs) learn to mean-shift in O(1), and how we leverage this to employ DAEs as generic priors for image restoration. I will also discuss the case of Gaussian DAEs in a Bayesian framework, where the degradation noise and/or blur kernel are unknown. Experimental results demonstrate state of the art performance of the proposed DAE priors.

• Siavash Arjomand Bigdeli (*EPFL*)
Paolo Favaro (*University of Bern*)
Meiguang Jin (*University of Bern*)
Matthias Zwicker (*University of Maryland*)

Connect Maximum A Posteriori (MAP) Inference with Convolutional Neural Network for Image Restoration
The MAP model is a famous framework in the field of image restoration, and recent years have also witnessed the unprecedented success of CNNs in image denoising and super-resolution. In this talk, we intend to introduce some works on CNNs by referring to MAP inference in low level vision tasks: (1) design of a CNN denoiser, (2) extension of CNN denoisers for image restoration, and (3) other insights on CNN-based models delivered by MAP inference.

Shuhang Gu (*The Hong Kong Polytechnic University*)
Kai Zhang (*The Hong Kong Polytechnic University*)
Lei Zhang (*Hong Kong Polytechnic University*)
• Wangmeng Zuo (*Harbin Institute of Technology*)

On the Confluence of Deep Learning and Inverse Problems
While numerous low-level computer vision problems such as denoising, deconvolution or optical flow estimation were traditionally tackled with optimization approaches such as proximal methods, recently deep learning approaches trained on numerous examples demonstrated impressive and sometimes superior performance on respective tasks. In my presentation, I will discuss recent efforts to bring together these seemingly different paradigms, showing how deep learning can profit from proximal methods and how proximal methods can profit from deep learning.

• Daniel Cremers (*Technische Universität München*)
Thomas Frerix (*Technical University of Munich*)
Caner Hazirbas (*Technical University of Munich*)
Tim Meinhardt (*Technical University of Munich*)
Michael Moeller (*University of Siegen*)
Thomas Möllenhoff (*Technical University of Munich*)

MS53 Dimensionality Reduction Algorithms for Large-Scale Images

Organizers:
Salvatore Cuomo (*Dept. Mathematics and Applications "Renato Caccioppoli", University of Naples*)
Costantinos Siettos (*National Technical University of Athens*)
Lucia Russo (*Consiglio Nazionale delle Ricerche, Istituto di Ricerche sulla Combustione*)

MS53-1 - **Thursday, 07 at 14:00** Room H (Palazzina B - Building B, floor 0)

MRI image enhancement by using a numerical procedure combining TV-ROF and histogram specification methods

The Rudin–Osher–Fatemi Total Variation (TV-ROF) method is a famous approach to solve the image denoising problem. In Magnetic Resonance Imaging (MRI) contexts the most adopted strategy consists in modifying the TV-ROF by adding penalty terms depending on “a priori” information available on the problem to be solved. Here we propose to combine TV-ROF and histogram specification methods to enhance the quality of the MRI reconstructed image by a double stage numerical procedure.

- Salvatore Cuomo (*Dept. Mathematics and Applications "Renato Caccioppoli", University of Naples*)

On the generation of reduced models by Proper Orthogonal Decomposition from experimental image data

This paper illustrates an image processing technique using the Proper Orthogonal Decomposition (POD) of infrared thermal data for the construction of reduced models starting from experimental data. We consider a thin steel plate with a point heat source in the middle activated at time=0. A TELOPS DSP-83 fast IR camera collects a sequence of infrared image data. The 2D samples constitute the data set used to generate a POD empirical basis. Galërkin projection of the heat conduction PDE onto the basis generates the finite dimensional approximate dynamical system. Results are compared with experimental data and analytical solution.

Gaetano Continillo (*University of Sannio, Benevento*)
- Lucia Russo (*Consiglio Nazionale delle Ricerche, Istituto di Ricerche sulla Combustione*)

Intrinsic Isometric Manifold Learning with Application to Unsupervised Localization from Image Data

Data living on manifolds commonly appear in many applications. We show that under certain conditions, it is possible to construct an intrinsic and isometric data representation which respects the latent intrinsic manifold geometry. Namely, instead of learning the structure of the observed manifold, we view the observed data only as a proxy and learn the structure of a latent unobserved intrinsic manifold. We show successful application to unsupervised indoor localization in ad-hoc sensor networks.

- Ariel Schwartz (*Technion - Israel Institute of Technology*)
Ronen Talmon (*Israel Institute of Technology*)

Construction of low dimensional Functional connectivity networks from fMRI data using manifold learning algorithms

Neuroimaging techniques, especially fMRI analysis provide images that are contained in a high dimensional space. In a typical fMRI scan more than 100,000 voxels are recorded at each time instance, thus one gets tens of millions of data if one also considers groups of subjects. Hence, one confronts with issues, that of (a) noise/ artifact removal and, (b) dimensionality reduction (Siettos and Starke, 2016). In this work, we employ a data-driven approach to dimensionality reduction with the aim to construct brain functional connectivity networks (FCN) as emerged through fMRI images. For the construction of the FCN we exploit state-of-the-art nonlinear manifold learning algorithms, namely Isometric Feature Mapping (ISOMAP) (Tenenbaum et al., 2000) and Diffusion Maps (Coifman et al., 2005) to embed the high dimensional space to lower order manifolds. We illustrate the efficiency of the methods through fMRI recordings acquired before and after the implementation of the Integrated Psychological Therapy (IPT) to a relatively small size of patients suffering from schizophrenia. IPT is a group medication program integrating neurocognitive and psychosocial rehabilitation. We show that while linear standard techniques fail to identify significant differences in the FCNs of the patients before and after the treatment the non-linear manifold embedded analysis reveals differences related both to the global properties of the FNC and regions of the brain, that are involved in higher order cognition functioning, goal-oriented tasks, social and moral reasoning. Siettos, C.I., Starke, J. (2016). Multiscale Modeling of Brain Dynamics: from Single Neurons and Networks to Mathematical Tools, WIREs Systems Biology and Medicine, 8(5), 438-458. Tenenbaum, J.B., De Silva, V., Langford, J.C. (2000). A global geometric framework for nonlinear dimensionality reduction, Science, 290 (5500), 2319-2323. Coifman,R.R., et al. (2005). Geometric diffusions as a tool for harmonic analysis and structure definition of data: Diffusion maps, Proceedings of the National Academy of Sciences of the United States of America, 102(21), 7426-7431.

- Costantinos Siettos (*National Technical University of Athens*)

MS53-2 - **Thursday, 07 at 16:30** Room H (Palazzina B - Building B, floor 0)

Contrast enhancement operators based on attractors identification in nonlinear dynamical systems

Dynamical systems like neural networks based on lateral inhibition have a large field of applications in image processing. We will propose some examples of dynamical flows used in image contrasting and contouring. First we recall the physiological basis of the retina function by showing the role of the lateral inhibition in the optical illusions thanks to a serious game for the early detection of the diabetic retinitis. Then, based on these biomedical considerations about the real vision mechanisms, we present an enhancement method for contrasting medical images, using either a discrete neural network approach, or its continuous version, i.e. a non-isotropic diffusion reaction partial differential system. Eventually, we introduce the notion of mixed potential Hamiltonian flow method, we compare it with the watershed method and we use it for contouring.

- Jacques Demongeot (*University of Grenoble Alpes (UGA)*)

Neural Manifolds: Sparse Dictionary Learning Approaches
Activity of large neural populations can be represented by few independent patterns called “synergies”. Synergies constrain neural dynamics in specific manifolds. Standard dimensionality-reduction techniques have been used to find sets of synergies. Neural spaces may contain distinct manifolds, each associated with specific tasks: is each manifold spanned by its own unique synergies, or do tasks in a class share some synergies that represent common features? We use sparse dictionary-learning approaches to tackle these open issues.

- Francesco Donnarumma (*Institute of Cognitive Sciences and Technologies, Rome*)
  Roberto Prevete (*DIETI University of Naples Federico II*)

Application of the Optical Flow Method for the analysis of flame propagation in a transparent internal combustion engine
High-definition, high sampling rate image sequences collected in experiments in an optically accessible engine are first processed to identify the flame front, and then analyzed by an optical flow estimation technique. The velocity magnitude on the flame front has an ECDF well fitted by a Rayleigh probability distribution with a single scalar parameter. The proposed non-intrusive method provides a fast statistical characterization of the flame propagation phenomenon in the engine combustion chamber.

Gaetano Continillo (*University of Sannio, Benevento*)
- Simone Lombardi (*Università degli Studi del Sannio*)
  Paolo Sementa (*Istituto Motori, Consiglio Nazionale delle Ricerche*)
  Bianca Maria Vaglievo (*Istituto Motori, Consiglio Nazionale delle Ricerche*)

Application of Decomposition Methods to the study of flames via image sequences
Sampled images in combustion experiments carry much information, both on flame morphology and, when collected in sequences, on flame statistics. Non-intrusive methods extract experimental basis function sets, and the statistical study of coefficients obtained by projection of the data set onto the basis allows various kinds of analysis. This work outlines possible applications, via proper data treatment and real-time processing, in order to identify critical conditions and to design control strategies to avoid them.

- Gaetano Continillo (*University of Sannio, Benevento*)

MS54 Hybrid Approaches that Combine Deterministic and Statistical Regularization for Applied Inverse Problems

Organizers:
Cristiana Sebu (*University of Malta*)
Taufiquar Khan (*Clemson University*)

MS54-1 - **Thursday, 07 at 14:00** Room L (Palazzina B - Building B, floor 0)

Damage Detection in Concrete Using Electrical Impedance Tomography: Deterministic and Statistical Perspectives
The complete electrode model for the inverse problem in electrical impedance tomography for damage detection in concrete is presented. The inverse problem in EIT and regularization required to solve this ill-posed inverse problem is described. Both the deterministic and the statistical regularization approaches are explored particularly Gauss-Newton method, sparsity constraints, and Bayesian inversion using Markov Chain Monte Carlo (MCMC) methods are compared using real data.

- Taufiquar Khan (*Clemson University*)
  Thilo Strauss (*University of Washington*)

Ultrahighfield Magnetic Resonance Imaging of the Heart
Abstract: Cardiovascular disease is a major killer in western societies. Magnetic resonance imaging (MRI) is increasingly used for diagnostic assessment of the heart and vessels. Recently introduced ultrahigh field strength MRI systems will enable the development of new contrast mechanisms and improve the spatiotemporal resolution as well as the quantitative assessment of the cardiovascular system. An overview of the technology will be given including an outlook on potential perspectives for collaboration with the mathematical community.

- Laura Schreiber (*Comprehensive Heart Failure Centre, University of Wurzburg*)

Bayesian approach to optical flow in synthetic schlieren tomography

Synthetic schlieren tomography is an optical technique to measure ultrasound pressure fields. Prior to reconstruction of the pressure, images of a photographed target with and without perturbations caused by the ultrasound are analyzed with optical flow methods. In this talk, Bayesian formulation of a Horn-Schunck type optical flow approach is utilized. Displacement field is estimated and compared to traditional approaches. Impact of the approach on estimation of entire pressure field is assessed.

- Aki Pulkkinen (*University of Eastern Finland*)

Electrical impedance tomography-based abdominal obesity estimation using deep learning

We propose a deep learning method for abdominal electrical impedance tomography (EIT) to estimate abdominal obesity. EIT for evaluating abdominal obesity is a challenging problem that is an ill-posed absolute imaging problem. The proposed method allows to find an useful solution within a restricted admissible set, accounting for prior information on abdominal anatomy. It found that a specially designed training data used in the deep learning process reduces the ill-posedness in the absolute EIT problem.

Kyounghun Lee (*Yonsei University*)
Jin Keun Seo (*Yonsei University*)
- Minha Yoo (*National Institute for Mathematical Sciences*)

MS54-2 - **Thursday, 07 at 16:30** Room L (Palazzina B - Building B, floor 0)

Imaging the solar interior

We discuss the reconstruction of flows in the interior of the sun from correlation measurements of line-of-sight velocities on the solar surface. Since these measurements are extremely noisy, it is mandatory to determine and use the covariance structure of the noise. The expected value of the data corresponds to the imaginary part of Green's function for an acoustic time-harmonic wave equation. We discuss computational and theoretical results for this large scale inverse problem.

Damien Fournier (*University of Goettingen*)
Laurent Gizon (*Max-Planck-Institut für Sonnensystemforschung*)
- Thorsten Hohage (*University of Goettingen*)

Maximum-a-posteriori estimation with unknown regularisation parameters: combining deterministicand Bayesian approaches

This talk presents a highly efficient Bayesian computation methodology to solve imaging inverse problems with unknown regularisation parameters. A main novelty of this methodology is that it uses stochastic optimisation algorithms that are driven by proximal Markov chain Monte Carlo samplers, tightly integrating modern high-dimensional Monte Carlo sampling and convex optimisation approaches. The proposed methodology is demonstrated on several challenging imaging problems and compared to other techniques to set regularisation parameters.

- Ana Fernandez Vidal (*Heriot-Watt University*)

Marcelo Pereyra (*Harriott-Watt University*)

Photoacoustic imaging using sparsity in curvelet frame

In photoacoustic tomography, the acoustic propagation time across the specimen is the ultimate limit on sequential sampling frequency. Any further speed-up can only be obtained by parallel acquisition and subsampling/compressed sensing. In this talk, we consider the photoacoustic reconstruction problem from compressed/subsampled measurements utilizing the sparsity of photoacoustic data or photoacoustic image in the Curvelet frame. We discuss the relative merits of the two approaches and demonstrate the results on 3D simulated and real data.

Simon Arridge (*University College London*)
Marta Betcke (*University College London*)
Ben Cox (*Department of Medical Physics, University College London*)
Nam Huynh (-)
Felix Lucka (*CWI & UCL*)
- Bolin Pan (*University College London*)

Reconstructing a convex inclusion with one measurement of electrode data in the inverse conductivity problem

In 2000, Ikehata introduced the enclosure method for Electrical Impedance Tomography which aims at finding information of anomalies inside an unknown body. In idealised setting, it was shown that a convex hull that contains all the anomalies can be recovered from the Dirichlet-to-Neumann map. In this talk, I will present a modified version of the enclosure method to reconstruct the convex hull from one measurement of the electrode data in more practical setting.

Bastian Harrach (*Goethe-Universität Frankfurt am Main*)
Masaru Ikehata (*Hiroshima University*)
Vesa Kaarnioja (*University of Helsinki*)
- Minh Mach (*University of Helsinki*)

MS54-3 - **Friday, 08 at 14:00** Room L (Palazzina B - Building B, floor 0)

Recovery from model errors in magnetic particle imaging - approximation error modeling approach

Magnetic particle imaging is a novel imaging technique based on a linear reconstruction problem consisting of the computation of the magnetic particle distribution given the measured induced voltage. We formulate the reconstruction problem in a Bayesian framework and apply approximation error modeling in order to incorporate the uncertainties of the model in the reconstruction scheme. Numerical results will be presented to show the image quality improvement.

- Christina Brandt (*University of Hamburg*)

Deterministic methods for conductivity imaging for breast and skin cancer detection

We present non-iterative reconstruction algorithms developed for conductivity imaging with real data collected on a planar array of electrodes. Such an electrode configuration as well as the proposed imaging techniques are intended to be used for breast cancer detection. The performance of the algorithms was tested on both numerically simulated and real data, and small inclusions with conductivities three or four times the background were successfully detected.

- Cristiana Sebu (*University of Malta*)

Total variation regularized Acousto-Electric Tomography with Neumann conditions

We consider the Acousto-Electric Tomography problem with interior power density data together with Neumann boundary conditions for BV-constrained conductivities. We tackle this problem by reformulation as a PDE-constrained TV-regularized optimization problem and attack this by linearization and Langragian formulation. The resulting TV-term is approximated by a lagged diffusivity step. Compuations are done using the FEniCS package for Python by iteratively updating the linearization. In conclusion this algorithm provides a reconstruction scheme, when not violating approximations.

- Bjørn Christian Skov Jensen (*Technical University of Denmark*)

Combining iterative and statistical inversion algorithms in imaging

Iterative solvers for linear systems with an early stopping rule provide a fast and efficient way of solving ill-posed inverse problems. The regularization by stopping the iterations, however, does not translate directly into the language of Bayesian priors. In this talk, the stopping rules are revisited in the Bayesian context and the question how to modify them to correspond to prior information is addressed.

- Erkki Somersalo (*Case Western Reserve University*)

MS54-4 - Friday, 08 at 16:30 Room L (Palazzina B - Building B, floor 0)

Simulation of changes on optical coherence tomography data in healthy and in disease conditions

We present a methodology to assess cell level alterations on the human retina responsible for functional changes observable in the Optical Coherence Tomography data in healthy ageing and in disease conditions. The methodology is based in a multilayer Monte Carlo computational model of the human retina. The optical properties of each layer are obtained by solving the Maxwell's equations on representative domains of small regions of those layers, using a Discontinuous Galerkin Finite Element Method.

- Aderito Araujo (*University of Coimbra*)

Gap Safe Screening Rules for Sparsity Enforcing Penalties

In high dimensional regression settings, sparsity enforcing penalties have proved useful to regularize the data-fitting term. A recently introduced technique called screening rules propose to ignore some variables in the optimization leveraging the expected sparsity of the solutions and consequently leading to faster solvers. In this work, we propose a unifying framework for generalized linear models regularized with standard sparsity enforcing penalties such as l1 or l1/l2 norms.

- Ndiaye Eugene (*Telecom ParisTech*)
  Olivier Fercoq (*Telecom ParisTech*)
  Alexandre Gramfort (*University Paris Saclay*)
  Joseph Salmon (*Telecom ParisTech*)

On the electro-sensing of weakly electric fish

In this talk, our objective is to understand the electro-perception mechanism of weakly electric species of fish, which have the ability to recognise the environment around them in complete darkness by generating a weak electrical field at different frequencies, and perceiving the transdermal potential perturbation. The electro-sensing inverse problem consists in recovering the shape and location of a target with known conductivity profile from measurements of the electric potential on the skin.

- Faouzi Triki (*University of Grenoble Alpes*)

Regularization for Bayesian inverse problems using domain truncation and uncertainty quantification

This talk proposes new methods for reducing high-dimensional parameter and state spaces in large-scale Bayesian inverse problems. We focus on problems with spatially-concentrated observations or dynamics which have high uncertainty in areas far from the domain of interest. We first solve the deterministic inverse problem to estimate the uncertainty, and then solve the statistical Bayesian inverse problem only over the domain with low uncertainty. Numerical tests with a PDE-constrained inverse problem show improved recovery over the full domain.

- Tan Bui-Thanh (*The University of Texas at Austin*)
  Ellen Le (*The University of Texas at Austin*)
  Vishwas Rao (*The University of Texas at Austin*)

MS55 Advances of regularization techniques in iterative reconstruction

Organizers:
Zichao (Wendy) Di (*Argonne National Lab*)
Marc Aurèle Gilles (*Cornell University*)

MS55-1 - Thursday, 07 at 14:00 Room P (Palazzina B - Building B, floor 0)

3D x-ray imaging beyond the depth of focus limit
Ptychography is a coherent diffractive imaging method whereby a beam is scanned across an object and diffraction patterns are recorded. It allows for imaging of nanometer scale objects. Algorithms which perform ptychographic reconstruction typically assume that the object being imaged is within the depth of focus which limits the resolution for very fine scales. We present a first-order algorithm for reconstructing three-dimensional images of objects which don't fit in the depth of focus.

- Marc Aurèle Gilles (*Cornell University*)

Reducing the effects of bad data measurements using variance based weighted joint sparsity
We introduce the variance based joint sparsity (VBJS) method for sparse signal recovery and image reconstruction from multiple measurement vectors. Joint sparsity techniques employing $\ell\_2, 1$ minimization are typically used, but the algorithm is computationally intensive and requires fine tuning of parameters. The VBJS method uses a weighted ℓ_1 joint sparsity algorithm, where the weights depend on the pixel-wise variance. The VBJS method is accurate, robust, cost efficient and also reduces the effects of false data.

Anne Gelb (*Dartmouth College*)
- Theresa Scarnati (*Air Force Research Laboratory*)

Plug-and-Play Unplugged: Optimization Free Regularization using Consensus Equilibrium
Recently, the Plug-&-Play method was introduced as a way to use advanced non-parametric denoising algorithms such as BM3D and CNNs as prior models in inverse problems. In this paper, we introduce a generalization of P&P which we call Multi-Agent Consensus Equilibrium (MACE). MACE addresses two limitations of P&P. First, it allows for the introduction of multiple prior or data terms or agents. These agents may, for example, represent multiple uncertain priors, or multiple uncertain data models. Second, MACE defines regularized version in terms of balance equations rather than optimization. This allows for a much more general framework of well-defined inverse operators with potentially superior performance.

- Charles Bouman (*Purdue University*)

Learning better models for inverse problems in imaging
In this talk, I will present our recent activities in learning better models for inverse problems in imaging. We consider classical variational models used for inverse problems but generalized these models by introducing a large number of free model parameters. We learn the free model parameters by minimizing a loss function comparing the reconstructed images obtained from the variational models with ground truth solutions from a training data base. I will also show very recent results on learning "deeper" regularizers that are already able to capture semantic information of images. We show applications to different inverse problems in imaging where we put a particular focus on image reconstruction from undersampled MRI data.

Kerstin Hammernik (*Graz University of Technology*)
Teresa Klatzer (*Graz University of Technology*)
Florian Knoll (*New York University*)
Erich Kobler (*Graz University of Technology*)
- Thomas Pock (*Graz University of Technology*)

MS55-2 - Thursday, 07 at 16:30 Room P (Palazzina B - Building B, floor 0)

Optimization Problems with Sparsity-Inducing Terms
We consider several optimization problems that contain the l_0-norm expression. These problems are considered to be extremely difficult to solve and analyze due to the nonconvexity and discontinuity of the l_0 expression. We establish under some symmetry assumptions a hierarchy between stationarity-based optimality conditions and conditions based on coordinate-wise optimality. These results also imply a hierarchy between several corresponding algorithms. A key mathematical tool used in the analysis is the proximal mapping of symmetric functions including l_0-norm expressions.

Amir Beck (*Tel-Aviv University*)
- Nadav Hallak (*Technion - Israel Institute of Technology*)

High-resolution x-ray imaging from sparse, incomplete and uncertain data
As the sophistication and speed of today's experiments grow, collecting the most informative data has become greatly relevant, necessitating the development of algorithms that can provide good quality reconstructions from measurements due to reduced photon efficiency, higher radiation doses, and inaccuracies of the stages, which leads to noisy and sparse datasets. In this talk, I will target scanning-based x-ray imaging and microscopy applications, and describe how computational approaches can be adopted to enable faster and reliable information extraction from measurements.

- Doga Gursoy (*Argonne National Laboratory*)

Spectral approximation of fractional PDEs in image processing and phase field modeling
Fractional differential operators provide an attractive mathematical tool to model effects with limited regularity properties. Particular examples are image processing and phase field models in which jumps across lower dimensional subsets and sharp transitions across interfaces are of interest. The numerical solution of corresponding model problems via a spectral method is analyzed. Its efficiency and features of the model problems are illustrated by numerical experiments.

- Harbir Antil (*George Mason University*)

Blind Image Fusion for Hyperspectral Imaging with Directional Total Variation
We present the problem of simultaneously increasing the spatial resolution and deconvolving channels of hyperspectral images where the blurring kernels are unknown. A high resolution image is incorporated into a directional total variation prior for the corresponding variational model. The non-smoothness and non-convexity of the objective function is treated using the PALM-algorithm. Numerical results on remote sensing data show the potential of the proposed method and suggest that it is robust with respect to mis-registration.

- Leon Bungert (*University of Münster*)
  David Coomes (*Forest Ecology and Conservation Group, Department of Plant Sciences, University of Cambridge*)
  Matthias J. Ehrhardt (*University of Cambridge*)
  Marc Aurèle Gilles (*Cornell University*)
  Jennifer Rasch (*Fraunhofer Heinrich Hertz Institute*)
  Rafael Reisenhofer (*University of Bremen*)
  Carola-Bibiane Schönlieb (*University of Cambridge*)

MS56 Mathematical and Computational Aspects in Magnetic Particle Imaging

Organizers:
Tobias Kluth (*University of Bremen*)
Christina Brandt (*University of Hamburg*)

MS56-1 - **Wednesday, 06 at 13:00** Matemates (Matemates, floor 0)

Mathematical models in magnetic particle imaging (MPI)
In magnetic particle imaging potential measurements are obtained by exploiting the particle's nonlinear response to an applied dynamic magnetic field to recover the particle concentration. It is frequently modeled by a linear Fredholm integral equation of the first kind. In this talk we analyze the inverse problem obtained from the equilibrium model which is based on the Langevin function. We further discuss how particle relaxation influences image reconstruction in MPI.

- Tobias Kluth (*University of Bremen*)

Modeling the system function in MPI
The forward operator in magnetic particle imaging is given by an integral equation of the first kind. The integration kernel is called the system function and describes the potential of magnetic particles to induce a signal in the receive coils by a change in its magnetization. The system function is not known explicitly and demands for a data-driven computation that must also include relaxation effects. The talk subsumes actual modeling aspects.

- Anne Wald (*Saarland University*)

Time-Frequency-Preprocessing of MPI Raw Signals
Subtracting empty scanner measurements reduces the influence of stationary background artifacts, but also requires additional computation and acquisition time while recording system matrices. Experimental evidence indicates that background subtractions can be replaced by a suitable high-pass-filtering of complex 2D-DCT coefficients of the system matrix. In combination with soft-thresholding our approach also reveals frequency components which partially remain buried in stationary noise even after background correction. This might lead to further improvements of image reconstructions.

- Florian Lieb (*University of Applied Sciences, Aschaffenburg*)
  Hans-Georg Stark (*Hochschule Aschaffenburg*)

Model-based reconstruction for multivariate MPI
In the context of MPI approaches measuring the system's response to shifted delta peaks together with algebraic reconstruction methods are widely used; due to reasons of time consumption, also in practice, model-based approaches are desirable. The talk considers model based reconstruction for MPI with a particular emphasis on the multivariate situation. We investigate the MPI core operator and its ill-posedness properties. We obtain reconstruction formulae in 2D and 3D.

- Andreas Weinmann (*Hochschule Darmstadt*)

MS56-2 - **Wednesday, 06 at 15:30** Matemates (Matemates, floor 0)

Fast Image Reconstruction by Exploiting Redundancies and Sparsities in the Magnetic Particle Imaging Operator

The relation between the measured signal and the particle distribution in MPI can be described by a linear system of equations. Since it is challenging to precisely model the particle physics, the system matrix is usually explicitly arranged. In this work we will present an alternative approach that approximates the individual matrix rows by tensor products of Chebyshev polynomials. This allows to fully diagonalize the MPI system matrix and in turn enables fast reconstruction.

- Knopp Tobias (*University Medical Center Hamburg-Eppendorf/Hamburg University of Technology*)

Fast temporal regularized reconstructions for magnetic particle imaging

Magnetic Particle Imaging (MPI) is capable of capturing fast dynamic processes in 3D volumes, based on the non-linear response of the magnetic nanoparticles to an applied magnetic field. The image reconstruction is computationally demanding due to a non-sparse system matrix. In this study we propose a quadratic spatio-temporal regularization that can be efficiently solved. Results are presented for simulated and experimental measurement data.

Christina Brandt (*University of Hamburg*)
- Andreas Hauptmann (*University College London*)

Chebyshev spectral methods for the reconstruction in Magnetic Particle Imaging

In this talk, we will discuss the usage of spectral methods for an efficient reconstruction In Magnetic Particle Imaging. In particular, we will analyze how the usage of different Chebyshev transforms leads to a sparse representation of the underlying system matrix and how sampling on particular node points of the Lissajous acquisition paths can be combined with the Chebyshev transform in order to get a fast reconstruction of the particle density.

- Wolfgang Erb (*University of Hawaii at Manoa*)

Edge preserving and noise reducing reconstruction for magnetic particle imaging

We develop an efficient edge preserving and noise reducing reconstruction method for MPI using a nonnegative fused lasso model. We devise a discretization adapted to the acquisition geometry of a preclinical MPI scanner and an efficient solver for that setup. Our prototype implementation processes a 3D volume within a few seconds. We demonstrate the improvement in reconstruction quality over the state-of-the-art method in an experimental medical setup for in-vitro angioplasty.

- Martin Storath (*Universität Heidelberg*)

MS57 Recent Trends in Photometric 3D-reconstruction

Organizers:
Jean-Denis Durou (*IRIT, Université de Toulouse*)
Maurizio Falcone (*Dipartimento di Matematica, Università di Roma "La Sapienza"*)

MS57-1 - Thursday, 07 at 14:00 Room E (Palazzina A - Building A, floor 2)

On Overparametrized Variational Methods for Photometric Problems

In this talk several methods for Photometric Depth Reconstruction will be surveyed, with particular emphasis on variational methods that were proposed in conjunction with over-parametrized models for the 3D surfaces. The over-parametrized modeling has provided several successful methods in other computer vision and image processing problems, such as motion analysis and image denoising, hence we shall argue that it should be applied to a wider range of 3D from images problems.

- Alfred Bruckstein (*Technion, Israel Institute of Technology*)

Combining Photometric Techniques with RGB-D Sensing

Low cost RGB-D sensors allow easy access to depth data. This data is often prone to noise, missing fine details and does not have the same resolution as the RGB data. Photometric techniques however can recover fine geometric details based on an RGB image, but introduce some man-made regularity assumptions to the scenario of interest. Combining photometric techniques with RGB-D data shows that some depth prior information leads to a much more natural sensor-made regularization.

- Björn Häfner (*Technical University Munich*)

Critical contours anchor shape inferences

Different subjects perceive shape from shading information similiarly in qualitative form but differently in quantitative detail. We capture this in a model for shape-from-shading inferences that is based on computing the Morse-Smale complex from image gradients. Critical contours, which approximate an artist's drawing, capture robust 1-cells from the image. Our main theorem is that they correspond with critical contours on the surface (slant) for diverse rendering functions.

Benjamin Kunsberg (*Brown University*)
- Steven Zucker (*Yale University*)

A Variational Approach to Shape-from-shading Under Natural Illumination

We propose a novel variational approach to shape-from-shading. It is based on a modification version of the Horn and Brooks approach into an integrated, constrained variational model which simultaneously estimates both the depth map and its gradient. Numerical solution can be estimated by resorting to an ADMM algorithm. We show that this approach is straightforward to extend in order to handle non-directional, natural illumination, RGB images, or various regularizers.

- Yvain Quéau (*L@bISEN Yncrea Ouest-Vision Lab / TU Munich*)

MS57-2 - **Thursday, 07 at 16:30** Room E (Palazzina A - Building A, floor 2)

Models and numerics for extending classic photometric stereo
In this talk recent work in addressing non-Lambertian effects in photometric stereo is presented. This comes along with investigations of how to resolve effectively some of the numerical problems encountered in that process. Thereby also integration of surface normals is considered. The proceeding is mainly based on partial differential equations arising in orthographic as well as perspective models.

- Michael Breuss (*Brandenburg University of Technology*)

Variational Reflectance Estimation from Multi-view Images
In this talk, we will discuss reflectance estimation from a set of multi-view images, assuming known geometry, for relighting purposes. The approach we put forward turns the input images into reflectance maps, through a robust variational method. It can be applied in several lighting configurations: known or unknown, and fixed or image-depending. Experiments on both synthetic and real datasets are carried out to validate the proposed strategy.

- Jean Mélou (*IRIT, Université de Toulouse*)

A unified differential approach to photo-polarimetric shape estimation
We explore the combination of Shape-from-Polarization constraints with photometric constraints (i.e. photo-polarimetric shape estimation) provided by one or two light sources. We propose several alternative differential constraints and show how to express them in a unified partial differential system which solves directly for surface height. Combinations of these constraints provide different practical advantages, as for example an albedo invariant height estimation. Numerical results on synthetic and real-world data confirm the effectiveness of our proposed method.

- Silvia Tozza (*INdAM/Dept. Mathematics, University of Rome "La Sapienza"*)

High-Quality 3D Reconstruction by Joint Appearance and Geometry Optimization with Spatially-Varying Lighting
We present a novel method to obtain high-quality 3D reconstructions from consumer RGB-D sensors. Our core idea is to simultaneously optimize for geometry encoded in a signed distance field, textures from automatically-selected keyframes, and their camera poses along with material and scene lighting. To this end, we propose a joint surface reconstruction approach that utilizes Shape-from-Shading techniques and spatially-varying spherical harmonics. We demonstrate that our method dramatically improves both reconstructed scene geometry and surface texture.

- Robert Maier (*TU Munich*)

MS58 Instruments and techniques for biomedical research

Organizers:
Alberto Leardini (*Laboratory of Movement Analysis and Functional-Clinical Evaluation of Prosthesis, Istituto Ortopedico Rizzoli, Bologna*)

MS58-1 - **Thursday, 07 at 14:00** Room F (Palazzina A - Building A, floor 2)

Quantitative Cone-Beam CT: New Technologies, Algorithms, and Applications in Orthopedic Imaging
Recent advances in cone-beam CT, including scanners for weight-bearing imaging of the extremities and high-resolution CMOS detectors, are enabling new quantitative applications in orthopedics: micro-morphometry of trabecular bone, measurements of bone mineral content, and assessment of joint morphology and biomechanics under load. The underlying algorithmic developments involve model-based reconstruction using models of system blur and polyenergetic x-ray propagation, and methods for enhanced visualization and statistical analysis of micro and macroscopic features of skeletal anatomy.

Michael Brehler (*Department of Biomedical Engineering, Johns Hopkins University*)
Qian Cao (*Department of Biomedical Engineering, Johns Hopkins University*)
Jeffrey Siewerdsen (*Johns Hopkins University*)
Alejandro Sisniega (*Department of Biomedical Engineering, Johns Hopkins University*)
J. Webster Stayman (*Department of Biomedical Engineering, Johns Hopkins University*)
Steven Tilley II (*Department of Biomedical Engineering, Johns Hopkins University*)
- Wojciech Zbijewski (*Johns Hopkins University, Baltimore*)

Advances in Cone-Beam CT Image Quality and Dose Reduction Using Optimization-Based Image Reconstruction
Cone-beam CT is now prevalent in applications requiring high-resolution visualization of high-contrast bone, including dental-maxillofacial imaging and image-guided orthopaedic surgery. Emerging 3D image reconstruction methods propel capability further with respect to soft-tissue structures, addressing conventionally confounding factors of x-ray scatter, patient motion, and image noise. Optimization-based image reconstruction overcomes conventional noise-resolution tradeoffs and demonstrates image quality consistent with soft-tissue visualization in musculoskeletal imaging, imaging of acute intracranial hemorrhage, and image-guided interventions targeting soft-tissue lesions.

Grace J. Gang (*Department of Biomedical Engineering, Johns Hopkins University*)
Matthew Jacobson (*Department of Biomedical Engineering, Johns Hopkins University*)
• Jeffrey Siewerdsen (*Johns Hopkins University*)
Alejandro Sisniega (*Department of Biomedical Engineering, Johns Hopkins University*)
J. Webster Stayman (*Department of Biomedical Engineering, Johns Hopkins University*)
Ali Uneri (*Department of Biomedical Engineering, Johns Hopkins University*)
Wojciech Zbijewski (*Johns Hopkins University, Baltimore*)

3D-Printed Anti-Scatter Collimators for Artifact Reduction in Cone-Beam CT

The volumetric acquisition geometry for cone-beam CT (CBCT) results in increased scatter fraction, leading to image artifacts and errors in quantitative imaging. We describe the design of focused anti-scatter grids (ASGs) for CBCT, fabricated using 3D printing in dense metal. Septal wall thickness of less than 0.1mm can be achieved, resulting in transmission efficiency of over 80%. This approach may lead to nearly complete scatter rejection for CBCT, improving the performance of quantitative imaging systems.

Santiago Cobos Cobos (*Robarts Research Institute, Western University*)
• David Holdsworth (*Robarts Research Institute, Western University*)
Hristo Nikolov (*Robarts Research Institute, Western University*)
Steven Pollmann (*Robarts Research Institute, Western University*)

A Deep Imaging Architecture for Sparse-View Cone-Beam CT

Cone-beam computed tomography (CBCT) for 3D orthopedic imaging produces excellent image quality of soft tissue and bone structures. Of particular interest is the ability for CBCT to acquire weight-bearing 3D images of the lower extremities, enabling examination under natural loading conditions. For patients experiencing pain, acquisition time should be minimized to reduce potential for motion. Toward this aim, we propose sparse-view acquisition sampling coupled with deep learning methods designed to reduce associated artifacts.

David Foos (*Carestream health, Inc*)
• Zhimin Huo (*Carestream Health, Inc*)
Weijian Li (*University of Rochester*)
Haofu Liao (*University of Rochester*)
Yuan Lin (*Carestream Health, Inc*)
Jiebo Luo (*Department of Computer Science, University of Rochester*)
William Sehnert (*Carestream Health Inc., Rochester*)

MS58-2 - **Thursday, 07 at 16:30** Room F (Palazzina A - Building A, floor 2)

Multi-instrument Medical Imaging Analysis for Personalized Joint Replacement Design

In joint replacement, failures and patient dissatisfaction continue to be reported due to non-fully anatomy-based prostheses. This can now be improved by proper prosthesis design personalization, thanks to the recent progresses in advanced additive manufacturing, subject-specific joint modelling, and, especially, in medical imaging analysis. As for the latter, a number of tools exist, both for standard and innovative computer-tomography or magnetic-resonance, whose implications within personalized joint replacement are discussed here.

• Claudio Belvedere (*Istituto Ortopedico Rizzoli, Bologna*)
Paolo Caravaggi (*Istituto Ortopedico Rizzoli, Bologna*)
Stefano Durante (*Istituto Ortopedico Rizzoli, Bologna*)
Alberto Leardini (*Laboratory of Movement Analysis and Functional-Clinical Evaluation of Prosthesis, Istituto Ortopedico Rizzoli, Bologna*)
Sorin Siegler (*Drexel University, Philadelphia*)

Roentgen-Stereophotogrammetric-Analysis (RSA) for the assessment of Joint Replacements

RSA methodology allows robustly designed studies for quantitative assessment of new implant designs, materials and techniques that are predictive of long-term performance with two years of follow-up whilst limiting the number of patients exposed to unproven treatments.

• Richie Gill (*Department of Mechanical Engineering, University of Bath*)

ALBA: a Rapid Prototyping Framework for Computer Aided Medicine

The Agile Library for Biomedical Application is an open-source rapid development framework (in C++) for the Computer Aided Medicine. ALBA reduces the effort to obtain a fully working and usable application: lots of features are included and in most cases the programmer can simply select the right components from the ALMA toolbox. It contains also installer scripts; build server configuration and the necessary components for applications-building. Three exemplar applications based on ALBA will be shown.

Gianluigi Crimi (*Istituto Ortopedico Rizzoli, Bologna*)
Enrico Schileo (*Istituto Ortopedico Rizzoli, Bologna*)
• Fulvia Taddei (*Istituto Ortopedico Rizzoli, Bologna*)
Giordano Valente (*Istituto Ortopedico Rizzoli, Bologna*)
Nicola Vanella (*Istituto Ortopedico Rizzoli, Bologna*)

Virtual Modeling e 3D Printing to support clinical research
Three-dimensional anatomic models are being used with increasing frequency and utility in medicine for pre-operative planning, education and improved patient understanding of surgical procedures. The aim of this presentation is to share the recent experience in virtual modeling and 3D printing carried out at Laboratory of Bioengineering in collaboration with specialized surgeries at S.Orsola-Malpighi Hospital: we give an overview of our laboratory's 3D modeling workflow, focusing on current clinical applications and providing illustrative case descriptions.

- Laura Cercenelli (*Laboratory of Bioengineering, Department of Experimental Diagnostic and Specialty Medicine (DIMES), University of Bologna, Policlinico S. Orsola Malpighi*)
  Emanuela Marcelli (*Laboratory of Bioengineering, Department of Experimental Diagnostic and Specialty Medicine (DIMES), University of Bologna, Policlinico S. Orsola Malpighi*)

MS59 Approaches for fast optimisation in imaging and inverse problems

Organizers:
Jingwei Liang (*University of Cambridge*)
Carola-Bibiane Schönlieb (*University of Cambridge*)
Mila Nikolova (*CMLA - CNRS ENS Cachan, University Paris-Saclay*)

MS59-1 - Thursday, 07 at 14:00 Room B (Palazzina A - Building A, floor 1)

Convergence of Inertial Dynamics and Proximal-based Algorithms Governed by Maximal Monotone Operators
Let H be a real Hilbert space. Given a maximal monotone operator $A : H- > 2^H$, we study the asymptotic behavior, of the trajectories of the second-order differential equation $x''(t) + tx'(t) + A'(x'(t)) = 0$, $t > t0 > 0$, where A' is the Yosida regularization of A, along with a new Regularized Inertial Proximal Algorithm. A proper tuning of the parameters allows to prove weak convergence of the trajectories to solutions of the inclusion $0 \in A(x)$.

- Hedy Attouch (*Université de Montpellier*)

Proximal Interior Point Algorithm For Large Scale Image Processing Problems
The solution of many problems in imaging sciences involves the minimization of a cost function in a feasible convex domain. The latter constraints can be efficiently tackled by adding a logarithmic barrier to the cost function multiplied by a weight tending progressively to zero. We propose a novel interior point method for minimizing a non-smooth convex function under general convex constraints. Its practical efficiency is illustrated through numerical experiments on large scale image recovery applications.

Emilie Chouzenoux (*Université Paris-Est Marne-la-Vallée*)
- Marie-Caroline Corbineau (*CentraleSupélec, Université Paris Saclay, Gif-sur-Yvette*)
  Jean-Christophe Pesquet (*Université Paris-Saclay*)

Preconditioned Proximal-Point Methods for Imaging Applications
Employing the ideas of nonlinear preconditioning and testing of the proximal point method, we formalise common arguments in convergence rate and convergence proofs of optimisation methods to the verification of a simple iteration-wise inequality. When applied to fixed-point operators, the latter can be seen as a generalisation of firm non-expansivity or the α-averaged property. In this talk we demonstrate the effectiveness of the general approach on several classical algorithms, as well as their stochastic variants.

- Tuomo Valkonen (*University of Liverpool*)

Adaptive Fista
An optimized extrapolated proximal gradient method is studied and relations to proximal quasi-Newton methods are revealed. The generic form of the proposed update scheme is related to the accelerated proximal gradient method (also known as FISTA), however we adapt the extrapolation parameter locally. Convergence is proved in a general non-convex setting. Using the equivalence to proximal quasi-Newton methods, new convergence guarantees for these methods are obtained.

- Peter Ochs (*Saarland University*)
  Thomas Pock (*Graz University of Technology*)

MS59-2 - Thursday, 07 at 16:30 Room B (Palazzina A - Building A, floor 1)

Inertial Proximal ADMM for Linearly Constrained Separable Convex Optimization
We propose a new class of inertial proximal alternating direction method of multipliers (ADMMs), which unifies inertial proximal point method and proximal ADMM. The proposed algorithmic framework is very general in the sense that the weighting matrices in the proximal terms can be only positive semidefinite. We established convergence as well as asymptotic o(1/k) and nonasymptotic O(1/k) rates of convergence for the best primal function value and feasibility residues.

- Raymond H. Chan (*Department of Mathematics, The Chinese University of Hong Kong*)

Accelerated Alternating Descent Methods for Dykstra-like Problems
We present an alternating descent scheme for problems involving nonsmooth objectives with a quadratic term. Our algorithm performs in each variable several descent steps, which improves the performances over a single step. Thanks to a FISTAlike trick, this scheme can also be accelerated. Linear convergence rates are established under strongly convexity. An application of this work is the implementation of a fast parallel solver for the proximity operator of the Total Variation for color images.

- Pauline Tan (*CMLA, École normale supérieure Paris-Saclay*)

Preconditioning and Acceleration Techniques for the Douglas-Rachford Iteration
We present preconditioned and accelerated versions of the Douglas-Rachford (DR) splitting method. The methods enable to replace the solution of a linear system in each step in the DR iteration by approximate solvers without the need of controlling the error. These iterations are shown to converge in Hilbert space under minimal assumptions. Further, strong convexity of one or both of the functionals allow for accelerations that yield improved rates of $O(1/k^2)$ and $O(w^k)$, $0 < w < 1$, respectively.

- Kristian Bredies (*Universität Graz*)
  Hongpeng Sun (*Renmin University of China*)

Lower Complexity Bound for Linearized Augmented Lagrangian Method
First-order methods have been extremely popular in recent years. However, naive gradient methods generally converge slowly. Hence, much efforts have been made to accelerate various first-order methods. In this talk, I will first present an accelerated linearized augmented Lagrangian method (LALM), where linearization is applied to the smooth part. For linearly constrained convex problems, LALM achieves $O(1/k^2)$ rate. Then I will show that if linearization is also applied to the augmented term, $O(1/k)$ is optimal.

- Yangyang Xu (*Rensselaer Polytechnic Institute*)

MS59-3 - **Friday, 08 at 16:30** Room A (Palazzina A - Building A, floor 0)

FSI Schemes: Fast Semi-Iterative Solvers for PDEs and Optimisation Methods
We introduce a simple and highly efficient acceleration strategy, for accelerating methods like projected gradient descent method, which leads to so-called Fast Semi-Iterative schemes that extrapolate the basic solver iteration with the previous iterate. To derive suitable extrapolation parameters, we establish a recursion relation that connects box filtering with an explicit scheme for 1D homogeneous diffusion. Our experiments show their benefits for anisotropic diffusion inpainting, nonsmooth regularisation, and Nesterov's worst case problems.

- Joachim Weickert (*Saarland University*)

Imaging by Krylov Methods
Krylov methods are well-known and efficient iterative solvers for linear systems of equations, and they are often employed as iterative regularization methods for linear inverse problems. Krylov methods are well-suited for imaging problems. In this talk we will explore classical Krylov methods when applied to solve Tikhonov-like regularized problems, and introduce new flexible Krylov methods that allow to efficiently incorporate nonnegativity constraints and 1-norm penalization terms within the solution process.

- Silvia Gazzola (*University of Bath*)

Inexact Half-Quadratic Optimization for Inverse Problems in Imaging
Half-quadratic optimization amounts to solving a sequence of positive definite systems (the inner systems) and has the advantages of simplicity and versatility. We focus on the inexact process in which the inner systems are solved to a fixed arbitrary accuracy. We show that this process converges to a stationary point of the objective under minimal conditions ubiquitous in regularized inverse problems, and we propose a numerically stable implementation using a truncated conjugate gradient method.

- Marc Robini (*INSA de Lyon*)

Make FISTA Faster Again
The "fast iterative shrinkage-thresholding algorithm" (FISTA) is a widely used algorithms in the literature. However, despite its optimal $O(1/k^2)$ theoretical convergence rate, oftentimes its practical performance is not as desired owing to the oscillation behaviour. In this talk, we discuss a simple yet effective modification to the algorithm which has two advantages: 1) it enables us to prove the convergence of the generated sequence; 2) it shows superior practical performance compared to the original FISTA.

Jalal Fadili (*Université Caen*)
- Jingwei Liang (*University of Cambridge*)
  Gabriel Peyré (*ENS Paris*)

MS60 Computational and Compressive Imaging Technologies and Applications

Organizers:

Robert Muise (*Lockheed Martin*)
Richard Baraniuk (*Rice University*)

MS60-1 - **Thursday, 07 at 16:30** Room A (Palazzina A - Building A, floor 0)

A concept for Wide Field-of-View Imaging
A novel compressive imaging model is proposed that multiplexes segments of the field of view onto an infrared focal plane array. Similar to compound imaging, our model is based on combining pixels from a surface comprising of different parts of the FOV. We formalize this superposition of pixels in a global multiplexing process reducing the number of detectors required of the FPA. We present an analysis of the Signal-to-Noise Ratio (SNR) for the full rank and compressive collection paradigms for a target detection and tracking scenario.

- Robert Muise (*Lockheed Martin*)

Computational sensing approaches for enhanced active imaging
Active optical sensing is used for time of flight measurements and imaging in degraded vision condition. However, classical optical imaging relays on lines-of-sight sampling and ranging is bandwidth limited. Recently, computational sensing approaches have brought new sensing capabilities and enhanced the spatial and temporal resolution. Now, active imaging devices are able to image and track objects outside the direct field of view and to measure ranges with super-resolution.

- Martin Laurenzis (*French-German Research Institute of Saint-Louis*)

Time-of-Flight Imaging in Scattering Environments
In traditional line-of-sight optical imaging, an image is obtained using the direct light arriving from the scene under investigation to the imaging sensor. Thanks to recent breakthroughs in computer vision and computational imaging, there exist recovery techniques capable of exploiting the time-of-flight (temporal) information of scattered (indirect) photons, which allows to reconstruct the 3D image of a target not in the direct path of the imaging system.

- Marco La Manna (*University of Wisconsin - Madison*)

Spectral Methods for Passive Imaging: Non-asymptotic Performance and Robustness
We will discuss recent results on a classic problem in signal processing: multichannel blind deconvolution. We observe the convolution of a signal unknown source vector with M different channel response vectors; from these observations, our task is to estimate the M responses. Traditionally, this is formulated as a null space approximation problem; given that the channel responses have limited length, we can form a matrix from the observations that is guaranteed to have a null space of dimension 1, and knowledge of this null space immediately reveals the channel responses up to a global constant. The stability of this process in the presence of noise depends on the "spectral gap" of this matrix. We will demonstrate the effect that different channel models have on this spectral gap, and derive performance guarantees for two different algorithms to perform the channel estimation. We will also discuss provable guarantees for a more structured bilinear model, where the ensemble of channel responses is modeled as lying in a low-dimensional subspace but with each channel modulated by an independent gain. Under this model, we show how the channel estimates can be found by minimizing a quadratic functional over a non-convex set. We analyze two methods for solving this non-convex program, and provide performance guarantees for each. The work presented in this talk was done in collaboration with Kiryung Lee, Felix Krahmer, and Ning Tian.

- Justin Romberg (*Georgia Tech*)

MS60-2 - **Friday, 08 at 14:00** Room B (Palazzina A - Building A, floor 1)

Efficient Signal Reconstruction for Optically Multiplexed Imagers
To achieve a wide field of view without some of the disadvantages of conventional wide field of view systems, multiplexed imaging systems superimpose multiple images onto a common focal plane. Recovery of a wide field of view conventional image from these multiplexed measurements typically requires multiple frames. This implicitly assumes a static scene, effectively imposing a sampling rate requirement, which in turn makes real time performance challenging to achieve. This talk will describe work on reducing scene sampling requirements, relaxing the static scene assumption, and improving the computational complexity of image formation algorithms. Results will be shown in simulation and using an infrared wide field of view multiplexed sensor developed at MIT Lincoln Laboratory based on a novel division of aperture sensor architecture. Finally, we will highlight recent developments of optically multiplexed sensors at our laboratory and relate them to the problems we discussed.

- Yaron Rachlin (*MIT Lincoln Laboratory*)

Fast Detection of Compressively-Sensed IR Targets Using Stochastically Trained Least Squares and Compressed Quadratic Correlation Filters
Target detection on a high resolution midwave infrared focal plane array is cost prohibitive in some applications. But, due to the compressibility of infrared image patches, the high resolution requirement could be reduced with target detection capability preserved. As the most probable coefficient indices of the support set of the infrared image patches could be learnt from the training data, we develop STLS for MWIR image reconstruction. Using the same measurement matrix as in STLS, we construct CQCF for compressed infrared target detection. Numerical simulations show that the recognition performance of our algorithm matches that of the standard full reconstruction methods but at a fraction of the execution time.

- Brian Millikan (*University of Central Florida*)

DiffuserCam: Lensless Single-exposure 3D Imaging
This talk will describe new microscopes that use computational imaging – the joint design of optical systems and inverse algorithms - to enable 3D imaging from a single-shot with a lensless camera consisting of only a scattering element (diffuser) placed in front of a 2D image sensor. Our reconstruction algorithms are based on large-scale nonlinear non-convex optimization with sparsity-based regularizers similar to compressed sensing.

Nicholas Antipa (*UC Berkeley*)
Reinhard Heckel (*UC Berkeley*)
Grace Kuo (*UC Berkeley*)
Fanglin Liu (*UC Berkeley*)
Ren Ng (*UC Berkeley*)
- Laura Waller (*University of California, Berkeley*)

Kyrollos Yanny (*UC Berkeley*)

Phase Retrieval: Tradeoffs and New Algorithms
Phase retrieval (PR) algorithms play a key role in many modern computational imagers. For instance, in ptychography and coherent inverse scattering, PR algorithms enable imaging past the diffraction limit and through multiple scattering materials. We study the tradeoffs associated with the panoply of PR algorithms, including the required number of measurements, computational complexity, and robustness to the measurement data distribution. To address the shortcomings of current methods, we introduce and test a new robust PR algorithm that is significantly faster.

Richard Baraniuk (*Rice University*)
- Christopher Metzler (*Rice University*)

Ashok Veeraraghavan (*Rice University*)

MS60-3 - Friday, 08 at 16:30 Room B (Palazzina A - Building A, floor 1)

Imaging and Sensing Around the Corner: An Information-theoretic Approach
Using an information-theoretic approach we quantify the fundamental limits of imaging and sensing around the corner/obstacles using passive measurements. We show that using lightfield measurements one can estimate object position and achieve low-resolution imaging using a high-fidelity forward model.

- Amit Ashok (*University of Arizona*)

Computer graphics meets estimation theory: Computing parameter estimation lower bounds for non-line-of-sight plenoptic imaging systems
We present a framework to compute lower bounds for parameter estimation from noisy plenoptic observations. Our particular focus is on indirect imaging problems, where the observations do not contain line-of-sight information about the parameter(s) of interest. Using computer graphics rendering software to synthesize the (often complicated) dependence among parameter(s) of interest and observations, we numerically evaluate Barankin bounds for these tasks. We demonstrate our results on some canonical example scenes.

Jarvis Haupt (*University of Minnesota*)
Richard Paxman (*MDA Information Systems, LLC*)
- Abhinav V. Sambasivan (*University of Minnesota*)

UNCOVER: Unconstrained Natural-light Coherency Vector-field-imaging by Exploiting Randomness

- Aristide Dogariu (*University of Central Florida*)

Computational memory effect imaging
Angular memory effect imaging is a technique for imaging through an intervening scattering medium. The general method has a number of highly-specific constraints which limit applicability of the technique. In this talk I will discuss how coding and dictionary methods from computational and compressive sensing can overcome some of these limitations, particularly with respect to temporal and spectral bandwidths of the source and the resulting contrast of the speckle patterns recorded at the detector.

- Michael Gehm (*Duke University*)

MS61 Imaging with Light and Sound

Organizers:
Felix Lucka (*CWI & UCL*)
Tanja Tarvainen (*University of Eastern Finland*)

MS61-1 - Friday, 08 at 09:30 Room H (Palazzina B - Building B, floor 0)

A stability analysis for photoacoustics in the presence of attenuation

We analyze the ill-posedness of the photoacoustic imaging problem in the case of an attenuating medium. To this end, we introduce an attenuated photoacoustic operator and determine the asymptotic behavior of its singular values. We show that for strong attenuation the singular values decay exponentially while for weak attenuation they are decaying like in the non-attenuating case.

Peter Elbau (*University of Vienna*)
- Otmar Scherzer (*Computational Science Center, University of Vienna*)
Cong Shi (*Georg-August-Universität Göttingen*)

Photoacoustic computed tomography in heterogeneous elastic media
Photoacoustic computed tomography (PACT) is an emerging imaging modality that has potential for a wide range of preclinical and clinical imaging applications. In this talk, we review recent advancements in image reconstruction approaches for PACT in acoustically heterogeneous media. Such advancements include physics-based models of the measurement process for elastic media and associated optimization-based inversion methods. Open challenges related to the joint reconstruction of optical and acoustic parameters in PACT will also be presented.

- Mark Anastasio (*Washington University in St. Louis*)

The Averaged Kaczmarz Iteration for Solving Inverse Problems
We introduce a new iterative regularization method for solving imaging problems and other inverse problems that can be written as systems of linear or non-linear equations. The proposed averaged Kaczmarz (AVEK) method can be seen as a hybrid method between the Landweber and the Kaczmarz method. We present a convergence analysis of AVEK and present numerical results for its application to photo-acoustic tomography.

Markus Haltmeier (*University Innsbruck*)
- Housen Li (*Georg-August-Universität Göttingen*)

Bayesian approach to photoacoustic image reconstruction
We approach photoacoustic tomography in the framework of Bayesian inverse problems. The parameters are treated as random variables, and the probability distribution of the initial pressure is estimated using the measurements, acoustic model and prior information. Point estimates for image reconstruction and evaluation of the reliability of the reconstructed image are computed. We demonstrate the feasibility of the approach with numerical simulations and experimental data.

Aki Pulkkinen (*University of Eastern Finland*)
Tanja Tarvainen (*University of Eastern Finland*)
- Jenni Tick (*University of Eastern Finland*)

MS61-2 - **Friday, 08 at 14:00** Room H (Palazzina B - Building B, floor 0)

Image reconstruction in hybrid optical imaging modalities using Monte-Carlo solutions to the transport equation
The physics, resolution, and imaging depth of hybrid techniques such as photoacoustic tomography (PAT) is such that model-based approaches to the quantitative inverse problem require use of the radiative transport equation (RTE). Solutions to the RTE are typically sought via stochastic Monte-Carlo methods. In this work we couple our Radiance Monte-Carlo technique with a new stochastic optimisation method which allows us to demonstrate fast simultaneous reconstruction of the absorption and scattering coefficient in three dimensions.

- Samuel Powell (*University College London*)

Coherent acousto-optic imaging
A method to reconstruct the optical properties of a highly-scattering medium from coherent acousto-optic measurements is proposed. The method is based on the solution to an inverse problem for the radiative transport equation with internal data. A stability estimate and a direct reconstruction procedure are described.

- John C Schotland (*University of Michigan*)

Time-resolved optical tomography of biological tissue by means of structured illumination and single pixel camera detection
Time-resolved Diffuse Optical Tomography is a valuable tool to localize and characterize heterogeneities inside a biological tissue. Novel strategies based on structured light illumination and compressive-sensing detection have been exploited to reduce the dataset while preserving the information content. In this work, we present a setup based on those strategies implementing an adaptive scheme based on Singular-Value Decomposition (SVD) to generate a set of optimal input and output patterns.

Simon Arridge (*University College London*)
Andrea Bassi (*Dept. Physics - Politecnico di Milano*)
Marta Betcke (*University College London*)
- Cosimo D'Andrea (*Politecnico di Milano*)
Andrea Farina (*Consiglio Nazionale delle Ricerche (CNR), Istituto di Fotonica e Nanotecnologie (IFN)*)
Gianluca Valentini (*Dept. Physics - Politecnico di Milano*)

Location of sensors in thermo-acoustic tomography
This talk is devoted to determine optimal sensors location to achieve photoacoustic reconstruction. We check an appropriate location of sensors for two series of measures, in two steps: first, we reconstruct possible initial data by solving a worst-case

design like problem. Second, we determine from the knowledge of these initial conditions the optimal location of sensors for observing in the best way the corresponding solution of the wave equation.

- Maïtine Bergounioux (*CNRS - Université d'Orléans UMR 7013*)
  Elie Bretin (*University of Lyon*)
  Yannick Privat (*University of Paris*)

MS61-3 - **Friday, 08 at 16:30** Room H (Palazzina B - Building B, floor 0)

Anisotropic and higher-order regularisation for photoacoustic tomography reconstruction
We present a modular framework for photoacoustic tomography enabling easy switching between regularisers for an iterative reconstruction algorithm. In the case of non-homogeneous optical density (fluence rate), reconstruction employing total generalised variation gives higher quality results than first-order total variation or direct reconstruction methods. When imaging vascular structures, using directional wavelets in the regularisation helps to recover the expected anisotropic structures. Methods are tested on 2D synthetic and experimental data.

- Yoeri Boink (*University of Twente*)

Improving photoacoustic mammography by using intrinsic a priori information
In photoacoustic measurements with local illumination, two photoacoustic waves are generated simultaneously: one where an absorbing abnormality is, and a second one near the interface of the tissue. This local optically generated acoustic wave, propagating from the sub-surface throughout the medium, carries information of purely acoustic nature that can be introduced, if properly filtered, as prior knowledge or constraint in the photoacoustic reconstruction process, especially if the abnormality presents also an acoustic contrast (e.g. tumors).

- Anabela Da Silva (*Aix-Marseille Université, CNRS, Centrale Marseille, Institut Fresnel UMR 7249*)
  Gasteau Damien (*Aix-Marseille Université, CNRS, Centrale Marseille, Institut Fresnel UMR 7249*)
  Metwally Khaled (*Aix-Marseille Université, CNRS, Centrale Marseille, Institut Fresnel UMR 7249, Marseille*)
  Mensah Serge (*Aix-Marseille Université, CNRS, CNRS, Centrale Marseille, LMA UPR 7051*)

A one-step reconstruction method for photoacoustics with multispectral data
We present a one-step approach for numerical reconstructions in photoacoustics where we intend to reconstruct partial information on both the ultrasound speed and the optical absorption/scattering. We assume that data from multiple optical wavelength are available in this setup. We will also discuss briefly some related theoretical issues.

Kui Ren (*University of Texas at Austin*)
- Yimin Zhong (*University of California at Irvine*)

3D Quantitative photoacoustic tomography (qPAT) using an adjoint Monte Carlo inversion scheme: application to recovering blood oxygenation
To recover absolute blood oxygenation from high resolution PAT images, the fluence needs to be corrected. However, qPAT is a large scale inverse problem. Finite difference gradient methods or gradient-free parameter searches are unsuitable for inverting 3D images. Adjoint methods by contrast provide the parameter search gradient efficiently. An adjoint radiative transfer equation formulation using a Monte-Carlo fluence approximation is used and validated in silico and on tissue phantom data. Convergence and limitations are discussed.

- Bernhard Kaplan (*Zuse Institute Berlin*)
  Jan Laufer (*Martin-Luther-Univ Halle-Wittenberg*)

MS62 Imaging models with non-linear constraints

Organizers:
Tuomo Valkonen (*University of Liverpool*)
Juan Carlos De Los Reyes (*Escuela Politécnica Nacional*)

MS62-1 - **Friday, 08 at 09:30** Room M (Palazzina B - Building B, floor 0)

Learning neural field equations for brain imaging

- Christoph Brune (*University of Twente*)

A New Variational Approach for Limited Angle Tomography
The limited angle problem in Computed Tomography is unavoidable and results in severely ill-posed inverse problems with strong reconstruction artefacts. We propose a joint approach which simultaneously refines our estimate for the missing data and the desired reconstruction to minimise these artefacts. Such a model naturally leads us to consider non-linear constraints and non-convex, non-smooth optimisation. We shall review and extend recent results in this area for practical implementation.

Martin Benning (*University of Cambridge*)
Christoph Brune (*University of Twente*)

Rien Lagerwerf (*Centrum Wiskunde & Informatica*)
Carola-Bibiane Schönlieb (*University of Cambridge*)
• Rob Tovey (*University of Cambridge*)

Total variation priors in electrical impedance tomography

In electrical impedance tomography (EIT), the spatially distributed electrical conductivity is reconstructed based on surface potential measurements. Due to the ill-posedness of the image reconstruction problem, the quality of reconstructions depends heavily on available prior information on the target. This talk considers especially total variation (TV) priors, which favor sharp edges in the conductivity distribution. We discuss differences between two TV models, isotropic and anisotropic TV, and show examples of applications to non-destructive material testing.

Gerardo González (*University of Eastern Finland*)
Ville Kolehmainen (*University of Eastern Finland*)
Mohammad Pour-Ghaz (*North Carolina State University*)
• Aku Seppänen (*University of Eastern Finland*)

A semi-infinite bilevel optimization approach for spatially-dependent parameter selection in total generalized variation image denoising

We study a bilevel semi-infinite optimization approach for spatially dependent parameter learning in total generalized variation image denoising. We present some analytical results like the existence of solutions for the bilivel problem and the Fréchet differentiability of the solution operator, which allows to prove existence of Lagrange multipliers. In addition, we prove existence of the adjoint state which allows to obtain a gradient characterization. The multipliers associated with the constraints are regular Borel measures which are very difficult to compute. In order to overcome this issue, we propose Moreau-Yosida regularization, where the optimality system associated with the regularized problem is derived and we prove that the solutions of the regularized problems converge to the solution of the original one. The proposed numerical strategy is to use a second-order quasi-Newton method, specifically the BFGS method, together with the Newton Semi-Smooth algorithms for the resolution of TGV image denoising model.

• Kateryn Herrera (*Escuela Politécnica Nacional*)

MS62-2 - **Friday, 08 at 14:00** Room M (Palazzina B - Building B, floor 0)

Accelerated primal-dual methods for nonlinear inverse problems

First order primal-dual algorithms for nonsmooth optimisation have already demonstrated considerable potential for solving inverse problems in image reconstruction and optimal control. However, their extension to nonlinear forward operators still requires investigation. Based on the idea of testing, we analyse the convergence of a nonlinear extension of the Chambolle-Pock hybrid gradient method in infinite-dimensional Hilbert spaces. We derive step length conditions as well as acceleration rules for suitably point-based monotone problems.

• Stanislav Mazurenko (*University of Liverpool*)
Tuomo Valkonen (*University of Liverpool*)

A two-point gradient method for nonlinear ill-posed problems

We present and analyse a class of gradient based iterative methods for solving nonlinear ill-posed problems which are inspired by Landweber iteration and Nesterov's acceleration scheme and promise to be good alternatives to second order methods. The usefulness of these methods is demonstrated on a numerical example problems based on the nonlinear inverse problem of single photon emission computed tomography (SPECT).

• Simon Hubmer (*Johannes Kepler University Linz*)
Ronny Ramlau (*Kepler University Linz and Johann Radon Institute*)

A fast non regularized numerical algorithm for solving bilevel denoising problems

We study bilevel optimization problems restricted to variational inequalities of the second kind with application to image denoising tasks. Several learning problems in image processing can be formulated in the context of a bilevel optimization problem. In such problems the lower level corresponds to a variational formulation for a specific imaging task (denoising, inpainting, segmentation, etc.) and the higher level problem uses the solution provided by the lower level to compute a quality measure using a training dataset. Even though previous work has been proposed by using a smoothed version of the lower level problem in order to characterize an optimality condition, we will focus our efforts on a non-smoothed version of the non-differentiable terms. We will find optimality conditions of the bilevel problem by exploting the directional differentiability of the solution operator of the lower level problem and propose a numeric scheme based on a Trust Region algorithm in order to find candidate solutions.

• David Villacis (*Escuela Politécnica Nacional*)

Preconditioners for PDE-constrained optimization problems, with application to image metamorphosis

PDE-constrained optimization problems have a wide range of applications across mathematics and applied science, so it is important to develop feasible and robust methods to solve such problems. In this talk we focus on an inverse problem model for image metamorphosis, where the PDE constraint is given by a transport equation. We derive fast iterative methods for the solution of the resulting matrix systems, using effective saddle-point preconditioners.

• John Pearson (*University of Edinburgh*)

MS63 Geometric methods for shape analysis with applications to biomedical imaging and computational anatomy

Organizers:
Martin Bauer (*Florida State University*)
Nicolas Charon (*Johns Hopkins University*)

MS63-1 - Friday, 08 at 09:30 Room I (Palazzina B - Building B, floor 0)

Barycentric Subspace Analysis, a generalisation of PCA to Manifolds
To generalize Principal Component Analysis (PCA) to Riemannian manifolds, we first propose barycentric subspaces, implicitly defined as the locus of weighted means of k+1 reference points. This locally defines submanifolds of dimension k which can naturally be nested, allowing the construction of inductive forward or backward nested subspaces minimizing the unexplained variance. To optimize the whole hierarchy consistently, Barycentric Subspaces Analysis (BSA) proposes to optimize the accumulated unexplained variance on flags of linear subspaces.

- Xavier Pennec (*Université Côte d'Azur and Inria*)

Generalizations of Wasserstein metric and their applications to shape matching
We discuss the extension of the L2-Wasserstein metric in different contexts of interest. After reviewing the extension of the Wasserstein metric to the space of nonnegative Radon measure, we present an efficient algorithm to solve it based on entropic regularization. We showcase applications to diffeomorphic matching of embedded surfaces and we discuss its application to images. Last, we present an extension of these transport distances to the case of cone valued measures.

- François-Xavier Vialard (*University Paris-Dauphine*)

LDDMM models of a heart contraction
While LDDMM methods and algorithms have proven their worth when comparing macroscopic differences between organs, it is ill-suited to generate a heartbeat, which requires a torsion in the muscle that does not naturally appear through shape matching. In this talk, we show various possible models to generate a heartbeat from a relaxed state to a contracted state while in the framework of LDDMMs, using for example constraints or artificially generated fibers, and their success (or lack of success) in modeling a heartbeat while keeping computations to a manageable level.

- Sylvain Arguillere (*Institut Camille Jordan*)

Regularized optimal mass transport with applications to density matching
The geometric approach to optimal transport and information theory has triggered the interpretation of probability densities as an infinite-dimensional Riemannian manifold. The most studied Riemannian structures are the Wasserstein metric of optimal mass transport, and the Fisher–Rao metric. On the space of smooth probability densities, none of these Riemannian metrics are geodesically completes. Here we study geodesic equations for higher-order Sobolev metrics. We give order conditions for global existence and uniqueness, thereby providing geodesic completeness.

- Martin Bauer (*Florida State University*)

MS64 Images and Finite Elements

Organizers:
Roland Herzog (*Technische Universität Chemnitz*)
Stephan Schmidt (*University of Würzburg*)

MS64-1 - Friday, 08 at 09:30 Room L (Palazzina B - Building B, floor 0)

Discrete total variation with finite elements
The total-variation (TV) seminorm is ubiquitous as a regularizing functional in image analysis and related applications. We propose and analyze a discrete analog of the TV-seminorm for functions belonging to a space of globally discontinuous or continuous finite element functions on a geometrically conforming mesh. We show that our discrete TV functional admits a dual representation close to the continuous formulation and allows for efficient implementations of classical image restoration algorithms.

Marc Herrmann (*University of Würzburg*)
- Roland Herzog (*Technische Universität Chemnitz*)
Stephan Schmidt (*University of Würzburg*)
José Vidal Núñez (*Technische Universität Chemnitz*)
Gerd Wachsmuth (*Technische Universität Chemnitz*)

Adaptive finite element approximation of the ROF model
We present a fully computable a posteriori error estimate for the finite element approximation of the Rudin-Osher-Fatemi problem. We propose an adaptive refinement strategy relying on the fact that the primal-dual gap controls the L^2-error between the solution and an FE-approximation and on an accurate conforming discretization of both the primal and the

dual problem and reliable iterative solution techniques. Numerical experiments show a significant improvement over approximations on uniformly refined triangulations.

Sören Bartels (*University of Freiburg*)
- Marijo Milicevic (*University of Freiburg*)

Fast and robust boundary segmentation using 2nd order shape sensitivity of variational models
Many tasks in image processing, e.g. segmentation, surface reconstruction, are naturally expressed as energy minimization problems, in which the free variables are shapes, such as curves in 2d or surfaces in 3d. Iterative shape optimization can be used to solve these problems, but can have difficulties, such as slow convergence, sensitivity to initialization, robustness issues. We have developed a framework that leverages 2nd order shape derivatives of the shape energies for a shape-Newton algorithm, and implemented it efficiently with a finite element discretization. Our algorithm shows superior performance on real examples, compared with traditional approaches.

- Gunay Dogan (*Theiss Research, NIST*)

Adaptive finite elements for Mumford-Shah-type functionals in transport network modelling
We show how models for transportation networks can be reduced to Mumford-Shah-type image inpainting problems. Classical functional lifting allows to relax the inpainting problem into a convex optimization in a higher-dimensional space. We present a corresponding adaptive finite element discretization with heuristic refinement strategies based on the duality gap and an active-set type approach to deal with the large number of involved nonlocal convex constraints and their update after grid refinement.

- Rossmanith Carolin (*Westfälische Wilhelms-Universität Münster*)
Benedikt Wirth (*Universität Münster*)

MS65 Machine learning techniques for image reconstruction

Organizers:
Markus Haltmeier (*University Innsbruck*)
Linh Nguyen (*University of Idaho*)

MS65-1 - Friday, 08 at 09:30 Room P (Palazzina B - Building B, floor 0)

Deep learning for photoacoustic tomography
In this talk, we will review recent progresses on deep learning for photoacoustic tomography.

Markus Haltmeier (*University Innsbruck*)
- Linh Nguyen (*University of Idaho*)

Deep Learning Approaches for MR Image Reconstruction
We propose and compare two different machine learning approaches for cardiac MR image reconstruction. The first class of approaches uses dictionary learning techniques for compressed sensing MR image reconstruction. The second class of approaches uses convolutional neural networks for MR image reconstruction. We evaluate both approaches in terms of reconstruction quality and computational speed.

- Daniel Rueckert (*Imperial College London*)

Deep convolutional framelets: a general deep learning framework for inverse problems
Recently, deep learning approaches with various network architectures have achieved significant performance improvement over existing iterative reconstruction methods in various inverse problems. However, it is still unclear why these deep learning architectures work. Here we show that the long-searched-for missing link is the deep convolutional framelets expansion for representing a signal by convolving local and non-local bases using multi-level decomposition. Using numerical experiments with various inverse problems, we confirm the validity of our discovery.

Eunju Cha (*KAIST*)
Yoseob Han (*KAIST*)
- Jong Chul Ye (*Department of Bio and Brain Engineering, Korea Advanced Institute of Science and Technology*)

Deep Learning for Photoacoustic Tomography from Sparse Data
We improve image reconstruction from sparse data in photoacoustic tomography using a deep convolutional network. The weights of the convolutional network are adjusted prior to the actual image reconstruction through training with pairs of reconstructions including artifacts and the corresponding artifact-free images. We demonstrate with simulated and experimental data that the proposed approach provides reconstructed images with a quality comparable to state of the art approaches and reduced numerical costs.

Stephan Antholzer (*University of Innsbruck*)
Markus Haltmeier (*University Innsbruck*)
Robert Nuster (*Karl-Franzens-Universität Graz*)
- Johannes Schwab (*Universität Innsbruck*)

MS65-2 - **Friday, 08 at 16:30** Room M (Palazzina B - Building B, floor 0)

Deep learning in computational microscopy
Using deep learning, we demonstrate significant advances in different modes of microscopic imaging, including bright-field, holographic and mobile-phone based microscopy tools, increasing their imaging throughput, resolution and depth-of-field, while also eliminating or correcting for undesired spatial and/or spectral artifacts. This deep learning based framework can be broadly applied for solving inverse problems in computational microscopic imaging, and especially benefit imaging modalities where an accurate modeling of the image formation process is challenging.

- Yair Rivenson (*University of California Los Angeles*)

Task Based Reconstruction using Deep Learning
Reconstruction in inverse problems is often one step in a procedure where the reconstructions is used for decision making associated to a task. The talk will use statistical decision theory for extending recent iterative learned methods to include tasks that can be formulated as a supervised learning task, e.g., segmentation, comparison, classification, registration, or caption generation. We will outline this framework and show examples of task based reconstructions in the context of tomographic imaging.

Jonas Adler (*KTH Royal Institute of Technology*)
- Ozan Öktem (*KTH - Royal Institute of Technology*)

Machine learning in compressed sensing
We give an overview of algorithms for compressed sensing that are based on neural networks. We experimentally show (using simulated data) that methods using convolutional neural networks are faster than traditional algorithms based on convex optimization, while giving similar results. We then investigate the possible real world usage of this methods for the compression of data acquired by a Time-of-Flight camera.

- Stephan Antholzer (*University of Innsbruck*)

Finding best approximation pairs with Douglas-Rachford
We consider the problem, that has various applications in imaging, of finding a pair of points, in two convex sets, such that the distance between the points is as small as possible. Assuming that the convex sets are polyhedrons, and that the angle between any pair of faces of these polyhedrons is lower bounded by a positive constant, we will describe the local as well as the global convergence rate of a widely-used algorithm that solves this problem: the Douglas-Rachford method.

- Irene Waldspurger (*CEREMADE (Université Paris-Dauphine)*)

MS66 Spatial statistics in microscopy imaging

Organizers:
Kervrann Charles (*Inria*)

MS66-1 - **Friday, 08 at 09:30** Matemates (Matemates, floor 0)

GcoPS: a fast automatic colocalization method for 3D live cell imaging and super-resolution microscopy
The GcoPS method is dedicated to the co-localization of fluorescence image pairs for conventional and super-resolution microscopy. This fast procedure is controlled by a p-value and tests whether the Pearson correlation between two binary images is significantly positive. It amounts to quantifying the interaction strength by the area/volume of the intersection between the two binary images viewed as random distributions of geometrical objects. GcoPS handles 2D/3D images, variable SNRs and any kind of cell shapes.

- Kervrann Charles (*Inria*)

Marked point processes for detecting objects in microscopy
The marked point process framework has been successfully developed in the field of image analysis to detect a configuration of predefined objects. We s present a simple model that shows how some of the challenges specific to biological data are well addressed by the methodology. We further describe an extension to address other challenges due, for example, to the shape variability in biological material. We illustrate this framework on different populations of cells.

- Descombes Xavier (*Inria Sophia-Antipolis*)

Spatial statistics extends co-localization analysis to non-local interaction analysis
We reformulate the classical object-based co-localization measure in the context of spatial statistics. This allows us to generalize object-based co-localization analysis to a statistical framework over spatial point processes. The framework is based on a model of effective pairwise interaction potentials and the specification of a null hypothesis for the expected pattern in the absence of interaction. The classical object-based co-localization measure is included in our framework as a special case, highlighting several implicit assumptions.

- Ivo Sbalzarini (*TU Dresden / Max Planck Insitute of Molecular Cell Biology and Genetics*)

Spatial patterns in large-scale bioimaging data: applications in spatial transcriptomics and phenomics
In this talk, I will focus on recent developments in the emerging field of Spatial Transcriptomics, where we study the spatial aspects of gene expression. In recent years, it has become apparent that not only the number of RNA molecules, but also their spatial distribution inside cells is important for understanding this fundamental process. Here, I will present methods to characterize spatial patterns by machine learning approaches and simulation of realistic images.

- Walter Thomas (*CBIO, Mines ParisTech*)

MS67 Advances and new directions in seismic imaging and inversion

Organizers:
Mauricio Sacchi (*University of Alberta*)
Sergey Fomel (*University of Texas, Austin*)
Laurent Demanet (*MIT*)

MS67-1 - Friday, 08 at 09:30 Room G (Palazzina A - Building A, floor 0)

Comet interior imaging using radar tomography.
The Rosetta mission to comet 67P/C-G revolutionized comet science, but left major questions on the table. Are cometary nuclei primordial or are they collisionally-evolved as predicted by modern theories of planet formation? The CONSERT radar experiment sounded the interior of the nucleus showing it to be transparent to a depth of kilometers at 90 MHz, thus demonstrating the feasibility of a 3D global reflection tomography. The Comet Radar Explorer mission will acquire a dense network of in-phase radar echoes from orbit to obtain a high resolution 3D image. Full wavefield tomography facilitate high quality imaging of the comet interiors, particularly if the comet nucleus is characterized by complex structure and large contrasts of physical properties. Knowledge of the comet shape and all-around orbital radar acquisition enable accurate and computationally-efficient 3D wavefield tomography.

- Paul Sava (*Colorado School of Mines*)

Seismic image matching
Numerous applications in seismic image analysis require matching two or more images. Examples include time-lapse and multicomponent image registration, migration deconvolution, full waveform inversion, adaptive subtraction of multiples, etc. Some applications benefit from separating the matching procedure into components, such as scaling, shifting, and smoothing. I review different techniques for seismic image matching and compare them using synthetic and field data examples.

- Sergey Fomel (*University of Texas, Austin*)
  Sarah Greer (*University of Texas at Austin*)

Data-to-Born transform for inversion and imaging with seismic waves
We consider an inverse problem for the acoustic wave equation, where an array of sensors probes an unknown medium with pulses and measures the scattered waves. The goal is to determine from these measurements the structure of the scattering medium, modeled by a spatially varying acoustic impedance function. Many conventional inversion algorithms assume that the dependency of the scattered waves on the unknown impedance is approximately linear. The linearization, known as the Born approximation, is not accurate in strongly scattering media, where the waves undergo multiple reflections before reaching the sensors. This results in artifacts in the impedance reconstructions. We show that it is possible to remove the multiple scattering effects from the data, using a reduced order model (ROM). The ROM is an orthogonal projection of the wave equation propagator on the subspace spanned by the time domain snapshots of the wavefields. While the snapshots are only known at sensor locations, this information is enough to construct the ROM. Once the ROM in constructed, we use its perturbations to generate a new data set that the same impedance would generate if the waves in the medium propagated according to Born approximation. We refer to such procedure as the Data-to-Born transform. Once the multiple scattering effects are removed from the data by the transform, it can be fed to conventional linearized inversion workflows.

- Alexander Mamonov (*University of Houston*)

Direct waveform inversion (DWI) by explicit time-space causality
The full waveform inversion (FWI) is widely used to obtain images using recorded waveforms and it can be cast into a global nonlinear optimization problem. There are many known challenges in FWI. Using time-space causality of the wavefield, we propose to convert the global nonlinear optimization into many local linear inversions that can be directly solved (DWI). The conversion has no information loss. DWI naturally uses all data types and is unconditionally convergent and efficient.

- Yingcai Zheng (*University of Houston*)

MS67-2 - Friday, 08 at 14:00 Room G (Palazzina A - Building A, floor 0)

Efficient estimates of uncertainty in time-lapse seismic imaging

Multiple seismic data sets are often recorded to monitor changes in Earth properties. Results from studies using Full Waveform Inversion (FWI) to recover 4D changes have been encouraging thus far. Since 4D monitoring involves looking for small changes in localized regions, understanding the uncertainty in the measurement of those changes is key. We present an efficient way of creating big samples of data in a fast and computationally inexpensive way. We then use them in a statistical inversion technique to evaluate the performance of current 4D FWI techniques.

• Maria Kotsi (*Memorial University of Newfoundland*)
Alison Malcolm (*Memorial University of Newfoundland*)

Experiments in bandwidth extension

This talk considers the basic question of frequency extrapolation of bandlimited recordings of scattered waves. I will discuss two methods that were shown to give meaningful results for seismic imaging: (i) a model reduction approach, where the phases of atomic seismic events are estimated by tracking, and (ii) a model extension approach, based on TV-regularized least-squares inversion of the extended Born modeling operator. Both methods are meaningful in the sense that they can help bootstrap the frequency sweeps for full waveform inversion. Joint work with Yunyue Elita Li.

• Laurent Demanet (*MIT*)

Imaging complex near surface using noisy and narrow band surface wave data

Surface wave data are processed to retrieve dispersion curves that are inverted to estimate velocity models of the subsurface. Recent approaches avoids the inversion step using data transforms that estimate directly the velocity. Dispersion curves are discontinuous and noisy data that requires interpolation and smoothing.

• Valentina Socco (*Politecnico di Torino*)

Multi-domain target-oriented imaging using extreme-scale matrix factorization

In this work, we present an alternative approach to re-datum both sources and receivers at depth, under the framework of reflectivity-based extended images with two-way wave propagation in the background medium. In our work, we will consider a linear algebra approach to deal with the low-rank representation of extended image volumes with full offsets. We will never build entirely the resulting matrix but get only actions of it on well-chosen probing vectors, based on Low-Rank decomposition or randomized SVD. The proposed scheme allows us to have access to all the energy of the extended image volume matrix and still overcome the computational cost and memory usage associated with the number of wave-equation solutions and explicit storage employed by conventional migration methods. Experimental results on complex geological models demonstrate the efficacy of proposed methodology in performing multi-domain target imaging.

Marie Graff-Kray (*Dr.*)
• Felix J. Herrmann (*Georgia Institute of Technology*)
Rajiv Kumar (*Georgia Institute of Technology*)
Ivan Vasconcelos (*Dept. of Earth Sciences, Utrecht University*)

MS67-3 - Friday, 08 at 16:30 Room G (Palazzina A - Building A, floor 0)

Multi-parameter full-waveform inversion: the influence of the parameterization

In multi-parameter full-waveform inversion (FWI) the choice of parameterization is fundamental to correctly separate the different parameter classes. We investigate the influence of the parameterization on the parameter separation for an elastic isotropic FWI problem from a mathematical standpoint. We also study this influence numerically using a simple model containing multiple anomalies in each parameter class positioned at different locations.

• Ettore Biondi (*Stanford University*)

Retrieving full-wavefields within the medium from incomplete, one-sided data

Retrieving detailed and accurate images of targets that lie beneath or behind unknown complex overburdens or obstacles is a highly challenging problem in waveform-based imaging, such as in seismic, acoustic or radar applications. This problem is particularly difficult when experimental limitations are such that the medium in question cannot be fully surrounded by both by sources and receivers, thus only limited aperture, one-sided scattered-wave data are available. Overcoming some of the issues arising from having one-sided data, we will present an imaging framework based on wavefield redatuming, i.e., on retrieving scattered fields within the medium where observations are otherwise not available, that decouples the influence of the overburden from that of the target in imaging and inversion: thus separately allowing for better target images and/or overburden/obstacle characterization. The key enabler for this is solving an intermediate inverse scattering problem for the medium's focusing functions, in the context of 3D Marchenko field equations: these fields encode the effects of different portions of the medium without the need to first characterize medium properties. In this talk, we will review the 3D Marchenko system, discuss the theoretical and numerical inverse-problem aspects of retrieving focusing functions, and show examples of imaging options from one-sided data that are enabled by this framework.

Joeri Brackenhoff (*TU Delft*)
Matteo Ravasi (*Statoil*)
Christian Reinicke (*TU Delft*)
Tristan van Leeuwen (*Utrecht University*)
• Ivan Vasconcelos (*Dept. of Earth Sciences, Utrecht University*)

Salt Geometry Reconstruction in Seismic Imaging

Full-Waveform Inversion attempts to estimate a high-resolution model of the Earth by inverting all the seismic data. This procedure fails if the Earth model contains high-contrast bodies such as salt. These bodies are important for hydrocarbon exploration.We propose a parametric level-set method to estimate these geometries by incorporating prior information about their properties. Tests ona suite of idealized salt geometries show that the proposed method is stable against a modest amount of noise.

- Ajinkya Kadu (*Mathematics Department, Utrecht University*)
  Wim Mulder (*Shell Global Solutions*)
  Tristan van Leeuwen (*Utrecht University*)

Edge preserving filter for full waveform inversion

Full waveform inversion (FWI) provides accurate subsurface images. In spite of its success, the application of FWI in areas with high-velocity contrast remains a challenging problem. Quadratic regularization methods are often adopted to stabilize inverse problems. Unfortunately, edges and sharp discontinuities are not adequately preserved by quadratic regularization. During the iterative FWI method, an edge-preserving filter, on the other hand, can gradually incorporate sharpness into seismic images. We use an edge-preserving filter to stabilize FWI.

Amsalu Anagaw (*University of Alberta*)
- Mauricio Sacchi (*University of Alberta*)

MS68 Multi-channel image reconstruction approaches

Organizers:
Jakob Jorgensen (*University of Manchester*)
Daniil Kazantsev (*University of Manchester*)

MS68-1 - Friday, 08 at 09:30 Room C (Palazzina A - Building A, floor 1)

Joint image reconstruction of multi-channel X-ray computed tomography data for material science

Rapidly developing technology of photon-counting or energy-discriminating detectors has provided an additional spectral dimension to conventional X-ray grayscale imaging.The energy-binned data, however, suffer from low signal-to-noise ratio, acquisition artifacts, and frequently angular undersampled conditions. Since energy-channels are mutually correlated it can be advantageous to incorporate additional knowledge into the reconstruction algorithm. We propose a novel iterative method which jointly reconstructs all energy channels while imposing a strong structural correlation between them.

- Daniil Kazantsev (*University of Manchester*)

Collaborative Regularization Models for Color Imaging Problems

By considering the gradient of a multichannel image as a 3D tensor with dimensions corresponding to the image domain, spatial derivatives and channels, we introduce collaborative sparsity enforcing norms to address the ill-posedness of color imaging problems. We obtain a regularization framework for color images that uses different channel couplings and enables joint directions of smoothing. We analyze which of the arising models are best suited for color image denoising and other inverse problems.

- Joan Duran (*Universitat de les Illes Balears*)
  Catalina Sbert (*Universitat de les Illes Balears*)

Electron tomography combining spectral and non-spectral modalities

Using electron tomography, the three-dimensional structural and chemical information of materials can be characterized at the nanometer level. The most commonly used image signals are acquired using scanning TEM (STEM), which is a high-resolution and non-spectral modality. In addition, the spectral imaging mode called energy dispersive X-ray spectroscopy (EDS) can be adopted in electron tomography to directly map the chemical composition in 3D. However, EDS imaging presents low signal-to-noise ratios, which limits the resolution. In this presentation, I will introduce the approaches to combine the two complementary modalities in one tomographic reconstruction process for acquiring high-resolution chemical information in 3D.

Joost Batenburg (*CWI, Amsterdam*)
- Zhichao Zhong (*Centrum Wiskunde & Informatica*)

Multi-channel high-resolution x-ray tomography

Recent years witnessed a proliferation of hard x-ray imaging instruments at the synchrotron and laboratory-based facilities that can provide resolutions down to few tens of nanometers. However, tomography at these fine scales is particularly challenging, because of the reduced photon efficiency, higher radiation doses, and inaccuracies of the stages, which leads to noisy and sparse datasets. In this talk, I will first give recent developments for scanning-based x-ray imaging and microscopy applications, and then describe how existing and new algorithmic approaches can be adopted to enable faster and reliable information extraction from complex multi-dimensional measurement data.

- Doga Gursoy (*Argonne National Laboratory*)

MS69 Anisotropic multi scale methods and biomedical imaging

Organizers:
Davide Barbieri (*Universidad Autonoma de Madrid*)
Demetrio Labate (*University of Houston*)

MS69-1 - **Wednesday, 06 at 15:30** Room F (Palazzina A - Building A, floor 2)

Shearlet-based compressed sensing for fast 3D cardiac MR imaging
High-resolution three-dimensional (3D) cardiovascular magnetic resonance (CMR) is a valuable medical imaging technique, but its widespread application in clinical practice is hampered by long acquisition times. In this talk, we present a novel compressed sensing (CS) reconstruction approach based on an iterative reweighting procedure using shearlets as a sparsifying transform allowing for fast 3D CMR (3DShearCS).

Stephanie Funk (*Charite*)
Christoph Kolbitsch (*Physikalisch-Technische Bundesanstalt*)
• Gitta Kutyniok (*Technische Universität Berlin*)
Jackie Ma (*Fraunhofer Institute for Telecommunications–Heinrich Hertz Institute*)
Maximilian März (*Technische Universität Berlin*)
Tobias Schaeffter (*Physikalisch-Technische Bundesanstalt*)
Jeanette Schulz-Menger (*Charite*)

Geometric multiscale representions and neuroscience imaging
Advances in imaging acquisition and labeling techniques in recent years have increased the availability of high resolution images in the field of neuroscience. To process such data there is a need for improved algorithms that are capable of capturing complex morphological structures in multidimensional data in a highly sensitive and comprehensive manner. I will present methods from multiscale analysis targeted to neuroscience imaging for the automated extraction of morphological features from fluorescent images of neuronas.

• Demetrio Labate (*University of Houston*)

New reproducing kernel Hilbert spaces for features extraction
We will discuss reproducing formulas associated to non square integrable irreducible representations of semidirect products. The main sources of this degeneracy are the zero measure of dual orbits, and the noncompactness of stabilizers. We will show how to recover L2 structures without compromising the group structure for general scalar representations, and characterize reproducing formulas for vector valued representations. Applications to quasi-regular representations of anisotropic group orbits will be discussed.

• Davide Barbieri (*Universidad Autonoma de Madrid*)

Optimal Paths for Variants of the 2D and 3D Reeds-Shepp Car for Tracking of Blood Vessels and Fibers in Medical Images
We consider a PDE framework for computing shortest paths for the 2D and 3D Reeds-Shepp car. We minimize a data-driven total-variation functional on position-and-orientation space, allowing only forward motion, to track complex elongated structures in images. We compute (quasi)-distance maps and (approximate) optimal sub-Finslerian/sub-Riemannian geodesics via Eikonal PDEs and gradient descent, with convergence results and comparison to exact solutions. We show benefits in: 1) vessel tracking in 2D medical images, 2) fiber tracking in DW-MRI-data.

• Remco Duits (*Technische Universiteit Eindhoven*)
Stephan Meesters (*Eindhoven University of Technology*)
Jean-Marie Mirebeau (*Université Paris-Sud - CNRS - Université Paris-Saclay*)
Jorg Portegies (*Eindhoven University of Technology*)

MS70 Innovative Challenging Applications in Imaging Sciences

Organizers:
Roberto Mecca (*University of Bologna and University of Cambridge*)
Giulia Scalet (*Dept. Civil Engineering and Architecture, University of Pavia*)
Federica Sciacchitano (*Dept. Mathematics, University of Genoa*)

MS70-1 - **Friday, 08 at 09:30** Room D (Palazzina A - Building A, floor 1)

Modeling and Learning Deep Representations, in Theory and in Practice
We establish a connection between nonconvex optimization of the kind used in Deep Learning, and nonlinear partial differential equations (PDEs). We interpret empirically successful relaxation techniques motivated from statistical physics for training deep neural networks as solutions of a viscous HamiltonJacobi (HJ) PDE. The underlying stochastic control interpretation allows us to prove that these techniques perform better than stochastic gradient descent (SGD). Moreover,

we derive this PDE from a stochastic homogenization problem which proves connections to algorithms for distributed training of deep networks like ElasticSGD. Our analysis provides insight into the geometry of the energy landscape and suggests new algorithms based on the non-viscous HamiltonJacobi PDE that can effectively tackle the high dimensionality of modern neural networks. Joint work with Pratik Chaudhari, Adam Oberman, Stanley Osher and Guillaume Carlier. Preview at: ArXiv 1704.04932

Pratik Chaudhari (*University of California, Los Angeles, UCLA*)
- Stefano Soatto (*University of California, Los Angeles*)

Case study in learning to understand: 3D face reconstruction

We have been able to show that neural networks can recover the geometric structure of a human face from a single given image. In this talk I will review the steps we took towards that goal, starting with a simple projection onto the Blanz-Vetter linear model coupled with shape from shading reconstruction that provides the fine significant details. Then, by learning the axiomatic shape from shading into a network that part was also translated to the deep learning world. Finally, I will show how one could remove the restriction of a target linear sub-space to train a wholistic reconstruction network. Based on joint papers with Matan Sela, Elad Richardson, and and Roy Or-El.

- Ron Kimmel (*Technion - Israel Institute of Technology*)

A Multidisciplinary Approach to Personalized Design of Orthopaedic Implants and other Devices

The design of orthopaedic implants and other devices such as joint prostheses etc. can now take advantage of the modern technology of additive manufacturing. This allows full personalisation of the overall treatment, starting from medical imaging of the specific patient and going through muscolo-skeletal modelling, implant design and device fabrication. This necessarily needs a multidisciplinary approach because of the number of experts involved in this process.

Claudio Belvedere (*Istituto Ortopedico Rizzoli, Bologna*)
Paolo Caravaggi (*Istituto Ortopedico Rizzoli, Bologna*)
Stefano Durante (*Istituto Ortopedico Rizzoli, Bologna*)
Alessandro Fortunato (*University of Bologna*)
- Alberto Leardini (*Laboratory of Movement Analysis and Functional-Clinical Evaluation of Prosthesis, Istituto Ortopedico Rizzoli, Bologna*)

Pancreatic cancer identification strategy on CT images based on higher-order statistics

Pancreatic Ductal AdenoCarcinoma (PDAC), one of the most common exocrine pancreas cancer, is characterised by a particular shaded appearance on MDCT images, that makes very hard a clear identification of its border. Moreover, clinical experience states that the actual size of the tumour is usually bigger than evaluated on MDCT, suggesting that part of the tumour is not-visible on MDCT. We propose higher-order statistics as an approach to detect grayscale differences non-visible to human eye.

Ferdinando Auricchio (*Department of Civil Engineering and Architecture, University of Pavia*)
- Stefania Marconi (*Department of Civil Engineering and Architecture, University of Pavia*)
Erika Negrello (*University of Pavia*)
Andrea Pietrabissa (*Policlinico San Matteo, Pavia*)
Luigi Pugliese (*Policlinico San Matteo, Pavia*)

MS70-2 - Friday, 08 at 14:00 Room D (Palazzina A - Building A, floor 1)

How flexible is your scanner?

With the collaboration of CWI, XRE, Nikhef and ASI, we are excited to introduce the Flex Ray scanner: a custom-built, highly flexible lab CT system, where one can simulate various tomography geometries; the acquired information is immediately available as reconstructions, and collecting spectral information is also an option. In my talk I will be highlighting the current capabilities of our scanner, projects undertaken so far, and our vision for raising the standards of today's imaging systems.

- Sophia Bethany Coban (*Centrum Wiskunde & Informatica, University of Manchester*)

Classifying stroke using electrical impedance tomography

Stroke has two forms: bleeding in the brain (hemorrhagic), or a blood clot preventing blood flow (ischemic). A portable device for detecting the type of stroke would be a life-saver. Now ischemia lowers the conductivity of brain tissue, while hemorrhage raises it. EIT is an imaging method for recovering internal electric conductivity from boundary measurements. Therefore, EIT offers a promising approach for cost-effective stroke classification, although the resistive skull makes the inverse problem very difficult.

- Samuli Siltanen (*University of Helsinki*)

Evolution of barcode technology: mathematical models for advanced decoding algorithms

A crucial requirement for automatic barcode reading algorithms is real-time processing also on cheap, poorly performing hardware. Moreover, robustness against potential distortions of the processed signals (noise, blur, poor illumination, low resolution etc.) is a desirable property. After a brief introduction on the barcode world, with a view of related mathematical/statistical formulation of the decoding process, we will briefly outline some important open problems with related state-of-the-art research directions for the industrial barcode reading community.

- Francesco Deppieri (*DATALOGIC*)

Image analysis and biometrics @ Fingerprints
"Fingerprints" is a leading biometrics company with the main development focus on biometric systems comprising sensors, algorithms, software and packaging technologies. As part of the R&D Organization, the Algorithm development group works on advancing biometric system solutions in terms of security, convenience and performance. In this talk some algorithmic concepts of fingerprint sensing and the authentication process at "Fingerprints" is presented and the main challenges with regards to hardware design and real-time matching are discussed.

- Sara Soltani (*Fingerprint Cards, R&D Algorithm Development*)

MS71 Nonlinear and adaptive regularization for image restoration

Organizers:
Claudio Estatico (*University of Genoa*)
Giuseppe Rodriguez (*University of Cagliari*)

MS71-1 - Friday, 08 at 09:30 Main room - aula magna - SP.I.S.A. (SP.I.S.A., floor 0)

Adaptive image restoration in variable exponent Lebesgue spaces
We propose an iterative regularization algorithm in variable exponent Lebesgue spaces $L^p(.)$, which is able to automatically set up different regularization levels in different regions of the domain. Basically, modelling in $L^p(.)$ spaces allows to assign pointwise regularization parameters, associated to different values of the function parameter p(.). This is useful in image deblurring problems, where background, low intensity, and high intensity values of the image to restore require different filtering (i.e., regularization) levels.

- Claudio Estatico (*University of Genoa*)

On an elliptical trust-region procedure for ill-posed nonlinear least squares problems
We consider the numerical solution of noisy ill-posed nonlinear least squares problems with small residual. They arise when a mathematical model approximating a true distribution is fit to given data, in parameter estimation, experimental design and imaging problems. We propose an elliptical trust-region reformulation of a Levenberg-Marquardt procedure that, thanks to an appropriate choice of the trust-region radius, guarantees an automatic choice of the regularization parameters. Constrained problems are considered, too. Numerical results are provided.

- Stefania Bellavia (*University of Florence*)
  Elisa Riccietti (*University of Florence*)

Poisson imaging reconstruction by means of a consistent adaptive regularization method promoting (grouped) sparsity
Imaging reconstruction problems are usually addressed by minimizing a noise-dependent data-misfit term plus an l_1 penalty term (or an l_1/l_2 penalty) which is chosen to enforce the sparsity (or the grouped-sparsity) of image coefficients on a given suitable basis. In this work we propose an adaptive regularization method for Poisson imaging which promotes (grouped) sparsity in a consistent manner and it overcomes the need for expensive optimization strategies commonly applied with Poisson measurements.

  Federico Benvenuto (*University of Genoa*)
- Sabrina Guastavino (*University of Genoa*)

An infimal-convolution modelling for mixed image denoising problems
We consider the problem of denoising images corrupted by a mixture of noise distributions, which is typical for instance in astronomy and microscopy applications. The resulting variational model is the joint MAP estimator of the likelihood function and combines single data fitting terms in a nonlinear infimal convolution fashion. A well-posedeness analysis in suitable function spaces is provided. For the efficient computation of the numerical solution, a SemiSmooth Newton method is used.

- Luca Calatroni (*CMAP, École Polytechnique CNRS*)
  Juan Carlos De Los Reyes (*Escuela Politécnica Nacional*)
  Carola-Bibiane Schönlieb (*University of Cambridge*)

MS72 Inverse problems with imperfect forward models

Organizers:
Yury Korolev (*University of Cambridge*)
Martin Burger (*University of Muenster*)

MS72-1 - **Wednesday, 06 at 09:30** Room D (Palazzina A - Building A, floor 1)

A lattice analogue of the residual method for inverse problems with imperfect forward models

The residual method consists in minimizing a regularization functional over a feasible set defined by fidelity constraints. These fidelity constraints can account for errors in the forward operator, however, in the classical setting in normed spaces, this results in a non-convex optimization problem. In partially ordered spaces fidelity constraints can be expressed in a way that yields convex feasible sets. We will present the theory and applications in deblurring with uncertainty in the blurring kernel.

Martin Burger (*University of Muenster*)
- Yury Korolev (*University of Cambridge*)

All-at-once formulation and regularization of inverse problems

The conventional way of formulating inverse problems, such as parameter identification in PDEs, is via some forward operator, which is the composition of the observation operator with the parameter-to-state-map for the underlying PDE model. Recently, all-at-once formulations have been considered as an alternative to this reduced formulation, avoiding the numerical evaluation of a parameter-to-state-map. Here the model and the observation are considered simultaneously as one large system with the state and the parameter as unknowns.

- Barbara Kaltenbacher (*Alpen-Adria-Universität Klagenfurt*)

Deep learning for trivial inverse problems

Models used in inverse problems are never complete and even more importantly such models, perhaps optimal in given function spaces, hardly cover realistic inputs stemming from only a subset of the space of the unknowns, which however is unknown. Hence, data driven corrections to analytical models can compensate for both shortcomings. We analyze mathematically neural networks for solving almost trivial inverse problems and discuss data driven updates to the analytical model of magnetic particle imaging.

Hannes Albers (*University of Bremen*)
Tobias Kluth (*University of Bremen*)
- Peter Maass (*University of Bremen*)

Spatio-temporal imaging by joint motion and image reconstruction and its application to spat-temporal MRI

In this talk, we describe a variational model for spatio-temporal Magnetic Resonance Imaging (MRI) that allows linking the computation - in a single model - of the reconstruction of an image sequence from Fourier measurements to the inherent dynamics in the scene. More precisely, we recast the image formation and motion estimation problems as an unconstrained minimisation problem that is solved, iteratively, by breaking it up into two more computationally tractable problems. Particularly, we focus our model to solve the central limitation of MRI, which is the linear relation between the necessary measures to form an image and the acquisition time. We show that injecting physical motion into the compressed sensing computation produces a better approximation of the image formation, that, in fact, is closer to the gold-standard. We also demonstrate that the synergy created by our variational model turns out to have positive clinical potentials in terms of improving image quality. Finally, we shall close this talk by suggesting a further improvement of our model by creating a connection between our variational model and machine learning.

- Angelica I. Aviles-Rivero (*University of Cambridge*)
Carola-Bibiane Schönlieb (*University of Cambridge*)

MS72-2 - **Wednesday, 06 at 13:00** Room D (Palazzina A - Building A, floor 1)

Bayesian imaging inverse problems with partially unknown models

This talk presents a general Bayesian computation framework for performing inference in inverse problems with forward models that are partially unknown. A main novelty of the framework is that it uses MCMC-driven stochastic optimisation methods that tightly integrate modern high-dimensional Monte Carlo sampling and convex optimisation approaches. The proposed methodology is illustrated on a range of challenging imaging problems and compared to other techniques from the state of the art.

- Marcelo Pereyra (*Harriott-Watt University*)

Improved source estimation in EEG with Bayesian modelling of the unknown skull conductivity

The estimation and visualization of active parts of the brain from EEG recordings is referred to as the EEG source imaging. The source estimation is highly sensitive to modeling uncertainties of the computational model, especially the electrical properties of the head tissues. We show that the exact knowledge of the skull conductivity is not always necessary, since it can be taken into account statistically in the inversion by using the Bayesian approximation error approach.

- Alexandra Koulouri (*Aristotle University of Thessaloniki*)

A time-regularized blind deconvolution method via non-convex optimisation

Radio-astronomical imaging aims to probe a sky intensity image through an antenna array. The reconstruction quality highly depends on the calibration accuracy of the radio telescope. In this context, unknown time-dependent calibration kernels appearing in the measurement equation must be estimated. We rely on an alternating forward-backward structure to jointly estimate the sky image and the kernels, by solving a non-convex minimization problem incorporating data fidelity and advanced regularization terms.

Arwa Dabbech (*Heriot-Watt University*)
- Audrey Repetti (*Heriot-Watt University, Edinburgh*)
Pierre-Antoine Thouvenin (*Institut National Polytechnique de Toulouse*)
Yves Wiaux (*Heriot-Watt University*)

Accounting for model-errors in PDE-constrained optimization
Many inverse problems can be cast as a PDE-constrained optimization problem with non-linear equality constraints. By enforcing these constraints, however, we are tacitly assuming that the underlying PDE model is an accurate description of the underlying process. To account for imperfect models, I propose a relaxed formulation that treats the constraints through an additive penalty. I discuss ways to design efficient algorithms through the use of variable projection and present some numerical examples.

- Tristan van Leeuwen (*Utrecht University*)

MS73 Mathematical Methods for Spatiotemporal Imaging

Organizers:
Chong Chen (*LSEC, ICMSEC, Academy of Mathematics and Systems Science, Chinese Academy of Sciences*)
Barbara Gris (*Laboratoire Jacques-Louis Lions*)
Ozan Öktem (*KTH - Royal Institute of Technology*)

MS73-1 - **Friday, 08 at 14:00** Room P (Palazzina B - Building B, floor 0)

Large diffeomorphic deformation based image reconstruction method for spatiotemporal imaging
We propose a new image reconstruction model for spatiotemporal imaging in large deformation diffeomorphic metric mapping framework. This model can be divided into two sub-problems, where one is the usually static image reconstruction, and the other is the so-called indirect image registration. The indirect registration uses diffeomorphisms that transform the template to be reconstructed through a group action, which are generated by a flow equation that is defined by a velocity field with certain regularity.

- Chong Chen (*LSEC, ICMSEC, Academy of Mathematics and Systems Science, Chinese Academy of Sciences*)
Barbara Gris (*Laboratoire Jacques-Louis Lions*)
Ozan Öktem (*KTH - Royal Institute of Technology*)

Optical flow constrained joint motion estimation and reconstruction for dynamic inverse problems

- Andreas Hauptmann (*University College London*)

4D Reconstruction of motion corrected dynamic MR PET list mode data with regularization in the time domain
We present a method to reconstruct 4D images from MR PET list mode data with motion correction. We estimate a high resolution motion vector field from a short time MR acquisition and extend this frame using data driven PET techniques. Finally we reconstruct a motion corrected fully 4D image using time activity curves. We present results on clinical data.

- Fjedor Gaede (*Institute for Computational and Applied Mathematics, University of Münster*)

Generalized Sinkhorn Iterations for Regularizing Inverse Problems Using Optimal Mass Transport
The optimal transport problem gives a geometric framework for optimal mappings, but is computationally expensive and often intractable for large imaging problems. A recent development to address this is to use Sinkhorn iterations, and we extend this idea for fast computation of the proximal operator of the optimal transport cost. This opens up for using optimal transport in variational formulations for solving inverse problems in imaging, e.g., spatio-temporal reconstruction and problems with prior information.

Johan Karlsson (*KTH - Royal Institute of Technology*)
- Axel Ringh (*KTH - Royal Institute of Technology*)

MS73-2 - **Friday, 08 at 16:30** Room P (Palazzina B - Building B, floor 0)

Joint Motion Estimation and Source Identification with an Application to the Analysis of Cell Membranes
The main motivation for this work is to identify tissue loss and growth in kymographs of fluorescently labelled cell membranes in live Drosophila embryos. We propose a variational model based on mass conservation with a source term together with convective regularisation, discuss its numerical solution, and present experimental results. This is joint work with Nilankur Dutta, Jocelyn Étienne, and Carola-Bibiane Schönlieb.

Nilankur Dutta (*LIPHY, Université Grenoble Alpes*)
Jocelyn Étienne (*LIPHY, Université Grenoble Alpes*)
- Lukas F. Lang (*University of Cambridge*)
Carola-Bibiane Schönlieb (*University of Cambridge*)

Respiratory motion correction in PET/CT and PET/MR
We present the headlines of a maximum-likelihood image reconstruction and motion estimation method in positron emission tomography (PET). The basics of PET imaging, Poisson spatial processes and expectation maximisation (EM) reconstruction are revisited. We then introduce our algorithm and the quasi-Newton approach we adopted for motion estimation prom projection data. Finally, we present results on patient PET/CT and PET/MRI data.

Alexandre Bousse (*Institute of Nuclear Medicine, University of College London*)
- Elise Emond (*University College London*)

Learning digital models of Alzheimer's Disease progression
We will present mixed-effects models that relate the long-term history of phenomena based on short-term longitudinal observations. Complex dynamics involve non-linear interactions between features with various temporal characteristic. Riemannian geometry tools allow to model such spatiotemporal trajectories, describing average dynamics whose variations correspond to individual progression patterns. A stochastic version of the EM algorithm was used to estimated digital models of the Alzheimer's Disease progression, at both a population and individual level.

- Igor Koval (*Brain and Spine Institute, INRIA*)

MS74 Sequential Monte Carlo methods for inverse estimation in imaging science

Organizers:
Narayan Puthanmadam Subramaniyam (*Aalto University*)
Sara Sommariva (*Aalto University*)

MS74-1 - Friday, 08 at 14:00 Matemates (Matemates, floor 0)

Expectation–maximization algorithm with a Rao-Blackwellized particle smoother for joint estimation of neural sources and connectivity from MEG data
In this talk I will present an approach for the joint estimation of neural source locations, amplitudes and their interactions (functional connectivity) from magnetoencephalographic (MEG) signals. By formulating a state-space for the source locations and their moments, estimation of functional connectivity is reduced to system identification problem in a non-linear state space with a tractable linear sub-structure, whose solution is derived using a Rao-Blackwellized particle smoother (RBPS) combined with an expectation-maximization (EM) algorithm.

Xi Chen (*Cavendish Laboratory, University of Cambridge*)
Lauri Parkkonen (*Aalto University*)
- Narayan Puthanmadam Subramaniyam (*Aalto University*)
Simo Särkkä (*Aalto University, Department of Electrical Engineering and Automation*)
Sara Sommariva (*Aalto University*)
Filip Tronarp (*Aalto University, Department of Electrical Engineering and Automation*)

Tracking of cyclists in the velodrome using IMU and timing sensors
In this presentation we will describe novel Bayesian data fusion algorithms for localising cyclists on the velodrome race track. The path of the cyclist is described using a dynamical model expressed in the intrinsic coordinates of the bike, and we show how to fuse this with timing measurements derived from a video capture system and intertial measurements from a gyrometer and accelerometer attached to the bike. A combination of Rao-Blackwellised particle filtering/smoothing and optimal proposal particle filtering is developed for solution of this task.

Simon Godsill (*University of Cambridge*)
- Jiaming Liang (*University of Cambridge*)

Rao-Blackwellized particle filtering in multiple target tracking
This talk is concerned with application of Rao-Blackwellized particle filtering to multiple target tracking. In particular, the aim is to discuss formulation of track-based multiple target tracking as Rao-Blackwellized particle filtering in exactly or approximately conditionally Gaussian state-space models. In that formulation, the unknown data-associations and the unknown number of targets act as the non-linear variables which are sampled with sequential Monte Carlo. The aim is also to discuss the corresponding smoothing problem as well as sampling of parameters with particle MCMC methods.

- Simo Särkkä (*Aalto University, Department of Electrical Engineering and Automation*)

Bayesan sequential Monte Carlo approaches to simulated EEG-fMRI and EEG-fNIRS data
Due to the complementary nature of electrical and hemodynamic brain activity, joint data analysis can afford a better understanding of the underlying neural activity estimation. We propose a Bayesian sequential Monte Carlo approach (particle filter, PF), applied to simulated recordings of electrical (EEG) and neurovascular mediated hemodynamic activity (fNIRS/fMRI). The feasibility of the procedure and the improvements in both electrical and hemodynamic brain activity reconstruction when using the PF on combined measurements are shown.

- Filippo Zappasodi (*"G.d'Annunzio" University, Chieti*)

MS75 Geometric methods for shape analysis with applications to biomedical imaging and computational anatomy, Part II

Organizers:
Joan Alexis Glaunès (*MAP5, Université Paris Descartes*)
Sergey Kushnarev (*Singapore University of Technology and Design*)
Mario Micheli (*Harvey Mudd College*)

MS75-1 - Friday, 08 at 14:00 Room I (Palazzina B - Building B, floor 0)

Shape analysis through geometric distributions.
This talk will discuss the current state and development of frameworks like measures, currents, oriented and unoriented varifolds in diverse applications to shape analysis. We will emphasize the interest of the resulting metrics for diffeomorphic and non-diffeomorphic registration as well as shape classification.

- Nicolas Charon (*Johns Hopkins University*)

Constant and linear kernels on normal cycles for shape analysis
To define a dissimilarity measure between geometrical structures, we propose to use a representation of shapes with normal cycles (an object associated with the normal bundle of the shape which encodes all the curvature information). Using kernel metrics on normal cycles, we define a metric between shapes that fits in a framework of inexact registration. It allows for a matching that takes into account the region of high curvature and the boundaries of the shapes.

Joan Alexis Glaunès (*MAP5, Université Paris Descartes*)
- Pierre Roussillon (*Centre de Mathématiques et de Leurs Applications, Ecole Normale Supérieure Paris-Saclay*)

Bridge Simulation and Metric Estimation on Lie Groups and Orbit Spaces
Joint work with Stefan Sommer, Alexis Arnaudon and Line Kuhnel. Performing statistical inference of non-linear Manifold valued data has wide ranging applications in wide ranging fields including bioinformatics, shape analysis, medical imaging, computational anatomy, computer vision, and information geometry. Most common existing statistical inference techniques assume that the Manifold is a Riemannian Manifold with a pre defined canonical metric. In this talk I will present some of our recent work in estimating the Metric structure of the manifold.

- Sarang Joshi (*Scientific Computing and Imaging (SCI) Institute, the University of Utah*)

Development of the cortical surface via landmarks: labeling and trajectories of sulcal pits.
In brain surface analysis, modeling the development of the cortical surface from gestation to adulthood remains a challenge. Cortical folds, the sulci, have different levels of reproducibility across the population, but even for the most reproducible their shape presents a large variability. The subdivision of these folds in sulcal basins allows to better address this variability to identify homologies between different cortices. To each basin is associated a unique point of maximal depth called sulcal pit. Modeling the basins with oriented varifolds and using the reproducibility of these sulcal pits allow us to propose a new method to automatically identify homologous basins across subjects and to build an atlas map of these basins.

- Irène Kaltenmark (*Neurosciences Institut of La Timone (INT), Aix-Marseille University*)

MS75-2 - Friday, 08 at 16:30 Room I (Palazzina B - Building B, floor 0)

Estimating and using deformation constraints
A general approach for matching two shapes is based on the estimation of a deformation (a diffeomorphism) transforming the first one into the second one. We developed a new framework in order to build diffeomorphisms so that a prior on deformation patterns can be easily incorporated. This prior can for instance correspond to an additional knowledge one has on the data under study. Our framework is based on the notion of deformation modules which are structures capable of generating vector fields of a particular chosen type and parametrized in small dimension. Several deformation modules can combine and interact in order to general a multi-modular diffeomorphisms. I will present how this framework allows to incorporate a prior in a deformation model by first building an adapted deformation module and then using it to build modular deformations.

- Barbara Gris (*Laboratoire Jacques-Louis Lions*)

Normalized Hamiltonians for measure transport
In this talk, we propose to rescale the classical kernel cometric tensor of LDDMM theory to impose a stochasticity condition. We show that this operation breaks the right-invariance property of LDDMM metrics on spaces of diffeomorphisms, and replaces it with an awareness to the mass of the transported shape. Made computationally tractable by automatic differentiation libraries, the kernel normalization trick turns an extrinsic image deformation routine into an intrinsic measure transportation program.

- Jean Feydy (*Centre de Mathématiques et de Leurs Applications, Ecole Normale Supérieure Paris-Saclay*)

Computation of crowded geodesics on the universal Teichmüller space
The problems of geometric shape classification, identification, and cliquing are important considerations in pattern theory and computer vision. A popular mathematical approach is to consider the space of shapes as a metrized Riemannian manifold and to subsequently compute distances between points (i.e., shapes) on the manifold. We consider a particular

metrization of planar shapes that has the attractive properties of scale and translation invariance: the Weil-Peterson metric on the universal Teichmueller space. This metrization reduces the Riemannian structure to anaylsis of univariate functions. However, sufficiently complicated shapes induce "crowding" in the univariate functional representations: extremely fine structure that must be resolved in order to correctly model the topological shape space. We present a numerical technique that is effective at resolving shapes with reasonable amounts of crowding, and provide associated computational results. Finally, we identify current shortcomings and discuss in-development solutions to these problems.

• Sergey Kushnarev (*Singapore University of Technology and Design*)
Akil Narayan (*Scientific Computing and Imaging (SCI) Institute, the University of Utah*)

TEMPO: Feature-endowed Teichmüller extremal mappings of point clouds for geometry processing and shape classification

In recent decades, the use of 3D point clouds has been widespread in computer industry. The development of techniques in analysing point clouds is increasingly important. In particular, mapping of point clouds has been a challenging problem. In this talk, I will introduce a discrete analogue of the Teichmuller extremal mappings, which guarantees uniform conformality distortions, on point cloud surfaces. Based on the discrete analogue, we develop a novel method called TEMPO for computing Teichmuller extremal mappings between feature-endowed point clouds. Using our proposed method, the Teichmuller metric can be computed for evaluating the dissimilarity between point clouds. Consequently, our algorithm enables accurate shape recognition and classification. The idea can also be applied to geometry processing of 3D shapes. Experimental results will be demonstrated to show the effectiveness of our proposed method.

• Ronald Lui (*Chinese University of Hong Kong*)

MS76 Solving Inverse Problems in minutes: Software for imaging

Organizers:
Ozan Öktem (*KTH - Royal Institute of Technology*)
Holger Kohr (*Thermo Fisher Scientific*)
Jonas Adler (*KTH Royal Institute of Technology*)

MS76-1 - Friday, 08 at 14:00 Room F (Palazzina A - Building A, floor 2)

Software for prototyping inverse problems with real data

In this talk we present ODL (Operator Discretization Library, https://github.com/odlgroup/odl), a Python framework for fast prototyping in inverse problems. It features classes and functions that closely resemble mathematical structure, for instance an "Operator" class with "derivative" and "adjoint", or "Functional" with "gradient", "convex_conj" and "proximal". This allows to represent and solve inverse problems on a high level, while harnessing the computational power of optimized libraries for subtasks. We will demonstrate the concept on practically relevant cases.

Jonas Adler (*KTH Royal Institute of Technology*)
• Holger Kohr (*Thermo Fisher Scientific*)
Ozan Öktem (*KTH - Royal Institute of Technology*)

STIR: an Open Source library for PET and SPECT image reconstruction

STIR is Open Source software providing a Multi-Platform Object-Oriented framework for all data manipulations in tomographic imaging. Currently, the emphasis is on image reconstruction in emission tomography (PET and SPECT). Motion correction and parametric imaging is also supported. STIR is implemented in C++ but provides both a Python and MATLAB interface. STIR has an active developer community contributing new features. It can be downloaded from http://stir.sourceforge.net.

Nikolaos Efthymiou (*University of Hull*)
• Kris Thielemans (*Institute of Nuclear Medicine, University of College London*)
Charalampos Tsoumpas (*University of Leeds*)

Solving inverse problems in imaging with Shearlab.jl

Shearlab.jl (https://github.com/arsenal9971/Shearlab.jl) is a Julia Library with a toolbox for multidimensional data processing using the shearlet system as representation system, which is known to provide optimally sparse approximation of functions governed by anisotropic features. This talk will be focused on the use of the library for solving ill-posed inverse problems in imaging by sparse regularization applied to problem classes such as image denoising and image inpainting. Finally, we will discuss how to optimize the implementation using gpu accelerators.

• Héctor Andrade Loarca (*TU Berlin*)

Iterative tomography within minutes using RTK

In the past 10 years, many inverse problem approaches have been proposed for tomographic reconstruction. The Reconstruction ToolKit (RTK) is an open-source library for fast circular cone-beam CT, which provides efficient implementations of some of these "iterative" methods. In order to reach clinically acceptable reconstruction times, RTK combines GPU and multi-core implementations with algorithmic accelerations: ordered subsets, preconditioning, and empirical design of regularized reconstruction methods.

- Cyril Mory (*CREATIS, Lyon*)

MS76-2 - **Friday, 08 at 16:30** Room F (Palazzina A - Building A, floor 2)

Learning to Solve Inverse Problems with ODL

- Jonas Adler (*KTH Royal Institute of Technology*)

Efficient Image Optimization with Domain Specific Languages
Domain specific languages (DSLs) for optimization, such as AMPL and CVX, are widely used in fields such as control, finance, and power optimization where problems involve at most thousands of variables. Extending DSLs for optimization to image reconstruction, in which problems may have millions of variables, requires new approaches. We discuss recent work on DSLs for image optimization, focusing on generation of efficient solvers and viewing solvers as computational graphs.

- Steven Diamond (*Stanford University*)

Using the ASTRA Toolbox for implementing tomographic reconstruction algorithms
The ASTRA Toolbox is an open-source library with Python and Matlab interfaces offering GPU-accelerated forward and backprojection operators for algorithm developers. Since these are often the most time-consuming components of algorithms for tomographic reconstruction, this aids scaling algorithms to realistic data sizes. ASTRA has a very flexible support for projection geometries, and can model a wide range of experimental set-ups. In this talk, we will look at current and future features of the ASTRA Toolbox.

- Willem Jan Palenstijn (*Centrum Wiskunde & Informatica, Amsterdam*)

The RVL Framework Applied to Full Waveform Inversion
The Rice Vector Library (RVL) is a C++ package that provides mathematics-emulating abstract classes for expressing coordinate-free linear algebra and nonlinear optimization algorithms over Hilbert spaces. Design principles of RVL allow for the separation of access/manipulation of application dependent data structures from the underlying mathematical representation of optimization/linear algebra algorithms. We illustrate its use in solving in particular the Full Waveform Inversion seismic problem for joint source-medium parameter estimation.

- Mario Bencomo (*Department of Computational and Applied Mathematics (CAAM), Rice University*)
  William Symes (*Rice University*)

MS77 Advances in Ultrasound Tomography

Organizers:
Jennifer Mueller (*Colorado State University*)
Raul Gonzalez Lima (*Universidade de São Paulo*)

MS77-1 - **Friday, 08 at 14:00** Room C (Palazzina A - Building A, floor 1)

Low frequency Ultrasound Tomography Transducer for bedside lung monitoring
The present work describes the design of ultrasound transducers for lung monitoring. The central frequency shall be in the range of 50 to 150 kHz. A belt of transducers will be attached to the human thorax, the geometry of the tranducers must be compatible with the bedside use. It is investigated the acoustic field, the effect of a backing material to absorb the backward acoustic waves and the mechanical longitudinal stiffness of the transducer. A structural modal analysis of the transducer reveals the vibration modes of the contact plate. Numerical simulations of the transducer attached to a biological tissue are performed.

  Luis Henrique Camargo Quiroz (*Universidade de São Paulo*)
- Raul Gonzalez Lima (*Universidade de São Paulo*)
  Ely Lopes (*Universidade de São Paulo*)

Full-wave form inversion for breast cancer detection
Ultrasound is gaining interest as an alternative for X-ray mammography. By measuring the acoustic wave field accurately, the opportunity arises to reconstruct speed of sound profiles inside the breast. These profiles are useful to differentiate between cancerous and healthy breast tissues. Reconstructing these profiles from the measured wave field is a non-linear inverse problem. In my presentation, I will show how full-wave nonlinear inversion can be used to obtain speed of sound profiles.

- Koen W. A. van Dongen (*TU Delft*)

Modeling and direct reconstruction in ultrasound tomography
In medical applications of ultrasound tomography, the possibilities for transducer placement are constrained by the geometry of the human body. In this talk, optimal transducer placement and excitation patterns will be discussed for several geometries, and their effects on image quality and computation time will be compared for simulated medical imaging data reconstructed using iterative and a direct (D-bar) method.

- Jennifer Mueller (*Colorado State University*)

Qualitative ultrasound imaging from real and synthetic data through fast non-iterative schemes
We discuss different settings of the so-called qualitative (sampling) imaging methods for ultrasound measurements, with examples showing promising robustness from both synthetic and real ultrasound fixed-frequency data. Approximate knowledge of the background medium as well as multistatic data are required. Nevertheless, among other features, these algorithms are fast as they do not need forward solvers, and do not involve linearizations such as Born/Rytov, taking into full account multiple scattering effects which allow more flexible contrasts.

- Wagner Muniz (*Federal University of Santa Catarina, Brazil*)

MS77-2 - **Friday, 08 at 16:30** Room C (Palazzina A - Building A, floor 1)

Breast Imaging with 3D Ultrasound Computer Tomography
Ultrasound Tomography is an emerging technology for early breast cancer diagnosis. At Karlsruhe Institute of Technology we are developing a 3D ultrasound computer tomography device which may overcome the limitations of current 2D systems. In this overview talk we explore system design aspects, the challenges for tomographic reconstruction, present first clinical results and discuss recent as well as future advancements.

- Torsten Hopp (*Karlsruhe Institute of Technology*)

Three-dimensional time-domain waveform inversion for breast ultrasound tomography
Ultrasound computed tomography (USCT) is a promising medical imaging modality that offers several novel tissue contrasts and holds great potential for breast cancer screening. Waveform inversion-based image reconstruction methods account for higher order diffraction effects and can produce high-resolution USCT images. However, many USCT studies have assumed a 2D imaging model, which can result in image artifacts in practice. In this work, a waveform inversion method for 3D USCT is reported.

- Mark Anastasio (*Washington University in St. Louis*)
  Luca Forte (*Washington University in St. Louis*)

Ultrasound computed tomography using a wave equation with fractional Laplacian absorption
Ultrasound CT can be used to estimate maps of the sound speed and acoustic absorption. The frequency-dependence of absorption in biological tissue empirically follows a power-law with a non-integer exponent. Such behaviour can be incorporated into the wave equation as a term depending on a fractional time derivative or a fractional Laplacian. The latter has computational advantages. The use of this model in full-wave inversions for both the sound speed and absorption will be described.

- Ben Cox (*Department of Medical Physics, University College London*)

The use of standard CT-Scans for the development of an anatomical atlas for Ultrasound Tomography
Ultrasound Tomography (UST) may be an aid, together with Electrical Impedance Tomography, to monitor the lung in ICU environment. One approach to solve the UST inverse problem is to use Bayes's Theorem. The prior probability density function is in term of tissues sound velocities of the human thorax. Standard CT-scans may be used for anatomical information after correction of the scapula position and correction of the skin geometry due to the belt of transducers placement.

- Tayran Mila Mendes Olegario (*Department of Mechanical Engineering, University of Sao Paulo*)

MS78 Recent developments in variational image modeling

Organizers:
Sonia Tabti (*Université de Caen, CNRS*)
Rabin Julien (*CNRS, Normandie Univ.*)

MS78-1 - **Friday, 08 at 16:30** Matemates (Matemates, floor 0)

Symmetric upwind scheme for discrete Non-Local Total Variation. Applications in image and point-cloud processing.
Discrete formulations of the weighted Total Variation (TV) based on upwind schemes have been proposed for imaging problems in a local setting by Chambolle et al. in 2011 and in a non-local setting for graphs by Elmoataz et al. in 2008. Two new graph-based upwind and symmetric formulations expressed with the euclidean and infinite norms respectively are proposed. Theoretical and practical interest of such formulations is demonstrated in image and point cloud processing applications.

Abderrahim Elmoataz (*University of Caen Normandie, CNRS*)
Rabin Julien (*CNRS, Normandie Univ.*)
- Sonia Tabti (*Université de Caen, CNRS*)

Regularized non-local Total Variation and application in image restoration
The usual Non-Local Total Variation (NLTV) term penalizes discrepancy between some specified pairs of pixels, a weight value is computed between these two pixels to measure their dissimilarity. In this presentation, we describe a stable scheme to regularize weight values in the NLTV model, allowing to restore them when they are difficult to define. We also show that the proposed model better recovers thin structures on inpainting, zooming and denoising problems.

- Zhi Li (*Department of Computational Mathematics, Science and Engineering (CMSE) Michigan State University*)
Francois Malgouyres (*Institut de Mathématiques de Toulouse, Université Paul Sabatier*)
Tieyong Zeng (*Department of Mathematics, The Chinese University of Hong Kong, Shatin, N.T.*)

Combining Local Regularity Estimation and Total Variation Optimization for Scale-Free Texture Segmentation
Texture segmentation still constitutes an ongoing challenge, especially when processing large-size images. In this contribution we focus on (i) extracting simultaneously characteristics such as local regularity and local variance, integrating a scale-free (or fractal) wavelet-leader modeling that allowed the problem to be reformulated in a convex optimization framework by including a Total Variation penalization and (ii) investigating the potential of block-coordinate strategies in order to deal with the memory and computational cost induced by the minimization.

Patrice Abry (*CNRS, Laboratoire de Physique de l'ENS de Lyon*)
- Pascal Barbara (*Laboratoire de Physique de l'ENS de Lyon*)
Nelly Pustelnik (*CNRS, Laboratoire de Physique de l'ENS de Lyon*)

Image restoration and segmentation using the Ambrosio-Tortorelli functional and discrete calculus
The Mumford-Shah (MS) functional is an influential variational model in image segmentation and restoration. The minimizers of Ambrosio-Tortorelli (AT) functional can be shown to converge to a MS minimizer. Hence, we formulate AT using the full framework of discrete calculus, which is able to sharply represent discontinuities thanks to a more sophisticated topological framework. We show that we are able to represent sharp discontinuities with high stability to noise in comparison with finite difference schemes.

- Marion Foare (*Laboratoire de Physique, ENS Lyon*)
Jacques-Olivier Lachaud (*Laboratoire de Mathématiques, Université Savoie Mont-Blanc*)
Hugues Talbot (*Laboratoire d'Informatique Gaspard-Monge, Université Paris-Est, ESIEE*)

MS79 From optimization to regularization in inverse problems and machine learning

Organizers:
Silvia Villa (*Politecnico di Milano*)
Lorenzo Rosasco (*University of Genoa, Istituto Italiano di Tecnologia; Massachusetts Institute of Technology*)

MS79-1 - **Friday, 08 at 16:30** Room D (Palazzina A - Building A, floor 1)

Parameter learning for total variation type regularisation schemes
In this talk we will discuss the optimisation of a parametrised total variation regularisation approach in which the parameters correspond to weights in front of different total variation type regularisers and multiple convex discrepancy terms including L2, L1 and Kullback-Leibler discrepancies. Parameters in this model will be optimised with respect to a loss function that assesses the quality of the solution when compared to a training set of desirable solutions. The well-posedness, numerical solution and applications of this approach in image denoising will be discussed.

Luca Calatroni (*CMAP, École Polytechnique CNRS*)
Juan Carlos De Los Reyes (*Escuela Politécnica Nacional*)
- Carola-Bibiane Schönlieb (*University of Cambridge*)
Tuomo Valkonen (*University of Liverpool*)

Inexact variable metric forward-backward methods for convex and nonconvex optimization
In this talk we focus on variable metric forward-backward algorithms, where the metric underlying the backward/proximal step may change at each iteration to better capture the local features of the objective function and constraints. The main theoretical convergence properties will be described in the convex and nonconvex case and practical implementation issues will be discussed.

- Silvia Bonettini (*University of Modena and Reggio Emilia*)

A Random Block-Coordinate Douglas-Rachford Splitting Method with Low Computational Complexity for Binary Logistic Regression
We propose a new optimization algorithm for sparse logistic regression based on a stochastic version of the Douglas-Rachford splitting method. Our algorithm sweeps the training set by randomly selecting a mini-batch of data at each iteration, and it allows us to update the variables in a block coordinate manner. Our approach leverages the proximity operator of the logistic loss, which is expressed with the generalized Lambert W function. Experiments carried out on standard datasets demonstrate the efficiency of our approach w.r.t. stochastic gradient-like methods.

Luis M. Bricenio-Arias (*Departamento de Matemática, Universidad Técnica Federico Santa María, Valparaíso*)

Giovanni Chierchia (*Université Paris Est, LIGM UMR 8049, CNRS, ENPC, ESIEE Paris, UPEM, Noisy-le-Grand.*)
- Emilie Chouzenoux (*Université Paris-Est Marne-la-Vallée*)
Jean-Christophe Pesquet (*Université Paris-Saclay*)

Iterative optimization and regularization: convergence and stability

In this talk we will review common first order optimization methods from a regularization perspective. In particular, we will discuss the interplay and effect of acceleration for convergence and stability.

- Lorenzo Rosasco (*University of Genoa, Istituto Italiano di Tecnologia; Massachusetts Institute of Technology*)

Contributed Presentations Abstracts

CP1 Contributed session 1

Chairs:
Michele Piana (*Dept. Mathematics, University of Genoa*)

CP1-1 - **Tuesday, 05 at 13:30** Room 1 (Redenti, floor 0)

Efficient projection onto the infinity-1 ball using Newton's root-finding method
The projection onto the ℓ_1,∞ ball ($P\ell\_1,\infty$) has been applied in cognitive neuroscience and classification tasks, and it is an example of mixed norms, which recently have gained popularity for inducing group sparsity priors in several applications. We present a new algorithm, eight times faster than the state-of-the-art, to solve $P\ell\_1,\infty$ for which we have derived an analytical expression that allows us to apply Newton's root-finding method along with an effective pruning strategy.

Gustavo Chau (*Pontificia Universidad Catolica del Peru*)
- Paul Rodriguez (*Pontificia Universidad Catolica del Peru*)

Brendt Wohlberg (*Los Alamos National Laboratory*)

Image Recovery by Block-Iterative Asynchronous Proximal Splitting
[1] introduces a new class of proximal splitting algorithms that differ from existing methods in that they are both block-iterative and asynchronous, and allow for individual conditioning of the functions. We present the first numerical applications of the method to imaging, and discuss how its flexibility leads to extremely fast implementations. Extensive numerical simulations are provided. Joint work with L. Glaudin. [1] P. Combettes and J. Eckstein, Asynchronous block-iterative decomposition.., Mathematical Programming, 2017.

- Patrick Combettes (*North Carolina State University*)

Fast l0 sparse approximation problem via a Scaled Alternating Optimization
Inspired by techniques used for alternating optimization of nonconvex functions, we propose a simple yet effective algorithm with better trade-off between accuracy and computation time than the state-of-the-art for the nonconvex ℓ_0 regularized optimization (ℓ_0-RO) problem. Given an initial solution, we first find the vanilla solution to ℓ_0-RO via a descent method (Nesterov's AGP), to then estimate a new one by scaling the dictionary involved in ℓ_0-RO, considering only a reduced number of its atoms.

- Paul Rodriguez (*Pontificia Universidad Catolica del Peru*)

Composite Optimization by Nonconvex Majorization-Minimization
Many tasks in imaging can be modeled as the minimization of non-convex composite functions. Interpreting previous optimization methods as majorization-minimization algorithms show that convex majorizers were previously considered. Yet, certain classes of non-convex majorizers still allow solving each sub-problem to (near)-optimality, leading to a provably convergent optimization scheme. Numerical results illustrate that by applying this scheme, one can achieve superior local optima compared to descent methods, while being significantly more efficient than global optimization methods.

- Jonas Geiping (*University of Siegen*)
  Michael Moeller (*University of Siegen*)

A class of primal-dual proximal algorithms for learned optimization

Inspired by recent advances in machine learning, and in particular by the concept of learning an optimizer, we investigate a class of proximal primal-dual optimizers with a fixed amount of memory. We derive convergence criteria and find several sub-classes corresponding to classical optimization methods such as Chambolle-Pock and Douglas-Rachford methods. Finally, we discuss the choice of algorithm instances for concrete problems.

Jonas Adler (*KTH Royal Institute of Technology*)
- Sebastian Banert (*KTH - Royal Institute of Technology*)
  Johan Karlsson (*KTH - Royal Institute of Technology*)
  Ozan Öktem (*KTH - Royal Institute of Technology*)
  Axel Ringh (*KTH - Royal Institute of Technology*)

CP2 Contributed session 2

Chairs:
Serena Morigi (*Dept. Mathematics, University of Bologna*)

CP2-1 - Tuesday, 05 at 16:00 Room 1 (Redenti, floor 0)

Fractional differentiation for image classification

The image classifier consists of two interacting modules: feature extraction and linear classification. Feature extraction relies on evaluating spatial derivatives of integer or fractional order of the image, followed by non-linear transformations in the Fourier domain. Linear classification relies on multivariate statistical analysis of feature vectors. Training minimizes a loss function: the latter depends on the parameter n-tuple which controls feature extraction. Application: discrimination of bacterial spores among airborne particulate material.

- Giovanni Franco Crosta (*University of Milan Bicocca, Dept. Earth- and Environmental Sciences*)

Hurst Parameter Estimation of Fractional Brownian Surfaces

The Hurst parameter of a fractional Brownian motion (fBm) on a smooth manifold determines the regularity of the corresponding fractional Brownian surface (fBs). Estimating the regularity of a given fBs is difficult since the underlying fBm is unknown. We propose here the first spectral-regression algorithm to estimate the Hurst parameter of a given fBs. The algorithm is evaluated on a set of simulated fractional Brownian spheres and we present an application to brain surfaces.

Olivier Coulon (*Aix-Marseille University, Institut de Neurosciences de La Timone*)
Julien Lefèvre (*Aix-Marseille University*)
Hamed Rabiei (*Aix-Marseille University*)
- Frédéric Richard (*Aix-Marseille University*)

Error Analysis for Filtered Back Projection Reconstructions in Fractional Sobolev Spaces

The filtered back projection formula allows to reconstruct bivariate functions from given Radon samples, where low-pass filters of finite bandwidth are employed to stabilize the reconstruction. Our aim is to analyze the inherent approximation error incurred by the low-pass filter. We prove error estimates in fractional Sobolev spaces along with asymptotic convergence rates as the bandwidth goes to infinity, where we observe saturation at fractional order depending on smoothness properties of the filter's window function.

- Matthias Beckmann (*University of Hamburg*)
  Armin Iske (*Dept. Mathematics, University of Hamburg*)

Unsupervised Segmentation of Colonic Polyps in NBI Images based on Wasserstein distances

We propose an automatic and unsupervised method for the segmentation of colonic polyps for in vivo Narrow-Band-Imaging (NBI) data, during optical colonoscopy, aiming at the prevention of colon cancer. The method is based on the Chan & Vese segmentation model and involves the sum of different Wasserstein distances, relying on histograms of suitable image descriptors, such as the intensity, texture, scale and orientation.

- Isabel Figueiredo (*University of Coimbra*)
  Pedro Figueiredo (*Faculty of Medicine, University of Coimbra and Department of Gastroenterology, CHUC, Coimbra*)
  Luís Pinto (*Department of Mathematics, University of Coimbra*)
  Richard Tsai (*Department of Mathematics, University of Texas at Austin, and KTH Royal Institute of Technology, Sweden.*)

PDE based Segmentation of Vector-valued Texture Images using Sobolev Gradients

In this paper, we propose a method for minimization of segmentation model for vector-valued texture images. The texture in the image will be smooth by using L_0 gradient norm and then the segmentation model will be minimized through sobolev gradient for fast convergence. The better performance of the method will observed from the experimental results. Results of the proposed method are compared with L^2 gradients.

Noor Badshah (*University of Engineering and Technology Peshawar*)
Hassan Shah (*University of Engineering and Technology Peshawar*)
- Fahim Ullah (*University of Engineering and Technology Peshawar*)

Variational Shape Prior Segmentation With an Initial Curve Based on Image Registration Technique
In this talk, we propose a novel model for the shape prior segmentation that produces robust results using the hierarchical image segmentation and an attraction term. Moreover, we adopt an image registration technique and a multi-region image segmentation to get an initial for a given shape prior. Finally, we consider the free-form deformation in obtaining the shape function from the reference shape prior for real-world images.

- Chang-Ock Lee (*KAIST*)
Doyeob Yeo (*Electronics and Telecommunications Research Institute*)

CP3 Contributed session 3

Chairs:
Elena Loli Piccolomini (*Dept. Computer Science and Engineering, University of Bologna*)

CP3-1 - Wednesday, 06 at 09:30 Room 1 (Redenti, floor 0)

Chest radiograph Image Enhancement, A Total Variation-Undecimated Wavelets Approach
Most often medical images such as chest radiographs have low dynamic range and many of their targeted features are difficult to identify. Intensity transformations such as wavelet thresholding that improve image quality introduces unwanted artifacts into the image. A combined total variation-undecimated wavelet enhancement algorithm that leads to a high level chest radiograph image denoising in lung nodules detection while preserving important features and reducing the average number of false positives and false negatives is proposed.

- Anthony Aidoo (*Eastern Connecticut State University*)

Spatiotemporal PET reconstruction using total variation based priors
In this talk, we focus on dynamic Positron Emission data reconstruction. We present regularization methods that are based on different edge preserving priors adapted to problems corrupted by Poisson noise. In particular, we consider spatiotemporal Total Variation (TV), Total Generalised Variation (TGV) reconstructions and their extensions to the infimal convolution approach as proposed by Holler and Kunisch. The numerical solutions of the corresponding variational problems are evaluated using Primal-Dual Hybrid Gradient (PDHG) optimisation methods under diagonal preconditioning. We compare them with the state of the art techniques as Expectation Maximization (EM) reconstruction and Filtered backprojection for simulated dynamic brain data. This is a joint work with Clovis Tauber (INSERM, Tours) and Maïtine Bergounioux (MAPMO, Orléans).

Maïtine Bergounioux (*CNRS - Université d'Orléans UMR 7013*)
- Evangelos Papoutsellis (*Université Francois Rabelais de Tours*)
Clovis Tauber (*UMRS Inserm U930, Imagerie et Cerveau, Université de Tours*)

Edge-Adaptive Image Reconstruction
Total variation and high order total variation methods for image reconstruction rely on sparsity throughout some domain. The spatial variation of the sparsity is not typically accounted for, however. We propose a new method for image reconstruction from non-uniform Fourier data that uses edge detection to indicate regions of sparsity and targets regularization appropriately.

Richard Archibald (*Oak Ridge National Laboratory*)
- Victor Churchill (*Dartmouth College*)
Anne Gelb (*Dartmouth College*)

X-ray tomography in periodic slabs
I will consider X-ray tomography in a product of an interval and a Euclidean space of any dimension. If one does not assume compact support or suitable decay, the X-ray transform has a non-trivial kernel. I will characterize the kernel for periodic functions. I will also discuss tensor tomography. The kernel consists of tensor fields of two kinds, and it can be fully characterized. This is based on joint work with Gunther Uhlmann.

- Joonas Ilmavirta (*University of Jyväskylä*)

Quantitative Photoacoustic Tomography
Quantitative photoacoustic tomography is an imaging technique that estimates choromophore concentrations by combining optical information and the ultrasonic waves that arise from the photoacoustic effect. The discontinuous Galerkin method is used to the model photoacoustic wave propagation in a fluid with an elastic layer. Inversion is done within the Bayesian framework using adjoint wavefields. Bayesian approximation error approach is used to marginalise over the geometry of the elastic layer.

- Hwan Goh (*University of Auckland*)

Adaptive Truncated Total Least Squares for an Inverse Scattering Problem from Ultrasound Tomography

In ultrasound tomography, we need to solve the inverse and the forward model to approximate a scattering function. This inverse scattering problem is constructed and solved using distorted Born iterative (DBI) method. Using the Born approximation (BA) as an initial guess, it solves three sub-problems, the most difficult of which is an inverse problem for the scattering function. Two truncated total least squares algorithms are considered for solving a regularized version of this inverse problem.

Mohamed Almekkaway (*The Pennsylvania State University*)
- Jesse Barlow (*The Pennsylvania State University*)

Anita Carevic' (*University of Split*)
Ivan Slapnicar (*University of Split*)
Xingzhao Yun (*The Pennsylvania State University*)

CP4 Contributed session 4

Chairs:
Fabiana Zama (*Dept. Mathematics, University of Bologna*)

CP4-1 - Wednesday, 06 at 13:00 Room 1 (Redenti, floor 0)

CORVO: a software tool for computing volume of complex biological structures in medical images and videos

We present CORVO (Computing Organoids' VOlume in medical images), a tool for calculating the volume of complex time-changing 3D structure from medical images and/or videos. CORVO is equipped with an advanced statistical data processing method to distinguish noise from signal and to compare and analyze the time dynamics of 3D structures. We tested CORVO for the analysis of agonist-induced variation of rectal organoids volume.

Anna Baruzzi (*Department of Medicine, University of Verona*)
Sara Caldrer (*Department of Medicine, University of Verona*)
Michela Lecca (*Fondazione Bruno Kessler - Center for Information and Communication Technology*)
- Paola Lecca (*Department of Medicine, University of Verona*)

Paola Melotti (*Centro Fibrosi Cistica Azienda Ospedaliera Universitaria Integrata Verona*)
Claudio Sorio (*Department of Medicine, University of Verona*)

Resampling Strategies in Medical Imaging

PET-CT, PET-MR, or SPECT-CT allows simultaneous acquisition of functional and structural images which facilitates spatial localization of physiological processes to physical organs or ROIs. However, resolution is severely degraded by physical factors that compromise quantitative accuracy of functional parameters. The resolution and SNR could be boosted by utilizing complementary/correlated information from co-registered, high-resolution structural images. The high-resolution image is resampled to obtain voxel-wise correspondences. This work explores the impact of resampling strategies in medical imaging.

- Hassan Mohy-ud-Din (*School of Science and Engineering, LUMS*)

Breast Cancer Classification via Deep Convolutional Neural Networks

Detecting and treating tumors in early stages is key to reducing cancer mortality. We present automatic classification techniques for breast lesions in screening mammography. The images undergo data augmentation, preprocessing with global and local contrast normalizations, and then combined with various scales of rotationally symmetric Laplacian of Gaussian filters. We employ the deep convolutional neural networks to extract the discriminative information from the data, and characterize benign and malignant lesions. The performance is compared against the state-of-the-art image descriptors, such as HOG and SVM.

- Jue Wang (*Union College*)

Yongjian Yu (*Axon Connected LLC*)

Mathematical analysis of Magnetic Resonance Fingerprinting

Magnetic resonance fingerprinting (Ma et al, Nature, 2013) is a method for estimating multiple spatially varying medium parameters from a single MRI experiment. It differs from standard MRI in that spins are not brought to a stationary state, as RF flip angles and repetition times may vary during the entire experiment. We will discuss a mathematical model for MRF imaging and a quantitative basis for the choice of the various parameters.

- Chris Stolk (*University of Amsterdam*)

Magnetic resonance-based quantitative imaging of the electric properties at radiofrequency without phase information.

Electric properties tomography of human bodies from measurements performed by magnetic resonance imaging (MRI) is an innovative research field emerged in last years and denoted as MREPT. The accuracy of most MREPT approaches proposed in literature suffers from the impossibility of measuring the phase of the MRI transmit coil sensitivity. A variation of the contrast source inversion technique for MREPT, specifically conceived to work without the phase information, will be described.

- Alessandro Arduino (*Istituto Nazionale di Ricerca Metrologica (INRiM)*)
  Oriano Bottauscio (*Istituto Nazionale di Ricerca Metrologica (INRiM)*)
  Mario Chiampi (*Politecnico di Torino*)
  Luca Zilberti (*Istituto Nazionale di Ricerca Metrologica (INRiM)*)

CP5 Contributed session 5

Chairs:
Salvatore Cuomo (*Dept. Mathematics and Applications "Renato Caccioppoli", University of Naples*)

CP5-1 - **Wednesday, 06 at 15:30** Room 1 (Redenti, floor 0)

A new wavelet based metric for color image similarity assessment
Following the first promising preliminary results, we study different strategies for the extension to color images of the Wavelet Normalised Root Mean Squared Error (WNRMSE), a new image similarity assessment metric, previously introduced and extensively studied by the authors for monochromatic images. The theoretical properties of the resulting color image metrics are studied, and the different extension strategies are tested and compared on the standard benchmark database TID2013.

Maria Grazia Albanesi (*Department of Electrical, Computer and Biomedical Engineering, University of Pavia*)
Riccardo Amadeo (*Department of Electrical, Computer and Biomedical Engineering, University of Pavia*)
- Silvia Bertoluzza (*CNR, IMATI "Enrico Magenes"*)

Multiwavelet Design by Matrix Spectral Factorization
Given a multiscaling function with symbol $H(z)$, its low-pass product filter has the symbol $P(z) = H(z)H(z)^*$. We are interested in finding $H(z)$, given a $P(z)$ with desirable features. Unfortunately, desirable $P(z)$ cause numerical problems with the factorization algorithm. I will describe the setup of the problem, and various attempts to speed up its convergence and improve accuracy.

- Fritz Keinert (*Iowa State University*)

Cone-Adapted Shearlets and Radon Transforms
We show that the cone-adapted shearlet coefficients can be computed by means of three classical transforms: the affine Radon transform, a 1D wavelet transform and a 1D convolution. This yields formulas that open new perspectives both for finding a new algorithm to compute shearlet coefficients and for the inversion of the Radon transform. Furthermore, the strong connection between shearlets and wavelets suggests an alternative proof of the wavefront set resolution properties of the shearlet transform.

- Francesca Bartolucci (*University of Genoa*)
  Filippo De Mari (*University of Genoa*)
  Ernesto De Vito (*University of Genoa*)
  Francesca Odone (*University of Genoa*)

A variational model for simultaneous video inpainting and motion estimation
We consider a functional proposed by Lauze and Nielsen (2004) for motion compensated inpainting and recently applied by the same authors to problems of video deinterlacing (2008) and video super-resolution (2011). We modify their model in order to achieve better variational properties and we study the corresponding relaxed functional, wich gives information about numerical algorithms designed for the original functional. Minimizers of the relaxed functional are vector valued functions of bounded variation, so that a video content which is discontinuous along the boundaries of moving objects can be reconstructed. Moreover, we find a representation formula of the relaxed functional which shows explicitly the role of discontinuities of the various functions involved in the variational model. Joint work with R. March.

- Giuseppe Riey (*University of Calabria*)

Relative Velocity Estimation from a single Uniform Linear motion Blurred Image using The Discrete Cosine Transform
Motion blur usually happens to image recording systems. Nowadays, this rich source of data is mostly dismissed in favor of image restoration. We introduce a novel approach for estimating kinematic quantities such as direction and speed of motion using the Discrete Cosine Transform (DCT). The mean relative error of our DCT PSeudo Cepstrum for speed estimation was 5.15%. The DCT frequency analysis is more accurate than all competitors evaluated.

- Jimy Alexander Cortes (*Universidad Tecnologica de Pereira*)
  Juan Bernardo Gómez (*Universidad Nacional de Colombia*)
  Juan Carlos Riaño (*Universidad Nacional de Colombia*)

Coherent interferometric imaging of sources in fluid flow
In this communication we present a coherent interferometric (CINT) imaging algorithm to localize acoustic sources in random fluid flows. It uses empirical correlations of the acoustic waves recorded at the bottom of the flow to possibly locate the sources emitting the waves above it. We rely on an analytical model of wave transmission in randomly stratified fluid flows to develop the algorithm. This model is established in a particular regime of separation of scales.

- Etienne Gay (*ONERA*)

CP6 Contributed session 6

Chairs:
Luigi Di Stefano (*Dept. Computer Science and Engineering, University of Bologna*)

CP6-1 - Thursday, 07 at 09:30 Room 1 (Redenti, floor 0)

Comparison of unsupervised methods to quantify the width of elongated structures.
We compare different unsupervised approaches to quantify the width of elongated structures in biological images. Two approaches detect first the centerline of the structure and rely on topological asymptotics of various cost functions and a fourth order elliptic PDE. The other approaches aim at detecting directly the boundaries of the structures: the gold standard is Canny's edge detector, and the last is based on topological asymptotics of a second order elliptic PDE.

- Jerome Fehrenbach (*University of Toulouse*)
  de Gournay Frederic (*INSA Toulouse*)

Clustering based dictionary learning
Usual methods for dictionary learning applied to multidimensional data require a first vectorization step, loosing the intrinsic spatial correlation of the samples. We present a method based on a generalization of the Haar wavelet transform that builds a dictionary from a hierarchical clustering of the data. Depending on the chosen clustering method, no vectorization of the data is required. We will present numerical results in the case of two dimensional patches extracted from natural images.

- Renato Budinich (*University of Göttingen*)
  Gerlind Plonka (*University of Goettingen*)

Non-negative image reconstruction based on tensor dictionary learning
Tensor-based dictionary learning is a natural approach to form accurate, compressible representations of high-dimensional data (Soltani, Kilmer, Hansen, BIT 2016). In this talk, we explore the generalizability of these tensor dictionaries for image reconstruction problems. For instance, can a dictionary learned from a certain class of images be used to reconstruct a wider variety of images? To reconstruct images efficiently and sparsely from tensor dictionaries, we present a tensor-based Modified Residual Norm Steepest Descent algorithm.

Misha Kilmer (*Tufts University*)
- Elizabeth Newman (*Tufts University*)

Comparison of Generalized and Classical Reweighted Algorithms for Recovering Sparse Signals
We introduce a generalized l1 greedy algorithm for recovering sparse signals and demonstrate its superior performance over the classical reweighted l1 minimization algorithm (Candes, et. al) and the l1 greedy algorithm (Petukhov and Kozlov). Moreover, we show our algorithm is better at detecting small entries of unknown sparse signals thereby dramatically speeding up their recovery via l1 minimization. Finally, we discuss how to improve our algorithm by adapting the wavelet technique of semisoft thresholding.

Edward Arroyo (*School of Professional Studies, Northwestern University*)
- Fangjun Arroyo (*Francis Marion University*)

From digital images to bar codes
The recognition of objects in digital images is a key problem in computer vision. It has received the attention of many researchers in order to evaluate and improve the performance of descriptors but mainly the shape descriptor. In this talk, we will consider the persistent homology which is an algebraic tool to measure the topological features of shapes of high dimensional data. We use complexes to represent continuous spaces and specially the cubical complexes that are considered the basis of digital images. Using cubical complexes inside of triangulation reduce significantly the size of complexes. We represent this algebraic characterization as bare-codes that are a finite union of intervals and which are considered the shape descriptor. The benefits of this approach will be presented at the last section of this talk in the Arabic handwriting recognition using structural and syntactic pattern attributes.

- My Ismail Mamouni (*CRMEF Rabat*)

Combined Shearlet shrinkage and Yaroslavsky's filter for image denoising
We have proposed a denoising method by combining shearlet transform method and weighted Yaroslavsky's filter (YF) for a wide class of cartoon like images with various properties such as thin features and naturalistic. The weights of the Yaroslavsky's filter are also achieved by pixel similarities in the restored image achieved from shearlet transform method. The theoretical results are confirmed via simulations for images corrupted by additive white Gaussian noise. Experimental results illustrate that proposed approach has good effect on suppressing the pseudo-Gibbs and shearlet-like artifacts and can obtain better performance in terms of mean square error (MSE), peak signal to noise ratio (PSNR) and structural similarity (SSIM) index rather than classical shearlet transform method.

- Reza Abazari (*University of Tabriz*)

Mehrdad Lakestani (*University of Tabriz*)

CP7 Contributed session 7

Chairs:
Gerardo Toraldo (*University of Naples Federico II*)

CP7-1 - Thursday, 07 at 14:00 Room 1 (Redenti, floor 0)

Image Compression Using Two Dimensional DCT and Least Squares Interpolation

Recently we published a new image compression method utilizing a combination of discrete cosine transform and least squares interpolation method. In this talk, we will present a discussion of the mathematical background, outline of the approach, complexity computations, pseudocode, and an explanation of how to implement the algorithm for applications that require the coded bits to be binary streams. We then provide the results, including comparisons to many recently published works. Also, we compare our work versus both JPEG and JPEG 2000, where we have significant improvement. The results indicate positive progress and effectiveness of the new approach in terms of comparability to other works and applicability in real time applications.

- Sameh Eisa (*University of California, Irvine*)

Fast Tensor Principal Component Analysis for Volumetric Image Processing

The image compression based on principal component analysis is a well-established fundamental technique. Organs, cells and micro-structures in cells dealt with in biomedical image analysis are volumetric images. Tensor expression of volumetric images allows us to derive unified frameworks to process and analyse these volumetric images dealt with in medical and biological sciences. We develop a fast approximate tensor principal component analysis for volumetric images by using tensor decomposition.

- Atsushi Imiya (*IMIT, Chiba University*)

Mathematical analysis on out-of-sample extensions of dimensionality reduction by diffusion mapping

Many unsupervised learning algorithms provide dimensionality reduction (DR), among which the diffusion mapping is proved attractive and effective. However, these method cannot be straightforwardly applied for DR of new coming set. The out-of-sample extension is to find DR of the new set using an extension technique based on the same DR method for the training set. Many papers have developed out-of-extension algorithms based on Nystrom approximation and shown their validity by numerical experiments. However, the mathematical theory for the extension still need a further consideration. Based on the reproducing kernel Hilbert space (RKHS) theory, we give a mathematical analysis on such out-of-sample extensions. We treat an out-of-sample extension operator as an extension of the identity on the RKHS. Then the Nystrom-type extension becomes an orthogonal embedding on the RKHS. We then present the conditions for the exact extension and estimate the errors of the extensions.

- Jianzhong Wang (*Sam Houston State University*)

Adaptive Eigenspace Regularization For Inverse Scattering Problems

A nonlinear optimization method is proposed for inverse scattering problems in the frequency domain, when the unknown medium is characterized by one or several spatially varying parameters. The time-harmonic inverse medium problem is formulated as a PDE-constrained optimization problem and solved by an inexact truncated Newton-type method combined with frequency stepping. Instead of a grid-based discrete representation combined with standard Tikhonov-type regularization, each parameter is projected to a (small and slowly increasing) fi
nite-dimensional subspace, which is iteratively adapted during the optimization.

- Marcus Grote (*University of Basel*)
  Uri Nahum (*University of Basel*)

An improved nonlocal L_1 minimization method for image denoising

We propose a new image denoising algorithm by incorporating the L_1-regularization technique and the least squares method. In order to improve the quality of the reconstructed images, we adopt a high order least squares method along with new iterative nonlocal weights. In particular, we devise a measurement to estimate the nonlocal similarities between patches by using both data values and their derivatives. Some experimental results are presented to demonstrate the capability of the proposed algorithm.

Byeongseon Jeong (*Institute of Mathematical Sciences, Ewha Womans University, Seoul 120-750*)
Yunjin Park (*Department of Mathematics, Ewha Womans University, Seoul 120-750*)
- Hyoseon Yang (*Institute of Mathematical Sciences, Ewha Womans University*)
  Jungho Yoon (*Department of Mathematics, Ewha Womans University, Seoul 120-750*)

Texture Inpainting Using Efficient Gaussian Conditional Simulation

For texture images, the inpainting problem can be formulated as a random field conditional simulation within the masked area given the unmasked pixels. We propose such an approach for stationary Gaussian textures and show that the traditional algorithm for Gaussian conditional simulation can be implemented efficiently using the Fourier representation of the covariance operator. The resulting algorithm is able to inpaint large holes of any shape in a texture. Joint work with Arthur Leclaire ; http://epubs.siam.org/doi/10.1137/16M1109047

• Bruno Galerne (*Université Paris Descartes*)
Arthur Leclaire (*CMLA, ENS Cachan*)

CP8 Contributed session 8

Chairs:
Luca Zanni (*University of Modena and Reggio Emilia*)

CP8-1 - Thursday, 07 at 16:30 Room 1 (Redenti, floor 0)

Fast super-resolution of hyperspectral 2D Raman maps with a joint positivity constraint
Raman images are restored using constrained interior point least squares (C-IPLS). Nonnegative source separation reduces the dimensionality of the data cube, substantially decreasing computation time. C-IPLS is then simultaneously applied to all resulting map images with each weighted sum over co-localised pixel constrained to positivity. The respective weights are determined by the separated sources. Joint positivity significantly improves the quality of physical characterisation and spatial resolution is enhanced from 400nm to better than 50nm.

Tim Batten (*Spectroscopy Products Division, Renishaw plc*)
Bernard Humbert (*Institute des Materiaux Jean Rouxel Nantes, University of Nantes*)
Said Moussaoui (*Laboratoire des Sciences du Numérique de Nantes UMR CNRS 6004, Ecole Centrale de Nantes*)
• Dominik J. Winterauer (*Renishaw plc, University of Nantes*)

Sparse Diffraction Signature Modeling of Progressively Loaded Aluminum Alloy
High energy X-ray diffraction data collected in-situ during loading experiments permits probing crystal structure of a plastically deforming material sample. The proposed image representation assumes the intensity signal to be a sparse nonnegative superposition of Gaussian basis functions drawn from an over-complete dictionary and facilitates analysis of data from material with arbitrary crystal granularity. The representation is shown to capture data morphology and reveal information about the sample's processing history in experimental data.

• Daniel Banco (*Tufts University*)
Armand Beaudoin (*University of Illinois Urbana-Champaign*)
Eric Miller (*Tufts University*)
Matthew Miller (*Cornell University*)

On the uniqueness for an inverse mixed elastic scattering problem
The inverse problem of elastic scattering by an impenetrable obstacle surrounded by a piecewise homogeneous medium is studied. The corresponding direct scattering problem is mathematically modeled and well-posedness issues are discussed. An essential mixed reciprocity relation is given, uniqueness results for the determination of the impenetrable obstacle with its physical property are proved, and last but not least, the unique determination of the penetrable interface contains the obstacle in its interior is also established.

• Vassilios Sevroglou (*University of Piraeus*)

Joint image formation and phase error correction using synthetic aperture radar data
In this investigation we thoroughly analyze phase errors in synthetic aperture radar data, comparing our results to classic autofocusing algorithms, and propose a joint image formation and phase estimation algorithm based on high order total variation and phase synchronization. Our technique models the true correlation of phase errors, while enforcing smoothness and sharpness of edges within the scene. Numerical results show that our autofocusing technique is robust to various phase errors, phase wrappings, and noise.

Anne Gelb (*Dartmouth College*)
• Theresa Scarnati (*Air Force Research Laboratory*)

Variational Approach to Fourier Phase Retrieval
[Joint work with Gero Friesecke] We consider phase retrieval on the space of square integrable functions. Assuming object space knowledge of the image (such as positivity or support), we show that the Error-Reduction algorithm may be viewed as a discretized gradient flow (without the need to explicitly impose object space constraints). We use this setting to analyze stagnation properties of the Error-Reduction algorithm and propose a novel Error-Reduction variant that outperforms standard algorithms.

• Tsipenyuk Arseniy (*Technical University of Munich*)
Gero Friesecke (*Technical University of Munich*)

State estimation with golden angle acquisition in fMRI
Functional magnetic resonance imaging (fMRI) is an imaging modality widely used to study physiological processes. State estimation methods can be used to reconstruct fMRI images even from highly undersampled data. Using conventional radial sampling, however, can cause suboptimal results with state estimation methods. In this talk we present an alternative radial sampling method based on golden angle. This method allows for improved results compared to conventional radial sampling when using state estimation methods.

- Ville-Veikko Wettenhovi (*University of Eastern Finland*)

CP9 Contributed session 9

Chairs:
Patrizio Frosini (*University of Bologna*)

CP9-1 - Friday, 08 at 09:30 Room 1 (Redenti, floor 0)

Partially Coherent Ptychography
The superposition of the signal from a blurred illumination results in partially coherent measurements. Here we propose the Gradient Decomposition of the Probe (GDP), a model that exploits the blurring kernel separability. We describe a first-order splitting algorithm GDP-ADMM to solve the .non-linear blind partially coherent phase retrieval problem. Remarkably, GDP-ADMM produces satisfactory results even when the ratio between kernel and beam size is more than one, or or when the distance between successive acquisitions is almost twice as large as the beam width.

Huibin Chang (*School of Math. Sci., Tianjin Normal University*)
Pablo Enfedaque (*Lawrence Berkeley Lab*)
Hari Krishnan (*Lawrence Berkeley Lab*)
- Stefano Marchesini (*Lawrence Berkeley Nat'l Lab*)

Imaging with Photonic Integrated Circuits
We discuss continued development of a compact one-dimensional imaging interferometer array implemented on a photonic integrated circuit. Two-dimensional images were reconstructed from observations of test scenes at different angles. This research was developed with funding from the Defense Advanced Research Projects Agency (DARPA). The views, opinions and/or findings expressed are those of the author(s) and should not be interpreted as representing the official views or policies of the Department of Defense or the U.S. Government.

Katherine Badham (*Lockheed Martin Advanced Technology Center*)
Guy Chriqui (*Lockheed Martin Advanced Technology Center*)
Alan Duncan (*Lockheed Martin Advanced Technology Center*)
Richard Kendrick (*Lockheed Martin Advanced Technology Center*)
Chad Ogden (*Lockheed Martin Advanced Technology Center*)
Tiehui Su (*University of California Davis*)
- Samuel Thurman (*Lockheed Martin Coherent Technologies*)
Danielle Wuchenich (*Lockheed Martin Advanced Technology Center*)
S. J. B. Yoo (*University of California Davis*)

On the application of frame decompositions to 3D reconstruction
To compute shape from a sequence of defocused images, we make a connection between the geometrical approach of Favaro et al. and frame theory, interpreting defocusing operators as analysis operators of frames. In order to solve the inverse problem we impose regularization conditions with respect to frame decompositions in a cosparse setting and solve two minimization problems - one for dictionary learning, one for reconstructing the shape.

- Anastasia Zakharova (*National Institute of Applied Sciences, Rouen*)

Shape Registration With Normal Cycles
To define a dissimilarity measure between geometrical structures, we propose to use a representation of shapes with normal cycles (an object associated with the normal bundle of the shape which encodes all the curvature information). Using kernel metrics on normal cycles, we define a metric between shapes that fits in a framework of inexact registration. It allows for a matching that takes into account the region of high curvature and the boundaries of the shapes.

- Roussillon Pierre (*Ecole Normale Supérieure Paris-Saclay*)

The cone-beam transform and spherical convolution operators
The cone-beam tomography consists of integrating a function defined on the three-dimensional space along every ray that starts on a certain scanning curve. Based on Grangeat's formula, Louis [2016, Inverse Problems, 32 115005] states a reconstruction formula based on a new generalized Funk-Radon transform. In this talk, we give a singular value decomposition of this generalized Funk-Radon transform and discuss its application to the cone-beam integrals.

- Michael Quellmalz (*Technische Universität Chemnitz*)

Fast and stable lagrangian method for image segmentation
Fast and stable Lagrangian approach for digital image segmentation is presented in this work. The Lagrangian approach is based on a discretization of an intrinsic partial differential equation for an evolving curve position vector. Since only the curve discretization by grid points is used it can be very fast. It enables that topological changes which may occur during the curve evolution from the initial guess to a final segmentation result are also resolved in a very fast way. The curve evolution model which we use for the Lagrangian segmentation includes an expanding force in the normal direction, an advective term driving the curve from both sides to an edge and a curvature regularization. The numerical procedures are based on stable semi-implicit scheme in curvature part and on inflow implicit/ outflow explicit method in advective

part which corresponds to tangential redistribution of grid points. The tangential velocity which is used to stabilize the Lagrangian computations keeps the evolving curve discretized uniformly and this fact allows the fast O(n) solution of the topological changes. We present all our model and we show its behavior in medical and also satellite image data segmentation.

Karol Mikula (*Slovak University of Technology*)
• Jozef Urbán (*Slovak University of Technology*)

CP10 Contributed session 10

Chairs:
Carolina Beccari (*Dept. Mathematics, University of Bologna*)

CP10-1 - Friday, 08 at 14:00 Room 1 (Redenti, floor 0)

Bluebild: accurate and efficient radio-astronomy imaging on the sphere
Radio astronomy imaging has been primarily focused on a planar approximation to a portion of the observed sphere. We present an efficient algorithm that reconstructs directly on the celestial sphere. It leverages an analytic Hilbert space framework to produce a continuous image description that may be stored independently of resolution, and sampled up to the fundamental limit of the telescope. The algorithm is inherently simpler and more intuitive than previous methods, as well as faster.

• Paul Hurley (*IBM Research, Zurich*)
Matthieu Simeoni (*EPFL / IBM Research*)

Approximation of Functions Over Manifolds by Moving Least Squares
We present an algorithm for approximating a function defined over a manifold utilizing only noisy function values at locations sampled from the manifold with noise. To produce the approximation we do not require any knowledge regarding the manifold other than its dimension. The approximation scheme is based upon the Manifold Moving Least-Squares (MMLS). We compare, using numerical experiments, the presented algorithm to state-of-the-art algorithms for regression over manifolds and show its resistans to noise.

• Yariv Aizenbud (*Tel Aviv University*)
Barak Sober (*Tel-Aviv University*)

Three dimensional shape reconstruction from liquid displacement using parametric level set methods
We consider the reconstruction of a 3D object from measurements of liquid displacement, exploiting Archimedes law. These measurements are obtained by draining fluid from a container while the object is placed inside in various angles. The reconstruction is obtained by fitting simulations to the measurements, which leads to an inverse problem. To impose proper regularization, we use a parametric level set approach. We show that this way the reconstruction is obtained more accurately and efficiently than with other common approaches.

Andrei Sharf (*Ben Gurion University of the Negev*)
• Eran Treister (*Ben Gurion University of the Negev*)

Detection of cardiac ischemic regions from non-invasive electrical measurements
The cardiac electrical activity can be described through a semilinear parabolic equation coupled with nonlinear ODE, together with a passive conductor model of the torso. We aim at indentifying ischemias, i.e. regions where the coefficients of the equations describing the cardiac electrical activity are altered, taking advantage of data acquired on the boundary of the torso. For this purpose, we formulate a constraint optimization problem with Total-Variation regularization and adopt a phase-field approach.

Elena Beretta (*Politecnico di Milano*)
• Luca Ratti (*Politecnico di Milano*)
Marco Verani (*Politecnico di Milano*)

Three-dimensional volume reconstruction using two-dimensional parallel slices
We propose a variational framework for the three-dimensional volume reconstruction from 2-D slices. The proposed method is based on modified Cahn-Hilliard equation. To satisfy constraints accurately as well as obtain a smooth result, we propose pre-smoothing procedure. After splitting a grayscale image into binary channels, we perform binary inpainting. Then we introduce smoothing and shock filter when combining binary results. We applied our results for reconstruction of 3-D human body from slices of CT images.

• Junwoo Kim (*KAIST*)
Chang-Ock Lee (*KAIST*)

Reconstruction of a compactly supported sound profile in the presence of a random background medium
We present different methods to reconstruct an unknown compact sound profile embedded in a random noisy background medium, given measurements of the scattered field and information about the probability distribution of the background medium and the sound profile. In the methods presented, we apply the Gauss-Newton method with the recursive

linearization algorithm. A fast direct solver is used to speed-up the solution of the forward model, which allowed simulations with thousands of samples.

George Biros (*Institute for Computational Engineering and Sciences, University of Texas at Austin*)
- Carlos Borges (*ICES - UT Austin*)

CP11 Contributed session 11

Chairs:
Germana Landi (*University of Bologna*)

CP11-1 - Friday, 08 at 16:30 Room 1 (Redenti, floor 0)

Fixed-lag smoother for reduced state space model
Time-variant inverse problems are naturally cast as state space problems. In state estimation, using a smoother as the estimator results in a smaller estimation errors than a Kalman-type filter. However, this induces an augmented high-dimensional problem. To deal with this challenge, we construct a reduced state space model incorporating approximation errors. We derive the corresponding fixed-lag smoother and apply to an imaging problem induced by a stochastic advection-diffusion equation with unknown temporal boundary conditions.

- Pascal Eun Sig Cheon (*University of Auckland*)

Mesh refinement in FEM based imaging with hierarchical Bayesian methods
Hierarchical conditionally Gaussian priors, combined with efficient iterative solvers of linear systems, provide an efficient tool for solving inverse imaging problems in which the unknown is believed to be a blocky image. In this talk, we discuss how these methods can be used to guide targeted mesh refinement in imaging problems involving finite element computations.

Daniela Calvetti (*Case Western Reserve University*)
- Anna Cosmo (*Politecnico di Milano*)
Simona Perotto (*MOX, Politecnico di Milano*)
Erkki Somersalo (*Case Western Reserve University*)

Extended Pseudo-Morphological Processing for Blob Detection
Blob detection has great applications in cellular microscopic image analysis. We present a new method to filter closely located microorganisms. We adopt counter harmonic mean to calculate robustly morphological operations. Then approximate a single-pixel-wide line structuring element by a flattened Gaussian structuring element function. The maximum of the pseudo-morphologically opened images is calculated, and subtracted from the input image. Our method achieves effective detection of close blobs without shape constraints and needs not rotate image.

Jue Wang (*Union College*)
- Yongjian Yu (*Axon Connected LLC*)

A Parallel Integro-Differential Approach to the Solution of a 3D Subsurface Imaging Problem.
In this paper, a parallel integro-differential approach to the solution of the 3-D subsurface scattering problem is presented. The method is a further development of the previously proposed by author and his colloquies computational algorithm for the recovery of unknown coefficient in the 2D Helmholtz Equation. The reconstructed images represent the electromagnetic properties of the respective underground regions. A parallel implementation of the developed method is main novel elements in the proposed computational framework.

Ronald Gonzales (*Idaho State University*)
- Yury Gryazin (*Idaho State University*)
Yun Teck Lee (*Idaho State University*)

A more efficient method for solving the Radiative Trasport Equation (RTE)
Analytic methods of solving inverse problems to recover optical properties turbid media from optical imaging data require that the RTE be solved numerous times. Therefore, computation time of these methods is limited by the optimization method used and the computation time. We present a novel method for approximating RTE solutions which provides similar accuracy to the standard spherical harmonic method with a significant time reduction. We show a comparison using Spatial Frequency Domain Imaging data.

- Sean Horan (*University of California, Irvine*)
Vasan Venugopalan (*University of California, Irvine*)

Composite surrogate solution of the stochastic planar elasticity problem using sparse grids and measurements
A stochastic extension of Navier's equations of elasticity is considered that accounts for uncertainties in the domain and material parameters. We consider a setting where a set of measurement data is combined with a simulated surrogate model formed using sparse grid stochastic collocation. By using this approach, we obtain a solution that recovers both the simulated model and the set of measurements. The accuracy of this approach is discussed both theoretically and in numerical experiments.

Harri Hakula (*Aalto University*)
- Vesa Kaarnioja (*University of Helsinki*)

Posters Abstracts

1 **Efficient splitting strategies for structured illumination microscopy**

Emmanuel Soubies (*EPFL, Biomedical Imaging Group, Lausanne VD*)
Michael Unser (*EPFL, Lausanne*)

2 **Identification and Analysis of Intranuclear Protein Patterns in Fluorescence Microscopy Cell Images**

Laura Antonelli (*Institute for High-Performance Computing and Networking ICAR-CNR, Naples*)
Francesco Gregoretti (*Institute for High-Performance Computing and Networking ICAR-CNR, Napoli*)
Chiara Lanzuolo (*Institute of Cellular Biology and Neurobiology, Milano; Istituto Nazionale di Genetica Molecolare "Romeo ed Enrica Invernizzi", INGM, Milano*)
Federica Lucini (*Istituto Nazionale di Genetica Molecolare "Romeo ed Enrica Invernizzi", INGM, Milano*)
Gennaro Oliva (*Institute for High-Performance Computing and Networking ICAR-CNR, Napoli*)

3 **Restoration of multispectral images based on the anisotropic diffusion**

Savita Nandal (*Department of Mathematics Indian Institute of Technology Roorkee,*)
Kumar Sanjeev (*Department of Mathematics, Indian institute of Technology Roorkee,*)

4 **A Neuromathematical Model for Geometrical Optical Illusions**

Giovanna Citti (*Dept. Mathematics, University of Bologna*)
Benedetta Franceschiello (*Fondation Asile des Aveugles, Centre hospitalier universitaire vaudois (LINE)*)
Alessandro Sarti (*CNRS - EHESS*)

5 **Accurate discontinuous Galerkin schemes for seismic traveltimes and amplitudes in heterogeneous anisotropic media**

Philippe Le Bouteiller (*Univ. Grenoble Alpes*)
Ludovic Métivier (*Univ. Grenoble Alpes*)
Jean Virieux (*Univ. Grenoble Alpes*)

6 **Anisotropic image osmosis filtering for visual computing**

Luca Calatroni (*CMAP, École Polytechnique CNRS*)
Simone Parisotto (*University of Cambridge*)

7 **Distances between Tensor Subspaces for Image Analysis**

Atsushi Imiya (*IMIT, Chiba University*)

8 **Morphing of Manifold-Valued Images inspired by Discrete Geodesics in Image Spaces**

Sebastian Neumayer (*TU Kaiserslautern*)

9 **Partial difference equations and stochastic games for graph signal processing**

Pierre Buyssens (-)
Abderrahim Elmoataz (*University of Caen Normandie, CNRS*)

10 **4D computed tomography of foot and ankle using spatio-temporal regularization**

Marta Betcke (*University College London*)

Nargiza Djurabekova (*University College London*)
Andrew Goldberg (*University College London*)
David Hawkes (*University College London*)
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