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IP1

Exploiting Tensor Structure in Imaging Applications

A tensor is a multiway array. Such objects arise naturally in imaging applications in the form of data structure: for example, a hyperspectral data cube is a third order tensor, a digital color video is a fourth order tensor, etc. Perhaps less obvious is the role tensors can play with respect to operator representations (blurring or dictionary operators, regularization) that arise in imaging science. Recent research has shown that the use of tensors and their decompositions can be instrumental in revealing latent correlations of data and operators residing in high-dimensional spaces. Once exposed, this latent structure can translate into an expressiveness that yields superior results in applications such as compression, completion, and operator approximation, to those obtained when viewing problems through the traditional matrix-based lens. In this talk, we give an overview of some popular tensor decompositions in context of imaging applications where they have been particularly effective and highlight challenges moving forward.

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IP2

Numerical Understanding of Neural Networks: From Representation to Learning Dynamics

In this talk I will present both numerical analysis and experiments to understand a few basic computational issues in using neural network to approximate functions: (1) the numerical error that can be achieved given a finite machine precision, (2) the learning dynamics and computation cost to achieve certain accuracy, and (3) structured and balanced approximation. These issues are studied for both approximation and optimization in asymptotic and non-asymptotic regimes. This is a joint work with Shijun Zhang, Yimin Zhong, and Haomin Zhou.

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IP3

Signal Reconstruction from Phase-only Measurements, Dithered Quantization or Quantized Corrupted Sensing

In recent years, the recovery of low-complexity signals (e.g., sparse signals, low rank matrices) has been extensively studied and analyzed, which can be applied to many imaging science applications. In this talk, we discuss several variants of the recovery problems including phase-only measurements, dithered one-bit quantization, and quantized corrupted sensing. We provide theoretical insight to formulate a scientific basis for solving such signal recovery problems. Numerical examples are also given to demonstrate the usefulness of these results.

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IP4

Scale-invariant Regularizations for Sparse Signal and Low-rank Tensor Recovery

Regularization plays a crucial role in addressing ill-posed problems by guiding solutions towards desired properties. In this presentation, I will introduce the ratio of the L1 and L2 norms, denoted as L1/L2, which acts as a scale-invariant and parameter-free regularization method for approximating the elusive L0 norm. Our theoretical analysis reveals a strong null space property (sNSP) and demonstrates that any sparse vector qualifies as a local minimizer of the L1/L2 model when a system matrix adheres to the sNSP condition. Furthermore, we extend the L1/L2 model to low-rank tensor recovery by introducing the tensor nuclear norm over the Frobenius norm (TNF). We show that local optimality can be ensured under an NSP-type condition. To find the model solution, I will discuss advanced optimization techniques such as alternating direction method of multipliers and proximal gradient descent, highlighting the trade-offs among accuracy, computational efficiency, and convergence guarantees. Throughout the presentation, we will explore various applications, including limited angle CT reconstruction and video background modeling, showcasing the superior performance of our approach compared to state-of-the-art methods.

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IP5

Multimodal Self-Supervised Learning and Applications to Visual Data Understanding

The role of multimodal self-supervised learning in extracting meaningful semantic features from data is crucial for many tasks involving visual data understanding. This talk will present a new contrastive method allowing to obtain robust visual feature representations that will be applied to multiple downstream tasks. Besides, several multimodal proposals for some problems in visual data understanding will be presented and discussed.

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IP6

Learned Forward and Inverse Problems for PDES in Imaging

Several problems in imaging are based on recovering coefficients of a PDE, resulting in a non-linear inverse problem that is typically solved by an iterative algorithm with the gradient obtained by an adjoint state method. When the forward problem is time-varying this corresponds to the method of time-reversal which convolves a forward and time-reversed field with the derivative of the spatial operator (sometimes called the imaging condition). Applications include full-waveform imaging (FWI) in Ultrasound Computed Tomography, PhotoAcoustic Tomography (PAT) and time-resolved Diffuse Optical Tomography (tDOT). Within Learned Physics approaches time reversal corresponds to the Neural ODE method for learning the time-derivative of an ODE parameterised by a neural

network. By combining the trained network with symbolic regression an interpretable model can be discovered. In this talk I will discuss application of these methods for solving some forward and inverse problems in imaging.

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IP7

Krylov Methods for Imaging: Classical and Novel Algorithmic Approaches

This talk is about iterative regularization methods based on Krylov subspaces, which can be efficiently employed to solve a variety of inverse problems in imaging. A special emphasis is given to the so-called 'hybrid projection methods', i.e., regularisation methods that combine projection onto Krylov subspaces and variational regularisation methods. Although such solvers, when based on some standard Krylov method such as LSQR and GMRES, are well-established for regularizing linear inverse problems, some recent results concerning the choice of regularization parameter(s) will be presented. The talk will also present some novel hybrid projection methods that (1) exploit flexible Krylov subspace methods coupled with some generic p-norm regularization, or (2) exploit inexact Krylov subspace methods to handle separable nonlinear inverse problems.

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SP1

SIAG/Imaging Science Best Paper Prize Lecture - Implicit Regularization in Nonconvex Statistical Estimation: Gradient Descent Converges Linearly for Phase Retrieval, Matrix Completion and Blind Deconvolution

Recent years have seen significant progress in designing efficient nonconvex procedures for statistical estimation. These procedures often require regularization to ensure fast convergence. This paper reveals that gradient descent implicitly enforces proper regularization, even without explicit regularization terms. It follows a trajectory within a basin that has favorable geometry, leading to aggressive yet stable optimization. We demonstrate this implicit regulatization phenomenon in phase retrieval, low-rank matrix completion, and blind deconvolution problems, showing near-optimal statistical and computational guarantees. Our approach, a leave-one-out perturbation argument, marries statistical modeling with optimization theory, providing a general recipe for analyzing iterative algorithms' trajectories.

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CP1

Reconstruction and Isolation of Different Dynamics in Video Data via Untrained Generator Network with Disentangled Latent Space and Applications to Cardiac Mri

Reconstruction, processing and isolating different types of dynamics in video data is a highly relevant problem in video analysis. Applications can be found in dynamic medical or biological imaging, where the analysis and further processing of the dynamics of interest is often complicated by additional, unwanted dynamics, such as contrast, breathing and patient motion. This work empirically shows that a representation of a video data via untrained generator networks, together with disentangled latent space variables allows to efficiently reconstruct a video with different dynamics from a highly under-sampled data. The latent space disentanglement that uses minimal, one-dimensional information on some of the underlying dynamics, allows to efficiently isolate different, highly non-linear dynamic types. In particular, such a representation allows to freeze any selection of dynamic types, and to obtain accurate independent representations of the other dynamics of interest. Obtaining such a representation does not require any pre-training on a training data set, i.e., all parameters of the generator network are learned directly from a single video. We illustrate the performance of the method on phantom and real-data MRI examples, where the dynamic images with different dynamic types such as cardiac motion, contrast, respiratory motion and body motion are reconstructed. The method successfully separates the given dynamics.

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CP1

A New Selective Segmentation Model for Texture Images and Solution Through Difference Equations

Segmentation of texture images is an active area of the image processing. Selective segmentation is the process of extracting a region of interest (ROI) in the image. In this paper, we propose a new model for selective segmentation of texture images, by smoothing the texture and segmentation simultaneously. The proposed model uses L_0 gradient norm for smoothing of the texture and Badshah-Chen energy with local Gaussian data fitting for selective segmentation. The proposed model is minimized to get gradient descent by using Euler Lagranges equation, which is then discretized through finite differences and the corresponding difference equation is solved by using additive operator splitting method. Experimental results of the proposed model is compared with the existing selective segmentation models.

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CP1

An Extended Asymmetric Sigmoid with Perceptron(SIGTRON) for Imbalanced Linear Classification

This talk introduces a new polynomial parameterized sigmoid model called SIGTRON and its companion convex model called SIGTRON-imbalanced classification (SIC) model that employs a virtual SIGTRON-induced loss. In contrast to the conventional π-weighted cost-sensitive learning model, the SIC model does not have an external π-weight on the loss but has internal parameters in the virtual SIGTRON-induced loss. As a consequence, when the given training dataset is close to the well-balanced condition, we show that the SIC model is more adaptive to variations of the dataset, such as the inconsistency of the scale-class-imbalance ratio between the training and test datasets. This adaptation is achieved by creating a skewed hyperplane equation. Additionally, we present a quasi-Newton optimization(L-BFGS) framework for the virtual convex loss by developing an interval-based bisection line search. Empirically, we have observed that the proposed approach outperforms π-weighted convex focal loss and LIBLINEAR(logistic regression, SVM, and L2SVM) in terms of test classification accuracy with 51 two-class and 67 multi-class datasets. In binary classification problems, where the scale-class-imbalance ratio of the training dataset is not significant but the inconsistency exists, a group of SIC models with the best test accuracy for each dataset (TOP1) outperforms kernel-based LIBSVM.

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CP1

Towards Precise Eye Tissue Analysis: A Deep Learning Approach to Hyperspectral Imaging Segmentation

Biomedical hyperspectral imaging has emerged as a powerful tool for non-invasive examination and analysis of biological tissues. By capturing a wide range of spectral information at each pixel, hyperspectral imaging provides unique insights into tissue composition and pathology. In our research, we focus on leveraging this cutting-edge technology to enhance our understanding of ocular health. Specifically, we utilize hyperspectral images of eye tissues, including the retina, choroid, sclera, and muscle fibers, to perform precise segmentation and characterization. This segmentation task is critical for various clinical applications, such as diagnosing eye diseases and monitoring treatment responses. To tackle the challenging task of segmenting hyperspectral eye tissue images, we employ deep learning techniques, such as U-Net architectures. These methods enable us to automatically partition the hyperspectral data into distinct tissue regions, providing valuable information for ophthalmologists and researchers. Our conference talk will delve into the details of our approach, highlighting the effectiveness of deep learning in biomedical hyperspectral image analysis. By showcasing our results and insights, we aim to contribute to the growing body of knowledge in the field of ocular health and inspire further advancements in biomedical hyperspectral imaging research.

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CP2

Robust Width Adversarial Defense

Deep neural networks are vulnerable to so-called *adversarial examples*: inputs which are intentionally constructed to cause the model to make incorrect predictions or classifications. Adversarial examples are often visually indistinguishable from their non-perturbed counterparts, making them hard to detect. As such, they pose significant threats to the reliability of deep learning systems. In this work, we study an adversarial defense based on the Robust Width Property (RWP), which was recently introduced for compressed sensing. We show that a specific pre-processing scheme of the inputs to the neural network based on the RWP gives adversarial robustness guarantees for images that are approximately sparse. In particular, this allows to study the robust accuracy of a model-independent defense in terms of both the subspaces of the ideal (unperturbed) images as well as the adversarially perturbed inputs. For example, local robustness guarantees can be obtained even if the perturbation and/or underlying image are outside but close to the assumed subspaces. We give some recent results on robust adversarial defenses based on partial Fourier measurement matrices and wavelet/shearlet L1 sparsity priors.

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CP2

Morphological Discrete Neural Networks for Image Processing

A classical approach to designing binary image operators is Mathematical Morphology (MM). We propose the Discrete Morphological Neural Networks (DMNN) for binary image analysis to represent W-operators and estimate them via machine learning. A DMNN architecture, which is represented by a Morphological Computational Graph, is designed as in the classical heuristic design of morphological operators, in which the designer should combine a set of MM operators and Boolean operations based on prior information and theoretical knowledge. Then, once the architecture is fixed, instead of adjusting its parameters by hand, we propose a lattice gradient descent algorithm (LGDA) to train these parameters based on a sample of input and output images under the usual machine learning approach. We also propose a stochastic version of the LGDA that is more efficient, is scalable and can obtain small error in practical problems. The class represented by a DMNN can be quite general or specialized according to expected properties of the target operator, i.e., prior information, and the semantic expressed by algebraic properties of classes of operators is a differential relative to other methods. The main contribution of this work is the merger of the two main paradigms for designing morphological operators: classical heuristic design and automatic design via machine learning. Thus, conciliating classical heuristic

morphological operator design with machine learning.

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CP2
Utilising Variational Autoencoders in Photoacoustic Tomography

Photoacoustic tomography (PAT) is a hybrid imaging modality combining optical contrast with high resolution of ultrasound imaging. In the inverse problem of PAT, a so-called initial pressure induced by the photoacoustic effect is estimated from measured photoacoustic ultrasound waves. The inverse problem of PAT can, however, be challenging to solve due to high computational cost, limited view measurement geometries, and ill-posedness of the inverse problem. Furthermore, most of the approaches for the inverse problem of PAT do not provide information regarding the reliability of the reconstructed images. In this work, we propose a deep learning approach for PAT based on variational Bayesian methods. In the approach, the variational autoender (VAE) and the recently proposed uncertainty quantification VAE are utilised to formulate an estimate of a posterior distribution in the latent space of the VAE. The approach is studied using numerical simulations and the results are compared to the solution of the Bayesian inverse problem. The results show that the proposed methods allows for fast image reconstruction with reliability estimates in PAT. This is joint work with Tanja Tarvainen, University of Eastern Finland.

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CP3
Real-Time Bayesian Inversion for Moving Boundary Problems

We present a variational framework for solving a tomographic Bayesian inverse problem constrained by a moving boundary problem, motivated by Resin Transfer Moulding (RTM). RTM is one of the most commonly used processes for the manufacturing of fibre-reinforced composites. Our aim is to update our probabilistic knowledge of the materials permeability, on the fly, as resin is being injected through it by inverting pressure measurements. We study fast Gaussian approximations to the posterior. In particular, we develop the linearisation around the maximum a-posteriori (LMAP) estimate in the one-dimensional moving boundary setting. Central to this is a non-linear optimisation problem which is solved iteratively with the Levenberg-Marquardt algorithm. Using synthetic experiments, the speed and accuracy of LMAP is compared to a Markov chain Monte Carlo (MCMC) benchmark and the derivative-free Ensemble Kalman Inversion (EKI) algorithm. We then describe a routine which is transferrable

to the two- and three-dimensional settings, which requires the use of shape derivatives.

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CP3
Improving Autoencoder Image Interpolation via Dynamic Optimal Transport

Autoencoders are important generative models that, among others, have the ability to interpolate image sequences. However, interpolated images are usually not semantically meaningful. In this paper, motivated by dynamic optimal transport, we consider image interpolation as a mass transfer problem and propose a novel regularization term to penalize non-smooth and unrealistic changes in the interpolation result. Specifically, we define the path energy function for each path connecting the source and target images. The autoencoder is trained to generate the L^2 optimal transport geodesic path when decoding a linear interpolation of their latent codes. With a simple extension, this model can handle complicated environments, such as allowing mass transfer between obstacles and unbalanced optimal transport. A key feature of the proposed method is that it is physics-driven and can generate robust and realistic interpretation results even when only very limited training data are available.

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CP3
Mathematical Modelling and Simulation of Joint Image Restoration and Segmentation: An AI Perspective

Lot of work has been done in image restoration and segmentation independently. There are very few joint models which tackle these problems jointly. Aim of this paper is to propose a model which segment given image and restore its intensity distortion. The proposed model will be based on total generalized variation (TGV) as a regularization for the restoration of images and local intensity-based data fitting for the segmentation of images. The proposed model will be minimized by using variational optimization techniques and the differential equations arisen from minimization will be solved numerically. The proposed model will be tested on various type of synthetic and real images to check its performance. Some available datasets will be used to check the effectiveness of the proposed model. Data loss functions and pre-processing methods play very important and significant role in deep learning and machine learning techniques. Keeping good results of the proposed model on different real datasets, this model will be hybridized with ResBCU-Net.

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CP3

Efficient Neural Network Approaches for Conditional Optimal Transport with Applications in Bayesian Inference

This presentation focuses on COT-Flow, a neural network approach designed for approximating solutions to dynamic conditional optimal transport (COT) problems. This method is tailored for sampling and density estimation of conditional probability distributions, essential in Bayesian inference. COT-Flow represents target conditional distributions as transformations of a manageable reference distribution within the measure transport framework. Despite a slower training pace, it offers faster sampling, showcasing its effectiveness and efficiency through comparisons with state-of-the-art alternatives using benchmark datasets and Bayesian inverse problems.

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CP4

A Fast Integral Equation Solver for Surface PDEs

Elliptic PDEs on a surface embedded in three dimensions occur in many forward problems in imaging. For example, they are used in the study of surface wave phenomenon and in electromagnetic scattering problems, where they can be used to find Hodge decompositions of tangential vector fields. PDEs on surfaces are also frequently used in computer graphics for shape analysis and surface interpolation problems. In this talk, we present a method for converting a broad class of elliptic PDEs on a general smooth surface into second kind Fredholm integral equations. Doing so ensures the equations are well conditioned and makes it possible to construct high-order numerical solvers. To derive the integral equation, we extend the known method for the Laplace-Beltrami problem [Kropinski and Nigam, 2014] on a sphere to a broader class of equations on general smooth surfaces. Specifically, we observe that the Greens function of a corresponding PDE in the plane gives a parametrix (an approximate Greens function) for the PDE on a surface. We then use that parametrix to derive an integral equation form of the PDE. If time allows, we will also talk about how the structure and simplicity of the resulting integral equation can be leveraged to efficiently solve the discretized linear system.

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CP4

An Adaptive Moments-Based Interface Reconstruction Using Intersection of the Cell with One Half-Plane, Two Half-Planes and a Circle

We present a new adaptive moment-of-fluid (A-MOF) interface reconstruction method. It uses the zeroth, first, and second moments of the fragment of material inside a cell of the mesh to construct a shape that approximates the respective material fragment. The new method requires information about the material moments only for the cell under consideration. The adaptive method chooses between shapes obtained by the intersection of the cell with one half-plane, two half-planes, or a circle. The A-MOF method allows to exactly reproduce several convex shapes: corners, filaments, and their concave cell-complements; as well as pieces of the circles and its cell-compliments. Interface reconstruction is formulated as a local (for each cell), non-linear, equality constrained optimization problem, which does not require additional communication and allows for an efficient parallel implementation. In conclusion, we present an extensive set of test problems, both for interface reconstruction on a single cell, and for reconstruction of a variety of shapes on the entire mesh.

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CP4

Phaseless Multi-Static Sar Imaging via Stochastic Illumination and Non-Convex Optimization

Phaseless synthetic aperture radar (SAR) is a novel imaging approach that has profound implications for system design, cost, and robustness in remote sensing applications. Conventional SAR systems lack the illumination diversity to reliably deploy state-of-the-art algorithmic procedures from the phase retrieval literature. In this work, we use stochastically generated waveforms put forth in the radar coincidence imaging literature in conjunction with non-convex optimization for phaseless SAR imaging. We leverage a multi-static configuration to illuminate the scene of interest by the superposition of random frequency modulated waveforms to approximate a Gaussian incident field, which facilitates leveraging optimization-based solvers that have established theoretical guarantees for phase retrieval. Despite the favorable spatial incoherence properties of the scene illumination one can generate with this configuration, phaseless coincidence imaging has limitations as it is a linear reconstruction technique that requires either a prohibitively large number of transmitters or a large number of distributed receivers unless the scene consists of well-separated point-targets. The optimization-based approach evades limiting assumptions on the scene of interest associated with linear reconstruction with a single receiver and mitigates the arising system complexity and sample complexity needed with the spatial averaging approach for phaseless SAR.

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CP5

Estimation of off-the-Grid Sparse Spikes for Super-Resolution with over-Parametrized Projected Gradient Descent

We study the problem of sparse spike estimation in the continuous setting for super-resolution. Our goal is to recover

the position and amplitude of spikes modeled as Dirac measures observed through a linear operator. State-of-the-art algorithms such as Sliding Continuous Orthogonal Matching Pursuit (COMP) [Keriven et al, Compressive k-means] and Sliding Frank-Wolfe (SFW) [Denoyelle et al, The SFW Algorithm] work similarly. They both add a spike maximally correlated with the residual between observations and the current estimation, and they perform a descent on all parameters (Sliding step) at each iteration. The main problem with these algorithms : the computation time of these descents increases quadratically with respect to the number of recovered spikes. We introduced [Bnard et al, Fast off-the-grid sparse recovery of OP PGD] a new algorithm based on Sliding COMP aiming to reduce the large computation time by removing the sliding step at each iteration. This algorithm is the Over-Parametrized COMP with Projected Gradient Descent. In this contribution [Bnard et al, Estimation of off-the-grid sparse spikes with OP PGD], we provide a theoretical study of approximate recovery with our chosen initialization method: COMP without Sliding. Then we study the effect of over-parametrization on the gradient descent which highlights the benefits of the projection step. Finally, we show the improved computation time of our algorithm compared to state-of-the-art model-based methods.

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CP5

Matrix Completion Via Memoryless Scalar Quantization

In imaging or sensing processes, inherent measurement limitations necessitate subsampling schemes, resulting in the matrix completion problem. Notably, in real applications, we solely record quantized values. We delve into the impact of memoryless scalar quantization on matrix completion. We broaden our theoretical discussion to encompass the coarse quantization scenario with a dithering scheme, where the only available information for low-rank matrix recovery is few-bit low-resolution data. Our primary motivation for this research is to evaluate the recovery performance of nuclear norm minimization in handling quantized matrix problems without the use of any regularization terms such as those stemming from maximum likelihood estimation. We furnish theoretical guarantees for both scenarios: when access to dithers is available during the reconstruction process, and when we have access solely to the statistical properties of the dithers. Additionally, we conduct a comprehensive analysis of the effects of sign flips and prequantization noise on the recovery performance, particularly when the impact of sign flips is quantified using the well-known Hamming distance in the upper bound of recovery error.

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CP5

Log-Sum Regularized Kaczmarz Algorithms for High-Order Tensor Recovery

Sparse and low rank tensor recovery has emerged as a significant research area with applications in many fields such as computer vision. In classical sparse signal recovery, to circumvent the NP-hardness of minimizing the vector ℓ_0-norm or matrix rank, convex relaxation techniques are typically employed in practice. For example, the log-sum penalty, a robust convex approximation of the ℓ_0 pseudo-norm, has proven effective as a regularizer for solving sparse and low-rank optimization problems. Recently, Kaczmarz algorithms have shown great potential in recovering third-order tensors, particularly with imaging applications. Motivated by the utility of log-sum regularization and the Kaczmarz algorithm, we propose a novel log-sum regularized Kaczmarz algorithmic framework for high-order tensor recovery with convergence guarantees, together with block variants. Numerical experiments on synthetic and real-world data justify the excellent performance of the proposed methods. Furthermore, applications to image destriping demonstrate the efficiency of the algorithms in practice.

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CP5

3D Poissonian Image Deblurring Via Patch-Based Tensor Logarithmic Schatten-p Minimization

In medical and biological image processing, multi-dimensional images are often corrupted by blur and Poisson noise. In this paper, we first propose a new tensor logarithmic Schatten-p (t-log-Sp) low-rank measure and an iteratively reweighted Schatten-p minimization (IRSpM) algorithm for minimizing such measure. Furthermore, we adopt this low-rank measure to regularize the non-local tensors formed by similar 3D image patches and develop a patch-based non-local low-rank model. The data fidelity term of the model characterizes the Poisson noise distribution and blur operator. The optimization model is further solved by an alternating minimization technique combined with variable splitting. Experimental results tested on 3D fluorescence microscope images show that the proposed patch-based tensor logarithmic Schatten-p minimization (TLSpM) method outperforms state-of-the-art methods in terms of image evaluation metrics and visual quality.

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CP5

A Novel Tensor Regularization of Nuclear over Frobenius Norms for Low Rank Tensor Completion

In this paper, we consider a low-rank tensor completion (LRTC) problem. Based on the tensor singular value decomposition (t-SVD), we propose the ratio of the tensor nuclear norm and the tensor Frobenius norm (TNF) as a novel nonconvex surrogate of tensor's tubal rank in LRTC. The rationale of the proposed model for enforcing a low rank structure is analyzed as its theoretical properties. Specifically, we introduce a null space property (NSP) type condition, under which a low-rank tensor is a local minimum for the proposed TNF model. Numerically, we employ the alternating direction method of multipliers (ADMM) to secure a model solution with guaranteed subsequential convergence under specific conditions. Extensive experiments demonstrate the superiority of our proposed model over state-of-the-art methods.

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CP6

Pk-Pd Modelling in Radiopharmaceutical Research

To perform accurately the quantitative analysis of brain PET images and their meaningful interpretation, we need to have a precise knowledge of the functional brain areas in the individual patient. The animalities of the tracer uptake in a subjects brain can be easily localized. In this study, we present the Time Activity Curves (TACs) for different brain regions. Brain region uptakes exhibit a characteristic uptake pattern. This will help to localizing the main brain regions involved in progression of disease. We walk through Brain Image Analysis by taking the following steps:

- Identification of gray and white matter of Anatomical MR using tissue segmentation.

- Averaged dynamic PET baseline matched to 3d T1 weighted Anatomical reference MRI through rigid matching

- Normalization of the matching PET & MRI results to the MR template space in fusion mode using Probability Maps Transformations

- Maximum probability Atlas using Brain Segments.

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CP6

Robust 2D Demodulation with the Structure Multivector

The monogenic signal (MS) was introduced by Felsberg and Sommer and, independently, Larkin, in 2000 under the name vortex operator. It is a two-dimensional (2D) analog of the well known analytic signal, and allows for direct amplitude and phase demodulation of modulated images so long as the signal is intrinsically one-dimensional (i1D). Felsbergs thesis also introduced the structure multivector (SMV) as a model allowing for intrinsically 2D (i2D) structure. While the monogenic signal has become a fairly well-known tool in the image processing community, the SMV is little used, although even in the case of i1D signals it provides a more robust orientation than the MS. This work, which is in collaboration with Dr. Naoki Saito, showcases the advantage of using the SMV in place of the MS in the presence of noise (or various i2D structure), and how, as a result, standard applications of the MS can be improved by instead using the SMV. Some applications include phase-based fingerprint registration and single-image phase estimation of fringe patterns.

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CP7

Fractional Order Nonlinear Diffusion Filter for Multiplicative Noise Removal

The existing partial differential equation (PDE) based models for multiplicative noise removal pay more attention on removing the noise than the texture preservation. In this paper, we propose a fractional PDE model by weaving the time fractional Caputo derivative into a gray-level indicator based nonlinear diffusion filter. Through various numerical experiments, the proposed model has shown to better preserve the texture and remove the multiplicative gamma noise than the state-of-the-art PDE models, in terms of visual quality of the restored image and peak-signal-to-noise ratio (PSNR).

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CP7

Follow the White Rabbit: Spatially Correlated Heteroskedastic Noise Meets Clipping

Understanding the interplay between noise and clipping is vital for the characterization of signal-dependent statistics of imaging sensors, especially when dealing with capture at low signal-to-noise ratio or when maximizing the cover-

age of a narrow dynamic range. This talk looks into the special and much overlooked case of spatially correlated heteroskedastic noise subject to clipping, including extreme cases of under- and over-exposure. We demonstrate various unexpected and often surprising as well as counter-intuitive phenomena which can significantly disrupt the noise analysis and other operations in an image restoration pipeline. To effectively deal with such phenomena, we derive a scale-invariant model that quantifies the effect of clipping on spatially correlated noise for basic noise estimators, including robust ones. We further present an adaptation of the noise estimation approach based on maximum-likelihood fitting of heteroskedastic observations [Foi, IEEE TIP, 2008]. We validate our model on synthetic data and real acquisitions in confocal microscopy.

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CP7

Optimized Variance-Stabilizing and Exact Unbiased Inverse Transformations for the Non-Central χ and χ^2 Distributions

We present a family of optimized forward and inverse variance-stabilizing transformations (VST) for the non-central χ and non-central χ^2 distributions with arbitrary, integer as well as non-integer, number of degrees of freedom. The transformations simultaneously provide stabilization that is asymptotically optimal (rectifying an earlier result [Bar-Lev & Boukai, 2007]), that is near-optimal even at low signal-to-noise ratios, and they ensure exact unbiased inversion across the entire parameter space. They generalize and improve over the methodology developed for the Rice distribution in [Foi, 2011], which corresponds to the particular case with 2 degrees of freedom. The developed family of transformations is especially relevant for adoption in multi-coil magnetic resonance imaging (MRI), where noisy acquisitions are commonly modeled through the non-central χ distribution. By supporting non-integer degrees of freedom, our proposal is applicable to parallel-MRI reconstruction and to practical cases where there is correlation between coils, which lead to a reduction in the effective number of degrees of freedom [Aja-Fernndez & Tristn-Vega, 2012]. We demonstrate that ordinary restoration methods for additive standard Gaussian noise, when plugged between the proposed forward and inverse transformations, can match and even outperform estimators specifically designed for non-central χ distributed data [Pieciak et al., 2018].

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CP7

Copula-Based Modeling of Multivariate Imaging Data Distributions

Accurately modeling the joint distribution of data across different imaging modalities is crucial for optimizing imaging analysis and operational efficiency. This paper proposes an approach of using copulas to construct multivariate distributions for pairs of imaging modalities. The method begins by fitting appropriate marginal distributions to individual imaging modality data and subsequently builds a covariance matrix based on the training dataset. A copula is then employed to model the dependency structure between the imaging modalities. By adding correlations into the marginal distributions, the approach enables the creation of joint distributions that better capture real-world imaging data behaviors. The proposed methodology is presented alongside code implementations for clarity. Furthermore, the paper discusses the potential challenges associated with the chosen copula and introduces avenues for exploring alternative copulas to account for more complex dependency patterns. The performance evaluation of the resulting multivariate distribution is also examined using techniques like cross entropy and KL divergence. The proposed approach offers a systematic framework for addressing imaging analysis challenges by providing a flexible and efficient means of modeling multivariate imaging data distributions, facilitating improved decision-making and operational strategies in various applications

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MS1

Curvature Corrected Semi-Nonnegative Matrix Factorization of Manifold-Valued Data with Applications to Diffusion Tensor Imaging

Many techniques in the imaging sciences produce data that take on values on manifolds, such as the manifold of $n \times n$ symmetric positive definite matrices $\mathcal{P}(n)$ and the 3D rotation group SO(3). Low-dimensional representations of such data are useful for data analysis, and algorithms for computing these representations need to account for the geometry of the underlying manifold. In this talk, I will first present a general framework for curvature-corrected low rank factorizations of manifold-valued data. Using this framework, we develop a scheme for curvature corrected semi-nonnegative matrix factorization of manifold-valued data. As a case study, we apply our method to data collected via diffusion tensor magnetic resonance imaging, which take on values in $\mathcal{P}(3)$.

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MS1
Local Optimality of General Tensor Factorized Optimizations

Tensors, a multi-dimensional generalization of vectors and matrices, provide natural representations for multi-way datasets and find numerous applications in signal processing and machine learning. In this work, we consider tensor optimization with a convex and well-conditioned objective function and reformulate it into a non-convex optimization using the Burer-Monteiro type parameterization. We analyze the local convergence of applying vanilla gradient descent to the factored formulation and establish a local regularity condition under mild assumptions. We also provide a linear convergence analysis of the gradient descent algorithm started in a neighborhood of the true tensor factors.

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MS1
Towards Constituting Mathematical Structures for Learning to Optimize

Learning to Optimize (L2O), a technique that utilizes machine learning to learn an optimization algorithm automatically from data, has gained arising attention in recent years. A generic L2O approach parameterizes the iterative update rule and learns the update direction as a black-box network. While the generic approach is widely applicable, the learned model can overfit and may not generalize well to out-of-distribution test sets. In this paper, we derive the basic mathematical conditions that successful update rules commonly satisfy. Consequently, we propose a novel L2O model with a mathematics-inspired structure that is broadly applicable and generalized well to out-of-distribution problems. Numerical simulations validate our theoretical findings and demonstrate the superior empirical performance of the proposed L2O model.

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MS1
Optimal Transport in the Design of Freeform Optical Surfaces

The theory of optimal transport has been used successfully to model several freeform lens design problems. A freeform optical surface, refers to an optical surface (lens or mirror) whose shape lacks rotational symmetry and the use of such surfaces allows generation of spatially efficient optical devices. In this talk, we formulate a law of refraction for anisotropic media by using Fermats principle of least time and exhibit the existence of a far field refracting lens by using optimal transport techniques.

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MS2
Image Registration Using Stationary Velocity Fields and Matrix Groups

Coordinate-based neural representations emerged as a potent instrument for solving partial differential equations (PINNs) and vision tasks (neural fields). The neural architecture can be utilized to parametrize the deformation field in the context of non-rigid 3D image registration. Finding a parameterization that is sufficiently expressible and amendable for subsequent optimization is critical. We aim to combine two previous approaches. First, representing the deformation as the solution of a flow equation using stationary velocity fields to ensure diffeomorphic deformations. Second, a mapping to the special Euclidean group to capture rotational movements better. The corresponding velocity field maps now to the right invariant vector fields on the matrix group as a manifold. The flow equation is approximated using a scaling and squaring approach. The effect of the parameterization is evaluated by bidirectional registration on 3D-medical data.

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MS2
Learning Homeomorphic Image Registration via Conformal-Invariant Hyperelastic Regularisation

Deformable image registration is a fundamental task in medical image analysis and crucial for many clinical applications. Deep learning-based approaches have recently been widely studied for deformable medical image registration and achieved promising results. However, existing deep-learning image registration techniques do not theoretically guarantee topology-preserving transformations. However, that is an essential property to preserve anatomical structures and obtain plausible deformations that can be used in clinical settings. We, therefore, propose a novel framework for pair-wise unsupervised deformable image registration. Firstly, we introduce a new regularizer based on conformal-invariant properties in a nonlinear elasticity setting. Our regulariser enforces the deformation field to be smooth, invertible, and orientation-preserving, which yields clinically meaningful deformations. Secondly, we boost the performance of our regulariser through coordinate MLPs, where one can view the to-be-registered images as continuously differentiable entities. We then perform numerical experiments to demonstrate visually and via metrics that our framework outperforms current techniques in image registration.

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MS2

Scikit-Shapes: a Convenient Library for 3D Shape Analysis and Registration

Scikit-Shapes is a user-friendly Python toolbox designed to simplify the integration of various geometric data types, including images, volumes, point clouds, and meshes, into machine learning pipelines. It follows the model of scikit-image, aiming for full compatibility with scikit-learn and the scipy ecosystem. One of its key features is the ability to register shapes and compute distances. The library's registration engine adopts a plug-and-play design philosophy, allowing users to freely combine deformation models and loss functions. This flexibility enables the implementation of various registration methods within a unified framework, facilitating comparisons. In the presentation, we demonstrate how to express algorithms such as ICP, thin-plate splines, LDDMM, or elastic registration. At its core, Scikit-Shapes relies on the PyTorch ecosystem for computational operations. This offers the potential for GPU acceleration, further enhancing its computational efficiency. Scikit-Shapes is not just a static toolbox; we aim to develop a community-driven project. Our commitment is to continually expand the arsenal of available geometric data science methods through external contributions. We have designed our codebase to facilitate the addition of new features and their seamless integration into existing shape analysis pipelines.

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MS2

Bridging Image Registration and Neural ODEs

In this talk I will present neural ordinary differential equations (neural ODEs), an effective class of deep learning models for generation and supervised learning, as high-dimensional instances of image registration problems. I will also demonstrate a few ways in which the connection can be used to motivate new methods for machine learning but also computational algorithms for image registration.

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MS3

Deep Inverse: a PyTorch Library for Solving Inverse Problems with Deep Learning

Despite the ever-increasing research effort in the field of imaging inverse problems, most deep learning-based algorithms are built from scratch, are hard to generalize beyond the specific problem they were designed to solve, and the results reported in papers are often hard to reproduce. In order to tackle these pitfalls, I will present Deep Inverse (https://deepinv.github.io/), an open-source PyTorch library for solving imaging inverse problems with deep learning. The library covers most of the steps in modern imaging pipelines, from the definition of the forward sensing operator to the training of unfolded reconstruction networks in a supervised or self-supervised way.

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MS3

JuliaImageRecon: Efficient, Reproducible and Open-Source Image Reconstruction

Julia is a relatively new open-source programming language that combines many of the best features of languages like Python and tools like Matlab. One interacts with Julia like other high-level scripting languages, e.g., through Jupyter notebooks, yet Julia has excellent computational performance because it is built on top of the LLVM compiler. This talk will illustrate some of language features in the context of implementing computational imaging applications like image denoising and tomographic image reconstruction.

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MS3

Cuqipy: Computational Uncertainty Quantification for Inverse Problems in Python

In this talk we present CUQIpy (pronounced cookie pie) - a new computational modelling environment in Python that uses uncertainty quantification (UQ) to access and quantify the uncertainties in solutions to inverse problems. The overall goal of the software package is to allow both expert and non-expert (without deep knowledge of statistics and UQ) users to perform UQ related analysis of their inverse problem while focusing on the modelling aspects. To achieve this goal the package utilizes state-of-the-art tools and methods in statistics and scientific computing specifically tuned to the ill-posed and often large-scale nature of inverse problems to make UQ feasible. We showcase the software on problems relevant to imaging science such as computed tomography and partial differential equation-based inverse problems. CUQIpy is developed as part of the CUQI project at the Technical University of Denmark and is available at https://cuqi-dtu.github.io/CUQIpy .

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MS4

Subgradient Langevin Methods for Sampling from Non-Smooth Potentials

We present algorithms for sampling from probability distributions π on $\mathbb{R}^d$ admitting a density of the form $\pi(x) \propto e^{-U(x)}$, where $U(x) = F(x) + G(Kx)$ with K being a linear operator and G being non-differentiable. We consider two different methods, both employing a subgradient step with respect to $G \circ K$, but, depending on the regularity of F, either an explicit or an implicit gradient step with respect to F. For both methods, we provide non-asymptotic convergence results, with improved convergence results for more regular F. Further, we show numerical experiments for simple 2D examples, illustrating the convergence rates, and for examples of Bayesian imaging, showing the practical feasibility of the proposed methods for high dimensional data.

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MS4

Embedding Denoising Diffusion Models into Plug-and-play Unadjusted Langevin Sampling for Image Restoration

Score-based denoising diffusion methods have recently emerged as a powerful framework to solve image restoration tasks, especially plug-and-play strategies that integrate a pre-trained prior model with a data-fidelity model specified during test time. The results delivered by such methods are usually remarkably realistic. However, the methods sometimes fail to correctly enforce measurement consistency and deliver solutions with strong hallucinations as a result. To circumvent this difficulty, we propose to incorporate a pre-trained denoising diffusion model within a plug-and-play unadjusted Langevin algorithm. This simultaneously resolves the issue of measurement consistency and allows for the automatic calibration of key model hyper-parameters. We illustrate the effectiveness of the approach through a range of experiments and comparisons with other techniques.

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MS4

Primal-Dual Dynamics for Langevin Sampling

We analyze a primal-dual type Langevin algorithm that has recently been proposed for the task of sampling from log-concave, non-smooth distributions. Unlike other first order discretizations of Langevin diffusion, the primal-dual scheme does not arise from a time-continuous diffusion SDE which has the target distribution as its stationary solution. We therefore have to analyze both the time-discrete setting and the time-continuous limit, prove their stability as well as bounds on the distance to the true target distribution and consider possible modifications using non-homogeneous diffusion equations. The theoretical results are validated in numerical experiments, where we apply the sampling algorithm to typical posterior distributions in imaging inverse problems.

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MS4

Bayesian Posterior Sampling for Position-Blind Ptychography

Ptychography is a computational imaging technique that utilizes redundancy by scanning and recording multiple diffraction patterns from spatially overlapping segments of a specimen. While ptychography is known to robustly recover both the specimen's complex transfer function and the illumination function simultaneously and can even correct for errors in scan position, attacking the extreme case of "position-blind ptychography" – i.e., having lost all scan position information – has not been attempted to the best of our knowledge. As solution methods for this problem, we investigate and compare the feasibility of regularized optimization methods to Bayesian posterior sampling methods making use of expressive, data-driven image priors in the form of score-based generative models (diffusion models). Since score-based solution methods for inverse problems are sampling-based and can offer straightforward access to multiple possible solutions, we analyze and develop sampling methods for position-blind ptychography, and evaluate their ability to provide useful quantifications of uncertainties in the reconstructions.

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MS5

Semi-supervised Segmentation of Histopathology Images with Noise-Aware Topological Consistency

In digital pathology, segmenting densely distributed objects like glands and nuclei is crucial for downstream analysis. Since detailed pixel-wise annotations are very time-consuming, we need semi-supervised segmentation methods that can learn from unlabeled images. Existing semi-supervised methods are often prone to topological errors, e.g., missing or incorrectly merged/separated glands or nuclei. To address this issue, we propose TopoSemiSeg, the first semi-supervised method that learns the topological representation from unlabeled histopathology images. The major challenge is for unlabeled images; we only have predictions carrying noisy topology. To this end, we introduce a noise-aware topological consistency loss to align the representations of a teacher and a student model. By decomposing the topology of the prediction into signal topology and noisy topology, we ensure that the models learn the true topological signals and become robust to noise. Extensive experiments on public histopathology image datasets show the superiority of our method, especially on topology-aware evaluation metrics.

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MS5

Learning Pose Image Manifolds Using Geometry-Preserving Gans and Elasticae

This paper investigates the challenge of learning image manifolds, specifically **pose manifolds**, of 3D objects using limited training data. It proposes a DNN approach to manifold learning and for predicting images of objects for novel, continuous 3D rotations. The approach uses two distinct concepts: (1) **Geometric Style-GAN** (Geom-SGAN), which maps images to low-dimensional latent representations and maintains the (first-order) manifold geometry. That is, it seeks to preserve the pairwise distances between base points and their tangent spaces, and (2) uses Euler's **elastica** to smoothly interpolate between directed points (points + tangent directions) in the low-dimensional latent space. When mapped back to the larger image space, the resulting interpolations resemble videos of rotating objects. Extensive experiments establish the superiority of this framework in learning paths on rotation manifolds, both visually and quantitatively, relative to state-of-the-art GANs and VAEs.

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MS5

Salient Conditional Diffusion for Defending Against Backdoor Attacks

We propose an algorithm, Salient Conditional Diffusion (Sancdifi), a novel defense against backdoor attacks. Sancdifi uses a denoising diffusion probabilistic model (DDPM) to degrade an image with noise and then recover said image. Critically, we compute saliency- based masks to approximate anisotropic diffusion in the forward process, allowing for stronger diffusion on the most salient pixels. As a result, Sancdifi is highly effective at diffusing out triggers in data poisoned by backdoor attacks, as well as mitigating image-wide adversarial perturbations. Since the region of strong diffusion is restricted, we reliably recover salient features when applied to clean data. This performance is achieved without requiring access to the model parameters of the Trojan network, meaning Sancdifi operates as a state-of-the-art black-box defense.

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MS6

Efficient Krylov Subspace Methods for Large-scale Hierarchical Bayesian Inverse Problems

Uncertainty quantification for large-scale inverse problems remains a challenging task. For linear inverse problems with additive Gaussian noise and Gaussian priors, the posterior is Gaussian but sampling can be challenging, especially for problems with a very large number of unknown parameters (e.g., dynamic inverse problems) and for problems where computation of the square root and inverse of the prior covariance matrix are not feasible. Moreover, for hierarchical problems where several hyperparameters that define the prior and the noise model must be estimated from the data, the posterior distribution may no longer be Gaussian, even if the forward operator is linear. Performing large-scale uncertainty quantification for these hierarchical settings requires new computational techniques. In this work, we consider generalized Golub-Kahan based methods for large-scale, hierarchical Bayesian inverse problems. We consider a hierarchical Bayesian framework and exploit generalized Golub-Kahan based methods to efficiently sample from the posterior distribution. Numerical examples from dynamic photoacoustic tomography and atmospheric inverse modeling demonstrate the effectiveness of the described approaches.

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MS6

Real-Time Linearized Eit Reconstructions Using a Database of Simulated Eit Images

Electrical Impedance Tomography (EIT) is a non-ionizing technology for imaging of a patient's internal body structure from administration of currents and measuring the resulting voltages at electrodes across the body's surface and solving an inverse problem to estimate the electrical properties of the body. Among the existing methods, the NOSER algorithm reconstructs cross-sectional images in real-time using one step of a Newton's method solver aiming to minimize the sum of the squared differences between estimated and actual measurements using a constant conductivity model as an initial guess. In this talk we discuss the creation of an Anatomical Atlas from CT scans of 89 infants to build a database of simulated EIT images. Using this database, we create an estimate of a mean chest cavity and its corresponding effect on the estimated voltage measurements. This allows us to use a more accurate initial condition than is seen in NOSER while maintaining the speed benefits of performing a single Newton's method step, resulting in more detailed images while maintaining real-time implementation. We will compare reconstructed images using each algorithm on simulated and experimentally measured voltages.

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MS6

Using Eit Data to Help Image the Electrical Activity of the Heart

The inverse problem of electrocardiography (ECG) is to image the electrical activity of the heart using voltage measurements made on the bodys surface. These voltage measurements depend nonlinearly on the conductivity distribution inside the chest. The ACT5 system allows one to measure Electrical Impedance Tomography (EIT) and ECG data simultaneously allowing one to use both sets of data in real time. Using the EIT data, we can reconstruct the conductivity distribution inside the chest using a 3D linearized conductivity reconstruction algorithm. In this talk, focus is placed on reconstructing the Total Cardiac Vector which is approximated as a single dipole source. To measure the accuracy of the reconstructions, we compare the measured voltages taken from the ACT5 system with the reconstructed body surface map which are the predicted voltages from our reconstructed dipole sources. In this talk, it will be discussed how we can improve our ability to reconstruct the body surface map by using more realistic models and finally how using the reconstructed conductivity from the EIT data effects the path of the Total Cardiac Vector. Reconstructions using multiple dipole sources inside the heart will also be presented as a way to show how the reconstructed body surface maps can be further improved by reconstructing additional dipole sources.

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MS7
Optimal Control of Branched Flow

Branched flow is a wave scattering phenomenon that produces a tree-like pattern and is understood to be ubiquitous across different systems such as height fluctuations of tsunamis, pulsar radiation propagating through the interstellar medium, the flow of electrons in semiconductors, and, more recently, light propagation in thin soap films. Besides being a novel scientific phenomenon, branched flow of light has been proposed as a means for probing biological membranes, thus making its mathematical description important for applications. In this talk, we will show how to numerically reproduce branched flow using Schrdinger dynamics in random media. We will then formulate and solve an optimization problem that addresses the problem of maximally illuminating dark regions in the media.

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MS7
A Hybrid Algorithm for Restoring Grain Orientations of Material Microstructures

Metals typically consist of a crystalline structure made of "crystal grains." The orientation of these grains plays a crucial role in determining the metal's properties like elasticity, strength, and fracture points. These orientations are usually measured using techniques such as electron backscatter diffraction (EBSD). The orientations are recorded as Euler angles; however, these measurements can have missing areas due to errors in instrumentation. Such gaps can lead to incorrect assessments of the material's structural properties, which might cause dangerous situations. The challenge is to accurately complete the missing orientation data, a process known in image processing as "inpainting." Two primary methods for inpainting are exemplar-based techniques and machine learning algorithms, like partial convolutional neural networks. The exemplar-based method finds a region with a similar neighborhood in the data. In contrast, the machine learning approach uses extensive training datasets to fill the missing area optimally. Our study introduces a hybrid method for EBSD data inpainting. We start by filling the unknown areas using a partial convolutional network supported by a large set of simulated datasets. Subsequently, these results and known regions are applied as exemplars in Criminisi's inpainting algorithm to scan the remaining image. We demonstrate that this hybrid technique yields better results than using either approach independently.

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MS7
Alternate Neural Network Frameworks for Data Structures in Inverse Imaging Problems

Inverse imaging problems (e.g., compressive recovery and denoising) depend on a priori decisions regarding, for example, regularization and signal models. We present alternate neural network frameworks that improve performance in a variety of applications.

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MS8
Functional Lifting - Overview and Prospects for Phase Retrieval

Solving imaging problems numerically is especially challenging when the underlying mathematical problem is nonconvex. This talk addresses relaxation and functional lifting strategies which are used to reformulate non-convex problems as convex problems over a larger solution space and discusses their prospects with respect to the phase retrieval problem.

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MS8
Nonlinear Inverse Problems in Refractive Phase Retrieval for Near-Field X-Ray Tomography

Refractive phase retrieval in near-field tomography often encounters nonlinear inverse problems, posing challenges and opportunities in imaging science. This talk will explore the mathematical framework of nonlinear inverse problems in near-field tomography and how nonlinear optimization techniques tailored for phase retrieval. Furthermore, we showcase case studies to discuss its practical applications, challenges, and future prospects.

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MS8
Background Denoising for Ptychography via Wigner Distribution Deconvolution

We consider ptychographic reconstruction, a special case of the phase retrieval problem. Ptychography is a computational imaging technique that aims to reconstruct the object of interest from a set of diffraction patterns. Each of them is obtained by a localized illumination of the object, which is shifted after each illumination to cover its whole domain. In this work, we consider ptychographic measurements corrupted with background noise, a type of additive noise that is independent of the shift, i.e., the same for all diffraction patterns. Two algorithms are provided, for arbitrary objects and so-called phase objects that do not absorb the light and only scatter it. For the second type, a uniqueness of reconstruction is established for almost every object. Our approach is based on the Wigner Distribution Deconvolution, which lifts the object to a higher-dimensional matrix space where the recovery can be reformulated as a linear system. Background noise only affects a few equations of the linear system that are therefore discarded. The lost information is then restored using redundancy in the higher dimensional space and the object is extracted from its matrix representation. As the dimension of the matrix space is typically linear in the object's dimension, this results in a fast non-iterative method.

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MS9
Discovering Stochastic Dynamics from Noisy Data

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MS9
Leveraging Joint Sparsity Using Bayesian Methods in 3D SAR Imaging

Three-dimensional synthetic aperture radar imaging is an active and growing field of research with various applications in both military and civilian domains. Sparsity-promoting computational inverse methods have proven to be effective in providing point estimates for these volumetric images. Such techniques have been enhanced by using sequential joint sparsity information from nearby aperture windows. This investigation extends these ideas by introducing a Bayesian approach that leverages the assumption of sequential joint sparsity. Our new approach enables uncertainty quantification in addition to obtaining a point estimate. As demonstrated in real and simulated experiments, our approach compares favorably to currently used methodology for point estimate approximations. This work was done in collaboration with JR Jamora at the Air Force Research Laboratory in Dayton, Ohio.

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MS9
p-MGARD: Variable order Multigrid Compression of Scientific Data

MGARD (MultiGrid Adaptive Reduction of Data) is an algorithm for compression and refactoring of scientific data based on the theory of multigrid methods. The core algorithm is built around stable multilevel decompositions of conforming piecewise linear C^0 finite element spaces enabling accurate error control in different norms and derived quantities of interest. Here we extend this construction to higher order elements and propose a reformulation of the algorithm as a lifting scheme with variable order polynomial predictors. We derive a simple rule for an adaptive decomposition of Cartesian grids into elements of varying orders along with an efficient implementation featuring linear time complexity. To demonstrate the effectiveness of this approach, we provide comparisons with the core algorithm utilizing linear predictors, using several real-world datasets.

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MS9
Streaming Compression of Scientific Data Through Surrogate Modeling

The production of scientific data, either via simulation or experiments, is undergoing a stage of exponential growth, which makes data compression important and often necessary for storing and utilizing large scientific data sets. As opposed to classical offline compression algorithms that perform compression on a readily available data set, streaming compression algorithms compress data online while the data generated from simulation or experiments are still flowing through the system. This feature makes streaming compression algorithms well-suited for scientific

data compression in situations where storing the full data set offline is often impractical. Often scientific data can be viewed as snapshots of a solution to some possibly unknown partial differential equation. Under this assumption, data driven surrogate modeling techniques can be applied in order to recover a governing differential equation. In this talk, well discuss some streaming data compression approaches which utilize data driven surrogate modeling techniques.

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MS10
From Likelihood Free Estimators to Regularized Inversion for Nonlinear Inverse Problems

Likelihood free estimators can be a desirable alternative to nonlinear inverse problems due to their computational complexity. However on inference, such estimators yield a solution with unknown data misfit. In this talk we explore the connection between such estimators and regularized inversion and show that it is possible to obtain a regularization operator that is consistent with the likelihood free estimators.

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MS10
CLAIRE: Scalable Algorithms for Diffeomorphic Image Registration

We discuss numerical methods for optimal control problems governed by geodesic flows of diffeomorphisms. Our contributions are designing effective numerical methods and fast computational kernels that scale on heterogeneous, high-performance computing platforms. We discuss efficient numerical methods, implementation aspects, and performance of the proposed method for inference and UQ. The considered inverse problem is infinite-dimensional in principle. We seek to establish spatial correspondences between two views (images) of the same object. In principle, these correspondences are modeled as geodesic flows of diffeomorphisms. The solution of the associated optimality conditions poses significant mathematical and numerical challenges; the optimization problem is non-convex and non-linear, which, upon discretization, results in high-dimensional ill-conditioned systems. Our solvers are based on state-of-the-art algorithms to enable fast convergence and short runtime. We use adjoint-based first- and second-order methods for numerical optimization. We report results for real and synthetic data to study the rate of convergence, time-to-solution, numerical accuracy, and scalability of our solvers. As a highlight, we will showcase results for a GPU-accelerated implementation termed CLAIRE that allows us to solve clinically relevant 3D image registration problems with high accuracy in under 5 seconds on a single GPU and scales up to 100s of GPUs.

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MS10

From Nodes to Networks: Topological Deep Learning for Human Pose Dynamics

Developing robust models for human pose prediction is foundational to creating safer, more intelligent interactions between people and real-world autonomous technology. Designing such models poses a significant challenge. Namely, representing human movement requires, at a minimum, recording the positions of all its joints in space and time. This results in high-dimensional data that encodes intricate joint correlations spanning multiple time scales. Current model architectures often incorporate graph convolutional networks to model pairwise spatial attention between joints and produce embeddings for classification or prediction. However, human movement cannot be adequately summarized by pairwise joint relationships alone—movement as simple as walking requires multiple joints to be coordinated at once. To capture these relationships, we need to include higher-order relations between joints. Such representation of higher-order relations has only recently become possible with the advent of topological deep learning (TDL). In this talk, we ask how we can instead preserve and learn the intricacy of the body's spatio-temporal relationships by leveraging data representations from TDL. We provide a systematic framework for augmenting state-of-the-art models with the higher-order message-passing characteristic of TDL.

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MS10

Robust Hybrid 3D Image Registration Using Learned Segments

Variational image registration methods are a powerful tool in medical imaging. A drawback of these methods is the sensitivity to initialization, which often relies on user input such as manual landmark detection. To overcome this difficulty we propose a fully-automated hybrid registration approach which builds on the great success of artificial intelligence in segmentation of anatomical structures: Based on features derived from segmentations we perform a landmark-based registration followed by an intensity-guided registration. We also propose a new coupling regularization which is used in both phases of the registration in order to ensure a seamless transformation. Experimental results in 3D show that our registration approach can be easily applied even to challenging medical data, such as lung CT imaging.

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MS11

Asymptotic Analysis and Truncated Backpropaga-

tion for the Unrolled Primal-Dual Algorithm

Algorithm unrolling combines the advantages of model based optimization with the flexibility of data-based methods by adapting a parameterized objective to a distribution of problem instances from a finite sample from that distribution. At inference time, a fixed number of iterations of a suitable optimization algorithm is used to make predictions on unseen data. To compute gradients for learning, the last iterate is differentiated with respect to the parameters by backpropagation schemes that get expensive when the number of unrolled iterations gets large. Therefore, only few unrolled iterations are used which compromises the claimed interpretability in terms of the underlying optimization objective. In this work, we consider convex objective functions, derive an explicit limit of the parameter gradients for a large number of unrolled iterations, derive a training procedure that is computationally tractable and retains interpretability, and show the effectiveness of the method using the example of image denoising.

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MS11

Accelerated Posterior Sampling for Imaging Inverse Problems Using Data-driven Priors

We are interested in solving image restoration problems using Bayesian computation, and thus enabling uncertainty quantification on the obtained results. In problems with a non-Gaussian noise characteristic, the log-posterior target distributions do not fulfil the regularity properties required to use Euclidean Langevin Monte Carlo sampling algorithms, such as Lipschitz-smoothness and (strong) log-concavity. Instead, discrete sampling schemes can be derived from Riemannian Langevin diffusion algorithms, using a metric capturing the local geometry of the log-posterior. The resulting mirror-descent like sampling algorithms are similar to the Bregman proximal gradient algorithm which use Bregman divergences to alter the geometry and impose a smooth approximation of the potential. We explore how data-driven priors can be incorporated within mirror Langevin algorithms and show that we can accelerate posterior sampling while obtaining more accurate results.

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MS11

Unsupervised Learning of Deep Data Fidelities in Unfolded Algorithms

Over the past decade various strategies have been proposed in order to improve classical variational models. Among these, there is the so called algorithm unfolding, which is also well versed to incorporate deep learning techniques. However, due to the intrinsic nature of the learning process, the model that is obtained often suffers, up to a variable degree, from a dependance on the data. In a context of image deblurring, we propose to train the deep unfolding through an unsupervised no-reference image quality measure. The resulting framework enables us to learn the model for one image at a time. Moreover, its structure also allows us to adapt the data fidelity term to the intensity of the remain-

ing blur through the iterations.

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MS11
Unrolled Proximal Neural Networks Within Plug-and-Play Algorithms

A common approach to solve inverse imaging problems relies on finding a maximum a posteriori (MAP) estimate of the original unknown image, by solving a minimization problem. In this context, iterative proximal algorithms are widely used. Recently, these algorithms have been paired with deep learning strategies, to further improve the estimate quality. In particular, proximal neural networks (PNNs) have been introduced, obtained by unrolling a proximal algorithm as for finding a MAP estimate, but over a fixed number of iterations, with learned linear operators and parameters. In this presentation we propose a unified framework to build PNNs for the Gaussian denoising task. We further show that accelerated inertial versions of these algorithms enable skip connections in the associated NN layers. We propose different learning strategies for our PNN framework, and investigate their robustness (Lipschitz property) and denoising efficiency. Finally, we assess their robustness when plugged in a forward-backward algorithm for an image deblurring problem.

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MS12
CIL - A Versatile Python Framework for Tomographic Imaging

In this talk, we introduce the Core Imaging Library (CIL), a Python-based open-source framework designed for addressing inverse problems in imaging, with a specific emphasis on tomographic imaging and reconstruction. The talk will delve into the key components of CIL, highlighting its core functionalities. Additionally, we will demonstrate the versatility of CIL through diverse applications, including Cone-Beam X-ray laminography, Dynamic X-CT, Hyperspectral CT, and Positron Emission Tomography. Also, we present the new and flexible optimisation API that allows the users to engage in Stochastic Optimisation using a plethora of variance-reduced algorithms for tomography reconstruction. Finally, we will explore a promising solution aimed to unify various open source imaging software platforms through the implementation of the Data-Array API.

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MS12
PyTomography: A GPU-accelerated Python Library for Medical Image Reconstruction

PyTomography is a GPU-accelerated, open-source, and user-friendly medical image reconstruction library, designed to serve as a central platform for the development, validation, and deployment of current and novel tomographic reconstruction algorithms. It was developed using Python and inherits the GPU-accelerated functionality of PyTorch for fast computations and simple integration with neural networks. The software uses a modular design that decouples the system matrix from reconstruction algorithms, simplifying the process of integrating new imaging modalities or developing novel reconstruction techniques. As example developments, SPECT and PET reconstruction are demonstrated using (i) standard clinical reconstruction algorithms and (ii) AI-based reconstruction techniques. PyTomography is publicly shared on GitHub, aiming to foster community development of novel applications in medical imaging.

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MS12
Experiences with STIR and SIRF: Open Source Software for Image Reconstruction for PET, SPECT and MRI Data.

Software for Tomographic Image Reconstruction (STIR) and the Synergistic Image Reconstruction Framework (SIRF) enable researchers to reconstruct data from clinical as well as research systems. STIR is currently still the only OSS for nuclear medicine that offers complete data processing, including estimation of acquisition model parameters, scatter etc. SIRF on the other hand integrates other packages to provide a consistent interface to the user. In this talk, I will give a brief overview of their capabilities and interactions with other OSS projects. In addition, I will discuss challenges such as encouraging uptake by users and contributions by developers, software sustainability and interaction with vendors, reflecting on 25 years of OSS development.

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MS12
Computational Imaging with SCICO

Scientific Computational Imaging Code (SCICO) is an open-source Python package for solving the inverse problems that arise in scientific imaging applications, including X-ray, proton, or neutron radiography, seismic imaging, ptychography, and light microscopy. Its primary focus is providing methods for solving ill-posed inverse problems by using an appropriate prior model of the reconstruction space. SCICO includes a growing suite of operators, cost functionals, regularizers, and optimization routines that may be combined to solve a wide range of problems, and is designed so that it is easy to add new building blocks. SCICO is built on top of JAX rather than NumPy, enabling GPU/TPU acceleration, just-in-time compilation, and automatic gradient functionality, which is used to automatically compute the adjoints of linear operators. This presentation will provide an overview of the library design and illustrate its application with some examples.

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MS13
Accelerating Sampling with Score-Based Diffusion Models Using Closed-Form Dynamics

Diffusion models have recently emerged as a powerful framework for generative modeling. They consist of a forward process that perturbs input data with Gaussian noise and a reverse process that learns a score function to generate samples by denoising. Despite their tremendous success, they are mostly formulated on finite-dimensional Euclidean spaces, excluding their application to domains such as scientific computing where the data consist of functions. In this presentation, we propose two improvements for sampling distributions with probabilistic diffusion models. First, we introduce a mathematically rigorous framework called Denoising Diffusion Operators (DDOs) for applying diffusion models in function space. In DDOs, the forward process perturbs input functions using a Gaussian process and learns an appropriate score function in infinite dimensions. We show that our discretized algorithm generates accurate samples at a fixed cost that is independent of the data resolution. Second, we propose a method to reduce the cost of sample generation by leveraging the closed-form formula for the score of the perturbed data distribution. Our approach blends the closed-form score and the learned score to define an approximate dynamical system that can be efficiently integrated with larger time-steps. We numerically verify that our improvements capture the statistics of high-resolution fluid dynamics problems and popular imaging datasets.

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MS13
Score-Based Generative Models for PET Image Reconstruction

Score-based generative models have demonstrated highly promising results for medical image reconstruction tasks in magnetic resonance imaging or computed tomography. However, their application to Positron Emission Tomography (PET) is still largely unexplored. PET image reconstruction involves a variety of challenges, including Poisson noise with high variance and a wide dynamic range. To address these challenges, we propose several PET-specific adaptations of score-based generative models. The proposed framework is developed for both 2D and 3D PET. In addition, we provide an extension to guided reconstruction using magnetic resonance images. We validate the approach through extensive 2D and 3D *in-silico* experiments with a model trained on patient-realistic data without lesions, and evaluate on data without lesions as well as out-of-distribution data with lesions. This demonstrates the proposed method's robustness and significant potential for improved PET reconstruction.

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MS13
Proximal Nested Sampling with Data-Driven Priors for Inverse Imaging Problems

Proximal nested sampling was introduced recently to open up Bayesian model selection for high-dimensional problems such as inverse imaging problems. The framework develops a constrained Langevin approach to nested sampling, leveraging techniques from proximal calculus to enforce the likelihood constraint. It is suitable for models with a log-convex likelihood, which are ubiquitous in the imaging sciences. The focus of the talk is two fold. First, I will review proximal nested sampling in a pedagogical manner. Second, I will show how proximal nested sampling can be ex-

tended in an empirical Bayes setting to support data-driven priors, such as deep neural networks learned from training data. Numerous imaging examples and experiments will be covered throughout.

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MS13

Noise-Free Sampling Algorithms via Regularized Wasserstein Proximals

We consider the problem of sampling from a distribution governed by a potential function. This work proposes an explicit score based MCMC method that is deterministic, resulting in a deterministic evolution for particles rather than a stochastic differential equation evolution. The score term is given in closed form by a regularized Wasserstein proximal, using a kernel convolution that is approximated by sampling. We demonstrate fast convergence on various problems and show improved dimensional dependence of mixing time bounds for the case of Gaussian distributions compared to the unadjusted Langevin algorithm (ULA) and the Metropolis-adjusted Langevin algorithm (MALA). We additionally derive closed form expressions for the distributions at each iterate for quadratic potential functions, characterizing the variance reduction. Empirical results demonstrate that the particles behave in an organized manner, converging and lying on level set contours of the potential.

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MS15

Leveraging Block Matrix-to-Tensor Mappings and Tensor Decompositions for Imaging Problems

Block-structured matrices naturally occur in image processing applications. Recent work in tensor mathematics introduced methods to map block-structured matrices to 3-way tensors and back again. An additional Kronecker structure is revealed in the original matrix by applying tensor decompositions before mapping back to a matrix. This talk discusses these methods and their applications for efficiently solving inverse problems in imaging.

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MS15

Projected Tensor-Tensor Products for Multidimensional Data Compression

Tensor-tensor products have demonstrated success in wide-ranging applications involving multidimensional data. These tensor operations look and feel like matrix multiplication, thereby extending desirable properties of standard matrix algebra to tensors. The underlying multiplication relies on an invertible matrix, which can be computationally demanding and memory intensive for large tensors. In this work, we propose a projected tensor-tensor product which replaces the expensive invertible matrix with a cheap orthogonal projection onto a low-dimensional subspace. We illustrate that projected products still preserve many linear algebraic properties and demonstrate their utility in imaging applications, such as video and hyperspectral image compression.

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MS15

Eit Reconstruction Using Virtual X-Rays and Machine Learning

We introduce a new reconstruction algorithm for electrical impedance tomography, which provides a connection between EIT and traditional X-ray tomography, based on the idea of "virtual X-rays". We divide the exponentially ill-posed and nonlinear inverse problem of EIT into separate steps. We start by mathematically calculating so-called virtual X-ray projection data from the measurement data. Then we perform explicit algebraic operations and one-dimensional integration, ending up with a blurry and nonlinearly transformed Radon sinogram. We use neural networks to remove the higher-order scattering terms and perform deconvolution. Finally, we can compute a reconstruction of the conductivity using the inverse Radon transform. We demonstrate the method with experimental data.

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MS15

Spatial Regularization for Deep Learning-Based Segmentation of Medical Images

Deep learning methods have achieved outstanding results in many image processing and computer vision tasks, such as image segmentation. However, they usually do not consider spatial dependencies among pixels/voxels in the image. To obtain better results, some methods have been proposed to apply classic spatial regularization, such as total variation, into deep learning models. However, they are difficult to implement and inefficient. And for some challenging images, especially those with fine structures and low contrast, classical regularizations are not suitable. We derived a new regularization to improve the connectivity of segmentation results and make it applicable to deep learning. Our experimental results show that for both deep learning methods and unsupervised methods, the proposed method can improve performance by increasing connectivity and dealing with low contrast, and therefore enhance segmentation results.

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MS16

Variable Projection Method for Mixed Gaussian Models

The variable projection method has been developed as a powerful tool for solving separable nonlinear least squares problems. It has proven effective in cases where the underlying model consists of a linear combination of nonlinear functions, such as exponential functions. A modified version of the variable projection method to address a challenging semi-blind deconvolution problem involving mixed Gaussian kernels is employed. The aim is to recover the original signal accurately while estimating the mixed Gaussian kernel utilized during the convolution process. The numerical results obtained through the implementation of the proposed algorithm are presented.

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MS16

A Spatially Varying MCMC Approach to Deblurring X-Ray Images

Many scientific experiments such as those found in astronomy, geology, microbiology, and X-ray radiography require the use of high-energy instruments to capture images. Since blur and noise are inevitably present in any imaging system, the images must be deblurred to extract the full information content. Mathematically, image deblurring is an ill-posed inverse problem that requires regularization. The regularization, in turn, has a large effect on the deblurred image: different regularization strengths, and types, lead to drastically different reconstructions. Moreover, many images contain a mixture of smooth and sharp features which suggests the use of multi-regularization, i.e., varying the type of regularization (e.g. Tikhonov or total variation) across the image. We address these issues by formulating the image deblurring problem within a hierarchical Bayesian framework in which we spatially adapt the strength and type of regularization across the image. In this way, the image itself, along with corresponding regularization strength at each pixel, are described jointly by a posterior distribution which we can sample by Markov chain Monte Carlo (MCMC) methods. We illustrate our techniques on simplified test problems and apply them to high-energy X-ray images taken at the Nevada National Security Site. Numerical tests show that our new method is robustly applicable and increases the quality of the image reconstruction when compared to other Bayesian methods.

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MS17

A Spectral Problem in Flat Lens Design

We consider the problem of wave propagating from a region of interest in the "object plane" to another region of interest in the "image plane". We show that if we look for the phase screen placed between the two planes that maximizes the number of degrees of freedom that can be transmitted between the two regions, we obtain a spectral problem and the solution can be found in terms of the classic thin lens phase.

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MS18

Decoupling The Fully-Connected Layers: A Network Reduction Technique

We introduce a novel approach to reducing the number of units in fully connected layers of a deep neural network. Leveraging a separation of the hidden layers of the original network into decoupled shallow networks, we present a sparsification technique that efficiently reduces the complexity of each shallow network, ultimately leading to the emergence of a global sparse deep network. Our proposed approach holds significant promise in advancing the development of more efficient, storage-friendly, and scalable sparse neural network architectures.

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MS18

Statistical Learning Theory of Deep Neural Networks for Data with Low-Dimensional Structures

In the past decade, deep learning has made astonishing breakthroughs in various real-world applications. It is a common belief that deep neural networks are good at learning various geometric structures hidden in data sets. One of the central interests in deep learning theory is to understand why deep neural networks are successful, and how they utilize low-dimensional data structures. In this talk, I will present some statistical learning theory of deep neural networks where data are concentrated on or near a low-dimensional manifold. The learning tasks include regression, classification, feature representation and operator learning. When data are sampled on a low-dimensional manifold, the sample complexity crucially depends on the intrinsic dimension of the manifold instead of the ambient dimension of the data. These results demonstrate that deep neural networks are adaptive to low-dimensional geometric structures of data sets.

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MS19

Model-Aware Learning for Image Reconstruction Problems in Fluorescence Microscopy

Recent approaches to super-resolution fluorescence microscopy exploit the analysis of fluorescence fluctuations over short acquisition times. Mathematically, the problem can be cast in the form of an ill-posed inverse problem and solved using advanced regularisation models and non-convex optimisation tools which are prone to tedious parameter tuning, numerical bottlenecks and potential appearance of artefacts. To overcome these issues, we consider physics-inspired learning approaches to incorporate data knowledge so as to better model data and/or regularisation terms. In particular I will discuss how theoretically-grounded plug play gradient-step denoisers and algorithmic unrolling methods can be effectively used to learn implicitly the unknown image prior and present an unsupervised physics-inspired generative adversarial framework reconstructing a high-resolution images temporal sequences of low-resolution data.

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MS19

A Biology-Based Modeling Approach for Characterizing High-Grade Glioma Response to Radiation Therapy from Patient Mris

Radiation therapy (RT) is a fundamental component of the post-resection treatment and management of high-grade gliomas. RT efficacy, however, can vary within and across tumors resulting in disease progression. Thus, there is a need to identify (or predict) RT efficacy for individual patients and tailor RT plans to target tumor regions which are more resilient to RT. We present a biology-based modeling approach which leverages quantitative patient magnetic resonance imaging (MRI) data collected before, during, and after therapy to predict patient outcomes and areas of disease progression. Serial imaging data are first registered to the pre-RT imaging visit and the enhancing and non-enhancing tumor regions are identified on anatomical images. Within the tumor regions, tumor cellularity was estimated using the apparent diffusion coefficient estimated from diffusion-weighted MRI to yield a 3D time course of tumor burden. Using tumor cellularity estimates collected before the end of RT, we calibrated a mechanically-coupled reaction-diffusion to return estimates of tumor cell proliferation, tumor cell diffusion, and sensitivity to RT. The calibrated model was then used to predict treatment response which was compared directly to the observed response at future imaging visits at the whole tumor and voxel level. Using this approach, our image-driven biology-based modeling framework was able to provide predictions of response 1-month post-RT with low tumor and voxel level errors.

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MS19

Neural Differential Equations for Medical Image Prediction and Segmentation Tasks

In this talk, we will discuss recent progress in incorporating ODEs and PDEs in medical image prediction and segmentation. First, we present a PDE-guided deep learning framework to learn the underlying tumor cell dynamics influenced by radiotherapy. A two-branch neural network is designed to encode a reaction-diffusion equation with an unknown operator approximated by a neural network. Starting from pre-treatment PET images and radiation dose distributions, this model shows promising results in predicting the post-treatment PET images and the influence of the imposed radiotherapy. Second, we propose a Neural-ODE based method for interpreting the behavior of neural networks in multi-parametric medical image segmentation tasks. We characterize the continuous evolution of images with multi-modality from inputs to segmentation results using Neural ODEs. We also design an accumulative contribution curve to quantify the utilization of each modality in the learned dynamics. In a multi-parametric MRI-based glioma segmentation study, the proposed method successfully identifies key MR modalities. This method offers a new tool for optimizing inputs and enhancing the interpretability of deep learning models for multimodal image segmentation.

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MS19

From Formulas to Futures: Mathematical Insights into Endosomal Escape

The research project focuses on developing a new method to measure the endosomal escape following the successful delivery of siRNAs (small interfering RNAs) into ovarian cancer cells using fusogenic peptides. The objective is to counteract the rapid degradation of siRNAs in the endosome, a problem that the specially designed fusogenic peptides address. These peptides, created by Dr. Alexander-Bryant, attach to siRNAs and facilitate their movement from the endosome into the cytosol. Our goal here is to develop and optimize statistical models to quantify the endosomal escape of siRNAs in cancer cells.

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MS20

Proximal Unfolded Neural Networks for Anisotropic Scalefree Texture Segmentation

Texture segmentation is a key task in image processing for which many models have been considered. In this work we focus on textures characterized by anisotropy and scale-free statistics, two generic properties perceived as orientation and regularity. From results on wavelet analysis of gaussian fields, we propose to combine a complex dual-tree multiscale (wavelet) analysis within an inverse problem formulation in order to estimate anisotropic scale-free local features. A penalized variational formulation is proposed to recover the segmentation as piece-wise constant estimates of the features. A primal-dual proximal algorithm accelerated by strong convexity is devised. The resulting algorithm can be interpreted as a neural network with model driven filters and activation functions. In the unrolled approach the different filters can be learned from the available data. Identifying the roles of the different filters with respect to the corresponding variational problem allows to design interpretable convergent neural networks.

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MS20

Learning Data-Driven Priors for Image Reconstruction: From Bilevel Optimisation to Neural Network-Based Unrolled Schemes

Combining model-based variational methods for image reconstruction with deep learning techniques has recently attracted a significant amount of attention. The aim is to combine the interpretability of a model-based method with the state-of-the-art performance of deep neural networks. We introduce an image reconstruction approach that achieves such a combination which we motivate by recent developments in learned algorithm unrolling as well as by bilevel optimisation schemes for regularisation parameter estimation. We consider a network consisting of two parts: The first part uses a deep convolutional neural network (CNN) to estimate a spatially varying (and temporally for dynamic problems) regularisation parameter for a classical variational problem (e.g. TV). The resulting parameter is fed to the second network which unrolls a finite number of iterations of a solution algorithm (e.g. PDHG). The overall network is trained end-to-end in a supervised fashion. This results to an interpretable algorithm since the black-box nature of the CNN is placed on the regularisation parameter and not to the image. We prove consistency of the scheme by showing that, as the number of unrolled iterations tends to infinity, the unrolled energy functional used for the supervised learning *Gamma*-converges to the functional that incorporates the exact solution map of the TV-minimization. We also provide a series of numerical examples that show the applicability of our approach.

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MS21

A Mathematical Theory of Computational Resolu-

tion Limit and Super-Resolution

There is a fundamental diffraction barrier in optical imaging systems which is called the resolution limit. Rayleigh investigated this problem and formulated the well-known Rayleigh limit. However, the Rayleigh limit is empirical and only considers the resolving ability of the human visual system. On the other hand, resolving sources separated below the Rayleigh limit to achieve so-called super-resolution has been demonstrated in many numerical experiments. In this talk, I will propose a new concept computational resolution limit which reveals the fundamental limits in superresolving the number and locations of point sources from a data-processing point of view. I derive sharp estimates to the computational resolution limits and they are determined by the cutoff frequency, signal-to-noise ratio, and the sparsity of sources. As a direct consequence, it is demonstrated that l_0 optimization achieves the optimal order resolution in solving super-resolution problems. For the case when resolving two point sources, the resolution estimate is improved to an exact formula, which rigorously answers the long-standing question of diffraction limit in very general circumstances. I also propose an optimal algorithm for distinguishing images generated by single or two point sources. Additionally, the theoretical results were generalized to the imaging of positive sources and imaging in multi-dimensional spaces.

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MS21

Multi-Parameter Super-Resolution Imaging of Single Nanoparticles

Noble metal nanoparticles (10 100 nm in size) support localized surface plasmons, which are light-driven collective oscillations of their surface conduction electrons. Plasmons not only give metal nanoparticles brilliant colors that depend on their shape, size, composition, and environment, but also enable a whole suite of applications, from biosensing to photocatalysis. However, even for a relatively homogeneous population of nanoparticles (say, 100 nm long gold nanorods), each nanoparticle will have variations in size and shape, and this heterogeneity can have significant impact on their resulting properties. Single particle optical microscopy allows us to map this heterogeneity by studying how each nanoparticle interacts with light, but unfortunately, lacks the ability to resolve the nanoparticle shape and size due to the optical diffraction limit. This talk will describe a recently-developed super-resolution imaging technique known as calcite-assisted localization and kinetics (CLocK) microscopy that allows us to uncover structural information that is hidden in a traditional diffraction-limited optical image. The talk will compare and contrast image analysis methods using analytical functions versus machine learning and discuss future challenges and opportunities in determining nanostructure using an all-optical approach.

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MS22

Subspace Method of Moments for 3-D Single-

Particle Cryo-EM Reconstruction

Cryo-electron microscopy (Cryo-EM) is a powerful imaging technique for recovering the 3-D structure of biological molecules from their noisy 2-D projections taken from different unknown viewing angles. In this talk, we introduce an efficient method-of-moments-based algorithm for 3-D single-particle reconstruction. We use data-driven low-rank tensor techniques to compress the first three moments formed by sample images. The 3-D structure and the distribution of the viewing angles can be jointly reconstructed from the compressed first three moments.

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MS23

Range Description of a Conical Radon Transform

In this talk I will discuss a range description for the Conical Radon Transform, which integrates a function on $\mathbb{R}^n$ over families of circular cones. Transforms of this type are known to arise naturally as models of Compton camera imaging and single-scattering optical tomography (in the latter case, when $n = 2$). The main results (which depend on the parity of n) provide a description of the range of the transform on the space $C_0^\infty(\mathbb{R}^n)$.

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MS23

An Online Bayesian Algorithm for Tracking Radiation Sources with the Compton Imager

In this work, we introduce the Compton imager, an emission imaging system relying on Compton scattering. This system differs from the well-known Compton camera, since the sensors of our Compton imager can simultaneously act as scatterers and absorbers. We aim at localizing and estimating the energy of point-like sources, from the interactions of their photons with the imager. Sources can potentially move during data acquisition; hence we only consider a very few events (e.g. 10 events per source), possibly noisy, and assume that the sources are fixed during that period. Some of these events could be outliers. We propose a Bayesian filtering algorithm to solve this radioactive source localisation problem. This algorithm processes each event one by one and improves iteratively the estimation of the localisation of the sources. The required number of iterations of this algorithm is thus the number of events which needs to be processed. This algorithm is less demanding in terms of computation requirements than some MCMC schemes. Simulations are carried out and prove the efficiency of this algorithm.

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MS23

Analysis of Reconstruction of Singularities of a Function from its Discrete Radon Transform Data

In this talk we overview recent results on the analysis of reconstruction from discrete Radon transform data. We call our approach Local Reconstruction Analysis, or LRA. LRA yields simple formulas describing the reconstruction from discrete data in a neighborhood of the singularities of f in a variety of settings. We call these formulas the Discrete Transition Behavior (DTB). The DTB function provides the most direct, fully quantitative link between the data sampling rate and resolution. This link is now established for a wide range of integral transforms, conormal distributions f, and reconstruction operators. Recently the LRA was generalized to the reconstruction of objects with rough edges. Numerical experiments demonstrate that the DTB functions are highly accurate even for objects with fractal boundaries.

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MS23

Analytic Methods for Image Reconstruction from Compton Camera Data

This talk addresses the overdetermined problem of inverting the cone (or Compton) transform that integrates a function over conical surfaces in n-dimensions. The study of the cone transform originates from Compton camera imaging, a nuclear imaging method for the passive detection of gamma-ray sources. We present a new identity relating the n-dimensional cone and Radon transforms through spherical convolutions with arbitrary weight functions. This relationship leads to various inversion formulas for the cone transform in n-dimensions under a mild assumption on the geometry of detectors. We present two such formulas along with the results of their numerical implementation using synthetic phantoms.

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MS24

Development of an Imaging Biomarker for Detection of Hepatocellular Carcinoma

Limited methods exist to accurately characterize risk of malignant progression of liver lesions in patients undergoing surveillance for hepatocellular carcinoma (HCC). This study investigates the utilization of radiomics to differentiate between malignant versus non-malignant lesions. Patients with liver cirrhosis undergoing MRI surveillance were studied retrospectively. Controls (n=99) were patients without lesions during surveillance. Cases (n=48) were defined as patients with LI-RADS 3 and 4 lesions who developed HCC within the study period. Radiomics signals of liver parenchyma between cases and controls were compared. A workflow for quantitatively evaluating radiomics biomarkers to differentiate cases and controls will be presented.

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MS24

Task-based Assessment for Neural Network Reconstructions: Optimizing Undersampled MRI Based on Human Observer Signal Detection

Neural networks are being used to reconstruct undersampled magnetic resonance imaging (MRI). Because of the complexity of the artifacts in the reconstructed images, task-based approaches of image quality are needed. Common metrics for evaluating image quality like the normalized root mean squared error (NRMSE) and structural similarity (SSIM) are global metrics which average out impact of subtle features in the images. Using measures of image quality which incorporate a subtle signal for a specific task allow for image quality assessment which locally evaluates the effect of undersampling on a signal detection. We used a U-Net to reconstruct under-sampled images with 2x, 3x, 4x and 5x fold 1-D undersampling rates. Cross validation was performed with both structural similarity (SSIM) and mean squared error (MSE) losses. A two alternative forced choice (2-AFC) observer study was carried out for detecting a subtle signal (small blurred disk) from images. We found that for both loss functions, the human observer performance on the 2-AFC studies led to a choice of a 2x undersampling but the SSIM and NRMSE led to a choice of a 3x undersampling. For this task, SSIM and NRMSE overestimate the achievable undersampling using a U-Net before a steep loss of image quality when compared to the performance of human observers in the detection of a subtle lesion. We will also extend this work to evaluating deep learning reconstructions which incorporate data agreement (i.e. MoDL).

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MS24

Deep Learning-based Artifact Detection and Correction in Lung 4DCT

Four-dimensional computed tomography (4DCT) scans are often corrupted by respiratory motion artifacts caused by irregular patient breathing patterns during image acquisition. These artifacts can significantly compromise the accuracy of CT-derived metrics and mask anatomic structures, posing significant challenges in radiation treatment planning and diagnostic accuracy. We present novel deep learning frameworks for 4DCT respiratory motion artifact detection and artifact correction in 4DCT images. Our approach uses a 2D U-net convolutional neural network (CNN) tailored for artifact detection in 2D coronal slices. Furthermore, for artifact correction, we employ a conditional generative adversarial network (GAN) capable of synthesizing artifact-free 4DCT images. We assess the efficacy of our artifact detection approach by comparing to manually-annotated artifacts defined by a trained image analyst. We report areas under the receiver operating characteristic and precision-recall curves to quantify detection performance. Moreover, we evaluate the ability of the GAN network to correct artifacts using metrics such as the structural similarity index, peak signal-to-noise ratio, and difference images. The significance of our proposed framework is underscored by its potential to improve radiation treatment planning and increased diagnostic accuracy through improved image quality.

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MS24

Using Pre-treatment MRI Data to Drive an Integrated Mechanism- and Data-driven Model to Predict the Response of Breast Cancer to Therapy

The goal of this project is to use multi-parametric MRI to integrate mechanism-based modeling and deep learning to predict the spatio-temporal response of breast cancer to neoadjuvant (i.e., pre-surgical) therapy (NAT)and do so before treatment is initiated. Patients enrolled in the breast cancer Moonshot Program at MD Anderson received multi-parametric MRI exams before (V1) and during (V2, V3) NAT. For each patient, we calibrate a simplified version of our mechanism-based model [1] to all imaging visits to determine model parameters describing the spatiotemporal changes in tumor cellularity in response to NAT. We then train a convolutional neural network (CNN) over a cohort ($n = 94$) to predict the calibrated model parameters from the V1 MRI data. The predicted parameters are then used in the mechanism-based model to predict tumor cellularity at V2 and V3. Receiver operator characteristic analysis shows that the CNN-predicted tumor cellularity at V3 achieves an area under curve of 0.72 in the test cohort ($n = 24$) in differentiating between patients who do and do not respond to therapy. We are working to improve this result by adjusting our CNN to predict calibrated parameters in our more comprehensive mechanism-based model [1]. To the best of our knowledge, this is the first time spatio-temporally resolved predictions of tumor response have been obtained using only pre-treatment images. [1] Jarrett *et al. Nat Protoc*, 2021;16:5309-38.

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MS25

Discretization-Invariant Operator Learning for Solving Inverse Problems

This talk discusses the challenging task of determining variable coefficients within PDEs from measurement data. We introduce a novel neural network, "pseudo-differential IAEnet" (pd-IAEnet), which draws inspiration from pseudo-differential operators. pd-IAEnet achieves significantly enhanced computational speed and accuracy with fewer parameters compared to conventional models. Extensive benchmark evaluations are conducted across a range of inverse problems, including Electrical Impedance Tomography (EIT), optical tomography, and seismic imaging, consistently demonstrating pd-IAEnet's superior accuracy. Notably, pd-IAEnet exhibits robustness in the presence of measurement noise, a critical characteristic for real-world applications. An exceptional feature is its discretization invariance, enabling effective training on data from diverse discretization schemes while maintaining accuracy on different meshes. In summary, pd-IAEnet offers a potent and efficient solution for addressing inverse PDE problems, contributing to improved computational efficiency, robustness, and adaptability to a wide array of data sources.

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MS25

A Bilevel Optimization Approach for Inverse Mean-Field Games

In this work, we introduce a bilevel optimization framework for addressing inverse mean-field games, alongside an exploration of numerical methods tailored for this bilevel problem. The primary benefit of our bilevel formulation lies in maintaining the convexity of the objective function and the linearity of constraints in the forward problem. Our work focuses on inverse mean-field games characterized by unknown obstacles and metrics. We show numerical stability for these two types of inverse problems. More importantly, we, for the first time, establish the identifiability of the inverse mean-field game with unknown obstacles via the solution of the resultant bilevel problem. The bilevel approach enables us to employ an alternating gradient-based optimization algorithm with a provable convergence guarantee.

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MS25

Inverse Optimal Transport (IOT) - Learning Cost Functions for Optimal Transport

The inverse problem of optimal transport (OT) aims at recovering the ground cost function from observed transport plan or its samples. It has been cast as a bi-level optimization problem in the literature, where each iteration requires solving a forward OT problem and causes substantial computational cost overall. In this work, we derive an equivalent but much simpler unconstrained and convex optimization formulation of the inverse OT problem, which can be further augmented by customizable regularization and solved efficiently. We provide a complete characterization of the new optimization problem and its solution space. To validate the effectiveness of this framework, we present a deep learning-based method that trains the cost function as a deep neural network using the samples of transport plan for the continuous case. Numerical results demonstrate promising efficiency and accuracy advantages of the proposed methods. This is based on joint work with Shaojun Ma (Goldman-Sacks), Haodong Sun (Wells Fargo), Xiaojing Ye (GSU, Math) and Hongyuan Zha (CUHK, Shenzhen).

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MS26

Applications of Region Force Based Selective Geodesic Segmentation Model in Medical Imaging

In medical imaging, selective segmentation allows precise analysis of anatomical data by isolating certain structures, such as tumour detection, and segmenting the hip or knee for implant design. In recent years, the advancement of medical imaging modalities such as X-ray, ultrasound, computed tomography (CT), magnetic resonance imaging (MRI), and positron emission tomography has compelled researchers to develop new medical image-segmentation algorithms. In this work, we combine features from the new region force term based on statistical interpretation and geodesic distance penalty term in a single selective segmentation framework. The region force term is an improved version of previous selective fitting terms utilised in segmentation models. Segmentation solution is achieved by using the Primal-Dual Hybrid Gradient method on dual formulation with established convergence analysis. In comparison with previous segmentation models, the proposed model is independent of user input and allows for segmentation in medical images with high precision scores. Utilizing the proposed segmentation model in clinical workflow can help clinicians identify the spatial location of a brain tumour on MR images. The proposed algorithm can be

considered as a substitute for label-intense manual tumour delineation task which requires a significant amount of time and experienced clinicians.

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MS26
High Order Riemannian Total Variation for Image Restoration

In this talk, we present a high order Total Variation (TV) for vector-valued functions on manifolds, and which is determined by the following geometric triplet: a connection and a positive definite metric on the tangent bundle of the manifold, and a positive definite scalar product on the vector space. Then, we insert the high order TV into a Deep Image Prior, yielding a new variational model for the restoration of multichannel images. For a well-chosen geometric triplet, experiments conducted on various image restoration tasks up to the order 3 show that the higher the order, the better the results. Moreover, for a given order, the proposed model outperforms its Euclidean counterpart.

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MS26
Structure-Preserving Optimal Transport

Optimal transport (OT) as a powerful mathematical theory has a wide range of applications in both engineering and medical fields. It studies the transformations between probability distributions in many scenarios. This talk focuses on the OT algorithms with structural constraints and their applications for shape analysis and processing.

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MS26
Variational Framework for Super-Resolution 3D Surface Reconstruction from Limited Inputs in Multimodal Imaging

In many imaging applications, the obtained images are often in low resolution or even have missing data due to practical and hardware limitations, which can impact subsequent 3D reconstruction. For instance, X-ray imaging car-

ries radiation risks, limiting data collection time. Terahertz (THz) imaging, while safe, is slow and affected by diffraction and noise. Magnetic Resonance Imaging (MRI) struggles with the small region of interest in a high-resolution image. To address these challenges, a new framework using the Euler-Elastica regulariser is presented to reconstruct high-resolution surfaces from a few low-resolution 2D slices, combining mathematical models with local edge features and global smoothness. Two algorithms are developed (a projected gradient descent method and the alternating direction method of multipliers), and quantitative comparisons based on discrete curvatures show superiority over other regularisers. Practical examples in X-ray, MRI, and THz imaging validate its effectiveness, offering potential applications in medical imaging and computer vision. Joint work with Prof Ke Chen (Strathclyde and Liverpool), and Prof Shang-Hua Yang (NTHU, Taiwan).

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MS27
Multimodal Data Analysis in Image Reconstruction

The acquisition of rich multimodal datasets from diverse frameworks, such as scientific instruments and computers, plays a pivotal role in advancing our understanding of targeted phenomena. Nevertheless, the effective fusion of disparate modalities is essential for maximally harnessing the additional diversity inherent in multimodal data for scientific discovery. This presentation will delve into optimization-based methodologies designed to facilitate inverse problems solving by aggregating multimodal dataset. Through the exploration of various image reconstruction challenges, the discussion aims to illustrate the efficacy of these approaches.

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MS27
Crack Detection with Convolutional Neural Networks

A machine learning algorithm has been designed to automate the identification of corrosion and crack formation in canisters used to store Pu-bearing material. An hourglass neural network is trained on efficiently labeled training data generated by a laser confocal microscope or scanning electron microscope. Methods and parameters of the labeling and the machine learning algorithm have been tuned for optimal results.

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MS27
Advancements in Explainable Architectures for Limited Angle Tomography

Deep unfolding is a technique that allows to combine iterative optimization algorithms with tools from neural networks. In particular, it is used to reconstruct images by un-

folding classical iterative methods and learning their inner parameters by using supervised learning techniques. This kind of approaches needs a large number of iterations to reach a good reconstruction and this requirement leads to problems such as the gradient vanishing or a huge memory consumption during the training. Moreover their expressivity is quite limited by the choices done in the problem formulation. Exploiting the modularity of Plug-and-Play methods, we propose to unfold an inertial scheme with theoretical convergence guarantees, in order to obtain a fast algorithm which jointly learns a correction of the normal operator and the image prior. The numerical experiments on limited-angle CT achieve promising results, showing the benefits of our proposal.

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MS27
Convergent Data-Driven Regularisation in Inverse Problems

In the last decade, processing of imaging data has undergone a paradigm shift from knowledge driven approaches, deriving imaging models from first principles, to purely data driven approaches, instead deriving models from data. Most inverse problems of interest are ill-posed and require appropriate mathematical treatment for recovering meaningful solutions and while purely data-driven learning have been able to achieve remarkable empirical success for image reconstruction, they often lack rigorous reconstruction guarantees. In this talk I will discuss image reconstruction methods that operate at the interface of these paradigms and feature both a knowledge driven (mathematical modelling) and a data driven (machine learning) component. Methods discussed include data-driven variational models, plug-and-play approaches, learned iterative schemes and learned post-processing. A particular emphasis will be made on learned methods with mathematically rigorous reconstruction guarantees, and their theoretical properties will be discussed.

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MS28
Curvature Regularization Strategies in Inverse Obstacle Scattering

We use the phrase inverse obstacle scattering to distinguish it from inverse medium scattering. An object is recovered from its scattering data in both settings. In the former, the boundary of a homogeneous obstacle is recovered while in the latter, a (smoothly) varying material property is recov-ered. We use a standard formulation of the inverse obstacle scattering problem as a nonlinear, non-convex optimization problem for the domain boundary (and possibly other physical properties). It is well known that such optimization problems can be ill-posed. Typically, some regularization depending on the curvature is imposed to improve the ill-posedness. Here we explore the effects of specific choices of curvature-based regularization strategies and their impact on the performance of the obstacle recovery problem. Suitable optimization methods are discussed and examples for various boundary conditions and material parameters are presented.

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MS28
Solving the Inverse Volume Problem in 3D Using Multifrequency Data

In this work, we describe a fast, stable, and accurate algorithm to solve the inverse problem of reconstructing the smooth sound profile of a three-dimensional medium using multifrequency scattered data. To solve this inverse problem, we recast it as a constraint optimization problem. Since optimization problem using multifrequency data is computationally expensive, we use Chen's recursive linearization algorithm to solve a series of single-frequency inverse scattering problems at successively higher frequencies. The individual single-frequency inverse problems are inherently ill-posed and nonlinear. We deal with the nonlinearity by using an iterative optimization method, in this case, Gauss-Newton's method at lower frequencies, and the steepest descent method at higher frequencies. The inherent ill-posed nature of the problem is addressed by constraining the search space for our domain, focusing on a band-limited representation of the sound profile. Our work is substantiated with numerical results showcasing the effectiveness of our solver in reconstructing both obstacles and smooth sound profiles.

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MS28
Fast Algorithms for Particulate Fluid Suspensions

A wide range of applications in science and industry, from

the study of cell mechanics to smart material design involve understanding how soft matter works, and more specifically, the study and simulation of all kinds of viscous fluid suspensions: colloidal particles, fibers, fluid drops, bubbles, vesicles. In this talk, we will discuss a competitive framework for dense stokesian suspension simulation based on boundary integral methods. In this presentation, we will highlight recent and ongoing work aimed at addressing numerical challenges, acceleration and increasing robustness for this approach.

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MS28

A Fast Method for Solving a Fractional Helmholtz Inverse Problem

Inverse scattering is an important class of problems that allows one to recover internal properties of an opaque object. One of the main difficulties in solving these problems is inherent nonlinearity. In this talk, I will describe a fast implementation of a nonlinear reconstruction method, the inverse Born series. Numerical simulations will be discussed for an inverse problem in quantum optics.

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MS29

Mathematical Theory for Electromagnetic Scattering Resonances and Field Enhancement in a Subwavelength Annular Gap

This work presents a mathematical theory for electromagnetic scattering resonances in a subwavelength annular hole embedded in a metallic slab, with the annulus width O(h). We develop a multiscale framework for the underlying scattering problem based upon a combination of the integral equation in the exterior domain and the waveguide mode expansion inside the tiny hole. The matching of the electromagnetic field over the hole aperture leads to a sequence of decoupled infinite systems, which are used to set up the resonance conditions for the scattering problem. By performing rigorous analysis for the infinite systems and the resonance conditions, we characterize all the resonances in a bounded domain over the complex plane. It is shown that the resonances are associated with the transverse electric (TE) and transverse electromagnetic (TEM) waveguide modes in the annular hole, and they are close to the real axis with the imaginary parts of order. We also investigate resonant scattering when an incident wave is present. It is proved that the electromagnetic field is amplified with order $O(h^{-1})$ at the resonant frequencies that are associated with the TE modes in the annular hole. On the other hand, one particular resonance associated with the TEM mode cannot be excited by a plane wave but can be excited with a near-field electric dipole source, leading to field enhancement of order $O(h^{-1})$.

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MS29

Computing Proximity Operators for Scale and Signed Permutation Invariant Functions

This presentation delves into the computation of proximity operators for scale and signed permutation invariant functions. A scale-invariant function demonstrates resilience to uniform scaling, while a signed permutation invariant function maintains its form despite permutations and sign changes applied to its input variables. Notable examples include the ℓ_0 function and the ratios of ℓ_1/ℓ_2 and its square. The computation of proximity operators for these functions holds significant importance in sparse signal recovery. This talk will detail a method for explicitly computing the proximity operator of $(\ell_1/\ell_2)^2$ and introduce an efficient algorithm for the proximity operator of ℓ_1/ℓ_2.

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MS29

Computational Imaging of Small-Amplitude Biperiodic Surfaces with Acoustic Superlens

We consider the problem of imaging a biperiodic surface by acoustic waves. A slab of double negative metamaterial is placed above the surface and the scattered field is measured on the top boundary of the slab. The imaged surface is assumed to be a small perturbation of the flat surface so that we can make a transformed field expansion to linearize the problem and obtain a simple reconstruction formula. We show by analysis of the formula and numerical experiments that the resolution of the reconstruction can be greatly enhanced due to the double negative slab.

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MS29

Imaging Point Sources in Unknown Heterogeneous Media

Imaging point sources in heterogeneous environments from boundary or far-field measurements has been extensively studied in the past. In most existing results, the environment, represented by the refractive index function in the model equation, is assumed known in the imaging process. In this work, we investigate the impact of environment uncertainty on the reconstruction of point sources inside it. Following the techniques developed by El Badia and El Hajj (C. R. Acad. Sci. Paris, Ser. I, 350 (2012), 1031-1035), we derive stability of reconstructing point sources in heterogeneous media with respect to measurement error as well as smooth changes in the environment, that is, the refractive index. Numerical simulations with synthetic data are presented to further explore the derived stability properties.

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MS30

Quantum Computing for Inverse Problems on Graphs and an NP-Complete Inverse Problem

We consider an inverse problem for a finite graph (X, E) where we are given a subset of vertices $B \subset X$ and the distances $d_{(X,E)}(b_1, b_2)$ of all vertices $b_1, b_2 \in B$. The distance of points $x_1, x_2 \in X$ is defined as the minimal number of edges needed to connect two vertices, so all edges have length 1. The inverse problem is a discrete version the inverse travel time problem in geophysics. We will show that this problem has unique solution under certain conditions and develop quantum computing methods to solve it. We prove the following uniqueness result: when (X, E) is a tree and B is the set of leaves of the tree, the graph (X, E) can be uniquely determined in the class of all graphs having a fixed number of vertices. We present a quantum computing algorithm which produces a graph (X, E), or one of those, which has a given number of vertices and the required distances between vertices in B. To this end we develop an algorithm that takes in a qubit representation of a graph and combine it with Grover's search algorithm. The algorithm can be implemented using only $O(|X|^2)$ qubits, the same order as the number of elements in the adjacency matrix of (X, E). Finally, we consider applications in theory of computation, and show that a slight modification of the above inverse problem is NP-complete: all NP-problems can be reduced to a discrete inverse problem we consider.

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MS30

Inverse Problems on Graphs

We study the discrete version of Gelfands inverse spectral problem, formulated as follows for a finite weighted graph and the graph Laplacian on it. Suppose we are given a subset B of vertices and the spectral data $\{\lambda_j, \phi_j|_B\}$, where λ_j are the eigenvalues of the graph Laplacian and $\phi_j|_B$ are the values of the corresponding eigenfunctions on B. We consider if these data uniquely determine the graph structure and the weights. In general, this problem is not uniquely solvable without assumptions on the graph or the set B due to counterexamples. We introduce a so-called Two-Points Condition on graphs (with respect to B), and prove that the inverse spectral problem is uniquely solvable under this condition. We also consider inverse problems for random walks on finite graphs. We show that under the Two-Points Condition, the graph structure and the transition matrix of the random walk can be uniquely recovered

from the distributions of the first passing times on B.

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MS30

Analysis and Reduction of Metal Artifacts in X-Ray Tomography

Due to beam-hardening effects, metal objects in X-ray CT often produce streaking artefacts which cause degradation in image reconstruction. It is known that the nature of the phenomena is nonlinear. An outstanding inverse problem is to identify the nonlinearity which is crucial for developing artefact reduction method. In this talk, we show how to use microlocal techniques to extract information of the nonlinearity. In particular, we discuss the interesting connection between the artefact generation and geometry of metal objects.

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MS31

Understanding and Improving Implicit Neural Representations for Inverse Problems

Implicit Neural Representations (INRs) are known to encode useful priors for solving inverse problems such as image denoising, super resolution, tomography, and novel view synthesis. INR performance for inverse problems is dictated by architectural and initialization choices, both of which require further empirical and theoretical study by the research community. In this talk I will first present our work on wavelet activation functions, which enable strong implicit biases useful for solving a range of inverse problems. Next, I will discuss theoretical insights into how parameter initialization matters for INR performance. Finally, I will conclude by presenting SplineCam, a geometric framework for visualizing and understanding the underlying functional geometries of INRs.

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MS31

CoIL: Coordinate-Based Internal Learning for Tomographic Imaging

We propose Coordinate-based Internal Learning (CoIL) as a new deep-learning (DL) methodology for continuous representation of measurements. Unlike traditional DL methods that learn a mapping from the measurements to the desired image, CoIL trains a multilayer perceptron (MLP) to encode the complete measurement field by mapping the coordinates of the measurements to their responses. CoIL is a self-supervised method that requires no training examples

besides the measurements of the test object itself. Once the MLP is trained, CoIL generates new measurements that can be used within most image reconstruction methods. We validate CoIL on sparse-view computed tomography using several widely used reconstruction methods, including purely model-based methods and those based on DL. Our results demonstrate the ability of CoIL to consistently improve the performance of all the considered methods by providing high-fidelity measurement fields.

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MS31
Sampling Theorems for Implicit Neural Representations

Implicit neural representations (INRs) have emerged as a powerful tool inverse for solving inverse problems in computer vision and computational imaging. Rather than representing images as a discrete collection of pixels, INRs represent images as a continuous domain function via a neural network taking spatial coordinates as inputs. However, unlike discrete image representations, little is known about the sample complexity of estimating images using INRs in the context of linear inverse problems. Towards this end, we derive necessary and sufficient conditions under which an image is exactly recoverable from its low-pass Fourier coefficients when fitting a two-layer (i.e., single hidden-layer) INR with a Fourier features layer. In particular, we relate the sample complexity to the minimum effective width needed to realize the ground truth image as an INR.

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MS31
Implicit Neural Representation Learning for Medical Imaging

Image reconstruction is an inverse problem that solves for a computational image based on sampled sensor measurement. Sparsely sampled image reconstruction poses additional challenges due to limited measurements. In this work, we propose a methodology of implicit Neural Representation learning with Prior embedding (NeRP) to reconstruct a computational image from sparsely sampled measurements. The method differs fundamentally from previous deep learning-based image reconstruction approaches in that NeRP exploits the internal information in a personalized image prior and the physics of the sparsely sampled measurements to produce a representation of the unknown subject. NeRP is a general methodology that can generalize to different imaging modalities such as computed tomography (CT) and magnetic resonance imaging (MRI), and furthermore, learning spatial-temporal representations with personalized prior for longitudinal study. NeRP has shown potential values in different clinical applications.

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MS33
Recover All Coefficients in the Schrodinger Equation by Finitely Sets of Measurements

We consider the inverse problem of recovering all spatial dependent coefficients in the Schrödinger equation defined on an open bounded domain with smooth enough boundary. We show that by appropriately selecting finitely many initial conditions and a boundary condition we can uniquely and stably recover all the coefficients from the corresponding boundary measurements of their solutions.

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MS33
Score-Based Approaches to Sparse Data Assimilation Problems

Though machine learning models have started to replace high fidelity numerical models for problems such as weather prediction while being able to make predictive steps in a fraction of the time, new data measurements are hard to assimilate to the model without the use of reanalysis data from numerical solutions. We look into score-based approaches to incorporate sparse observational data to enhance model trajectory alignment with the true data.

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MS33
Stable Determination of Time-Dependent Collision Kernel in the Nonlinear Boltzmann Equation

We consider an inverse problem for the nonlinear Boltzmann equation with a time-dependent kernel in dimensions $n \geq 2$. We establish a logarithm-type stability result for the collision kernel from measurements under certain additional conditions. A uniqueness result is derived as an immediate consequence of the stability result. Our approach relies on second-order linearization, multivariate finite differences, as well as the stability of the light-ray transform.

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MS34
Self-supervised Dual-domain Balanced Dropblock-network for Low-dose CT Denoising

Self-supervised learning has been successfully applied in LDCT denoising. Conventional methods operate only in the image domain, ignoring valuable priors in the sinogram domain. Recently proposed dual-domain methods address this limitation but encounter issues with blurring artifacts in the reconstructed image due to the inhomogeneous noise in low-dose sinograms. To tackle this challenge, we propose SDBDNet, an end-to-end dual-domain self-supervised network that designed based on the properties of inhomogeneous noise and the principle of moderate sinogram-domain denoising. Specifically, we split the sinogram into two subsets based on the positions of detector cells to generate similar paired data with independent noise. These sub-sinograms are then restored to their original size using 1-D interpolation and learning-based correction. To achieve adaptive and moderate smoothing in the sinogram domain, we integrate Dropblock, a type of convolution

layer with regularization, and set a weighted average between the denoised sinograms and their noisy counterparts, leading to a well-balanced dual-domain approach. Experiments show that SDBDNet outperforms some popular non-learning and self-supervised learning methods, demonstrating its effectiveness and outstanding performance.

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MS34
Ricci Curvature Based Volumetric Segmentation

The level set method has played a critical role among many image segmentation approaches. Several edge detectors, such as the gradient, have been applied to its regularisation term. However, traditional edge detectors lack high-order information and are sensitive to image noise. To tackle this problem, we introduce a method to calculate the Ricci curvature tensor, a vital curvature in three-dimensional Riemannian geometry. In addition, we propose incorporating the curvature into the regularisation term. Experiments suggest that our method outperforms the state-of-the-art level set methods and achieves a comparable result with the U-net in the Brain Tumour Segmentation (BRATS) dataset.

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MS34
Non-Convex Regularization in a Deep-Learning Framework for Sparse Tomography

Based on recent works in deep learning-based image processing and non-convex iterative optimization, an efficient and robust framework is presented here for tomographic image reconstruction. In many modern and low-dose protocols, tomographic image reconstruction involves the recovery of physical quantities from sparse X-ray projection data. It is a challenging task because the lack of information (due to the subsampling) creates artifacts on images and because a good reconstruction is required in a very short time, but its computational cost is very high. Traditional model-based regularized approaches provide good and mathematically grounded reconstructions by forcing sparsity in the image gradient magnitude, which has proven to be an effective means for reducing the artifacts in biological and medical imaging. Many popular regularizers employ non-convex Lp quasinorms (with p smaller than 1). On the other hand, deep learning approaches have been widely proposed to achieve more accurate images, but they typically disregard the mathematical problem statement and the ill-posedness of the underlying model. In this talk, we present a new hybrid solver where a convolutional neural network is used to speed up the iterative reconstruction while preserving converging features. The approach's accuracy and stability are discussed in case of unknown noise affecting the data.

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MS34
Variational Model-Based Loss Functions for Enhanced Image Segmentation: Novel Averages and Robust Objective Functionals

Deep learning methods in computer vision tasks are currently benefiting from the integration of variational model-based loss functions. Specifically, well-designed variational model-based loss functions contribute to enhanced segmentation results. Recent observations suggest that the quality of segmentation can be significantly improved by representing regions using suitable average values. Essentially, altering these average values serves as a means to control the segmentation quality. In other words, averages can be considered as parameters influencing segmentation outcomes. This presentation aims to introduce novel generalized averages and a unique objective functional tailored to produce these averages as its minimizers. The proposed objective functional can be effectively employed as a robust loss function, ensuring robust and controlled image segmentation. The ability to manipulate average values provides a mechanism for achieving diverse and desired segmentation outcomes in real-time. We will delve into the details of these innovative techniques, highlighting their potential applications and benefits for computer vision tasks during the talk.

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MS35
Full Waveform Inversion with Quantified Uncertainty in Geophysics

This presentation explores Bayesian approximation as an inverse method for detecting inclusion in stratified media

from noisy measurement of wave fields on the surface. Finite elements and non-reflecting boundary conditions are applied to address the direct formulation of wave equation, with the introduction of Gaussian noise in measurements to handle uncertainty. The second part focuses on inclusion determination within a Bayesian framework. We first determine the maximum a posteriori approximation (MAP) by optimizing error functionals which measure the deviation from the recorded data, regularized with a priori information. We devise an automatic Levenberg-Marquardt-Fletcher type optimization scheme based on the use of adaptive finite element meshes to solve wave equation constraints with changing discontinuities and algorithmic differentiation. Laplace approximation estimates uncertainty about the MAP point, aiming for the main mode of the posterior density. Markov Chain Monte Carlo studies offer a more detailed description at a higher computational cost. During sampling, adaptive meshes are replaced to uniform meshes, impacting precision near material interfaces. Caution should be exerted when interpreting secondary modes, since some of them may be related to the mesh quality and the numerical noise it creates.

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MS35

Inferring Ocean Seabed with Uncertain Regularity

The accurate understanding of the structure of the seabed is essential in designing effective solutions to combat and mitigate the negative global impacts of climate change. The seabed serves as a critical source of information for various applications, including the safety assessment of offshore wind farms, establishing global transport routes, and identifying potential locations for catastrophic oceanic events. However, current technologies are limited in their ability to provide accurate seabed location data, especially for large-scale and deep ocean areas. This work introduces a novel approach that leverages elastic waves to explore the seabed. By considering the seabed as a thin interface, we are able to significantly reduce the complexity of the problem. Additionally, we employ regularization techniques that exploit the regularity of the seabed, resulting in accelerated computations. Another key contribution of our method is the estimation of uncertainty levels in the regularity of the seabed, which can play a crucial role in risk assessments for global solutions aimed at combating climate change. This talk will showcase the significant advancements in accuracy, efficiency, and reliability for large-scale and deep ocean imaging.

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MS35

Goal-Oriented Dimension Reduction for Ensemble Kalman Inversion

Inverse problems lie at the heart of imaging sciences. Some key examples include computed tomography, wavefield imaging and magnetic resonance imaging. When attaining high dimension, inverse problems become quite computationally expensive to solve. In turn, this has significantly increased the need for computationally cost-efficient, and accurate, inversion algorithms. In this work, we present a goal-oriented model reduction framework for Ensemble Kalman Inversion (EKI), an iterative methodology for solving inverse problems that unites ideas from the optimization and Bayesian perspectives on inverse problems. Our model reduction method is based on adapting balanced truncation, a system-theoretic projection-based model reduction method, to the inference setting. Specifically, we consider the linear Gaussian inference problem of uncovering the initial state of a linear dynamical system, given noisy and sparse output measurements in time. Our numerical results indicate that reduced EKI models achieve the same accuracy as the full EKI algorithm with multiple-order-of-magnitude reduction in computational cost.

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MS36

Linearized Optimal Transport with Input Convex Neural Networks for Point Cloud Classification

We focus on the problem of classifying distributions and point clouds via the linear optimal transport embedding. This is a method for embedding distributions into a Hilbert space with guarantees on when this embedding is nearly isometric to Wasserstein-2 distance. However, learning these embeddings is expensive with traditional optimal transport solvers. In this talk, we focus on two tasks: learning optimal transport maps with neural networks, and training a classifier on the learned maps. For the first task, we prove that our approach linearly embeds certain classes of probability distributions into Euclidean space nearly isometrically with high probability. Consequently, we can correctly classify these families of distributions using neural networks with finite input dimension, provided that the classes are separable in the space of distributions. This result establishes theoretical guarantees for neural networks as a method for classifying distributions and point clouds. It can similarly be viewed as incorporating geometric priors into the Deep Sets family of algorithms. We demonstrate the benefits of this geometric perspective in small data problems where there are only a handful of point clouds in the training data.

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MS36

Learning In-Between Imagery Dynamics via Physical Latent Spaces

We present a framework designed to learn the underlying dynamics between two images observed at consecutive time steps. The complex nature of image data and the lack of temporal information pose significant challenges in capturing the unique evolving patterns. Our proposed method focuses on estimating the intermediary stages of image evolution, allowing for interpretability through latent dynamics while preserving spatial correlations with the image. By incorporating a latent variable that follows a physical model expressed in partial differential equations (PDEs), our approach ensures the interpretability of the learned model and provides insight into corresponding image dynamics. We demonstrate the robustness and effectiveness of our learning framework through a series of numerical tests using geoscientific imagery data.

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MS36

Connections Between Bayesian Inference, Posterior Mean Estimation, and Hamilton-Jacobi PDEs

Variational and Bayesian methods are widely used to solve image-denoising problems. In a Bayesian setting, these methods correspond to using maximum a posteriori (MAP) estimators and posterior mean (PM) estimators for reconstructing images. The former is well understood theoretically; it is known, for instance, that a broad class of MAP estimators correspond to solutions of first-order Hamilton–Jacobi partial differential equations (HJ PDEs). In particular, the image-denoising properties of those MAP estimators follow readily from the solution properties of these HJ PDEs. The latter, in contrast, is less well understood theoretically. In this talk, I will present novel theoretical connections between HJ PDEs and a broad class of PM estimators. Specifically, we show that solutions to some viscous HJ PDEs with initial data describe a general class of posterior mean estimators with quadratic data fidelity term and log-concave prior. We use these connections to establish representation formulas and various properties of PM estimators. In particular, we use these connections to show that some Bayesian PM estimators can be expressed as proximal mappings of smooth functions and derive representation formulas for these functions.

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MS36

Robust Feature Extraction from Acoustic Wavefields for Object Classification Using Scattering Transforms

We will discuss a method to classify objects illuminated by sound waves (e.g., via sonar or bioacoustics), which is insensitive to geometric deformations of the objects (e.g., position change, rotations, shape deformations, etc.). The first step constructs redundant features that are insensitive to those deformations by computing the scattering transform representation of input acoustic wavefields. Here, I also introduce the Monogenic Wavelet Scattering Network (MWSN), which uses the Monogenic Wavelet Transform (a higher-dimensional extension of the 1D Analytic Wavelet Transform) as its base convolution filters. The next step is to reduce the dimensionality of the MWSN coefficients, e.g., PCA or the Local Discriminant Basis (LDB) algorithm. Finally, these compressed features are fed to the LASSO-based multiclass logistic regression, which further extracts a small number of critical features and classifies them. We will demonstrate its power using both synthetic and real examples and compare its performance with other invariant pattern classification techniques. Finally, we will discuss an idea of interpreting the scattering transform coefficients by finding an elementary input signal pattern that most correlates with the given scattering transform coefficients using nonlinear optimization.

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MS37

Single-Shot Plug-and-Play Methods for Inverse Problems

The utilisation of Plug-and-Play (PnP) priors in inverse problems has become increasingly prominent in recent years. This preference is based on the mathematical equivalence between the general proximal operator and the regularised denoiser, facilitating the adaptation of various off-the-shelf denoiser priors to a wide range of inverse problems. However, existing PnP models predominantly rely on pre-trained denoisers using large datasets. In this work, we introduce Single-Shot PnP methods (SS-PnP), shifting the focus to solving inverse problems with minimal data. First, we integrate Single-Shot proximal denoisers into iterative methods, enabling training with single instances. Second, we propose implicit neural priors based on a novel function that preserves relevant frequencies to capture fine details while avoiding the issue of vanishing gradients. We demonstrate, through extensive numerical and visual experiments, that our method leads to better approximations.

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MS37

On the Robustness of Normalizing Flows for Inverse Problems in Imaging

Deep learning techniques have demonstrated great potential for solving ill-posed inverse problems in imaging. Among them, conditional normalizing flow-based methods

have a unique advantage over other deep learning methods, which is the capability of generating diverse solutions for a given input. Most normalizing flows for inverse problems in imaging employ the conditional affine coupling layer that can generate diverse images quickly. However, unintended severe errors are occasionally observed in the output. In this talk, we address this critical issue by investigating the origins of these errors and proposing the conditions to avoid them.

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MS37
Medical Image Segmentation Based on Deep Active Contour and Mean Curvature Loss Function

Medical image segmentation is a crucial way in the field of clinical analysis and applications. Though deep learning techniques recently play a crucial role in several scenarios, the training at the individual pixel level leads to lack geometric prior information. Scholars proposed to integrate the Chan-Vese model into the loss function for training which can take into account the region and length of the region inside and outside the segmentation process and then improve the performance in medical image segmentation. However, these methods still lack an effective characterization of the segmented region. To overcome this problem, we introduce the mean curvature as a geometric natural constraint and propose a Deep Active Contour and Mean Curvature (DACMC) loss function where the convolution kernel is used to approximate the mean curvature to save computational cost. We have validated the performance of our method on the liver and spleen dataset. Our proposed method demonstrate new state-of-the-art performance on several segmentation dataset.

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MS37
TRIDENT: The Nonlinear Trilogy for Implicit Neural Representations

Implicit neural representations (INRs) have garnered significant interest recently for their ability to model complex, high-dimensional data without explicit parameterisation. In this work, we introduce TRIDENT, a novel function for implicit neural representations characterised by a trilogy of nonlinearities. Firstly, it is designed to represent high-order features through order compactness. Secondly, TRIDENT efficiently captures frequency information, a feature called frequency compactness. Thirdly, it has the capability to represent signals or images such that most of its energy is concentrated in a limited spatial region, denoting spatial compactness. We demonstrated through extensive experiments on various inverse problems that our proposed function outperforms existing implicit neural representation functions.

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MS38
Linearized Boundary Control Methods for Acoustic Inverse Boundary Value Problem

We consider the acoustic inverse boundary value problem of recovering a sound speed/potential from near field data represented by the Neumann-to-Dirichlet map. We develop linearized boundary control methods to analyze the stability and reconstruction of the unknowns. The analysis leads to reconstructive algorithms that are validated in 1D. This is joint work with Lauri Oksanen (University of Helsinki) and Tianyu Yang (Michigan State University).

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MS38
IFF: A Super-Resolution Algorithm for Multiple Measurements

We propose a super-resolution algorithm, called Iterative Focusing-localization and Filtering (IFF), to resolve closely spaced point sources from their multiple measurements that are obtained by using multiple unknown illumination patterns. The new proposed algorithm has a distinct feature in that it reconstructs the point sources one by one in an iterative manner and hence requires no prior information about the source numbers. The new feature also allows for a subsampling strategy that can circumvent the computation of singular-value decomposition for large matrices as in the usual subspace methods. A theoretical analysis of the methods behind the algorithm is also provided. The derived results imply a phase transition phenomenon in the reconstruction of source locations which is confirmed in the numerical experiment. Numerical results show that the algorithm can achieve a stable reconstruction for point sources with a minimum separation distance that is close to the theoretical limit.

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MS40
Some New Results for Image Registration of Textured Images

Image registration has been an active and yet challenging research topic, especially when a deformable and diffeomorphic map is desired. In this talk we first briefly review several variational models and then focus on the new task of trying to register two related textured images in which image intensities cannot be used directly. The more general case is to register two textured images from different image modalities. To solve this problem, we employ image decomposition models in which texture is modelled as oscillating components of an image, following the works of Meyer, Vese and Osher, and Shen. However, as image registration is essentially to align image features, the previous works of locating such features by image gradients are less ideal. We have extended such models to use both gradients and second order information to extract image features and hence the new models fundamentally improve image registration of multi-modal images. This is joint work with

Huan Han (Wuhan).

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MS40
Optimal Algorithms for Elastic Shape Analysis

Shape analysis is a fundamental area of computer vision, critical to object recognition, classification, shape retrieval. Central to shape analysis is the definition of a shape space and efficient algorithms to compute the distance between the shape representations residing in the shape space. In this work, we adopt the square-root velocity functions of Srivastava et al. (PAMI, 2011) as the shape representation, and we develop efficient optimization algorithms to compute the shape distance between two closed curves based on the SRVF representations. This shape representation is elastic, thus a monotonically-increasing reparameterization function matching the SRVF of one curve to the other needs to be computed. Moreover, the starting point on one closed curve needs to be matched to the right starting point on the other closed curve, and the curve needs to be optimally rotated as well to match the other curve. To solve this problem, we introduce compact discretizations of curves, then develop novel optimization algorithms, by building on efficient solutions for the subproblems, i.e. FFT-based rigid alignment, linear-time dynamic programming and iterative optimization for reparameterization. We integrate these in a global optimization framework and obtain efficient algorithms that compute strong minima. We demonstrate the effectiveness of our elastic shape distance algorithms with extensive numerical experiments, and find significant improvements compared to previous approaches.

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MS40
Quasiconformal Density-Equalizing Map and Applications

Density-equalizing maps, driven by prescribed density information, often lack control over geometric distortions and bijectivity, particularly for surfaces with complex topologies. To address these issues, we propose a novel method for computing bijective density-equalizing quasiconformal (DEQ) flattening maps for connected open surfaces. Our approach formulates the density diffusion process as a quasiconformal flow, effectively controlling angle distortions and ensuring bijectivity through energy minimization with the Beltrami coefficient. We introduce an iterative scheme to optimize the shape of the target planar circular domain and the density-equalizing quasiconformal map, enabling optimal parameterization of multiply-connected surfaces. Furthermore, our method extends to compute spherical density-equalizing maps for genus-0 closed surfaces. Additionally, landmark constraints can be incorporated into our proposed method to achieve consistent feature alignment. Using proposed methods, a large variety of bijective density-equalizing parameterizations can be achieved. Applications to surface registration, remeshing, and data visualization are presented to demonstrate the effectiveness of our methods.

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MS40
Discrete Morse Theory, Persistent Homology and Forman-Ricci Curvature

It was observed experimentally that Persistent Homology of networks and hypernetworks schemes based on Forman's discrete Morse Theory and on the 1-dimensional version of Forman's Ricci curvature not only both perform well, but they also produce practically identical results. We show that this apparently paradoxical fact can be easily explained in terms of Banchoff's discrete Morse Theory. This allows us to prove that there exists a curvature-based, efficient Persistent Homology scheme for networks and hypernetworks. Moreover, we show that the proposed method can be broadened to include more general types of networks, by using Bloch's extension of Banchoff's work. We also point out a manner in which one can canonically associate a simplicial complex structure to a hypernetwork, directed or undirected. In particular, this allows for the extension and simplification of the geometric Persistent Homology methods of networks. Furthermore, such a construction allows for an easy investigation of the topological and geometric properties of hypergraphs.

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MS41
Objective Assessment of Deep Learning-Based Image Denoising and the Impact of Incorporating Task-Information

It is widely accepted that the assessment and refinement of biomedical imaging technologies should be performed by objective, i.e., task-based, measures of image quality (IQ). However, the objective evaluation of deep learning-based image formation technologies remains largely lacking, despite the breakneck speed at which they are being developed. In this work, we report studies in which the performance of deep a learning-based image restoration method is objectively assessed. The performance of the ideal observer (IO) and common linear numerical observers are quantified, and detection efficiencies are computed to assess the potential impact of deep learning on signal detection performance in this application. The numerical results indicate that, in the cases considered, the application of a deep image formation network can result in a loss of task-relevant information in the image, despite improvement in traditional computer-vision metrics. We also demonstrate that traditional and objective IQ measures can vary in opposite ways as a function of network depth. In a second study, we incorporate information about a signal detection task into the design of denoising network and investigate the tradeoff between traditional and task-based IQ measures.

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MS41

Advantages of Task-Specific Full Reference Image Quality Assessment

First, we will provide examples of failures when using standard full reference (FR) image quality (IQ) measures for the assessment of novel algorithms with medical images. Although the occurring severe problems are known, there still has not been a paradigm shift yet. As improvement is urgently needed to increase explainability, fairness and generalizability of novel methods in machine learning and beyond, we will provide suggestions for future directions as well as a checklist for the usage of FR-IQA measures. Secondly, we will provide suggestions for task-specific FR-IQA metrics and discuss their benefits. Finally, we will shortly present a novel dataset with chest X-ray images containing expert annotations that will allow to test novel quality measures for medical images in a reproducible way.

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MS41

Introduction to Fairness in Machine Learning for Medical Images and beyond

This introductory talk to the minisymposium explores fairness in ML with radiological imaging and beyond.

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MS41

Using causal models to design better evaluations of algorithmic fairness in healthcare

In this talk, I aim to describe challenges with the validity and reliability of model evaluations that aim to measure properties related to fairness, bias, and generalizability. I argue that designing an evaluation well requires domain-specific context to understand how the concept of interest (e.g., fairness or bias) manifests observationally and how it can (or in some cases, cannot) be disambiguated from other phenomena. This implies that the most appropriate evaluation strategy is contextual, and there is no one-size-fits-all approach. The approach is to use causal graphical models as a tool for formal specification of domain knowledge regarding data generating processes, mechanisms for sampling, selection, and measurement, and the properties of the intended use and target population. This provides the means to characterize the expected statistical properties of a model learned under specific (potentially biased) data generating processes and to translate them into claims about the properties of the model in a target context of interest. I discuss concrete examples where this framework allows for reasoning about how different mechanisms affect evaluation, including (1) confounding variables in disaggregated evaluations, (2) distribution shift, and (3) observa-tional biases, including selection bias and label bias.

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MS42

Big Data Inverse Problems: Insight Through Supervised Machine Learning

Emerging fields such as data analytics, machine learning, and uncertainty quantification heavily rely on efficient computational methods for solving inverse problems. With growing model complexities and ever-increasing data volumes, state-of-the-art inference method exceeded their limits of applicability, and novel methods are urgently needed. In this talk, we present novel methods for the broad spectrum of inverse problems where the aim is to reconstruct quantities with a sparse representation on some vector space. The associated optimization problems with L1 regularization have received significant attention, due to their wide applicability in compressed sensing, dictionary learning, and imaging problems, to name a few. We present a new method based on variable projection and describe a new approach that uses deep neural networks (DNNs) to obtain regularization parameters for solving inverse problems.

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MS42

Optimal Experimental Design for Weak-Constrained 4D Data Assimilation

Weak-Constraint 4D-Var (WC4D-Var) is a data assimilation technique widely employed in fields such as meteorology and oceanography and aims to integrate numerical models with observational data. This work develops methods for optimal experimental design in the context of WC4D-Var. We first derive the optimality criterion for D-optimal experimental design in the WC4d-Var setting, which involves measuring the information gain from the forecast prior to the posterior. We then develop efficient randomized algorithms to evaluate this criterion by exploiting the structure of the problem. We will demonstrate the performance of our algorithms on a model problem involving the heat equation.

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MS42

Proximal Splitting Algorithms and Langevin Monte-Carlo Methods for Few-View Industrial Computed Tomography

In industrial x-ray computed tomography (CT), there is a need of reducing both the experimental and computational time when the goal is defect detection of a large number of industrial components. In addition, the obtained results

must include an assessment of their associated uncertainty. Experimentally, this can achieved by significantly reducing the number of CT projections and the acquisition time per projection, leading to a noisy few-view CT reconstruction problem. In this talk, we will illustrate some of the challenges associated with this problem, focusing on the involved mathematical models and their computational feasibility when working with high-resolution cone-beam CT systems. In particular, we will present a complementary methodology that combines tools from non-smooth convex optimization and Bayesian uncertainty quantification. Specifically, we explore total variation and wavelet-based regularized reconstructions solved with primal-dual proximal splitting algorithms and how they can be integrated or complemented with proximal Langevin Markov Chain Monte Carlo sampling algorithms within a Bayesian framework.

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MS42

Stability for Nonlinear Inverse Problems with Low Dimensional Priors

In this talk I will review some stability properties of a large class of inverse problems in infinite dimensional (Banach) spaces, especially nonlinear and ill-posed (e.g. electrical impedance tomography). The main focus will be on how to improve stability by imposing low dimensional priors on the unknown, in a deterministic setting, using functional analytic techniques. The low dimensional priors considered will be mainly finite dimensional linear subspaces and finite dimensional manifolds. These results can be combined with manifold learning techniques (in particular based on generative models) to learn a low dimensional parameterization of the unknown, which yields again stability under suitable conditions. This is based on a series of works done in collaboration with G.S. Alberti (University of Genoa), A. Arroyo (Complutense Madrid), J. Hertrich (TU Berlin), S. Sciutto (University of Genoa).

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MS43

Identification of Differential Equation with Weak Form and Frequency Domain

We consider identifying differential equation from one set of noisy observation. We assume that the governing equation can be expressed as a linear combination of different linear and nonlinear differential terms. This talk will discuss using weak form for ODE and PDE recovery and how identifying differential equation can be directly done in the Fourier domain. Fourier Ident shows robustness against complex dynamics and higher level of noise.

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MS43

Learning Dynamics guided by Mean-field Games

Mean field game (MFG) problems analyze the strategic movements of a large number of similar rational agents seeking to minimize their costs. However, in many practical applications, the cost function of MFGs may not be available, rendering the associated agent dynamics unavailable. In this talk, I will discuss our recent work on learning dynamics guided by MFGs. We begin by studying a low-dimensional setting using conventional discretization methods. We propose a bilevel optimization formulation for learning dynamics guided by MFGs with unknown obstacles and metrics. We also establish local unique identifiability results and design an alternating gradient algorithm with convergence analysis. Furthermore, we extend our proposed bi-level method to a deep learning-based algorithm by bridging the trajectory representation of MFG with a special type of deep generative model known as normalizing flows. Our numerical experiments demonstrate the efficacy of the proposed methods.

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MS43

Nearest Neighbor Sampling of Point Sets Using Rays

We propose a new framework for the sampling, compression, and analysis of distributions of point sets and other geometric objects embedded in Euclidean spaces. Our approach involves constructing a tensor called the RaySense sketch, which captures nearest neighbors from the underlying geometry of points along a set of rays. We explore various operations that can be performed on the RaySense sketch, leading to different properties and potential applications. Statistical information about the data set can be extracted from the sketch, independent of the ray set. Line integrals on point sets can be efficiently computed using the sketch. We also present several examples illustrating applications of the proposed strategy in practical scenarios.

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MS44
Utilizing Contrastive Learning for Graph-Based Active Learning of Sar Data

Transductive learning has the benefit of being able to leverage information from unlabeled data simultaneously with labeled data to make predictions, thus providing strong results in the low label rate regime. In particular, graph-based semi-supervised learning can achieve strong results on data classification with very few labels by propagating labels throughout the graph. Combining the transductive power of graph learning with feature embeddings from a neural network allows the process to explore diverse, non-linear datasets. Moreover, using active learning in such a regime can obtain remarkable results. We discuss the methods and results of graph learning with neural networks in an active learning framework, as well as attempts to combine the graph learning process with neural networks in a learnable, end-to-end framework.

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MS44
LocNet: Deep Learning-based Localization on Rotating Point spread Function with Applications to Telescope Imaging

Three-dimensional (3D) point source recovery from two-dimensional (2D) data is a challenging problem with wide-ranging applications in single-molecule localization microscopy and space-debris localization telescopy. Point spread function (PSF) engineering is a promising technique to solve this 3D localization problem. Specifically, we consider the problem of 3D localization of space debris from a 2D image using a rotating PSF where the depth information is encoded in the angle of rotation of a single-lobe PSF for each point source. Instead of applying a model-based optimization, we introduce a convolution neural network (CNN)-based approach to localize space debris automatically in 3D space. A hard sample training strategy is proposed to improve CNN's performance further. Contrary to the traditional model-based methods, our technique is efficient and outperforms the current state-of-the-art method by more than 11% in the precision rate with a comparable improvement in the recall rate.

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MS44
Inverse Evolution Layers: Physics-informed Regularizers for Deep Neural Networks on Image Segmentation

Traditional image processing methods employing partial differential equations (PDEs) offer a multitude of meaningful regulaizers, along with valuable theoretical foundations for a wide range of image-related tasks, making them highly desirable for integration into neural networks. In this paper, we propose a new type of regularizers to equip neural networks with properties derived from various PDE-based evolution models. Specifically, we propose inverse evolution layers (IELs) by considering the reverse process of evolution equations. These layers will serve as amplifiers of undesired properties and force the neural networks to minimize the production of outputs with undesired characteristics. Using IELs, one can achieve specific regularization objectives and endow neural networks' outputs with corresponding properties of the PDE models. Moreover, IELs are straightforward to construct and implement, and can be easily generalized to various physical evolutions and neural networks. Furthermore, we offer theoretical evidence that IELs indeed serve as an effective regularization mechanism. We also provide theoretical results to support the capacity of IELs in addressing other label-corrupted issue. These theoretical foundations not only enhance the generalizability and explainability of our approach but also provide guidance for the mathematically interpretable design of IELs.

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MS44
Image Segmentation Using Chan-Vese Energy Minimization Coupled with a CNN Provided Mask

We propose an hybrid method that combines CNN with classic enegy minimization for image segmentation. In the domain of convolutional neural networks (CNNs) for image segmentation, the reliability and consistency of results are of paramount importance, especially in critical applications like medical imaging. Our study introduces a groundbreaking attention mechanism within CNN frameworks, exemplified by the U-Net model, that incorporates Chan-Vese energy reduction. This novel approach refines segmentation outputs by enforcing constraints derived from the

solution of a relevant partial differential equation (PDE). We delve into the integration of this mechanism into the CNN architecture, elucidating the mathematical foundations and computational strategies used. Our research reveals that this method effectively captures essential spatial details in target areas, enhancing the precision of binary segmentation tasks. This precision is critical in medical contexts, where accuracy is vital. We validate the effectiveness of our approach through an exhaustive analysis of MRI brain scans, demonstrating not only improved segmentation quality but also its potential for broad application in medical imaging.

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MS45
Continuous U-Net: Faster, Greater and Noiseless

Image segmentation is a fundamental task in image analysis and clinical practice. The current state-of-the-art techniques are based on U-shape type encoder-decoder networks with skip connections, called U-Net. Despite the powerful performance reported by existing U-Net type networks, they suffer from several major limitations. Issues include the hard coding of the receptive field size, compromising the performance and computational cost, as well as the fact that they do not account for inherent noise in the data. They have problems associated with discrete layers, and do not offer any theoretical underpinning. In this work we introduce continuous U-Net, a novel family of networks for image segmentation. Firstly, continuous U-Net is a continuous deep neural network that introduces new dynamic blocks modelled by second order ordinary differential equations. Secondly, we provide theoretical guarantees for our network demonstrating faster convergence, higher robustness and less sensitivity to noise. Thirdly, we derive qualitative measures to tailor-made segmentation tasks. We demonstrate, through extensive numerical and visual results, that our model outperforms existing U-Net blocks for several medical image segmentation benchmarking datasets.

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MS45
Recent Generative Models for Inverse Problems in Imaging

This talk focuses on deep generative models to solve inverse problems, centering specifically on the use of Implicit Diffusion models as a powerful tool in image deblurring. We explore the integration of deep generative priors to enhance the robustness and effectiveness of image reconstruction techniques. The Implicit Diffusion framework, with its ability to model complex data distributions, serves as a key enabler for capturing latent structures in blurry images. We discuss the method's theoretical bases, its application in the context of image deblurring, and we show promising results, illustrating the potential of deep generative models to strongly enhance solutions to challenging inverse problems in imaging science.

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MS45
Towards Robust Hyperspectral Unmixing Against Non-Uniform Spectral Sampling

Unmixing is a crucial technique in analyzing hyperspectral imaging (HSI) data, which involves identifying the endmembers present in the data and estimating their abundance maps. Due to some practical constraints in atmospheric environment, HSI data is usually non-uniformly distributed along the spectral domain, which brings incomplete spectral information in the hyperspectral unmixing. To overcome this issue, we propose nonnegative matrix functional factorization (NMFF) which is an extension of classical nonnegative matrix factorization (NMF) for hyperspectral unmixing. In particular, we present a novel functional factorization model by incorporating the implicit neural representations (INR) to learn about endmembers. Our method effectively characterizes endmembers by learning a continuous representation through INR with positional encoding, capturing the non-uniform distribution of spectral wavelengths. This distinct approach streamlines NMFF's iterative process for abundance extraction, bypassing the conventionally complex and cumbersome processing. When tested on various datasets, our hyperspectral unmixing approach consistently outperforms established techniques, showcasing the enhanced capabilities of our proposed model.

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MS45
Delta-Prox: Differentiable Proximal Algorithm Modeling for Large-Scale Optimization

This talk will introduce Delta-Prox, a domain-specific modeling language and compiler for large-scale optimization problems using differentiable proximal algorithms. Delta-Prox allows users to specify optimization objective functions of unknowns concisely at a high level, and intelligently compiles the problem into compute and memory-efficient differentiable solvers. One of the core features of Delta-Prox is its full differentiability, which supports hybrid model- and learning-based solvers integrating proximal optimization with neural network pipelines. Example applications of this methodology include learning-based priors and/or sample-dependent inner-loop optimization schedulers, learned with optimized algorithm unrolling, deep equilibrium learning or deep reinforcement learning. With a few lines of code, we show Delta-Prox can generate performant solvers for a range of image optimization problems, including end-to-end computational optics, image deraining, and compressive magnetic resonance imaging. We also demonstrate Delta-Prox can be used in a completely orthogonal application domain of integrated energy system planning, an essential task in the energy crisis and the clean energy transition, where it outperforms state-of-the-art CVXPY and commercial Gurobi solvers. The project page of this work can be found in https:

//light.princeton.edu/publication/delta_prox/

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MS46
Graph Learning for MRI Reconstruction

Deep learning models have been widely applied for fast Magnetic Resonance Imaging (MRI). The majority of existing deep learning models for MRI reconstruction work on data with Euclidean or regular grids structures, which fail to explore the high-dimensional features encapsulated in non-Euclidean manifolds extracted from MR data. In addition, non-local self-similarity is an important property of MR images that many existing models overlook. Graph-based models offer a promising alternative, enabling the exploration of non-Euclidean relationships and effectively utilizing the non-local self-similarity inherent in MR images. These models provide a more intuitive and accurate representation of MRI data. In addition, the graph connection learnt by the network can provide interpretability for MRI reconstruction. In this talk, we will first introduce the background of MRI and MRI reconstruction, and provide a case study for deep learning-based MRI reconstruction. Then we will review the graph-based natural image restoration. After that a case study for Graph-based MRI reconstruction model will be introduced. Finally, we will discuss the existing limitation for graph-based MRI reconstruction model and future research direction.

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MS46
Hybrid Spectral Denoising Transformer with Guided Attention

we present a Hybrid Spectral Denoising Transformer (HSDT) for hyperspectral image denoising. Challenges in adapting transformer for HSI arise from the capabilities to tackle existing limitations of CNN-based methods in capturing the global and local spatial-spectral correlations while maintaining efficiency and flexibility. To address these issues, we introduce a hybrid approach that combines the advantages of both models with a Spatial-Spectral Separable Convolution (S3Conv), Guided Spectral Self-Attention (GSSA), and Self-Modulated Feed-Forward Network (SM-FFN). Our S3Conv works as a lightweight alternative to 3D convolution, which extracts more spatial-spectral correlated features while keeping the flexibility to tackle HSIs with an arbitrary number of bands. These features are then adaptively processed by GSSA which performs 3D self-attention across the spectral bands, guided by a set of learnable queries that encode the spectral signatures. This not only enriches our model with powerful capabilities for identifying global spectral correlations but also maintains linear complexity. Moreover, our SM-FFN proposes the self-modulation that intensifies the activations of more informative regions, which further strengthens the aggregated features. The experiments are conducted on various datasets under both simulated and real-world noise, and it shows that our HSDT significantly outperforms the existing state-of-the-art methods while maintaining low computational overhead.

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MS46
Multi-Tracer PET Image Reconstruction and Artificial Intelligence-based Medical Imaging Application

Positron Emission Tomography (PET) is a mature and advanced nuclear medicine molecular imaging technology that can conduct quantitative research at the living molecular or cellular level of organisms. Clinically, single radiotracer positron emission tomography (PET) imaging is a commonly used examination method; however, since each radioactive tracer reflects the information of only one kind of cell, it easily causes false negatives or false positives in disease diagnosis. On the other hand, the dynamic PET parametric Ki provides better quantification and improve specificity as compared to conventional static PET; however, dynamic parametric imaging is difficult to implement clinically due to the long acquisition time (1 h). In response to the above problems, this paper proposes a multi-tracer PET image reconstruction algorithm and a deep learning-based dynamic PET parametric Ki image generation model, with improving the current mature algorithm framework to apply them to multi-tracer PET and dynamic PET. The experiment achieves high-quality imaging results, especially improving the ability of PET imaging to characterize diseased tissues, helping the accuracy of clinical diagnosis, and promoting the application of multi-tracer PET and dynamic PET in clinical practice.

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MS46
Physics-Informed Self-Supervised Learning for MRI Reconstruction

Magnetic Resonance Imaging (MRI) is pivotal for modern diagnostics, yet its utility is hampered by long acquisition times. We introduce a novel physics-informed self-supervised learning framework for MRI reconstruction that significantly reduces these times while preserving image fidelity. Leveraging the underlying physics of signal formation, our model employs a self-supervised scheme that learns to reconstruct high-quality images from undersampled k-space data without reliance on fully-sampled ground truth references. This is achieved by integrating a physics-informed regularization term that embeds the MRI signal acquisition process directly into the learning model, guiding it towards plausible reconstructions. Our method demonstrates superior performance over traditional methods, particularly in retaining fine details and reducing artifacts. Extensive evaluations on clinical datasets show our approach not only accelerates the MRI process but also enhances the reconstruction quality, potentially transforming the clinical workflow and patient experience. The proposed method promises to be a stepping-stone towards real-time, high-resolution MRI diagnostics.

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MS47

Bregman-Based Inversion of Second-Order Residual Networks

Many imaging problems such as blind image deconvolution require the solution of nonlinear inverse problems. In this talk, we study a second-order residual neural network architecture for the approximation of nonlinear forward problems, keeping in mind that we want to invert the forward problem. An interesting aspect of this architecture is that it will allow us to formulate a convex variational regularisation method for the inversion of this second-order residual network, where the data fidelity term is based on a tailored Bregman distance. We will discuss theoretical aspects of this regularisation method, propose provably convergent algorithms to solve the underlying optimisation problem and present numerical results for selected imaging problems. This is joint work with Alexandra Valavanis from Queen Mary University of London.

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MS47

Regularized Bregman Approaches for Parameter Learning in Imaging

We study a class of parameter learning problems for regularization functionals in imaging which can be phrased as a bilevel optimization problem. In this context, the upper-level problem aims at minimizing a loss functional for the solution of a convex lower-level variational problem involving trainable parameters for the regularizer. We show that relaxing the commonly-used quadratic loss with a suitable Bregman distance enables a reformulation in terms of a convex monolevel problem, in particular with respect to the parameters. Convex optimization algorithms that are efficient for the solution of the monolevel training problem are presented and the application to parameter learning for (weighted) total variation denoising is discussed.

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MS47

Generalized Relaxations of ℓ_0-Regularized Inverse Problems with Non-Quadratic Data Terms

In the context of exact continuous relaxations for the least square problem with the ℓ_0 regularizer, we extend the existing theory to encompass non-quadratic data terms such as Kullback-Leibler divergence and logistic regression. We address the minimization problems of a general data term with the ℓ_0 regularizer. First, we present a result on the existence of global minimizers. Then, we propose the ℓ_0 Bregman relaxation serves as an approximation to the ℓ_0 norm and leads to exact continuous relaxations, showing that the set of minimizers stay unchanged and that the proposed relaxation reduces the non-convexity of the problem by eliminating certain local minimizers. Since these relaxations are continuous, they further possess fewer local minimzers than the original problem, which makes them amenable for optimization. Finally, a tailored Bregman

proximal gradient algorithm is used for the numerical solution of the relaxed problem. Several numerical results for problems involving widely-used non-quadratic data terms (Kullback-Leibler divergence, logistic regression) will be shown.

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MS47

On Stochastic Methods for Solving Inverse Problems in Select Banach Spaces

In this work we present a mathematical framework and analysis for a minibatch SGD in Banach spaces for select linear and non-linear inverse problems. Analysis in the Banach space setting presents unique challenges, requiring novel mathematical tools. This is achieved by combining insights from Hilbert space theory with approaches from modern optimisation. The developed theory and algorithms open doors for a wide range of applications, and we present some future challenges and directions.

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MS48

Geometric Design of Kirigami Metamaterials

Kirigami, the traditional art of paper cutting, has recently emerged as a promising paradigm for mechanical metamaterials. While many prior works have studied the geometry and mechanics of certain periodic kirigami tessellations, the computational design of more complex structures is less understood. In this talk, I will present several mathematical design frameworks for modulating the geometry of kirigami tessellations. In particular, by identifying the geometric constraints controlling the compatibility, compact reconfigurability and rigid-deployability of the kirigami structures, we can achieve a wide range of patterns that can be deployed into pre-specified shapes in two or three dimensions.

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MS48

Topological Shape and Data Analysis for Materials Imaging

We introduce principles for combining Topological Data Analysis (TDA) and Separable Shape Tensors (SST) to motivate novel perspectives on texture and shape in imaging data. Specifically, we elaborate on bi-filtrations as a formal mechanism to elucidate persistent topological structures in concert with an efficient manifold learning of discrete, separable shapes. We apply these interpretations to electron back-scatter diffraction (EBSD) scans of a differing material crystalline lattice microstructures to quantify intuitive features. More broadly, this framework has the potential to impact various fields where quantifying texture (topol-

ogy) and level-sets (shape) is tantamount to characteristics of image.

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MS48

Shape-Graph Matching Network (sgm-Net): Registration for Statistical Shape Analysis

This paper studies the statistical analysis of shapes of data objects called **shape graphs**, a set of nodes connected by articulated curves with arbitrary shapes. A critical need here is a constrained registration of points (nodes to nodes, edges to edges) across objects. This requires optimization over the permutations, made challenging by differences in nodes (in terms of numbers, locations) and edges (in terms of shapes, placements, and sizes) across objects. This paper tackles this registration problem using a novel neural-network architecture and formulates it using an unsupervised loss function derived from the **elastic shape metric**. This architecture results in (1) state-of-the-art performance and (2) an **order of magnitude reduction** in the computational cost relative to baseline approaches. We demonstrate the effectiveness of the proposed approach using both simulated data and real-world, publicly available 2D and 3D shape graphs. Code and data will be publicly available after review to foster research.

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MS48

Shape Prior Segmentation Using Harmonic Beltrami Signature

This talk presents a novel image segmentation method that incorporates the Harmonic Beltrami Signature (HBS) as shape prior knowledge. The HBS represents 2D simply-connected shapes that are invariant to translation, rotation, and scaling. By leveraging the HBS, the proposed method enables direct shape similarity measurement using the L^2 distance between signatures, while also encoding shapes robustly against perturbations. The method integrates the HBS into a baseline Beltrami coefficient segmentation framework. It utilizes reference shape boundaries and computes corresponding HBS as prior knowledge. This HBS prior guides the segmentation of partially damaged or occluded objects towards the reference shape(s), ensuring their similarity. Experimental results on synthetic and natural images validate these benefits, and comparisons with baseline segmentation models show significant improvements. This work is supported by HKRGC GRF (Project ID: 14307622).

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MS49

Assessing the Robustness of Radiomic Features for Generalisable Prediction Outcomes

Radiomic image features extracted from radiological images are becoming a promising non-invasive method to obtain quantitative measurements for tumour classification and therapy response assessment in oncological research. These features include characteristics related to the distribution of the pixel values in the images, as well as shape measurements and analysis of first and higher order textures, and convey information from imaging data that may not be visible to the human eye, thus providing valuable quantitative, reader-independent information. However, despite its increasingly established application and potential in precision oncology, there is still a need for standardisation criteria, as well as further validation of feature robustness with respect to imaging acquisition protocols, reconstruction parameters and patient demographics. In this talk, I will discuss the studies that we have carried out in our group in a variety of cancers (hepatic, renal and ovarian), in order to establish the robustness and reliability of CT-derived radiomic features. I will also present use-cases in which the impact of these studies has been further analysed in terms of generalisability of prediction outcomes in real-world datasets. Finally, I will mention the efforts to make the extraction of these features, and predictions based on them, accessible in tools used by radiologists.

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MS49

Bridging the Discrete and Continuous: Towards Reliable and Fair Algorithms in Medical Imaging

Accuracy and reliability are paramount in the evolving domain of artificial intelligence-based medical imaging analysis. This talk presents a comprehensive analysis of two projects that delve into the intricacies of model repeatability and the benefits of capturing the continuous spectrum of disease severity. First, we investigate model repeatability, a critical aspect often overshadowed by an overemphasis on classification performance. In assessing the repeatability of various model types across diverse medical imaging tasks, we found that Monte Carlo dropout methods significantly improve repeatability. Notably, our findings emphasize the convergence of increased classification accuracy with enhanced repeatability, especially at class boundaries. Second, many clinical variables, though represented discretely in ordinal categories, stem from an underlying continuous spectrum. We present a framework capable of predicting continuously valued variables, even when trained solely on discrete ordinal labels. Our results establish the superiority of models recognizing ordinal relationships, like ordinal classification, showcasing their potential in accurately mirroring the intrinsic continuous nature of the data. Interweaving insights from these projects, we conclude that the confluence of robust repeatability and harnessing the full spectrum of disease severity are steps toward AI algorithms that are both reliable and individually fair.

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MS49

Assessment of Learned Denoisers Trained on Standardized, Simulated and Experimental Low-Dose Ct Data

Like in many other research fields, recent developments in computational imaging have focused on applying machine learning to their main challenges. To improve the performance of algorithms, data-driven methods are used for different image processing tasks, e.g. noise reduction. Generally, these data-driven methods heavily rely on the availability of high-quality data on which they are trained. They are trained on either simulated or real noisy data and are applied to both real and simulated data. In this work we use 2D slices of X-ray computed tomography images published in the carefully designed study 2DeteCT A large 2D experimental, trainable and expandable CT data collection for machine learning [Kiss et al., Sci Data 10, 576, 2023]. This experimental data was acquired by the group for Computational Imaging at the Centrum Wiskunde & Informatica and is openly available on Zenodo. The data collection consists of 5,000 distinct image slices acquired in three different modes. The resulting images are either clean, noisy, or artifact inflicted. Using the paired data of clean and noisy images we create a setting for supervised learning that machine learning based noise reduction algorithms can be trained on. Furthermore, the clean data was used as a basis for generating simulated noisy data. With this setup we are able to assess learned denoisers on standardized, simulated and experimental low-dose CT data.

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MS49

Improving Fairness and Standardization of Learning Tasks with Chest X-Ray Images

We present an automated quality control tool to quickly curate and standardize large data sets of chest radiographs. The study evaluates its performance on diverse external datasets, including 22,500 patients. The multi-platform tool is straightforward to use and freely available online. We will discuss the importance of such a standardisation tool for downstream tasks in medical imaging. In the second part of the talk we will provide results of experiments that compare classification results when using raw versus curated chest X-rays as input data.

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MS50

Operator Learning on Systems with Low-Dimensional Structures Through Model Reduction

Operator learning is a recently popular paradigm for inverse problems on physical systems, involving a data-driven machine learning model that can learn the underlying solution operator of the system. These solution operators are between infinite-dimensional function spaces, but they often exhibit low-dimensional structures. In this talk, we propose Auto-Encoder-based Neural Networks (AENet) for learning the latent features of the input functions and mapping these latent features to the corresponding solutions. We present theoretical and empirical results that validates the of a non-linear method such as AENet over other recently proposed model reduction based algorithms.

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MS50

A Step Toward Fast and Automatic Reinforcement Learning

Nowadays, reinforcement learning has been successfully in a myriad of applications. The goal of reinforcement learning is to obtain an optimal policy that maximizes the reward. A major obstacle to reinforcement learning is that its training is time-consuming and requires lots of parameter tuning. In general, the training problem is formulated as the minimization of a stochastic least squares loss plus Tikhonov regularization. In this work, we consider a class of iterative sampling methods that can automatically update the Tikhonov parameter in each iteration. This saves time from tuning the Tikhonov parameter. Experimental results demonstrate the competitiveness of our approach.

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MS50

Understanding Score-Based Generative Models through the Lens of Wasserstein Proximal Operators

Abstract: This presentation delves into the fundamental concepts of score-based generative models (SGMs) by framing them as entropically regularized Wasserstein proximal operators (WPO) in the context of cross-entropy. The connection between SGMs and mean-field games (MFG) is explored, showcasing the unique structure of SGM-MFG and its ability to have the Hamilton-Jacobi-Bellman (HJB) equation solely characterize SGMs. This characterization is further revealed to be equivalent to an uncontrolled Fokker-Planck equation through a Cole-Hopf transform. Additionally, we introduce a terminal condition that enhances both manifold learning and generalization, demystifying the artificial nature of SGMs and solidifying score-matching as a well-posed optimization problem.

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MS50

Symmetry-Preserving Machine Learning for Computer Vision and Scientific Computing

Symmetry is ubiquitous in machine learning and scientific computing, with compelling implications for model development. Equivariant neural networks, specifically designed to preserve group symmetry, have shown marked improvements in learning tasks with inherent group structures, especially when faced with limited data. This talk will explore our recent and ongoing works in this field, with applications in both imaging science and scientific computing.

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MS51

Comparing 3D CGO-based Algorithms: tEXP and t0 vs. the tB method on Simulated and Experimental Data

Complex Geometric Optics (CGO)-based algorithms are an attractive option for EIT image reconstruction as they are direct (non-iterative), fast (real-time), and capable of both absolute and time-difference imaging. Regularization takes place via truncation of the nonphysical scattering transform data, a type of nonlinear Fourier transform data, which stabilizes the inversion process but inherently leads to smoothed reconstructions. These methods require a special Greens function, called the Faddeev Greens function, that takes into consideration the exponential behavior of the CGOs. While the constructive proofs for the 3D setting were published in the late 1980s, their numerical implementation on electrode data took place only recently. To do this, approximations were made, bypassing the computation of the exponentially growing Faddeev GF in the calculation of the scattering data. These simplified methods, called the tEXP and t0 methods, have been shown to be robust to modeling errors on 3D experimental tank data, yet the question remained, could we do better if we used the true Faddeev GF? In this talk we explore whether the increased computational burden of using the Faddeev GF pays off. We present their first 3D reconstructions using electrode data (simulated + experimental). Comparisons to t0 and tEXP reconstructions are shown for each example and a detailed study of the effect of the number of electrodes and discretization of the scattering domain is presented.

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MS51

Real-Time Pulmonary Imaging of Pediatric Patients with Eit and An Anatomical Atlas

Electrical impedance tomography (EIT) is a real-time non-ionizing medical imaging technique in which electric fields are used to form images of organ function and structure. Regional ventilation and perfusion images can be used to diagnose and monitor lung pathology both at the bedside and longitudinally. In this talk we will present methods of EIT imaging and analysis, including quantitative EIT-derived measures of lung function applied to patients with acute respiratory distress syndrome and to pediatric patients of Childrens Hospital Colorado.

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MS51

Using Calderon's Method as an Initial State for Indirect Methods

This talk presents a combination of direct and indirect methods. In particular, Calderón's method is used as an initial state for the NOSER algorithm to produce fast and improved reconstructions compared to either algorithm on its own. Results are shown for simulations and experimental data.

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MS51

Electric Imaging with Virtual X-Rays: a Microlocal Decomposition of Eit

A connection between Electrical Impedance Tomography (EIT) and X-ray tomography was found in [Greenleaf et al. 2018] using microlocal analysis. Fourier transform applied to the spectral parameter of Complex Geometric Optics solutions produces virtual X-ray projections, enabling a novel filtered back-projection type nonlinear reconstruction algorithm for EIT. This approach is called Virtual Hybrid Edge Detection. It is remarkable how this new approach decomposes the EIT image reconstruction process in several steps, where all ill-posedness is confined in two linear steps. Therefore, we can separate the nonlinearity and ill-posedness of the fundamental EIT problem. Furthermore, the new decomposition enables gray-box machine learning approaches as only one or two (mathematically well-structured) steps in the imaging chain are solved using neural networks. The new approach finds applications in the classification of stroke into ischemic/hemorrhagic.

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MS52

Region Segmentation Defined As the Unit Ball for the Geodesic Distance with Respect to a CNN Generated Riemannian Metric

Leveraging geodesic distances and the geometrical information they convey is key for many data-oriented applications in imaging. Geodesic distance computation has been used for long for image segmentation using Image based metrics. We introduce a new method by generating isotropic Riemannian metrics adapted to a problem using CNN and give as illustrations an example of application. We then apply this idea to the segmentation of brain tumours as unit balls for the geodesic distance computed with the metric potential output by a CNN, thus imposing geometrical and topological constraints on the output mask. We show that geodesic distance modules work well in machine learning frameworks and can be used to achieve state-of-the-art performances while ensuring geometrical and/or topological properties.

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MS52

Unsupervised Single-Image Joint Image Segmentation and Denoising

In this work, we develop an unsupervised method for the joint segmentation and denoising of a single image. To this end, we combine the advantages of a variational segmentation method with the power of a self-supervised, single-image based deep learning approach. One major strength of our method lies in the fact, that in contrast to data-driven methods, where huge amounts of labeled samples are necessary, our model can segment an image into multiple meaningful regions without any training database. Further, we introduce a novel energy functional in which denoising and segmentation are coupled in a way that both tasks benefit from each other. The limitations of existing single-image based variational segmentation methods, which are not capable of dealing with high noise or generic texture, are tackled by this specific combination with self-supervised image denoising. We propose a unified optimisation strategy and show that, especially for very noisy images available in microscopy, our proposed joint approach outperforms its sequential counterpart as well as alternative methods focused purely on denoising or segmentation. Another comparison is conducted with a supervised deep learning approach designed for the same application, highlighting the good performance of our approach.

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MS52

Data-driven Model Based Tomographic Reconstruction with Continuous Neural Networks

The tremendous recent advances in the field of machine learning have the potential not only to simplify and support our daily lives but also to provide new approaches within a scientific context as for example in the field of inverse problems. In recent years, classical knowledge-driven approaches for inverse problems have been complemented by data-driven methods exploiting even this power of machine and especially deep learning. Purely data-driven methods, however, come with the drawback of disregarding prior knowledge of the problem. Especially for more complex inverse problems like tomographic image reconstruction, it has been shown to be beneficial to incorporate this knowledge into the problem solving process. Lately, continuous neural networks that solve an ODE parametrising the underlying continuous dynamics instead of computing the output of a discrete sequence of layers, have become more popular. As a memory and parameter efficient type of neural networks, they have been applied e.g., in the context of image segmentation. In this talk we will explore the use of continuous neural networks in data-driven inverse problems and tomographic reconstruction in particular.

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MS52

Unsupervised Segmentation Using Deep Learning and Gaussian Mixture Model

The recent emergence of deep learning has led to a great deal of work on designing supervised deep semantic segmentation algorithms. As in many tasks sufficient pixel-level labels are very difficult to obtain we propose a method, which combines a Gaussian mixture model (GMM) with deep learning techniques. The GMM method assumes that the pixel values of each sub region can be modelled by a Gaussian distribution. In order to partition an image into different regions the parameter vectors that minimize the negative log-likelihood function regarding the

GMM have to be approximated. For this task, usually iterative optimization methods such as the expectation-maximization (EM) algorithm are used. However, we propose to estimate these parameters directly from the image using a convolutional neural network (CNN). We thus slightly change the iterative procedure in the EM-algorithm replacing the expectation step by a gradient step with regard to the networks parameters which comes with two main advantages. As once trained, the network is able to predict label probabilities very quickly compared with time consuming iterative optimization methods. Secondly, due to the deep image prior our method is able to partly overcome one of the main disadvantages of GMM, which is not taking into account correlations between neighboring pixels. We demonstrate the advantages of our method in various experiments on the example of myocardial infarct segmentation on multi-sequence MR images.

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MS53

Efficient Hybrid Methods for Hyperparameter Estimation in Large-Scale Linear Inverse Problems

In Bayesian inverse problems, there are several hyperparameters that define the prior and the noise model and must be estimated from the data. For linear inverse problems with additive Gaussian noise and Gaussian priors defined using Matern covariance models, we estimate the hyperparameters using the maximum a posteriori estimate of the marginalized posterior distribution. However, this is a computationally intensive task since it involves computing log determinants. To address this challenge, we consider a stochastic average approximation (SAA) of the objective function and use preconditioned Lanczos methods to efficiently approximate the objective function and the gradient.

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MS53

Assemble Learnable Mumford-Shah Type Model with Multi-Grid Technique for Image Segmentation

The classical Mumford-Shah (MS) model has been successful in some medical image segmentation tasks, providing segmentation results with smooth boundaries of objects. However, the MS model, which operates at the pixel level of the images, faces challenges when dealing with medical images with low contrast or unclear edges. In this work, we begin by using a feature extractor to capture high-dimensional deep features that contain more comprehensive semantic information than pixel-level data alone. Inspired by the MS model, we develop a variational model that incorporates Threshold Dynamics (TD) regularization for segmenting each feature. We obtain the final segmentation result for the original image by assembling segmentation results of all the features. This process results in MS-MGNet, a lightweight trainable segmentation network with a similar architecture to many encoder-decoder networks. The intermediate layers of MS-MGNet are designed by unrolling the numerical scheme based on the multigrid method for solving the variational model. Compared to

some relevant methods, experimental results on the selected datasets with low contrast or unclear edges show that the proposed method can achieve better segmentation performance with fewer parameters, even when trained on smaller datasets.

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MS53

Uncertainty-aware Graph-based Hyperspectral Image Classification

Hyperspectral imaging (HSI) technology captures spectral information across a broad wavelength range, providing richer pixel features compared to traditional color images with only three channels. In this paper, we focus on quantifying epistemic and aleatoric uncertainties associated with the HSI classification (HSIC), as these two uncertainties are effective for out-of-distribution (OOD) and misclassification detection, respectively. In particular, we adapt two advanced uncertainty quantification models, evidential GCNs (EGCN) and graph posterior networks (GPN), designed for node classifications in graphs, into the realm of HSIC. We first reveal theoretically that a popular uncertainty cross-entropy (UCE) loss function is insufficient to produce good epistemic uncertainty when learning EGCNs. To mitigate the limitations, we propose two regularization terms. One leverages the inherent property of HSI data where each feature vector is a linear combination of the spectra signatures of the confounding materials, while the other is the total variation (TV) regularization to enforce the spatial smoothness of the evidence with edge-preserving. We demonstrate the effectiveness of the proposed regularization terms on both EGCN and GPN on three real-world HSIC datasets for OOD and misclassification detection tasks.

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MS53

A Similarity Graph-Based Max-Flow Technique for Image Segmentation

The max-flow problem entails the computation of a maximum feasible flow from a source to a sink through a flow network under constraints. Its connection to total variation presents an opportunity to apply the problem to image segmentation tasks by incorporating a graph-based setting. In this talk, we integrate max-flow techniques and graph-based frameworks to derive an algorithm for image segmentation. The algorithm involves graph-based convex optimization via max-flow techniques in image segmentation problems involving region parameters. In particular, this method covers the case where the region parameters are unknown. The model simultaneously finds these region parameters and segments the image into a pre-specified number of regions. The proposed method is validated using experiments on benchmark data sets.

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MS54

Deep Image Restoration and Reconstruction Through Implicit Neural

Implicit neural representations (INRs) have garnered significant interest recently for their ability to model complex, high-dimensional data without explicit parameterisation. In this work, we introduce TRIDENT, a novel function for implicit neural representations characterised by a trilogy of nonlinearities. Firstly, it is designed to represent high-order features through order compactness. Secondly, TRIDENT efficiently captures frequency information, a feature called frequency compactness. Thirdly, it has the capability to represent signals or images such that most of its energy is concentrated in a limited spatial region, denoting spatial compactness. We demonstrated through extensive experiments on various inverse problems that our proposed function outperforms existing implicit neural representation functions.

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MS54

Efficient Numerical Methods for Optimization Problems Governed by Transport Equations

We present our recent work on efficient numerical methods for optimization problems governed by transport equations. The constructs of our problem formulation are transport equations for image intensities and a geodesic equation on the group of diffeomorhpisms. Our contributions are efficient numerical methods for optimization and Bayesian inference. We discuss numerical time integration, optimization and preconditioning, as well as strategies to approximate the covariance of the negative log posterior. We demonstrate the performance of our methods for synthetic test examples and real world data.

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MS54

You Only Look at Patches: A Patch-wise Framework for 3D Unsupervised Medical Image Registration

Medical image registration is a fundamental task for a wide range of clinical procedures. Automatic systems have been developed for image registration, where the majority of solutions are supervised techniques. However, those techniques rely on a large and well-representative corpus of ground truth, which is a strong assumption in the medical domain. To address this challenge, we propose a novel unified unsupervised framework for image registration and segmentation. The highlight of our framework

is that patch-based representation is key for performance gain. We first propose a patch-based contrastive strategy that enforces locality conditions and richer feature representation. Secondly, we propose a patch stitching strategy to eliminate artifacts. We demonstrate, through our experiments, that our technique outperforms current state-of-the-art unsupervised techniques.

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MS54

All-in-One Adverse Weather Removal in Videos

Although convolutional neural networks have been proposed to remove adverse weather conditions in single images using a single set of pre-trained weights, they fail to restore weather videos due to the absence of temporal information. Furthermore, existing methods for removing adverse weather conditions (e.g., rain, fog, and snow) from videos can only handle one type of adverse weather. In this work, we propose the first framework for restoring videos from all adverse weather conditions by developing a video adverse-weather-component suppression network (ViWS-Net). To achieve this, we first devise a weather-agnostic video transformer encoder with multiple transformer stages. Moreover, we design a long short-term temporal modeling mechanism for weather messenger to early fuse input adjacent video frames. We further introduce a weather discriminator with gradient reversion, to maintain the weather-invariant information and suppress the weather-specific information in pixel features, by adversarially predicting weather types. Finally, we develop a messenger-driven video transformer decoder to retrieve the residual weather-specific feature, which is spatiotemporally aggregated with hierarchical pixel features and refined to predict the clean target frame of input videos. Experimental results, on benchmark datasets and real-world weather videos, demonstrate that our ViWS-Net outperforms existing methods in terms of restoring videos degraded by any weather condition.

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MS55

Dual-Domain Deep D-bar Method for Solving Electrical Impedance Tomography

Regularized D-bar methods, are one of the most prominent method for solving Electrical Impedance Tomography (EIT) problems due to its efficiency and simplicity. It provides a direct approach by applying low-pass filtering to the scattering data in the nonlinear Fourier domain, thereby yielding smoothed conductivity approximation. However D-bar images often present low contrast and low resolution due to absence of accurate high frequency data and ill-posedness of the problem. In this paper, we proposed a multi-scale neural network architecture to retrieve D-bar image sequences from low-contrast to high-contrast resolutions. To further accentuate the spatial features of the conductivity distribution, the widely adopted U-net has been tailored for conductivity image calibration from the predicted D-bar image sequences. Compared to the single-scale structure, our proposed multi-scale structure exhibits superior capabilities in reducing artifacts and refining con-

ductivity approximation. We have devised a surrogate GPU-based Richardson iterative method to accelerate the dataset augmentation process by D-bar. Numerical results are presented for simulated EIT data from the KIT4 and ACT4 systems to demonstrate notable improvements in absolute EIT imaging quality when compared to existing methodologies.

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MS55

Texture Edge Detection via Patch Consensus

While well-known segmentation method are often based on homogeneity of regions, we focus on finding boundaries between different textured regions. We propose a training-free method to detect the boundary of texture by considering consensus of patch responses away from the boundary. We derive the necessary condition for textures to be distinguished, and analyze the size of the patch with respect to the scale of textures. Various experiments are presented to validate our model.

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MS55

Image Recovery Under non-Gaussian Noise

Cauchy noise, as a typical non-Gaussian noise, appears frequently in many important fields, such as radar, medical, and biomedical imaging. Here, we focus on image recovery under Cauchy noise. Instead of the celebrated total variation or low-rank prior, we adopt a novel deep-learning-based image denoiser prior to effectively remove Cauchy noise with blur. To preserve more detailed texture and better balance between the receptive field size and the computational cost, we apply the multi-level wavelet convolutional neural network (MWCNN) to train this denoiser. Frequently appearing in medical imaging, Rician noise leads to an interesting nonconvex optimization problem, termed as the MAP-Rician model, which is based on the Maximum a Posteriori (MAP) estimation approach. As the MAP-Rician model is deeply rooted in Bayesian analysis, we want to understand its mathematical analysis carefully. Moreover, one needs to properly select a suitable algorithm for tackling this nonconvex problem to get the best performance. Indeed, we first present a theoretical result about the existence of a minimizer for the MAP-Rician model under mild conditions. Next, we aim to adopt an efficient boosted difference of convex functions algorithm (BDCA) to handle this challenging problem. Theoretically, using the Kurdyka-Lojasiewicz (KL) property, the convergence of the numerical algorithm can be guaranteed.

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MS55

Counting Objects by Diffused Index: Geometry-Free and Training-Free Approach

Counting objects is a fundamental but challenging problem. In this talk, I introduce diffusion-based, geometry-free, and learning-free methodologies to count the number of objects in images. The main idea is to represent each object by a unique index value regardless of its intensity or size, and to simply count the number of index values. First, I place different vectors, refer to as seed vectors, uniformly throughout the mask image. The mask image has boundary information of the objects to be counted. Secondly, the seeds are diffused using an edge-weighted harmonic variational optimization model within each object. An optimal solution of the model is obtained when the distributed seeds are completely diffused such that there is a unique intensity within each object, which we refer to as an index. For computational efficiency, we stop the diffusion process before a full convergence, and propose to cluster these diffused index values. We explore scalar and multi-dimensional seed vectors. For Scalar seeds, we use Gaussian fitting in histogram to count, while for vector seeds, we exploit a high-dimensional clustering method for the final step of counting via clustering. We present counting results in various applications such as bi- ological cells, agriculture, concert crowd, and transportation. Some comparisons with existing methods are presented.

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MS56

Geometric Regularizations for 3D Shape Generation

Generative models, which map a latent parameter space to instances in an ambient space, provide data priors for solving inverse problems from sparse and noisy measurements. A standard scheme of these models is probabilistic, which aligns the induced ambient distribution of a generative model from a prior distribution of the latent space with the empirical ambient distribution of training instances. While this paradigm has proven to be quite successful on images, its current applications in 3D generation encounter fundamental challenges in the limited training data and generalization behavior. The key difference between image generation and shape generation is that 3D shapes possess various priors in geometry, topology, and physical properties. Existing probabilistic 3D generative approaches do not preserve these desired properties, resulting in synthesized shapes with various types of distortions. In this talk, I will discuss recent work that seeks to establish a novel geometric framework for learning shape generators. The key idea is to model various geometric, physical, and topological priors of 3D shapes as suitable regularization losses by developing computational tools in differential geometry and computational topology. We will discuss the applications in deformable shape generation, latent space design, joint shape matching, and 3D man-made shape generation.

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MS56

Fast Iterative Solvers for PDE-constrained Optimization in Diffeomorphic Image Registration

We present efficient algorithms for diffeomorphic image registration. We formulate diffeomorphic image registration problem as an optimization problem governed by transport equations for image intensities and a geodesic equation on the group of diffeomorphisms. The underlying inverse problem is inherently ill-posed and infinite-dimensional in the continuum, resulting in high-dimensional, ill-conditioned inversion operators after discretization. This poses significant mathematical and computational challenges. We will showcase our work on designing fast numerical methods for solving the inverse problem. We will showcase fast numerical methods for evaluating forward and adjoint operators, as well as effective strategies for numerical optimization. We test the performance of the designed numerical methods on synthetic and real-world data.

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MS56

Exploring the Universe with Elastic Shape Analysis

The recent introduction of high-resolution detectors in modern astronomical surveys has led to rapid growth in the quantity and complexity of imaging and geometric data in the field of astronomy. In turn, this has led to a need for efficient computational tools to process and analyze this data adequately. In particular, certain challenging problems of interest in astronomy can be effectively addressed using tools from the field of elastic shape analysis. In this talk, we will give a brief overview of such problems, including supernova detection and photometric redshift estimation. We then present a novel computational pipeline for automated galaxy clustering based on variational methods for the partial registration of shape-graphs, and demonstrate results on simulated and real data from the Hyper-Suprime Cam (HSC) survey.

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MS56

Multiscale Approach for Variational Problem Joint Diffeomorphic Image Registration

Image registration matches the features of two images by minimizing the intensity difference, so that useful and complementary information can be extracted from the mapping. However, in real life problems, images may be affected by the imaging environment, such as varying illumination and noise during the process of imaging acquisition. This may lead to the local intensity distortion, which makes it meaningless to minimize the intensity difference in the

traditional registration framework. To address this problem, we propose a variational model for joint image registration and intensity correction. Based on this model, a related greedy matching problem is solved by introducing a multiscale approach for joint image registration and intensity correction. An alternating direction method (ADM) is proposed to solve each multiscale step, and the convergence of the ADM method is proved. For the numerical implementation, a coarse-to-fine strategy is further proposed to accel- erate the numerical algorithm, and the convergence of the proposed coarse-to-fine strategy is also established. Some numerical tests are performed to validate the efficiency of the proposed algorithm.

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MS57

Applying Linear Algebra to Real-World Large-Scale Tomography: Krylov Subspace Algorithms and the Tigre Toolbox

Krylov subspace methods are commonly used for inverse problems due to their intrinsic regularization properties. Moreover, these methods are naturally suited to solve large-scale problems, as they only require matrix-vector products with the system matrix (and its adjoint) to compute approximate solutions, and they display a very fast convergence. Even if this class of methods has been widely researched and studied in the numerical linear algebra community, its use in applied medical physics and applied engineering is still very limited. e.g. in realistic large-scale computed tomography (CT) problems, and more specifically in cone beam CT (CBCT). This work attempts to breach this gap by providing a general framework for the most relevant Krylov subspace methods applied to 3D CT problems, including the most well-known Krylov solvers for non-square systems (CGLS, LSQR, LSMR), possibly in combination with Tikhonov regularization, and methods that incorporate total variation regularization. This is provided within an open source framework: the tomographic iterative GPU-based reconstruction toolbox, with the idea of promoting accessibility and reproducibility of the results for the algorithms presented. Finally, numerical results in synthetic and real-world 3D CT applications (medical CBCT and -CT datasets) are provided to showcase and compare the different Krylov subspace methods presented in the paper, as well as their suitability for different kinds of problems.

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MS57

Streaming Methods for Linear and Nonlinear Inverse Problems and Alternating Least Squares

As big data applications become ever more prominent, we often need to solve problems such as linear or nonlinear inversion, while handling only a small amount of data at a time. This may happen because the volume of data is massive, or that data comes in at a rate that only sampled data can be used, or because the data comes in continually, so the data set is never complete. Hence, we need to design solvers and regression methods that can perform partial solves on limited data, store a limited selection of the data or information derived from the data, and combine this

with incoming data or data read from secondary memory to incrementally improve the approximate solutions. In this presentation, we focus on different ways that the data may be accessed, selected, and combined to incrementally or iteratively improve the solution. This is joint work with Mirjeta Pasha, Misha Kilmer, and Sejal Gupta

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MS57
GMRES-Based Methods for Unmatched Projectors in X-Ray CT

We consider iterative reconstruction methods for X-ray computed tomography, given a discretization $A\,x \approx b$. The matrix A represents the *forward projector* while the transpose represents the *back projector* that maps the data back onto the solution domain. In large-scale CT problems, A is too large to store, and we compute the multiplications with A and A^T in a matrix-free fashion. Optimal use of GPUs calls for the use of different discretization methods for the forward projector and the back projector. Hence, the matrix B which represents the back projector is different from the transpose A^T of the forward projector, and we say that B is an *unmatched back projector*. The consequence is that iterative solvers based on multiplications with A and B solve the *unmatched normal equations* in one of the forms $B\,A\,x = B\,b$ or $A\,B\,y = b$, $x = B\,y$. We use the well-known GMRES algorithm to solve these systems, and our work is based on the recent AB-GMRES and BA-GMRES variants. We study the performance of these methods when applied to CT reconstruction. We also show how to terminate the iterations at the point of semi-convergence, before the noise starts to dominate the iteration vectors. Our numerical experiments demonstrate that AB- and BA-GMRES can be used successfully to solve large-scale CT reconstruction problems with an unmatched back projector.

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MS57
Efficient Saa Methods for Hyperparameter Estimation in Bayesian Inverse Problems

In Bayesian inverse problems, there are several hyperparameters that define the prior and the noise model and must be estimated from the data. For linear inverse problems with additive Gaussian noise and Gaussian priors defined using Matern covariance models, we estimate the hyperparameters using the maximum a posteriori estimate of the marginalized posterior distribution. However, this is a computationally intensive task since it involves computing log determinants. To address this challenge, we consider a stochastic average approximation (SAA) of the objective function and use preconditioned Lanczos methods to efficiently approximate the objective function and the gradient. We propose the use of two different preconditioners: an approach based on the generalized Golub Kahan, and another that uses a low-rank approximation of the prior covariance matrix. We demonstrate the performance of our approach on synthetic and real data inverse problems from tomography and atmospheric transport.

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MS58
Leveraging Graph-Based U-Nets to Improve Speed and Quality of Eit Reconstruction for Stroke Monitoring

Many nonlinear inverse problems are solved via optimization based methods performed on irregular meshes common in FEM. However, most learning-based methods, in particular in imaging applications, focus on data coming from regular pixel grids and thus use traditional pixel-based convolutional layers and max-pooling layers. Using those methods would then require interpolating the solution from the irregular mesh to the pixel mesh, performing the learning task, and interpolating back to the irregular mesh. By instead considering the data on its natural irregular mesh, a learning task can be performed by viewing the underlying irregular mesh as a graph and using graph-based convolutions and pooling. For the stroke-monitoring application in EIT, the goal is to determine whether a significant change has occurred using real-time monitoring. If so, this would trigger a follow-up CT scan to assess treatment. In this talk we employ graph-based post-processing U-nets, with specialized pooling layers, on 3D EIT images for improved quality and reduced computational cost. Performing the learning directly on the graphs allows added flexibility to train the models on 2D simulations and then use them directly on 3D data as the graph framework merely cares about the connections between the mesh elements/nodes (not dimension). Results for experimental tank data are presented.

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MS58

Bedside Monitoring of Brain Hemorrhage Using EIT a Feasibility Study Using Simulated Data from Anatomically Accurate Head Model

In this talk, we discuss the development of electrical impedance tomography (EIT) based technology for bedside monitoring of hemorrhagic stroke. We explain the background for this novel application of EIT and the image reconstruction method we have developed for it. Feasibility of the approach is studied with simulated data from anatomically highly accurate head model.

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MS58

Electrical Imaging of Civil Structures and Materials

The presented work highlights recent advances in the implementation of Electrical Impedance Tomography (EIT) for imaging damage and lifecycle processes in civil structures and materials. Namely, we focus on the development of new imaging frameworks for handling this task, including conventional optimization and machine learning. Taking a pragmatic vantage, we will highlight EIT in the context of sensing skin crack imaging, moisture flow in porous materials and stress/strain sensing in nanocomposites. A discussion on paths forward and potential avenues for future research will be presented.

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MS59

Blood Vessels Variational Segmentation with a Learned Reconnecting Regularization Term

Blood vessels segmentation is a challenge due to their complex geometry, and low contrast in biomedical images. The emergence of deep learning provides significant representation power but remains dependent on the available annotated dataset, even with the development of semi-supervised methods. Recently, we have developed an approach combining deep learning and variational methods, introducing a regularization term learned through deep learning. This term offers easier generalization than deep neural models for segmentation and can be easily integrated into variational optimization schemes. To enhance blood vessel segmentation, we propose learning a vessel-specific feature: connectivity. Connectivity is often compromised during segmentation, yet it is crucial for applications such as 3D modeling and blood flow simulation. Thus, we learn reconnecting regularization terms in 2D and 3D from synthetic binary vascular trees. These terms can be integrated into a variational segmentation scheme, enabling vascular network detection across various datasets without requiring annotations. We tested our method on different datasets with 2D retinal fundus images and 3D liver CT volume scans. We demonstrate that it better preserves the structure of vascular networks in real images compared to traditional unsupervised and semi-supervised

methods, while improving the overall connectivity of the vascular tree.

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MS59

Graph-based Active Learning for Nearly Blind Hyperspectral Unmixing

Hyperspectral unmixing is an effective tool to ascertain the material composition of each pixel in a hyperspectral image with typically hundreds of spectral channels. In this paper, we propose two graph-based semi-supervised unmixing methods. The first one directly applies graph learning to the unmixing problem, while the second one solves an optimization problem that combines the linear unmixing model and a graph-based regularization term. Following a semi-supervised framework, our methods require a very small number of training pixels that can be selected by a graph-based active learning method. We assume to obtain the ground truth information at these selected pixels, which can be either the exact abundance value or the one-hot pseudo label. In practice, the latter is much easier to obtain, which can be achieved by minimally involving a human in the loop. Compared to other popular blind unmixing methods, our methods significantly improve performance with minimal supervision. Specifically, the experiments demonstrate that the proposed methods improve the state-of-the-art blind unmixing approaches by 50% or more using only 0.4% of training pixels.

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MS59

Variational Multichannel Multiclass Segmentation Using Unsupervised Lifting with CNNs

In this talk we will present an image segmentation approach, that combines convolutional neural networks (CNNs) with classical variational methods. The proposed

method decomposes the image into multiple feature maps with CNNs, and minimizes a segmentation functional with a flexible number of regions. The approach is fully unsupervised and does not need any training data. We present initial results, on various types of images.

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MS60
Shape Complexity in Medical Imaging

Shape complexity is a practically useful shape descriptor that has been studied by various fields, such as computer vision, psychology, mathematical morphology, and design, and has found diverse applications, including shape retrieval, measuring neurological development, and computer-aided design. However, its role in medical imaging is underexplored. This presentation considers multiple shape complexity measures, investigating their potential leverage within the deep learning framework for various medical imaging tasks.

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MS60
Data-Driven Regularization for Inverse Problems in Computational Imaging

Extracting scientific insights from costly experiments is often challenging. Quantities of interest usually cannot be measured directly, and therefore, the problem is mathematically formulated as an inverse problem, associating the available measurements (input) with the quantities of interest (solution) via a forward model, a mathematical model of the measurement process. In practical terms, it is rarely feasible to take enough measurements to uniquely determine the solution, resulting in an under-determined, ill-posed problem with a potentially infinite number of solutions. The usual approach to deal with this ambiguity is to introduce a regularization function that encodes prior knowledge and allows to constrain the solution to satisfy desirable properties. This, however, requires the solution of a computationally expensive optimization problem. In this talk we review some of the alternative Machine Learning (ML) approaches recently developed which are based on the process of unfolding the optimization into a feed-forward network structure. ML models that encode data-driven priors and combine them with unfolded optimization constitute a framework that is more amenable to theoretical analysis and that can significantly reduce processing times for a diverse set of computational imaging inverse problems.

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MS60
Diffusion Based Purification for Improved Robustness of Physics-Based Deep Learning Image Reconstruction

Deep learning (DL) has significantly advanced magnetic resonance image (MRI) reconstruction, outperforming traditional methods. However, recent studies have exposed vulnerabilities in DL-based reconstruction models, particularly their susceptibility to worst-case additive measurement perturbations and variations in training/testing settings, such as acceleration factors, k-space sampling locations, etc. This paper addresses these challenges by introducing a robustification strategy that enhances the resilience of DL-based MRI reconstruction using pretrained diffusion models as noise purifiers. In contrast to conventional robustification methods like adversarial training (AT), our approach eliminates the need to address a minimax optimization problem, requiring only fine-tuning on purified examples. Experimental results demonstrate the effectiveness of our method in mitigating instabilities compared to leading robustification approaches, including AT and randomized smoothing. Our work contributes to the development of more robust and reliable DL-based MRI reconstruction techniques, advancing the field's applicability and reliability.

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MS60
Simplifying Full Waveform Inversion via Domain-Independent Self-Supervised Learning

Deep learning has marked a significant advancement in geophysics, especially in tackling the intricate challenge of full waveform inversion (FWI). This breakthrough has enabled the effective prediction of subsurface velocity maps from seismic data. The process involves transforming seismic data into subsurface velocity maps, a task we have approached as a sophisticated form of image translation. This paper discusses a remarkable discovery: when encoders and decoders are trained independently within their specific domains through self-supervised learning, a linear relationship emerges in their latent spaces, transcending domain boundaries. This finding not only sheds light on the underlying mechanics of FWI but also elegantly unites multiple FWI datasets. These datasets can efficiently uti-

lize a shared set of self-trained encoders and decoders, each adapted with distinct linear mappings. Building upon these insights, we introduce SimFWI, a novel methodology comprising two key steps: firstly, the independent learning of seismic encoders and velocity decoders across various datasets using masked image modeling, and secondly, the customization of a linear mapping for each dataset. Our experiments reveal that SimFWI matches the performance of traditionally trained models, which rely on paired seismic data and velocity maps, thereby opening new avenues in geophysical research.

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MS61

Ray-Based Implicit Function for Neural Surface and Scene Representation

We introduce a new implicit shape representation called Primary Ray-based Implicit Function (PRIF). In contrast to most existing approaches based on the signed distance function (SDF) which handles spatial locations, our representation operates on oriented rays. Specifically, PRIF is formulated to directly produce the surface hit point of a given input ray, without the expensive sphere-tracing operations, hence enabling efficient shape extraction and differentiable rendering. We demonstrate that neural networks trained to encode PRIF achieve successes in various tasks including single shape representation, category-wise shape generation, shape completion from sparse or noisy observations, inverse rendering for camera pose estimation, and neural rendering with color.

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MS61

p-Poisson Surface Reconstruction in Curl-Free Flow from Point Clouds

Shape representations are imperative for 3D computer vision. In this talk, we introduce a deep-learning-based approach for reconstructing a surface from an unorganized point cloud. The implicit representation of the surface as a level set of a function provides the advantage of producing watertight results and greater flexibility in representing diverse topologies. We leverage the p-Poisson equation to effectively learn the signed distance function (SDF). To enhance the accuracy of reconstructing the SDF, we introduce a variable splitting strategy that integrates the gradient of the SDF as an auxiliary variable. Additionally, to facilitate the learning, we impose a curl-free condition to the auxiliary variable, utilizing the irrotational property of the conservative vector field. Various numerical results show that the appropriate supervision of partial differential equations and fundamental characteristics of differential vector fields is sufficient for the successful reconstruction of high-quality surfaces, without requiring any additional a priori knowledge of the surface.

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MS61

Understanding 3D Neural-Implicit Geometries in Numerical Simulation

In performing a physical simulation, geometry is foundational. For natural scenes such as forests or city-scale urban environments obtaining a high-quality 3D geometry is non-trivial. Scanners such as LiDAR are often impractical and traditional photogrammetry techniques can be lacking in quality. Recently, work such as Neural Radiance Fields (NeRF) and Neural Surfaces (NeuS) have used neural networks to predict implicit function representations of 3D geometries from images. The impressive capabilities of these methods make them an attractive option for performing tasks in computational geometry for modeling and simulation, such as grid generation for numerical partial differential equations (PDEs). In order to do this, though, one needs to obtain a mathematically systematic assessment of the errors of such methods specifically as they affect the accuracy and stability of numerical PDE solvers. In this work, we explore neural implicit methods for 3D geometry reconstruction and their compatibility with the Embedded Boundary method, an approach for finite volume discretization that uses implicit signed distance functions as geometric inputs. Previous work on neural implicit methods has studied their accuracy from a visual standpoint, but as we will show, the commonly used metrics in the graphics and computer vision literature do not tell us much about the effect on stability of numerical methods or the accuracy of the final simulation.

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MS61

Signal Processing-Inspired Implicit Neural Representations

Implicit Neural Representations (INRs) have emerged as a powerful new tool for modeling diverse signals. The performance of INRs in terms of the training time, and robustness in representation, is primarily dictated by the architectural choices within the multilayer perceptron (MLP). In this talk, we will dive into two specific innovations inspired by classical signal processing tools. First, I will talk about how INRs can be combined with Laplacian pyramids to obtain a multiscale INR (MINER) framework that enables training even gigapixel images within a short time. Second, I will talk about how wavelets as a non-linearity enables strong implicit biases for image-based representations. This wavelet INR (WIRE) can solve a wide range of inverse problems including image denoising, super resolution, tomography, and novel view synthesis. I will finally talk about the geometric intuition behind WIRE, and how tools from harmonic analysis enables us to develop a theoretical framework to study INRs.

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MS62

Virtual Parallel-Beam Projections from Electrical

Impedance Data

Recent advancements have revealed deep physical and mathematical connections between electrical impedance tomography (EIT) and parallel-beam imaging modalities (e.g. X-ray CT). These surprising new results indicate that real-world electrical measurements based on nonlinear wave phenomena may be processed into a virtual projection image with geometry matching the sinogram obtained from straight-line X-ray tomography. A sinogram contains geometric information about the target's internal structure beyond what is present in a standard EIT reconstruction. If desired, this sinogram may also be inverted to produce a reconstruction of the internal conductivity distribution. In this talk we discuss the process of obtaining such a virtual projection image from real-world voltage and current measurements collected from an EIT machine.

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MS62

Online Optimization for Dynamic Electrical Impedance Tomography

Online optimization generally studies the convergence of optimization methods as more data is introduced into the problem; think of deep learning as more training samples become available. We adapt the idea to dynamic inverse problems that naturally evolve in time. We introduce an improved primal-dual online method specifically suited to these problems, and demonstrate its performance on dynamic monitoring of electrical impedance tomography.

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MS62

An Unsupervised Way to Optimize MRI Sampling Trajectories for Arterial Spin Labeling Magnetic Resonance Fingerprinting

Arterial Spin Labeling Magnetic Resonance Fingerprinting (ASL-MRF) is a quantitative perfusion imaging technique that allows the estimation of multiple hemodynamic parameters in a single scan. A fast sampling technique is one of the crucial steps in improving the signal-to-noise ratio, which helps to enhance the sensitivity of estimating hemodynamic parameters. In contrast to recently developed data-driven methods for optimizing sampling trajectories, which require extensive ground truth training data and long training time, we propose an unsupervised approach. This approach is data-free and particularly suitable for ASL-MRF applications, as obtaining ground truth data in ASL-MRF is challenging. Our results from both simulated and real scans validate the effectiveness of our method.

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MS62

Accelerating Bayesian Inference with Surrogates: A Case Study on Nitrate Fertilizer Estimation Using CUQIpy

Nitrate pollution poses a significant global environmental challenge, exacerbated by the widespread use of high-nitrate fertilizers in agriculture. The accurate estimation and control of nitrate fertilizer application on farms are imperative to address this issue. In this study, we propose a novel approach to infer fertilizer quantities used on farms based on scattered measurements of nitrate concentration, employing Markov-chain Monte Carlo (MCMC) sampling. While MCMC has proven effective, its efficiency is hindered by the computational expense associated with repeated runs of groundwater transport models. Moreover, the majority of groundwater transport models lack the capability to compute gradients, limiting the application of advanced gradient-based sampling methods. To overcome these challenges, our study leverages the Delayed Acceptance (DA) scheme, a two-stage sampling approach that utilizes an approximated likelihood. This approximated likelihood is computed using a reduced transport model, which, although less accurate, significantly reduces computational costs compared to exact transport models. The implementation of our approach is based on CUQIpy (https://cuqi-dtu.github.io/CUQIpy/), and numerical results demonstrate the effectiveness of the DA sampling method in reducing computational time. This approach offers a promising avenue for accurately estimating fertilizer usage in the context of mitigating nitrate pollution.

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MS63

Geometric Inverse Problems and Gas Giants

In this talk, a gas giant planet is a manifold equipped with a Riemannian metric that is singular at the boundary in a specific way. I will explain how our novel geometric model is derived and I will discuss our recent results on geometric inverse problems on gas giants. There is one key difference between terrestrial planets, like the Earth, and gas giants, like Jupiter. In gas, the density of matter goes to zero at the surface, whereas in rock, the sound speed is bounded from below by a positive constant even at the surface. I will explain how the standard Riemannian models for rocky planets have to be modified to account for the vanishing of density. Surprisingly little is known about the geometry of the arising Riemannian metrics, which we call gas giant metrics. We will see an overview of the geometry of gas giants. In particular, we will compute the Hausdorff dimension of a gas giant. We will consider two inverse problems with origins in seismology and prove the following two

results. Up to natural obstructions, a gas giant metric is uniquely determined by certain travel time measurements. A smooth function on a gas giant is uniquely determined by the knowledge of its integrals over the maximal geodesics of a gas giant. The talk is based on joint work with Maarten de Hoop, Joonas Ilmavirta and Rafe Mazzeo. A preprint is available at https://arxiv.org/abs/2403.05475.

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MS63
Gauge Freedoms in the Anisotropic Elastic Dirichlet-to-Neumann Map

The topic of this talk is an inverse problem related to the elastic wave equation. We are interested in recovering the stiffness tensor and density of mass of a material from the corresponding Dirichlet-to-Neumann map. We address to what extent the parameters are uniquely determined by this map. In this context coordinate transformations and gauge freedoms between the parameters play a role. We present insights on these aspects to present gauge freedoms in the Dirichlet-to-Neumann map for both the Euclidean and Riemannian elastic wave equation.

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MS63
Partial Data Inverse Problems for Magnetic Schrdinger Operators with Potentials of Low Regularity

In this talk we discuss partial data inverse boundary problems for magnetic Schrdinger operators on bounded domains in the Euclidean space as well as some Riemannian manifolds with boundary. In particular, we show that the knowledge of the set of the Cauchy data on a portion of the boundary of a domain in the Euclidean space of dimension $n \geq 3$ for the magnetic Schrdinger operator with a magnetic potential of class $W^{1,n} \cap L^{\infty}$, and an electric potential of class L^n, determines uniquely the magnetic field as well as the electric potential. Our result is an extension of global uniqueness results of Dos Santos Ferreira–Kenig–Sjstrand–Uhlmann (2007) and Knudsen–Salo (2007), to the case of less regular electromagnetic potentials. Our approach is based on boundary Carleman estimates for the magnetic Schrdinger operator, regularization arguments, as well as the invertibility of the geodesic X-ray transform.

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MS64
WeightNet: Weight Learning for Image Denoising

Due to its impact on subsequent image processing tasks, image denoising plays a crucial and fundamental role in image processing. In the context of weighted total variation (TV) minimization for image denoising, the choice of an appropriate weight is of utmost importance. In this paper, we propose the use of weighted TV and introduce a data-driven approach to determine the weights using a Weight-Net, as opposed to the traditional Euler's elastics. Initially, we carefully select suitable input features for WeightNet that effectively address image denoising problems through weighted TV. Subsequently, we choose an appropriate network architecture for WeightNet, drawing inspiration from previous works. Finally, we evaluate the effectiveness of our proposed method by comparing it with TV and TC models on both synthetic and real image datasets. The numerical results demonstrate that our proposed method outperforms the classical TV and TC methods in terms of denoising performance.

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MS64
A Total Scaled-Gradient Variation Regularization Framework and Its Accelerated Operator-Splitting Solver

In image modeling, piecewise-linear structure is the simplest and important extension of piecewise-constant structure. In this talk, by sparse modeling of piecewise-linear structures, we propose a total scaled-gradient variation (TSGV) regularization framework (with a class of scaling functions) in the context of variational image denoising. A general high-order denoising model using this regularization framework and Lp-based fidelity (p?[1,+8)) is studied both theoretically and computationally. We establish two theorems showing its edge and corner contrast preservation under proper assumptions on the scaling function, by introducing some new and key inequality estimations. To solve our high-order model, we design an accelerated operator-splitting (AOS) solver by combining inertial extrapolation and some approximation techniques to the operator-splitting (OS) method based on Lie scheme and Marchuk-Yanenko discretization. To the best of our knowledge, this is the first to combine acceleration techniques with such basic operator-splitting method used widely to solve non-convex and nonsmooth high-order models. Our AOS solver is easy to implement. It not only inherits the advantages of Lie scheme type of operator-splitting methods, but also becomes more efficient. Numerical experiments demonstrate that our method usually generates denoising results with higher PSNR values by adjusting fewer parameters and using much less running time than the compared high-order methods.

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MS65
Incremental Tensor Decompositions for Compressing Image-Based Data Streams

Efficient compression of image-based data streams is crucial in data-driven applications. Even when the data can be stored on disk, traditional one-shot compression algorithms have excessive memory requirements. Furthermore, other incremental algorithms, e.g., those based on backpropagation, often require extensive data and multiple passes for learning, leading to prolonged training times. In this presentation we introduce two novel incremental tensor decomposition algorithms for tensor-train and hierarchical-Tucker formats. These algorithms, called TT-ICE and HIT, respectively, compress incremental high-dimensional data with a single pass. In contrast to many alternatives, TT-ICE and HIT are rank-adaptive and provide approximation guarantees for the training data. By leveraging the

properties of their respective tensor decomposition formats, TT-ICE and HIT achieve computational efficiency and low memory footprint, enabling the use of tensor-based tools even on resource-limited hardware. On a dataset composed of ATARI gameplay sequences, TT-ICE was shown to be $2.7 - 10.8\times$ faster than backpropagation based methods and $8 - 23.5\times$ faster than the state of the art incremental tensor-train decomposition algorithms[Aksoy et al., An Incremental Tensor Train Decomposition Algorithm, 2022]. In this talk, we will provide a performance comparison for TT-ICE and HIT by presenting an analysis of their application to the OpenAI MineRL dataset.

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MS65
Descent Methods for Tensor Image Data

In applications involving imaging data, large-scale data is a common challenge. In this presentation, we introduce an iterative method for approximating the solution of large-scale multi-linear systems, represented in the form A*X=B under the tensor t-product. Unlike previously proposed randomized iterative strategies, such as the tensor randomized Kaczmarz method (row slice sketching) or the tensor Gauss-Seidel method (column slice sketching), which are natural extensions of their matrix counterparts, our approach delves into a distinct scenario utilizing frontal slice sketching. In particular, we explore a context where frontal slices, such as video frames, arrive sequentially over time, and access to only one frontal slice at any given moment is available. This talk will present our novel approach, shedding light on its applicability and potential benefits in approximating solutions to large-scale multi-linear systems.

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MS65
Iterative Hard Thresholding Algorithms for Tensor Recovery

Due to the explosive growth of large-scale data sets, tensors have been a vital tool to analyze and process high-dimensional data. Different from the matrix case, tensor decomposition has been defined in various formats, which can be further used to define the best low-rank approximation of a tensor to significantly reduce the dimensionality for signal compression and recovery. In this paper, we consider the low-rank tensor recovery problem when the tubal rank of the underlying tensor is given or estimated a priori. We propose a novel class of iterative singular tube hard thresholding algorithms for tensor recovery based on the low-tubal-rank tensor approximation, including basic, accelerated deterministic and stochastic versions. Convergence guarantees are provided along with the special case when the measurements are linear. Numerical experiments on tensor compressive sensing and color image inpainting are conducted to demonstrate convergence and computational efficiency in practice.

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MS65
Tensor BM-Decomposition for Compression and Analysis of Spatio-Temporal Third-order Data

Given tensors $\mathcal{A}, \mathcal{B}$, and $\mathcal{C}$ of size $m \times 1 \times n$, $m \times p \times 1$, and $1 \times p \times n$, respectively, their Bhattacharya-Mesner (BM) product will result in a third order tensor of dimension $m \times p \times n$ and BM-rank of 1 (Mesner and Bhattacharya, 1990). Thus, if a third-order tensor can be written as a sum of a small number of such BM-rank 1 terms, this BM-decomposition (BMD) offers an implicitly compressed representation of the tensor. In this talk, we will give a generative model which illustrates that spatio-temporal video data can be expected to have a low BM-rank. We also present and study the properties of an iterative algorithm for computing an approximate BMD. We will show several numerical experiments comparing our tensor BM-decomposition with methods such as DMD and SS-SVD to demonstrate the ability of our algorithm to extract important temporal information from video data while simultaneously compressing the data.

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MS66
Hybrid Hessenberg Solvers for Inverse Problems

Inverse problems arise in a variety of applications: machine learning, image processing, finance, mathematical biology, and more. Solution schemes are formulated by applying algorithms that incorporate regularization techniques and/or statistical approaches. In most cases these solution schemes involve the need to solve large-scale ill-conditioned linear systems that are corrupted by noise and other errors. In this talk we consider new hybrid Krylov subspace methods to solve these linear systems, including how to choose regularization parameters.

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MS66

Automatic Balancing Parameter Selection for Tikhonov-Tv Regularization

This talk presents a new local anisotropic regularization method that penalizes the weighted directional derivatives of the solution one wishes to recover, enhancing its structure. The regularized solution and the local orientation parameters for the novel regularization terms are automatically and simultaneously recovered by solving a bilevel optimization problem, where the lower level problem is Tikhonov regularization equipped with the novel regularization terms, while the objective function of the upper level problem encodes some natural assumptions about the local orientation parameters and the Tikhonov regularization parameter. The performance of the proposed algorithm is successfully demonstrated on denoising problems and linear inverse problems in geophysics.

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MS66

Recycling Mmgks for Large-Scale Dynamic and Streaming Data

To reconstruct images with sharp edges, Tikhonov regularization with regularization term involving the ℓ_q-norm of the gradient image is typical. In practice, the constrained problem is replaced with a sequence of problems with 2-norm weighted gradient, with weights determined from the current solution estimate. The Majorization Minimization Generalized Krylov Subspace (MM-GKS) algorithm (Huang, et al., BIT, 2017) works to solve the sequence without returning to the full-scale problems. A basis for a small dimensional solution space is constructed using Golub-Kahan bidiagonalization. A current solution and regularization parameter are cheap to compute from the corresponding projected problem. The solution space is expanded if deemed necessary, the weights are adjusted, and a new projected problem of dimension one larger is generated and solved. This expansion of the basis is repeated until the desired solution is reached. However, for large-scale problems requiring many expansion steps, storage as well as overhead associated with orthogonalizations can tax the memory capacity and require an overwhelming amount of computational time. The method we propose, Recycling MM-GKS (or RMM-GKS), is similar in spirit but encodes edge information earlier and works to minimize memory requirements by alternating between enlarging and compressing the solution spaces. We demonstrate results on dynamic photoacoustic tomographic data and streaming X-ray CT imaging data.

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MS66

Error Estimates for GolubKahan Bidiagonalization with Tikhonov Regularization for Illposed Operator Equations

Linear ill-posed operator equations arise in various areas of science and engineering. The presence of errors in the operator and the data often makes the computation of an accurate approximate solution difficult. We compute an approximate solution of an ill-posed operator equation by first determining an approximation of the operators of generally fairly small dimension by carrying out a few steps of a continuous version of the GolubKahan bidiagonalization (GKB) process to the noisy operator. Then Tikhonov regularization is applied to the low-dimensional problem so obtained and the regularization parameter is determined by solving a low-dimensional nonlinear equation. The effect of the errors incurred in each step of the solution process is analyzed. Computed examples illustrate the theory presented.

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MS67

Score-Based Priors for Bayesian Computational Imaging

Priors are essential for solving ill-posed imaging problems, affecting both the quality and uncertainty of reconstructed images. Diffusion models can express complicated image priors, but recent approaches extending diffusion models to inverse problems do not capture a true Bayesian posterior of images conditioned on measurements. We propose turning score-based diffusion models into principled image priors ("score-based priors") for analyzing an image posterior. In particular, we appeal to the log-probability function of a score-based diffusion model as a standalone prior function that can be plugged into any established algorithm for Bayesian inference. We demonstrate this with a variational-inference approach for sampling from an approximate image posterior. Our approach is hyperparameter-free, and we show that it results in more-accurate posteriors than other diffusion-model-based methods. We highlight black-hole imaging from radio interferometry as a promising application of our approach. Designing a black-hole prior is a challenging task due to the absence of true images of black holes and the risk of imposing undesirable biases. Using our posterior-sampling approach with score-based priors, we offer a principled strategy for understanding the role of bias in black-hole imaging. We

demonstrate this on Event Horizon Telescope (EHT) data and re-imagine the M87* black hole with various score-based priors imposing different visual biases.

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MS67
A Mathematical Explanation of Encoder-Decoder Based Neural Networks

For problems in image processing and many other fields, a large class of effective neural networks has encoder-decoder-based architectures. Although these networks have made impressive performances, mathematical explanations of their architectures are still underdeveloped. In this talk, we study the encoder-decoder-based network architecture from the algorithmic perspective and provide a mathematical explanation. We use the two-phase Potts model for image segmentation as an example for our explanations. We associate the segmentation problem with a control problem in the continuous setting. Then, the continuous control model is time discretized by an operator splitting scheme, the PottsMGNet, and space discretized by the multigrid method. We show that the resulting discrete PottsMGNet is equivalent to an encoder-decoder-based network. With minor modifications, it is shown that a number of the popular encoder-decoder-based neural networks are just instances of the proposed PottsMGNet. By incorporating the Soft-Threshold-Dynamics into the PottsMGNet as a regularizer, the PottsMGNet has shown to be robust with the network parameters such as network width and depth and achieved remarkable performance on datasets with very large noise.

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MS67
Machine Learning Enabled Optical Modeling: Connecting The Phase and Space Domains

In formulating an inverse problem, there comes a point at which we must consider how accurately we wish to model the corresponding forward process. Between the extremes of no modeling and over modeling, we often aim to find an approximation which represents the true process while keeping the inverse problem reasonable. In this talk, we talk about the role of machine learning for enabling better optical models for inverse problems. We suggest the goal should not be to replace physics with a deep network but rather use small networks to solve key problems we cannot overcome analytically, keeping the rest of the physics untouched. To demonstrate this idea, we consider the connection between a phase aberration and its associated point spread function. This leads us to discuss a learned mapping known as the phase-to-space (P2S) transform. We discuss how it is being used and where we anticipate it can have further applications, as well as outlining other areas to which these ideas may be applied.

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MS67
Deep Learning Methods for Computer Generated Holography

Computer Generated Holography (CGH) is an inverse problem where the goal is to synthesize a custom illumination pattern by modulating the phase or the amplitude of a light beam, with constraints imposed by the wave propagation equation. Since CGH is a high-dimensional, non-convex, nonlinear optimization problem, even approximate solutions can take several hours to identify. Iterative optimization algorithms are slow, and incompatible with many potetntial CGH applications in computer vision, AR,VR, and scientific microscopy, where the ability to modulate light both rapidly and precisely is critical to interact in real time with human vision and with biological functions. In this presentation, we will show how our lab has recently leveraged the capabilities of deep learning models to synthesize 3D holograms at record speeds, with models that can be trained offline. We will also show that structure of deep learning models facilitates task-based optical technology design, by optimizing illumination patterns not only to render images, but directly to achieve the desired outcome (e.g. optical activation of cellular functions, immersive human image perception).

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MS68
Optimal Transport in Imaging and its Application to Thermography-Based Watermark Recognition

The goal of this introductory talk is to tease the contents of the following contributions in the minisymposium 'Computational Optimal Transport meets Imaging' by introducing Optimal Transport and giving an overview of its various applications in inverse problems and imaging sciences. Following this, we focus on a specific application in filigranology, the study of watermarks in cultural artefacts like historical manuscripts, which nowadays involves digitization methods like thermography as well as computational tools from image processing and machine learning. Based on task-specific requirements including comprehensibility and complexity control of the method while taking account of very few and noisy data, we propose a processing chain for the automatic recognition of watermarks in thermographs. In a first stage, our approach maps raw thermography data to binarized watermarks and, in a second stage, it makes use of certain sliced variants of Optimal Transport to construct a suitable feature representation that allows for an efficient classification using support vector machines. The effectiveness of our approach is illustrated by numerical experiments with thermography data of historical music manuscripts. This talk is based on joint work with Dominik Hauser and H. Siegfried Stiehl (University of Hamburg).

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MS68

Iterative Slicing and Matching for Fast Measure Transport

In this talk, we will discuss iterative schemes for measure transfer and approximation problems, which are defined through a slicing-and-matching procedure. Similar to the sliced Wasserstein distance, these schemes benefit from the availability of closed-form solutions for the one-dimensional optimal transport problem and the associated computational advantages. While such schemes have already been successfully utilized in data science applications, not too many results on their convergence are available. The main contribution of this paper is an almost sure convergence proof for stochastic slicing-and-matching schemes. The proof builds on an interpretation as a stochastic gradient descent scheme on the Wasserstein space. Numerical examples on step-wise image morphing are demonstrated as well.

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MS68

Accelerate Sampling Using Birth-Death Dynamics

I will discuss the birth-death dynamics for sampling multimodal probability distributions, which is the spherical Hellinger gradient flow of relative entropy. The advantage of the birth-death dynamics is that, unlike any local dynamics such as Langevin dynamics, it allows global movement of mass directly from one mode to another, without the difficulty of going through low probability regions. We prove that the birth death dynamics converges to the unique invariant measure with a uniform rate under some mild conditions, showing its potential of overcoming metastability. We will also show that on torus, the kernelized dynamics, which is used for numerical simulation, Gamma-converges to the idealized dynamics as the kernel bandwidth shrinks to zero.

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MS69

Efficient Surface Reconstruction from Point-Cloud with Curvature Regularization

In this talk, we will introduce fast algorithms for surface reconstruction from point clouds. Extending from a clas-sical variational model involving minimizing the distance from the surface to point clouds weighted by surface area, we propose a model where the mean curvature of the reconstructed level-set surface is regularized. Our reconstruction shows appealing properties including robustness to noise and improved recovery of the concave characteristics of the underlying surfaces. We numerically address the high-order and non-convex optimization problem by proposing fast algorithms based on operator-splitting and ADMM paradigms. Compared to the classical discretization of the involved Euler-Lagrange equation, our algorithms achieve significant acceleration. We will demonstrate the effectiveness of our approach with numerous examples.

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MS69

Optimization Involving Surfaces

Surface optimization is a critical aspect in diverse fields, spanning physics, engineering, computer graphics, fluids, and material sciences. In this talk, we will share our recent findings related to surface optimization for eigenvalue problems. Our approach involves the development of various computational methods based on parameterization of conformal classes to optimize Steklov eigenvalues and Laplace-Beltrami eigenvalues. Additionally, we will explore applications of these methods.

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MS69

Surface Reconstruction Using Directional G-norm

We propose a method to reconstruct surface from noisy point cloud data, by obtaining a clean zero level set of their signed distance function (SDF). Due to the noise in the given point cloud, the distance function is oscillatory and lacks smoothness, especially near the data point. We denoise the SDF using a modified G-norm and provide an insight into how noisy data corrupts reconstruction of surfaces. We apply Augmented Lagrangian Method to optimize the objective energy function and solve the subproblems.

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MS69

A Fast Minimization Algorithm for the Euler Elastica Model Based on a Bilinear Decomposition

Euler elastica (EE), as a regulariser for the curvature and length of the image surface's level lines, has found various applications in image processing. However, developing fast and stable algorithms for optimizing the EE energy is a great challenge due to its strong nonlinearity and singularity. In this talk, we will present a novel fast hybrid

alternating minimization method (HALM) algorithm for the Euler elastica model based on a bilinear decomposition. Specifically, we decompose the gradient of the underlying image into the product of its magnitude and normal vector, resulting in a bilinear constraint. Using this decomposition, we reformulate the EE energy as a smooth functional in which the singularity in the original energy disappears and the strong nonlinearity is mitigated. Instead of strictly enforcing the bilinear constraint, we penalize it in the objective function and optimize the augmented objective function with the proposed HALM. The HALM algorithm comprises three sub-minimization problems, and each is either solved in the closed form or approximated by fast solvers, making the new algorithm highly accurate and efficient. We also prove the global convergence of the minimizing sequence generated by the algorithm under mild conditions. Numerical experiments show that the new algorithm produces good results with much-improved efficiency compared to other state-of-the-art algorithms for the EE model.

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MS70

Fast Alternating Direction Multipliers Method by Generalized Krylov Subspaces

The Alternating Direction Multipliers Method (ADMM) is a very popular and powerful algorithm for the solution of many optimization problems. In the recent years it has been widely used for the solution of ill-posed inverse problems, in particular, for imaging. However, one of its drawback is the possibly high computational cost, since at each iteration, it requires the solution of a large-scale least squares problem. In this talk we propose a computationally attractive implementation of ADMM, with particular attention to imaging problems. We significantly decrease the computational cost by projecting the original large scale problem into a low-dimensional subspace by means of Generalized Krylov Subspaces (GKS). The dimension of the projection space is not an additional parameter of the method as it increases with the iterations. The construction of GKS allows for very fast computations, regardless of the increasing size of the problem. Several computed examples show the good performances of the proposed method.

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MS70

Oracle-Compressed Sensing in Nonlinear Electrical Impedance Tomograph

Sparse recovery principles play an important role in solving nonlinear ill-posed inverse problems. We investigate a general framework for compressed sensing where the measurements are non-linear and possibly corrupted by noise, and its applicability to the ill-posed EIT inverse reconstruction problem. We propose an Oracle, based on a graph neural network, which is first applied to predict the conductivity support from nonlinear measurements. Then, this information is used to evaluate the non-null values of conductivity variation through a constrained proximal gradient method to finally achieve a stable recovery of the conductivity on the entire domain.

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MS70

Efficient Natural Gradient Descent Methods for Large-Scale PDE-Based Optimization Problems

Large-scale optimization is at the forefront of modern data science and scientific computing. First-order methods are workhorses for large-scale optimization problems due to modest computational cost and simplicity of implementation. Nevertheless, these methods are often agnostic to the structural properties of the problem under consideration and suffer from slow convergence, being trapped in bad local minima, etc. Natural gradient descent is an acceleration technique in optimization that takes advantage of the problems geometric structure and preconditions the objective functions gradient by a suitable natural metric. Hence parameter update directions correspond to the steepest descent on a corresponding natural manifold instead of the Euclidean parameter space rendering a parametrization invariant descent direction on that manifold. Despite its success in statistical inference and machine learning, the natural gradient descent method is far from a mainstream computational technique due to the computational complexity of calculating and inverting the preconditioning matrix. This work aims at a unified computational framework and streamlining the computation of a general natural gradient flow via the systematic application of efficient tools from numerical linear algebra. We obtain efficient and robust numerical methods for natural gradient flows without directly calculating, storing, or inverting the dense preconditioning matrix.

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MS70

Approximate Preconditioning of Iterative Refinement Methods for Linear Inverse Problems

Many problems in science and engineering give rise to linear systems of equations that are commonly referred to as large-scale linear discrete ill-posed problems. These problems arise for instance, from the discretization of Fredholm integral equations of the first kind. The matrices that define these problems are typically severely ill-conditioned and may be rank deficient. Because of this, the solution of linear discrete ill-posed problems may not exist or be extremely sensitive to perturbations caused by error in the available data. These difficulties can be reduced by applying regularization to iterative refinement type methods which may be viewed as a preconditioned Landweber method. Using a filter factor analysis, we demonstrate that low precision matrix approximants can be useful in the con-

struction of these preconditioners.

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MS71

Improving Image Reconstruction by Considering Motion in Magnetic Particle Imaging

Magnetic particle imaging (MPI) is a tracer-based medical imaging technique invented by Gleich and Weizenecker in 2005. It allows for the reconstruction of the spatial distribution of magnetic nanoparticles injected into the blood flow via exploiting their non-linear magnetization response to changing magnetic fields. MPI has the potential to be a fast imaging technique which make it interesting for applications such as blood flow imaging and instrument tracking. Therefore, one might not only be interested in the reconstruction of the particle distribution but also of the motion or flow itself. Current systems are using a field-free line (FFL) or field-free point (FFP) for spatial encoding and model based reconstruction is performed under ideal assumptions such as static particle distributions, ideal magnetic fields and lack of motion. In the case of a sequential line rotation of the FFL, the MPI data can be linked to Radon transformed particle distributions. Nevertheless, most scanners are based on the FFP excitation and measurements of the forward operator to avoid limitations of the model based approaches. However, in both cases field imperfections and motion may occur which results in artifacts in the reconstructed images. We will give on overview about different strategies in magnetic particle imaging to reduce these artifacts by model and show numerical reconstruction results from simulated as well as real dynamic data

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MS71

Data-Consistent Motion Estimation in MRI

Magnetic Resonance Imaging allows high resolution data acquisition with the downside of motion sensitivity due to relatively long acquisition times. Even during the acquisition of a single 2D slice, motion can severely corrupt the image. Retrospective motion correction strategies do not interfere during acquisition time but operate on the motion affected data. The acquisition trajectory as well as the space of images and deformations affect how and up to which accuracy motion can be estimated and validated. As well, the strategy for motion estimation is highly confined to the scenario at hand. Suitable acquisition strategies allow to sample data with subtle redundancy. Hence motion estimation can be accomplished by considering the data consistency term. In most applications, however, the trajectories are cartesian like in the HASTE sequence. These classical sampling schemes show no or only marginal temporal redundancy. Hence, in practice, residual based optimizations will fail to produce motion artifact free images. To this end a learned iterative procedure can be

used, to substantiate GAN predictions and achieve data consistency. We show that, dependent on the complexity of deformations, even small details which have initially been erased by GANs can be recovered.

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MS71

Dynamic Tomography Regularization Using Optimal Space-Time Priors

We consider a sequence of sparse and dynamic tomography problems and regularize them in both spatial- and temporal domains using the cylindrical shearlet representation system. Our choice of sparsity promoting regularization is motivated by the fact that the cylindrical shearlet system provides the optimal finite-term approximation rate for the class of cartoon-like videos. Once we have a well-defined problem setting, we obtain convergence rates in different noise conditions by randomly sampling the projection angles. The theoretical rates and validated with numerical tests using real dynamic tomography data.

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MS71

Solving Dynamic Inverse Problems with Neural Fields

In Dynamic Inverse Problems we are interested in the reconstruction of a space-time process from time-dependent measurements. In several cases of interest, such as dynamic free-breathing cardiac MRI, the acquisition of measurements is slow with respect to the motion of the process (e.g., moving organs), hence, only highly under-sampled measurements can be acquired. A naive approach to solving this problem is to neglect the dynamic nature of the process and proceed with a frame-by-frame reconstruction, however, this may lead to over-smoothed results. To regularize this problem a motion model that relates the image sequence and the motion expressed in terms of a velocity field is introduced. In this talk, instead of the commonly used grid-based methods, we use space-time continuous representations via Neural Fields, this is, both images and motion are parametrized as neural networks. We investigate the advantages of mesh-free representations and how do they compare to traditional grid-based methods,

the implicit regularization that neural fields impose, and different motion models.

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MS72

An Inverse Problem for the Kaluza-Klein Field Equations

Kaluza-Klein theory is a simple geometric unification of general relativity and electromagnetism. The associated field equations describe non-linear relationship between the gravitational field, electromagnetic 2-form and scalar field. By controlling the electromagnetic field on a boundary, one generates propagating singularities which interact through the nonlinearities. The interactions generate gravitational waves which propagate back to the boundary where they are observed. This talk is about determination of the conformal class of a vacuum background metric from such observations.

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MS72

Recovery of Time-Dependent Coefficients in Hyperbolic Equations on Riemannian Manifolds from Partial Data

In this talk we discuss inverse problems of determining time-dependent coefficients appearing in the wave equation in a compact Riemannian manifold of dimension three or higher. More specifically, we are concerned with the case of conformally transversally anisotropic manifolds, or in other words, compact Riemannian manifolds with boundary conformally embedded in a product of the Euclidean line and a transversal manifold. With an additional assumption of the attenuated geodesic ray transform being injective on the transversal manifold, we prove that the knowledge of a certain partial Cauchy data set determines time-dependent coefficients of the wave equation uniquely in a space-time cylinder. We shall discuss two problems: (1) Recovery of a potential appearing in the wave equation, when the Dirichlet and Neumann values are measured on opposite parts of the lateral boundary of the space-time cylinder. (2) Recovery of both a damping coefficient and a potential appearing in the wave equation, when the Dirichlet values are measured on the whole lateral boundary and the Neumann data is collected on roughly half of the boundary.

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MS72

Recovery of a Complete Riemannian Manifold Using the Local Source-to-Solution Operator for the Electro-Magnetic Wave Operator

We consider the inverse problem of determining the uniqueness of the topology and smooth structure of a smooth manifold and the uniqueness the coefficients of an Electro-Magnetic Wave Operator using the local source-to-solution operator which maps a source term and to the solution to the wave equation on an open observation set for all time. With this data, we show how to determine the topological and smooth structure of the manifold from the PDE data by determining the distance functions on this observation set. We then show the uniqueness of the lower order terms up to a gauge in the first order terms.

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MS72

Caldern Problem for Quasilinear Anisotropic Conductivities in Two Dimensions

We will discuss the unique identifiability, module the natural obstruction, for the Caldern problem for quasilinear anisotropic conductivities in two dimensions from the associated Dirichlet-to-Neumann map. We reduce the problem to the isotropic case using isothermal coordinates. For this case, we prove the result by using the method of higher order linearization and Bukhgeim's CGO solutions.

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MS73

Cross-Concentrated Sampling for Tensor Completion

In this talk, I will introduce a novel sampling model for the tensor completion problem, termed Tensor Cross-Concentrated Sampling (TCCS). This model extends the concept of matrix cross-concentrated sampling (CCS) to tensor setting, offering a novel method for tensor sampling. The TCCS model specifically targets horizontal and lateral subtensors, providing an important approach to partial observations that seeks to overcome the limitations of traditional unbiased sampling techniques. Furthermore, I will discuss a corresponding solver, the Iterative Tensor CUR Decomposition for Tensor Completion (ITCUR-TC), which is designed to effectively tackle the TCCS-based tensor completion challenges. To conclude, I will demonstrate the efficacy of our model and solver through their application to both synthetic and real-world datasets.

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MS73

Optimal Tensor Algebras for Image Compression

Many data are naturally represented as multiway arrays or tensors, and as a result, multilinear data analysis tools have revolutionized feature extraction and data compression. Recent advances in matrix-mimetic tensor algebras have made it possible to preserve linear algebraic properties in higher dimensions and, as a result, to obtain optimal representations of multiway data. Matrix-mimeticity arises from interpreting tensors as t-linear operators, which

in turn are parameterized by invertible linear transformations. The choice of transformation is critical to representation quality, and thus far, has been made heuristically. In this talk, we will learn data-dependent, orthogonal transformations by leveraging the optimality of matrix-mimetic representations. In particular, we will exploit the coupling between transformations and optimal tensor representations using variable projection. We will highlight the efficacy of our proposed approach on image compression and reduced order modeling tasks.

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MS73
Matrix and Tensor Dictionary Reconstruction for Static and Dynamic Inverse Problems

Encoding prior beliefs such as smoothness, sparsity, and/or edge-preserving into an inverse problem is shown to be beneficial as it increases the reconstruction quality and allows for more accurate estimations. Embedding a learned dictionary into the prior allows to encode features derived from selected training images. In this work, we develop a general framework that makes use of pre-learned data-driven dictionaries in both matrix and tensor forms for reconstructing static and dynamic inverse problems efficiently. We use examples from a wide range of applications such as image deblurring, superresolution, computerized, and photoacoustic tomography to illustrate the effectiveness of the methods described.

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MS73
Undersampling Raster Scans in Spectromicroscopy Using Higher Order Data Completion for Reduced Dose and Faster Measurements

X-ray spectromicroscopy is a powerful tool for studying material distributions, which is extracted from the data using a combination of PCA and cluster analysis. However, the traditional data collection setting has some significant weaknesses (e.g., long scanning times and material degradation due to x-ray radiation). It has been demonstrated [O Townsend, Undersampling Raster Scans in Spectromicrsocopy for reduced dose and faster measurements, 2022] that iterative methods based on low-rank matrix completion are well suited for recovery of near identical results from sparse undersampled data, greatly reducing the experimental time. However, the data sets formed through spectromicroscopy experiments are naturally 3D tensors, allowing for further improvement in data recovery if we

can avoid the first step of flattening the data into matrices. In this talk, we present a novel iterative algorithm for low rank *tensor* completion, recovering the missing entries in the datas native space. The new method allows the selection of robust sampling patterns, tensor multi-rank and undersampling ratio, while minimising the impact of undersampling on the cluster analysis. Results obtained on real data will be illustrated.

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MS74
Poisson Tailored Neural Blind Deconvolution for Biomedical Imaging

Several imaging domains (Biology, Medicine, Astronomy) share a common model for the image acquisition process:

$$g = Hx^* + b$$

where x^* is the clean image, H is the blurring linear operator, b is a constant background term and g is the recorded image, affected by Poisson noise. When H is unknown, one resorts to blind deconvolution techniques to compute an estimation $\tilde{x}$ and $\tilde{H}$ of both x^* and H. We present the Double Deep Image Prior for Poisson noise approach: via the Deep Image Prior method we parameterizes x and H with two neural networks:

$$\tilde{x} \sim \mathcal{N}_x(\theta), \ \tilde{H} \sim \mathcal{N}_H(\phi)$$

with weights θ, ϕ and which are trained by solving:

$$\arg\min_{\theta,\phi} KL(\mathcal{N}_x(\theta), \mathcal{N}_H(\phi); g, b) + f_1(\mathcal{N}_x(\theta)) + f_2(\mathcal{N}_H(\phi)),$$

where KL is the Kullback-Leibler function and f_1 and f_2 are regularization terms preserving some characteristics on x and H (e.g., sparseness). The novelty of this approach relies on encompassing box constraints on the PSF for avoiding the collapse to the trivial solution $\tilde{x} = g$ and $\tilde{H}$ equal to the Dirac's delta. The minimization problem is solved via a Proximal Gradient Descent-Ascent method. The numerical experiments are carried on both synthetic and real Poisson data, with H consisting in a Gaussian operator. We extend this approach also to speckle imaging problems.

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MS74

Learning Techniques for Dealing with Small Training Data

Image segmentation for each broad class of images may be satisfactorily done quickly and reliably when the number of trained data is large enough. This is consistent with the theory available for image classification: accuracy is correlated with size of trained data. For some application areas such as from digital pathology, there exist problems where it is either time-consuming to acquire enough trained data or impossible to get any at all. In this talk, we present our preliminary work towards using variational models to assist the augmentation of training data and hence to increase the accuracy of learning methods or to enable learning process. Joint works with Drs L Burrows, H R Zhang, D Sculthorpe and A Mukherjee etc.

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MS74

To Be Or Not to Be Stable: a Challenge in Biomedical Imaging with Deep Learning

This talk introduces a hybrid approach for solving inverse problems in Sparse-view Computed Tomography (SparseCT) by incorporating end-to-end Neural Networks within a traditional regularized iterative method. To ensure the stability of our method, we extend the theoretical framework of regularization theory from Engl et al. This extension allows us to analyze situations where the reconstruction algorithm does not converge to the pseudo-inverse solution when the noise level approaches zero, as is the case for neural networks. Utilizing the tools provided by this theoretical framework, we offer insights into the mathematical properties of the proposed approach, bridging the reliability gap between traditional regularization techniques and modern neural network methodologies for biomedical imaging applications.

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MS74

Mixed Precision Arithmetic for Iterative Biomedical Imaging Algorithms

In recent years a substantial amount of work has been done on developing mixed-precision algorithms for linear systems, methods that can exploit capabilities of modern GPU architectures. However, very little work has been done for large-scale ill-conditioned problems that arise in biomedical imaging applications. Special considerations, which normally do not arise when solving well-conditioned problems, such as incorporating regularization into the developed methods, need to be considered. In this talk we consider iterative refinement methods, and show the connection to iterated Tikhonov regularization and the preconditioned Landweber method.

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MS75

Attenuation Model for Photoacoustic Tomography with Pressure and Shear Waves

Photoacoustic tomography (PAT) is a relatively low-cost non-invasive biomedical imaging modality, which combines the advantages of optical imaging (e.g., high contrast) and ultrasound imaging. In this talk, we will first provide a brief overview of PAT, covering its physical processes, a historical embedding, and the mathematical standard model. Next, we will enhance the model of photoacoustic imaging by involving pressure and shear waves. To the end, the ill-posedness of the inverse problem in the attenuating medium as well as the asymptotic behavior of its singular values will be surveyed.

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MS75

High Dynamic Range Image Processing for Medical Ultrasound

A specific application of multi-frame imaging that are widely applied in technology is high dynamic range (HDR) imaging, which is well-known for applications in smartphones, mobile devices, television and displays industry, gaming industry and digital art. Dynamic range is the range of tonal difference between the lightest light and darkest dark of an image. The higher the dynamic range, the more potential shades can be represented. HDR imaging fuses images of the same scene taking under different exposure settings into one image with more tonal details. As technology advances, HDR imaging is likely to become even more pervasive and sophisticated across not only photography and videography, but also in medical ultrasound. In this talk, we want to discuss theoretical insight and present different algorithms for improving HDR ultrasound image quality, as well as the invariant properties of PDE and variational methods under HDR imaging technique.

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MS75

Saturation-Value Blind Color Image Deblurring with Geometric Spatial-Feature Prior

Blind deblurring for color images has long been a challenging computer vision task. The intrinsic color structures within image channels have typically been disregarded in many excellent works. We investigate employing regularizations in the hue, saturation, and value (HSV) color space via the quaternion framework in order to better retain the internal relationship among the multiple channels and reduce color distortions and color artifacts. We observe that a geometric spatial-feature prior utilized in the intermediate latent image successfully enhances the kernel accuracy for the blind deblurring variational models, preserving the salient edges while decreasing the unfavorable structures. Motivated by this, we develop a saturation-value geometric spatial-feature prior in the HSV color space via the quaternion framework for blind color image deblurring, which fa-

cilitates blur kernel estimation. An alternating optimization strategy combined with a primal-dual projected gradient method can effectively solve this novel proposed model. Extensive experimental results show that our model outperforms state-of-the-art methods in blind color image deblurring by a wide margin, demonstrating the effectiveness of the proposed model.

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MS76
Exploring Symmetry-Preserving Machine Learning: Sample Complexity and Implicit Bias

Symmetry is ubiquitous in machine learning (ML) and scientific computing, with compelling implications for model development. ML models that preserve group symmetry have shown marked improvements in learning tasks with inherent group structures, especially when faced with limited data. This talk will explore our recent and ongoing work toward understanding the gain of equivariant models. I will first talk about how group symmetry can help reduce the sample cost of generative models, which have wide applications in image generation. By developing variational representations of probability divergence with embedded symmetry, I will share both theoretical insights and empirical findings, in a way explaining why symmetry-preserving generative models can generate good samples with limited training data. Time permitting, I will discuss the training dynamics and implicit bias of equivariant neural networks for binary classification. By precisely identifying the solutions to which equivariant neural networks converge when trained under gradient flow, I will clarify why these models excel over their non-equivariant counterparts in group symmetric learning tasks.

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MS76
Low-Rank Approaches for Reduced Networks in Inverse Problems

Machine learning has become an important tool for inverse problems in imaging, used in hyperparameter estimation, uncertainty quantification, and full inversion, among other problems. In this work, we discuss a novel approach for inverse problems that utilizes surrogate models and exploits modern machine learning techniques using dimensionality reduction techniques (e.g., low-rank and latent representations). We consider a decoupled approach for surrogate modeling, where unsupervised learning approaches or autoencoders are used to efficiently represent the input and target spaces separately, and a supervised learning approach is used to represent the mapping between latent spaces. We demonstrate that our approach is superior in scenarios where training data for unsupervised learning is easily available, but the number of input/target pairs for supervised learning is small.

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MS76
Probabilistic Imaging: Large-Scale Posterior Sampling with Score-Based Priors

Estimating high-quality images while also quantifying their uncertainty are two desired features in an image reconstruction algorithm for solving ill-posed inverse problems. In this talk, we will introduce plug-and-play Monte Carlo (PMC), which is a principled framework for characterizing the space of possible solutions to a general inverse problem. PMC incorporates expressive score-based generative priors for high-quality image reconstruction while also performing uncertainty quantification via posterior sampling. In particular, we will introduce two PMC algorithms which can be viewed as the sampling analogues of the traditional plug-and-play priors (PnP) and regularization by denoising (RED) algorithms. We also establish a theoretical analysis for characterizing the convergence of the PMC algorithms. Our analysis provides non-asymptotic stationarity guarantees for both algorithms, even in the presence of non-log-concave likelihoods and imperfect score networks. We demonstrate the performance of the PMC algorithms on multiple representative inverse problems with both linear and nonlinear forward models. Experimental results show that PMC significantly improves reconstruction quality and enables high-fidelity uncertainty quantification.

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MS76
Swap-Net: A Memory-Efficient 2.5D Network for 3D Image Reconstruction

The reconstruction of 3D Cone-beam Computed Tomography (CBCT) images from a limited set of projections is an important inverse problem in many imaging applications from medicine to industrial settings. The performance of traditional methods such as filtered back projection (FBP) and model-based regularization is sub-optimal when the number of available projections is limited. In the past decade, deep learning (DL) has gained great popularity for solving CT inverse problems. Typically, supervised DL ap-

proaches for 3D image reconstruction are based on training a 2D convolution neural network (CNN) in a slice-by-slice manner or a 3D CNN that performs the whole volume reconstruction via 3D convolution. However, the suboptimal performance of the 2D CNN and the computational expense of 3D CNN limit their potential application. This work proposes Swap-Net, a memory-efficient 2.5D cascade network for Sparse-view 3D image reconstruction. Swap-Net produces 3D volume reconstruction in an end-to-end fashion without using full 3D convolutions. Our results show that our method consistently outperforms baseline methods both quantitatively in terms of artifact-reduction and detail-preservation.

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MS77
Gromov-Wasserstein Transport and Barycenters

Gromov-Wasserstein optimal transport is a generalization of the classical optimal transport problem and allows the comparison of two arbitrary metric measure spaces via the so-called Gromov-Wasserstein metric. Due to its invariance under measure- and distance-preserving transformations, this metric has many applications in graph and shape analysis. Unfortunately, the computation of the Gromov-Wasserstein distance is numerically expensive, limiting its application in machine learning like in classification tasks. To overcome this issue, we propose a linear version of the Gromov-Wasserstein metric, which is based on the geometric structure of the Gromov-Wasserstein space. Numerical examples illustrate that the linear Gromov-Wasserstein transport can replace the expensive computation of pairwise Gromov-Wasserstein distances in certain applications. Furthermore, we introduce the concept of multi-marginal Gromov-Wasserstein transport between a set of metric measure spaces as well as its regularized and unbalanced versions. As a special case, we discuss multi-marginal fused variants, which combine the structure information of an metric measure space with label information from an additional label space. The multi-marginal Gromov-Wasserstein transport has a close relation to (unbalanced, fused) Gromov-Wasserstein barycenter.

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MS77
Sparsity and Optimization Algorithms for Dynamic Imaging

In this talk we introduce a Frank-Wolfe-type algorithm for sparse optimization in Banach spaces. The functional we want to optimize consist of the sum of a smooth fidelity term and of a convex one-homogeneous regularizer. We exploit the sparse structure of the variational problem by designing iterates as linear combinations of extremal points of the unit ball of the regularizer. For such iterates

we prove global sublinear convergence of the algorithm. Then, under additional structural assumptions, we prove a local linear convergence rate.We apply this algorithm to the problem of particles tracking from heavily undersampled MRI data. This talk is based on the works cited below. [1] K. Bredies, M. Carioni, S. Fanzon, D. Walter. *Asymptotic linear convergence of Fully-Corrective Generalized Conditional Gradient methods.* Mathematical Programming, 2023 [2] K. Bredies, S. Fanzon. *An optimal transport approach for solving dynamic inverse problems in spaces of measures.* ESAIM:M2AN, 54(6): 2351-2382, 2020 [3] K. Bredies, M. Carioni, S. Fanzon, F. Romero. *A Generalized Conditional Gradient Method for Dynamic Inverse Problems with Optimal Transport Regularization.* Found Comput Math, 2022 [4] K. Bredies, M. Carioni, S. Fanzon. *On the extremal points of the ball of the Benamou–Brenier energy.* Bull. London Math. Soc., 53: 1436-1452, 2021

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MS77
Manifold Learning in Wasserstein Space

We give conditions sufficient for the linear approximation of a submanifold of the Wasserstein space to be equivalent (in the metric sense) to the restricted shortest-path Wasserstein distance on the submanifold. We then show how the latent manifold structure of the submanifold can be learned from samples and pairwise extrinsic Wasserstein distances. In particular, we show that the submanifold metric space can be asymptotically recovered in the sense of Gromov-Hausdorff from an appropriate graph. In addition, we demonstrate how tangent spaces can be asymptotically recovered via spectral analysis of a suitable "covariance operator' using optimal transport maps.

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MS77
Hv Geometry for Signed Signal Comparison

To compare and interpolate signals, we investigate a Riemannian geometry on the space of signals. The metric allows discontinuous signals and measures both horizontal (thus providing many benefits of the Wasserstein metric) and vertical deformations. Moreover, it allows for signed signals, which overcomes the main deficiency of optimal transportation-based metrics in signal processing. We characterize the metric properties of the space of signals and establish the regularity and stability of geodesics. Furthermore, we introduce an efficient numerical scheme to compute the geodesics and present several experiments that highlight the nature of the metric. This is joint work with Ruiyu Han (CMU) and Dejan Slepcev (CMU).

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MS79
Crystallographic Data Restoration Using Weighted Total Variation Flow and a Hybrid Deep Learning Method

Polycrystalline materials are composed of multiple crys-

tal grain assemblies. The technique of electron-backscatter diffraction (EBSD), used in scanning electron microscopy (SEM), is applied to collect information about the orientation of these grains. Such data is vital for quantitatively analyzing and understanding the properties of the materials. Nevertheless, EBSD images often include numerous misoriented pixels that appear as noise and may also show regions where data is missing due to instrumentation errors. Many algorithms widely used for reconstructing the grain orientation need tuning of algorithm-specific parameters. This aspect is not ideal for the users of these algorithms, as the parameter tuning may require a deep understanding of these methods. This talk will present our ongoing work that uses U-net, a convolutional neural network, to restore the grain orientation data. Our approach is a significant step toward making the restoration of the grain orientation free of parameters and efficient. In addition, we implement a hybrid exemplar-based and deep learning technique to inpaint (fill in) the missing data of the crystal structure.

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MS79

Total Directional Variation-Based Crack Detection for Geophysical Image Restoration and Enhancement in a Multimodality Setting

The cartography of large-scale fractures in textured terrains such as cliffs has been of growing interest to geologists, both from a structural and hydrological viewpoint. Until now, this task has been carried out manually by a cartographer. This presentation introduces a variational model to enhance and reconstruct cracks at two geological sites in Normandy, France. To this end, we aim to process thermal infrared and visible data together. Indeed, some information is available in the thermal framework but not in the visible one, and conversely. Initially, we study a variational model based on the decomposition of images into the sum of a component containing the cracks, obtained using a total directional variation operator, and another one including the remaining information superfluous for the analysis. Next, the existence of minimisers is established. Finally, the fusion of the results obtained independently for each modality is achieved, placing ourselves in the Riemannian geometry framework.

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MS79

Multiscale Hierarchical Decomposition Methods for Images Corrupted by Multiplicative Noise

Recovering images corrupted by multiplicative noise is a well known challenging task. Motivated by the success of multiscale hierarchical decomposition methods (MHDM) in image processing, we adapt a variety of both classical and new multiplicative noise removing models to the MHDM form. On the basis of previous work, we further present a tight and a refined version of the corresponding multiplicative MHDM. We discuss existence and uniqueness of solutions for the proposed models, and additionally, provide convergence properties. Moreover, we present a discrepancy principle stopping criterion which prevents recovering excess noise in the multiscale reconstruction. Through comprehensive numerical experiments and comparisons, we qualitatively and quantitatively evaluate the validity of all proposed models for denoising and deblurring images degraded by multiplicative noise.

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MS79

Diffractive Information Processing and Computational Imaging

We introduce diffractive optical networks - an all-optical computing architecture comprising multiple spatially engineered surfaces. The design of these networks involves, for a given task, digitally optimizing the diffractive layer features responsible for modulating the amplitude and/or the phase of the incident light using supervised learning. Following this one-time optimization, the layers are fabricated and assembled into a physical hardware that completes the desired computation all-optically at the speed of light propagation without requiring external power. Initially demonstrated for all-optical classification of objects, diffractive networks were subsequently used for computational imaging tasks. These include imaging through random unknown diffusers, privacy-preserving cameras, multispectral imaging, and unidirectional imaging, among others. Diffractive networks are also capable of all-optical quantitative phase imaging (QPI) as well as reconstruction of holograms. As universal linear processors, diffractive networks can simultaneously perform numerous complex-valued linear transformations through wavelength/polarization multiplexing. Similarly, under spatially incoherent light, diffractive networks can be optimized to perform any arbitrary linear transformation of input intensities, synthesizing arbitrary spatially-varying point spread functions. In summary, diffractive networks have opened up new avenues for com-

putational imaging and optical image processing.

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MS80
Posterior Sampling Via Sliced MMD Flows with the Negative Distance Kernel

Maximum mean discrepancy (MMD) flows suffer from high computational costs in large scale computations. We show that MMD with Riesz kernels $K(x,y) = -\|x - y\|^r$, $r \in (0,2)$ coincides with the MMD of its sliced version. As a consequence, the computation of gradients of MMDs can be performed in the one-dimensional setting. For $r = 1$, a simple sorting algorithm can be applied to reduce the complexity from $O(MN + N^2)$ to $O((M + N)\log(M + N))$ for two measures with M and N support points. For the implementations, we approximate the gradient of the sliced MMD by using only a finite number P of slices and show that the resulting error has complexity $O(\sqrt{d/P})$, where d is the data dimension. These results enable us to train generative models by approximating MMD gradient flows by neural networks even for image applications. By approximating the joint distribution of ground truth and observations, we use them for posterior sampling in inverse problems and conditional generative modelling.

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MS80
Uncertainty Quantification of Inclusion Boundaries

In this talk, we introduce a Bayesian framework for reconstructing the boundaries that represent targeted features in an image, as well as the regularity (i.e., roughness vs. smoothness) of these boundaries. This regularity often carries crucial infor mation in many inverse problem applications, e.g., for identifying malignant tissues in medical imaging. We represent the boundary as a radial function and characterize the regularity of this function by means of its fractional differentiability. We propose a hierarchical Bayesian formulation which, simultaneously, estimates the function and its regularity, and in addition we quantify the uncertainties in the estimates. Numerical results suggest that the proposed method is a reliable approach for estimating and characterizing object boundaries in imaging applications, as illustrated with examples from X-ray CT and image inpainting. We also show that our method is robust under various noise types, noise levels, and incomplete data.

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MS80
Dual-grid Parameter Choice Method for Total Variation Regularized Image Deblurring

We present a new parameter choice method for total variation (TV) deblurring of images. The method is based on a dual-grid computation of the solution. Instead of a single grid we have 2 grids with different discretisation. The first grid is the same were the measurement is given. The origin of the second grid is shifted half a pixel width both horizontally and vertically. Note that the underlying true image is the same for both grids. Assume that the pixel size is much smaller than a typical constant valued area in an image. The premise of the study is that when solving the TV regularised noisy deblurring problem with a large enough parameter the solutions on both grids will converge to the same image. The proposed algorithm looks for the smallest parameter with which convergence can be numerically detected. The method has been tested on both simulated and real image data. Preliminary computational experiments suggest that an optimal parameter can be chosen by monitoring the sparsity of the difference of the dual-grid solutions while changing the regularisation parameter size.

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MS80
Conditional Gradients for Total Variation Regularization with PDE Constraints: A Graph Cuts Approach

Variational regularization with total variation penalties is a popular tool for challenging applications such as image deconvolution or the discovery of different material properties within an otherwise homogeneous medium. This is attributed to the observation that TV-penalties favour piecewise constant reconstructions while retaining convexity of the regularizer. On the downside, their intricate properties significantly complicate every aspect of their analysis, from the derivation of first-order optimality conditions to their discrete approximation and the choice of a suitable solution algorithm. In this talk, we discuss the efficient solution of (discretized) minimization problems with total variation penalties by fully-corrective generalized conditional gradient methods. This family of algorithms provably approximates minimizers by finite linear combinations of characteristic functions which are updated by switching between set insertion and global correction steps. While the latter corresponds to the resolution of finite dimensional, LASSO-like problems, the former is realized by a suitable graph-cut problem. The practical efficiency of the

method is demonstrated in several examples.

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MT1
Computational Optimal Transport in Imaging Science

See description

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MT1
Computational Optimal Transport in Imaging Science

See description

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MT2
Deep Learning Techniques for Wave-Based Imaging

Input your abstract, including TeX commands, here. The abstract should be no longer than 1500 characters, including spaces. Only input the abstract text. Don't include title or author information here.

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MT2
Deep Learning Techniques for Wave-Based Imaging

Input your abstract, including TeX commands, here. The abstract should be no longer than 1500 characters, including spaces. Only input the abstract text. Don't include title or author information here.

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PP1
Dynamics of a Model of Coronavirus Disease with Fear Effect, Treatment Function and Variable Recovery Rate

This paper develops, validates and analyses the behavior of a compartmental model for the transmission of COVID-19 disease in Saudi Arabia. The population is struc- tured upon four classes: susceptible (S), exposed (E), infectious (I) and removed (R) individuals. This SEIR model assumes a bilinear incidence rate and a non-linear re- covery rate that depends on the quality of health services. The model also takes into consideration a treatment function and incorporates the effect of fear due to the dis- ease. We derive the expression of the basic reproduction number and the equilibrium points of the model. We show that when the reproduction number is less than one the disease-free equilibrium is stable and the model predicts a backward bifurcation. When the reproduction number is larger than one, the model is found to predict a stable periodic behavior. Numerical simulations using parameter values fitted to Saudi Arabia are used to analyze the effects of model parameters on the different dynamic behavior predicted by the model.

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PP1
Federated Analysis of MRI Data Using Coinstac

Neuroimaging analysis can be significantly improved when worldwide datasets from various research groups focusing on similar problems can be combined for large-scale analyses, providing a complement and extension to existing open datasets. Assembling Magnetic Resonance Imaging (MRI) datasets not only require expensive and time-consuming centralization but is generally restricted due to data privacy or regulatory concerns. Federated analysis can help overcome these limitations, where the collaborating sites perform analysis locally on their data without data sharing and instead share the learnt parameters with one of the participating sites, where it aggregates these model parameters to generate a global model that is shared with the other participating sites. In this work, we propose two federated algorithms to perform linear mixed effects (LME) and brain age estimation (BAE) for MRI data implemented in Collaborative Informatics and Neuroimaging Suite Toolkit for Anonymous Computation (COINSTAC) framework. Our goal is to reduce the performance gap between centralized and federated models. For LME, we use T1-weighted sMRI images to compare voxel-wise parameter estimates of federated and centralized LME models using residual mean squares metric. For BAE, we extract brain structural features from sMRI data and train federated models. Our results for federated LME and BAE methods using sMRI show the federated models have similar performance compared to their centralized models.

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PP1
Inversion of the Modulo Radon Transform via Orthogonal Matching Pursuit

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

conventional Radon transform. In this case, Radon projections are folded via a modulo non-linearity, which allows HDR values to be mapped into the dynamic range of the sensor and, thus, avoids saturation or clipping. The folded measurements are then mapped back to their ambient range using reconstruction algorithms. In this talk we introduce a novel Fourier domain recovery method based on the Orthogonal Matching Pursuit (OMP) algorithm and Filtered Back Projection (FBP) formula. The proposed OMP-FBP method offers several advantages; it is agnostic to the modulo threshold or the number of folds, can handle much lower sampling rates than previous approaches and is empirically stable to noise and outliers. The effectivity of the OMP-FBP recovery method is illustrated by numerical experiments.

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PP1
Discrete Funk-Radon Transforms Based on Weighted Least Squares Approximation

This poster deals with the computation of the Funk-Radon transform from a finite set of spherical values. Popular approaches in the field of diffusion Magnetic Resonance Imaging combine spectral properties of the transform with regularized least-squares approximation. In this poster, we introduce and we study some variation of this principle; we consider weighted least-squares approximation, with weights from a spherical quadrature rule, and without regularization. We compare the numerical performance of this approach for two quadrature rules on the equiangular Cubed Sphere. In particular, we test the method on low-resolution Cubed Spheres, for which the optimal quadrature rule enjoys interesting properties and has just been found. [1] J.-B. Bellet, A discrete Funk transform on the Cubed Sphere, Journal of Computational and Applied Mathematics, 429 (2023). [2] J.-B. Bellet, M. Brachet, and J.-P. Croisille, Quadrature and symmetry on the Cubed Sphere, Journal of Computational and Applied Mathematics, 409 (2022). [3] M. Descoteaux, E. Angelino, S. Fitzgibbons, and R. Deriche, Regularized, Fast, and Robust Analytical Q-Ball Imaging, Magnetic Resonance in Medicine, 58 (2007), pp. 497-510. [4] C. P. Hess, P. Mukherjee, E. T. Han, D. Xu, and D. B. Vigneron, Q-Ball Reconstruction of Multimodal Fiber Orientations Using The Spherical Harmonic Basis, Magnetic Resonance in Medicine, 56 (2006), pp. 104-117.

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PP1
Scikit-Shape: Python Toolbox for Shape and Image Analysis

We introduce a Python package for image segmentation and shape analysis. Our package implements various building blocks to solve such problems, including algorithms for geometric regularization, elastic matching, adaptive discretization, and fast Newton-type minimization schemes. The package leverages the NumPy/SciPy ecosystem, making them as easy to use as Matlab, also compatible with existing Python tools. Our algorithms is freely available as an open source package for the research community at: http://scikit-shape.org

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PP1
Vemos: Visual Explorer for Metrics of Similarity

Similarity and dissimilarity metrics are a fundamental component of many tasks requiring the analysis and comparison of complex, often visual data. Applications ranging from computer vision to forensics require ways to effectively identify images, find clusters or outliers in data sets, or retrieve data items similar to a query item. However, finding an effective metric for a specific task is challenging due to the complexity of modern data sets and the myriad of possible similarity metrics arising from that complexity. We present VEMOS, a Python package that provides an accessible graphical user interface (GUI) for the evaluation of such comparison metrics. VEMOS provides user-friendly ways to examine individual data items or groups in a data set alongside analyses of metrics performance on the whole data set, such as clustering, multi-dimensional scaling, and retrieval performance analyses. VEMOS aims to help researchers and practitioners evaluate multiple comparison metrics (of similarity or dissimilarity) on rich, diverse data sets.

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PP1
Rda-Inr: Riemannian Diffeomorphic Autoencoding Via Implicit Neural Representations

Diffeomorphic registration frameworks such as Large Deformation Diffeomorphic Metric Mapping (LDDMM) are used in computer graphics and the medical domain for atlas building, statistical latent modeling, and pairwise and groupwise registration. In recent years, researchers have developed neural network-based approaches regarding diffeomorphic registration to improve the accuracy and computational efficiency of traditional methods. This poster focuses on a limitation of neural network-based atlas building and statistical latent modeling methods, namely that they either are (i) resolution dependent or (ii) disregard any data/problem-specific geometry needed for proper mean-variance analysis. In particular, we overcome this limitation by designing a novel encoder based on resolution-independent implicit neural representations. The encoder achieves resolution invariance for LDDMM-based statistical latent modeling and adds LDDMM Riemannian geometry to resolution-independent deep learning models for statistical latent modeling. We showcase that the Riemannian geometry aspect improves latent modeling and is required for a proper mean-variance analysis. Furthermore, to showcase the benefit of resolution independence for LDDMM-based data variability modeling, we show that our approach outperforms another neural network-based LDDMM latent code model. Our work paves a way to more research into how Riemannian geometry, shape/image analysis, and

deep learning can be combined.

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PP1
High Dynamic Range Imaging With One-Bit Modulo Sampling

Modulo sampling and dithered one-bit quantization have emerged as promising solutions to overcome the limitations of ADCs and sensors. Modulo sampling, with its high-resolution approach using modulo ADCs, offers an unlimited dynamic range, while dithered one-bit quantization offers reduced power consumption while operating at elevated sampling rates. Our goal is to explore the synergies between these two techniques, leveraging their unique advantages, and to apply them to non-bandlimited signals within spline spaces. One noteworthy application of these signals lies in High Dynamic Range imaging. In dithered one-bit sensing problems aimed at improving recovery performance, constraining the dynamic range of the signal is essential through the scale parameter of uniform dithers.An alternative approach to devising uniform dithers for one-bit sensing, aimed at eliminating the dependence on statistical properties of input signal, involves the use of modulo sampling. Modulo sampling offers a natural method for designing dithers that can span the dynamic range of measurements, aligning with our goal in achieving uniform quantization. Modulo sampling distributes modulo samples in a semi-uniform manner between the thresholds of the ADCs, thereby constraining the signal's dynamic range to match the ADC's threshold. When the scale parameter of uniform dithers is designed to be uniformly distributed within the dynamic range of the signal, it covers the signal's dynamic range.

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PP1
Learning Mmse Estimator of Sparse Signals via Generalized Huber Functions

Sparse modeling has been a recurring topic in signal processing, from wavelet based to optimization based based methods. In the recent deep learning based approach, it is empirically observed that the unbiased Convolution Neural Network (CNN) denoiser learns to denoise in a adaptive sparse-inducing basis, and learns the high dimensional densities via the score function. Despite the expressiveness of CNN, the learned score function approximates the true score function, but lacks Jacobian symmetry and monotone, thus can not be connected back to optimization problems and hard to interpret. We propose to learn the denoiser (minimum mean square estimator of sparse signals) via the generalized Huber functions (GHuber). Specifically, the denoiser is the solution to a regularized least square problem by sum and composition of GHubers with latent variables. The denoiser is trained as a deep equilibrium network, and we can guarantee its monotonicity

by maintaining the convexity of the each latent variable. We believe it is a potential step towards connecting the learning-based signal processing with classic interpretable approaches by investigating the learned regularizer.

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PP1
Holographic Imaging Methods for Immersive Near-Eye Displays

Holographic near-eye displays (HNEDs) have the potential to provide immersive 3D viewing experience without causing visual discomfort. However, generating holographic data to drive such displays is a challenging problem that requires a trade-off between light wave modelling accuracy and computational efficiency. In this presentation, we first analyse the visual correctness of holographic stereograms as an approximative holographic data representation and quantify the accuracy of accommodation visual cues provided by a holographic stereogram in relation to its design parameters. Further, we present a novel method for synthesizing holograms from light fields and depth maps, using a hybrid of planar and spherical wave models. This approach allows us to model the wavefronts of diffuse sources accurately, while preserving the correct specular reflections, thus reproducing realistic 3D scenes with correct defocus blur. We discuss the illumination conditions that allow us to use optimal sampling of the light field as well as the conditions for forming the hybrid for non-synthetic scenes. As the proposed method is computationally demanding, we examine machine learning models to accelerate the hologram synthesis. We specifically discuss the way to generate synthetic scenes with proper spatial and angular sampling to create realistic light field data sets. We show that our method can achieve real-time synthesis of immersive, high-quality holograms.

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PP1
Image-Based Method for Measuring Size of Gas Bubbles in Fluid Flow

We describe a method to identify, in photographs of gas bubbles suspended in liquid flow, the location and diameter of the bubbles. Challenges include discriminating in-focus from out-of-focus bubbles; densely packed, overlapping bubbles; and deformed (non-spherical) bubbles. Recent progress in algorithm development and comparison to human analysis is presented.

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PP1
A Method for Reconstructing Short-Scanning Amyloid PET Images with Multi-Domain Data

We present a deep learning algorithm designed to enhance the quality of amyloid PET images acquired in a short

time scan, leveraging multi-domain data. The proposed method is trained on pairs of PET images acquired during short (2 minutes) and standard (20 minutes) scanning periods, sourced from diverse domains. Learning relevant image features across these domains using a single network poses a challenge. Our primary innovation involves introducing a mapping label, facilitating the effective learning of specific image features between distinct domains. The network, trained with various mapping labels, can be applied to datasets in previously unseen domains (i.e., those obtained with new radio tracers, acquisition protocols, or PET scanners), by estimating an unknown mapping label for the unseen source domain. Internal, temporal, and external validations were performed to demonstrate that the proposed method for amyloid PET imaging can reduce scanning time while maintaining a high image quality.

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PP1
Improving Dsa Image Segmentation with Cnns

This poster introduces an innovative method for segmenting Digital Subtraction Angiography (DSA) images, a critical task in medical image analysis. Using Convolutional Neural Networks (CNNs), our approach employs an iterative process to expand segmented regions in growing directions. A CNN predicts class probability scores within a small pixel neighborhood, determining pixel inclusion based on a threshold. The process continues iteratively until no new pixels qualify for inclusion. Our method achieves remarkable segmentation accuracy while preserving biological features. This project aims to improve the accuracy of predictions of the DSA images. The combination of precision and preservation capabilities distinguishes our method, marking a notable advancement in the field of DSA image segmentation.

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PP1
Learned Large-Scale Robust Matrix Completion Via Deep Unfolding

Robust matrix completion (RMC) is a technique for recovering a low-rank matrix from a subset of its entries, where some of the entries are corrupted. In this study, we introduce a deep-learning-augmented approach to RMC, called Learned Robust Matrix Completion (LRMC). Our approach utilizes Deep Unfolding, which converts each iteration of the RMC algorithm into a Deep Neural Network (DNN) layer and leverages DNN training to optimize the performance of the algorithm. Through extensive empirical experiments on synthetic datasets and real-world applications, we demonstrate that LRMC outperforms state-of-the-art methods, suggesting it as an attractive choice for addressing RMC problems.

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PP1
Mathematical Foundations for a Level-Set-Based Convex Hull Extraction Algorithm

In this work, we propose a proper mathematical framework to analyse a novel level-set-based convex hull extraction algorithm. The target convex shape, modelled as the zero level-line of an unknown function, is viewed as a minimal argument of a suitably designed functional phrased in a subspace of the space of Special Bounded Hessian functions. Also, the convexity constraint is stated as a non-negativity criterion satisfied by the absolutely continuous part of the Laplacian of the unknown. A result of existence of minimisers is established for this preliminary problem. Then, to make the optimisation problem tractable from a numerical viewpoint, we provide an elliptic approximation of it, complemented by a Γ-convergence result, and a splitting-strategy-based algorithm involving subproblems with closed-form solutions. Numerical experiments showing that the proposed approach is a proper compromise between mathematical thoroughness and algorithmic relevancy conclude the presentation.

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PP1
Hyperspectral Image Destriping and Denoising via Tensor $l_{2,p}$ Group Sparsity and Nonlocal Low-Rank Priors

Hyperspectral images (HSIs) are often contaminated by various types of noise, such as Gaussian noise, impulse noise, strip noise, and dead lines. In this work, we propose an optimization model for destriping and denoising HSIs. Specifically, to remove sparse noise with line structures, we adopt the tensor $l_{2,p}$, $p \in (0,1)$, group sparsity measure to characterize stripes and dead lines. For the image prior, we divide the HSI into smaller blocks and stack the blocks with similar patterns into nonlocal similar group tensors. Each of these tensors encloses spatial, spectral, and self-similarity information and is further regularized by low-rank priors. To solve the resulting nonconvex nonsmooth model, we propose a proximal block coordinate descent algorithm and provide convergence results for the proposed method. We demonstrate its effectiveness through simulation and real image denoising experiments. The results show that our method achieves satisfactory denoising performance compared to state-of-the-art methods, both visually and quantitatively.

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PP1
Optimal Experimental Design for Control Problems Governed by PDE-Constrained Bayesian Inverse Problems

We propose a framework for Goal-Oriented Optimal Experimental Design (OED) of linear PDE-constrained Bayesian inverse problems coupled with an optimal control problem. In particular, we consider optimal control problems that are parameterized by the solution of an inverse problem. While classical Bayesian OED techniques provide designs that minimize the posterior uncertainty in the inversion parameter, these designs may not be ideal at minimizing the uncertainty in the optimal control. As experimental resources are often limited by cost or feasibility, one needs to prioritize the designs that minimize the uncertainty in the ultimate goal. As such, we propose design criteria and fast computational methods for finding sensor placements that minimize the uncertainty in the optimal control or the control objective. We present illustrative numerical experiments in the context of a heat transfer application, in which we reconstruct an ambient heat source term based on initial state measurements and, with the reconstructed dynamics, control a stationary source to achieve the target state within a given period of time.

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PP1
Ssim and L_2 Error Are Not Equivalent... Are They?

Assessing the similarity of two images is a complex task that can be addressed by considering the widely used structural similarity index measure (SSIM). It quantifies a perceptual structural similarity, and it is constructed by means of local weighted windows. In [1], a novel analysis carried out from an approximation theory viewpoint investigated the relationship between the SSIM and the classical L_2 error. As a main result, it was proved that to observe a practical benefit in using the SSIM instead of the L_2 error a local enough weight should be chosen. Otherwise, SSIM and L_2 error are in fact equivalent. Then, the theoretical findings were employed to obtain precise convergence rates for various image interpolation methods with respect to the considered structural similarity index. [1] Convergence results in image interpolation with the continuous SSIM, F. Marchetti, G. Santin - SIAM J. Imaging Sci. 15:4 (2022), pp. 1977–1999

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PP1
Brainchop: Next-Gen Web-Based Neuroimaging

Processing volumetric medical images within the browser presents unprecedented challenges compared to conventional backend tools. These challenges stem from the inherent limitations of browser environments. Consequently, there is a shortage of neuroimaging frontend tools capable of providing comprehensive end-to-end solutions for whole brain preprocessing and segmentation while preserving end- user data privacy. In this context, we introduce Brainchop (http://www.brainchop.org) as a groundbreaking in-browser neuroimaging tool that enables volumetric analysis of struc- tural MRI using pre-trained full-brain deep learning models, all without technical expertise or intricate setup procedures. This presentation outlines the processing pipeline of Brainchop and evaluates the performance of models across various soft- ware and hardware configurations. The results demonstrate the practicality of client-side processing for volumetric data, owing to the robust MeshNet architecture, even within the resource-constrained environment of web browsers.

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PP1
Histojs: Web-Based Analytical Tool for Multiplexed Imaging

The advancements in multiplexed imaging technologies have empowered us to capture single-cell proteomics and transcriptomics data with unprecedented detail and high spatial resolution at the single-cell level. The substantial volume of image data poses a challenge in accurately isolating and quantifying distinct cell types, which is essential for a comprehensive understanding of brain complexity, neurological disorders, potential biomarkers, and druggable targets for drug development. This surge in demand and challenges necessitates developing and validating state-of-the-art quantitative image analysis tools. In this context, we present HistoJS, a cutting-edge web-based bioimage visualization and analysis tool designed to cater to the dynamic landscape of multiplexed microscopy imaging. Committed to advancing healthcare, HistoJS prioritizes improvements in usability, accessibility, sustainability, scalability, and collaboration. By incorporating user-friendly interfaces and ensuring cross-platform compatibility, HistoJS delivers a seamless and accessible experience.

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PP1
Nonconvex Algorithms For Separable Nonnegative Matrix Factorization

Nonnegative Matrix Factorization (NMF) has emerged as a powerful tool in a wide range of applications, such as image processing and data analysis. In many real-world scenarios, the separability assumption plays a crucial role

in ensuring meaningful matrix factorization, as it enforces parts-based representations. Many convex relaxed methods have been developed to solve the separable NMF problem. However, the low-rankness of a matrix has not been fully exploited. In this work, we propose a novel separable NMF framework in the noise-free and noisy settings, based on the low-rankness assumption. In particular, we adopt a nonconvex regularization term, i.e., the ratio of matrix nuclear norm and Frobenius norm. The proposed method pursues low-rankness of the data in an adaptive way to efficiently guide the factorization. To address the nonconvexity of the proposed model, we reformulate it by introducing an auxiliary variable and then apply the alternating direction method of multipliers (ADMM). Identifiability and convergence analysis provide theoretical guarantees of our algorithms. Furthermore, a variety of numerical experiments on synthetic data and real-world image data demonstrate the efficiency of the proposed approaches in improving the quality of factorization and its potential impact on imaging applications.

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PP1

Demonstration of a Hybrid Restoration Algorithm for Grain Orientation Data of Materials

Metals have a polycrystalline structure with various crystal orientations, which is pivotal in determining their mechanical properties like elasticity and strength. Understanding these orientations is crucial, yet conventional techniques like electron backscatter diffraction (EBSD) often leave gaps in orientation data, affecting the accuracy of property predictions. Our research focuses on a hybrid 'inpainting' method to fill these data gaps, blending two main inpainting approaches: exemplar-based and deep learning algorithms. Exemplar-based methods utilize similar neighboring known data to predict missing information, while deep learning approaches leverage extensive training data for predictions. Our technique merges these strategies, initially employing a partial convolution neural network trained with synthetic EBSD data to estimate unknown orientations. These preliminary predictions enhance the data for a refined version of the exemplar-based algorithm by Criminisi et al. This strategy not only bridges the data gaps more effectively but also outperforms the accuracy achieved by either method alone, marking a significant advancement in predicting the material properties of metals. Our poster will demonstrate the results of our approach and make a statistical comparison with other methods.

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PP1

Multi-Contrast Piecewise Constant Image Recovery Using An Enhanced Parametric Level-Set Method

This work introduces an enhanced parametric level-set method, designed for the efficient reconstruction of multi-contrast piecewise constant images. Unlike conventional parametric level-set models, the new model demonstrates a unique capabilityit utilizes only a single level-set function to reconstruct scenes featuring piecewise constant objects where both the number and values of the objects contrasts are determined in conjunction with the geometries. We validate the effectiveness of the new model across a spectrum of linear and non-linear inverse problems, encompassing both 2D and 3D scenarios.

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PP1

Fine-Tuning of the Cone-Beam CT Image Enhancement Generative Model Using Human Feedback

This study explores a method to enhance the quality of CBCT (Cone Beam Computed Tomography) images in the field of bio-medicine by utilizing generative models. Specifically, it addresses image quality issues, a major drawback of CBCT, by employing human feedback in generative model-based research. This research is particularly significant as it offers a novel alternative within the context of medical data, where ground truth data is unavailable, making it reliant on unsupervised learning approaches. In the first stage, the study involves training a GAN (Generative Adversarial Network) model using unpaired CBCT and MDCT (Multi-Detector Computed Tomography) images. While this stage is generally effective for noise reduction, it can occasionally introduce additional artifacts. In the second stage, the focus shifts to fine-tuning the model with the goal of excluding unintended artifacts and generating high-quality images. This phase incorporates human feedback to minimize the generation of unintended artifacts. This research demonstrates the potential of fine-tuning generative models using human feedback in medical domains where ground truth data is absent. It introduces a promising direction for improving the quality of medical

images. Future research endeavors will involve further re-
finement of the human feedback reward function to expand
the scope of this research.

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PP1

Comparing Image Reconstructions of Different Methods for Simulated EIT Data

Electrical Impedance Tomography (EIT) is a portable, in-
expensive, noninvasive imaging system that does not use
ionizing radiation. Due to these properties, EIT has been
of great interest for many different medical applications. In
practice, electrodes are attached to a patient's body where
current is applied, and the resulting voltage is measured
to reconstruct internal electrical properties. However, the
EIT inverse problem is severely ill-posed due to the limited
amount of measurements from the partial boundary data,
and aggressive changes in the electrical properties inside
the body cause regularization difficulties. Here, we will
compare both non-iterative and iterative methods, as well
as machine learning methods, to improve image reconstruc-
tions. We will also explore the impact of the regularization
parameter and the mesh configuration on reconstruction
results. These methods will be compared using simulated
data with anomalies placed in varying locations.

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PP1

A Comparison of Two Iterative Methods for Solving Edge-Preserving Inverse Problems

We discuss two iterative methods for solving edge-
preserving inverse problems applied to image reconstruc-
tion: the Split Bregman and Majorization-Minimization
methods. Both methods deal with the non-smooth inverse
problem by solving a smooth minimization problem, but
they do so in different ways. The Split Bregman method
turns the problem into a smooth minimization problem
followed by a shrinkage step and an update. In contrast,
the Majorization-Minimization method first smooths the
functional and then minimizes the smoothed functional.
Numerical examples are used to compare the convergence
rates of the methods, the quality of their reconstructions,
and computational cost. We also discuss how to select
the parameters within each method, including the regular-
ization parameter in the minimization problem, and the
criteria for determining the stopping point within the al-
gorithms.

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PP1

Edge-Preserving Multilevel Methods for Signal Restoration

We present wavelet-based multilevel methods for recover-
ing edge information in signal restoration. At each level,
we solve a total variation regularized problem, which we
solve by an iterative reweighting least square approach.
We present numerical examples that show the effectiveness
of these proposed methods.

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PP1

Robust Retrieval of Material Chemical States in X-Ray Microspectroscopy

X-ray microspectroscopic techniques are essential for
studying morphological and chemical changes in materi-
als, providing high-resolution structural and spectroscopic
information. However, its practical data analysis for reli-
ably retrieving the chemical states remains a major obsta-
cle to accelerating the fundamental understanding of ma-
terials in many research fields. In this work, we propose a
novel data formulation model for X-ray microspectroscopy
and develop a dedicated unmixing framework to solve this
problem, which is robust to noise and spectral variabil-
ity. Moreover, this framework is not limited to analyzing
two-state material chemistry, making it an effective alter-
native to conventional and widely used methods. In ad-
dition, an alternative directional multiplier method with
explicit or implicit regularization is applied to obtain the
solution efficiently. Our framework can accurately identify
and characterize chemical states in complex and heteroge-
neous samples, even under challenging conditions such as
low signal-to-noise ratios and overlapping spectral features.
By testing six simulated datasets, our method improves the
existing methods by up to 151.84% and 136.33% in terms
of the peak signal-to-noise ratio (PSNR) and the structural
similarity index (SSIM) for the chemical phase map. Ex-
tensive experimental results on simulated and real datasets
demonstrate its effectiveness and reliability.

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PP1

Complex Phase Retrieval From One-bit Dither Samples

In various applications, acquiring information about an

object becomes challenging when measuring and recording the signal phase is either impossible or highly difficult. The presence of Analog-to-Digital Converters (ADCs) in the signal acquisition process intensifies the challenge, requiring the reconstruction of the object solely from quantized amplitude measurements. The most extreme scenario involves reconstructing the object from one-bit amplitude measurements. This presentation introduces an innovative technique for reconstructing signals from phaseless measurements obtained through one-bit ADCs. Our approach employs the Sampling Kaczmarz-Motzkin algorithm to efficiently optimize the phase retrieval objective. Notably, it capitalizes on the sample abundance inherent in one-bit sensing with dithering sequences, overcoming limitations posed by traditional convex phase retrieval methods, such as the computationally expensive semi-definiteness and rank constraints. Additionally, our approach streamlines computational efficiency by eliminating the need to lift-up the unknown signal. Theoretical guarantees for our proposed algorithm are also provided.

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