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Sparse data structures in 3DXRD

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Talk titles and abstracts

Martin Andersen

Generalized Row-Action Methods for Tomographic Imaging

We propose relaxed variants of Bertsekas' incremental proximal gradient methods. These methods generalize many existing row-action methods for tomographic imaging, and they provide a framework for deriving new incremental algorithms that incorporate different types of prior information via regularization. Despite their relatively poor global rate of convergence, these methods often exhibit fast initial convergence which is desirable in applications where low-accuracy solutions are acceptable. We demonstrate the efficiency of the approach with some numerical examples.

Simon Arridge

Sparsity Methods in Undersampled Dynamic Imaging

Sampling for 4D dynamic imaging in e.g. MRI, CT or PAT, is often considered in **k**-*t*-space, where the spatial samples are chosen in Fourier space as they vary in time. In order to accelerate data acquisition, various sparse sampling methods have been developed, and can be combined with sparsity constraint techniques. Amongst these are **k**-*t*-BLAST, **k**-*t*-FOCUSS, **k**-*t*-SLR, and **k**-*t*-RPCA. Recently “low-rank-plus-sparse” has been proposed as a way to specify sparsity jointly in space and time. In this talk I will review several of these methods and compare them in applications in dynamic MRI.

Andreas Bartels

Compressed Sensing in Imaging Mass Spectrometry Data

Imaging mass spectrometry (IMS) is a technique of analytical chemistry for spatially-resolved, label-free and multipurpose analysis of biological samples, which is able to detect spatial distribution of hundreds of molecules in one experiment. The hyperspectral IMS data is typically generated by a mass spectrometer analyzing the surface of the sample. In practice, for a tissue slice, at each point on a grid on the sample 200–300 measurements are taken. Summing all measurements at a point together, the result is a grid where each pixel represents a mass spectrum at the according point. Therefore, measuring takes quite a long time.

As the mathematical theory of compressed sensing (CS) has shown, under certain conditions it is possible to recover a signal from a number of linear measurements below the Shannon/Nyquist sampling rate [2]. As a result of this pleasant surprise, many applications of CS in image processing and comiputer vision have been widely explored [3].

In this talk, I will present a recently published compressed sensing approach to IMS [1] which potentially allows for faster data acquisition by collecting only a part of pixels in the hyperspectral image and reconstructing the full image from this data. I will discuss sparsity aspects in IMS and present an integrative approach to perform both peak-picking spectra and denoising m/z-images simultaneously, whereas the state of the art data analysis methods solve these problems separately. A result concerning the robustness of the recovery of both spectra and individual channels of the hyperspectral image as well as numerical reconstruction results of a rat brain coronal section will be shown.

[1] A. Bartels et al. *Compressed sensing in imaging mass spectrometry*. Inverse Problems, 29(12):125015 (24pp), 2013.
[2] E. J. Candès, J. Romberg and T. Tao. *Stable signal recovery from incomplete and inaccurate measurements*. Commun. Pure Appl. Math. 59(8):1207–1223, 2006.
[3] M. Golbabaee, S. Arberet and P. Vandergheynst. *Compressive source separation: theory and methods for hyperspectral imaging*. IEEE Trans. Image Proc. 22(12):5096–5110, 2013.

Marta Betcke

Compressed Sensing for High Resolution 3D Photoacoustic Tomography

Photoacoustic tomography (PAT) has become a powerful tool for biomedical imaging, particularly pre-clinical small animal imaging. Several different measurement systems have been demonstrated, in particular, optically addressed Fabry-Perot interferometer (FPI) sensors have been shown to provide exquisite images when a planar geometry is suitable. However, in its current incarnation the measurements must be made at each point sequentially, so these devices therefore suffer from slow data acquisition time. In this talk we will discuss a new PAT scanner capable of acquisition of compressed measurements. In this scanner we interrogate the whole sensor with a series of independent illumination patterns, so that each individual measurement is a scalar product of the illumination pattern and the acoustic field on the sensor. This is a direct analog of the single-pixel Rice camera implemented on FP interferometer. We will discuss various aspects of compressed data acquisition and image reconstruction for this novel device on both simulated and real data.

Thomas Blumensath

The Models, Measures and Methods of Compressed Sensing

In this talk I will give an informal introduction to some of the fundamental concepts of Compressed Sensing. Starting with a discussion of the mathematical ideas that underly compressed sensing theory I will introduce some of the major results in the field. The three pillars of Compressed Sensing, measurement, structure and algorithms, will be discussed in more depth. Focus will be on measurement issues arising in tomography, structures beyond sparsity and greedy algorithms.

Henrik Garde

Sparse Reconstruction in Electrical Impedance Tomography

Electrical impedance tomography is an imaging technique for which the electrical conductivity in the interior of an object is reconstructed from boundary measurements. The severe ill-posedness of the inverse boundary problem implies that regularization is required for practical reconstructions. For reconstructing small/sparse inhomogeneities in the conductivity, L1 regularization with a distributed regularization parameter is applied. This makes it possible to reconstruct the inhomogeneities even from partial boundary data. Using estimates of the sparsity of these inclusions as prior information, it is possible to further improve the resolution and contrast in the reconstruction.

Daniel Gerth

A Stochastic Convergence Analysis for Tikhonov-Regularization with Sparsity Constraints

In recent years, regularization methods based on the minimization of Tikhonov-type functionals with a linear bounded operator and a sparsity promoting penalty term have been discussed widely in literature. Convergence of the solution has been analysed assuming a deterministic error bound between the measured noisy data and the true data. Instead of this an explicit stochastic error model is considered in the talk. Namely, the case of a normally distributed error in each component of the measured data is addressed. This especially means arbitrarily large errors are allowed, but with low probability.The Tikhonov-functional is derived from a stochastic model using Bayes' formula. Deterministic results are lifted to this situation using the Ky Fan metric for the convergence analysis. After giving a general convergence theorem, Besov space penalties are considered. For this case, a parameter choice rule is presented which immediately leads to convergence rates in the Ky Fan metric with respect to the variance of the error. The theoretical results are illustrated in one dimensional and two dimensional numerical examples.

Adriana Gonzalez

Compressive Optical Deflectometric Tomography

Optical Deflectometric Tomography (ODT) is an imaging modality that aims at reconstructing the spatial distribution of the refractive index of a transparent object from the deflection of the light passing through the object. By reconstructing the Refractive Index Map (RIM) we are able to optically characterize transparent materials like optical fibers or multifocal intraocular lenses, whose complex surfaces present a real challenge in manufacture and control processes. In this talk we focus on the compressiveness of this imaging modality in terms of data acquisition and RIM reconstruction. At a first level, we perform a compressive ODT acquisition based on the spread spectrum compressed sensing framework, which allows to reconstruct the deflection map using relatively few measurements per orientation. At a second level, we demonstrate how to use the deflection information optimally to recover a high quality RIM with far less observations (number of orientations) than traditional methods. Numerically, the solution of both inverse problems rely on an accurate sensing model and on a primal-dual minimization scheme, which easily includes the sensing operators and regularization constraints.

Chunli Guo

A Sample Distortion Analysis for Compressed Imaging

We propose the notion of sample distortion function for i.i.d compressive distributions with the aim to fundamentally quantify the achievable reconstruction performance of compressed sensing for certain encoder-decoder pairs at a given undersampling ratio. The theoretical SD function is derived for the Gaussian encoder and Bayesian optimal approximate message passing (AMP) decoder thanks to the rigorous analysis of the AMP algorithm. We also show the convexity of the general SD function and derive two lower bounds. We then apply the SD framework to analyse compressed sensing for natural images using a multi-resolution statistical image model with either a generalized Gaussian distribution and the two-state Gaussian mixture distribution. For these scenarios we are able to achieve an optimal bandwise sample allocation and show that the corresponding SD function for natural images accurately predicts the observed compressed sensing performance gains. We further adopt Som and Schniter's turbo message passing approach to integrate the bandwise sampling with the exploitation of the hidden Markov tree structure of wavelet coefficients. Natural image simulation confirms the theoretical improvements and the effectiveness of bandwise sampling.

Jakob Jørgensen

Empirical Phase Transitions in Sparsity-Regularized Computed Tomography

Sparsity-exploiting reconstruction has proven useful for many applications of tomographic imaging including dose reduction in x-ray computed tomography (CT), even though theoretical recovery guarantees from compressed sensing (CS) do not apply. A theoretical understanding of the efficacy of exploiting sparsity in CT is therefore lacking. Instead we aim to empirically establish the role of sparsity in CT. In this talk, we present extensive empirical evidence of an average-case relation between image sparsity and the sufficient number of tomographic measurements for uniquely recovering the original image. We show that the sparsity-sampling plane is divided into no- and full-recovery regimes, that are often separated by a sharp phase transition, as known from CS. We show results for different image classes sparse in the image itself or its gradient, reconstruction based on L1 and total variation minimization and for noise-free and noisy data.

Mirza Karamehmedovic

Sparse Data Structures in 3DXRD

In 3D X-ray diffraction tomography (3DXRD) of polycrystals, the spatial and the orientational distribution of crystal grains are numerically reconstructed from the observed diffraction spots and rings. The high dimensionality of the solution space poses a significant computational challenge. In this talk I will present a sparsity-promoting mathematical framework for the 3DXRD and show supporting numerical results.

Dirk Lorenz

Sparse and TV Kaczmarz Solvers and the Linearized Bregman Method

We propose an algorithmic framework that leads to generalizations of both the Kaczmarz method and the linearized Bregman method. Moreover, we will obtain several generalizations of these methods such as a Kaczmarz solver that produces sparse solutions, a block-linearized Bregman solver and also methods for minimal-TV-solutions of underdetermined systems. We present various applications of the framework, e.g. to tomography, astronomy, radio interferometry and online compressed sensing.

Willem Jan Palenstijn

Reconstructing Objects with Sparse Boundaries: Total Variation vs. Discrete Tomography

Objects that have a relatively small boundary with respect to their volume can be reconstructed effectively from a small set of tomographic projections by exploiting this property as prior knowledge. Total Variation Minimization techniques (TV) and algorithms from Discrete Tomography (DT) approach this problem in different ways: in TV-based methods the boundary is minimized, while DT uses the assumption that the interior of the object consists of homogeneous regions. In this talk I will make a comparison between the two approaches and discuss their similarities and differences. Both approaches have their own strong points and weaknesses, but they can also be used effectively together for solving challenging limited data problems in tomography.

Stefania Petra

Weak Phase Transitions for the Recoverability of Co-/Sparse Images from Few Tomographic Projections

Compressed Sensing (CS) exploits the sparsity of signals and allows accurate reconstruction from a few linear, but random and non-adaptive measurements. Moreover, for such measurement ensembles, bounds on the required signal sparsity depending on the undersampling ratio can be derived, also known as Donoho-Tanner phase transitions, that guarantee exact recovery via l1-minimization. Unfortunately, sampling patterns as used in industrial tomographical set-ups with limited numbers of projections fall far short of common assumptions in CS. Thus, for such scenarios, CS provides neither theoretical guarantees of accurate reconstruction, nor any relation between sparsity and a sufficient number of measurements for recovery of sparse images from few tomographic projections. In this talk we investigate conditions for unique signal recovery based on sparse and cosparse signal models. We present a relation between image co-/sparsity and sufficient number of tomographic measurements for exact recovery similar to the settings in CS. Numerical recovery through linear programming reveals a high accuracy of the theoretical predictions. Additionally, we show that the transition from non-recovery to recovery is sharp for specific sparse images. The signal class covered by both sparse and cosparse models seems broad enough to cover relevant industrial applications of non-standard tomography, like particle image velocimetry and contactless quality inspection.

Michael Zibulevsky

Learned Shrinkage Approach for Low-Dose Reconstruction in Computed Tomography

We propose a direct nonlinear reconstruction algorithm for Computed Tomography (CT), designed to handle low-dose measurements. It involves the filtered back-projection and adaptive nonlinear filtering in both the projection and the image domains. The filter is an extension of the learned shrinkage method by Hel-Or and Shaked to the case of indirect observations. The shrinkage functions are learned using a training set of reference CT images. The optimization is performed with respect to an error functional in the image domain that combines the mean square error with a gradient-based penalty, promoting image sharpness. Our numerical simulations indicate that the proposed algorithm can manage well with noisy measurements, allowing a dose reduction by a factor of 4, while reducing noise and streak artifacts in the FBP reconstruction, comparable to the performance of a statistically based iterative algorithm.